IEC 62282-6-100

Edition 1.1 2012-10

INTERNATIONAL STANDARD

colour inside

Fuel cell technologies –
Part 6-100: Micro fuel cell power systems – Safety

IEC 62282-6-100:2010+A1:2012(E)

IEC Central Office
3, rue de Varembé
CH-1211 Geneva 20
Switzerland

Tel.: +41 22 919 02 11
Fax: +41 22 919 03 00
info@iec.ch
www.iec.ch

About the IEC

The International Electrotechnical Commission (IEC) is the leading global organization that prepares and publishes International Standards for all electrical, electronic and related technologies.

About IEC publications

The technical content of IEC publications is kept under constant review by the IEC. Please make sure that you have the latest edition, a corrigenda or an amendment might have been published.

Useful links:

IEC publications search - www.iec.ch/searchpub

The advanced search enables you to find IEC publications by a variety of criteria (reference number, text, technical committee,…).
It also gives information on projects, replaced and withdrawn publications.

IEC Just Published - webstore.iec.ch/justpublished

Stay up to date on all new IEC publications. Just Published details all new publications released. Available on-line and also once a month by email.

Electropedia - www.electropedia.org

The world's leading online dictionary of electronic and electrical terms containing more than 30 000 terms and definitions in English and French, with equivalent terms in additional languages. Also known as the International Electrotechnical Vocabulary (IEV) on-line.

Customer Service Centre - webstore.iec.ch/csc

If you wish to give us your feedback on this publication or need further assistance, please contact the Customer Service Centre: csc@iec.ch.

IEC 62282-6-100

Edition 1.1 2012-10

INTERNATIONAL STANDARD

colour inside

Fuel cell technologies –
Part 6-100: Micro fuel cell power systems – Safety

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

PRICE CODE **CV**

ICS 27.070

ISBN 978-2-8322-0423-8

Warning! Make sure that you obtained this publication from an authorized distributor.

CONTENTS

FOREWORD 9

1 Scope 12
1.1 General 12
1.2 Fuels and technologies covered 12
1.3 Equivalent level of safety 14
2 Normative references 14
3 Terms and definitions 15
4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges 19
4.1 General 19
4.2 FMEA / hazard analysis 19
4.3 General materials 19
4.4 Selection of materials 19
4.5 General construction 20
4.6 Fuel valves 20
4.7 Materials and construction – system 21
4.8 Ignition sources 21
4.9 Enclosures and acceptance strategies 22
4.9.1 Parts requiring a fire enclosure 22
4.9.2 Parts not requiring a fire enclosure 22
4.9.3 Materials for components and other parts outside fire enclosures 23
4.9.4 Materials for components and other parts inside fire enclosures 24
4.9.5 Mechanical enclosures 25
4.10 Protection against fire, explosion, corrosivity and toxicity hazard 25
4.11 Protection against electrical hazards 26
4.12 Fuel supply construction 26
4.12.1 Fuel cartridge construction 26
4.12.2 Fuel cartridge fill requirement 27
4.13 Protection against mechanical hazards 27
4.13.1 Piping and tubing other than fuel lines 27
4.13.2 Exterior surface and component temperature limits 27
4.13.3 Motors 28
4.14 Construction of electric device components 29
4.14.1 Limited power sources 29
4.14.2 Devices that use electronic controllers 30
4.14.3 Electrical conductors/wiring 30
4.14.4 Output terminal area 31
4.14.5 Electric components and attachments 31
4.14.6 Protection 31
5 Abnormal operating and fault conditions testing and requirements 32
5.1 General 32
5.2 Compliance testing 32
5.3 Passing criteria 33

5.4 Simulated faults and abnormal conditions for limited power and SELV circuits 33
5.5 Abnormal operation – electromechanical components 33
5.6 Abnormal operation of micro fuel cell power systems or units with integrated batteries 34
5.7 Abnormal operation – simulation of faults based on hazard analysis 34
6 Instructions and warnings for micro fuel cell power systems, micro fuel cell power units and fuel cartridges 35
6.1 General 35
6.2 Minimum markings required on the fuel cartridge 35
6.3 Minimum markings required on the micro fuel cell power system 35
6.4 Additional information required either on the fuel cartridge or on accompanying written information or on the micro fuel cell power system or micro fuel cell power unit 36
6.5 Technical documentation 36
7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges 37
7.1 General 37
7.2 Leakage measurement of methanol and the measuring procedure 38
7.3 Type tests 45
7.3.1 Pressure differential tests 45
7.3.2 Vibration test 47
7.3.3 Temperature cycling test 48
7.3.4 High temperature exposure test 49
7.3.5 Drop test 49
7.3.6 Compressive loading test 50
7.3.7 External short-circuit test 51
7.3.8 Surface, component and exhaust gas temperature test 52
7.3.9 Long-term storage test 52
7.3.10 High-temperature connection test 57
7.3.11 Connection cycling tests 57
7.3.12 Emission test 60

Annex A (normative) Formic acid micro fuel cell power systems 65
Annex B (normative) Hydrogen stored in hydrogen absorbing metal alloy and micro fuel cell power systems 97
Annex C (normative) Reformed methanol micro fuel cell power systems 146
Annex D (normative) Methanol clathrate compound micro fuel cell power systems 160
Annex E (normative) Borohydride micro fuel cell power systems: Class 8 (corrosive) compounds in indirect borohydride fuel cells 184
Annex F (normative) Borohydride micro fuel cell power systems: Class 4.3 (water reactive) compounds in indirect borohydride fuel cells 242
Annex G (normative) Borohydride micro fuel cell power systems: Class 8 (corrosive) compounds in direct borohydride fuel cells 300
Annex H (normative) Butane solid oxide micro fuel cell power systems 347
Bibliography 386

Figure 1 – Micro fuel cell power system block diagram..13
Figure 2 – Fuel cartridge leakage and mass loss test flow chart for pressure differential, vibration, drop, and compressive loading tests..39
Figure 3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test 40
Figure 4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests...41
Figure 5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test 42
Figure 6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test 43
Figure 7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test 44
Figure 8 – Temperature cycling..49
Figure 9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test ..56
Figure 10 – Operational emission rate testing apparatus...61
Figure 11 – Operational emission concentration testing apparatus.......................................61
Figure A.1 – Formic acid micro fuel cell power system block diagram – Replaces Figure 1 65
Figure A.2 – Fuel cartridge leakage and mass loss test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2 71
Figure A.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 72
Figure A.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss flow chart for pressure differential, vibration, temperature cycling test, drop, and compressive loading tests – Replaces Figure 4...73
Figure A.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5 74
Figure A.6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6.............75
Figure A.7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7..........76
Figure A.9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9 83
Figure A.10 – Operational emission rate testing apparatus – Replaces Figure 10 84
Figure A.11 – Operational emission concentration testing apparatus – Replaces Figure 11 85
Figure A.12 – Hydrogen emission test procedure for operating micro fuel cell power system...93
Figure B.2 – Fuel cartridge leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2..108
Figure B.3 – Fuel cartridge leakage test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 109
Figure B.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss flow chart for pressure differential, vibration, temperature cycling, drop, and compressive loading tests – Replaces Figure 4...110
Figure B.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5 111

Figure B.8 – Temperature cycling – Replaces Figure 8 121
Figure B.9 – Fuel cartridge hydrogen leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9 132
Figure B.10 – Operational emission rate testing apparatus – Replaces Figure 10 138
Figure B.12 – Hydrogen emission test procedure for operating micro fuel cell power system 142
Figure C.1 – General block diagram of a reformed methanol micro fuel cell power system – Replaces Figure 1 146
Figure C.10 – Operational emission rate testing apparatus – Replaces Figure 10 150
Figure C.11 – Operational emission concentration testing apparatus – Replaces Figure 11 151
Figure C.12 – Hydrogen emission test procedure for operating micro fuel cell power system 156
Figure D.1 – Methanol clathrate compound micro fuel cell power system block diagram – Replaces Figure 1 160
Figure D.2 – Fuel cartridge leakage and mass loss test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2 166
Figure D.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 167
Figure D.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4 168
Figure D.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5 169
Figure D.9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9 180
Figure D.12 – Fuel cartridge of methanol clathrate compound 161
Figure D.13 – Usage of methanol clathrate compound with micro fuel cell power unit 161
Figure E.1 – Micro fuel cell power system block diagram for liquid Class 8 (corrosive) borohydride compound fuel with onboard fuel processing – Replaces Figure 1 184
Figure E.2 – Fuel cartridge leakage and hydrogen leakage and test flow chart for vibration, drop, compressive loading – Replaces Figure 2 199
Figure E.3 – Fuel cartridge leakage and ~~mass loss~~ hydrogen leakage test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 201
Figure E.4 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4 203
Figure E.5 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for external short-circuit test – Replaces Figure 5 205
Figure E.6 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6 206
Figure E.7 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7 207
Figure E.8 – Temperature cycling – Replaces Figure 8 213
Figure E.9 – Fuel cartridge hydrogen leakage and mass loss test flowchart for long-term storage test – Replaces Figure 9 220

Figure E.10 – Operational emission rate testing apparatus – Replaces Figure 10 230
Figure E.11 – Operational emission concentration testing apparatus – Replaces Figure 11 231
Figure E.12 – Hydrogen emission test procedure for operating micro fuel cell power system – Replaces Figure 12 237
Figure E.13 – Micro fuel cell power system block diagram for liquid Class 8 (corrosive) borohydride compound fuel with fuel cartridge fuel processing 185
Figure E.14 – Micro fuel cell power system block diagram for solid Class 8 (corrosive) borohydride compound fuel with fuel cartridge fuel processing and cartridge fuel management 186
Figure E.15 – Micro fuel cell power system block diagram for solid Class 8 (corrosive) compound fuel with cartridge fuel processing and fuel management internal to the micro fuel cell power unit 187
Figure E.16 – Fuel cartridge leakage test flow chart for low external pressure test 239
Figure F.1 – Borohydride micro fuel cell power system block diagram for Class 4.3 (water reactive) compound fuel in indirect borohydride fuel cell system; fuel management in micro fuel cell power unit – Replaces Figure 1 243
Figure F.2 – Fuel cartridge leakage and hydrogen leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2 257
Figure F.3 – Fuel cartridge leakage and ~~mass loss~~ hydrogen leakage test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 259
Figure F.4 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4 261
Figure F.5 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for external short-circuit test – Replaces Figure 5 263
Figure F.6 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6 264
Figure F.7 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7 265
Figure F.8 – Temperature cycling – Replaces Figure 8 271
Figure F.9 – Fuel cartridge hydrogen leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9 278
Figure F.10 – Operational emission rate testing apparatus – Replaces Figure 10 288
Figure F.11 – Operational emission concentration testing apparatus – Replaces Figure 11 288
Figure F.12 – Borohydride micro fuel cell power system block diagram for Class 4.3 (water reactive) compound fuel in indirect borohydride fuel cell system; fuel management in fuel cartridge 244
Figure F.13 – Hydrogen emission test procedure for operating micro fuel cell power system 295
Figure F.14 – Fuel cartridge leakage test flow chart for ~~low~~ external pressure test 297
Figure G.1 – Direct borohydride micro fuel cell power system block diagram – Replaces Figure 1 300
Figure G.2 – Fuel cartridge leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2 311

Figure G.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 312

Figure G.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss flow chart for pressure differential, vibration, temperature cycling, drop, and compressive loading tests – Replaces Figure 4 313

Figure G.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5 314

Figure G.6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6 315

Figure G.7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7 316

Figure G.8 – Temperature cycling – Replaces Figure 8 322

Figure G.9 – Fuel cartridge hydrogen leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9 327

Figure G.10 – Operational emission rate testing apparatus – Replaces Figure 10 336

Figure G.11 – Operational emission concentration testing apparatus – Replaces Figure 11 337

Figure G.12 – Hydrogen emission test procedure for operating micro fuel cell power system 344

Figure G.13 – Fuel cartridge leakage test flow chart for low external pressure test 317

Figure H.1 – Butane solid oxide micro fuel cell power system block diagram – Replaces Figure 1 347

Figure H.2 – Fuel cartridge leakage and mass loss test flow chart for vibration, drop and compressive loading tests – Replaces Figure 2 354

Figure H.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3 355

Figure H.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4 356

Figure H.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5 357

Figure H.6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6 358

Figure H.7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7 359

Figure H.8 – Temperature cycling – Replaces Figure 8 365

Figure H.9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9 372

Figure H.10 – Operational emission rate testing apparatus – Replaces Figure 10 377

Figure H.11 – Operational emission concentration testing apparatus 378

Table 1 – Summary of material flammability requirements 23

Table 2 – Temperature limits 28

Table 3 – Limits for inherently limited power sources 29

Table 4 – Limits for power sources not inherently limited (Over-current protection required) 30

Table 5 – List of type tests ... 37
Table 6 – Laboratory standard conditions ... 38
Table 7 – Emission limits ... 64
Table A.5 – List of type tests – Replaces Table 5 ... 69
Table A.6 – Laboratory standard conditions – Replaces Table 6 ... 70
Table A.7 – Emission limits – Replaces Table 7 ... 94
Table A.8 – Occupational exposure limits ... 94
Table B.5 – List of type tests – Replaces Table 5 ... 106
Table B.6 – Laboratory standard conditions – Replaces Table 6 ... 107
Table B.7 – Emission limits – Replaces Table 7 ... 143
Table C.5 – List of type tests – Replaces Table 5 ... 149
Table C.6 – Laboratory standard conditions – Replaces Table 6 ... 150
Table C.7 – Emission limits – Replaces Table 7 ... 157
Table C.8 – Occupational exposure limits ... 157
Table D.5 – List of type tests – Replaces Table 5 ... 164
Table D.6 – Laboratory standard conditions – Replaces Table 6 ... 165
Table E.5 – List of type tests – Replaces table 5 ... 195
Table E.6 – Laboratory standard conditions – Replaces Table 6 ... 196
Table E.7 – Emission limits – Replaces Table 7 ... 236
Table F.5 – List of type tests – Replaces Table 5 ... 252
Table F.6 – Laboratory standard conditions – Replaces Table 6 ... 253
Table F.7 – Emission limits – Replaces Table 7 ... 294
Table G.5 – List of type tests – Replaces Table 5 ... 308
Table G.6 – Laboratory standard conditions – Replaces Table 6 ... 309
Table G.7 – Emission limits – Replaces Table 7 ... 343
Table H.5 – List of type tests – Replaces Table 5 ... 352
Table H.6 – Laboratory standard conditions – Replaces Table 6 ... 353
Table H.7 – Emission Limits – Replaces Table 7 ... 381
Table H.8 – Occupational exposure limits ... 382

INTERNATIONAL ELECTROTECHNICAL COMMISSION

FUEL CELL TECHNOLOGIES –

Part 6-100: Micro fuel cell power systems – Safety

FOREWORD

1) The International Electrotechnical Commission (IEC) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, IEC publishes International Standards, Technical Specifications, Technical Reports, Publicly Available Specifications (PAS) and Guides (hereafter referred to as “IEC Publication(s)”). Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.
2) The formal decisions or agreements of IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested IEC National Committees.
3) IEC Publications have the form of recommendations for international use and are accepted by IEC National Committees in that sense. While all reasonable efforts are made to ensure that the technical content of IEC Publications is accurate, IEC cannot be held responsible for the way in which they are used or for any misinterpretation by any end user.
4) In order to promote international uniformity, IEC National Committees undertake to apply IEC Publications transparently to the maximum extent possible in their national and regional publications. Any divergence between any IEC Publication and the corresponding national or regional publication shall be clearly indicated in the latter.
5) IEC itself does not provide any attestation of conformity. Independent certification bodies provide conformity assessment services and, in some areas, access to IEC marks of conformity. IEC is not responsible for any services carried out by independent certification bodies.
6) All users should ensure that they have the latest edition of this publication.
7) No liability shall attach to IEC or its directors, employees, servants or agents including individual experts and members of its technical committees and IEC National Committees for any personal injury, property damage or other damage of any nature whatsoever, whether direct or indirect, or for costs (including legal fees) and expenses arising out of the publication, use of, or reliance upon, this IEC Publication or any other IEC Publications.
8) Attention is drawn to the Normative references cited in this publication. Use of the referenced publications is indispensable for the correct application of this publication.
9) Attention is drawn to the possibility that some of the elements of this IEC Publication may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

This consolidated version of IEC 62282-6-100 consists of the first edition (2010) [documents 105/255/FDIS and 105/261/RVD], its amendment 1 (2012) [documents 105/402/FDIS and 105/408/RVD] and its corrigendum of December 2011. It bears the edition number 1.1.

The technical content is therefore identical to the base edition and its amendment and has been prepared for user convenience. A vertical line in the margin shows where the base publication has been modified by amendment 1. Additions and deletions are displayed in red, with deletions being struck through.

International Standard IEC 62282-6-100 has been prepared by IEC technical committee 105: Fuel cell technologies

This standard cancels and replaces IEC/PAS 62282-6-1 published in 2006. This first edition constitutes a technical revision.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

How to use this standard:

The subclauses and clauses of the main body of the text are modified, replaced or applied as they are in each of the annexes, which applies to a different technology. Instructions are written in Italic type.

a) For the methanol, and methanol and water fuels covered by Clauses 1 through 7, all requirements are given in Clauses 1 through 7 and the annexes should not be used for these fuels.
b) For the specific fuels and technologies covered by Annexes A through H, each annex outlines the additional or modified requirements with respect to the requirements contained in Clauses 1 through 7 for certification of such micro fuel cell power systems, micro fuel cell power units and their respective fuel cartridges covered by the specific annex.
c) Where possible, the numbering system of the annexes corresponds to the numbering of Clauses 1 through 7 and their subclauses. Requirements from Clauses 1 through 7 and their subclauses not specifically addressed in an annex apply to the fuels and technologies covered by that particular annex as written in Clauses 1 through 7.
d) Where an annex gives specific subclause direction – preceded by the annex letter designator – those specific subclauses in the annex reflect the additional or modified requirements for the fuels and technologies covered by the particular annex and shall be followed for that annex. Any additional subclauses have been assigned new numbers and shall be followed.
e) Modified or replacement figures or tables have been given modified table or figure designators – based on the figure or table number in Clauses 1 through 7 preceded by the annex letter designator. New figures or tables in the annexes have been given new figure or table designators and shall also be used.

A list of all parts of the IEC 62282 series, under the general title *Fuel cell technologies*, can be found on the IEC website.

The committee has decided that the contents of the base publication and its amendments will remain unchanged until the stability date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- reconfirmed,
- withdrawn,
- replaced by a revised edition, or
- amended.

NOTE The attention of National Committees is drawn to the fact that equipment manufacturers and testing organizations may need a transitional period following publication of a new, amended or revised IEC publication or one that replaces an existing Publicly Available Specification (PAS) in which to make products in accordance with the new requirements and to equip themselves for conducting new or revised tests.

It is the recommendation of the committee that the content of this publication be adopted for implementation nationally not earlier than 12 months from the date of publication.

In the meantime, IEC/PAS 62282-6-1 can still be ordered by contacting the local IEC member National Committee or the IEC Central Office.

A bilingual version of this publication may be issued at a later date.

IMPORTANT – The 'colour inside' logo on the cover page of this publication indicates that it contains colours which are considered to be useful for the correct understanding of its contents. Users should therefore print this document using a colour printer.

FUEL CELL TECHNOLOGIES –

Part 6-100: Micro fuel cell power systems – Safety

1 Scope

1.1 General

a) This consumer safety standard covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that are wearable or easily carried by hand, providing d.c. outputs that do not exceed 60 V d.c. and power outputs that do not exceed 240 VA. Portable fuel cell power systems that provide output levels that exceed these electrical limits are covered by IEC 62282-5-1.

b) Externally accessible circuitry is therefore considered to be safety extra low voltage (SELV) circuitry as defined in IEC 60950-1:2005, and as limited power circuits if further compliance with 2.5 of IEC 60950-1:2005 is demonstrated. Micro fuel cell power systems or units that have internal circuitry exceeding 60 V d.c. or 240 VA should be appropriately evaluated in accordance with the separate criteria of IEC 60950-1:2005.

c) This consumer safety standard covers all micro fuel cell power systems, micro fuel cell power units and fuel cartridges. This standard establishes requirements for all micro fuel cell power systems, micro fuel cell power units and fuel cartridges to ensure a reasonable degree of safety for normal use, reasonably foreseeable misuse, and consumer transportation of such items. The fuel cartridges covered by this standard are not intended to be refilled by the consumer. Fuel cartridges refilled by the manufacturer or by trained technicians shall meet all requirements of this standard.

d) These products are not intended for use in hazardous areas as defined by IEV 426-03-01.

1.2 Fuels and technologies covered

a) A micro fuel cell power system block diagram is shown in Figure 1.

b) All portions of this standard, including all annexes, apply to micro fuel cell power systems, micro fuel cell power units and fuel cartridges as defined in Subclause 1.1 above.

c) Clauses 1 through 7 of this standard cover direct methanol fuel cells using methanol or methanol and water solutions as fuel. Clauses 1 through 7 cover specific requirements for direct methanol fuel cells using proton exchange membrane technologies. Clauses 1 through 7 also cover general requirements applicable to all fuel cell technologies and all fuels covered in Annexes A through H.

d) Annexes A through H cover fuels and fuel cell technologies as follows.

   1) Annex A covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use formic acid in water solutions – that are comprised of less than 85 % formic acid by weight – as fuel. These systems and units use direct formic acid fuel cell technologies.

   2) Annex B covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use hydrogen gas – that has been stored in a hydrogen absorbing metal alloy – as fuel. These systems and units use proton exchange membrane fuel cell technologies.

   3) Annex C covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that convert methanol or methanol and water solutions through a reformer into hydrogen rich methanol reformate – which is then immediately fed to the fuel cell or fuel cell stack – as fuel. These systems and units use proton exchange membrane fuel cell technologies.

4) Annex D covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use methanol or methanol and water solutions – derived from methanol clathrate compounds – as fuel. These systems and units use direct methanol fuel cell technologies.

5) Annex E covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from Class 8 (corrosive) borohydride compounds as fuel. These systems and units use proton exchange membrane fuel cell technologies. The designs may include fuel processing subsystems to derive hydrogen gas from the borohydride compound fuel.

6) Annex F covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from Class 4.3 (water reactive) borohydride compounds as fuel. These systems and units use proton exchange membrane fuel cell technologies. The designs may include fuel processing subsystems to derive hydrogen gas from the borohydride compound fuel.

7) Annex G covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use Class 8 (corrosive) borohydride compounds as fuel. These systems and units use direct borohydride fuel cell technologies.

8) Annex H covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use butane and butane/propane mixtures – consisting of at least 75 % butane by mass – as fuel. These systems and units use solid oxide fuel cell technologies.

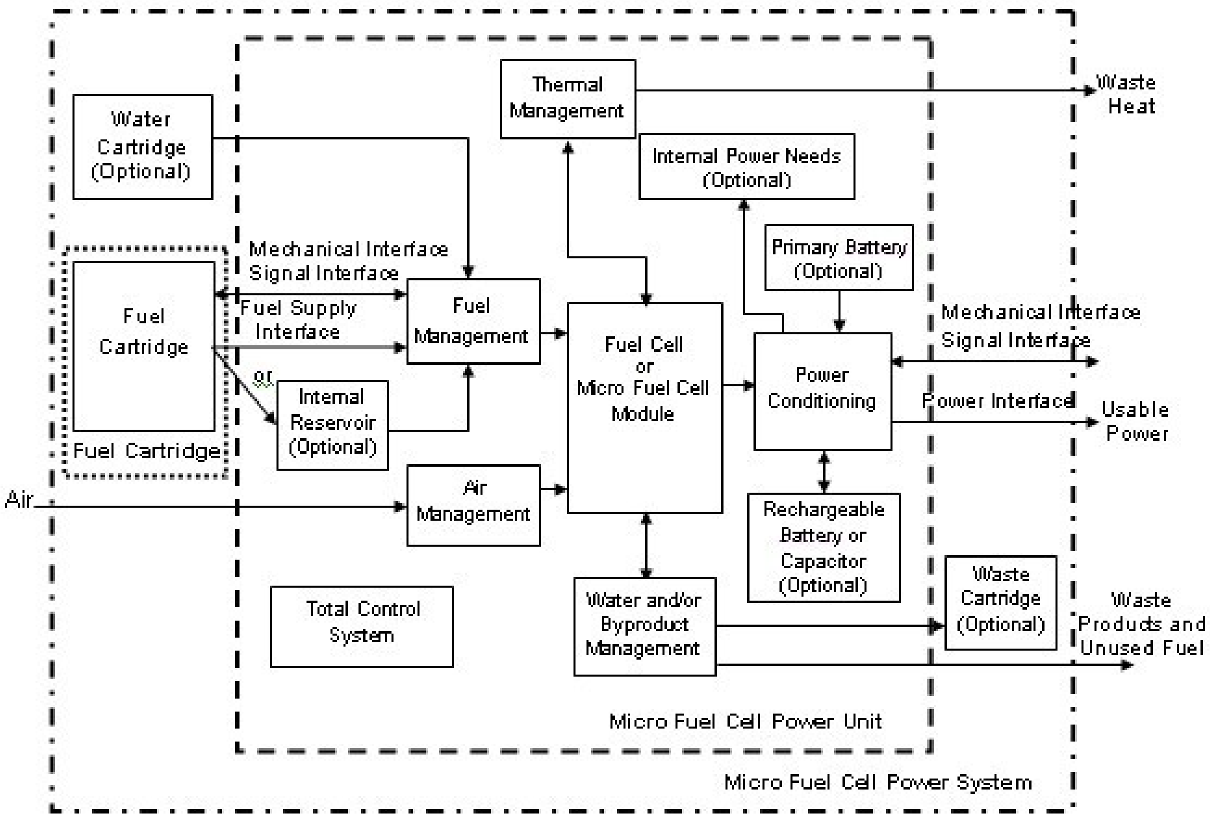


Figure 1 – Micro fuel cell power system block diagram

1.3 Equivalent level of safety

a) The requirements of this standard are not intended to constrain innovation. The manufacturer may consider fuels, materials, designs or constructions not specifically dealt with in this standard. These alternatives should be evaluated as to their ability to yield levels of safety equivalent to those prescribed by this standard.

b) It is understood that all micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall comply with applicable country and local requirements including, but not limited to, those concerning transportation, child-resistance and storage, where required.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-426:2008, *International Electrotechnical Vocabulary – Part 426: Equipment for explosive atmospheres*

IEC 60079-15:2005, *Electrical apparatus for explosive gas atmospheres – Part 15: Construction, test and marking of type of protection 'n' electrical apparatus*

IEC 60086-4, *Primary batteries – Part 4: Safety of lithium batteries*

IEC 60086-5, *Primary batteries – Part 5: Safety of batteries with aqueous electrolyte*

IEC 60695-1-1: *Fire hazard testing – Part 1-1: Guidance for assessing the fire hazard of electrotechnical products – General guidelines*

IEC 60695-2-11, *Fire hazard testing – Part 2-11: Glowing/hot-wire based test methods – Glow-wire flammability test method for end-products*

IEC 60695-11-10, *Fire hazard testing – Part 11-10: Test flames – 50 W horizontal and vertical flame test methods*

IEC 60730-1:1999, *Automatic electrical controls for household and similar use – Part 1: General requirements*
Amendment 1 (2003)
Amendment 2 (2007)[1)]

IEC 60950-1:2005, *Information technology equipment – Safety – Part 1: General requirements*

IEC 61032:1997, *Protection of persons and equipment by enclosures – Probes for verification*

IEC 62133:2002, *Secondary cells and batteries containing alkaline or other non-acid electrolytes – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications*

IEC 62281:2004, *Safety of primary and secondary lithium cells and batteries during transport*

ISO 175, *Plastics – Methods of test for determination of the effects of immersion in liquid chemicals*

ISO 188, *Rubber, vulcanized or thermoplastic – Accelerated ageing and heat resistance tests*

ISO 1817, *Rubber, vulcanized – Determination of the effect of liquids*

---

1) There exists a consolidated edition 3.2 (2007) that comprises IEC 60730-1 (1999), its Amendment 1 (2003) and its Amendment 2 (2007).

ISO 7010:2003, *Graphical symbols – Safety colours and safety signs – Safety signs used in workplaces and public areas*

ISO 9772, *Cellular plastics – Determination of horizontal burning characteristics of small specimens subjected to a small flame*

ISO 15649, *Petroleum and natural gas industries – Piping*

ISO 16000-3, *Indoor air – Part 3: Determination of formaldehyde and other carbonyl compounds – Active sampling method*

ISO 16000-6, *Indoor air – Part 6: Determination of volatile organic compounds in indoor and test chamber air by active sampling on Tenax TA sorbent, thermal desorption and gas chromatography using MS/FID*

ISO 16017-1, *Indoor, ambient and workplace air – Part 1: Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – Part 1: Pumped sampling*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
attached cartridge
fuel cartridge, which has its own enclosure that connects to the device powered by the micro fuel cell power system

3.2
electrical enclosure
parts of the micro fuel cell power system intended to limit access to parts that may be at hazardous voltages or hazardous energy level

3.3
exterior cartridge
fuel cartridge, which has its own enclosure that forms a portion of the enclosure of the device powered by the micro fuel cell power system

3.4
fire enclosure
parts of the micro fuel cell power system intended to minimize the spread of fire or flames from within

3.5
fuel
any of the following substances:

a) methanol or methanol and water solution;

b) formic acid and water solution;

c) hydrogen stored in hydrogen absorbing metal alloy;

d) borohydride compounds;

e) butane

NOTE Fuel a), methanol or methanol and water solution, is covered by Clauses 1 through 7 and Annexes C and D of the standard. Annex A, B, E, F, G and H cover fuels b) through e).

3.6
fuel cartridge
removable article that contains and supplies fuel to the micro fuel cell power unit or internal reservoir, not to be refilled by the user

3.7
fuel cell power system
generator system that uses a fuel cell module(s) electrically and thermally connected to generate usable electric energy and/or thermal energy

3.8
hazardous liquid fuel
any liquid fuel that has a methanol concentration greater than or equal to 4 %, or, for methanol concentrations less than 4 %, an amount greater than 5 ml. Other hazardous fuel definitions are given in Annexes A through H

3.9
insert cartridge
fuel cartridge, which has its own enclosure and is installed within the enclosure of the device powered by the micro fuel cell power system

3.10
internal reservoir
structure in a micro fuel cell power unit that stores fuel and cannot be removed

3.11
leakage
accessible hazardous liquid fuel outside the micro fuel cell power system or fuel cartridge

3.12
limited power sources
electrical supply either isolated from a mains supply or supplied by a battery or other device (i.e. fuel cell power unit) where the voltage, current and power levels are either inherently or non-inherently limited to levels that do not result in an electric shock or fire hazard

NOTE An inherently limited power source does not rely on a current-limiting device to meet limited power requirements although it may rely on an impedance to limit its output. However, a non-inherently limited power source relies upon a current-limiting device such as a fuse, etc. to meet limited power requirements.

3.13
toxic material
any material having a toxic hazard rating of 2 (medium) or higher, in the Sax's dangerous properties of industrial materials 11th Edition, or related reference guide

3.14
mechanical enclosure
parts of the micro fuel cell power system or micro fuel cell power unit intended to be a barrier to protect, shield, and control access to the internal components or material

3.15
micro fuel cell
fuel cell that is wearable or easily carried by hand, providing a d.c. output that does not exceed 60 V d.c. and power outputs that do not exceed 240 VA

3.16
micro fuel cell power system
micro fuel cell power unit and associated fuel cartridges that is wearable or easily carried by hand

3.17
micro fuel cell power unit
electric generator as defined in Figure 1, providing direct current output that does not exceed 60 V d.c. and continuous power output that does not exceed 240 VA

The micro fuel cell power unit does not include a fuel cartridge.

3.18
no accessible liquid
liquid fuel that is not subject to contact by consumers

3.19
no fuel vapour loss
vaporous fuel emission from fuel cartridge, non-operating micro fuel cell power system or unit limited to 0,08 g/h

Vaporous fuel emission for operating systems is limited to an amount defined in Subclause 7.3.12.

3.20
normal use conditions
range of conditions such as pressure, temperature, physical, chemical and thermal conditions of use as defined by the manufacturer

3.21
partially filled fuel cartridge
fuel cartridge that is approximately half filled with fuel (45 % – 55 % full)

3.22
rated power
manufacturer specified maximum continuous power capability of the micro fuel cell power system

3.23
satellite cartridge
fuel cartridge that is intended to be connected to and removed from the micro fuel cell power unit to transfer fuel to the internal reservoir inside the micro fuel cell power unit

3.24
refill valve
component of the non-user-refillable fuel cartridge that allows refilling the fuel cartridge only by trained technicians

3.25
shut-off valve
component of a fuel cartridge that controls the release of fuel

3.26
waste cartridge
cartridge that stores waste and byproducts from the micro fuel cell power unit

3.27
water cartridge
cartridge that is filled with water (no additives) to adjust fuel concentration

3.28
fuel management
components that might be used to control fuel properties if needed to support micro fuel cell power system operation; e.g., flow, concentration, cleanliness, temperature, humidity, or pressure

Not all micro fuel cell power systems will include all functions. Some micro fuel cell power systems will include additional functions.

3.29
air management
components that might be used to control air properties if needed to support micro fuel cell power system operation; e.g., flow, concentration, cleanliness, temperature, humidity, or pressure

Not all systems will include all functions. Some systems will include additional functions.

3.30
total control system
components of the micro fuel cell power system that coordinate properties of the micro fuel cell power system and reactants using electrical, mechanical, and/or digital inputs, outputs, software, and/or functions to effect proper micro fuel cell power system start-up, operation and shutdown, when necessary

3.31
primary battery (optional)
non-rechargeable battery

3.32
fuel cell
electrochemical device that converts the energy of the chemical reaction between a fuel, such as hydrogen or hydrogen rich gases, alcohols, hydrocarbons and an oxidant, such as air or oxygen, to d.c. power, heat and other reaction products

3.33
micro fuel cell module
assembly including a fuel cell stack(s) which electrochemically converts chemical energy to electric energy

3.34
fuel cell stack
assembly of two or more fuel cells which are electrically connected

3.35
non-operating
micro fuel cell power system or unit that is turned “off” or no longer operational

3.36
hazardous energy level
available power level of 240 VA or more having a duration of 60 s or more, or a stored energy level of 20 J or more (for example, from one or more capacitors), at a potential of 2 V or more

[1.2.8.10 of IEC 60950-1:2005]

4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

4.1 General

a) Compliance with the requirements of Clause 4 shall be verified during the review of the safety FMEA and/or during type tests specified in Clause 7.

b) The micro fuel cell power unit, when coupled to the fuel cartridge, shall be designed and constructed to avoid any credible risk of leakage, fire or explosion posed by the micro fuel cell power system itself or gases, vapours, liquids or other substances produced or used by the micro fuel cell power system.

c) To prevent a fire or explosion hazard within the micro fuel cell power system, the manufacturer shall eliminate potential ignition source(s) within areas where fuel is present (or can be potentially released).

d) Flammable, toxic or corrosive materials shall be kept within a closed containment system such as within fuel piping, in a reservoir, a fuel cartridge or similar enclosure.

4.2 FMEA / hazard analysis

4.2.1 A failure modes and effects analysis (FMEA) or equivalent reliability analysis shall be conducted by the manufacturer to identify faults which can have safety related consequences and the design features that serve to mitigate those faults. The analysis shall include failures that may result in leakage. Failures related to refilling of non-user refillable fuel cartridges, if anticipated by the manufacturer or trained technicians, shall be considered.

4.2.2 Guidance can be found in the following informative references: IEC 61025, *Fault tree analysis* and IEC 60812, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*.

4.2.3 It shall be the responsibility of the manufacturer to ensure that emissions from the micro fuel cell power system do not result in harmful or dangerous effects on the user or others during normal use, reasonably foreseeable misuse, and consumer transportation.

4.3 General materials

The materials and coating shall be resistant to degradation under the normal transportation and normal usage conditions over the manufacturer-defined life span of the product.

4.4 Selection of materials

4.4.1 Micro fuel cell power systems and units are expected to be exposed to a number of environmental conditions over the manufacturer-defined life span of the product such as vibration, shock, varying humidity levels and corrosive environments. Materials employed in the micro fuel cell power system or unit shall be resistant to these environmental conditions. If a micro fuel cell power system or unit is to be used in service where specific environmental conditions are beyond those accounted for in the required tests of this standard, then additional testing shall be performed to verify safety under those environmental conditions.

4.4.2 Metallic and non-metallic materials used to construct internal or external parts of the micro fuel cell power system or unit, in particular those exposed directly or indirectly to moisture, fuel and/or byproducts in either a gas or liquid form as well as all parts and materials used to seal or interconnect the same, e.g. welding consumables, shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable under the normal transportation and normal usage conditions within the manufacturer-defined life span of the product and for all test conditions; in particular, they shall be designed to retain their mechanical stability under normal use;

- they shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation;

- the chemical and physical properties necessary for operational safety shall not be significantly affected within the manufacturer-defined life span of the product; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, ageing resistance, the effects of temperature variations, the effects arising when materials are put together (e.g. galvanic corrosion), and the effects of ultraviolet radiation;
- where conditions of erosion, abrasion, corrosion or other chemical attack may arise, adequate measures shall be taken to
  - minimize that effect by appropriate design, e.g. additional thickness, or by appropriate protection, e.g. use of liners, cladding materials or surface coatings, taking due account of normal use;
  - permit replacement of parts which are most affected;
  - and draw attention, in the manual referred to in Clause 6, to type and frequency of inspection and maintenance measures necessary for continued safe use; where appropriate, it shall be indicated which parts are subject to wear and the criteria for replacement.

4.4.3 Elastomeric materials such as gaskets and tubing in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperatures that they are exposed to during normal use. Compliance shall be determined by the following: ISO 188 and ISO 1817.

4.4.4 Polymeric materials in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperature they are exposed to during normal use. Compliance shall be determined by ISO 175.

4.5 General construction

4.5.1 Micro fuel cell power systems and units shall have a safe construction that is resistant to dropping, vibration, crushing, environmental changes such as temperature, and atmospheric pressure fluctuations during normal use, reasonably foreseeable misuse, and consumer transportation of such items.

4.5.2 Connection mechanisms, including the connection between a detachable fuel cartridge and the micro fuel cell power unit, and the electrical connection between the micro fuel cell power system or unit and the device that it powers, shall be designed such that they cannot be attached at a wrong location or in an incomplete state in such a way that leakage or danger of electrical shock results.

4.5.3 An edge projection or corner of a micro fuel cell power unit and a fuel cartridge shall not be sufficiently sharp to result in a risk of injury to persons during intended use or user maintenance.

4.5.4 The effects of moisture and relative humidity shall be considered during the FMEA process.

4.6 Fuel valves

4.6.1 This subclause applies to all shut-off valves, filling valves, relief valves, refilling valves, including all fuel cartridge types.

4.6.2 Operating and pressure containing parts of the shut-off valve and relief valve assemblies shall last the manufacturer-defined life span of the product under normal conditions.

4.6.3 The valves shall have means to prevent leakage of fuel through normal use, reasonably foreseeable misuse, and storage of the fuel cartridge.

4.6.4 The valves shall not be susceptible to unintended actuation, or manual actuation by a user not using tools, that results in fuel leakage. Compliance shall be checked using test probe 11 of IEC 61032: *Protection of persons and equipment by enclosures – Probes for verification* and a force of 9,8 N.

4.6.5 There shall be no leakage of fuel or fuel vapour loss during storage, connection, disconnection or transferring of fuel from the fuel cartridge to the micro fuel cell power unit.

4.7 Materials and construction – system

4.7.1 The maximum quantity of fuel stored in the micro fuel cell power unit shall not be more than 200 ml.

4.7.2 The micro fuel cell power system or unit shall be designed such that an explosion cannot occur even if fuel leaks from or inside the micro fuel cell power system or unit. The design criteria for such means (for example, required ventilation rate) shall be provided by the micro fuel cell power system or unit manufacturer. The means shall be provided either by the micro fuel cell power system or unit manufacturer or by the manufacturer of the device powered by the micro fuel cell power system or unit.

4.7.3 Components and materials inside the micro fuel cell power system or unit shall be constructed or shall make use of such materials that propagation of fire and ignition is mitigated. The material flammability shall be such that a sustained fire will not be supported after electrical power and the fuel and oxidant supply have been terminated. This may be demonstrated through the selection of materials meeting FV 0, FV 1 or FV 2 in accordance with IEC 60695-1-1 and IEC 60695-11-10.

4.7.4 Micro fuel cell stack membranes are not required to have flammability ratings.

4.7.5 Other materials within the micro fuel cell stack which comprise less than 30 % of the total micro fuel cell stack mass are considered to be of limited quantity and are permissible without flammability ratings.

4.8 Ignition sources

To prevent a fire or explosion hazard within the micro fuel cell power system or unit, the manufacturer shall either eliminate potential unintentional ignition source(s) within areas where fuel is present (or can be potentially released) or shall ensure that immediate and controlled oxidation occurs through the use of a catalytic reactor.

Potential unintentional ignition sources shall be eliminated by one or more of the following.

- The surface temperatures shall not exceed 80 % of the auto-ignition temperature, expressed in degrees Celsius, of the flammable gas or vapour.
- Equipment containing materials or components capable of catalysing the reaction of flammable fluids with air shall be capable of suppressing the propagation of the reaction from the equipment to the surrounding flammable atmosphere.
- Electrical equipment and/or components, if subject to contact with fuel, shall be suitable for the area in which it is installed.
- The potential for static discharge sufficient to cause ignition shall be eliminated by proper material selection and proper bonding and grounding.
- Electrical components like fuses, other over-current protection devices, sensors, electric valves and solenoids, when operating under their intended condition, shall not produce thermal effects, arcs or sparks capable of igniting a flammable release of gas.

Immediate and controlled oxidation shall be ensured by the following:

- Catalytic reactors designed to safely control oxidation are acceptable. The temperature within such reactors may be greater than the auto-ignition temperature of the fluid. If the catalytic reactor deviates from proper operating conditions, as defined by the manufacturer, the micro fuel cell power system or unit shall be automatically transferred into a safe state.

4.9 Enclosures and acceptance strategies

A fire enclosure is required when temperatures of parts under fault conditions could be sufficient for ignition.

4.9.1 Parts requiring a fire enclosure

Except where Method 2 of 4.7.1 of IEC 60950-1:2005 is used exclusively, or as permitted in 4.7.2.2 of IEC 60950-1:2005, the following are considered to have a risk of ignition and, therefore, require a fire enclosure:

- power circuits not meeting the requirements of Table 3 or Table 4 (non-limited power circuits);
- components in circuits supplied by limited power sources as specified in 2.5 of IEC 60950-1:2005, but not mounted on material of flammability class V-1 or V-0 (IEC 60695-11-10) class material;
- components within a power supply unit or assembly having a limited power output as specified in 2.5 of IEC 60950-1:2005, including non-arcing over-current protective devices, limiting impedances, regulating networks and wiring, up to the point where the limited power source output criteria are met.

See Table 1 for material flammability requirements.

Compliance with 4.7.1 of IEC 60950-1:2005 and 4.7.2.2 of IEC 60950-1:2005 is checked by inspection and by evaluation of the data provided by the manufacturer. In the case where no data is provided, compliance is determined by tests.

4.9.2 Parts not requiring a fire enclosure

The following parts do not require a fire enclosure.

- Motors are not required to have fire enclosures if they comply with the applicable requirements outlined in Annex B of IEC 60950-1:2005.
- Electromechanical components complying with 5.3.5 of IEC 60950-1:2005.
- Wiring and cables insulated with PVC, TFE, PTFE, FEP, ETFE, PFA, neoprene, or polyimide.
- Components, including connectors, meeting the requirements of 4.7.3.2 of IEC 60950-1: 2005, which fill an opening in a fire enclosure.
- Connectors in circuits supplied by limited power sources complying with 2.5 of IEC 60950-1:2005.
- Other components in circuits supplied by limited power sources complying with 2.5 of IEC 60950-1:2005 and mounted on materials of flammability class V-1 or V-0 (IEC 60695-11-10) class material.
- Other components complying with Method 2 of 4.7.1 of IEC 60950-1:2005.
- Equipment, or a part of the equipment, having a momentary contact switch which the user has to activate continuously, and the release of which removes all power from the equipment or part.
- Fuel cartridges that do not contain electrical circuitry capable of causing ignition under fault conditions do not require a fire enclosure.

- Compliance with 4.7.1 of IEC 60950-1:2005 is checked by inspection and by evaluation of the data provided by the manufacturer. In the case where no data is provided, compliance is determined by tests.

Table 1 – Summary of material flammability requirements

Part		Requirements
Fire enclosure	Enclosure	V-1 (IEC 60695-11-10), or Test A.2 of IEC 60950-1:2005, or Hot wire test of IEC 60695-2-11 (if $<$ 13 mm air from sources of ignition)
	Parts which fill an opening	V-1 (IEC 60695-11-10), or Test A.2 of IEC 60950-1:2005, or Relevant IEC component standards
Outside the fire enclosure	Components and parts including mechanical and electrical enclosures	HB40 (IEC 60695-11-10) for thickness > 3 mm, or HB75 (IEC 60695-11-10) for thickness $<$ 3 mm, or HBF (foamed) (ISO 9772), or 550 °C glow wire test of IEC 60695-2-11, or see 4.9.3 for exceptions
Inside the fire enclosure	Components and parts including mechanical and electrical enclosures	V-2, or HF-2 (foamed) (ISO 9772), or Test A.2 of IEC 60950-1:2005, or Relevant IEC component standards, or see 4.9.4 for exceptions
Any location	Air filter assemblies	V-2 (IEC 60695-11-10), or HF-2 (foamed) (ISO 9772), or Test A.2 of IEC 60950-1:2005, or see 4.7.3.5 of IEC 60950-1:2005

4.9.3 Materials for components and other parts outside fire enclosures

4.9.3.1 Except as otherwise noted below, materials for components and other parts (including mechanical enclosures, electrical enclosures and decorative parts), located outside fire enclosures, shall be of flammability class HB75 if the thinnest significant thickness of this material is $<$ 3 mm, or flammability class HB40 if the thinnest significant thickness of this material is $>$ 3 mm, or flammability class HBF. See Table 1 for material flammability requirements.

NOTE Where a mechanical or an electrical enclosure also serves as a fire enclosure, the requirements for fire enclosures apply.

4.9.3.2 Requirements for materials in air filter assemblies are in 4.7.3.5 of IEC 60950-1: 2005. See Table 1 for material flammability requirements.

4.9.3.3 Connectors shall comply with one of the following:

a) be made of material of flammability class V-2; or
b) pass the tests of Clause A.2 of IEC 60950-1:2005; or
c) comply with the flammability requirements of the relevant IEC component standard; or
d) be mounted on material of flammability class V-1 or V-0 (IEC 60695-11-10) class material and be of a small size.

4.9.3.4 The requirement for materials for components and other parts to be of flammability class HB40, flammability class HB75, or flammability class HBF, does not apply to any of the following.

a) Electrical components that do not present a fire hazard under abnormal operating conditions when tested according to 5.3.7 of IEC 60950-1:2005.

b) Materials and components within an enclosure of 0,06 m^3 or less, consisting totally of metal and having no ventilation openings, or within a sealed unit containing an inert gas.

c) Components meeting the flammability requirements of a relevant IEC component standard which includes such requirements.

d) Electronic components, such as integrated-circuit packages, opto-coupler packages, capacitors and other small parts that are mounted on material of flammability class V-1 or V-0 (IEC 60695-11-10) class material.

e) Wiring, cables and connectors insulated with PVC, TFE, PTFE, FEP, ETFE, PFA, neoprene, or polyimide.

f) Individual clamps (not including helical wraps or other continuous forms), lacing tape, twine and cable ties used with wiring harnesses.

g) Gears, cams, belts, bearings and other small parts which would contribute negligible fuel to a fire, including decorative parts, labels, mounting feet, key caps, knobs and the like.

4.9.3.5 Compliance is checked by inspection of the equipment and material data sheets and, if necessary, by the appropriate test or tests in Annex A of IEC 60950-1:2005.

4.9.4 Materials for components and other parts inside fire enclosures

4.9.4.1 Requirements for materials in air filter assemblies are in 4.7.3.5 of IEC 60950-1: 2005. See Table 1 for material flammability requirements.

4.9.4.2 Inside fire enclosures, materials for components and other parts (including mechanical and electrical enclosures located inside fire enclosures) shall comply with one of the following:

a) be of flammability class V-2, or flammability class HF-2; or

b) pass the flammability test described in Clause A.2 of IEC 60950-1:2005; or

c) meet the flammability requirements of a relevant IEC component standard that includes such requirements.

d) See Table 1 for material flammability requirements.

4.9.4.3 The above requirement does not apply to any of the following:

- electrical components which do not present a fire hazard under abnormal operating conditions when tested according to 5.3.7 of IEC 60950-1:2005;
- materials and components within an enclosure of 0,06 m^3 or less, consisting totally of metal and having no ventilation openings, or within a sealed unit containing an inert gas;
- one or more layers of thin insulating material, such as adhesive tape, used directly on any surface within a fire enclosure, including the surface of current-carrying parts, provided that the combination of the thin insulating material and the surface of application complies with the requirements of flammability class V-2, or flammability class HF-2;

NOTE Where the thin insulating material referred to in the above exclusion is on the inner surface of the fire enclosure itself, the requirements in 4.6.2 of IEC 60950-1:2005 continue to apply to the fire enclosure.

- electronic components, such as integrated circuit packages, opto-coupler packages, capacitors and other small parts that are mounted on material of flammability class V-1 or V-0 (IEC 60695-11-10) class material;
- wiring, cables and connectors insulated with PVC, TFE, PTFE, FEP, ETFE, PFA, neoprene, or polyimide;

- individual clamps (not including helical wraps or other continuous forms), lacing tape, twine and cable ties used with wiring harnesses;
- wire which complies with the requirements for VW-1 or FT-1 or better, and which is so marked;
- the following parts, provided that they are separated from electrical parts (other than insulated wires and cables) which under fault conditions are likely to produce a temperature that could cause ignition, by at least 13 mm of air or by a solid barrier of material of flammability class V-1 or V-0 (IEC 60695-11-10) class material;
  - gears, cams, belts, bearings and other small parts which would contribute negligible fuel to a fire, including labels, mounting feet, key caps, knobs and the like;
  - tubing for air or any fluid systems, containers for powders or liquids and foamed plastic parts, provided that they are of flammability class HB75 if the thinnest significant thickness of the material is $<$ 3 mm, or flammability class HB40 if the thinnest significant thickness of the material is > 3 mm, or flammability class HBF.

4.9.4.4 Compliance is checked by inspection of the equipment and material data sheets and, if necessary, by the appropriate test or tests of Annex A of IEC 60950-1:2005.

4.9.5 Mechanical enclosures

4.9.5.1 A mechanical enclosure shall be sufficiently complete to contain or deflect parts which, because of failure or for other reasons, might become loose, separated or thrown from a moving part.

4.9.5.2 Compliance is checked by inspection of the construction and available data and, where necessary, by the relevant tests of 4.2.2, 4.2.3, 4.2.4, and 4.2.7 of IEC 60950-1:2005, and Type Testing in Clause 7 as applicable.

4.9.5.3 After the tests of 4.2.2, 4.2.3, 4.2.4 and 4.2.7 of IEC 60950-1:2005, the sample shall continue to comply with the requirements of 2.1.1 and 4.4.1 of IEC 60950-1:2005. It shall show no signs of interference with the operation of safety features such as thermal cut-outs, over-current protection devices or interlocks.

4.9.5.4 Damage to finish, cracks, dents and chips are disregarded if they do not adversely affect safety.

NOTE If a separate enclosure or part of an enclosure is used for a test, it may be necessary to reassemble such parts on the equipment in order to check compliance.

4.10 Protection against fire, explosion, corrosivity and toxicity hazard

4.10.1 Flammable, toxic and corrosive fluids shall be kept within a closed containment system such as within fuel piping, in a reservoir, a fuel cartridge or similar enclosure. Compliance shall be verified by type testing in accordance with Clause 7.

4.10.2 A micro fuel cell power system or unit may be equipped with a means of detecting concentration levels of fluids in Table 7 and shutting down the micro fuel cell power system or unit prior to exceeding the concentration limit.

4.10.3 Internal wiring and insulation in general shall not be exposed to fuel, oils, grease or similar substances, unless the insulation has been evaluated for contact with these substances.

4.11 Protection against electrical hazards

The voltages within the micro fuel cell power system or unit shall be within the SELV limits. Determinations shall be made in accordance with 2.2 of IEC 60950-1:2005. If internal voltages exceed 60 V d.c., the micro fuel cell power system or unit is to be further investigated in accordance with IEC 60950-1:2005. Circuits that exceed SELV shall meet the criteria for hazardous voltage circuits including electrical spacing, and accessibility criteria as received and after testing that could result in exposed parts in accordance with IEC 60950-1:2005.

Components in hazardous voltage circuits may require additional evaluation as well.

4.12 Fuel supply construction

4.12.1 Fuel cartridge construction

Fuel cartridges shall conform to the following requirements.

4.12.1.1 There shall be no leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with 7.3.3 and 7.3.4.

4.12.1.2 There shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Compliance shall be determined by type testing in accordance with 7.3.1.

4.12.1.3 Maximum fuel volume in the fuel cartridge shall not exceed 1 l.

4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance is checked by 7.3.11.

4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

4.12.1.6 A fuel cartridge shall be provided with a means to prevent mis-connection that would result in leakage of fuel when it is installed in a micro fuel cell power system. Compliance is checked by the connection cycling test, 7.3.11.

4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance is checked by the drop test, 7.3.5, and the connection cycling test, 7.3.11.

4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel to leak.

4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance is checked by:

- pressure differential tests, 7.3.1;
- vibration test, 7.3.2;

- temperature cycling test, 7.3.3;
- high temperature exposure test, 7.3.4;
- drop test, 7.3.5;
- compressive loading test, 7.3.6;
- long-term storage test, 7.3.9;
- high-temperature connection test, 7.3.10;
- connection cycling tests, 7.3.11.

4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

4.12.2 Fuel cartridge fill requirement

The fuel cartridge design and fuel fill amount shall allow fuel expansion without leakage to a fuel cartridge temperature of 70 ºC in the case of the fuel cartridge alone and when the fuel cartridge is constrained by the micro fuel cell power system or a comparable test fixture.

4.13 Protection against mechanical hazards

4.13.1 Piping and tubing other than fuel lines

Requirements are listed below for the construction of piping, tubing and fittings – other than fuel lines – inside the micro fuel cell power system or unit.

4.13.1.1 Where micro fuel cell power systems or units are designed for internal pressures over 100 kPa gauge, they shall be designed, constructed, and tested in accordance with ISO 15649.

4.13.1.2 Micro fuel cell power systems or units designed for operation below 100 kPa gauge or, in accordance with the applicable regional or national pressure equipment codes and standards not qualifying as pressurized systems, such as low-pressure water hoses, plastic tubing, or other connections to atmospheric or low-pressure tanks and similar containers, shall be constructed of suitable materials, and their related joints and fittings shall be designed and constructed with adequate strength and leakage resistance to prevent unintended releases.

4.13.1.3 Unions shall be designed to be leak tight using sealing methods resistant to the fluid transported and the ambient conditions of use.

4.13.1.4 The piping and tubing construction shall be provided with sufficient capability to resist pressure and other load weight, and there will be no danger of contamination or leakage of the line contents. Compliance is determined by 7.3.1 and 7.3.6.

4.13.1.5 The piping and tubing construction shall be provided with suitable measures to prevent freezing, breakage, corrosion, etc. Compliance for freezing is determined by 7.3.3. Compliance for breakage is shown in 7.3.5.

4.13.2 Exterior surface and component temperature limits

4.13.2.1 General

Micro fuel cell power systems and units shall not attain excessive temperatures during normal operation. Compliance shall be checked by determining the temperature of the various parts while operating at the manufacturer’s rated output in the manufacturer's rated maximum ambient operating temperature. The micro fuel cell power system or unit is operated at the manufacturer's rated maximum output until the maximum stabilised temperatures are reached.

During the test, thermal cut-outs and overload devices shall not operate. The temperature shall not exceed the values shown in Table 2.

4.13.2.2 Exterior surfaces

To eliminate any risk of burn injury caused by contact with the micro fuel cell power system or unit, the temperature of the external enclosure shall not exceed the value shown in Table 2.

4.13.2.3 Handles, knobs, grips and similar parts

The user is intended to touch handles, knobs, grips and similar parts in order to operate the micro fuel cell power system or unit. The temperature of handles, knobs, grips and similar parts intended to be touched shall not exceed the values shown in Table 2.

4.13.2.4 Components

4.13.2.4.1 Table 2 shows the maximum normal temperature for various exterior components. The temperature of such components shall not exceed the values shown in Table 2.

4.13.2.4.2 For components and electrical wiring equipped in the micro fuel cell power system or unit that are not shown in Table 2, their temperatures shall not exceed the maximum temperature for which the components and wiring are rated.

Table 2 – Temperature limits

Part	Temperature °C
External enclosure, handles, knobs, grips and the like which, in normal use, are held:	
– metal	50
– porcelain or vitreous material	60
– moulded material, rubber, or wood	70
Parts and materials in direct contact with potentially flammable gas or vapours Exception – Areas that are separately evaluated that utilize a high-temperature process.	80 % of the auto-ignition temperature of the potentially flammable gas or vapour

4.13.3 Motors

4.13.3.1 Whether operating under intended conditions or during an abnormal condition like running overload or locked rotor, the temperature of the motor shall not increase to the point where it acts to ignite a flammable release of gas.

4.13.3.2 Motor parts such as the motor brush, thermal overload device or other make/break component(s), which act to interrupt a circuit even if the interruption is transient in nature, shall not cause a hazard by producing an arc or thermal effect capable of igniting a flammable release of gas.

4.14 Construction of electric device components

4.14.1 Limited power sources

Limited power sources shall meet one of the following:

a) the output is inherently limited in compliance with Table 3; or

b) an impedance limits the output in compliance with Table 3. If a positive temperature coefficient device is used, it shall pass the tests specified in IEC 60730-1, Clause 15, 17, J.15 and J.17; or

c) a non-arcing over-current protective device is used and the output is limited in compliance with Table 4; or

d) a regulating network limits the output in compliance with Table 3, both under normal operating conditions and after any single fault (see 1.4.14 of IEC 60950-1:2005,) in the regulating network (open circuit or short circuit); or

e) a regulating network limits the output in compliance with Table 3 under normal operating conditions, and a non-arcing over-current protective device limits the output in compliance with Table 4 after any single fault (see 1.4.14 of IEC 60950-1:2005) in the regulating network (open circuit or short circuit). Where a non-arcing over-current protective device is used, it shall be a suitable fuse or a non-adjustable, non-auto-reset, electromechanical device.

Compliance is checked by inspection and measurement and, where appropriate, by examination of the manufacturer's data for batteries. Batteries shall be fully charged when conducting the measurements for V_{OC} *and* I_{SC} *according to Tables 3 and 4.*

Table 3 – Limits for inherently limited power sources

Output voltage- d.c. [a] (V_{OC}) V d.c.	Output current [b] (I_{SC}) A	Apparent power [c] (S) VA
≤ 20	≤ 8,0	≤ 5 x V_{OC}
20 < V_{OC} ≤ 30	≤ 8,0	≤ 100
30 < V_{OC} ≤ 60	≤ 150 / V_{OC}	≤ 100

a V_{oc}: Output voltage measured with all load circuits disconnected. Voltages are for ripple-free d.c.

b I_{sc}: Maximum output current with any non-capacitive load, including short circuit, measured 60 s after the application of the load.

c S: Maximum output VA with any non-capacitive load measured 60 s after the application of the load.

Table 4 – Limits for power sources not inherently limited (Over-current protection required)

Output voltage [a] (V_{oc}) V d.c.	Output current [b] (I_{sc}) A	Apparent power [c] (S) VA	Current rating of over-current protection [d] A
≤ 20	≤ 1 000 / V_{oc}	≤ 250	≤ 5,0
20 < V_{oc} ≤ 30			≤ 100 / V_{oc}
30 < V_{oc} ≤ 60			≤ 100 / V_{oc}

[a] V_{oc}: Output voltage measured with all load circuits disconnected. Voltages are for ripple free d.c.

[b] I_{sc}: Maximum output current with any non-capacitive load, including short circuit, measured 60 s after the application of the load. Current limiting impedances in the equipment remain in the circuit during measurement, but overcurrent protection means are bypassed.

[c] S (VA): Maximum output VA with any non-capacitive load measured 60 s after application of load. Current-limiting impedances in the equipment remain in the circuit during measurement, but overcurrent protection means are bypassed.

NOTE The reason for making measurements with overcurrent protection means bypassed is to determine the amount of energy that is available to cause possible overheating during the operating time of the overcurrent protection means. If the overcurrent protection means is a discrete arcing device, further evaluation with respect to its isolation from potentially flammable gas vapours is to be made.

[d] The current ratings of the overcurrent protection means are based on fuses and circuit breakers that break the circuit within 120 s with a current equal to 210 % of the current rating specified in Table 4.

4.14.2 Devices that use electronic controllers

4.14.2.1 Control systems

System software and electronic circuitry relied upon as the primary safety means as determined by the safety analysis of 4.2, shall comply with Annex H of IEC 60730-1.

Micro fuel cell power systems or units using electronic controllers shall conform to the following.

a) During the course of normal usage, in case of any single controller malfunction, safety shall not be compromised.

b) During the course of normal usage, safety shall not be compromised in cases where any single portion of the control circuit fails.

4.14.3 Electrical conductors/wiring

4.14.3.1 Electric components and wiring shall be laid out so as to minimize thermal effects.

4.14.3.2 The covering of the wires shall not become damaged during normal carrying, usage, or during periods of non-operation.

4.14.3.3 The conductor used in the wiring shall be as short as possible, and if necessary, locations shall be provided with insulation, protected from heat, immobilized, or provided with other treatment.

4.14.3.4 In the case where exposed lead wires or terminals that connect to the micro fuel cell power system or unit exterior are attached incorrectly, the micro fuel cell power system or unit either will not operate or will operate without any abnormality.

4.14.3.5 Except in the following cases, exposed lead wires or terminals that connect to the exterior of the micro fuel cell power system or unit shall be distinguishable by assigned numbers, letters, symbols, colours, etc.

a) The wires or terminals have different physical shapes to prevent incorrect connection.

b) There are only two lead wires or terminals, and interchanging those wires or terminals has no effect on micro fuel cell power system or unit operation.

4.14.3.6 Wireways shall be smooth and free from sharp edges.

4.14.3.7 Wires shall be protected so that they do not come into contact with burrs, or be subjected to pinching during assembly, and the like, which may cause damage to the insulation of conductors.

4.14.3.8 Insulated wires that pass through holes shall be protected to prevent abrasion or cutting damage. Compliance is checked by inspection.

4.14.3.9 With the micro fuel cell power system or unit operating under intended conditions, the temperature of wiring material including printed wiring on circuit boards shall not increase to the point where it acts to ignite a flammable release of gas.

4.14.3.10 In the event of the micro fuel cell power system or unit operating under the abnormal operating condition of an electrical overload, printed wiring on “open” circuit boards shall not produce an arc or thermal effect capable of igniting a flammable release of gas.

4.14.4 Output terminal area

The output terminal area shall be designed to prevent accidental contact with human hands. This restriction does not apply to the following types of output terminal areas.

a) An output terminal area for which, when in its attached state, there is no risk of accidental human contact.

b) An output terminal area for which the output voltage and current is inherently limited in compliance with Table 3; or an over-current protection device limits the output in compliance with Table 4.

4.14.5 Electric components and attachments

4.14.5.1 Electric components and attachments shall have sufficient electrical ratings for use within the micro fuel cell power system or unit.

4.14.5.2 Batteries used in the micro fuel cell power system or unit shall comply with the following safety standards, as applicable:

IEC 60086-4, IEC 60086-5, IEC 62133 and IEC 62281.

4.14.6 Protection

4.14.6.1 Objective of protection devices

A micro fuel cell power system or unit shall automatically and safely suspend operation of the micro fuel cell power system or unit when a situation arises that interferes with continued operation. In addition, a protection function shall be provided with the micro fuel cell power system or unit when necessary. Moreover, this protection function shall be able to operate during both start-up and shutdown of the micro fuel cell power system or unit.

4.14.6.2 Protection from short-circuit accidents

A function shall be provided to safely suspend operation or to provide protection in response to a short-circuited load.

4.14.6.3 Protection from electrical overloading

Micro fuel cell power systems and units shall be so designed as to reduce the risk of fire as a result of an abnormal electrical overloading condition.

5 Abnormal operating and fault conditions testing and requirements

5.1 General

a) Each micro fuel cell power system or unit shall be designed so that the risk of fire, leakage, or other hazard due to mechanical or electrical overload or failure, or due to abnormal operation or careless use, is limited as far as practicable.

b) After abnormal operation or a single fault, the micro fuel cell power system or unit shall remain in a safe condition.

c) It is permitted to use fusible links, thermal cut-outs, overcurrent protection devices and the like to provide adequate protection if investigated and found not to become an ignition source.

d) Compliance is checked by inspection and by the tests of 5.2.

5.2 Compliance testing

a) Before the start of each test, the micro fuel cell power system or unit shall be operating normally.

b) If a component or subassembly is so enclosed that short-circuiting or disconnection is not possible, it is permitted to make the tests on sample parts provided with special connecting leads. If this is not possible or not practical, the component or subassembly as a whole shall pass the tests.

c) The micro fuel cell power system or unit is tested by applying abnormal operation or a single fault condition that may occur in normal use and reasonably foreseeable misuse. Hazard analysis (see 4.2) shall be used for guidance in identifying key faults to test. In addition, the micro fuel cell power system or unit that is provided with a protective covering is tested with the covering in place under normal idling conditions until steady conditions are established.

d) The micro fuel cell power system or unit, circuit diagrams, FMEA, hazard analysis, and component specifications are to be examined to determine those fault conditions that might occur. Examples include:

   1) short circuits and open circuits of semiconductor devices and capacitors;

   2) faults causing continuous dissipation in resistors designed for intermittent dissipation;

   3) internal faults in integrated circuits causing excessive dissipation.

5.3 Passing criteria

During the tests of simulations of abnormal operating and fault conditions:

a) No fire or flame at any time. No explosion at any time. No leakage and no fuel vapour loss.

b) The micro fuel cell power system or unit shall not emit molten metal.

c) Circuit traces that are designed to intentionally open in a repeatable manner in non-incendive circuits shall be in accordance with IEC 60079-15, or shall be isolated from fuel areas.

d) Enclosures shall not deform in such a way as to cause access to hazardous parts.

e) The temperatures of thermal insulation systems of motors, transformers and other coil-wound components shall not exceed 150 °C (302 °F) for Class A, 165 °C (329 °F) for Class E, 175 °C (347 °F) for Class B, 190 °C (374 °F) for Class F and 210 °C (410 °F) for Class H materials. If the failure of the insulation would not result in hazardous energy levels becoming accessible, a maximum temperature of 300 °C (572 °F) is permitted. Higher temperatures are permitted for insulation made of glass or ceramic material.

f) The temperatures and arcing that may occur shall not be a potential ignition source. If such an occurrence is deemed to become a potential ignition source, other means shall be provided to prevent the arcing or high temperature from occurring.

g) Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods.

h) Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or unit.

5.4 Simulated faults and abnormal conditions for limited power and SELV circuits

a) Where it is required to apply simulated faults or abnormal operating conditions, these shall be applied in turn and one at a time.

b) Faults, that are the direct consequence of a simulated fault or abnormal operating condition, are considered to be part of that simulated fault or abnormal operating condition.

c) When applying simulated faults or abnormal operating conditions, accessories, supplies and consumable materials shall be in place if they are likely to have an effect on the outcome of the test.

d) When applying simulated faults or abnormal operating conditions, consideration should be given to the non-arcing overcurrent protection devices provided as part of the protection for the end-product against overcurrents and short circuits.

e) Consideration shall also be given to arcing parts in the end-product if the application of the micro fuel cell power system or unit may emit potentially flammable vapours during normal or abnormal operation.

f) Where there is a specific reference to a single fault, the single fault consists of a single failure of any insulation or a single failure of any component.

5.5 Abnormal operation – electromechanical components

Where a hazard is likely to occur, electromechanical components other than motors are checked for compliance by the following fault tests.

a) Mechanical movement shall be locked in the most disadvantageous position while the component is energized normally.

b) In the case of a component, which is normally energized intermittently, a fault shall be simulated in the drive circuit to cause continuous energizing of the component.

c) The duration of each test shall be in accordance with the following.

   1) For micro fuel cell power system or unit components whose failure to operate is not apparent to the user, the test duration shall be as long as necessary to establish steady conditions or up to the interruption of the circuit due to other consequences of the simulated fault condition, whichever is shorter.

   2) For other micro fuel cell power system or unit components, the test duration shall be 5 min or up to the interruption of the circuit due to a failure of the component (for example, burnout).

5.6 Abnormal operation of micro fuel cell power systems or units with integrated batteries

A rechargeable battery, charged in accordance with the manufacturer's design, and integrated with the micro fuel cell power system or unit or recommended by the manufacturer for use with the micro fuel cell power system or unit, shall be used for each of the following tests:

a) For evaluating the safety of rechargeable battery charging, a battery is charged for a period of 7 h in accordance with each of the following conditions.

   1) With the battery-charging circuit adjusted for its maximum charging rate (if such an adjustment exists); followed by any single component failure that is likely to occur in the charging circuit and which would result in overcharging of the battery. The battery is charged for a period of 7 h. The battery is then subjected to rapid discharge by open-circuiting or short-circuiting any current-limiting or voltage-limiting components in the load circuit of the battery under test.

   2) With any single component failure that is likely to occur and which would result in reversed charging of the battery. The battery is charged for a period of 7 h. The battery is then subjected to rapid discharge by open-circuiting or short-circuiting any current-limiting or voltage-limiting components in the load circuit of the battery under test.

b) After completion of the tests above, the micro fuel cell power system or unit shall be subjected to electric strength testing in accordance with guidance provided in IEC 60950-1: 2005.

c) These battery abnormal tests shall not result in any of the following:

   1) chemical or fuel leaks of the battery, micro fuel cell power system, micro fuel cell power unit, or fuel cartridge caused by cracking, rupturing or bursting of a jacket; or

   2) explosion of the battery or micro fuel cell power system, micro fuel cell power unit, or fuel cartridge, if such explosion could result in injury to a user;

   3) emission of flame or expulsion of molten metal to the outside of the micro fuel cell power system, micro fuel cell power unit, or fuel cartridge;

   4) ignition of the micro fuel cell power system, micro fuel cell power unit, or fuel cartridge or fuel contained therein.

5.7 Abnormal operation – simulation of faults based on hazard analysis

The following faults shall be simulated.

a) Any abnormal conditions deemed necessary, based on Clause 4, to evaluate the protection parameters provided for the micro fuel cell power system or unit, e.g. over-temperature protection, short circuit, stack voltage.

b) Short circuit, disconnection or overloading of all relevant components and parts unless they are contained within a fire enclosure that complies with all requirements for fire enclosures including materials, see 4.9.1 and 4.9.4.

NOTE An overload condition is any condition between normal load and the maximum current condition up to short circuit.

c) Temperatures in excess of the over-temperature protection circuitry to ensure the safety of the micro fuel cell power system or unit.

6 Instructions and warnings for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

6.1 General

All micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall be accompanied by appropriate safety information (instructions, warnings, or both) communicating the intended safe transportation, use, storage, maintenance and disposal of the product, including warnings regarding adequate ventilation for storage.

If space does not permit all markings on the fuel cartridge, markings corresponding to a) through f) in 6.2 may be on the smallest unit package, or on a package insert. The fuel cartridge shall also be marked with the appropriate signal word ("CAUTION", "WARNING" or "DANGER") and the general warning sign (W001 specified in ISO 7010:2003) plus the text:

"(See accompanying Warning Information.)".

6.2 Minimum markings required on the fuel cartridge

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE FLAMMABLE AND TOXIC, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) KEEP AWAY FROM CHILDREN.

d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES OR IGNITION SOURCES.

e) FOLLOW USAGE INSTRUCTIONS.

f) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

g) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

h) COMPOSITION AND AMOUNT OF FUEL.

i) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.

6.3 Minimum markings required on the micro fuel cell power system

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE FLAMMABLE AND TOXIC, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES OR IGNITION SOURCES.

d) FOLLOW USAGE INSTRUCTIONS.

e) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

f) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

g) COMPOSITION OF FUEL.

h) MAXIMUM CAPACITY OF FUEL IN THE INTERNAL RESERVOIR, IF APPLICABLE.

i) TEXT OR MARKING THAT INDICATES THAT THE MICRO FUEL CELL POWER SYSTEM COMPLIES WITH IEC 62282-6-100.

j) ELECTRICAL OUTPUT (VOLTAGE, CURRENT, RATED POWER).

6.4 Additional information required either on the fuel cartridge or on accompanying written information or on the micro fuel cell power system or micro fuel cell power unit

Usage instructions to include:

a) safety instructions and warnings;

b) text or markings on the micro fuel cell power system indicating that the micro fuel cell power system complies with IEC 62282-6-100;

c) all micro fuel cell power systems and micro fuel cell power units shall identify the fuel cartridge(s) which are acceptable for use with the micro fuel cell power systems and micro fuel cell power units;

d) minimum and maximum operating and storage temperatures.

6.5 Technical documentation

Technical documentation shall include a user information manual which shall include safety instructions and the following:

a) instructional information that educates the end-user in the proper use, function and disposal of the fuel cartridge, micro fuel cell power unit and/or micro fuel cell power system;

b) information that identifies the manufacturer of the micro fuel cell power unit and/or micro fuel cell power system, including company name, address, telephone number, and web site;

c) all warnings and instructions affixed to the micro fuel cell power system, micro fuel cell power unit or fuel cartridge shall be set forth in the manual. Additional information further explaining or enhancing those warnings and instructions may be provided in the manual;

d) instructions that the micro fuel cell power system or unit shall be used in a well-ventilated area.

Local laws may apply to these requirements. Consult individual country authorities for details.

The manufacturer of the micro fuel cell power system, micro fuel cell power unit and/or fuel cartridges shall specify the type and relevant characteristics of the fuel and, if applicable, the quality and relevant characteristics of the fuel and water to be employed with the micro fuel cell power system. This information shall be provided as part of the documentation provided with the micro fuel cell power system or unit.

The micro fuel cell power systems or units shall specify the fuel cartridge(s) that are intended for use with them. This information shall be provided as part of the documentation provided with the micro fuel cell power unit or micro fuel cell power system.

7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

7.1 General

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table 5 lists the type tests that shall be performed.

Table 5 – List of type tests

Test reference	Test item	Test sample
7.3.1	Pressure differential tests	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.2	Vibration test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.3	Temperature cycling test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.4	High temperature exposure test	Fuel cartridge Partially filled fuel cartridge
7.3.5	Drop test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.6	Compressive loading test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
7.3.9	Long-term storage test	Fuel cartridge Partially filled fuel cartridge
7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Partially filled fuel cartridge and micro fuel cell power unit
7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit
7.3.12	Emission test	Micro fuel cell power system or power unit
Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or partially filled, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test. Test sequence: Tests 7.3.2 and 7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests 7.3.1, 7.3.2 and 7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or units. Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer's discretion if it does not compromise the individual test.		

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table 6.

Table 6 – Laboratory standard conditions

Item	Condition
Laboratory temperature	Laboratory temperature is “room temperature” (standard temperature condition, 22 °C ± 5 °C)
Laboratory room atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen.

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

7.2 Leakage measurement of methanol and the measuring procedure

The leakage measurement of methanol shall be executed in principle in accordance with the procedure shown in Figures 2 through 7 respectively. Exceptions will be noted in the various subclauses.

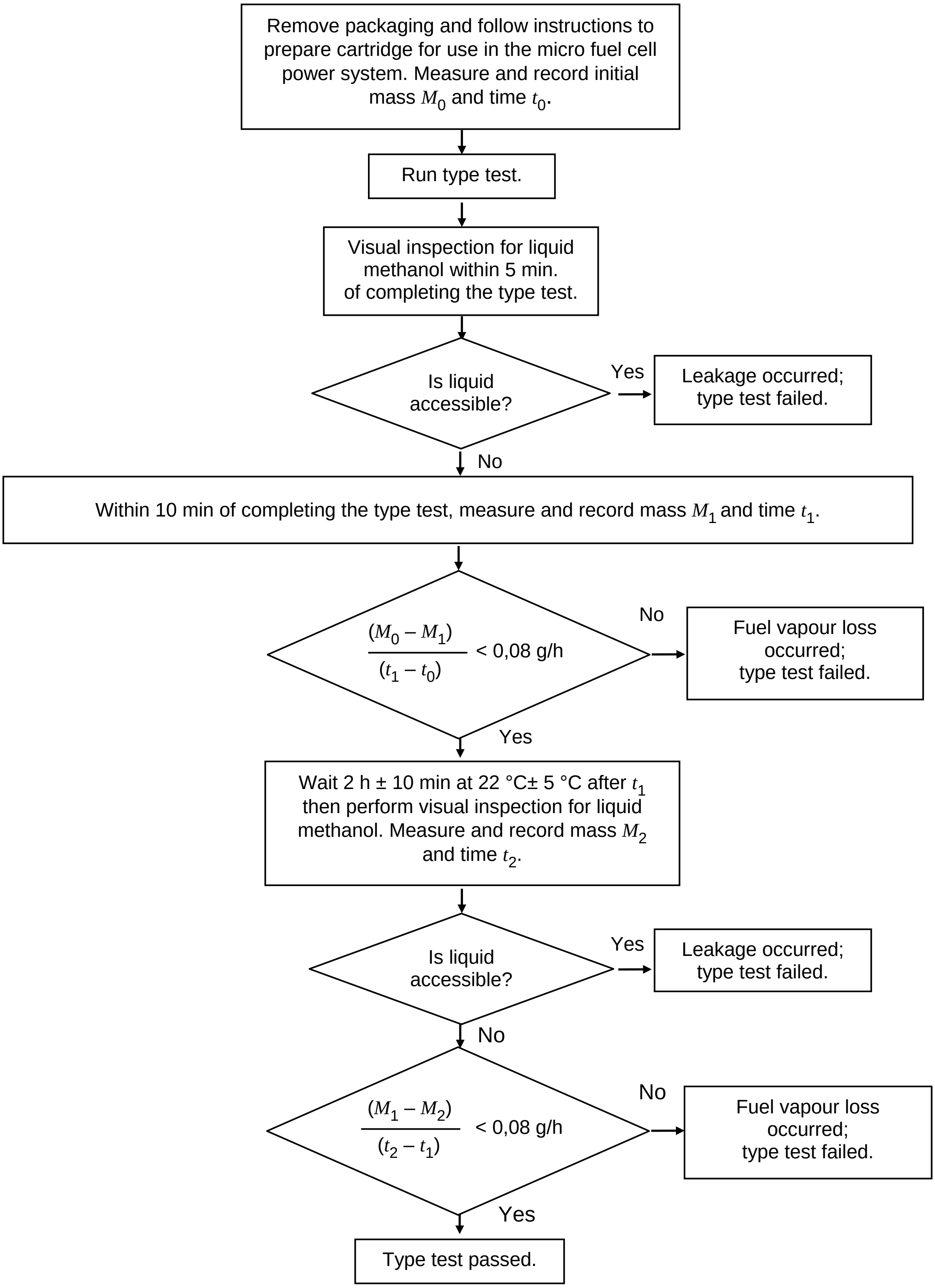


Figure 2 – Fuel cartridge leakage and mass loss test flow chart for pressure differential, vibration, drop, and compressive loading tests

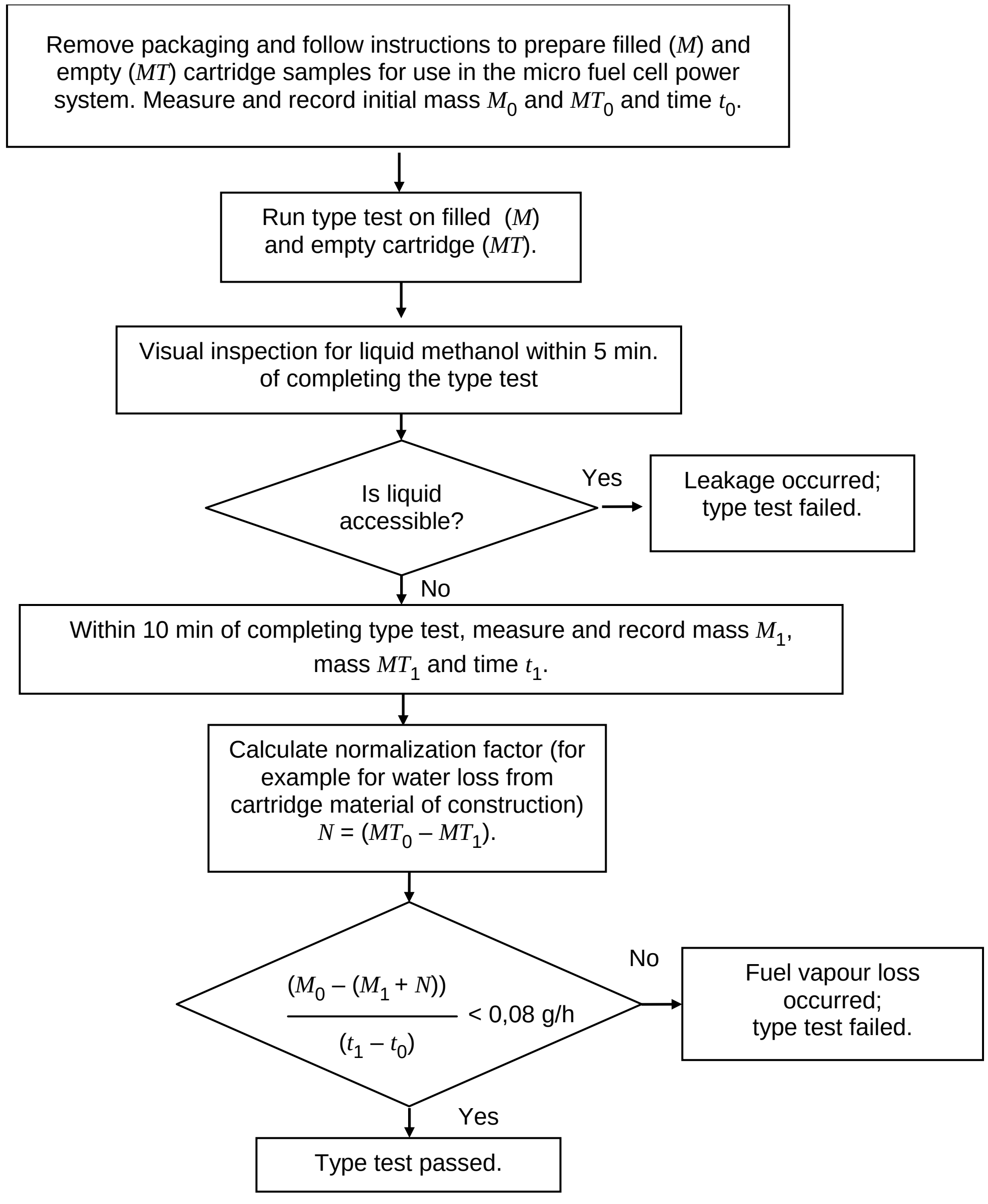


Figure 3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test

The maximum time interval $t_1 - t_0$ shall be set so that no more than half the fuel would be lost if it were escaping at the maximum allowable mass loss rate.

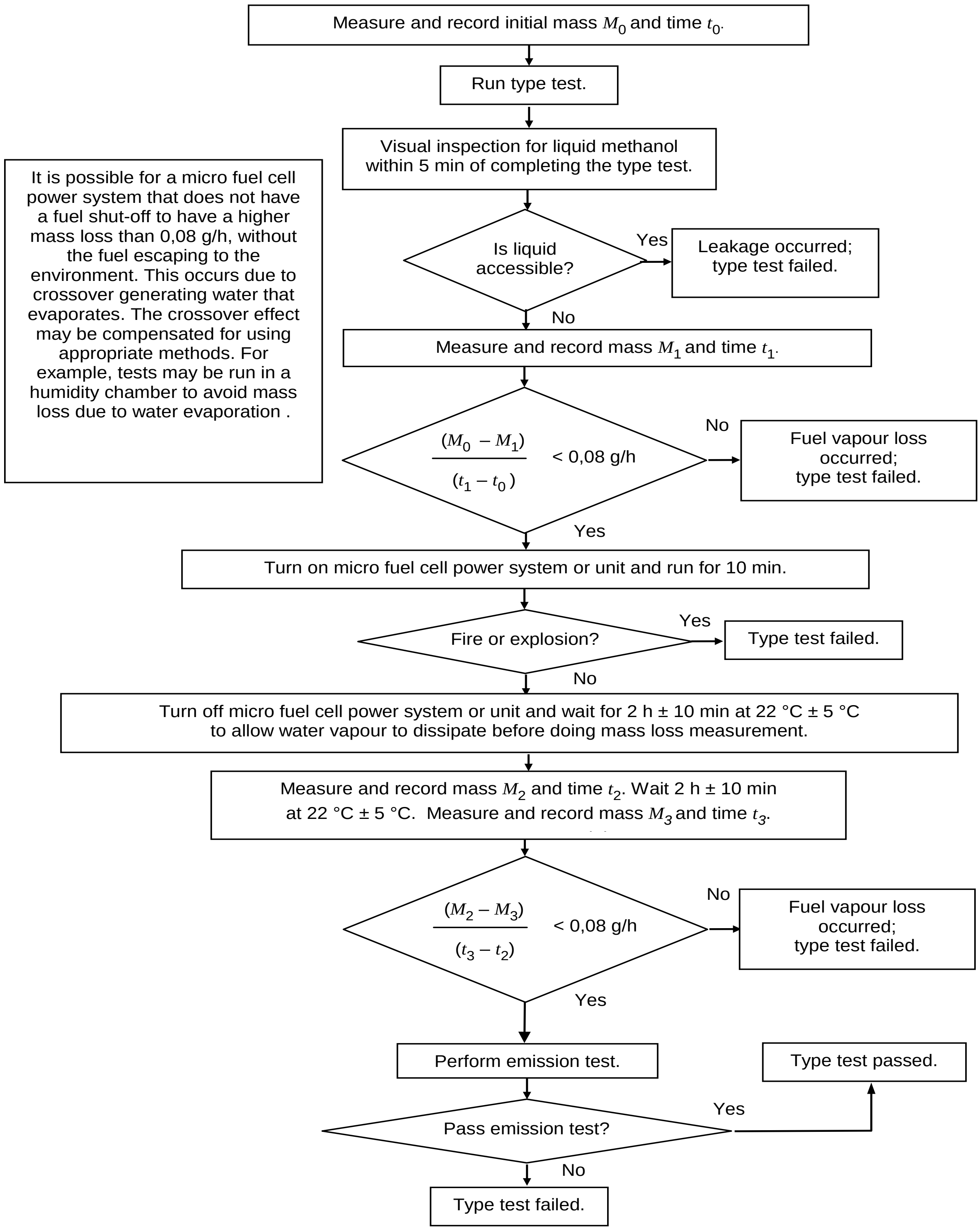


Figure 4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests

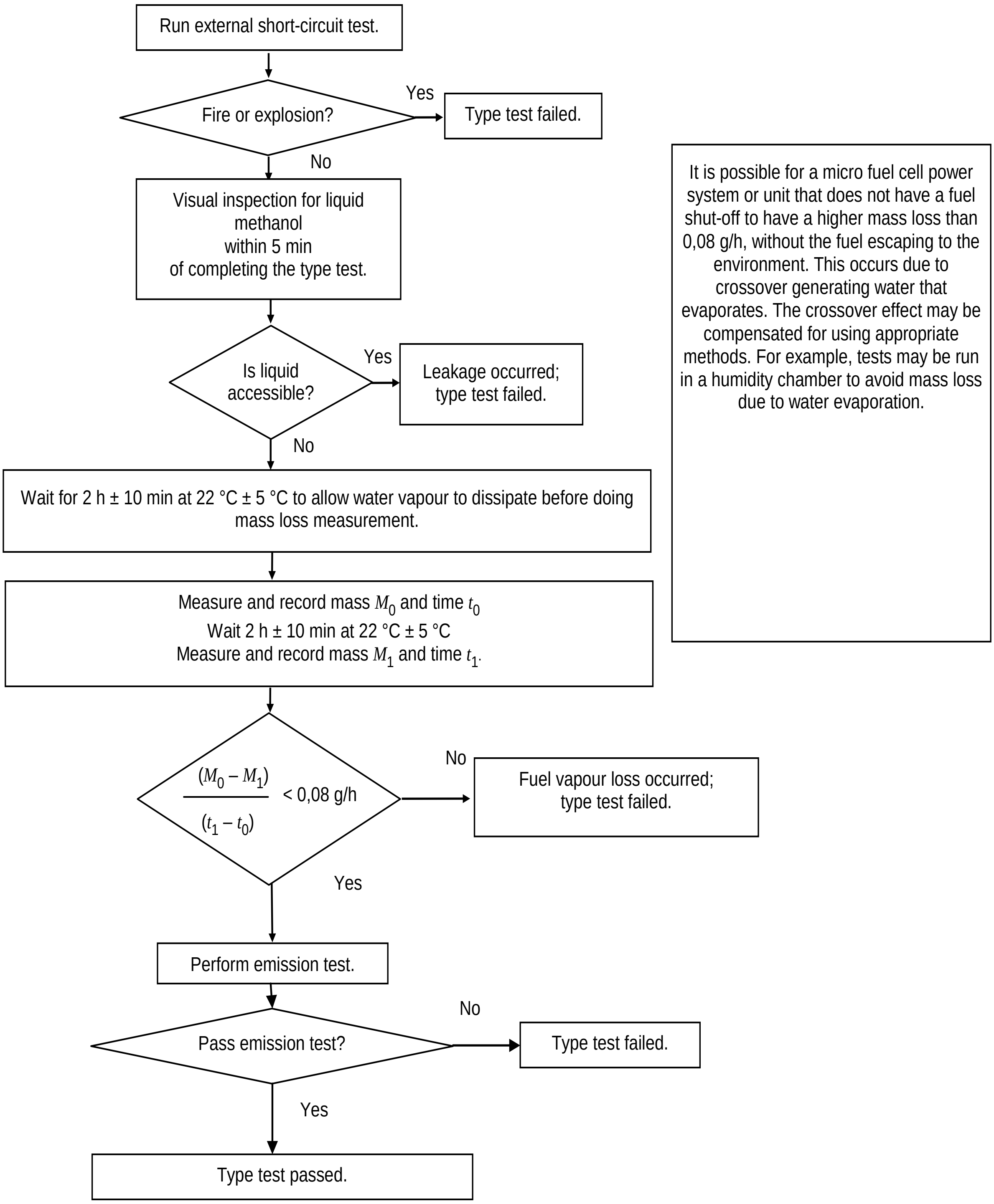


Figure 5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test

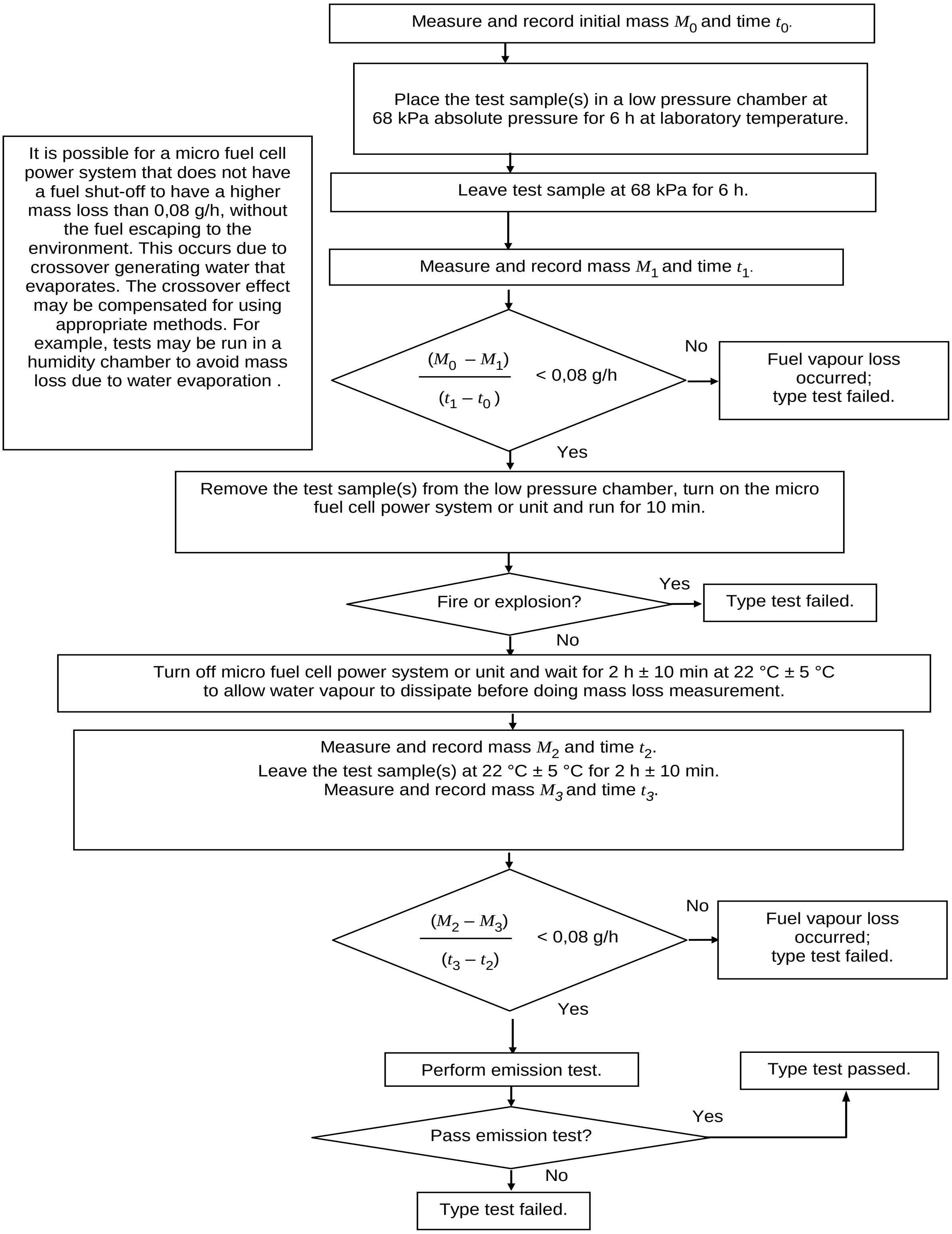


Figure 6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test

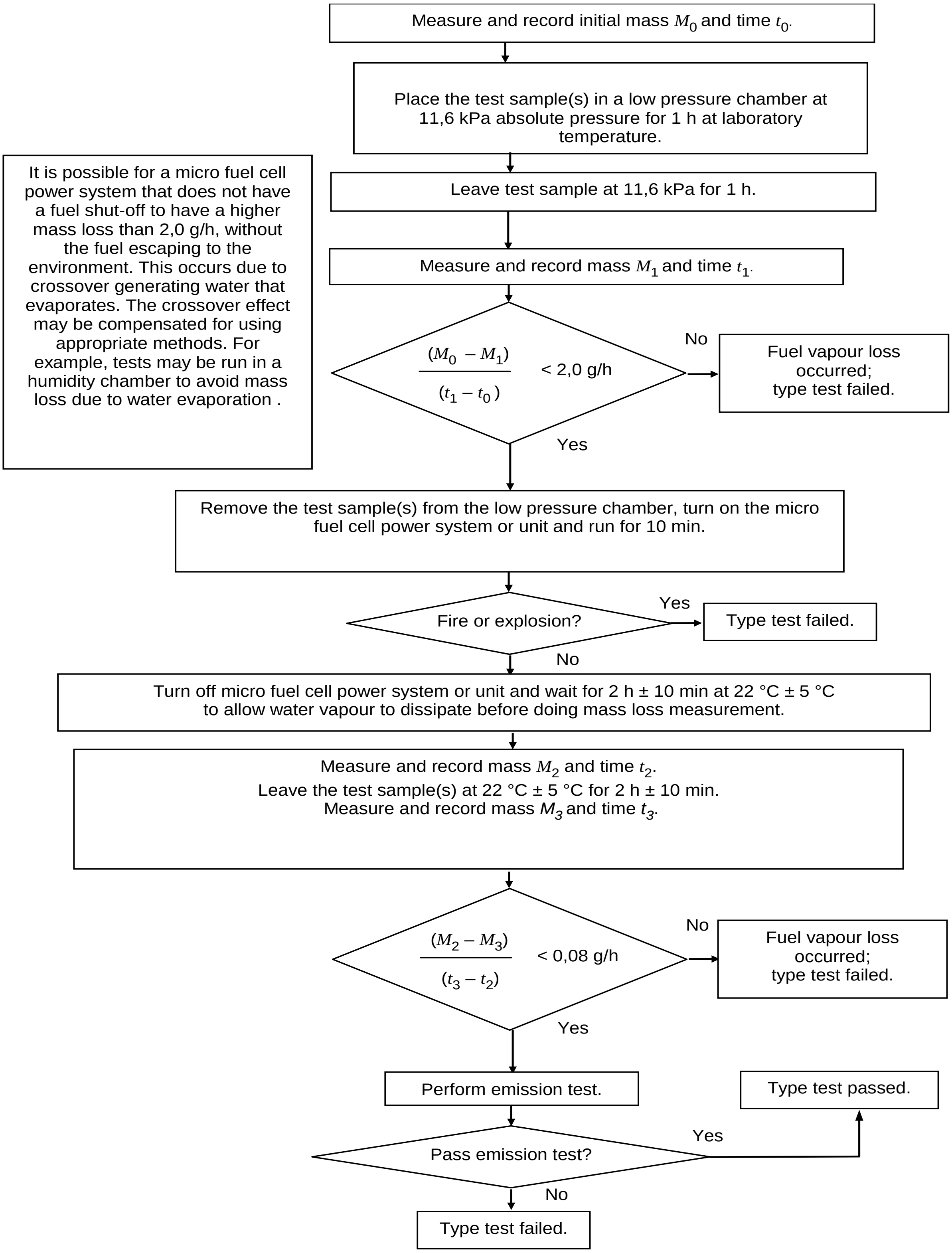


Figure 7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test

7.3 Type tests

7.3.1 Pressure differential tests

7.3.1.1 General

Portions of this test check compliance with Subclause 4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Depending upon which of the two limiting pressure conditions is greater, two options for testing are provided:

a) If 95 kPa internal gauge pressure plus normal working pressure of the fuel cartridge at 22 °C is greater than two times the gauge pressure of the fuel cartridge at 55 °C, either Subclause 7.3.1.2 or Subclause 7.3.1.3 may be used to verify compliance with Subclause 4.12.1.2.

b) If two times the gauge pressure of the fuel cartridge at 55 °C is greater than 95 kPa internal gauge pressure plus normal working pressure at 22 °C, Subclause 7.3.1.2 shall be used to verify compliance with Subclause 4.12.1.2.

7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

1) Using a suitable fluid medium such as water, pressurize the fuel cartridge body to an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. The pressure rise shall not exceed a rate of 60 kPa/s.

2) Maintain the maximum pressure for 30 min at laboratory temperature.

3) Using a suitable fluid medium such as water, pressurize the closed fuel cartridge valve to 95 kPa gauge pressure plus the normal working pressure of the cartridge at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. The pressure rise shall not exceed a rate of 60 kPa/s.

4) Maintain the maximum pressure for 30 min at laboratory temperature.

d) **Passing criteria:** No accessible liquid test medium leakage and no sudden drop of pressure during the course of the test. Leakage shall be checked visually. Invert the fuel cartridge and the fuel cartridge valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails.

7.3.1.3 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

1) Perform this test in accordance with Figure 2.

2) The sample shall be placed in a vacuum chamber and the pressure in the vacuum chamber shall be reduced to 95 kPa below normal atmospheric pressure.

3) Maintain the vacuum for 30 min.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no fuel vapour loss. See Figure 2. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure 6.

   2) Test samples shall be stored at a low external pressure of 68 kPa absolute pressure for 6 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure 6.

   3) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no accessible liquid leakage. See Figure 6. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test result is acceptable. During the 6 h test at 68 kPa absolute external pressure, the fuel vapour loss shall be less than 0,08 g/h.

7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure 7.

   2) Test samples shall be stored at a low external pressure of 11,6 kPa absolute pressure for 1 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure 7, with a fuel vapour loss at 11,6 kPa YES/NO passing criteria of less than 2,0 g/h on the basis of not exceeding 25 % of the lower flammability limit (LFL).

   3) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no accessible liquid leakage. See Figure 7. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test result is acceptable. During the 1 h test at 11,6 kPa absolute external pressure, the fuel vapour loss shall be less than 2,0 g/h.

7.3.2 Vibration test

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in 7.3.1 or a micro fuel cell power system used in 7.3.1.

b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure 2 for the fuel cartridge and Figure 4 for the micro fuel cell power system or unit.

2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured based upon Figure 2 for the fuel cartridge and Figure 4 for the micro fuel cell power system or unit. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

7.3.3 Temperature cycling test

a) **Test sample:** a fuel cartridge used in 7.3.2, a partially filled fuel cartridge used in 7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in 7.3.2 or a micro fuel cell power system used in 7.3.2.

b) **Purpose:** to simulate the effects of low temperature and high temperature exposure and the effects of extreme temperature change.

c) **Test procedure:**

1) Perform these tests in accordance with Figure 3 for the fuel cartridge and Figure 4 for the micro fuel cell power system or unit.

2) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

3) See Figure 8 for the temperature profile to be used.

4) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

5) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

6) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

7) The above process is to be done twice.

8) After 1 h at 22 °C ± 5 °C, leakage and fuel vapour loss shall be measured based upon the procedure described in Figure 3 (for fuel cartridge) and Figure 4 (for micro fuel cell power system or unit).

9) For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured based upon Figure 3 for the fuel cartridge and Figure 4 for the micro fuel cell power system or unit. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

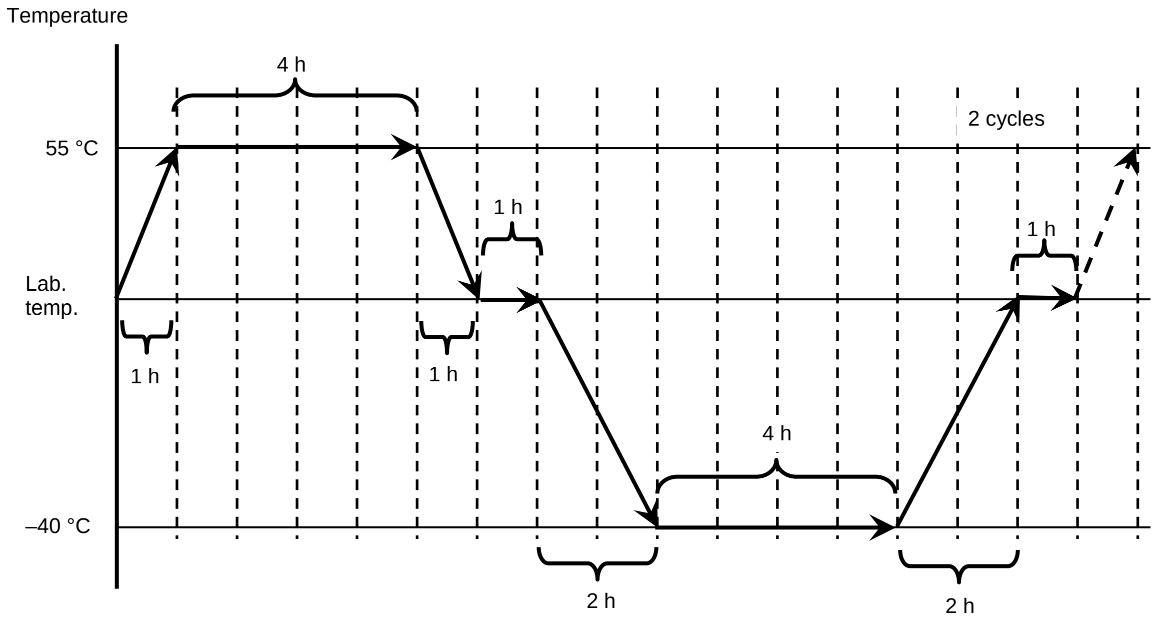


Figure 8 – Temperature cycling

7.3.4 High temperature exposure test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments.

c) **Test procedure:**

1) Two orientations shall be tested – valve up and valve down.

2) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

3) Remove the test sample to laboratory temperature.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure 3 for a fuel cartridge. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

7.3.5 Drop test

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

1) The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

2) The height of the drop shall be:

i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system;

ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge of more than 200 ml;

iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge of up to 200 ml.

3) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

4) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or unit may be used for all four drop orientations, or more than one micro fuel cell power system or unit may be used in subsequent drops, at the discretion of the manufacturer.

5) For all tests, drop orientations shall be:

i) valve up;

ii) valve down;

iii) two other mutually perpendicular orientations.

6) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured based upon Figure 2 for the fuel cartridge and Figure 4 for the micro fuel cell power system or unit. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable. If the micro fuel cell power system or unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

7.3.6 Compressive loading test

7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

1) The micro fuel cell power system or unit test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

5) Perform emission testing in accordance with 7.3.12 following the compressive loading test.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure 4. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions from micro fuel cell power system or unit shall meet the passing criteria in 7.3.12. If the micro fuel cell power system or unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge.

c) **Test procedure:**

   1) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

   2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

   3) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

   4) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure 2. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

7.3.7 External short-circuit test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

   1) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

   2) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

   3) Perform emission testing in accordance with 7.3.12 after each external short-circuit test.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure 5. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valves point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

Exterior surfaces shall not exceed temperatures in Table 2 during or after external short-circuit testing.

Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system or unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

NOTE The external short-circuit test can be done sequentially with the surface, component and exhaust gas temperature test using the same sample.

7.3.8 Surface, component and exhaust gas temperature test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to eliminate any risk of burn injury caused by contact with the enclosure of a micro fuel cell power system or unit and to eliminate any risk of burn injury caused by blown exhaust gas from vents and to verify compliance with component temperature ratings.

c) **Test procedure:**

   1) Temperatures shall be measured until temperatures stabilise within ± 2 °C for 5 min.

   2) This test shall be conducted at the manufacturer's rated ambient operating temperature.

   3) Temperature of the bare surface of micro fuel cell power units or micro fuel cell power systems operating at rated output shall be measured using infrared camera(s), thermocouples, or other suitable means.

   4) The micro fuel cell power system or unit shall be positioned for normal operation so that the exhaust gases are unimpeded.

   5) The temperature of exhaust gases shall be measured at a distance of 1 cm from the exhaust vent of the micro fuel cell power system or unit operating at rated output.

d) **Passing criteria:** The surface temperature of the micro fuel cell power system or micro fuel cell power unit parts where persons can touch easily shall not exceed the value shown in Table 2 depending upon the material. The temperature at 1 cm from the exhaust vent of the operating micro fuel cell power system or unit shall be less than 70 °C. During the test, thermal cut-outs and overload devices shall not operate.

   For components and electrical wiring in the micro fuel cell power system or unit that are not shown in Table 2, their temperatures shall not exceed the maximum temperature for which the components and wiring are rated. Safety related components shall be identified by the FMEA.

NOTE This test can be done sequentially with the external short-circuit test using the same sample.

7.3.9 Long-term storage test

7.3.9.1 General

Either 7.3.9.2 (Option 1), 7.3.9.3 (Option 2) or 7.3.9.4 (Option 3) may be used.

7.3.9.2 Option 1 – continuous weight measurement

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure 9):

   1) Use a load cell (continuous electronic weight sensing device) designed and calibrated for use at 50 °C ± 2 °C inside the temperature chamber.

2) Place the load cell in a temperature chamber at 50 °C ± 2 °C. Place the fuel cartridge on top of the load cell so that all the weight is being applied to the load cell. A fixture may be used to control the position of the fuel cartridge, to ensure all the weight is applied to the load cell.

3) Connect a digital readout to the load cell and collect the data either manually or automatically. The data should be collected with a high degree of confidence to assure that the fuel vapour loss does not exceed 0,08 g/h.

4) Measure and record initial mass M_{initial} and time t_i.

5) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

6) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{initial} and record time t_i. If the average mass loss rate is less than 0,08 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_f - t_i$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

7) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,08 g/h.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss and no liquid leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure 9. If the fuel cartridge fuel vapour loss is less than the 0,08 g/h fuel vapour loss criteria, then the test sample passes the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

7.3.9.3 Option 2 – periodic weight measurements

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure 9):

1) Measure and record initial mass M_{initial} and time t_i.

2) Place the fuel cartridge in a temperature chamber at 50 °C ± 2 °C. Weight measurements should be collected with a high degree of confidence to determine if the fuel vapour loss is less than 0,08 g/h with a minimum of once every three days.

3) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

4) The time in which the test samples are removed from the chamber for measurement shall not be included in the time the test sample is to be tested (28 days). Additional time should be added to get the test sample to the test temperature (50 °C ± 2 °C) each time the test sample is removed from the chamber. The test samples should only be stabilised at laboratory temperature if the mass loss will be affected.

5) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_f. If the average mass loss rate is less than 0,08 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_f - t_i$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

6) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,08 g/h.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss and no liquid leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure 9. If the fuel cartridge fuel vapour loss is less than the 0,08 g/h fuel vapour loss criteria, then the test sample passes the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

7.3.9.4 Option 3 – one weight measurement

This option is intended for fuel cartridges with very small leak rates.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure 9):

   1) Measure and record initial mass M_{initial} and time t_i.

   2) Place the fuel cartridges in a temperature chamber at 50 °C ± 2 °C. After 28 days, the fuel cartridges are removed from the chamber for measurement. The test samples should be stabilised at laboratory temperature if the mass loss will be affected. Then weight measurement is executed.

   3) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_f. If the average mass loss rate is less than 0,08 g/h, then the test sample passes the test for fuel vapour loss.

      i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

      ii) $\Delta t = t_f - t_i$ = 28 days × 24 h/day = 672 h.

      iii) M_{initial} = the initial mass of the fuel cartridge.

      iv) M_{final} = the final mass of the fuel cartridge.

   4) If the fuel cartridge is empty after 28 days, then the type test according to 7.3.9.2 Option 1 or 7.3.9.3 Option 2 shall be done.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss and no liquid leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure 9. If the fuel cartridge fuel vapour loss is less than the 0,08 g/h fuel vapour loss criteria, then the test sample passes the test for fuel vapour loss. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually

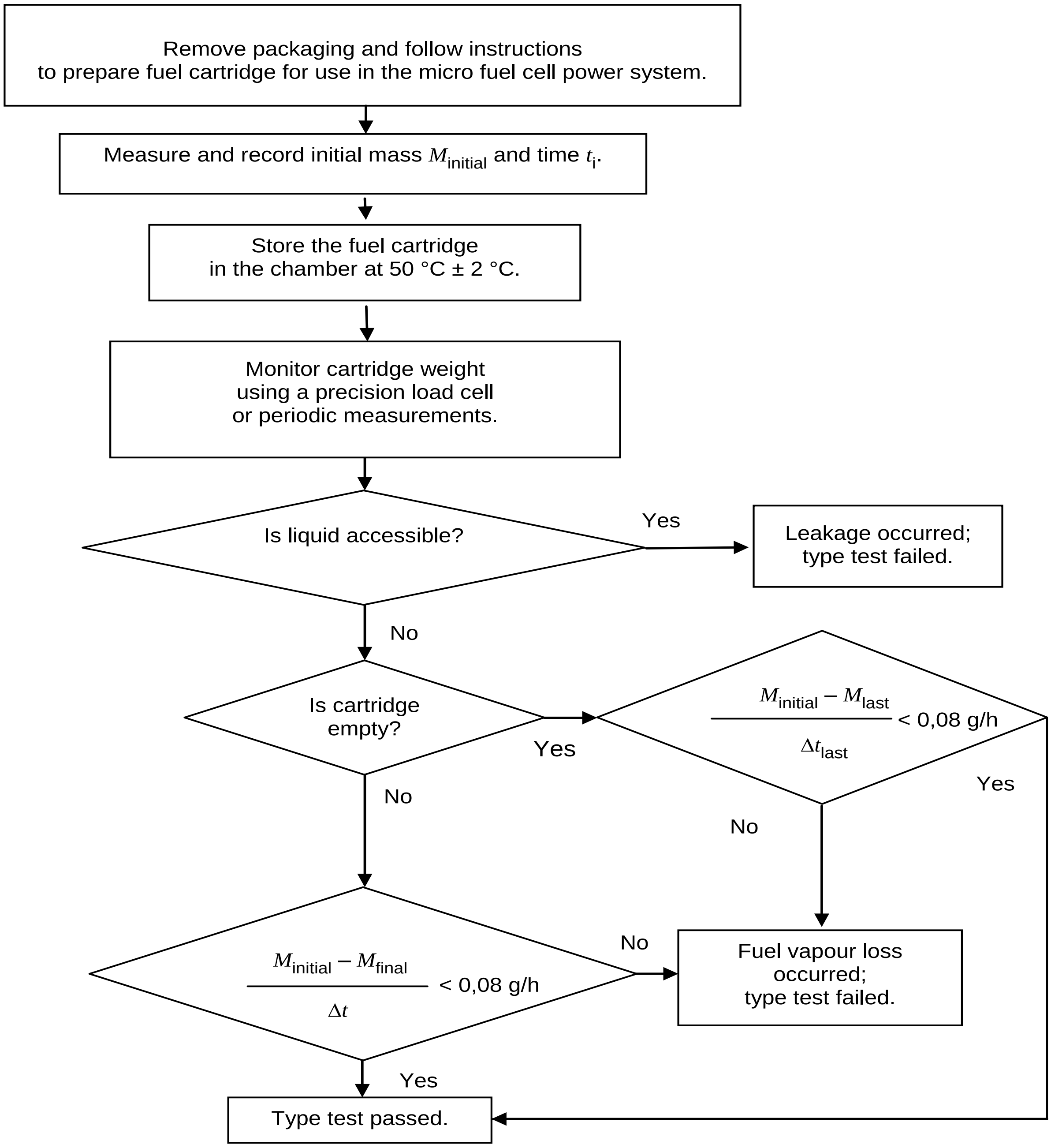


Figure 9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test

7.3.10 High temperature connection test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge and a micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage, no fire, no explosion.

c) **Test procedure:**

1) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.

2) The micro fuel cell power unit or test fixture with micro fuel cell power unit valve is kept at laboratory temperature.

3) Remove the test sample from the chamber and connect the fuel cartridge to the micro fuel cell power unit or test fixture with micro fuel cell power unit valve within 5 min of removal from the chamber.

4) Check for leakage upon connection.

5) Disconnect the fuel cartridge and check for leakage.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occurs, this is acceptable. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power unit valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

7.3.11 Connection cycling tests

7.3.11.1 Fuel cartridge

7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer’s instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer’s instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for leakage upon connection.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and check for leakage.

5) Repeat this twice more for a total of three connections and disconnections.

6) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper such that the valve points downward toward the indicating paper and look for signs of leakage.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for leakage.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power unit valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

7.3.11.1.2 Satellite cartridge

a) **Test sample:** an unused satellite fuel cartridge and an unused micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for leakage upon connection and initiate or simulate fuel flow.

2) Disconnect the fuel cartridge and check for leakage.

3) Repeat this twice more for a total of three connections and disconnections.

4) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

5) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

6) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

7) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

8) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

9) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and initiate or simulate fuel flow.

10) Disconnect the fuel cartridge and check for leakage.

11) Repeat steps 1 through 10 four more times for a total of 55 cycles, waiting 1 h between each set of 11 cycles.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power unit valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

7.3.11.2 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

   First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

   1) Connect the first fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.
   2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.
   3) Turn off the micro fuel cell power unit or stop simulated fuel flow.
   4) Disconnect the fuel cartridge and check for leakage.
   5) Repeat this twice more for a total of three connections and disconnections.
   6) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
   7) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.
   8) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
   9) Connect and disconnect the first fuel cartridge three more times for a total of ten connections and disconnections.
   10) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
   11) Connect the first fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.
   12) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.
   13) Turn off the micro fuel cell power unit or stop simulated fuel flow.
   14) Disconnect the first fuel cartridge and check for leakage.

15) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.
    i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections.
    ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.
    iii) Inversion of the micro fuel cell power unit or the fuel cartridges is not necessary, but, if leakage is found, the test fails.
    iv) Following this ageing, a final unused fuel cartridge will be tested.
16) Connect the final unused fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.
17) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.
18) Turn off the micro fuel cell power unit or stop simulated fuel flow.
19) Disconnect the fuel cartridge and check for leakage.
20) Repeat this twice more for a total of three connections and disconnections.
21) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
22) Connect and disconnect the final fuel cartridge four more times for a total of seven connections and disconnections.
23) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
24) Connect and disconnect the final fuel cartridge three more times for a total of ten connections and disconnections.
25) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
26) Connect the fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.
27) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.
28) Turn off the micro fuel cell power unit or stop simulated fuel flow.
29) Disconnect the fuel cartridge and check for leakage.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

7.3.12 Emission test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or micro fuel cell power unit – that is fuelled with methanol – emissions of carbon monoxide (CO), carbon dioxide (CO_2) and organic compounds such as methanol, formaldehyde, formic acid and methyl formate shall be maintained at less than the specified values. Maintaining these limits not only prevents inadvisable exposure but also ensures that an adequate supply of oxygen is maintained in the operating environment.

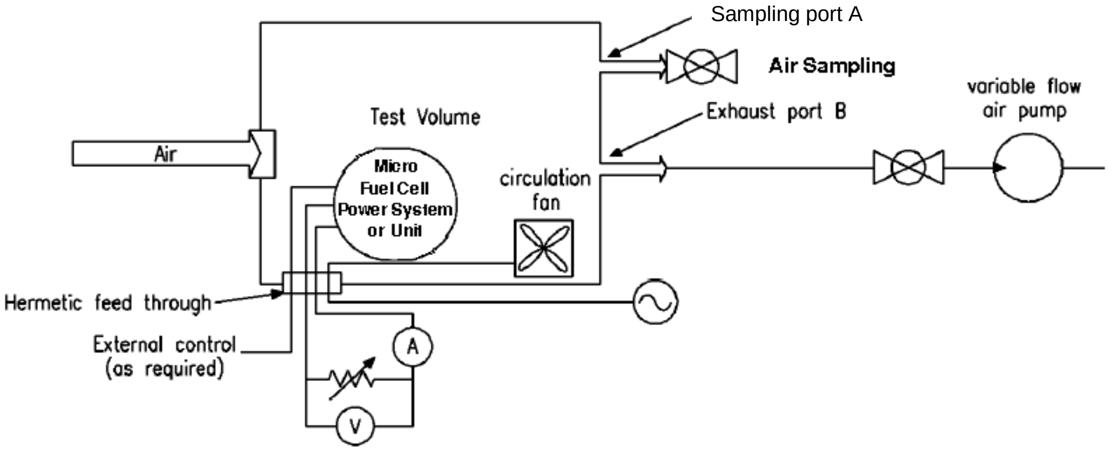


Figure 10 – Operational emission rate testing apparatus

c) **Test apparatus:** An example of the operational emission rate testing apparatus is shown in Figure 10. The configuration shown in Figure 10 is for emission rate testing of all micro fuel cell power systems or units. Emission rate testing in accordance with 7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units.

For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer's mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.) additional testing in accordance with 7.3.12 d) 2) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure 11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer's mouth or nose when in use) for emissions concentration limit testing.

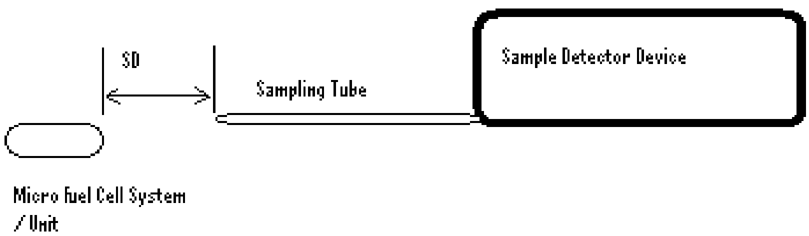


Figure 11 – Operational emission concentration testing apparatus

Emission gases might be composed of toxic organic materials such as methanol, formaldehyde, formic acid and methyl formate, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS) or a high-performance liquid chromatography (HPLC) system shall be used by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure 10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

The concentration of CO and CO_2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure 10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “DEVICE ON” position.

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure 10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure 10, while simultaneously measuring and recording the flow through the test chamber. The flow through the test chamber can be computed from the sum of the variable flow air pump flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber.

vi) Record the concentrations of the chemical compounds of interest. See Table 7.

vii) Calculate the emission rate of chemical compounds of interest being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

or

$$ER = (F_{\mathrm{i}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured emission rate to Table 7. If the emission rate is not less than the emission rate limit in Table 7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria 7.3.12 e) 1) i) and 7.3.12 e) 2) i).

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer's mouth or nose, the following additional emissions concentration sampling test shall be performed.

i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results.

ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power in the large open room while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure 11. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission concentration test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the "ON" position.

iii) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

iv) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure 11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer's mouth or nose when in use).

v) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

vi) Allow the sample flow rate to stabilise.

vii) Sample and record the micro fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

viii) Record the concentrations of the chemical compounds of interest. See Table 7.

ix) Compare the maximum measured concentrations to Table 7. If the emission concentrations are not less than the emission concentration limits in Table 7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria 7.3.12 e) 2) ii).

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table 7 shall be less than the emission rate limit value in Table 7 when tested in accordance with 7.3.12 d) 1). If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer’s mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table 7 shall be less than the emission rate limit value in Table 7 when tested in accordance with 7.3.12 d) 1). If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer’s mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall be less than the emission concentration limit in Table 7 when tested in accordance with 7.3.12 d) 2). If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

Table 7 – Emission limits

	Concentration limit	**Emission rate limit** [a]
Water	Unlimited	No limit
Methanol	0,26 g/m^3	2,6 g/h
Formaldehyde	0,000 1 g/m^3 [b]	0,000 6 g/h
CO	0,029 g/m^3	0,290 g/h
CO_2	9 g/m^3	60 g/h [c]
Formic acid	0,009 g/m^3	0,09 g/h
Methyl formate	0,245 g/m^3	2,45 g/h

[a] The emission rate limit was based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is over 20 m^3, so a product of 10 is conservative.

[b] WHO guideline limit is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The emission limit cannot push the background level above the guideline limit.

[c] A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO eight-hour concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

Annex A
(normative)

Formic acid micro fuel cell power systems

A.1 Scope

A.1.2 Fuels and technologies covered by this annex

Annex A covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use formic acid in water solutions - that are comprised of less than 85 % formic acid by weight - as fuel. These systems and units use direct formic acid fuel cell technologies.

Figure A.1 replaces Figure 1 showing a formic acid micro fuel cell power system block diagram for use with this annex.

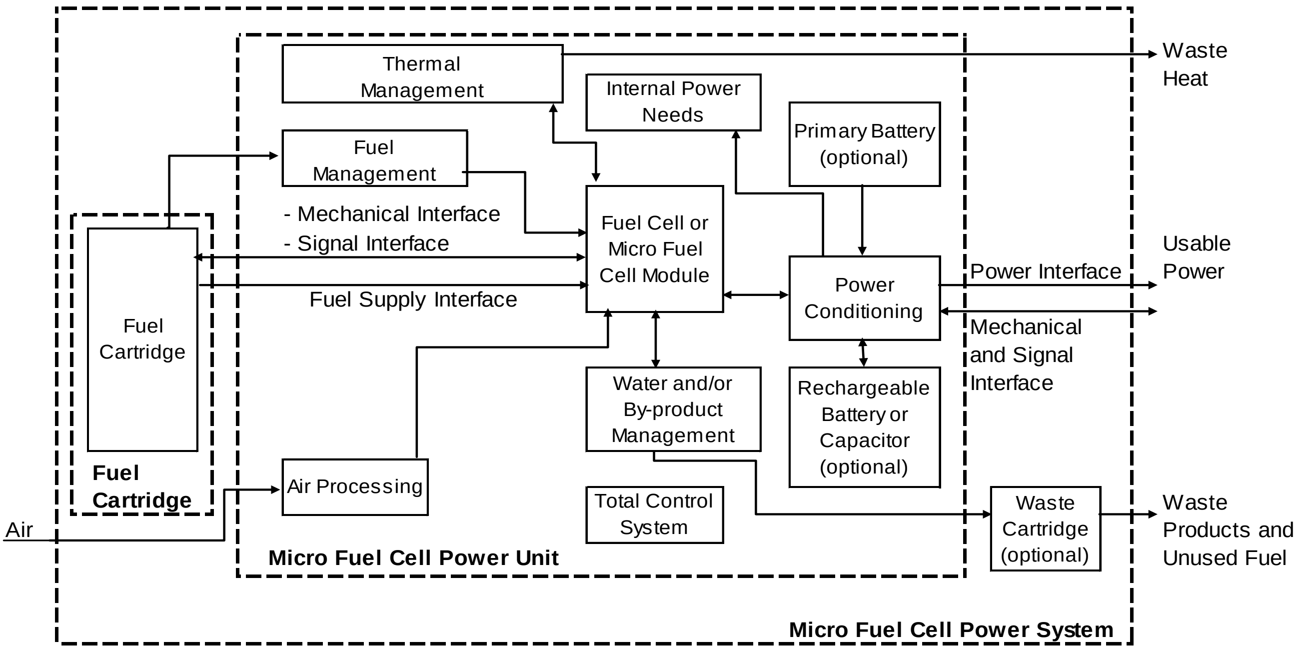


Figure A.1 – Formic acid micro fuel cell power system block diagram – Replaces Figure 1

A.1.3 Equivalent level of safety

This subclause replaces Subclause 1.3.

a) The requirements of this standard are not intended to constrain innovation. The manufacturer may consider fuels, materials, designs or constructions not specifically dealt with in this standard. These alternatives should be evaluated as to their ability to yield levels of safety equivalent to those prescribed by this standard.

b) It is understood that all micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall comply with applicable country and local requirements including, but not limited to, those concerning transportation, child-resistance, and storage, where required.

c) The following similarities between methanol and formic acid micro fuel cell power systems are provided to enhance understanding of why the formic acid requirements mimic methanol requirements with minimal changes.

1) The similarity in micro fuel cell power system components (see Figure 1 and Figure A.1).

2) Both types of micro fuel cell power systems use liquid fuels and both micro fuel cell power systems have the “no accessible liquid” criteria for no leakage (see definitions in Clause A.3).

3) Both types of micro fuel cell power systems may have similar gaseous emissions components and thus shall have similar criteria for measurement and analysis of the emissions, and the same considerations shall be made for emission risk levels.

4) Formaldehyde and methyl formate emissions seen in methanol micro fuel cell power systems are not present in formic acid micro fuel cell power systems. Theoretical reactions with formic acid and hydrogen can produce methanol, methyl formate and formaldehyde but these reactions have very high activation energies which can only be achieved with combinations of high temperatures – typically greater than 200 °C – with high pressures – typically greater than 10 MPa – and in the presence of hydrogenation catalysts such as transition metal oxides. These conditions are not expected to be seen in the formic acid micro fuel cell power system, thus the existence of these three emission products, as a result of a reduction reaction forming them, do not have to be considered in formic acid micro fuel cell power systems. Due to the extremely low permissible human exposure levels to formaldehyde, formaldehyde is being measured in the emission test for purposes of validation.

5) Hydrogen and carbon dioxide emissions are only possible when formic acid is exposed to temperatures greater than 150 °C or when it is in contact with decomposition catalysts with no load on the fuel cell. Formic acid fuel cartridges and micro fuel cell power units are not expected to be subjected to such high temperatures. Properly functioning non-operating micro fuel cell power systems shall have fail-safe mechanisms to prevent fuel flow to the catalysts. Failure modes and effects analysis and related testing shall ensure protection against such failure modes and ensure existence of relevant design mitigations.

6) Since even with the micro fuel cell power system off, carbon monoxide and formic acid vapour may be produced from a formic acid fuel cartridge and a micro fuel cell power system, the emission test shall be performed with the micro fuel cell power system off "DEVICE – OFF" as an additional test.

7) Carbon dioxide, carbon monoxide, formic acid vapour, hydrogen and water vapour are all possible emissions from an operational "DEVICE – ON" micro fuel cell power system.

8) Formic acid fuel below 85 % concentration by weight is non-flammable; thus warning statements for the product related to fuel flammability do not apply to formic acid micro fuel cell power system products.

A.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex A. All terms and definitions in Clause 3 not specifically mentioned here also apply.

A.3.5
fuel
formic acid and water solution less than 85 % formic acid concentration by weight

A.3.8
hazardous (corrosive) liquid fuel
formic acid fuel that has a pH less than 3,0 (pH of 3,0 is approximately 0,35 % formic acid by weight in water)

A.3.10
internal reservoir
not applicable to this Annex A

A.3.11
leakage
accessible hazardous liquid fuel outside the micro fuel cell power system or fuel cartridge or a positive pH indication of liquid formic acid (see A.3.37)

A.3.19
no fuel vapour loss
vaporous fuel emission from fuel cartridge, or micro fuel cell power system or unit limited to 0,018 g/h

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex A in addition to those given in Clause A.3 and in Clause 3.

A.3.37
positive pH indication of liquid formic acid
positive indication of the presence of acid (pH less than 3,0) on pH paper (acid base indicator paper) attached to the possible leak areas of the micro fuel cell power system during the type test.

A.3.38
device
either the micro fuel cell power system (see Figure A.1) or an end use product that incorporates a micro fuel cell power system as its power supply

A.3.39
"DEVICE – ON"
device with its power switch turned on and operating to produce power or unable to produce power due to a failure or other reasons

A.3.40
"DEVICE – OFF"
device with its power switch turned off and not producing power

A.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

A.4.12.1.3 *This requirement applies to formic acid fuel cartridges and replaces the corresponding requirement in Subclause 4.12.1.3. All other requirements of Clause 4 apply.*

The maximum formic acid fuel volume in the fuel cartridge shall not exceed 1 l.

A.6 Instructions and warnings for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

A.6.2 Minimum markings required on the fuel cartridge

These markings replace the markings required by Subclause 6.2.

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE CORROSIVE AND TOXIC, DO NOT DISASSEMBLE.
b) AVOID CONTACT WITH CONTENTS.
c) KEEP AWAY FROM CHILDREN.

d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.

e) FOLLOW USAGE INSTRUCTIONS.

f) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

g) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

h) COMPOSITION AND AMOUNT OF FUEL.

i) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.

A.6.3 Minimum markings required on the micro fuel cell power system

These markings replace the markings required by Subclause 6.3.

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE CORROSIVE AND TOXIC, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) DO NOT EXPOSE TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.

d) FOLLOW USAGE INSTRUCTIONS.

e) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

f) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

g) COMPOSITION AND AMOUNT OF FUEL.

h) MAXIMUM CAPACITY OF FUEL IN THE INTERNAL RESERVOIR, IF APPLICABLE.

i) TEXT OR MARKING THAT INDICATES THAT THE MICRO FUEL CELL POWER SYSTEM COMPLIES WITH IEC 62282-6-100.

j) ELECTRICAL OUT PUT (VOLTAGE, CURRENT, RATED POWER).

A.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

A.7.1 General

This Subclause A.7.1 replaces Subclause 7.1 for this annex when testing formic acid micro fuel cell power systems, formic acid micro fuel cell power units and formic acid fuel cartridges.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table A.5 lists the type tests that shall be performed. *Table A.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table A.6. *Table A.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table A.5 – List of type tests – Replaces Table 5

Test reference	Test item	Test sample
A.7.3.1	Pressure differential tests	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.2	Vibration test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.3	Temperature cycling test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.4	High temperature exposure test	Fuel cartridge Partially filled fuel cartridge
7.3.5	Drop test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.6	Compressive loading test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
A.7.3.9	Long-term storage test	Fuel cartridge Partially filled fuel cartridge
7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Partially filled fuel cartridge and micro fuel cell power unit
7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit
A.7.3.12	Emission test	Micro fuel cell power system or power unit

Table A.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or partially filled, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test.

Test sequence: Tests 7.3.2 and 7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests A.7.3.1, 7.3.2, and 7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer's discretion if it does not compromise the individual test.

Table A.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is “room temperature” (standard temperature condition, 22 °C ± 5 °C)
Laboratory room atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen.
Table A.6 replaces Table 6.	

A.7.2 Leakage measurement of formic acid and the measuring procedure

This Subclause A.7.2 replaces Subclause 7.2 for this annex when testing formic acid micro fuel cell power systems, formic acid micro fuel cell power units and formic acid fuel cartridges.

a) *The leakage measurement of formic acid shall be executed in principle in accordance with the procedures shown in Figures A.2 through A.7. These figures and their procedures replace the corresponding figures in Subclause 7.2.*

b) As an additional tool for finding formic acid leaks, pH paper, attached to the possible leak areas of the micro fuel cell power system, shall be used to aid in the visual check for liquid formic acid leaks (see definition of "positive pH indication of liquid formic acid"). This is an additional requirement in Annex A for formic acid fuel cells. For operational tests, reactant air passages into the micro fuel cell power system and exhaust ports should not be blocked with pH paper.

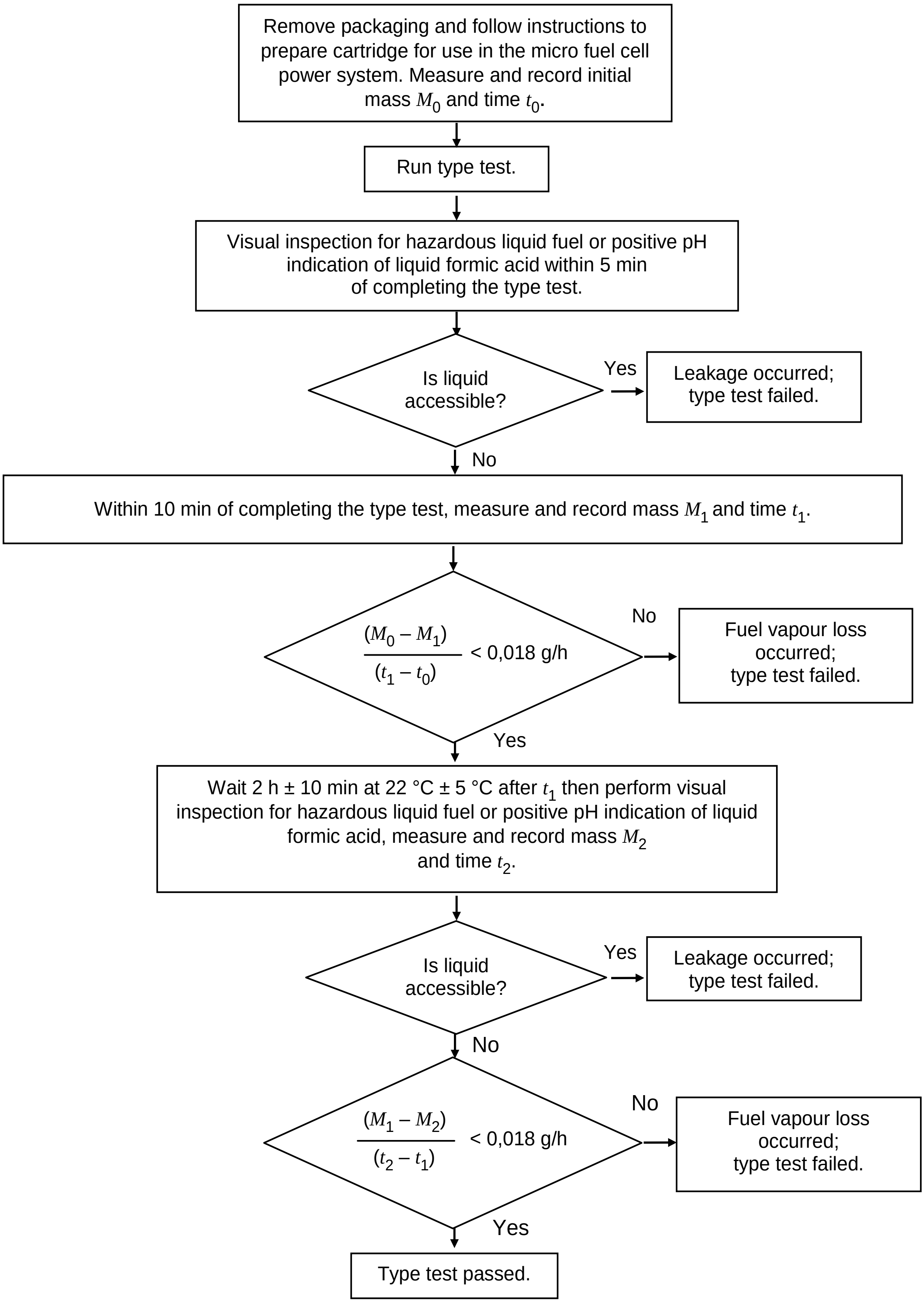


Figure A.2 – Fuel cartridge leakage and mass loss test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2

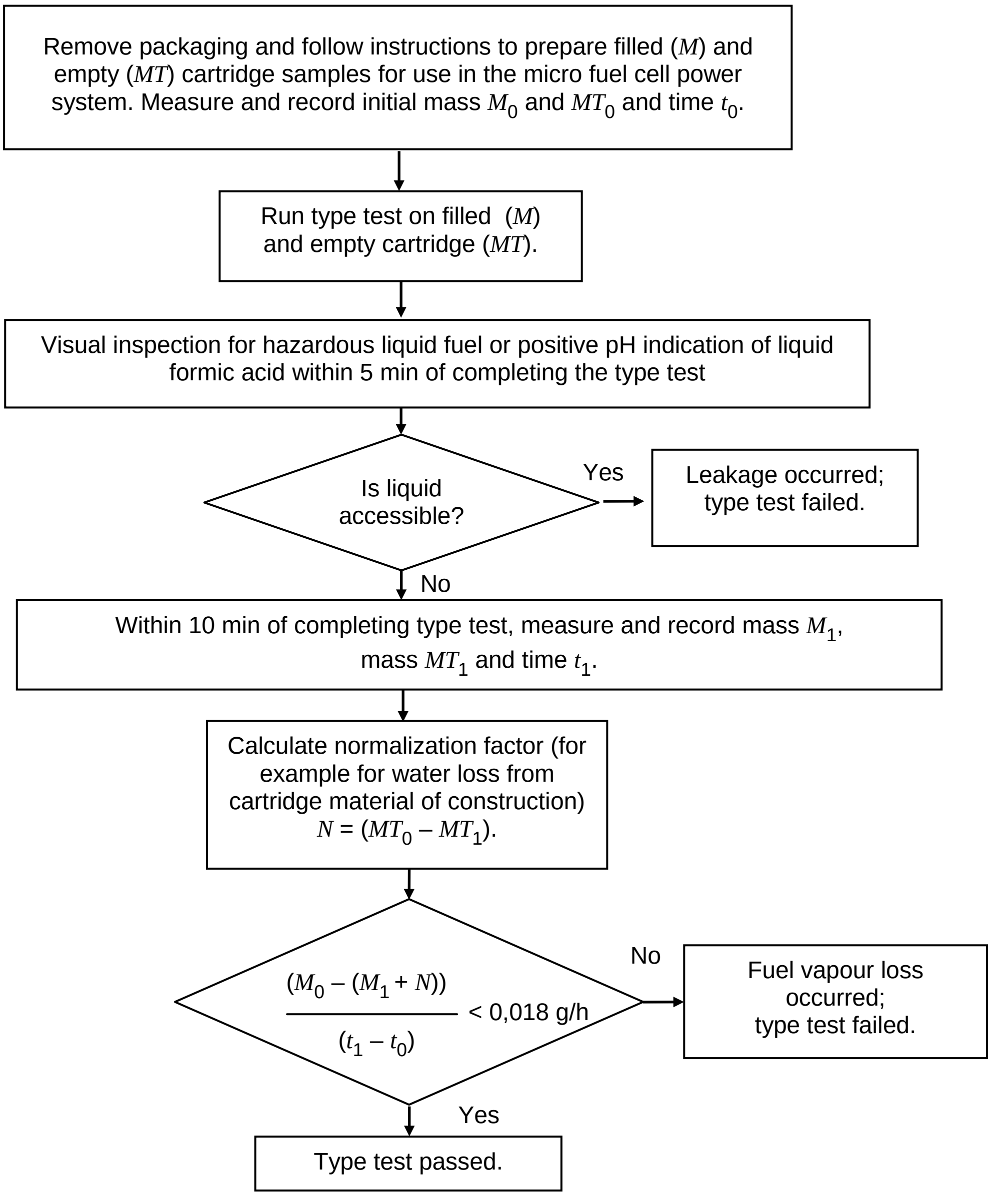


Figure A.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3

The maximum time interval $t_1 – t_0$ shall be set so that no more than half the fuel would be lost if it were escaping at the maximum allowable mass loss rate.

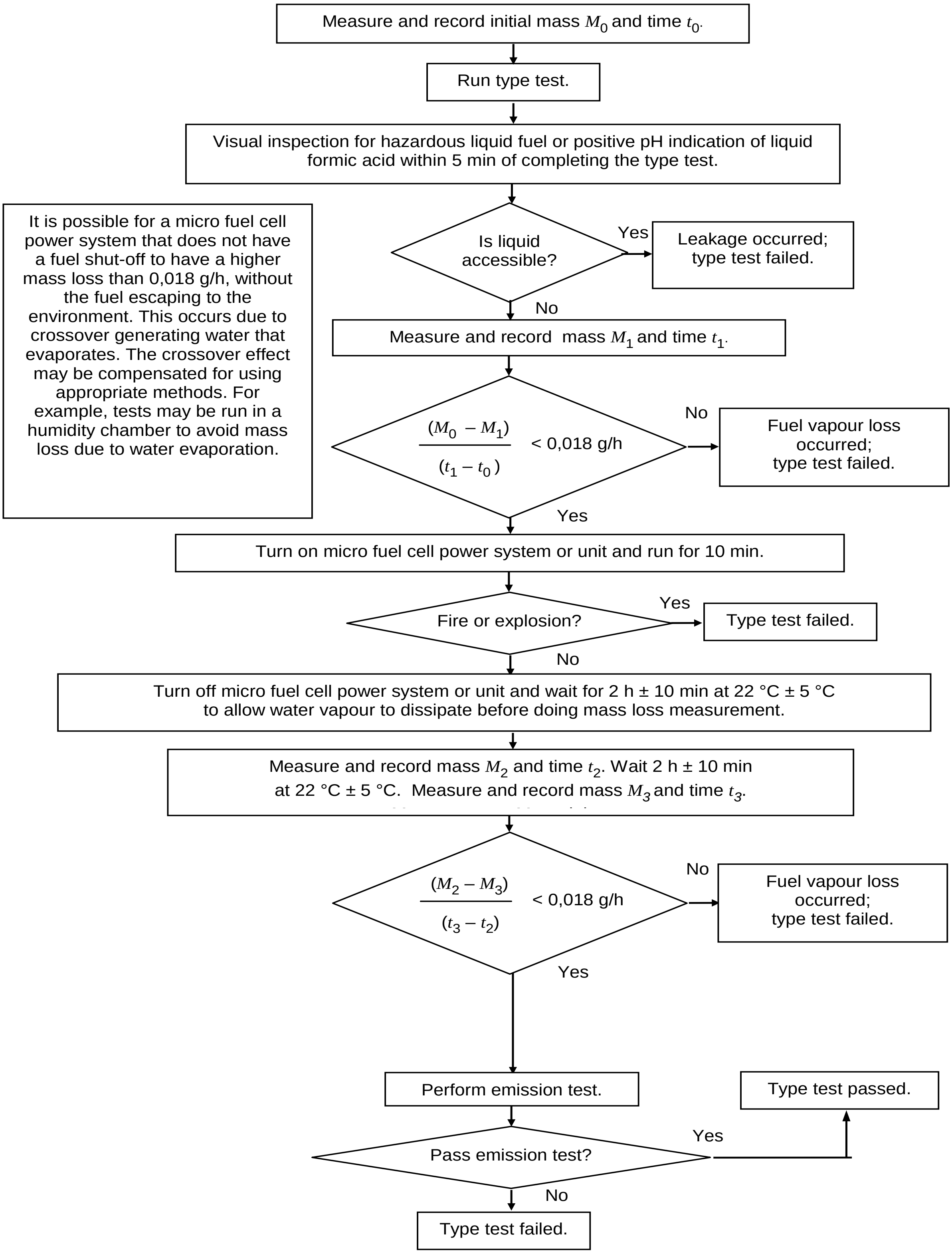


Figure A.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss flow chart for pressure differential, vibration, temperature cycling test, drop, and compressive loading tests – Replaces Figure 4

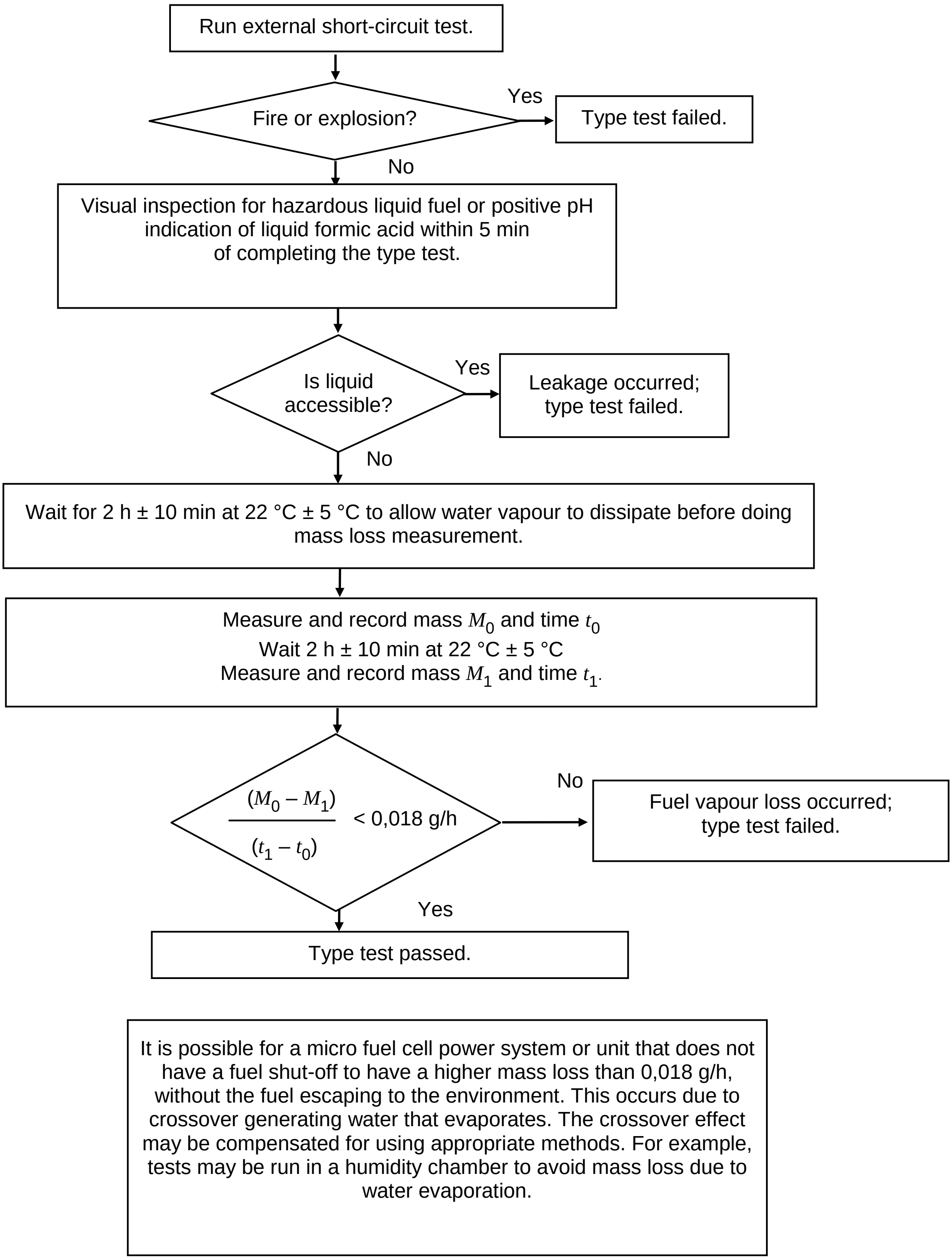


Figure A.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5

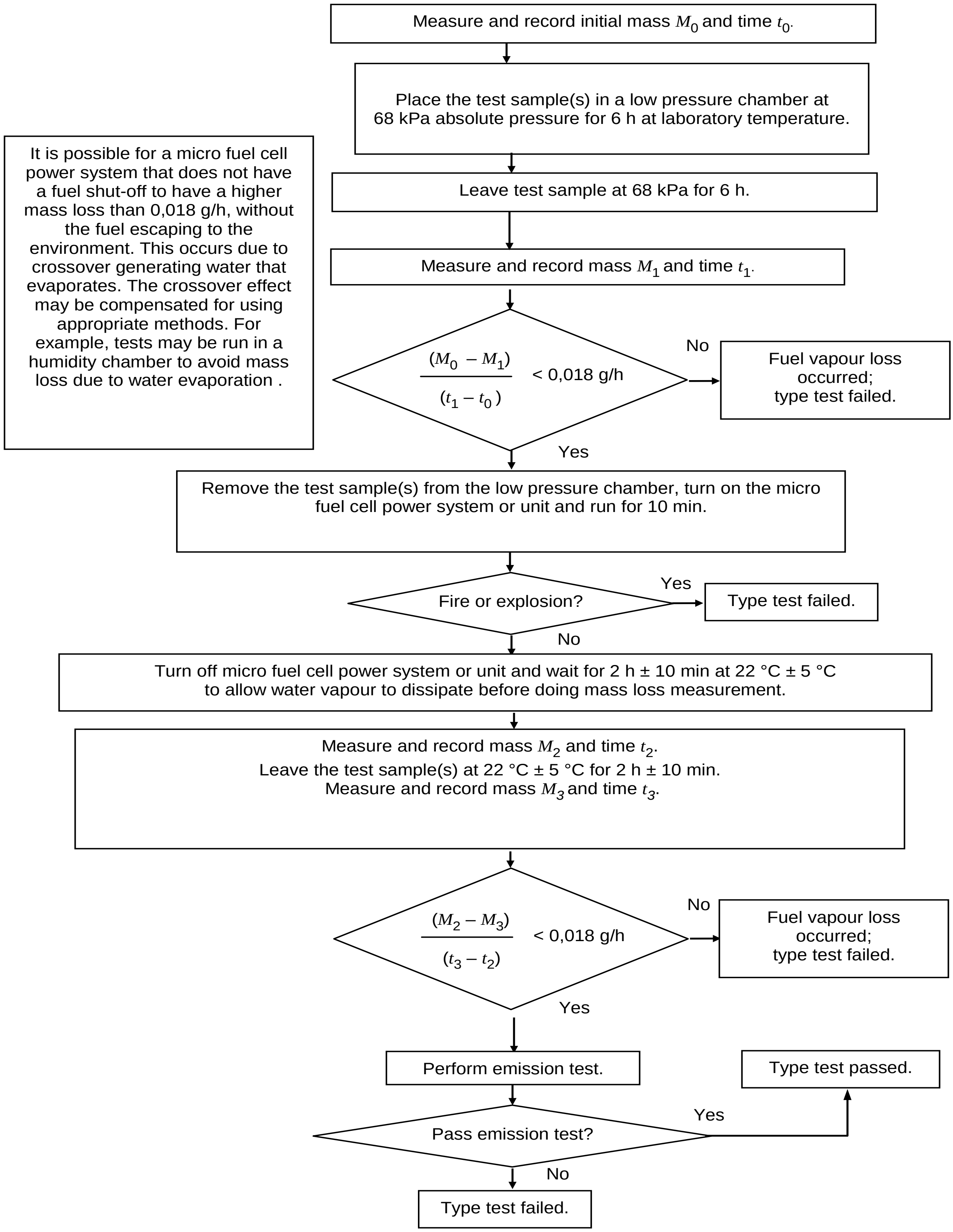


Figure A.6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6

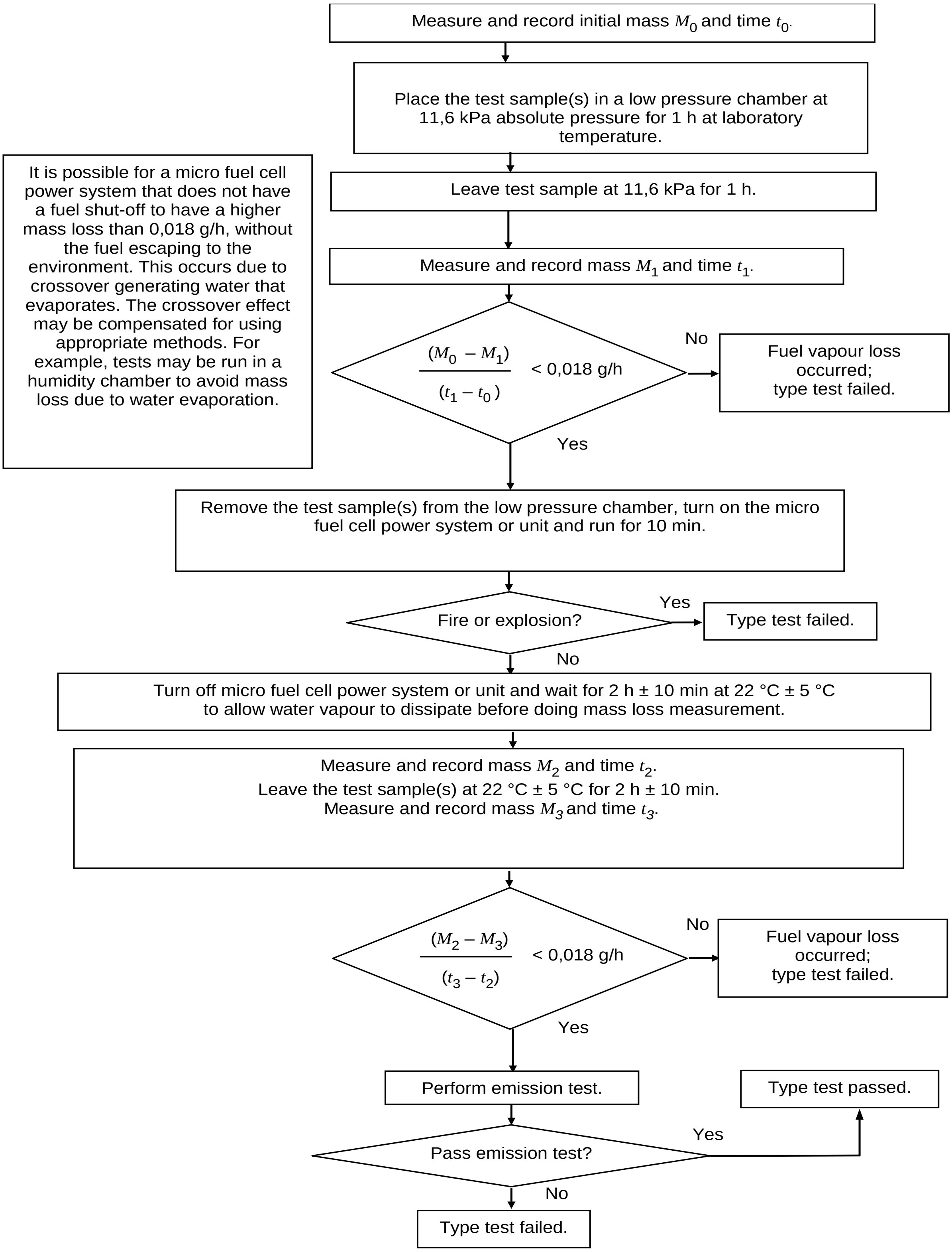


Figure A.7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7

A.7.3 Type tests

A.7.3.1 Pressure differential tests

A.7.3.1.1 General

Subclause A.7.3.1 replaces Subclause 7.3.1.

Portions of this test check compliance with Subclause 4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Depending upon which of the two limiting pressure conditions is greater, two options for testing are provided:

a) If 95 kPa internal gauge pressure plus normal working pressure of the fuel cartridge at 22 °C is greater than two times the gauge pressure of the fuel cartridge at 55 °C, either Subclause A.7.3.1.2 or Subclause A.7.3.1.3 may be used to verify compliance with Subclause 4.12.1.2.

b) If two times the gauge pressure of the fuel cartridge at 55 °C is greater than 95 kPa internal gauge pressure plus normal working pressure at 22 °C, Subclause A.7.3.1.2 shall be used to verify compliance with Subclause 4.12.1.2.

A.7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

1) Using a suitable fluid medium such as water, pressurize the fuel cartridge body to an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater.
2) The pressure rise shall not exceed a rate of 60 kPa/s.
3) Maintain the maximum pressure for 30 min at laboratory temperature.
4) Using a suitable fluid medium such as water, pressurize the closed fuel cartridge valve to 95 kPa gauge pressure plus the normal working pressure of the cartridge at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater.
5) The pressure rise shall not exceed a rate of 60 kPa/s.
6) Maintain the maximum pressure for 30 min at laboratory temperature.

d) **Passing criteria:** No accessible liquid test medium leakage and no sudden drop of pressure during the course of the test. Leakage shall be checked visually. Invert the fuel cartridge and the fuel cartridge valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails.

A.7.3.1.3 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

1) Perform this test in accordance with Figure A.2.

2) The sample shall be placed in a vacuum chamber and the pressure in the vacuum chamber shall be reduced to 95 kPa below normal atmospheric pressure.

3) Maintain the vacuum for 30 min.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no fuel vapour loss. See Figure A.2. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

A.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

A.7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all formic acid micro fuel cell power systems and formic acid micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure A.6.

2) Test samples shall be stored at a low external pressure of 68 kPa absolute pressure for 6 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure A.6.

3) For the micro fuel cell power system or unit, perform emission testing in accordance with A.7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no fuel vapour loss. See Figure A.6. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of A.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test result is acceptable. During the 6 h test at 68 kPa absolute external pressure, the fuel vapour loss shall be less than 0,018 g/h.

A.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all formic acid micro fuel cell power systems and formic acid micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure A.7.

   2) Test samples shall then be stored at a low external pressure of 11,6 kPa absolute pressure for 1 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure A.7, with a fuel vapour loss at 11,6 kPa YES/NO passing criteria of less than 0.018 g/h on the basis of not exceeding 25 % of the lower flammability limit (LFL).

   3) For the micro fuel cell power system or unit, perform emission testing in accordance with A.7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no fuel vapour loss. See Figure A.7. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of A.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of A.7.3.12, the emission test result is acceptable. During the 1 h test at 11,6 kPa absolute external pressure, the fuel vapour loss shall be less than 0,018 g/h.

A.7.3.9 Long-term storage test

A.7.3.9.1 General

Subclause A.7.3.9 replaces Subclause 7.3.9 for formic acid fuel cartridges testing in this Annex A. Figure A.9, included herein, replaces Figure 9 for this Annex A.

a) Either A.7.3.9.2 Option 1 – Continuous weight measurement, A.7.3.9.3 Option 2 – Periodic measurements or A.7.3.9.4 Option 3 – One weight measurement, may be used.

b) If the results of this test do not pass the 0,018 g/h limit for fuel vapour loss, then a full emission test (A.7.3.12) shall be performed for the fuel cartridge only situation at 50 °C in the 1 m^3 ACH volume with all emission components measured. "DEVICE – OFF" limits of Table A.7 shall be met.

A.7.3.9.2 Option 1 – Continuous weight measurement

Option 1 is not preferred for formic acid fuel cartridges due to the very low anticipated fuel vapour loss.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure A.9):

   1) Use a load cell (continuous electronic weight sensing device) designed and calibrated for use at 50 °C inside the temperature chamber.

2) Place the load cell in a temperature chamber at 50 °C ± 2 °C. Place the fuel cartridge on top of the load cell so that all the weight is being applied to the load cell. A fixture may be used to control the position of the fuel cartridge, to ensure all the weight is applied to the load cell.

3) Connect a digital readout to the load cell and collect the data either manually or automatically. The data should be collected with a high degree of confidence to assure that the fuel vapour loss does not exceed 0,018 g/h.

4) Measure and record initial mass M_{initial} and time t_{i}.

5) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

6) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,018 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

7) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,018 g/h.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss and no liquid leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure A.9. If the fuel cartridge fuel vapour loss is not less than 0,018 g/h, then the test sample fails the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

   If the results of this test do not pass the 0,018 g/h limit for fuel vapour loss, then a full emission test (A.7.3.12) shall be performed for the fuel cartridge only situation at 50 °C in the 1 m^3 ACH volume with all emission components measured. "DEVICE – OFF" limits of Table A.7 shall be met.

A.7.3.9.3 Option 2 – Periodic weight measurements

Option 2 is preferred for formic acid fuel cell cartridges.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure A.9):

1) Place the fuel cartridge in a temperature chamber at 50 °C ± 2 °C. Weight measurements should be collected with a high degree of confidence to determine if the fuel vapour loss does not exceed 0,018 g/h with a minimum of once every three days.

2) Measure and record initial mass M_{initial} and time t_{i}.

3) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

4) The time in which the test samples are removed from the chamber for measurement shall not be included in the time the test sample is to be tested (28 days). Additional time should be added to get the test sample to the test temperature (50 °C ± 2 °C) each time the test sample is removed from the chamber. The test samples should only be stabilised at laboratory temperature if the mass loss will be affected.

5) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,018 g/h, then the test sample passes the test for fuel vapour loss.

i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

iii) M_{initial} = the initial mass of the fuel cartridge.

iv) M_{final} = the final mass of the fuel cartridge.

6) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,018 g/h.

i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

iii) M_{initial} = the initial mass of the fuel cartridge.

iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire at any time, no explosion at any time, no fuel vapour loss and no liquid leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure A.9. If the fuel cartridge fuel vapour loss is not less than the 0,018 g/h fuel vapour loss criteria, then the test sample fails the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

If the results of this test do not pass the 0,018 g/h limit for fuel vapour loss, then a full emission test (A.7.3.12) shall be performed for the fuel cartridge only situation at 50 °C in the 1 m^3 ACH volume and all emission components measured. "DEVICE – OFF" limits of Table A.7 shall be met.

A.7.3.9.4 Option 3 – One weight measurement

This option is intended for fuel cartridges with very small leak rates. Option 3 may also be used for formic acid fuel cartridges with very small leak rates.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure A.9):

1) Measure and record initial mass M_{initial} and time t_{i}.

2) Place the fuel cartridges in a temperature chamber at 50 °C ± 2 °C. After 28 days, the fuel cartridges are removed from the chamber for measurement. The test samples should be stabilised at laboratory temperature if the mass loss will be affected. Then the weight measurement is executed.

3) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,018 g/h, then the test sample passes the test for fuel vapour loss.

i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

iii) M_{initial} = the initial mass of the fuel cartridge.

iv) M_{final} = the final mass of the fuel cartridge.

4) If the fuel cartridge is empty after 28 days, then the type test according to A.7.3.9.2 Option 1 or A.7.3.9.3 Option 2 shall be done.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss and no liquid leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure A.9. If the fuel cartridge fuel vapour loss is less than the 0,018 g/h fuel vapour loss criteria, then the test sample passes the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

If the results of this test are not less than the 0,018 g/h limit for fuel vapour loss, then a full emission test (A.7.3.12) shall be performed for the fuel cartridge only situation at 50 °C in the 1 m^3 ACH volume with all emission components measured. "DEVICE – OFF" limits of Table A.7 shall be met.

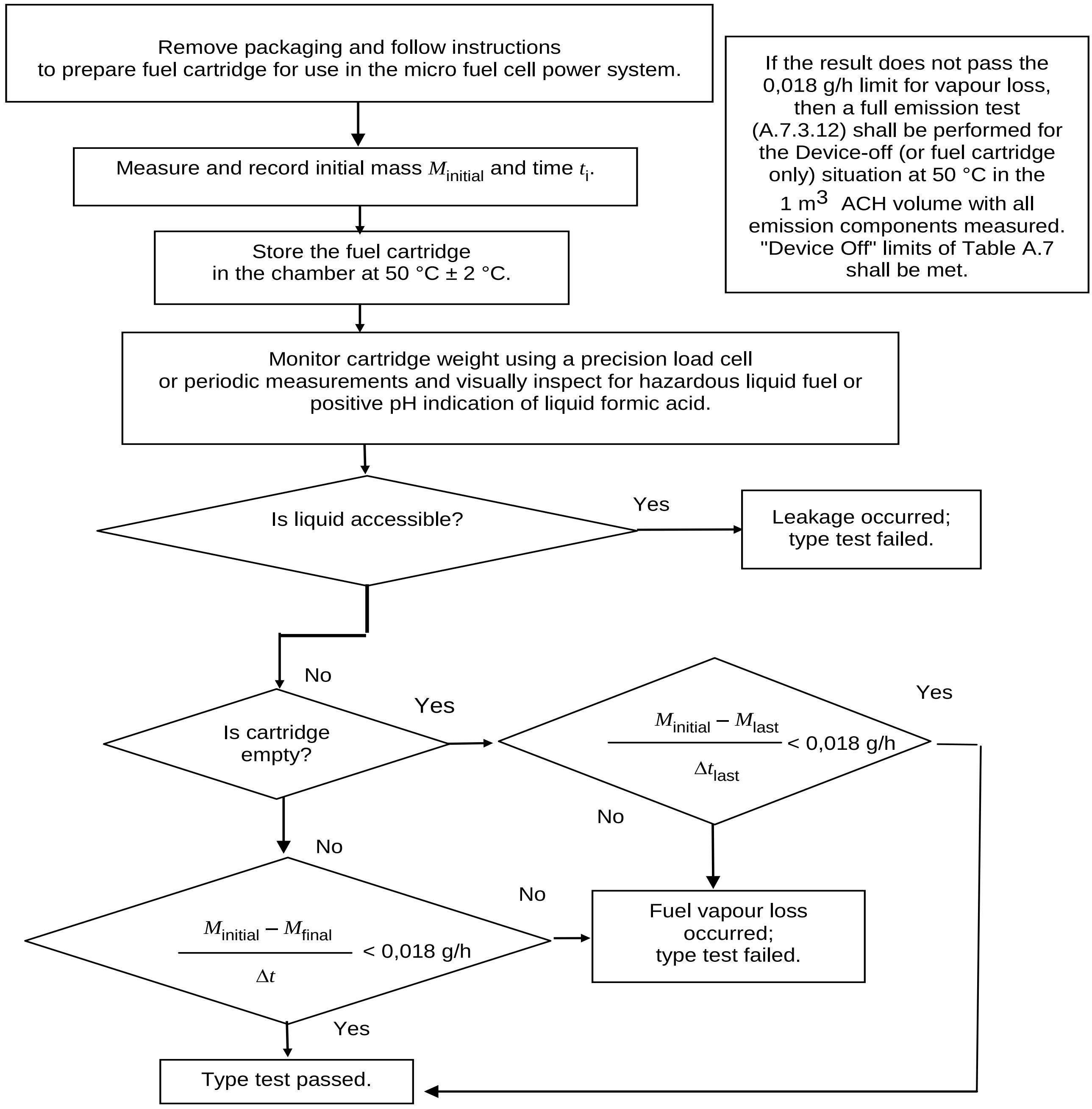


Figure A.9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9

NOTE The eight-hour time weighted average (TWA) limit for carbon monoxide is 25 ppmv[2)]. The fifteen-minute short term exposure limit (STEL) for carbon monoxide is 200 ppmv. Due to the extremely low formic acid to carbon monoxide decomposition rate at 50 °C and the human exposure limit to carbon monoxide being higher than formic acid (TWA = 5 ppmv and STEL = 10 ppmv), the assumption that all mass loss in this test is formic acid makes this evaluation more conservative. If result does not pass the 0,018 g/h limit for fuel vapour loss, a full emission test (A.7.3.12) is allowed.

2) ppmv = parts per million by volume.

A.7.3.12 Emission test

This Subclause A.7.3.12 shall replace Subclause 7.3.12 for formic acid micro fuel cell power systems or units tested in accordance with Annex A. The included Table A.7, Emission limits, replaces Table 7 in Subclause 7.3.12. The new additional Table A.8, Occupational exposure limits, is provided to inform the user regarding exposure limits. Figure A.10 replaces Figure 10 and is identical to Figure 10. Hydrogen emissions are evaluated separately. The procedure for hydrogen emission testing is detailed in Figure A.12, which is to be used as an additional figure when testing is done in accordance with Annex A.

a) **Test sample:** A micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit – that is fuelled with formic acid – emissions of formic acid vapours, carbon dioxide, carbon monoxide, formaldehyde, hydrogen, and water vapour shall be maintained at less than the specified values. Maintaining these limits not only prevents inadvisable exposure but also ensures an adequate supply of oxygen is maintained in the operating environment.

   Since even with the micro fuel cell power system off, carbon monoxide and formic acid vapour may be produced from a formic acid fuel cartridge and a micro fuel cell power system, the emission test shall also be performed with the micro fuel cell power system off ("DEVICE – OFF") as an additional test. Carbon monoxide and formic acid vapour shall be kept below the "DEVICE – OFF" limits given to avoid harmful exposures.

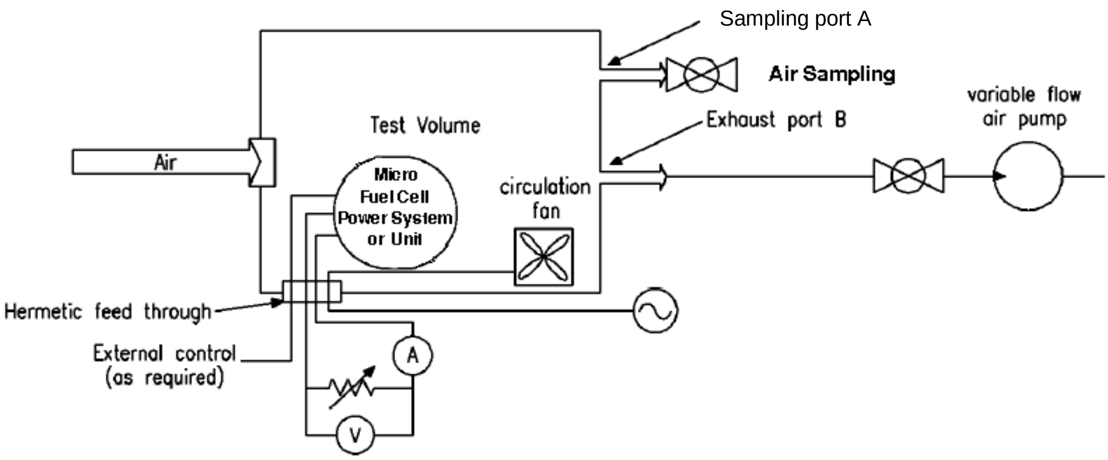


Figure A.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the operational emission test apparatus is shown in Figure A.10. The configuration shown in Figure A.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex A. Emission rate testing in accordance with A.7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex A.

   For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer's mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.), additional testing in accordance with A.7.3.12 d) 3) and A.7.3.12 d) 4) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure A.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer's mouth or nose when in use) for emissions concentration limit testing.

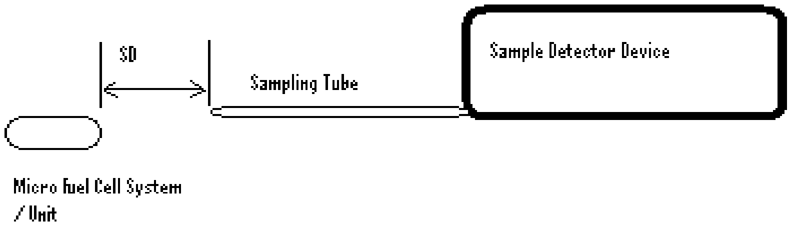


Figure A.11 – Operational emission concentration testing apparatus – Replaces Figure 11

Emission gases might be composed of toxic organic materials such as formic acid vapours, carbon dioxide, carbon monoxide and formaldehyde, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS) shall be used by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure A.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

The concentration of CO and CO_2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure A.12, which is to be used as an additional figure when testing is done in accordance with Annex A.*

Emission rate sampling tests shall be performed both with the micro fuel cell power system or unit on ("DEVICE – ON") and with the micro fuel cell power system or unit off ("DEVICE – OFF") as follows:

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed with the micro fuel cell power system or unit on ("DEVICE – ON") as follows.

   i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure A.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the "on" position ("DEVICE – ON").

   ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure A.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure A.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the concentrations of chemical compounds of interest. See Table A.7.

vii) Calculate the emission rate of chemical compounds of interest being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_\mathrm{P} + F_\mathrm{S}) \times C$$

or

$$ER = (F_\mathrm{i}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured "DEVICE – ON" emission rate to Table A.7. If the emission rate is not less than the emission rate limit in Table A.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria A.7.3.12 e) 1) i) and A.7.3.12 e) 2) i).

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed with the micro fuel cell power system or unit off ("DEVICE – OFF") as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure A.10 for 10 min or until 10 % of the fuel capacity of a full fuel cartridge is used up, whichever is less.

ii) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") and measure the emission rates with the micro fuel cell power system or unit off ("DEVICE – OFF") inside the small test chamber shown in Figure A.10.

iii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iv) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown on Figure 10.

v) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

vi) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure A.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vii) Record the concentrations of chemical compounds of interest. See Table A.7.

viii) Calculate the emission rate of chemical compounds being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_\mathrm{P} + F_\mathrm{S}) \times C$$

or

$$ER = (F_\mathrm{i}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

ix) Compare the maximum measured "DEVICE – OFF" emission rate to Table A.7. If the emission rate is not less than the emission rate limit in Table A.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria A.7.3.12 e) 1) i) and A.7.3.12 e) 2) i).

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

3) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer's mouth or nose, the following additional emissions concentration sampling test shall be performed with the micro fuel cell power system or unit on "DEVICE – ON" as follows.

i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power in the large open room while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure A.11. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission concentration test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “ON” position.

iii) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

iv) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure A.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer’s mouth or nose when in use).

v) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

vi) Allow the sample flow rate to stabilise.

vii) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

viii) Record the concentrations of the chemical compounds of interest. See Table A.7.

ix) Compare the maximum stabilized concentrations to Table A.7. If the emission concentrations are not less than the emission concentration limits in Table A.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria A.7.3.12 e) 2) ii).

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

4) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer’s mouth or nose, the following additional emissions concentration and emission rate sampling test shall be performed with the micro fuel cell power system or unit off "DEVICE – OFF" as follows.

i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power for 10 min or until 10 % of the fuel capacity of a full fuel cartridge is used up, whichever is less.

iii) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure A.11.

iv) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

v) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the emission concentration testing apparatus shown in Figure A.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer's mouth or nose when in use).

vi) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

vii) Allow the sample flow rate to stabilise.

viii) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

ix) Record the concentrations of the chemical compounds of interest. See Table A.7.

x) Compare the maximum stabilized concentrations to Table A.7. If the emission concentrations are not less than the emission concentration limits in Table A.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria A.7.3.12 e) 2) ii).

xi) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

5) Upon completion of the emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table A.7, "DEVICE – ON" hydrogen emissions are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure A.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the "on" position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure A.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure A.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the hydrogen concentration.

vii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_\mathrm{P} + F_\mathrm{S}) \times C$$

or

$$ER = (F_\mathrm{i}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured "DEVICE – ON" hydrogen emission rate to Table A.7.

NOTE This is a stabilised concentration measurement.

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

6) Upon completion of the hydrogen emissions measurements with "DEVICE – ON", hydrogen emissions with ("DEVICE – OFF") are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure A.10 for 10 min or until 10 % of the fuel capacity of a full fuel cartridge is used up, whichever is less.

ii) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") and measure the emission rates with the micro fuel cell power system or unit off ("DEVICE – OFF") inside the small test chamber shown in Figure A.10.

iii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iv) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown on Figure A.10.

v) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

vi) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure A.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vii) Record the hydrogen concentration.

viii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_\mathrm{P} + F_\mathrm{S}) \times C$$

or

$$ER = (F_\mathrm{i}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

ix) Compare the maximum measured "DEVICE – OFF" hydrogen emission rate to Table A.7.

NOTE This is a stabilised concentration measurement.

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

7) Evaluate the hydrogen emission rate as follows.

i) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and below the allowable 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or unit passes the test and no further testing is necessary.

ii) If the hydrogen emission rate measurement is not below the allowable 0,0032 g/h with the "DEVICE – OFF" and not below the total allowable 0,8 g/h with the "DEVICE – ON", the system or unit fails the test and no further testing is necessary.

iii) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and is below the total allowable 0,8 g/h with the "DEVICE – ON" but is not below 0,016 g/h with the "DEVICE – ON", then proceed with A.7.3.13, hydrogen point source gas loss detection test to verify that no single source of hydrogen exceeds 0,016 g/h.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table A.7 shall be less than the emission rate limit value in Table 7 when tested in accordance with A.7.3.12 d) 1) for "DEVICE – ON" and A.7.3.12 d) 2) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer’s mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table A.7 shall be less than the emission rate limit value in Table A.7 when tested in accordance with A.7.3.12 d) 1) for "DEVICE – ON" and A.7.3.12 d) 2) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer’s mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall be less than the emission concentration limit in Table A.7 when tested in accordance with A.7.3.12 d) 3) "DEVICE – ON" and A.7.3.12 d) 4) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

3) Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure A.12, which is to be used as an additional figure when testing is done in accordance with Annex A.* Upon completion of the hydrogen emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table A.7, hydrogen emissions are evaluated as follows.

i) **Passing criteria for non-operating systems:** The hydrogen emission rate shall be less than 0,0032 g/h with the "DEVICE – OFF".

ii) **Passing criteria for operational systems:** If the total hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or micro fuel cell power unit passes the emission test and no further testing is required. If the total hydrogen emission rate is not less than 0,8 g/h with the “DEVICE – ON”, the micro fuel cell power system or unit fails the emission test and no further testing is required. If the hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", A.7.3.13, hydrogen point source gas loss detection test shall be performed with acceptable results to show no more than 0,016 g/h hydrogen leakage from any single point leak.

NOTE 1 The allowable flammable hydrogen emission level that will not support a standing flame is 3 ml/min (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, *Codes and Standards Analysis*, 2001 *(USA)*). The non-flammable hydrogen emissions limit is based on the criteria that hydrogen emission does not build up to more than 25 % of LFL in the reference volume.

NOTE 2 Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

NOTE 3 Carbon dioxide, carbon monoxide and formic acid vapour emission level limits are based on toxicity and corrosivity (formic acid only) effects on humans while the hydrogen emissions level limit is based on the risk of creating a flammable atmosphere in confined spaces and the risk of a potential standing hydrogen flame.

NOTE 4 The formic acid flammability risk, based on the criteria of maintaining the concentration-in-air below 25 % of LFL, is orders of magnitude lower than the toxicity risk (flammability limit = 42 500 ppmv to toxicity limit = 5 ppmv). Thus, the formic acid toxicity level is used to set the limits of its emissions.

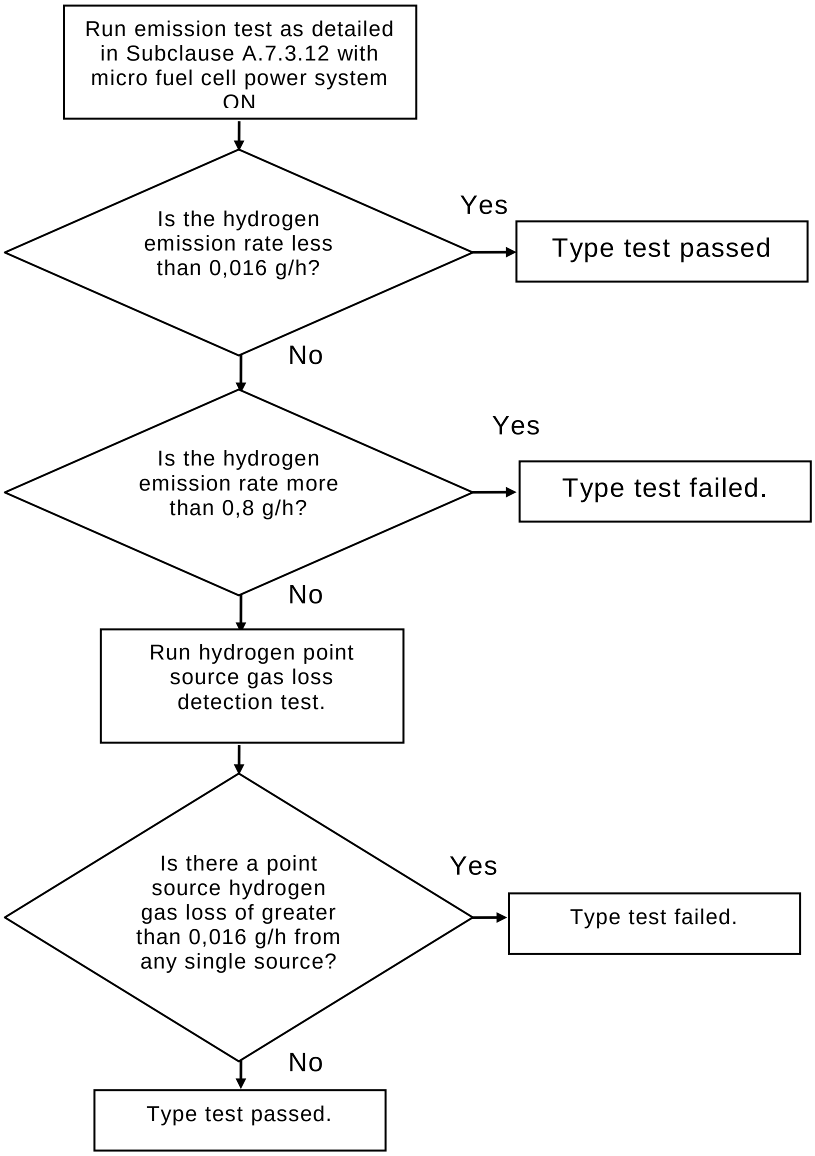


Figure A.12 – Hydrogen emission test procedure for operating micro fuel cell power system

Table A.7 – Emission limits – Replaces Table 7

Emissions	"DEVICE – OFF" Concentration limit [a] based on STEL values for "DEVICE – OFF" test condition	"DEVICE – ON" Concentration limit [a] based on TWA values for "DEVICE – ON" test condition	"DEVICE – OFF" Permissible emissions rate in 1 m^3 ACH volume [c]	"DEVICE – ON" Permissible emissions rate in 10 m^3 ACH volume [b]
Water	Unlimited	Unlimited		
CO	0,232 g/m^3	0,029 g/m^3	0,232 g/h	0,290 g/h
CO_2	54 g/m^3	9 g/m^3	Not applicable (see A.1.3.C.5)	60 g/h [d]
Formic acid	0,018 g/m^3	0,009 g/m^3	0,018 g/h	0,09 g/h
Formaldehyde [e]	0,000 1 g/m^3	0,000 1 g/m^3	0,000 06 g/h	0,000 6 g/h
Hydrogen [f]	See footnote f	0,8 g/m^3	0,0032 g/h	0,8 g/h total 0,016 g/h from single point leak

[a] The concentration limits for CO, CO_2 and formic acid in this table are the mg/m^3 equivalent of the TWA and STEL exposure limits, quoted in ppmv, in Table A.8.

[b] The "DEVICE – ON" emission rate limit was based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is over 20 m^3, so a product of 10 is conservative.

[c] The "DEVICE – OFF" emission rate is based on 1 m^3 ACH because it covers the reasonably foreseeable environments where micro fuel cell power systems may be stored. The limits are based on STEL values because it is reasonable to expect human exposure to such conditions being for short (equivalent to STEL parameters) durations.

[d] A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO eight-hour concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

[e] WHO guideline limit is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The emission limit cannot push the background level above the guideline limit.

[f] The hydrogen emission rate for the "DEVICE – OFF" state is based on a 0,283 m^3 volume, 0 ACH and 24-h duration for the emission environment. The emission rate for the "DEVICE – ON" state is as per note b but with an additional safety factor of 10.

Table A.8 – Occupational exposure limits

Emissions	**TWA exposure limit** (TWA – time weighted average over 8 h of operation)	**STEL value** (15 min exposures to a maximum of 4 times a day)
CO_2	< 5 000 ppmv	<30 000 ppmv
Formic acid	< 5 ppmv	<10 ppmv
CO	< 25 ppmv	<200 ppmv

A.7.3.13 Hydrogen point source gas loss detection test

The procedure for hydrogen emission testing is detailed in Figure A.12, which is to be used as an additional figure when testing is done in accordance with Annex A. This subclause shall be used if required by Subclause A.7.3.12 d) 7) ii) to show compliance with Table A.7, for formic acid micro fuel cell power systems and formic acid micro fuel cell power units. This subclause is required to be performed to meet the passing criteria of Subclause A.7.3.12 e) 3) ii) if the total hydrogen emission rate from an operational formic acid micro fuel cell power system or unit is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON". This subclause is additional to the requirements in Clause 7.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit – that is fuelled with formic acid – emission of hydrogen shall be maintained at less than the specified values in Table A.7. The hydrogen point source gas loss detection test shall be performed to determine that no single source on the micro fuel cell power system or unit can support a flame in all cases where such compliance cannot be definitively determined by the hydrogen emission test. Maintaining these limits ensures that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame and along with the other emissions testing ensures an adequate supply of oxygen is maintained in the operating environment.

c) **Test apparatus:** The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, a hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL. The response of the aforementioned hydrogen detectors is commonly slow, with a response time of many seconds, thus high sweep speeds may cause underestimation of the hydrogen concentration. It is important that the sweep speed shall be slow enough to accurately measure the hydrogen concentration.

d) **Test procedure:**

   1) The micro fuel cell power system or micro fuel cell power unit shall remain turned on ("DEVICE – ON") throughout the duration of the hydrogen point source gas loss detection test.

   2) The testing shall be conducted in a space with no substantial air movement. The measured wind speed 10 cm above the micro fuel cell power system or unit shall not exceed 0,02 m/s. The local concentration of hydrogen diffusion measured in this test is very susceptible to the effect of wind. It is desirable that wind speed anywhere in the test space is as close to zero as possible. Testing in a closed space, such as a glove box or equivalent chamber, is one available method to achieve this requirement.

   3) The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

   4) The sensor of the hydrogen detector shall sweep the micro fuel cell power system or unit at a distance no more than 3 mm normal to the surface of the micro fuel cell power system or unit. Consecutive linear sweeps shall not be more than 8 mm apart along the surface of the micro fuel cell power system or unit. The entire surface of the micro fuel cell power system or unit shall be swept in this manner.

5) An effective method for completing these sweeps would be to attach a stand off to the sensor that ensures that a spacing of 3 mm from the micro fuel cell power system or unit is maintained at all times. A pen or other marking utensil attached to the stand off could be used to identify swept areas and ensure that the distance between sweeps does not exceed 8 mm.

6) The sensor should always face directly downward, and the micro fuel cell power system or unit should be moved beneath it such that the surface directly below the sensor is always horizontal.

7) If no points are found where the hydrogen concentration is greater than 25 % LFL, the test is complete and the micro fuel cell power system or unit shall be considered to have passed.

8) When some point source sweeps show a large region of 25 % LFL or greater in the initial linear sweeps, recording the measured concentration values will assist in determining the starting point of secondary spiral sweeps. Point sources are supposed to be where local maximum values exist in the distribution of measured concentration values.

9) If any points are detected to have a hydrogen concentration of 25 % LFL or greater, a second test shall be conducted to ensure that the emission does not exceed 0,016 g/h of pure hydrogen from any single source.

10) The second test shall be performed with the sensor height adjusted to 6,5 mm above the micro fuel cell power system or unit.

11) A spiral sweep shall then be made, originating from the point where the detection of 25 % LFL or greater of hydrogen occurred during the initial linear sweep. The spiral sweep shall have a spacing of 1 mm or less between sweeps, and shall spiral out to a radial distance of at least 4 mm and far enough to detect the maximum hydrogen level from the particular hydrogen source.

12) If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. If the spiral sweep does not detect any hydrogen concentrations of 25 % LFL or greater, the micro fuel cell power system or unit passes the test.

e) **Passing criteria:** No gas loss of hydrogen from any single source at greater than 0,016 g/h as indicated by sweep testing. No indications of hydrogen that is 25 % of LFL during the primary sweep testing or no indications of hydrogen that is 25 % of LFL during the secondary sweep testing at 6,5 mm above the micro fuel cell power system or unit. If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. See Table A.7.

Annex B
(normative)

Hydrogen stored in hydrogen absorbing metal alloy and micro fuel cell power systems

B.1 Scope

B.1.2 Fuels and technologies covered by this annex

Annex B covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use hydrogen gas – that has been stored in a hydrogen absorbing metal alloy – as fuel. These systems and units use proton exchange membrane fuel cell technologies.

NOTE Fuel cartridges for this technology are referred to by ISO 16111:2008 as "metal hydride assemblies".

B.1.3 Equivalent level of safety

This subclause replaces Subclause 1.3 for this Annex B.

a) The requirements of this standard are not intended to constrain innovation. The manufacturer may consider fuels, materials, designs or constructions not specifically dealt with in this standard. These alternatives should be evaluated as to their ability to yield levels of safety equivalent to those prescribed by this standard.

b) It is understood that all micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall comply with applicable country and local requirements including, but not limited to, those concerning transportation, child-resistance, and storage, where required.

c) The following differences between methanol and hydrogen micro fuel cell power systems are provided to enhance understanding of why the hydrogen requirements contained in Annex B differ from the methanol requirements in the main body.

   i) Hydrogen is not toxic; therefore, many of the subclauses in the main body containing requirements, procedures, and tests in the main body dealing with toxicity are modified in this Annex B. In addition, the labelling requirements concerning toxicity are not required (refer to Clause B.6).

   ii) Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

   iii) The primary hazard of hydrogen gas is its flammability: the flammability range of hydrogen gas is about 4 % to 75 % concentration by volume in air at atmospheric pressure. Consequently, the "impermissible hydrogen gas loss" (refer to B.3.38) and hydrogen emission limits found in Annex B are based on not exceeding 25 % of the lower flammability limit (LFL) of hydrogen in a given reference volume. In addition, the hydrogen emission limits for operating micro fuel cell power systems or units are further monitored to ensure that no flame can be supported by any single point source hydrogen emission.

   iv) This Annex B considers hydrogen gas, stored in a (solid) hydrogen-absorbing metal alloy, as fuel. The systems do not contain any liquid fuel, which is why the definitions for "hazardous liquid fuel" and "no accessible liquid" are not applicable to this annex. This annex also defines and uses "impermissible hydrogen gas loss" instead of "no fuel vapour loss" as the criterion for non-operating micro fuel cell power systems or units. Furthermore, fuel cartridges are checked for hydrogen leakage using a liquid leak detector or equivalent method (see B.7.2.1) and visually inspected to ensure no "hydrogen absorbing metal alloy leakage" instead of being inspected for accessible liquid following type tests.

v) The possible by-products of operation of a hydrogen-powered PEM fuel cell are heat and water. Since the fuel does not contain any hydrocarbons (and therefore will not produce any derivative hydrocarbons on operation), the hydrocarbon emissions tested for in the main body are not tested for in this Annex B. Instead, only hydrogen emissions are tested for.

vi) Special considerations need to be taken into account when designing a fuel cartridge or internal reservoir containing a hydrogen absorbing metal alloy. To ensure safety of these devices, this Annex B requires that they are also designed, tested and certified to ISO 16111:2008 (refer to B.2, B.7.3.14 and B.7.3.15).

B.2 Normative references

In addition to the normative references specified in Clause 2, the following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16111:2008, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

B.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex B. All terms and conditions in Clause 3 not specifically mentioned here also apply.

B.3.5
fuel
hydrogen gas, stored in a hydrogen-absorbing metal alloy

B.3.8
hazardous liquid fuel
not applicable to this Annex B

B.3.11
leakage
not applicable to this Annex B

B.3.18
no accessible liquid
not applicable to this Annex B

B.3.19
no fuel vapour loss
not applicable to this Annex B

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex B in addition to those given in Clause B.3 and in Clause 3.

B.3.37
hydrogen leakage
hydrogen gas outside fuel containment system, including fuel cartridge and internal reservoir (see B.7.2.1)

B.3.38
impermissible hydrogen gas loss
hydrogen gas escaping non-operating micro fuel cell power system or micro fuel cell power unit greater than or equal to 0,0032 g/h

B.3.39
no hydrogen absorbing metal alloy leakage
no hydrogen absorbing metal alloy outside the micro fuel cell power system or micro fuel cell power unit or fuel cartridge

B.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

B.4.1 General

These requirements apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.1.

a) Compliance with the requirements of Clause B.4 shall be verified during the review of the safety FMEA and/or during type testing specified in Clause B.7.

b) The micro fuel cell power unit, when coupled to the fuel cartridge, shall be designed and constructed to avoid any credible risk of leakage, fire or explosion posed by the micro fuel cell power system itself or hydrogen or metal hydrides or other substances produced or used by the micro fuel cell power system.

c) To prevent a fire or explosion hazard within the micro fuel cell power system, the manufacturer shall eliminate potential ignition source(s) within areas where fuel is present (or can be potentially released).

d) Flammable, toxic or corrosive materials shall be kept within a closed containment system such as within fuel piping, in a reservoir, a fuel cartridge or similar enclosure.

B.4.3 General materials

These requirements apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.3.

a) The materials and coating shall be resistant to degradation under the normal transportation and normal usage conditions over the manufacturer-defined life span of the product.

b) Fuel cartridges shall comply with materials and construction requirements of ISO 16111:2008.

B.4.4 Selection of materials

a) These requirements of Subclause B.4.4 below apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

b) *These requirements replace the corresponding requirements of Subclause 4.4.*

B.4.4.1 Micro fuel cell power systems and units are expected to be exposed to a number of environmental conditions over the manufacturer-defined life span of the product such as vibration, shock, varying humidity levels and corrosive environments. Materials employed in the micro fuel cell power system or unit shall be resistant to these environmental conditions. If a micro fuel cell power system or unit is to be used in service where specific environmental conditions are beyond those accounted for in the required tests of this standard, then additional testing shall be performed to verify safety under those environmental conditions.

B.4.4.2 Metallic and non-metallic materials used to construct internal or external parts of the micro fuel cell power system or unit, in particular those exposed directly or indirectly to moisture, fuel and/or byproducts in either a gas or liquid form as well as all parts and materials used to seal or interconnect the same, e.g. welding consumables, shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable under the normal transportation and normal usage conditions within the manufacturer-defined life span of the product and for all test conditions; in particular, they shall be designed to retain their mechanical stability under normal use:

- they shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation;
- the chemical and physical properties necessary for operational safety shall not be significantly affected within the manufacturer-defined life span of the product; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, ageing resistance, the effects of temperature variations, the effects arising when materials are put together (e.g. galvanic corrosion), and the effects of ultraviolet radiation;
- where conditions of erosion, abrasion, corrosion or other chemical attack may arise, adequate measures shall be taken to
  - minimize that effect by appropriate design, e.g. additional thickness, or by appropriate protection, e.g. use of liners, cladding materials or surface coatings, taking due account of normal use;
  - permit replacement of parts which are most affected;
  - and draw attention, in the manual referred to in Clause 6, to type and frequency of inspection and maintenance measures necessary for continued safe use; where appropriate, it shall be indicated which parts are subject to wear and the criteria for replacement;
- fuel containing parts, such as piping systems, shall employ materials suitable for exposure to hydrogen, as defined in the material selection requirements of ISO 16111:2008, 5.2. In addition, Annex A of ISO 16111:2008 details material compatibility for hydrogen service.

B.4.4.3 Elastomeric materials such as gaskets and tubing in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperatures that they are exposed to during normal use. Compliance shall be determined by the following: ISO 188.

B.4.4.4 *Subclause 4.4.4 does not apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex B.*

B.4.6 Fuel valves

These requirements of Subclause B.4.6 apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.6. This subclause applies to all shut-off valves, filling valves, relief valves, refilling valves, including all fuel cartridge types.

B.4.6.1 Operating and pressure containing parts of the shut-off valve and relief valve assemblies shall last the manufacturer-defined life span of the product under normal conditions.

B.4.6.2 The valves shall have means to prevent leakage of fuel through normal use, reasonably foreseeable misuse, and storage of the fuel cartridge.

B.4.6.3 The valves shall not be susceptible to unintended actuation, or manual actuation by a user not using tools, that results in fuel leakage. Compliance shall be checked using test probe 11 of IEC 61032 and a force of 9,8 N.

B.4.6.4 There shall be no leakage of fuel or metal hydride material during storage, connection, disconnection or transferring of fuel from the fuel cartridge to the micro fuel cell power unit.

B.4.7 Materials and construction – system

These requirements of Subclause B.4.7 apply to micro fuel cell power systems and units covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.7.

B.4.7.1 The maximum quantity of hydrogen stored in the micro fuel cell power unit shall not be more than 25 g. The hydrogen stored in the micro fuel cell power unit internal reservoir may be stored in a hydrogen absorbing metal alloy.

B.4.7.2 The micro fuel cell power system or unit shall be designed such that an explosion cannot occur even if fuel leaks from or inside the micro fuel cell power system or unit. The design criteria for such means (for example, required ventilation rate) shall be provided by the micro fuel cell power system or unit manufacturer. The means shall be provided either by the micro fuel cell power system or unit manufacturer or by the manufacturer of the device powered by the micro fuel cell power system or unit.

B.4.7.3 Components and materials inside the micro fuel cell power system or unit shall be constructed or shall make use of such materials that propagation of fire and ignition is mitigated. The material flammability shall be such that a sustained fire will not be supported after electrical power and the fuel and oxidant supply have been terminated. This may be demonstrated through the selection of materials meeting FV 0, FV 1 or FV 2 in accordance with IEC 60695-1-1 and IEC 60695-11-10.

B.4.7.4 Exemptions

B.4.7.4.1 Micro fuel cell stack membranes are not required to have flammability ratings.

B.4.7.4.2 Other materials within the micro fuel cell stack which comprise less than 30 % of the total micro fuel cell stack mass are considered to be of limited quantity and are permissible without flammability ratings.

B.4.8 Ignition sources

These requirements of Subclause B.4.8 apply to micro fuel cell power systems and units covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.8.

To prevent a fire or explosion hazard within the micro fuel cell power system or unit, the manufacturer shall either eliminate potential unintentional ignition source(s) within areas where fuel is present (or can be potentially released) or shall ensure that immediate and controlled oxidation occurs through the use of a catalytic reactor.

Potential unintentional ignition sources shall be eliminated by one or more of the following.

- The surface temperatures shall not exceed 80 % of the auto-ignition temperature, expressed in degrees Celsius, of the flammable gas.
- Equipment containing materials or components capable of catalysing the reaction of flammable fluids with air shall be capable of suppressing the propagation of the reaction from the equipment to the surrounding flammable atmosphere.
- Electrical equipment and/or components, if subject to contact with fuel, shall be suitable for the area in which it is installed.
- The potential for static discharge sufficient to cause ignition shall be eliminated by proper material selection and proper bonding and grounding.

- Electrical components like fuses, other over-current protection devices, sensors, electric valves and solenoids when operating under their intended condition shall not produce thermal effects, arcs or sparks capable of igniting a flammable release of gas.

Immediate and controlled oxidation shall be ensured by the following.

- Catalytic reactors designed to safely control oxidation are acceptable. The temperature within such reactors may be greater than the auto-ignition temperature of the fluid. If the catalytic reactor deviates from proper operating conditions, as defined by the manufacturer, the micro fuel cell power system or unit shall be automatically transferred into a safe state.

B.4.10 Protection against fire, explosion, corrosivity and toxicity hazard

These requirements apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.10.

B.4.10.1 Flammable fluids, hydrogen gas in particular, shall be kept within a closed containment system, such as within fuel piping, in a reservoir, a fuel cartridge, or similar enclosure. Testing in accordance with B.7.2 verifies this requirement.

B.4.10.2 A micro fuel cell power system or unit may be equipped with a means of detecting concentration levels of fluids in Table B.7 and shutting down the micro fuel cell power system or unit prior to exceeding the concentration limit.

B.4.10.3 Internal wiring and insulation in general shall not be exposed to fuel, oils, grease or similar substances, unless the insulation has been evaluated for contact with these substances.

B.4.12 Fuel supply construction

B.4.12.1 Fuel cartridge construction

These requirements apply to the fuel cartridge covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.12.1. Fuel cartridges shall conform to the following requirements:

B.4.12.1.1 There shall be no hydrogen leakage and no hydrogen absorbing metal alloy leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with B.7.3.3 and B.7.3.4.

B.4.12.1.2 There shall be no hydrogen leakage and no hydrogen absorbing metal alloy leakage from the fuel cartridge after being subjected to a vacuum of 95 kPa below normal atmospheric pressure at 22 °C ± 5 °C. Compliance shall be determined by type testing in accordance with B.7.3.1.2. Cartridges shall comply with shell design requirements of ISO 16111:2008, 5.3 and with the no hydrogen leakage requirements of the leak test of ISO 16111:2008, 6.2.5.

B.4.12.1.3 The maximum quantity of hydrogen gas absorbed in a hydrogen absorbing metal alloy permitted in the fuel cartridge is 100 g.

B.4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel or hydrogen absorbing metal alloy leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance shall be determined by the connection cycling test, B.7.3.11.

B.4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

B.4.12.1.6 A fuel cartridge shall be provided with a means to prevent mis-connection that would result in leakage of fuel or hydrogen absorbing metal alloy when it is installed in a micro fuel cell power system. Compliance shall be determined by the connection cycling test, B.7.3.11.

B.4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel or hydrogen absorbing metal alloy when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance shall be determined by the drop test, B.7.3.5, and the connection cycling test, B.7.3.11.

B.4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

B.4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel or hydrogen absorbing metal alloy to leak.

B.4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance shall be determined by:

- Pressure differential tests, B.7.3.1;
- Vibration test, B.7.3.2;
- Temperature cycling test, B.7.3.3;
- High temperature exposure test, B.7.3.4;
- Drop test, B.7.3.5;
- Compressive loading test, B.7.3.6;
- Long-term storage test, B.7.3.9;
- High-temperature connection test, B.7.3.10;
- Connection cycling tests, B.7.3.11;
- Fuel cartridge integrity test B.7.3.14;
- Internal reservoir integrity test B.7.3.15.

B.4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

B.4.12.1.12 Fuel cartridges shall comply with ISO 16111:2008.

B.4.12.1.13 The maximum volumetric capacity of the fuel cartridge shall not exceed 1 l.

B.4.12.2 Fuel cartridge fill requirement

These requirements apply to micro fuel cell power systems and units covered by this Annex B. *These requirements replace the corresponding requirements of Subclause 4.12.2. Fuel cartridges shall conform to the following requirements:*

a) The fuel cartridge shall not be filled beyond its rated capacity, as defined in ISO 16111: 2008.
b) The pressure in the fuel cartridge or in the internal reservoir shall not exceed 5 MPa internal gauge pressure at 55 °C when the fuel cartridge or internal reservoir is filled to its rated capacity.

B.4.13 Protection against mechanical hazards

B.4.13.1 Piping and tubing other than fuel lines

These requirements apply to micro fuel cell power systems and units covered by this Annex B. These requirements replace the corresponding requirements of Subclause 4.13.1. Requirements are listed below for the construction of piping, tubing and fittings – other than fuel lines – inside the micro fuel cell power system or unit.

B.4.13.1.1 Where micro fuel cell power systems or units are designed for internal pressures over 100 kPa gauge, they shall be designed, constructed, and tested in accordance with ISO 15649.

B.4.13.1.2 Micro fuel cell power systems or units designed for operation below 100 kPa gauge or in accordance with the applicable regional or national pressure equipment codes and standards not qualifying as pressurized systems, such as low-pressure water hoses, plastic tubing, or other connections to atmospheric or low-pressure tanks and similar containers, shall be constructed of suitable materials, and their related joints and fittings shall be designed and constructed with adequate strength and leakage resistance to prevent unintended releases.

B.4.13.1.3 Unions shall be designed to be leak tight using sealing methods resistant to the fluid transported and the ambient conditions of use.

B.4.13.1.4 The piping and tubing construction shall be provided with sufficient capability to resist pressure and other load weight, and there will be no danger of contamination or leakage of the line contents. Compliance is determined by B.7.3.1 and B.7.3.6.

B.4.13.1.5 The piping and tubing construction shall be provided with suitable measures to prevent freezing, breakage, corrosion, etc. Compliance for freezing is determined by B.7.3.3. Compliance for breakage is shown in B.7.3.5.

B.6 Instructions and warnings for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

B.6.2 Minimum markings required on the fuel cartridge

These markings replace the markings required by Subclause 6.2.

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE FLAMMABLE, DO NOT DISASSEMBLE.
b) AVOID CONTACT WITH CONTENTS.
c) KEEP AWAY FROM CHILDREN.
d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.
e) FOLLOW USAGE INSTRUCTIONS.
f) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.
g) COMPOSITION AND AMOUNT OF FUEL.
h) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.
i) MARKINGS REQUIRED BY ISO 16111:2008.

B.6.3 Minimum markings required on the micro fuel cell power system

These markings replace the markings required by Subclause 6.3.

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE FLAMMABLE, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.

d) FOLLOW USAGE INSTRUCTIONS.

e) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

f) COMPOSITION AND AMOUNT OF FUEL.

g) MAXIMUM CAPACITY OF FUEL IN THE INTERNAL RESERVOIR, IF APPLICABLE.

h) TEXT OR MARKING THAT INDICATES THAT THE MICRO FUEL CELL POWER SYSTEM COMPLIES WITH IEC 62282-6-100.

i) ELECTRICAL OUTPUT (VOLTAGE, CURRENT, RATED POWER).

j) IF HYDROGEN ABSORBING METAL ALLOY IS PRESENT IN THE INTERNAL RESERVOIR, MARKINGS REQUIRED BY ISO 16111:2008 SHALL BE MARKED ON THE MICRO FUEL CELL POWER UNIT.

B.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

B.7.1 General

This Subclause B.7.1 replaces Subclause 7.1 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use hydrogen gas, stored in a hydrogen-absorbing metal alloy, as fuel.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table B.5 lists the type tests that shall be performed. *Table B.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table B.6. *Table B.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table B.5 – List of type tests – Replaces Table 5

Test reference	Test item	Test sample
B.7.3.1	Pressure differential tests	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
B.7.3.2	Vibration test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit used in B.7.3.1.3
B.7.3.3	Temperature cycling test	Fuel cartridge used in B.7.3.2 Partially filled fuel cartridge used in B.7.3.2 Micro fuel cell power system or power unit used in B.7.3.2
B.7.3.4	High temperature exposure test	Fuel cartridge Partially filled fuel cartridge
B.7.3.5	Drop test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
B.7.3.6	Compressive loading test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
B.7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
B.7.3.9	Long-term storage test	Fuel cartridge Partially filled fuel cartridge
B.7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Partially filled fuel cartridge and micro fuel cell power unit
B.7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit
B.7.3.12	Emission test	Micro fuel cell power system or power unit
B.7.3.14	Fuel cartridge integrity	Fuel cartridge (ISO 16111)
B.7.3.15	Internal reservoir integrity	Micro fuel cell power unit internal reservoir (ISO 16111)

Table B.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or partially filled, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test. The quantity of the samples for B.7.3.14 and B.7.3.15 shall be in accordance with ISO 16111:2008.

Test sequence: Tests B.7.3.2 and B.7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests B.7.3.1, B.7.3.2, and B.7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer’s discretion if it does not compromise the individual test.

Table B.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is “room temperature” (standard temperature condition, 22 °C ± 5 °C)
Laboratory atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen. The laboratory atmosphere contains not more than 0,008 % hydrogen
Table B.6 replaces Table 6.	

B.7.2 Leakage measurement of hydrogen and the measuring procedure

This Subclause B.7.2 replaces Subclause 7.2 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use hydrogen gas, stored in a hydrogen-absorbing metal alloy, as fuel.

a) *The leakage measurement of hydrogen shall be executed in principle in accordance with the procedures shown in Figures B.2 through B.5, B.9 and B.12, as applicable. These figures and their procedures, replace the corresponding figures in Subclause 7.2.*

b) Compliance with the no “hydrogen leakage” and no “impermissible hydrogen gas loss” requirement for all type tests specified in Subclause B.7.3 shall be determined by the hydrogen leakage measurement procedure of Subclause B.7.2.1 and the hydrogen gas loss measurement procedure of B.7.2.2 in conjunction with the definition of “hydrogen leakage” in Subclause B.3.37 and the definition of “impermissible hydrogen gas loss” in Subclause B.3.38, unless otherwise specified.

B.7.2.1 Hydrogen leakage measurement from fuel cartridges and/or internal reservoirs and measuring procedures

a) For fuel cartridges containing hydrogen stored in hydrogen absorbing metal alloy, the measurement of hydrogen leakage shall be done following each type test using a liquid leak detector (bubble forming) solution or other equivalent means on all possible leak locations of the fuel cartridge. See Figure B.2 and Figure B.3.

b) If the fuel cartridge is of the type that is refillable by the manufacturer (automated or by trained technicians), it shall be charged with hydrogen to its rated capacity at rated charging pressure prior to testing. If the fuel cartridge is not refillable, it shall be tested in the condition in which it completed the type test in question. The fuel cartridge shall be tested for leaks at laboratory temperature. There shall be no leakage from any point on the fuel cartridge.

c) For micro fuel cell power systems or micro fuel cell power units with an internal reservoir that contains hydrogen gas above ambient pressure, the measurement of hydrogen leakage shall be done following each type test using a liquid leak detector (bubble forming) solution or other equivalent means on all possible leak locations of the internal reservoir. The internal reservoir shall be tested for leaks at laboratory temperature. There shall be no leakage from any point on the internal reservoir.

d) Both for fuel cartridges containing hydrogen stored in hydrogen absorbing metal alloy, and for internal reservoirs containing hydrogen, no hydrogen leakage is allowed. Testing for hydrogen leakage with a liquid leak detector (bubble forming) solution is acceptable only if no bubbles are found.

NOTE The “no leakage” criteria for fuel cartridges containing hydrogen stored in a metal hydride has been chosen to be consistent with the 15th Edition of the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations; Special Provision 339 for UN 3479, Fuel Cell Cartridges *containing hydrogen in metal hydride*.

B.7.2.2 Hydrogen gas loss measurements from micro fuel cell power systems and micro fuel cell power units and measuring procedures

a) For micro fuel cell power systems, or micro fuel cell power units, following the completion of each type test, the micro fuel cell power system or unit shall be tested for hydrogen gas loss according to Figure B.4 or B.5, as applicable, as follows.

1) Perform hydrogen emission testing in accordance with B.7.3.12.2 with the micro fuel cell power system or unit turned off ("DEVICE – OFF"). Hydrogen gas loss shall be less than 0,0032 g/h.

2) Perform hydrogen emission testing in accordance with B.7.3.12.1 with the micro fuel cell power system or unit turned on ("DEVICE – ON") to test for hydrogen emissions whether or not the micro fuel cell power system or unit is operational. Hydrogen emissions shall be less than 0,8 g/h.

3) As required by B.7.3.12.1, if hydrogen emissions in accordance with B.7.3.12 with the micro fuel cell power system or unit turned on ("DEVICE – ON") in step B.7.2.2 a) 2) were greater than 0,016 g/h, perform the hydrogen point source gas loss detection test in accordance with B.7.3.13. If the micro fuel cell power system or unit fails the hydrogen point source gas loss detection test in accordance with B.7.3.13, the micro fuel cell power system or unit fails the type test and no further testing is necessary.

4) Total hydrogen emissions from an operational system shall be less than 0,8 g/h and hydrogen gas loss from any single point leak shall be less than 0,016 g/h. See Table B.7.

5) Total hydrogen gas loss from a non-operating system shall be less than 0,0032 g/h. See Table B.7.

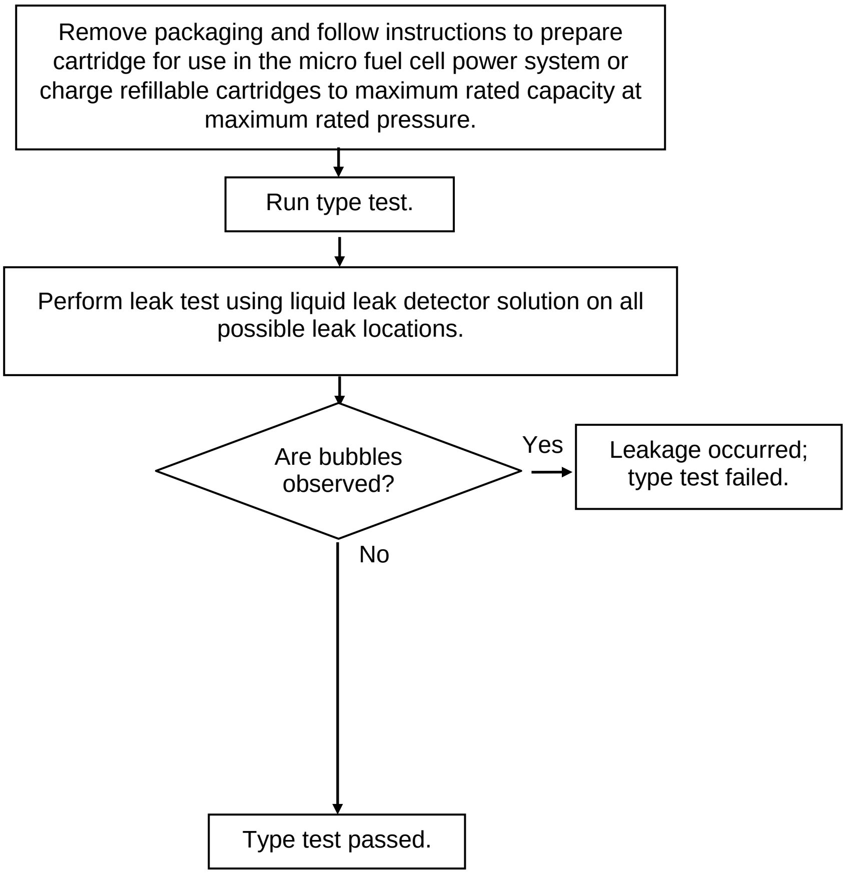


Figure B.2 – Fuel cartridge leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2

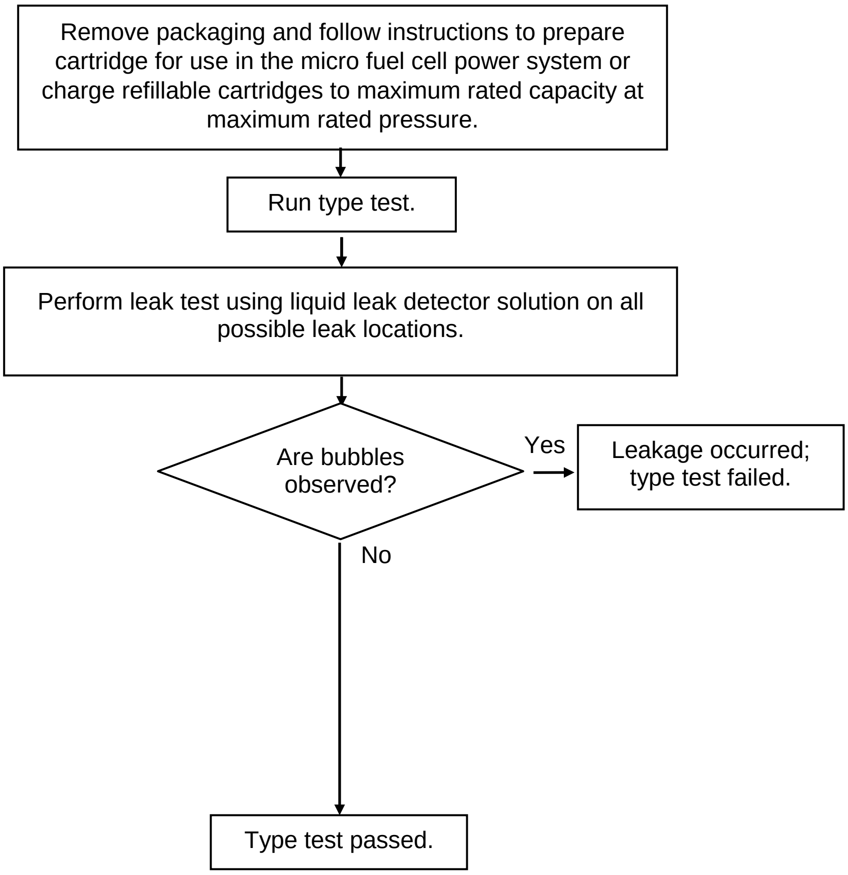


Figure B.3 – Fuel cartridge leakage test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3

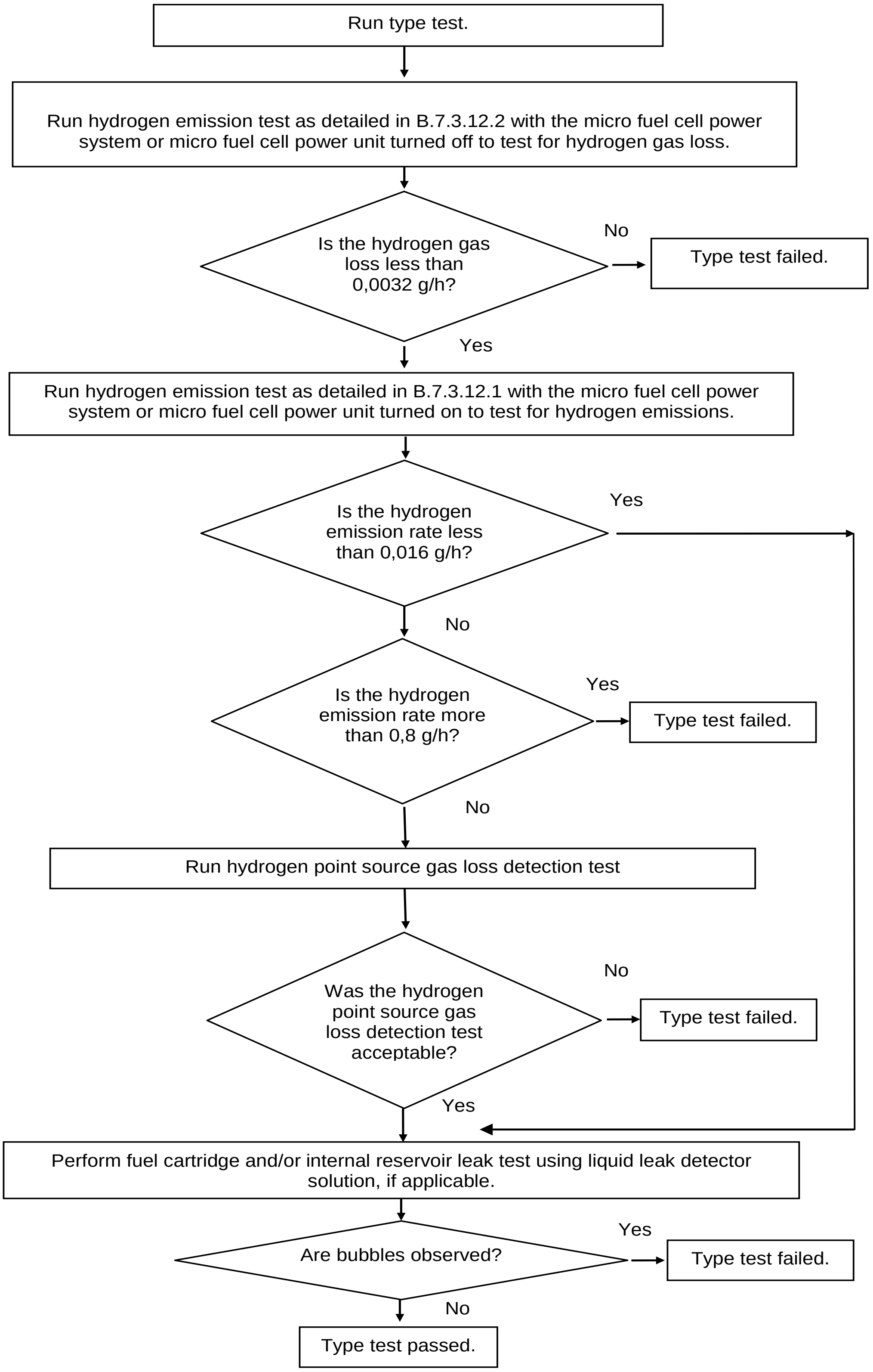


Figure B.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop, and compressive loading tests – Replaces Figure 4

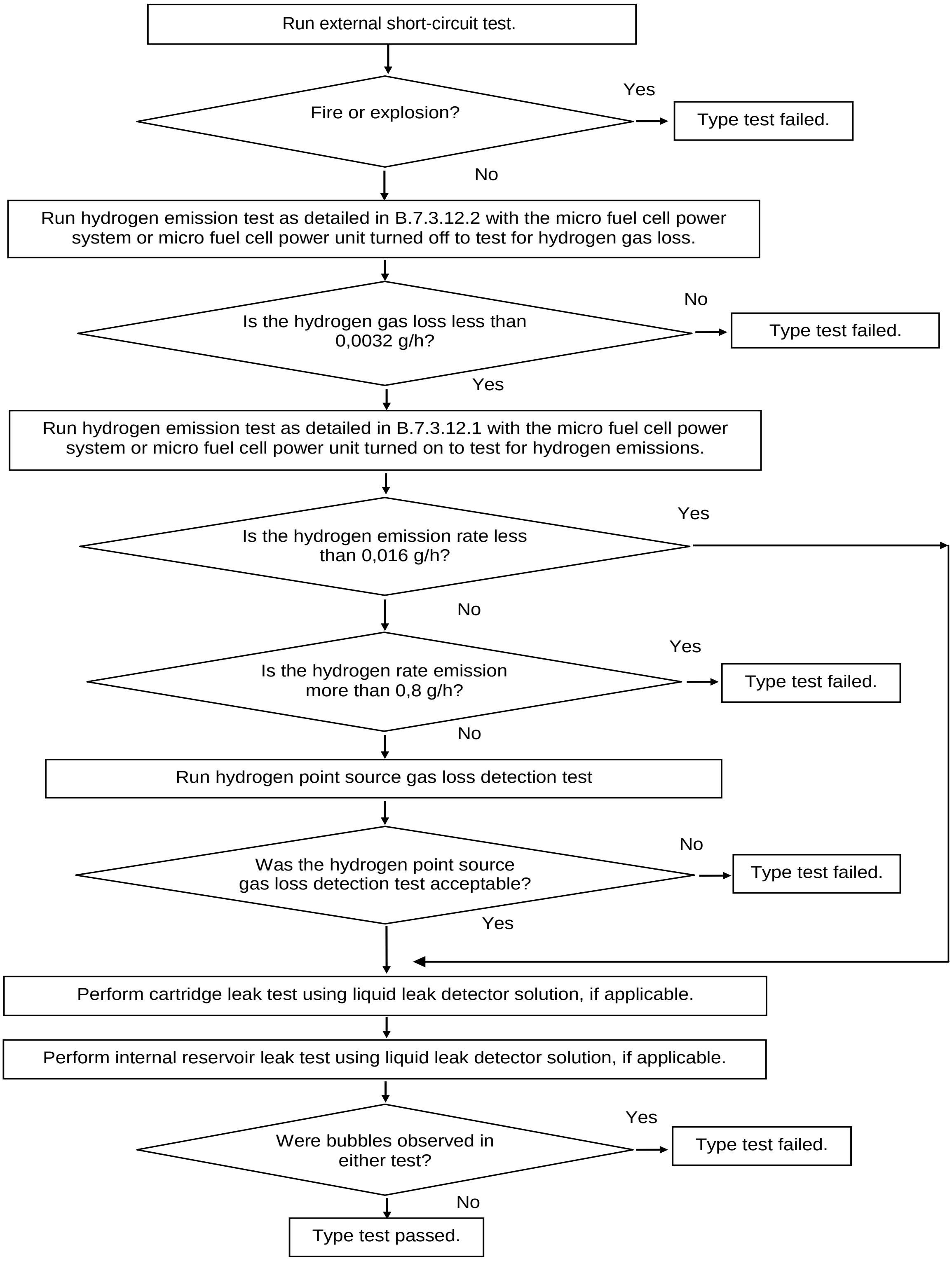


Figure B.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5

B.7.3 Type tests

B.7.3.1 Pressure differential tests

B.7.3.1.1 General

Subclause B.7.3.1 replaces Subclause 7.3.1.

Portions of this test check compliance with Subclause B.4.12.1.2 to verify that there shall be no hydrogen leakage and no hydrogen absorbing metal alloy leakage from the fuel cartridge after being subjected to a vacuum of 95 kPa below normal atmospheric pressure at 22 °C ± 5 °C.

B.7.3.1.2 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge

b) **Purpose:** to simulate the effects of low external pressure on a fuel cartridge and ensure no leakage.

c) **Test procedure:**

   Perform this test in accordance with Figure B.2.

   1) The sample shall be placed in a vacuum chamber and the pressure in the vacuum chamber shall be reduced to 95 kPa below normal atmospheric pressure.
   2) Maintain the vacuum for 30 min.
   3) Remove the sample from the vacuum chamber and check for leakage using the procedure given in B.7.2.1 using a liquid leak detector (bubble forming) solution and visually inspect the sample for hydrogen absorbing metal alloy leakage.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage and no hydrogen absorbing metal alloy leakage. See Figure B.2. Hydrogen leakage shall be checked using the hydrogen leakage measurement procedure in B.7.2.1. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.1.3 Micro fuel cell power system or micro fuel cell power unit 33,3 kPa pressure differential test

B.7.3.1.3.1 General

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex B. The test may be conducted using either of two test methods. Both test methods test the samples with at least a 33,3 kPa pressure differential using either low external pressure or internal pressurization to achieve the 33,3 kPa pressure differential.

Either B.7.3.1.3.2, Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test;

or alternatively;

B.7.3.1.3.3, Micro fuel cell power system or micro fuel cell power unit 33,3 kPa internal pressurization test, may be used.

B.7.3.1.3.2 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with the manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test apparatus:** Test samples shall be stored in a sealed vacuum chamber at a low external pressure of 68 kPa absolute pressure for 6 h. It is recommended that the size of the vacuum chamber provide more than 0,022 m^3 free air space and less than 0,28 m^3 free air space. The size of the chamber will affect the hydrogen concentration measurements, and should be selected to ensure safety throughout the test. Care should be taken to ensure that a flammable concentration of hydrogen will not accumulate in the sealed chamber. Suitable sampling equipment shall be used to sample for hydrogen concentration at the end of the test period.

d) **Test procedure:**

1) Calculate the hydrogen concentration in the test chamber that would result from the impermissible hydrogen gas loss rate of 0,0032 g/h of hydrogen during the six-hour test as follows:

$$C_{\text{pv}} = \frac{\dfrac{HLR \times t}{2 \times 1{,}00794\ {}^{\text{g}}\!/_{\text{mol}}} \times 22{,}4\ {}^{\text{l}}\!/_{\text{mol}}}{V} \times 100 = \frac{\dfrac{0{,}003\ 2\ {}^{\text{g}}\!/_{\text{h}} \times 6\text{h}}{2 \times 1{,}00794\ {}^{\text{g}}\!/_{\text{mol}}} \times 22{,}4\ {}^{\text{l}}\!/_{\text{mol}}}{V} \times 100 = \frac{0{,}213\text{l}}{V} \times 100$$

where

C_{pv} is the hydrogen concentration in % by volume that would result from a hydrogen gas loss rate of 0,0032 g/h of hydrogen in the vacuum chamber in 6 h;

V is the volume of the free space in the vacuum chamber, in standard litres;

HLR is the impermissible hydrogen gas loss rate of 0,0032 g/h;

t is the duration of the test, in this case, 6 h;

or simplified to:

$$C_{\text{pv}} = \frac{0{,}213\text{l}}{V} \times 100$$

where

C_{pv} is the hydrogen concentration in % by volume that would result from a hydrogen gas loss rate of 0,0032 g/h of hydrogen in the vacuum chamber in 6 h;

V is the volume of the free space in the vacuum chamber, in standard litres.

For example, in a vacuum chamber having 0,28 m^3 of free air space, a hydrogen concentration of 0,08 % indicates 0,0032 g/h hydrogen gas loss and fails the test.

2) Test samples shall be stored in the sealed vacuum chamber at a low external pressure of 68 kPa absolute pressure for at least 6 h at laboratory temperature.

3) At the end of the six-hour test period, re-pressurize the vacuum chamber to 101,3 kPa with known purity or bottled air meeting the requirements for laboratory atmosphere given in Table B.6. Allow the atmosphere in the vacuum chamber to stabilise or provide suitable mixing. The atmosphere in the vacuum chamber shall then be checked for hydrogen concentration.

4) Compare the measured hydrogen concentration in the vacuum chamber to the hydrogen concentration that would result from a hydrogen gas loss rate of 0,0032 g/h calculated in 1) above.

5) The hydrogen gas loss rate shall be less than the impermissible hydrogen gas loss limit of 0,0032 g/h in accordance with B.3.38 and shall be determined by ensuring that the hydrogen concentration in the vacuum chamber is less than the calculated hydrogen concentration that would result from a hydrogen gas loss rate of 0,0032 g/h. If the hydrogen concentration in the vacuum chamber is less than the hydrogen concentration C_{pv} calculated in 1) above, then the test sample passes the test for hydrogen gas loss.

6) Following the pressure differential test, remove the test sample from the vacuum chamber, and perform the hydrogen gas loss measurement in accordance with B.7.2.2.

7) If the test sample contains a fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1 on the fuel cartridge. No hydrogen leakage is allowed.

8) If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, hydrogen leakage shall be checked in B.7.3.3. See B.7.3.3 c) 7) iii).

e) **Passing criteria:**

1) No fire or flame at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss during the test shall be less than the impermissible hydrogen gas loss limit of 0,0032 g/h in accordance with B.3.38. The hydrogen concentration in the vacuum chamber shall be less than the calculated hydrogen concentration [C_{pv} .] that would result from a hydrogen gas loss rate of 0,0032 g/h. Hydrogen leakage shall meet the no “hydrogen leakage” requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Hydrogen absorbing metal alloy leakage shall be checked visually.

2) Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit following the type test. If the micro fuel cell power system or unit is not operational following the type test, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable

B.7.3.1.3.3 Micro fuel cell power system or micro fuel cell power unit 33,3 kPa internal pressurization test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with the manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test apparatus:** A sampling test chamber shall be equipped with ventilation, sampling and measuring instruments capable of accurately measuring air flow through the test chamber and the hydrogen concentration in the test chamber. The test chamber may be similar to the emission test apparatus shown in Figure B.10. The test chamber shall be supplied with clean air from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

d) **Test procedure:**

1) Place the samples in the sampling test chamber at laboratory temperature.

2) Using suitable adapters, connect the micro fuel cell power system or micro fuel cell power unit to a pressure regulated source of pure hydrogen external to the sampling chamber.

3) Pressurize the micro fuel cell power system or micro fuel cell power unit to 33,3 kPa gauge pressure with the pressure regulated source of pure hydrogen sufficient to maintain 33,3 kPa gauge pressure internal to the micro fuel cell power unit throughout the six-hour test.

4) The samples shall remain pressurized at 33,3 kPa gauge pressure in the sampling test chamber for at least 6 h at laboratory temperature.

5) Hydrogen gas loss from the micro fuel cell power system or unit shall be sampled continuously at the outlet of the test chamber, at an air sampling port similar to port A shown in Figure B.10.

6) Sample and record the gaseous contents of the test chamber through an air sampling port similar to port A shown in Figure B.10, while simultaneously measuring and recording the total air flow through the test chamber. The total air flow through the test chamber can be computed from the sum of the outlet air flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber. The flow rate through the test chamber and the hydrogen concentration in the test chamber shall be monitored continuously.

7) Calculate the hydrogen gas loss rate by multiplying the concentration of hydrogen in the test chamber by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state outlet air flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

   NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the hydrogen gas loss rate.

   See below:

   $$HLR = (F_\mathrm{o} + F_\mathrm{S}) \times C$$

   or

   $$HLR = (F_\mathrm{i}) \times C$$

   where

   HLR is the hydrogen gas loss rate in grams per hour;

   F_o is the outlet air flow rate in standard litres per hour;

   F_S is the sample flow rate in standard litres per hour;

   F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

   C is the concentration of hydrogen in grams per standard litre.

8) Compare the maximum calculated hydrogen gas loss rate to the impermissible hydrogen gas loss limit of 0,0032 g/h. If the maximum calculated hydrogen gas loss rate is less than the impermissible hydrogen gas loss limit of 0,0032 g/h, the system passes the test for hydrogen gas loss.

9) Following the pressure differential test, remove the test sample from the chamber, return the sample to normal operating pressure, and perform the hydrogen gas loss measurement in accordance with B.7.2.2.

10) If the test sample contains a fuel cartridge, perform hydrogen leakage measurement in accordance with B.7.2.1 on the fuel cartridge. No hydrogen leakage is allowed.

11) If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, hydrogen leakage shall be checked in B.7.3.3. See B.7.3.3 c) 7) iii).

e) **Passing criteria:**

1) No fire or flame at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss during the test shall be less than the impermissible hydrogen gas loss limit of 0,0032 g/h in accordance with B.3.38. Hydrogen leakage shall meet the no "hydrogen leakage" requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Hydrogen absorbing metal alloy leakage shall be checked visually.

2) Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit following the type test. If the micro fuel cell power system or unit is not operational following the type test, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable

B.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit 89,7 kPa pressure differential test

B.7.3.1.4.1 General

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex B. The test may be conducted using either of two test methods. Both test methods test the samples with at least a 89,7 kPa pressure differential using either low external pressure or internal pressurization to achieve the 89,7 kPa pressure differential.

Either B.7.3.1.4.2, Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test;

or alternatively;

B.7.3.1.4.3, Micro fuel cell power system or micro fuel cell power unit 89,7 kPa internal pressurization test, may be used.

B.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with the manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage. Hydrogen gas loss shall be less than 0,08 g/h on the basis of not exceeding 25 % of the lower flammability limit in a one-hour period.

c) **Test apparatus:** Test samples shall be stored in a sealed vacuum chamber at a low external pressure of 11,6 kPa absolute pressure for 1 h. It is recommended that the size of the vacuum chamber provide more than 0,09 m^3 free air space and less than 0,28 m^3 free air space. The size of the chamber will affect the hydrogen concentration measurements, and should be selected to ensure safety throughout the test. Care should be taken to ensure that a flammable concentration of hydrogen will not accumulate in the sealed chamber. Suitable sampling equipment shall be used to sample for hydrogen concentration at the end of the test period.

d) **Test procedure:**

1) Calculate the hydrogen concentration in the test chamber that would result from the maximum allowable hydrogen gas loss rate of 0,08 g/h of hydrogen during the one-hour test as follows:

$$C_{\mathrm{pv}} = \frac{\dfrac{HLR \times t}{2 \times 1{,}00794\ {}^{\mathrm{g}}\!/_{\mathrm{mol}}} \times 22{,}4\ {}^{\mathrm{l}}\!/_{\mathrm{mol}}}{V} \times 100 = \frac{\dfrac{0{,}08\ {}^{\mathrm{g}}\!/_{\mathrm{h}} \times 1\mathrm{h}}{2 \times 1{,}00794\ {}^{\mathrm{g}}\!/_{\mathrm{mol}}} \times 22{,}4\ {}^{\mathrm{l}}\!/_{\mathrm{mol}}}{V} \times 100 = \frac{0{,}9\mathrm{l}}{V} \times 100$$

where

C_{pv} is the hydrogen concentration in % by volume that would result from a hydrogen gas loss rate of 0,08 g/h of hydrogen in the vacuum chamber in 1 h;

V is the volume of the free space in the vacuum chamber, in standard litres;

HLR is the maximum allowable hydrogen gas loss rate of 0,08 g/h;

t is the duration of the test, in this case, 1 h;

or simplified to:

$$C_{\mathrm{pv}} = \frac{0{,}9\mathrm{l}}{V} \times 100$$

where

C_{pv} is the hydrogen concentration in % by volume that would result from a hydrogen gas loss rate of 0,08 g/h of hydrogen in the vacuum chamber in 1 h;

V is the volume of the free space in the vacuum chamber, in standard litres.

For example, in a vacuum chamber having 0,28 m^3 of free air space, a hydrogen concentration of 0,32 % indicates 0,08 g/h hydrogen gas loss and fails the test.

2) Test samples shall be stored in the sealed vacuum chamber at a low external pressure of 11,6 kPa absolute pressure for at least 1 h at laboratory temperature.

3) At the end of the one-hour test period, re-pressurize the vacuum chamber to 101,3 kPa with known purity or bottled air meeting the requirements for laboratory atmosphere given in Table B.6. Allow the atmosphere in the vacuum chamber to stabilise or provide suitable mixing. The atmosphere in the vacuum chamber shall then be checked for hydrogen concentration.

4) Compare the measured hydrogen concentration in the vacuum chamber to the hydrogen concentration that would result from a hydrogen gas loss rate of 0,08 g/h calculated in 1) above.

5) Hydrogen gas loss shall be less than 0,08 g/h on the basis of not exceeding 25 % of the lower flammability limit in a one-hour period and shall be determined by ensuring that the hydrogen concentration in the vacuum chamber is less than the calculated hydrogen concentration that would result from a hydrogen gas loss rate of less than the calculated hydrogen concentration that would result from a hydrogen gas loss rate of 0,08 g/h. If the hydrogen concentration in the vacuum chamber is less than the hydrogen concentration C_{pv} calculated in 1) above, then the test sample passes the test for hydrogen gas loss.

6) Following the pressure differential test, remove the test sample from the vacuum chamber, and perform hydrogen gas loss measurement in accordance with B.7.2.2.

7) If the test sample contains a fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1 on the fuel cartridge. No hydrogen leakage is allowed.

8) If the test sample contains an internal reservoir that contains hydrogen gas above ambient pressure, perform the hydrogen leakage measurement in accordance with B.7.2.1 on the internal reservoir. No hydrogen leakage is allowed.

e) **Passing criteria:**

1) No fire or flame at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss during the test shall be less than 0,08 g/h on the basis of not exceeding 25 % of the lower flammability limit in a one-hour period. The hydrogen concentration in the vacuum chamber shall be less than the calculated hydrogen concentration C_{pv} that would result from a hydrogen gas loss rate of 0,08 g/h. Hydrogen leakage shall meet the no "hydrogen leakage" requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Hydrogen absorbing metal alloy leakage shall be checked visually.

2) Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit following the type test. If the micro fuel cell power system or unit is not operational following the type test, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable

B.7.3.1.4.3 Micro fuel cell power system or micro fuel cell power unit 89,7 kPa internal pressurization test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with the manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test apparatus:** A sampling test chamber shall be equipped with ventilation, sampling and measuring instruments capable of accurately measuring air flow through the test chamber and the hydrogen concentration in the test chamber. The test chamber may be similar to the emission test apparatus shown in Figure B.10. The test chamber shall be supplied with clean air from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

d) **Test procedure:**

1) Place the samples in the sampling test chamber at laboratory temperature.

2) Using suitable adapters, connect the micro fuel cell power system or micro fuel cell power unit to a pressure regulated source of pure hydrogen external to the sampling chamber.

3) Pressurize the micro fuel cell power system or micro fuel cell power unit to 89,7 kPa gauge pressure with the pressure regulated source of pure hydrogen sufficient to maintain 89,7 kPa gauge pressure internal to the micro fuel cell power unit throughout the one-hour test.

4) The samples shall remain pressurized at 89,7 kPa gauge pressure in the sampling test chamber for at least 1 h at laboratory temperature.

5) Hydrogen gas loss from the micro fuel cell power system or unit shall be sampled continuously at the outlet of the test chamber, at an air sampling port similar to port A shown in Figure B.10.

6) Sample and record the gaseous contents of the test chamber through an air sampling port similar to port A shown in Figure B.10, while simultaneously measuring and recording the total air flow through the test chamber. The total air flow through the test chamber can be computed from the sum of the outlet air flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber. The flow rate through the test chamber and the hydrogen concentration in the test chamber shall be monitored continuously.

7) Calculate the hydrogen gas loss rate by multiplying the concentration of hydrogen in the test chamber by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state outlet air flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the hydrogen gas loss rate.

See below:

$$HLR = (F_{\mathrm{o}} + F_{\mathrm{S}}) \times C$$

or

$$HLR = (F_{\mathrm{i}}) \times C$$

where

HLR is the hydrogen gas loss rate in grams per hour;

F_{o} is the outlet air flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration of hydrogen in grams per standard litre.

8) Compare the maximum calculated hydrogen gas loss rate to 0,08 g/h, on the basis of not exceeding 25 % of the lower flammability limit in a one-hour period. If the maximum calculated hydrogen gas loss rate is less than 0,08 g/h, the system passes the test for hydrogen gas loss.

9) Following the pressure differential test, remove the test sample from the chamber, return the sample to normal operating pressure, and perform the hydrogen gas loss measurement in accordance with B.7.2.2.

10) If the test sample contains a fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1 on the fuel cartridge. No hydrogen leakage is allowed.

11) If the test sample contains an internal reservoir that contains hydrogen gas above ambient pressure, perform the hydrogen leakage measurement in accordance with B.7.2.1 on the internal reservoir. No hydrogen leakage is allowed.

e) **Passing criteria:**

1) No fire or flame at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss during the test shall be less than 0,08 g/h, on the basis of not exceeding 25 % of the lower flammability limit in a one-hour period. Hydrogen leakage shall meet the “no hydrogen leakage” requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Hydrogen absorbing metal alloy leakage shall be checked visually.

2) Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit following the type test. If the micro fuel cell power system or unit is not operational following the type test, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

B.7.3.2 Vibration test

Subclause B.7.3.2 replaces Subclause 7.3.2 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in B.7.3.1.3 or a micro fuel cell power system used in B.7.3.1.3.

b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure B.2 for the fuel cartridge and Figure B.4 for the micro fuel cell power system or unit.

2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) For the fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1. See Figure B.2.

7) For the micro fuel cell power system or micro fuel cell power unit, perform the hydrogen gas loss measurement in accordance with B.7.2.2. See Figure B.4.

8) If the micro fuel cell power system or unit contains a fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1.

9) If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, hydrogen leakage shall be checked in B.7.3.3. See B.7.3.3 c) 7) iii).

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually. If the micro fuel cell power unit or micro fuel cell power system is not operational, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

B.7.3.3 Temperature cycling test

Subclause B.7.3.3 replaces Subclause 7.3.3 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

a) **Test sample:** a fuel cartridge used in B.7.3.2, a partially filled fuel cartridge used in B.7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in B.7.3.2 or a micro fuel cell power system used in B.7.3.2.

b) **Purpose:** to simulate the effects of low-temperature and high temperature exposure and the effects of extreme temperature change.

c) **Test procedure:**

1) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

2) See Figure B.8 for the temperature profile to be used.

3) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

4) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min, then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

5) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

6) The above process is to be done twice.

7) After 1 h at 22 °C ± 5°C, perform the following hydrogen leakage tests.

   i) For the fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1. See Figure B.2.

   ii) For the micro fuel cell power system or micro fuel cell power unit, perform the hydrogen gas loss measurement in accordance with B.7.2.2. (This includes hydrogen emission testing in accordance with B.7.3.12). See Figure B.4.

   iii) If the micro fuel cell power system or unit contains a fuel cartridge, or an internal reservoir that contains hydrogen gas above ambient pressure, perform the hydrogen leakage measurement in accordance with B.7.2.1.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit. Hydrogen emissions shall meet the passing criteria in B.7.3.12. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually. If the micro fuel cell power unit or micro fuel cell power system is not operational, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

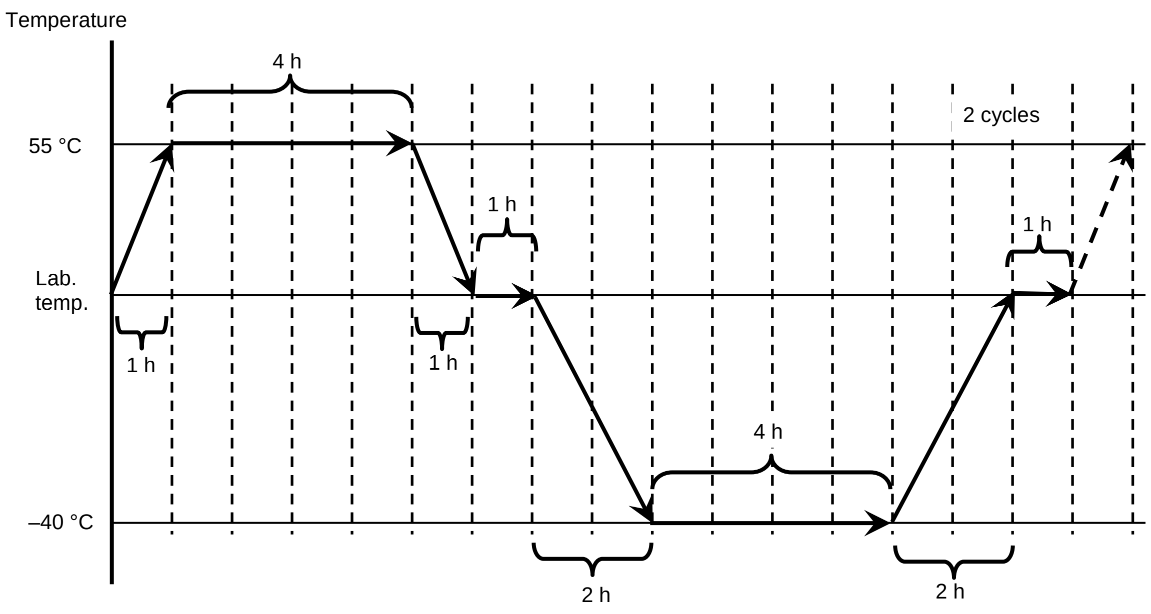


Figure B.8 – Temperature cycling – Replaces Figure 8

B.7.3.4 High temperature exposure test

Subclause B.7.3.4 replaces Subclause 7.3.4 for fuel cartridges covered by this Annex B.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments.

c) **Test procedure:**

1) Two orientations shall be tested – valve up and valve down.

2) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

3) Remove the test sample to laboratory temperature.

4) Perform the hydrogen leakage measurement in accordance with B.7.2.1. See Figure B.2.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.5 Drop test

Subclause B.7.3.5 replaces Subclause 7.3.5 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

If the drop test of ISO 16111:2008, 6.2.4 is performed using the same fuel cartridge for all four drop orientations, the fuel cartridge drop test of B.7.3.5 is not required. The drop test of ISO 16111:2008 is seen to be more rigorous, and therefore more than sufficient to ensure adequate safety of the fuel cartridge. If the drop test of ISO 16111:2008 is performed using a different fuel cartridge for each drop orientation, the fuel cartridge drop test of B.7.3.5 shall be performed in addition to the drop test of ISO 16111:2008.

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

1) The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

2) The height of the drop shall be:

i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system;

ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge with a water capacity of more than 200 ml;

iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge with a water capacity of up to 200 ml.

3) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

4) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or unit may be used for all four drop orientations, or more than one micro fuel cell power system or unit may be used in subsequent drops, at the discretion of the manufacturer.

5) For all tests, drop orientations shall be:

   i) valve up;

   ii) valve down;

   iii) two other mutually perpendicular orientations.

6) After each drop test, perform the following hydrogen leakage tests.

   i) For the fuel cartridge, perform the hydrogen leakage measurement in accordance with B.7.2.1. See Figure B.2.

   ii) For the micro fuel cell power system or micro fuel cell power unit, perform the hydrogen gas loss measurement in accordance with B.7.2.2. (This includes hydrogen emission testing in accordance with B.7.3.12.) See Figure B.4.

   iii) If the micro fuel cell power system or unit contains a fuel cartridge, or an internal reservoir that contains hydrogen gas above ambient pressure, perform the hydrogen leakage measurement in accordance with B.7.2.1.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit. Hydrogen emissions shall meet the passing criteria in B.7.3.12. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually. If the micro fuel cell power unit or micro fuel cell power system is not operational, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

   If the micro fuel cell power system or unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

B.7.3.6 Compressive loading test

Subclause B.7.3.6 replaces Subclause 7.3.6 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

B.7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

1) The micro fuel cell power system or unit test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

5) After the compressive loading test, perform the following hydrogen leakage tests.

   i) For the micro fuel cell power system or micro fuel cell power unit, perform the hydrogen gas loss measurement in accordance with B.7.2.2. (This includes hydrogen emission testing in accordance with B.7.3.12.) See Figure B.4.

ii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform the hydrogen leakage measurement in accordance with B.7.2.1.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit. Hydrogen emissions shall meet the passing criteria in B.7.3.12. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually. If the micro fuel cell power unit or micro fuel cell power system is not operational, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

B.7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge.

c) **Test procedure:**

1) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter.

5) For the sample, perform the hydrogen leakage measurement in accordance with B.7.2.1. See Figure B.2.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.7 External short-circuit test

Subclause B.7.3.7 replaces Subclause 7.3.7 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

1) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

2) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

3) Following the short-circuit test, perform the following hydrogen leakage testing in accordance with Figure B.5.

   i) For the micro fuel cell power system or micro fuel cell power unit, perform the hydrogen gas loss measurement in accordance with B.7.2.2. (This includes hydrogen emission testing in accordance with B.7.3.12). See Figure B.4.

   ii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurement in accordance with B.7.2.1.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power system or unit. Hydrogen emissions shall meet the passing criteria in B.7.3.12. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually. If the micro fuel cell power unit or micro fuel cell power system is not operational, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

   Exterior surfaces shall not exceed the temperatures shown in Table 2 during or after short circuit testing.

NOTE The external short-circuit test can be done sequentially with the surface component and exhaust gas temperature test using the same sample.

B.7.3.9 Long-term storage test

B.7.3.9.1 General

Subclause B.7.3.9 replaces Subclause 7.3.9 for fuel cartridges covered by this Annex B.

Five options are available. Any option may be used:

1) B.7.3.9.2 Option 1 – Continuous hydrogen concentration measurement;
2) B.7.3.9.3 Option 2 – Controlled flow hydrogen concentration measurement;
3) B.7.3.9.4 Option 3 – Continuous weight measurement;
4) B.7.3.9.5 Option 4 – Periodic weight measurements; or,
5) B.7.3.9.6 Option 5 – One weight measurement.

B.7.3.9.2 Option 1 – Continuous hydrogen concentration measurement

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test apparatus:** A temperature test chamber shall be equipped with sampling and monitoring instruments capable of accurately measuring air flow through the test chamber, and the hydrogen concentration in the test chamber. This temperature test chamber may be similar to the emission test apparatus shown in Figure B.10. The temperature test chamber shall be equipped with heaters capable of maintaining an internal temperature of 50 °C ± 2 °C with air flow through the system. It is recommended that the test chamber be equipped with a hydrogen sensor or other equivalent safety features to ensure that a flammable concentration of hydrogen is not permitted to accumulate in a closed volume.

d) **Test procedure:**

   1) The test chamber shall be equipped with a circulation fan, ventilation and measurement instruments capable of accurately measuring air flow through the chamber and accurately measuring hydrogen concentration in the chamber similar to the configuration in Figure B.10.

   2) The test chamber shall be supplied with clean air from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

3) Place the sample in the temperature test chamber at 50 °C ± 2°C.

4) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

5) Hydrogen gas loss from the fuel cartridge shall be sampled continuously at the outlet of the small test chamber, at air sampling port A similar to that shown in Figure B.10.

6) Sample and record the gaseous contents of the test chamber through an air sampling port similar to port A shown in Figure B.10, while simultaneously measuring and recording the total air flow through the test chamber. The total air flow through the test chamber can be computed from the sum of the outlet air flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber. The flow through the test chamber and the hydrogen concentration in the chamber shall be monitored continuously.

7) Calculate the hydrogen gas loss rate by multiplying the concentration of hydrogen in the test chamber by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state outlet air flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the hydrogen gas loss rate.

See below:

$$HLR = (F_{\mathrm{o}} + F_{\mathrm{S}}) \times C$$

or

$$HLR = (F_{\mathrm{i}}) \times C$$

where

HLR is the hydrogen gas loss rate in grams per hour;

F_{o} is the outlet air flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration of hydrogen in grams per standard litre.

8) At the end of the 28 days, perform hydrogen leakage testing in accordance with the hydrogen leakage measurement test of B.7.2.1 for the fuel cartridge. If the fuel cartridge is empty of hydrogen at the end of the 28 days, refill the cartridge (or pressurize using a suitable inert gas) to rated charging pressure according to the manufacturer’s instructions prior to executing the hydrogen leakage measurement.

e) **Passing criteria:** No hydrogen absorbing metal alloy leakage, no fire, no explosion. No hydrogen leakage at the end of the 28 day period as verified by the hydrogen leakage measurement procedure of B.7.2.1 for the fuel cartridge. The hydrogen concentration in the temperature test chamber shall not exceed 25 % LFL at any time during the test. The hydrogen gas loss rate from the cartridge shall be less than 0,0032 g/h at all times during the test. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.9.3 Option 2 – Controlled flow hydrogen concentration measurement

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test apparatus:** A temperature test chamber shall be equipped with sampling and monitoring instruments capable of accurately measuring air flow through the test chamber, and the hydrogen concentration in the test chamber. This temperature test chamber may be similar to the emission test apparatus shown in Figure B.10. The temperature test chamber must be equipped with heaters capable of maintaining an internal temperature of 50 °C ± 2 °C with air flow through the system. It is recommended that the test chamber be equipped with a hydrogen sensor or other equivalent safety features to ensure that a flammable concentration of hydrogen is not permitted to accumulate in a closed volume.

d) **Test procedure:**

1) The test chamber shall be equipped with a circulation fan, ventilation and measurement instruments capable of accurately measuring air flow through the chamber and a hydrogen detector calibrated to detect 25 % LFL (1 % by volume) of hydrogen concentration. The hydrogen detector shall provide an alarm or other indication of a hydrogen concentration of 25 % LFL (1 % by volume) in the test chamber. The test chamber shall have a free air volume (total volume minus volume of fuel cartridge and instrumentation inside the chamber) of less than 3,56 l to ensure adequate mixing and a homogeneous distribution in the chamber. The test chamber may utilize a configuration similar to that shown in Figure B.10, with appropriate modifications based on the free air space limitation.

2) The test chamber shall be supplied with clean air from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

3) The air flow rate through the chamber shall be controlled such that a hydrogen gas loss rate from the cartridge of 0,0032 g/h will result in a hydrogen concentration of 25 % LFL (1 % by volume) and result in an alarm or other indication from the hydrogen detector, according to the following formula:

$$F_{\mathrm{t}} = \frac{HLR \times SV}{C} = \frac{0{,}0032\ \mathrm{g/h} \times \left(\frac{22{,}4\ \mathrm{l/mol}}{2 \times 1{,}00794\ \mathrm{g/mol}}\right)}{0{,}25 \times 4\%} = 3{,}56\ \mathrm{l/h}$$

where

HLR is the hydrogen gas loss rate in grams per hour;

F_{t} is the air flow rate through the temperature test chamber in standard litres per hour;

C is the hydrogen concentration in grams per standard litre;

SV is the specific volume of one gram of hydrogen.

4) Place the sample in the temperature test chamber at 50 °C ± 2 °C.

5) Allow the concentration in the chamber to equilibrate prior to beginning the test. The time required will depend on the size of the chamber and capacity of the circulation fan.

6) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days. The hydrogen concentration in the test chamber and the air flow rate through the test chamber shall be monitored continuously throughout the test.

7) If the hydrogen concentration reaches 25 % LFL (1 % by volume), this indicates 0,0032 g/h of hydrogen gas loss from the sample and the sample shall be considered to have failed the test.

8) At the end of the 28 days, perform hydrogen leakage testing in accordance with the hydrogen leakage measurement test of B.7.2.1 for the fuel cartridge. If the fuel cartridge is empty of hydrogen at the end of the 28 days, refill the cartridge (or pressurize using a suitable inert gas) to rated charging pressure according to the manufacturer's instructions prior to executing the hydrogen leakage measurement.

e) **Passing criteria:** No hydrogen absorbing metal alloy leakage, no fire, no explosion. No hydrogen leakage at the end of the 28 day period as verified by the hydrogen leakage measurement procedure of B.7.2.1 for the fuel cartridge. The hydrogen concentration in the temperature test chamber shall not exceed 25 % LFL at any time during the test. The hydrogen gas loss rate from the sample shall be less than 0,0032 g/h at all times during the test. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.9.4 Option 3 – Continuous weight measurement

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test apparatus:** A temperature test chamber capable of maintaining an internal temperature of 50 °C ± 2° C. It is recommended that the test chamber be equipped with a hydrogen sensor, ventilation or other equivalent safety features to ensure that a flammable concentration of hydrogen is not permitted to accumulate in a closed volume.

d) **Test procedure** (See Figure B.9, which replaces Figure 9):

1) Use a load cell (continuous electronic weight sensing device) designed and calibrated for use at 50 °C inside the temperature chamber.

2) Place the load cell in a temperature chamber at 50 °C ± 2 °C. Place the fuel cartridge on top of the load cell so that all the weight is being applied to the load cell. A fixture may be used to control the position of the fuel cartridge, to ensure all the weight is applied to the load cell.

3) Connect a digital readout to the load cell and collect the data either manually or automatically. The data should be collected in a manner sufficient to provide a high degree of confidence that the hydrogen gas loss does not exceed 0,0032 g/h.

4) Measure and record initial mass M_{initial} and time t_{i}.

5) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

6) If the fuel cartridge still has fuel in the test sample at the end of the test, then calculate the hydrogen mass loss rate by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. Calculate the hydrogen mass loss rate using the difference in mass ($M_{\text{initial}} - M_{\text{final}}$) divided by the elapsed time ($t_{\text{f}} - t_{\text{i}}$) according to the following formula:

i) $\dfrac{(M_{\text{initial}} - M_{\text{final}})}{\Delta t} =$ hydrogen mass loss rate;

ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h;

iii) M_{initial} = the initial mass of the fuel cartridge;

iv) M_{final} = the final mass of the fuel cartridge.

7) If the hydrogen mass loss rate is less than 0,0032 g/h, then the test sample passes the test for hydrogen gas loss.

8) If the fuel cartridge contains no more hydrogen prior to the end of the test, the hydrogen mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. If the hydrogen mass loss rate is less than 0,0032 g/h, then the test sample passes the test for hydrogen gas loss.

   i) $\dfrac{(M_{\text{initial}} - M_{\text{final}})}{\Delta t} =$ hydrogen mass loss rate;

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when fuel still remained in the fuel cartridge;

   iii) M_{last} = the last weight measurement taken when fuel still remained in the fuel cartridge.

9) At the end of the 28 days, perform hydrogen leakage testing in accordance with the hydrogen leakage measurement test of B.7.2.1 for the fuel cartridge. If the fuel cartridge is empty of hydrogen at the end of the 28 days, refill the cartridge (or pressurize using a suitable inert gas) to rated charging pressure according to the manufacturer's instructions prior to executing the hydrogen leakage measurement.

e) **Passing criteria:** No hydrogen absorbing metal alloy leakage, no fire, no explosion. No hydrogen leakage at the end of the 28 day period as verified by the hydrogen leakage measurement procedure of B.7.2.1 for the fuel cartridge. The hydrogen mass loss rate shall be determined according to the test procedure and Figure B.9. The hydrogen mass loss rate shall be less than the 0,0032 g/h impermissible hydrogen gas loss criterion. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.9.5 Option 4 – Periodic weight measurements

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test apparatus:** A temperature test chamber capable of maintaining an internal temperature of 50 °C ± 2 °C. It is recommended that the test chamber be equipped with a hydrogen sensor, ventilation or other equivalent safety features to ensure that a flammable concentration of hydrogen is not permitted to accumulate in a closed volume.

d) **Test procedure** (See Figure B.9, which replaces Figure 9):

1) Place the fuel cartridge in a temperature chamber at 50 °C ± 2 °C. Weight measurements shall be collected in a manner sufficient to provide a high degree of confidence to determine if the hydrogen gas loss does not exceed 0,0032 g/h, with a minimum of once every three days.

2) Measure and record initial mass M_{initial} and time t_{i}.

3) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

4) The time in which the test samples are removed from the chamber for measurement shall not be included in the time the test sample is to be tested (28 days). Additional time should be added to get the test sample to the test temperature (50 °C ± 2 °C) each time the test sample is removed from the chamber. The test samples should only be stabilised at laboratory temperature if the mass loss will be affected.

5) If the fuel cartridge still has fuel in the test sample at the end of the test, then calculate the hydrogen mass loss rate by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_f. Calculate the hydrogen mass loss rate using the difference in mass ($M_{initial}$ – M_{final}) divided by the elapsed time (t_f – t_i) according to the following formula:

 i) $\frac{(M_{initial} - M_{final})}{\Delta t} =$ hydrogen mass loss rate;

 ii) $\Delta t = t_f - t_i$ = 28 days × 24 h/day = 672 h;

 iii) $M_{initial}$ = the initial mass of the fuel cartridge;

 iv) M_{final} = the final mass of the fuel cartridge.

6) If the hydrogen mass loss rate is less than 0,0032 g/h, then the test sample passes the test for hydrogen gas loss.

7) If the fuel cartridge contains no more hydrogen prior to the end of the test, the hydrogen mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. If the hydrogen mass loss rate is less than 0,0032 g/h, then the test sample passes the test for hydrogen gas loss.

 i) $\frac{(M_{initial} - M_{final})}{\Delta t} =$ hydrogen mass loss rate;

 ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when fuel still remained in the fuel cartridge;

 iii) M_{last} = the last weight measurement taken when fuel still remained in the fuel cartridge.

8) At the end of the 28 days, perform hydrogen leakage testing in accordance with the hydrogen leakage measurement test of B.7.2.1 for the fuel cartridge. If the fuel cartridge is empty of hydrogen at the end of the 28 days, refill the cartridge (or pressurize using a suitable inert gas) to rated charging pressure according to the manufacturer's instructions prior to executing the hydrogen leakage measurement.

e) **Passing criteria:** No hydrogen absorbing metal alloy leakage, no fire, no explosion. No hydrogen leakage at the end of the 28 day period as verified by the hydrogen leakage measurement procedure of B.7.2.1 for the fuel cartridge. The hydrogen mass loss rate shall be determined according to the test procedure and Figure B.9. The hydrogen mass loss rate shall be less than the 0,0032 g/h impermissible hydrogen gas loss criterion. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.9.6 Option 5 – One weight measurement

This option is intended for fuel cartridges containing more than 2 g of hydrogen gas.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test apparatus:** A temperature test chamber capable of maintaining an internal temperature of 50 °C ± 2 °C. It is recommended that the test chamber be equipped with a hydrogen sensor, ventilation or other equivalent safety features to ensure that a flammable concentration of hydrogen is not permitted to accumulate in a closed volume.

d) **Test procedure:**

1) Measure and record initial mass M_{initial} and time t_{i}.

2) Place the fuel cartridges in a temperature chamber at 50 °C ± 2 °C.

3) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

4) After 28 days, remove the fuel cartridges from the chamber for measurement. The test samples should be stabilised at laboratory temperature if the mass loss will be affected.

5) Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the fuel cartridge still has fuel in the test sample at the end of the test, then calculate hydrogen mass loss rate using the difference in mass (M_{initial} – M_{final}) divided by the elapsed time (t_f – t_i) according to the following formula:

   i) $\dfrac{(M_{\text{initial}} - M_{\text{final}})}{\Delta t} =$ hydrogen mass loss rate;

   ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h;

   iii) M_{initial} = the initial mass of the fuel cartridge;

   iv) M_{final} = the final mass of the fuel cartridge.

6) If the hydrogen mass loss rate is less than 0,0032 g/h, then the test sample passes the test for hydrogen gas loss.

7) At the end of the 28 days, perform hydrogen leakage testing in accordance with the hydrogen leakage measurement test of B.7.2.1 for the fuel cartridge.

8) If the fuel cartridge no longer contains hydrogen after 28 days, then the type test according to one of the following procedures shall be performed:

   i) B.7.3.9.2 Option 1 – Continuous hydrogen concentration measurement;

   ii) B.7.3.9.3 Option 2 – Controlled flow hydrogen concentration measurement;

   iii) B.7.3.9.4 Option 3 – Continuous weight measurement; or

   iv) B.7.3.9.5 Option 4 – Periodic weight measurements.

e) **Passing criteria:** No hydrogen absorbing metal alloy leakage, no fire, no explosion. No hydrogen leakage at the end of the 28 day period as verified by the hydrogen leakage measurement procedure of B.7.2.1 for the fuel cartridge. The hydrogen mass loss rate shall be less than the 0,0032 g/h impermissible hydrogen gas loss criteria. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually

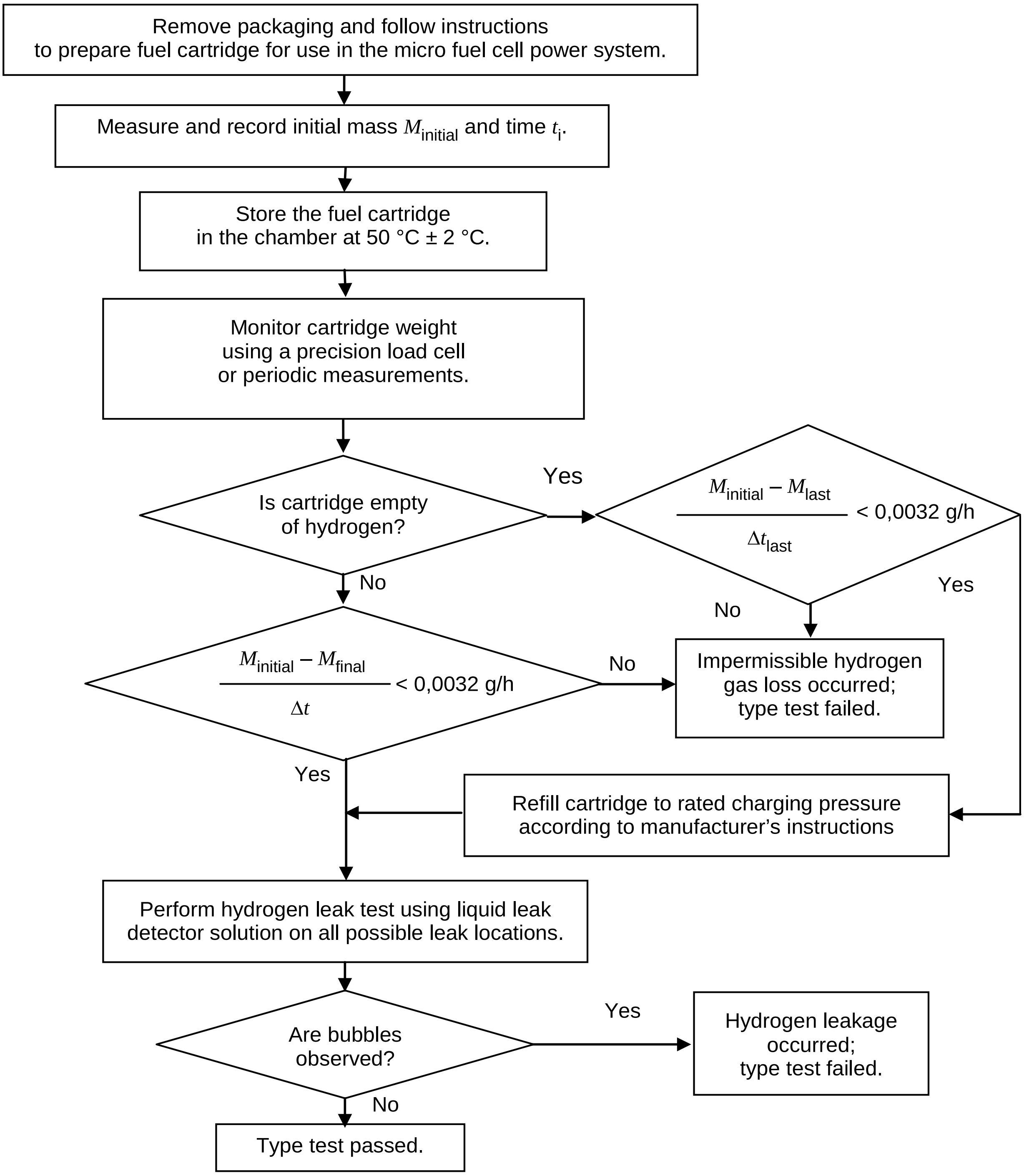


Figure B.9 – Fuel cartridge hydrogen leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9

B.7.3.10 High-temperature connection test

Subclause B.7.3.10 replaces Subclause 7.3.10 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge and a micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage, no fire, no explosion.

c) **Test procedure:**

   1) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.

   2) The micro fuel cell power unit or test fixture with micro fuel cell power unit valve is kept at laboratory temperature.

   3) Remove the test sample from the chamber and connect the fuel cartridge to the micro fuel cell power unit or test fixture with micro fuel cell power unit valve within 5 min of removal from the chamber.

   4) Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

   5) Disconnect the fuel cartridge and check for hydrogen leakage:

      i) for the fuel cartridge, perform hydrogen leakage measurement in accordance with B.7.2.1. See Figure B.3;

      ii) for the micro fuel cell power unit or test fixture with micro fuel cell power unit valve, use a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 on the fuel supply interface or valve to ensure no hydrogen leakage from the valve.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occurs, the test is acceptable. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.11 Connection cycling tests

Subclause B.7.3.11 replaces Subclause 7.3.11 for micro fuel cell power systems, units and fuel cartridges covered by this Annex B.

B.7.3.11.1 Fuel cartridge

B.7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

   1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

   2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

   3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

   4) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

5) Repeat steps 1 through 4, inclusive, twice more for a total of three connections and disconnections.

6) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

7) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

8) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

9) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

10) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

11) Turn off the micro fuel cell power unit or stop simulated fuel flow.

12) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.11.1.2 Satellite cartridge

a) **Test sample:** an unused satellite fuel cartridge and an unused micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer’s instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the satellite fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and initiate or simulate fuel flow. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

2) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

3) Repeat steps 1 and 2 twice more for a total of three connections and disconnections.

4) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

5) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

6) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

7) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

8) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and initiate or simulate fuel flow.

9) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 upon disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

10) Repeat steps 1 through 9 four more times for a total of 55 cycles, waiting 1 h between each set of 11 cycles.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 for the fuel cartridge. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually.

B.7.3.11.2 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

1) Connect the first fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 at the connection point, and all other points where hydrogen leakage may occur on connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1, in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

5) Repeat steps 1 through 4, inclusive, twice more for a total of three connections and disconnections.

6) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

7) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

8) Connect and disconnect the first fuel cartridge three more times for a total of ten connections and disconnections.

9) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1, in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

10) Connect the fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 at the connection point, and all other points where hydrogen leakage may occur on connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

11) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1, in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

14) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.

    i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections.

    ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.

    iii) Following this ageing, a final unused fuel cartridge will be tested.

15) Connect the final unused fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 at the connection point, and all other points where hydrogen leakage may occur on connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

16) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

17) Turn off the micro fuel cell power unit or stop simulated fuel flow.

18) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1, in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

19) Repeat steps 15 through 18, inclusive, twice more for a total of three connections and disconnections.

20) Connect and disconnect the final fuel cartridge four more times for a total of seven connections and disconnections.

21) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1, in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1. Connect and disconnect the final fuel cartridge three more times for a total of ten connections and disconnections.

22) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1, in particular at the connection valves of the fuel cartridge and the micro fuel cell power unit, and all other points where hydrogen leakage may occur on disconnection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

23) Connect the fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 at the connection point, and all other points where hydrogen leakage may occur on connection. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

24) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

25) Turn off the micro fuel cell power unit or stop simulated fuel flow.

26) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with B.7.2.1 for the fuel cartridge and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in B.7.2.1.

27) Perform the following hydrogen leakage tests.

    i) For the micro fuel cell power system or micro fuel cell power unit, perform hydrogen gas loss measurement in accordance with B.7.2.2 (this includes hydrogen emission testing in accordance with B.7.3.12). See Figure B.4.

    ii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurement in accordance with B.7.2.1.

d) **Passing criteria:** No fire at any time, no explosion at any time, and no hydrogen absorbing metal alloy leakage. Hydrogen gas loss shall meet the applicable requirements of B.7.2.2 for the micro fuel cell power unit. Hydrogen leakage shall meet the no hydrogen leakage requirements of B.7.2.1 at connection points when the fuel cartridge is connected to the micro fuel cell power unit, and at connection valves when disconnected, and for the fuel cartridge and the internal reservoir, if applicable. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen absorbing metal alloy leakage shall be checked visually. If the micro fuel cell power unit or micro fuel cell power system is not operational following the test, but the applicable requirements of B.7.2.1 and B.7.2.2 are met, the test is acceptable.

B.7.3.12 Emission test

This Subclause B.7.3.12 shall replace Subclause 7.3.12 for micro fuel cell power systems or micro fuel cell power units tested in accordance with this Annex B. The included Table B.7, Emission limits, replaces Table 7 in Subclause 7.3.12. Figure B.10 replaces Figure 10 and is identical to Figure 10. Hydrogen emissions are the only possible emission from these micro fuel cell power systems and micro fuel cell power units using hydrogen stored in metal hydride storage systems. The procedure for hydrogen emission testing is detailed in Figure B.12, which is to be used as an additional figure when testing is done in accordance with this Annex B.

Micro fuel cell power systems or units shall be tested according to B.7.3.12.1, Hydrogen emission test, DEVICE-ON. A second test procedure, B.7.3.12.2, Hydrogen emission test, DEVICE-OFF, is provided for use in conjunction with B.7.2.2, Hydrogen gas loss measurements from micro fuel cell power systems and micro fuel cell power units and measuring procedures.

B.7.3.12.1 Hydrogen emission test, DEVICE-ON

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or micro fuel cell power unit – that is fuelled with hydrogen – emissions of hydrogen are the only possible emissions. The purpose of this test is to make sure that hydrogen emissions are maintained low enough to ensure that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame (< 0,016 g/h, or 3 standard cubic centimeters per minute). Maintaining these limits not only prevents flammable mixtures from arising due to hydrogen emissions but also ensures that an adequate supply of oxygen is maintained in the operating environment.

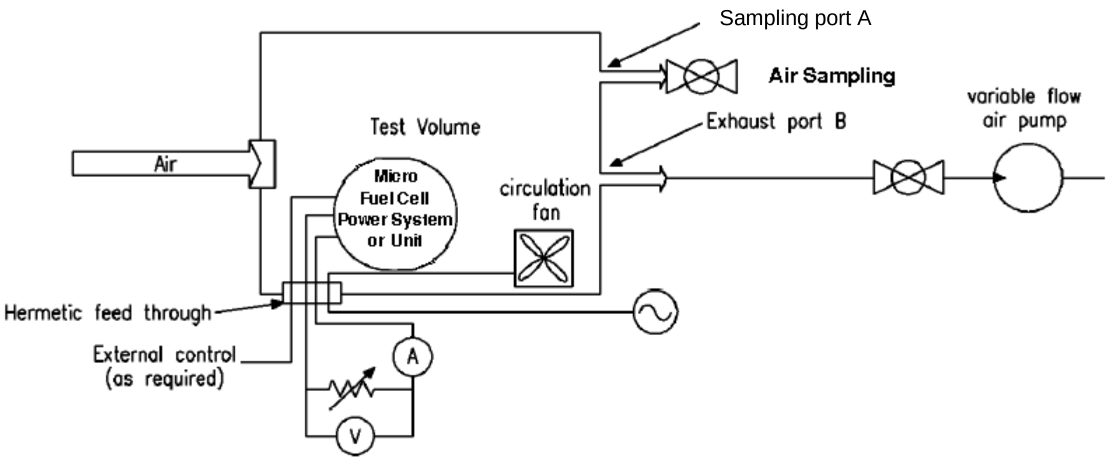


Figure B.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the operational emission rate testing apparatus is shown in Figure B.10. The configuration shown in Figure B.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex B. Hydrogen emission rate testing in accordance with B.7.3.12.1 d) is required for micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex B.

To analyse the hydrogen emissions, a mass spectrometer, gas chromatograph, or other suitable instrument calibrated to measure hydrogen concentration shall be used and connected to sampling port A in Figure B.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

d) **Test procedure:**

1) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure B.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the hydrogen emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

2) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

3) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure B.10.

4) Allow the test chamber inlet air flow rate, outlet air flow rate, circulation fan flow and sample flow rate to stabilise.

5) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure B.10, while simultaneously measuring and recording the total air flow through the test chamber. The total air flow through the test chamber may be computed from the sum of the outlet air flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber. The flow through the test chamber and the hydrogen concentration in the chamber shall be monitored continuously.

6) Record the hydrogen concentration.

7) Calculate the hydrogen emission rate being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state outlet air flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

   NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the hydrogen gas loss rate.

   See below:

   $$ER = (F_{\mathrm{o}} + F_{\mathrm{S}}) \times C$$

   or

   $$ER = (F_{\mathrm{i}}) \times C$$

   where

   ER is the hydrogen emission rate in grams per hour;

   F_{o} is the outlet air flow rate in litres per hour;

   F_{S} is the sample flow rate in litres per hour;

   F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

   C is the concentration in grams per litre.

8) Compare the maximum measured "DEVICE – ON" hydrogen emission rate to Table B.7.

   NOTE This is a stabilised concentration measurement.

9) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

10) If the hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the test is complete.

11) If the hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", perform hydrogen point source gas loss detection test in accordance with B.7.3.13.

12) If the hydrogen emission rate is greater than 0,8 g/h with the "DEVICE – ON", the test fails. No further testing is necessary.

e) **Passing criteria:**

The procedure for hydrogen emission testing is detailed in Figure B.12, which is to be used as an additional figure when testing is done in accordance with Annex B. Hydrogen emissions are evaluated as follows: If the total hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or micro fuel cell power unit passes the emission test and no further testing is required. If the total hydrogen emission rate is not less than 0,8 g/h with the “DEVICE – ON”, the micro fuel cell power system or unit fails the emission test and no further testing is required. If the hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", B.7.3.13, hydrogen point source gas loss detection test shall be performed with acceptable results to show no more than 0,016 g/h hydrogen leakage from any single point leak. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding the limit for non-operating systems in Table B.7, the test is acceptable.

NOTE 1 The allowable flammable hydrogen emission level that will not support a standing flame is 3 ml/min (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, *Codes and Standards Analysis*, 2001 *(USA)*). The non-flammable hydrogen emissions limit is based on the criteria that hydrogen emission does not build up to more than 25 % of LFL in the reference volume.

NOTE 2 Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

B.7.3.12.2 Hydrogen emission test, DEVICE-OFF

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under storage, or non-operating, conditions of a micro fuel cell power system or micro fuel cell power unit – that is fuelled with hydrogen – emissions of hydrogen are the only possible emissions. This test procedure is intended to be used in conjunction with the hydrogen gas loss test of B.7.2.2, to ensure that a non-operating micro fuel cell power system or micro fuel cell power unit does not exceed the impermissible hydrogen gas loss limit of 0,0032 g/h.

c) **Test apparatus:** An example of the operational emission rate testing apparatus is shown in Figure B.10. The configuration shown in Figure B.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex B.

To analyse the hydrogen emissions, a mass spectrometer, gas chromatograph, or other suitable instrument calibrated to measure hydrogen concentration shall be used and connected to sampling port A in Figure B.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

d) **Test procedure:**

1) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") and measure the hydrogen emission, or hydrogen gas loss, rates with the micro fuel cell power system or unit off ("DEVICE – OFF") inside the small test chamber shown in Figure B.10.

2) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

3) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown on Figure B.10.

4) Allow the test chamber inlet air flow rate, outlet air flow rate, circulation fan flow and sample flow rate to stabilise.

5) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure B.10, while simultaneously measuring and recording the total air flow through the test chamber. The total air flow through the test chamber may be computed from the sum of the outlet air flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber. The flow through the test chamber and the hydrogen concentration in the chamber shall be monitored continuously.

6) Record the hydrogen concentration.

7) Calculate the hydrogen gas loss rate being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state outlet air flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

   NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the hydrogen gas loss rate.

   $$HLR = (F_\mathrm{o} + F_\mathrm{S}) \times C$$

   or

   $$HLR = (F_\mathrm{i}) \times C$$

   where

   HLR is the emission rate in grams per hour;

   F_o is the outlet air flow rate in litres per hour;

   F_S is the sample flow rate in litres per hour;

   F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

   C is the concentration in grams per litre.

8) Compare the maximum measured "DEVICE – OFF" hydrogen gas loss rate to Table B.7.

   NOTE This is a stabilised concentration measurement.

9) Hydrogen gas loss rate measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

10) Evaluate the hydrogen gas loss rate as follows.

   i) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF", the micro fuel cell power system or unit passes the test and no further testing is necessary.

   ii) If the hydrogen emission rate measurement is not below the allowable 0,0032 g/h with the "DEVICE – OFF", the micro fuel cell power system or unit fails the test and no further testing is necessary.

e) **Passing criteria:**

   Passing criteria for non-operating systems: The hydrogen gas loss rate shall be less than 0,0032 g/h with the "DEVICE – OFF".

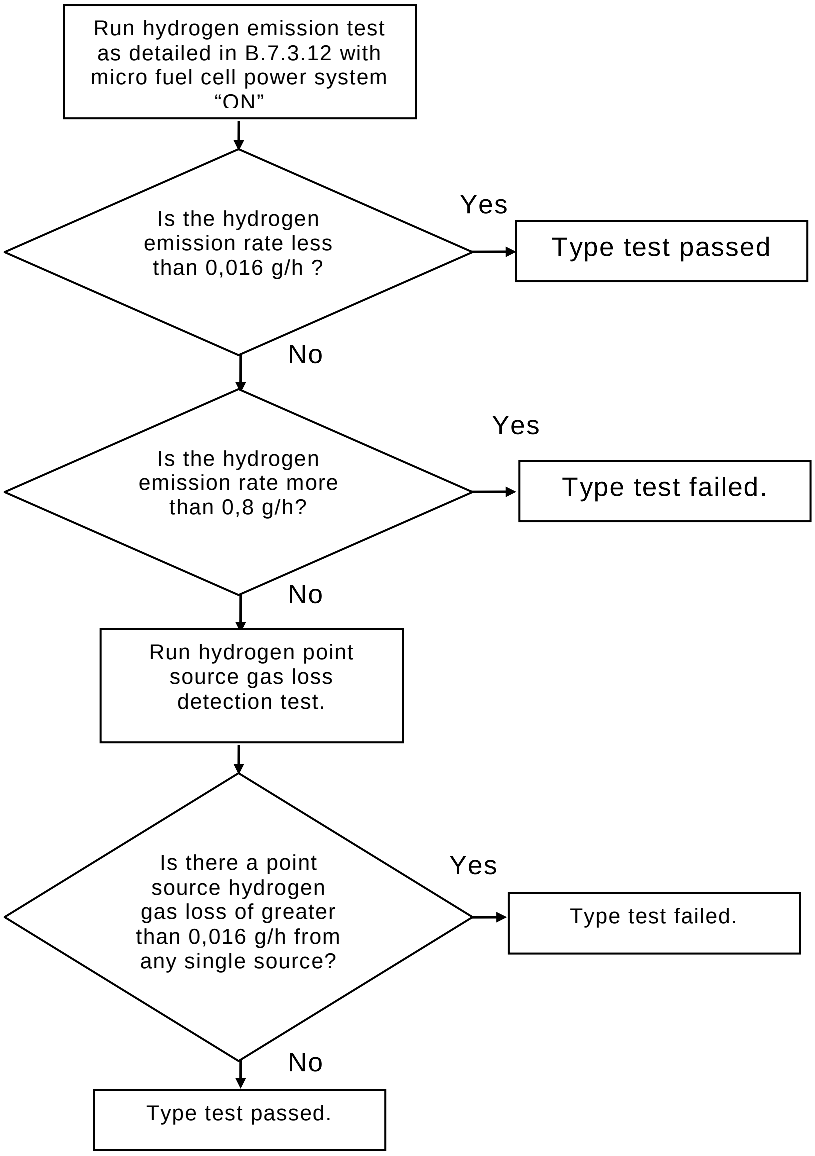


Figure B.12 – Hydrogen emission test procedure for operating micro fuel cell power system

Table B.7 – Emission limits – Replaces Table 7

Emissions	Operating system Permissible emissions rate limit [a] ("DEVICE – ON")	Non-operating system impermissible gas loss [b] (including "DEVICE – OFF")
Water	Unlimited	Unlimited
Hydrogen	0,8 g/h total 0,016 g/h from single point leak	0,0032 g/h

Table B.7 replaces Table 7.

[a] The operating emission rate limit is based on a product of a reference volume times air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume allocation per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is usually over 20 m^3, so a product of 10 is conservative. A further factor of safety of 10 has been added in this specific case.

[b] The "impermissible hydrogen gas loss" criteria for non-operating micro fuel cell power systems has been chosen based on a scenario of micro fuel cell power systems in an enclosed space with no ventilation. The space chosen has a volume of 0,28 m^3, or approximately 10 cubic feet. The criterion has been prescribed so that a hydrogen concentration of greater than 25 % LFL is not permitted to develop over a twenty-four hour (24 h) period, if three micro fuel cell power systems are in the enclosed space.

B.7.3.13 Hydrogen point source gas loss detection test

This subclause shall only be used if required by Subclause B.7.3.12.1 d) 11) to show compliance with Table B.7, for micro fuel cell power systems and micro fuel cell power units using hydrogen stored in metal hydride as fuel. *The procedure for hydrogen emission testing is detailed in Figure B.12, which is to be used as an additional figure when testing is done in accordance with Annex B.* This subclause is required to be performed to meet the passing criteria of Subclause B.7.3.12.1 e) if the total hydrogen emission rate from an operational micro fuel cell power system or unit is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON". This subclause is additional to the requirements in Clause 7.

a) **Test sample:** A micro fuel cell power unit or a micro fuel cell power system used in B.7.3.12.1.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit within the scope of this Annex B, emission of hydrogen shall be maintained at less than the specified values in Table B.7. The hydrogen point source gas loss detection test shall be performed to determine that no single source on the micro fuel cell power system or unit can support a flame in all cases where such compliance cannot be definitively determined by the hydrogen emission test. Maintaining these limits ensures that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame.

c) **Test apparatus:** The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, a hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

   NOTE The response of the aforementioned hydrogen detectors is commonly slow, with a response time of many seconds, thus high sweep speeds may cause underestimation of the hydrogen concentration. It is important that the sweep speed is slow enough to accurately measure the hydrogen concentration.

d) **Test procedure:**

1) The micro fuel cell power system or micro fuel cell power unit shall remain turned on ("DEVICE – ON") throughout the duration of the hydrogen point source gas loss detection test.

2) The testing shall be conducted in a space with no substantial air movement. The measured wind speed 10 cm above the micro fuel cell power system or unit shall not exceed 0,02 m/s.

NOTE 1 The local concentration of hydrogen diffusion measured in this test is very susceptible to the effect of wind. It is desirable that wind speed anywhere in the test space is as close to zero as possible. Testing in a closed space, such as a glove box or equivalent chamber, is one available method to achieve this requirement.

3) The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

NOTE 2 The response of the aforementioned hydrogen detectors is commonly slow – in the range of seconds – thus such high sweep speed may cause the underestimation of hydrogen concentration. It is noted that the sweep speed is slow enough to accurately measure the hydrogen concentration.

4) The sensor of the hydrogen detector shall sweep the micro fuel cell power system or unit at a distance no more than 3 mm normal to the surface of the micro fuel cell power system or unit. Consecutive linear sweeps shall not be more than 8 mm apart along the surface of the micro fuel cell power system or unit. The entire surface of the micro fuel cell power system or unit shall be swept in this manner.

5) An effective method for completing these sweeps would be to attach a stand off to the sensor that ensures that a spacing of 3 mm from the micro fuel cell power system or unit is maintained at all times. A pen or other marking utensil attached to the stand off could be used to identify swept areas and ensure that the distance between sweeps does not exceed 8 mm.

6) The sensor should always face directly downward, and the micro fuel cell power system or unit should be moved beneath it such that the surface directly below the sensor is always horizontal.

7) If no points are found where the hydrogen concentration is greater than 25 % LFL, the test is complete and the micro fuel cell power system or unit shall be considered to have passed.

NOTE 3 When some point source sweeps show a large region of 25 % LFL or greater in the initial linear sweeps, recording the measured concentration values will assist in determining the starting point of secondary spiral sweeps. Point sources are supposed to be where local maximum values exist in the distribution of measured concentration values.

8) If any points are detected to have a hydrogen concentration of 25 % LFL or greater, a second test shall be conducted to ensure that the emission does not exceed 0,016 g/h of pure hydrogen from any single source.

9) The second test shall be performed with the sensor height adjusted to 6,5 mm above the micro fuel cell power system or unit.

10) A spiral sweep shall then be made, originating from the point where the detection of 25 % LFL or greater of hydrogen occurred during the initial linear sweep. The spiral sweep shall have a spacing of 1 mm or less between sweeps, and shall spiral out to a radial distance of at least 4 mm and far enough to detect the maximum hydrogen level from the particular hydrogen source.

11) If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. If the spiral sweep does not detect any hydrogen concentrations of 25 % LFL or greater, the micro fuel cell power system or unit passes the test.

e) **Passing criteria:** No gas loss of hydrogen from any single source at greater than 0,016 g/h as indicated by sweep testing. No indications of hydrogen that is 25 % of LFL during the primary sweep testing or no indications of hydrogen that is 25 % of LFL during the secondary sweep testing at 6,5 mm above the micro fuel cell power system or unit. If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. See Table B.7.

B.7.3.14 Fuel cartridge integrity test

Subclause B.7.3.14 is to be done in addition to testing required in Clause 7 for fuel cartridges covered by this Annex B.

a) **Test sample:** fuel cartridges as required by ISO 16111:2008.

b) **Purpose:** to assure fuel cartridge integrity.

c) **Test procedure:**

Fuel cartridges shall be tested as a metal hydride assembly in accordance with ISO 16111:2008 and shall meet all requirements of that standard.

d) **Passing criteria:** Passing criteria is given in ISO 16111:2008.

B.7.3.15 Internal reservoir integrity test

Subclause B.7.3.15 is to be done in addition to testing required in Clause 7 for micro fuel cell power units covered by this Annex B that have a pressure regulator or valve between the micro fuel cell power unit and the internal fuel reservoir and the reservoir contains hydrogen absorbing metal alloy in the internal reservoir.

a) **Test sample:** a micro fuel cell power unit internal reservoir.

b) **Purpose:** to assure internal reservoir integrity.

c) **Test procedure:**

Internal reservoirs that have a pressure regulator or valve between the micro fuel cell power unit and the internal fuel reservoir and that contain metal hydride for the storage of hydrogen shall be tested in accordance with ISO 16111:2008 as a metal hydride assembly and shall meet all requirements of that standard.

d) **Passing criteria:** Passing criteria is given in ISO 16111:2008.

Annex C
(normative)

Reformed methanol micro fuel cell power systems

C.1 Scope

C.1.2 Fuels and technologies covered by this annex

Annex C covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that convert methanol or methanol and water solutions through a reformer into hydrogen rich methanol reformate, which is then immediately fed to the fuel cell or fuel cell stack, as fuel. These systems and units use proton exchange membrane fuel cell technologies.

Figure C.1 replaces Figure 1 showing a reformed methanol micro fuel cell power system block diagram for use with this Annex C.

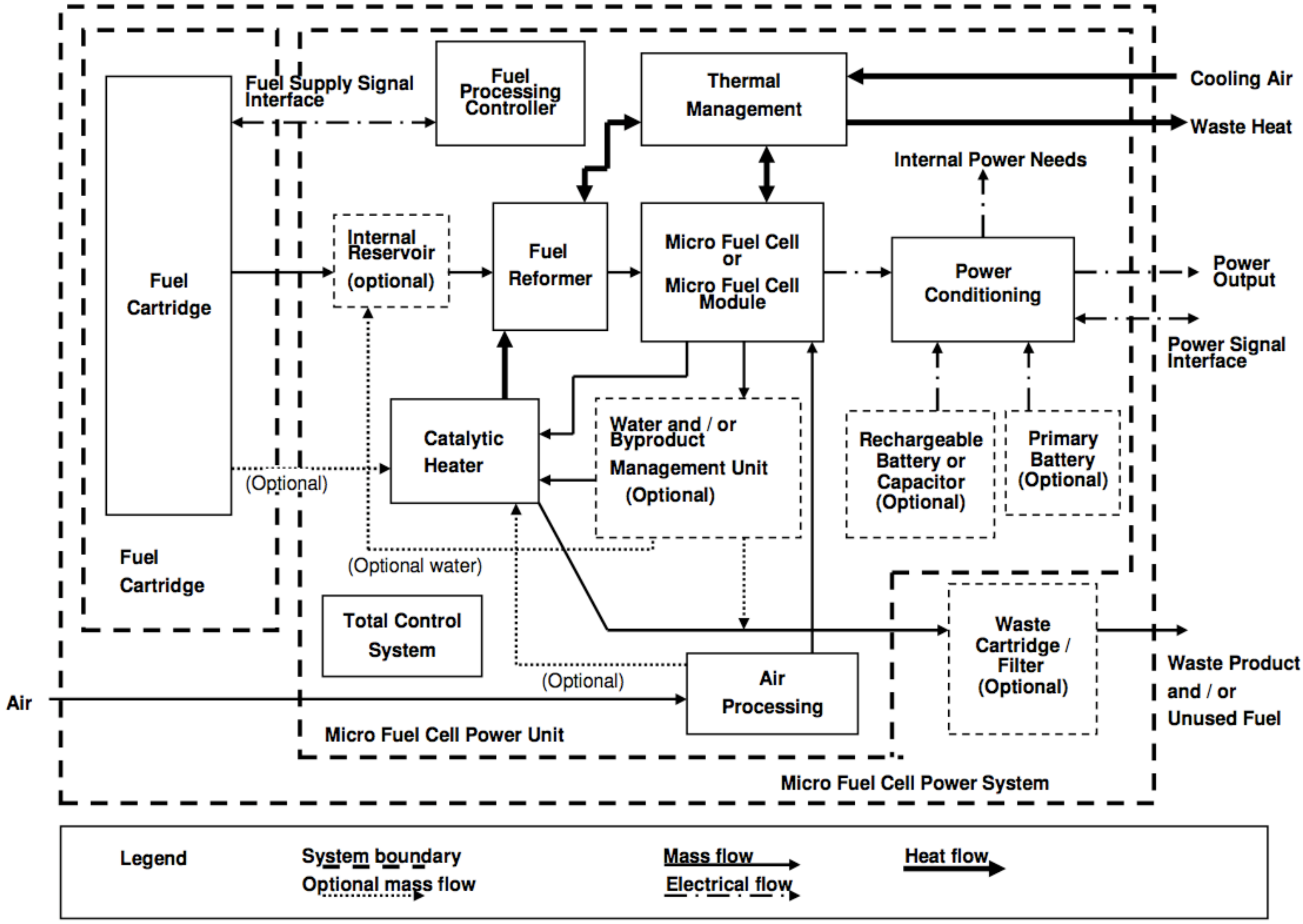


Figure C.1 – General block diagram of a reformed methanol micro fuel cell power system – Replaces Figure 1

C.3 Terms and definitions

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex C in addition to those given in Clause 3.

C.3.37
catalytic heater
device that oxidizes a fuel (e.g., methanol, hydrogen) and produces heat without a flame for applicable micro fuel cell power systems

C.3.38
impermissible hydrogen gas loss
hydrogen gas escaping non-operating micro fuel cell power system or micro fuel cell power unit greater than or equal to 0,0032 g/h

C.3.39
methanol fuel reformer (also referred to as "reformer")
device that converts methanol and water to hydrogen reformate (hydrogen, carbon dioxide, methanol, formaldehyde, carbon monoxide and methyl formate) for applicable micro fuel cell power systems

C.3.40
"DEVICE – ON"
device with its power switch turned on and operating to produce power or unable to produce power due to a failure or other reasons

C.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

C.4.10 Protection against fire, explosion, corrosivity and toxicity hazard

These requirements apply to micro fuel cell power systems and units covered by this Annex C. *These requirements replace the corresponding requirements of Subclause 4.10.*

C.4.10.1 Flammable, toxic and corrosive fluids shall be kept within a closed containment system such as within fuel piping, in a reservoir, a fuel cartridge or similar enclosure. Compliance shall be verified by type testing in accordance with Clause 7.

C.4.10.2 A micro fuel cell power system or unit may be equipped with a means of detecting concentration levels of fluids in Table 7 and shutting down the micro fuel cell power system or unit prior to exceeding the concentration limit.

C.4.10.3 Internal wiring and insulation in general shall not be exposed to fuel, oils, grease or similar substances, unless the insulation has been evaluated for contact with these substances.

C.4.10.4 Micro fuel cell power systems shall be designed in such a way that there is no risk of open flame in catalytic heaters (start, main and auxiliary catalytic heaters of a reformer section, tail gas catalytic heaters).

C.4.10.5 If air for catalytic heating is mixed with fuel gas, an effective means shall be provided to prevent the air from returning to the fuel gas line and to prevent the fuel gas from flowing into the air supply unit.

C.4.10.6 Controls for fuel and air feeds for reformers and catalytic heaters shall be designed to reliably maintain the fuel to air ratio.

C.4.10.7 Upon shutdown, hazardous gases in the reformer and catalytic heater process systems shall be safely contained, oxidized, or disposed.

C.4.10.8 For air-rich catalytic heater systems: The fuel and air supply shall be suitably controlled to provide air prior to reaction initiation and to prevent fuel from entering the reactor until the air supply is available.

C.4.10.9 For fuel-rich catalytic heater systems: The fuel and air supply shall be suitably controlled to provide fuel prior to reaction initiation and to prevent air from entering the reactor until the fuel is available.

C.4.10.10 The reaction initiation time of the catalytic heater shall be determined by considering the response time of the system control devices and the time required to build up the maximum allowable quantity of flammable mixture that can safely be contained in the system based on flow rates, fuel-air mixture flammability, and system dynamics and geometry.

C.4.10.11 The manufacturer shall ensure that the maximum quantity of flammable mixture that could credibly accumulate, if combusted, produces pressures and temperatures that can be contained within the components exposed to such conditions. All parts of reformer and catalytic heater systems shall be an open design (i.e., gases flow from reformer to stack to catalytic heater to exhaust), and there shall not be the possibility of building up high pressure within the components exposed to these open conditions.

C.4.10.12 Tubing and other fuel pathways shall be designed in such a way that there is no danger of leakage of gases from the fuel reformer or catalytic heater under normal use and reasonably foreseeable abuse generated by vibration, heat, pressure, etc.

C.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

C.7.1 General

This Subclause C.7.1 replaces Subclause 7.1 for this annex when testing reformed methanol micro fuel cell power systems, reformed methanol micro fuel cell power units and reformed methanol fuel cartridges.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table C.5 lists the type tests that must be performed. *Table C.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table C.6. *Table C.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table C.5 – List of type tests – Replaces Table 5

Test reference	Test item	Test sample
7.3.1	Pressure differential tests	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.2	Vibration test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.3	Temperature cycling test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.4	High temperature exposure test	Fuel cartridge Partially filled fuel cartridge
7.3.5	Drop test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.6	Compressive loading test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
7.3.9	Long-term storage test	Fuel cartridge Partially filled fuel cartridge
7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Partially filled fuel cartridge and micro fuel cell power unit
7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit
C.7.3.12	Emission test	Micro fuel cell power system or power unit
C.7.3.13	Hydrogen point source gas loss detection test	Micro fuel cell power system or power unit, if required
C.7.3.15	High temperature operation test	Micro fuel cell power system or power unit

Table C.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or partially filled, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test.

Test sequence: Tests 7.3.2 and 7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests 7.3.1, 7.3.2, and 7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer's discretion if it does not compromise the individual test.

Table C.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is "room temperature" (standard temperature condition, 22 °C ± 5 °C)
Laboratory room atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide, not more than 0,002 % carbon monoxide, and not more than 0,008 % hydrogen. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen.
Table C.6 replaces Table 6.	

C.7.3.12 Emission test

This Subclause C.7.3.12 shall replace Subclause 7.3.12 for reformed methanol micro fuel cell power systems or units tested in accordance with Annex C. Table C.7, Emission limits, replaces Table 7 in Subclause 7.3.12. Figure C.10 replaces Figure 10. The new additional Table C.8, Occupational exposure limits, is provided to inform the user regarding exposure limits. Hydrogen emissions are evaluated separately, and the procedure for hydrogen emission testing is detailed in Figure C.12, which is to be used as an additional figure when testing is done in accordance with Annex C.

Reformed methanol micro fuel cell power systems do not produce or store hydrogen when they are not operating. Since this is the case, hydrogen gas loss measurement is not needed for non operating reformed methanol micro fuel cell power units and micro fuel cell power systems. The emission test in C.7.3.12 is only done on operating (or attempts at operating) systems.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a reformed methanol micro fuel cell power system or a micro fuel cell power unit emissions of methanol vapours, carbon dioxide, carbon monoxide, formaldehyde, hydrogen, and water vapour shall be maintained at less than the specified values. Maintaining these limits not only prevents inadvisable exposure but also ensures an adequate supply of oxygen is maintained in the operating environment.

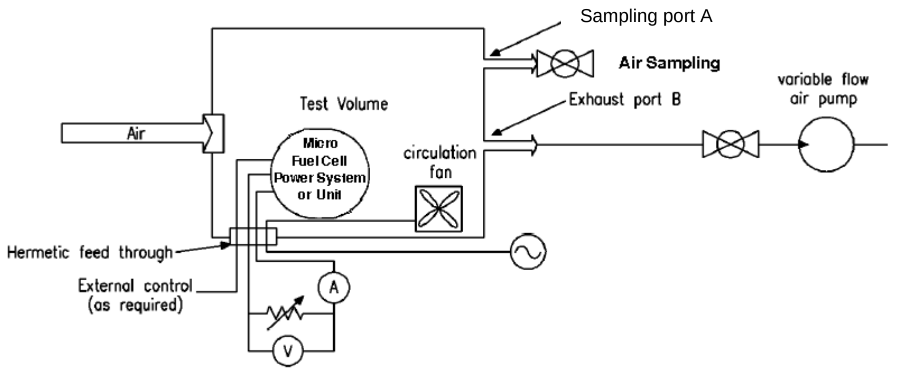


Figure C.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the operational emission test apparatus is shown in Figure C.10. The configuration shown in Figure C.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex C. Emission rate testing in accordance with C.7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex C.

For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer's mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.) additional testing in accordance with C.7.3.12 d) 3) and C.7.3.12 d) 4) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure C.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer's mouth or nose when in use) for emissions concentration limit testing.

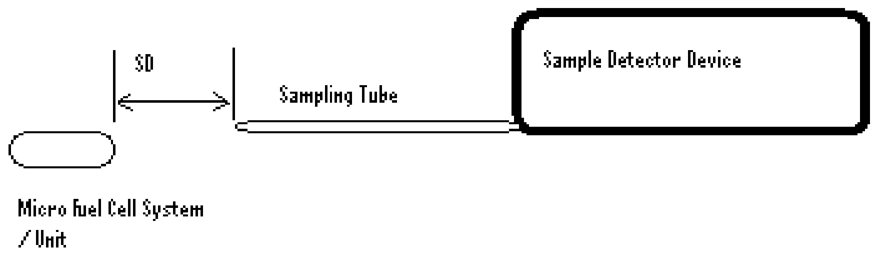


Figure C.11 – Operational emission concentration testing apparatus – Replaces Figure 11

Emission gases might be composed of toxic organic materials such as methanol vapours, carbon dioxide, carbon monoxide and formaldehyde, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS) shall be used by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure C.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

The concentration of CO and CO_2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure C.12, which is to be used as an additional figure when testing is done in accordance with Annex C.*

Emission rate sampling tests shall be performed both with the micro fuel cell power system or unit on ("DEVICE – ON") as follows.

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed with the micro fuel cell power system or unit on ("DEVICE – ON") as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure C.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure C.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure C.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the concentrations of chemical compounds of interest. See Table C.7.

vii) Calculate the emission rate of chemical compounds being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE 1 The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

or

$$ER = (F_{\mathrm{i}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured emission rate to Table C.7. If the emission rate is not less than the emission rate limit in Table C.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria C.7.3.12 e) 1) i) and C.7.3.12 e) 2) i).

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer's mouth or nose, the following additional emissions concentration sampling test shall be performed with the micro fuel cell power system or unit on "DEVICE – ON" as follows.

   i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

   ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power in the large open room while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure C.11. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission concentration test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the "ON" position ("DEVICE – ON").

   iii) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

   iv) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure C.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer's mouth or nose when in use).

   v) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

   vi) Allow the sample flow rate to stabilise.

   vii) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

   viii) Record the concentrations of the chemical compounds of interest. See Table C.7.

   ix) Compare the maximum measured concentrations to Table C.7. If the emission concentrations are not less than the emission concentration limits in Table C.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria C.7.3.12 e) 2) ii).

   x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

3) Upon completion of the emissions measurements with "DEVICE – ON" in accordance with Table C.7, "DEVICE – ON" hydrogen emissions are evaluated as follows.

   i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure C.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure C.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure C.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the hydrogen concentration.

vii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE 2 The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_\mathrm{P} + F_\mathrm{S}) \times C$$

or

$$ER = (F_\mathrm{i}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

F_i is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured "DEVICE – ON" hydrogen emission rate to Table C.7.

NOTE 3 This is a stabilised concentration measurement.

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

4) Evaluate the hydrogen emission rate as follows.

i) If the hydrogen emission rate measurement is below the allowable 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or unit passes the test and no further testing is necessary.

ii) If the hydrogen emission rate measurement is not below the total allowable 0,8 g/h with the "DEVICE – ON", the system or unit fails the test and no further testing is necessary.

iii) If the hydrogen emission rate measurement is below the total allowable 0,08 g/h with the "DEVICE – ON" but is not below 0,016 g/h with the "DEVICE – ON", then proceed with C.7.3.13, Hydrogen point source gas loss detection test to verify that no single source of hydrogen exceeds 0,016 g/h.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table C.7 shall be less than the emission rate limit value in Table 7 when tested in accordance with C.7.3.12 d) 1) for "DEVICE – ON." If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table C.7 shall be less than the emission rate limit value in Table C.7 when tested in accordance with C.7.3.12 d) 1) for "DEVICE – ON." If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer's mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall not exceed the emission concentration limit in Table C.7 when tested in accordance with C.7.3.12 d) 3) for "DEVICE – ON." If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

3) Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure C.12, which is to be used as an additional figure when testing is done in accordance with Annex C.* Upon completion of the hydrogen emissions measurements in accordance with Table C.7, hydrogen emissions are evaluated as follows:

i) **Passing criteria for operational systems:** If the total Hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or micro fuel cell power unit passes the emission test and no further testing is required. If the total Hydrogen emission rate is not less than 0,8 g/h with the "DEVICE – ON", the micro fuel cell power system or unit fails the emission test and no further testing is required. If the Hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", C.7.3.13, Hydrogen point source gas loss detection test must be performed with acceptable results to show no more than 0,016 g/h hydrogen leakage from any single point leak.

NOTE 4 The allowable flammable hydrogen emission level that will not support a standing flame is 3 ml/min (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, Codes and Standards Analysis, 2001 (USA)). The non-flammable hydrogen emissions limit is based on the criteria that hydrogen emission does not build up to more than 25 % of LFL in the reference volume.

NOTE 5 Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

NOTE 6 Carbon dioxide, carbon monoxide and formic acid vapour emission level limits are based on toxicity and corrosivity (formic acid only) effects on humans while the hydrogen emissions level limit is based on the risk of creating a flammable atmosphere in confined spaces and the risk of a potential standing hydrogen flame.

NOTE 7 The formic acid flammability risk, based on the criteria of maintaining the concentration-in-air below 25 % of LFL, is orders of magnitude lower than the toxicity risk (flammability limit = 42 500 ppmv to toxicity limit = 5 ppmv). Thus, the formic acid toxicity level is used to set the limits of its emissions.

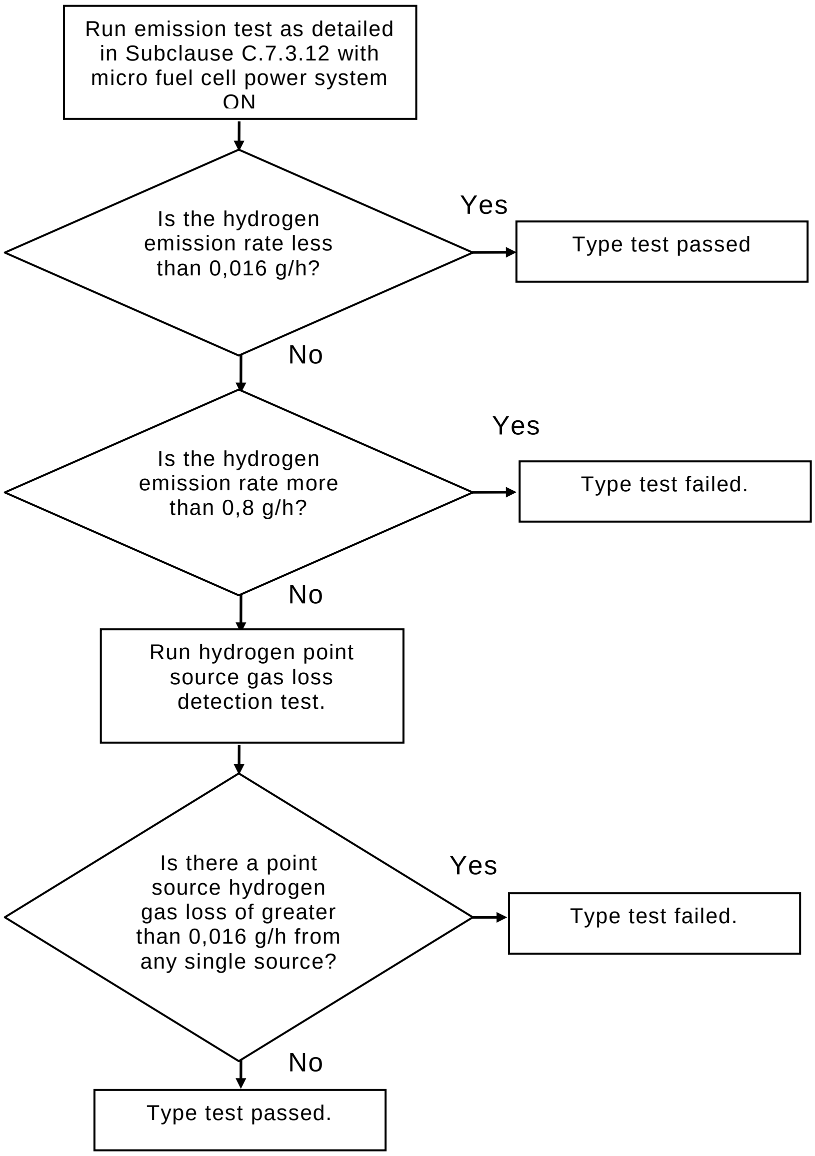


Figure C.12 – Hydrogen emission test procedure for operating micro fuel cell power system

Table C.7 – Emission limits – Replaces Table 7

	Concentration limit	Emission rate limit [a]
Water	Unlimited	No limit
Methanol	0,26 g/m^3	2,6 g/h
Formaldehyde	0,000 1 g/m^3 [b]	0,000 6 g/h
CO	0,029 g/m^3	0,290 g/h
CO_2	9 g/m^3	60 g/h [c]
Formic acid	0,009 g/m^3	0,09 g/h
Methyl formate	0,245 g/m^3	2,45 g/h
Hydrogen	Not applicable	0,8 g/h total 0,016 g/h from single point leak

[a] The emission rate limit was based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is over 20 m^3, so a product of 10 is conservative.

[b] WHO guideline limit is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The emission limit cannot push the background level above the guideline limit.

[c] A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO eight-hour concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

Table C.8 – Occupational exposure limits

Emissions	TWA exposure limit (TWA – time weighted average over 8 h of operation)	STEL value (15 min exposures to a maximum of 4 times a day)
CO_2	$<$ 5 000 ppmv	$<$30 000 ppmv
Formic acid	$<$ 5 ppmv	$<$10 ppmv
CO	$<$ 25 ppmv	$<$200 ppmv

C.7.3.13 Hydrogen point source gas loss detection test

The procedure for hydrogen emission testing is detailed in Figure C.12, which is to be used as an additional figure when testing is done in accordance with Annex C. This subclause is additional to the requirements in Clause 7.

This subclause shall be used if required by Subclause C.7.3.12 d) 4) iii) to show compliance with Table C.7, for reformed methanol micro fuel cell power systems and reformed methanol micro fuel cell power units. This subclause is required to be performed to meet the passing criteria of Subclause C.7.3.12 e) 3) i) if the total hydrogen emission rate from an operational reformed methanol micro fuel cell power system or unit is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON".

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit, emission of hydrogen shall be maintained at less than the specified values in Table C.7. The hydrogen point source gas loss detection test shall be performed to determine that no single source on the micro fuel cell power system or unit can support a flame in all cases where such compliance cannot be definitively determined by the hydrogen emission test. Maintaining these limits ensures that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame and along with the other emissions testing ensures an adequate supply of oxygen is maintained in the operating environment

c) **Test apparatus:** The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, a hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL. The response of the aforementioned hydrogen detectors is commonly slow, with a response time of many seconds, thus high sweep speeds may cause underestimation of the hydrogen concentration. It is important that the sweep speed shall be slow enough to accurately measure the hydrogen concentration.

d) **Test procedure:**

1) The micro fuel cell power system or micro fuel cell power unit shall remain turned on ("DEVICE – ON") throughout the duration of the hydrogen point source gas loss detection test.

2) The testing shall be conducted in a space with no substantial air movement. The measured wind speed 10 cm above the micro fuel cell power system or unit shall not exceed 0,02 m/s. The local concentration of hydrogen diffusion measured in this test is very susceptible to the effect of wind. It is desirable that wind speed anywhere in the test space is as close to zero as possible. Testing in a closed space, such as a glove box or equivalent chamber, is one available method to achieve this requirement.

3) The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

4) The sensor of the hydrogen detector shall sweep the micro fuel cell power system or unit at a distance no more than 3 mm normal to the surface of the micro fuel cell power system or unit. Consecutive linear sweeps shall not be more than 8 mm apart along the surface of the micro fuel cell power system or unit. The entire surface of the micro fuel cell power system or unit shall be swept in this manner.

5) An effective method for completing these sweeps would be to attach a stand off to the sensor that ensures that a spacing of 3 mm from the micro fuel cell power system or unit is maintained at all times. A pen or other marking utensil attached to the stand off could be used to identify swept areas and ensure that the distance between sweeps does not exceed 8 mm.

6) The sensor should always face directly downward, and the micro fuel cell power system or unit should be moved beneath it such that the surface directly below the sensor is always horizontal.

7) If no points are found where the hydrogen concentration is greater than 25 % LFL, the test is complete and the micro fuel cell power system or unit shall be considered to have passed.

8) When some point source sweeps show a large region of 25 % LFL or greater in the initial linear sweeps, recording the measured concentration values will assist in determining the starting point of secondary spiral sweeps. Point sources are supposed to be where local maximum values exist in the distribution of measured concentration values.

9) If any points are detected to have a hydrogen concentration of 25 % LFL or greater, a second test shall be conducted to ensure that the emission does not exceed 0,016 g/h of pure hydrogen from any single source.

10) The second test shall be performed with the sensor height adjusted to 6,5 mm above the micro fuel cell power system or unit.

11) A spiral sweep shall then be made, originating from the point where the detection of 25 % LFL or greater of hydrogen occurred during the initial linear sweep. The spiral sweep shall have a spacing of 1 mm or less between sweeps, and shall spiral out to a radial distance of at least 4 mm and far enough to detect the maximum hydrogen level from the particular hydrogen source.

12) If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. If the spiral sweep does not detect any hydrogen concentrations of 25 % LFL or greater, the micro fuel cell power system or unit passes the test.

e) **Passing criteria:** No gas loss of hydrogen from any single source at greater than 0,016 g/h as indicated by sweep testing. No indications of hydrogen that is 25 % of LFL during the primary sweep testing or no indications of hydrogen that is 25 % of LFL during the secondary sweep testing at 6,5 mm above the micro fuel cell power system or unit. If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. See Table C.7.

C.7.3.14 High temperature shutdown test

This subclause is additional to the requirements in Clause 7.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to verify that the micro fuel cell power system initiates a shutdown sequence within a reasonable time period if the reformer reaches an abnormal high temperature.

c) **Test procedure:**

   1) While the micro fuel cell power unit is operating at rated output, use the manufacturer‘s specified method for setting temperature to set a temperature 10 °C above the maximum operating temperature inside the reformer.

   2) Verify that the micro fuel cell power system shutdown sequence is initiated within 5 s of the reformer reaching the temperature set point.

d) **Passing criteria:** The micro fuel cell power system shutdown sequence is initiated within 5 s of the reformer reaching the temperature set point.

C.7.3.15 High temperature operation test

This subclause is additional to the requirements in Clause 7.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to verify that the micro fuel cell power system operates safely even if the reformer is at a temperature of 30 °C above the maximum operating temperature.

c) **Test procedure:**

   1) Disable the automatic shutdown mechanism described in C.7.3.14. Set the reformer temperature at 30 °C above the maximum operating temperature.

   2) Run the micro fuel cell power system at full load as specified by the manufacturer for 1 h at this elevated temperature.

d) **Passing criteria:** There shall be no emission of flame, and the micro fuel cell power system shall be in compliance with the emission requirements in Table 7 and C.7.3.12.

Annex D
(normative)

Methanol clathrate compound micro fuel cell power systems

D.1 Scope

D.1.2 Fuels and technologies covered by this annex

Annex D covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use methanol or methanol and water solutions – derived from methanol clathrate compounds – as fuel. These systems and units use direct methanol fuel cell technologies.

Figure D.1 replaces Figure 1 showing a methanol clathrate compound micro fuel cell power system block diagram for use with this annex.

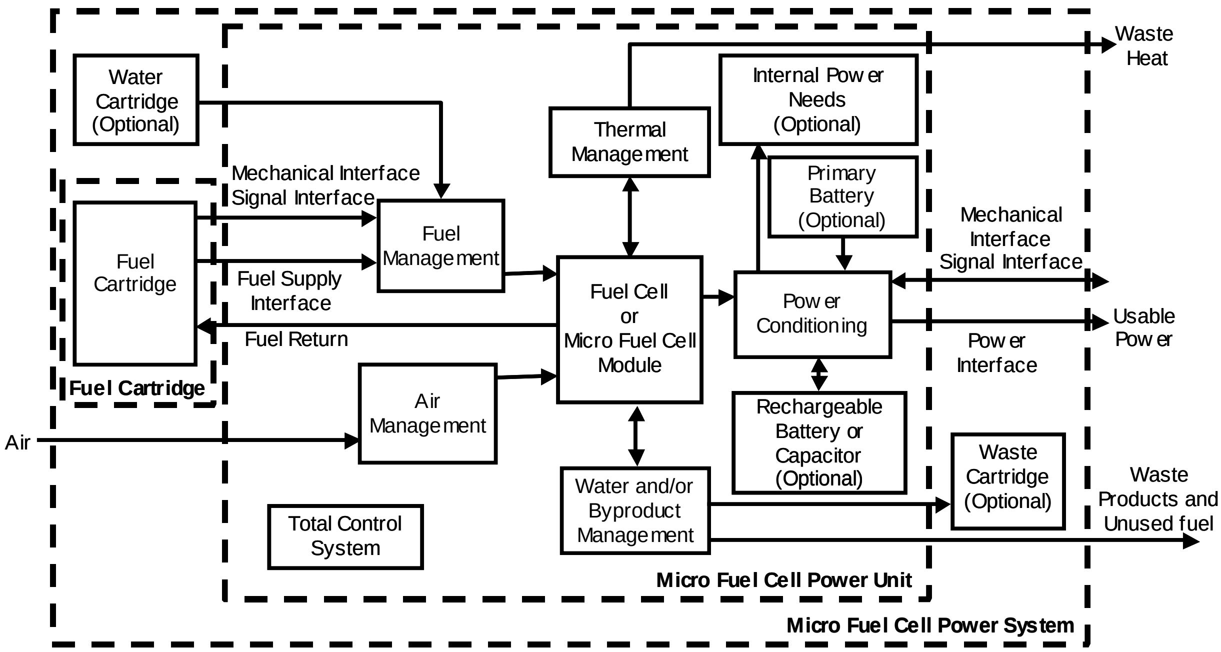


Figure D.1 – Methanol clathrate compound micro fuel cell power system block diagram – Replaces Figure 1

D.1.3 Equivalent level of safety

This subclause replaces Subclause 1.3.

a) The requirements of this standard are not intended to constrain innovation. The manufacturer may consider fuels, materials, designs or constructions not specifically dealt with in this standard. These alternatives should be evaluated as to their ability to yield levels of safety equivalent to those prescribed by this standard.

b) It is understood that all micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall comply with applicable country and local requirements including, but not limited to, those concerning transportation, child-resistance, and storage, where required.

c) The following discussion provides additional information regarding micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use methanol or methanol and water solutions – derived from methanol clathrate compounds – as fuel.

1) Methanol clathrate compound (MCC)[3] is a solid[4] that includes methanol. The fuel cartridge containing MCC does not contain liquid prior to use; therefore liquid leakage from an unused cartridge cannot occur. MCC is not classified as dangerous goods by the United Nations Recommendations on the Transport of Dangerous Goods Manual of Tests and Criteria, Fourth Revised Edition.

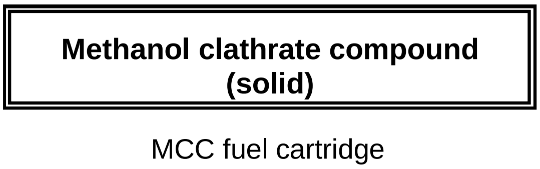


Figure D.12 – Fuel cartridge of methanol clathrate compound

2) When the fuel cartridge filled with the MCC is installed in the micro fuel cell power unit, water is injected into the fuel cartridge. Methanol solution is formed by the emission of methanol from the MCC into the injected water. The methanol solution is then used as fuel (Figure D.13).

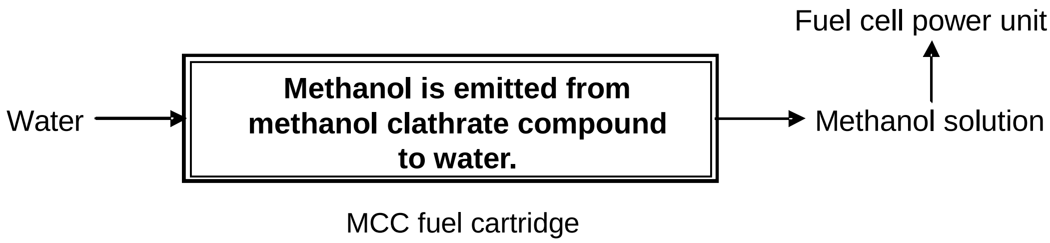


Figure D.13 – Usage of methanol clathrate compound with micro fuel cell power unit

3) An unused fuel cartridge only contains a solid material so no liquid leakage can occur. However, because a fuel cartridge used in a DMFC micro fuel cell power system contains a methanol solution, a leak evaluation of a fuel cartridge including water is carried out. Both an unused fuel cartridge and a used fuel cartridge (as defined by D.3.40) are used for type tests.

D.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex D. All terms and conditions in Clause 3 not specifically mentioned here also apply.

D.3.5
fuel
methanol and water solution, formed by the contact of methanol clathrate compound (MCC) and water

MCC is a solid substance and consists of methanol and non-hazardous materials that form a matrix to include MCC.

---

3 An organic addition compound that has an internal space that is completely enclosed. It is formed by the inclusion of methanol molecules in cavities formed by crystal lattices or present in large molecules.

4 Examined by ASTM D 4359-90: *Standard test method for determining whether a material is a liquid or a solid.*

D.3.23
satellite cartridge
not applicable to this Annex D

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex D in addition to those given in Clause D.3 and in Clause 3.

D.3.37
no accessible MCC powder
MCC powder fuel that is not subject to contact by consumers

D.3.38
no MCC powder leakage
no accessible MCC powder outside the micro fuel cell power system or fuel cartridge

D.3.39
non-hazardous
materials which when tested in accordance with the UN manual of tests and criteria are not classified as dangerous goods

D.3.40
used fuel cartridge
fuel cartridge to be used in type tests instead of actual used fuel cartridge

NOTE A used fuel cartridge is prepared by filling an unused fuel cartridge with water thereby forming a methanol solution.

D.4.12 Fuel supply construction

D.4.12.1 Fuel cartridge construction

These requirements apply to micro fuel cell power systems and units covered by this Annex D. These requirements replace the corresponding requirements of Subclause 4.12.1.

Fuel cartridges shall conform to the following requirements.

D.4.12.1.1 There shall be no leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with 7.3.3 and 7.3.4.

D.4.12.1.2 There shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Compliance shall be determined by type testing in accordance with D.7.3.1.

D.4.12.1.3 Maximum fuel volume in the fuel cartridge shall not exceed 1 l.

D.4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance is checked by D.7.3.11.

D.4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

D.4.12.1.6 A fuel cartridge shall be provided with a means to prevent mis-connection that would result in leakage of fuel when it is installed in a micro fuel cell power system. Compliance is checked by the connection cycling test, D.7.3.11.

D.4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance is checked by the drop test, D.7.3.5, and the connection cycling test, D.7.3.11.

D.4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

D.4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel to leak.

D.4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance is checked by:

- pressure differential tests, D.7.3.1;
- vibration test, D.7.3.2;
- temperature cycling test, D.7.3.3;
- high temperature exposure test, D.7.3.4;
- drop test, D.7.3.5;
- compressive loading test, D.7.3.6;
- long-term storage test, D.7.3.9;
- high-temperature connection test, D.7.3.10;
- connection cycling tests, D.7.3.11.

D.4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

D.4.12.2 Fuel cartridge fill requirement

The fuel cartridge design and fuel fill amount shall allow fuel expansion without leakage to a fuel cartridge temperature of 70 °C in the case of the fuel cartridge alone and when the fuel cartridge is constrained by the micro fuel cell power system or a comparable test fixture.

D.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

D.7.1 General

This Subclause D.7.1 replaces Subclause 7.1 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use methanol or methanol and water solutions – derived from methanol clathrate compounds – as fuel.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table D.5 lists the type tests that must be performed. *Table D.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table D.6. *Table D.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table D.5 – List of type tests – Replaces Table 5

Test reference	Test item	Test sample
D.7.3.1	Pressure differential tests	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
D.7.3.2	Vibration test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
D.7.3.3	Temperature cycling test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
D.7.3.4	High temperature exposure test	Fuel cartridge Used fuel cartridge
D.7.3.5	Drop test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
D.7.3.6	Compressive loading test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
D.7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
D.7.3.9	Long-term storage test	Fuel cartridge Used fuel cartridge
D.7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
D.7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
7.3.12	Emission test	Micro fuel cell power system or power unit

Table D.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or used, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test.

Test sequence: Tests D.7.3.2 and D.7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests D.7.3.1, D.7.3.2, and D.7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer's discretion if it does not compromise the individual test.

Table D.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is "room temperature" (standard temperature condition, 22 °C ± 5 °C)
Laboratory room atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen.
Table D.6 replaces Table 6.	

D.7.2 Leakage measurement of MCC and methanol, and the measuring procedure

This Subclause D.7.2 replaces Subclause 7.2 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use methanol or methanol and water solutions – derived from methanol clathrate compounds – as fuel.

These figures and their procedures, replace the corresponding figures in Subclause 7.2.

Inspection of MCC powder leakage shall be executed in type tests, because MCC powder is packed in an unused fuel cartridge. The leakage measurement of MCC powder and methanol shall be executed in principle in accordance with the procedure shown in Figures D.2 through D.5 respectively.

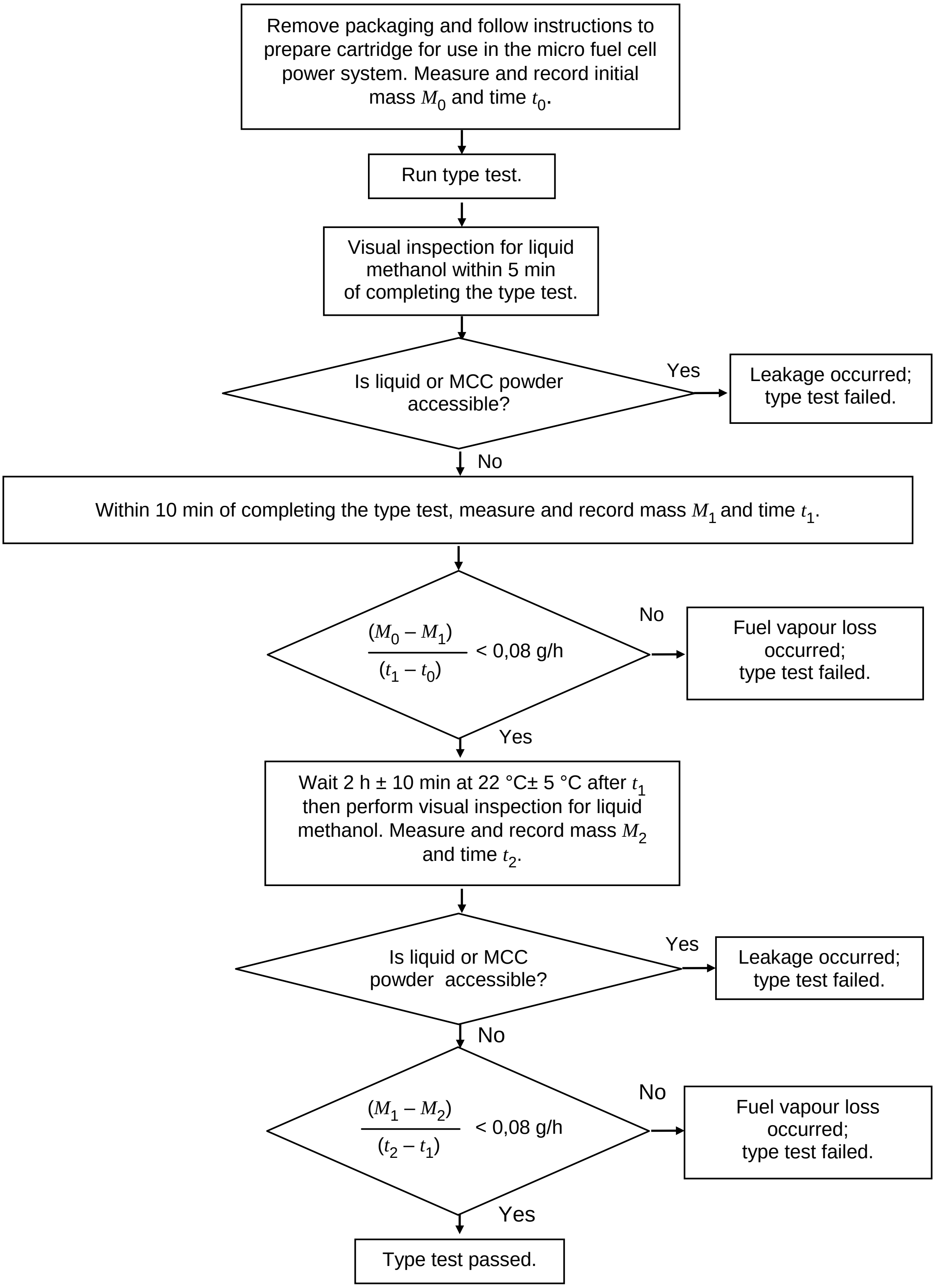


Figure D.2 – Fuel cartridge leakage and mass loss test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2

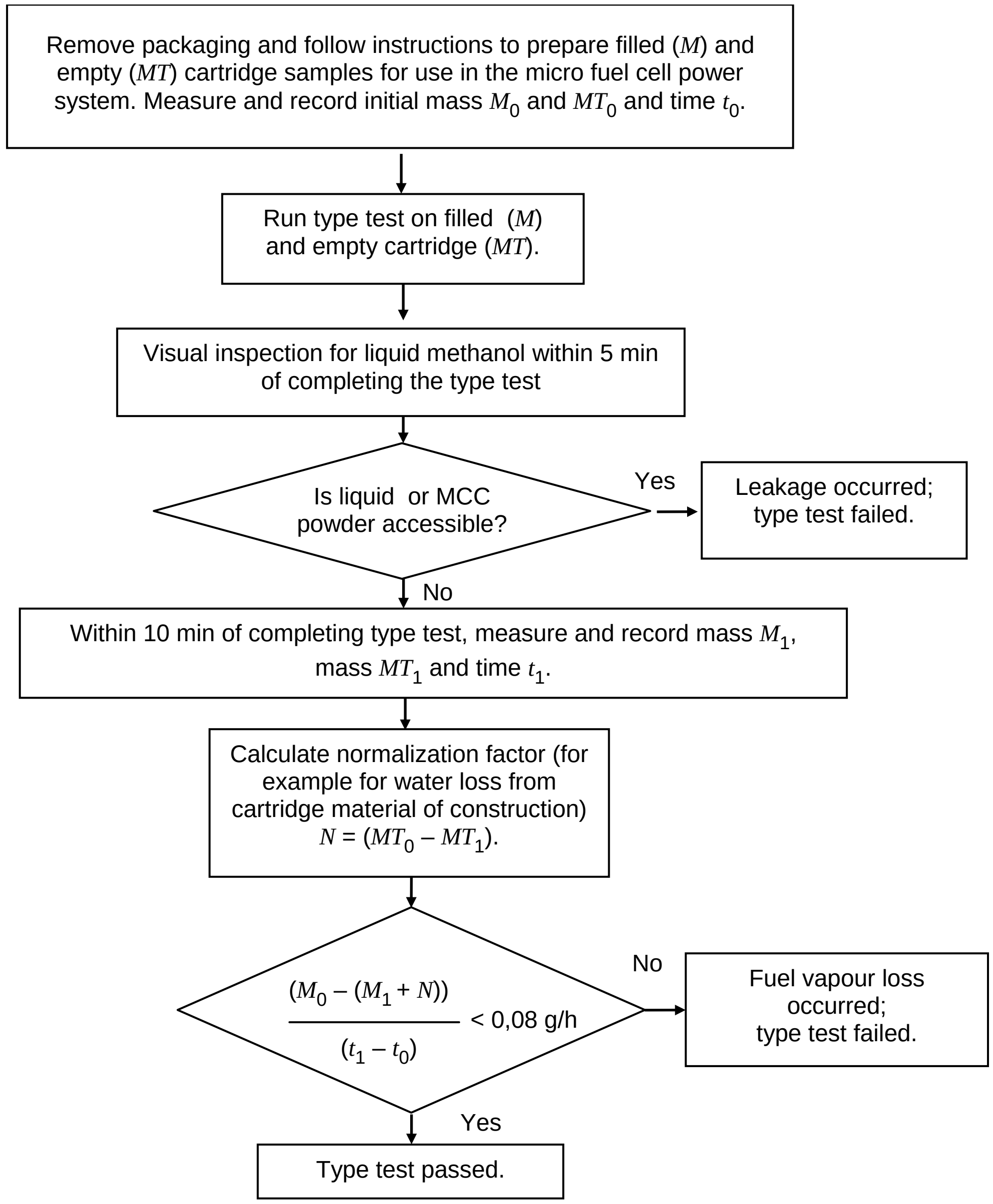


Figure D.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3

The maximum time interval $t_1 – t_0$ shall be set so that no more than half the fuel would be lost if it were escaping at the maximum allowable mass loss rate.

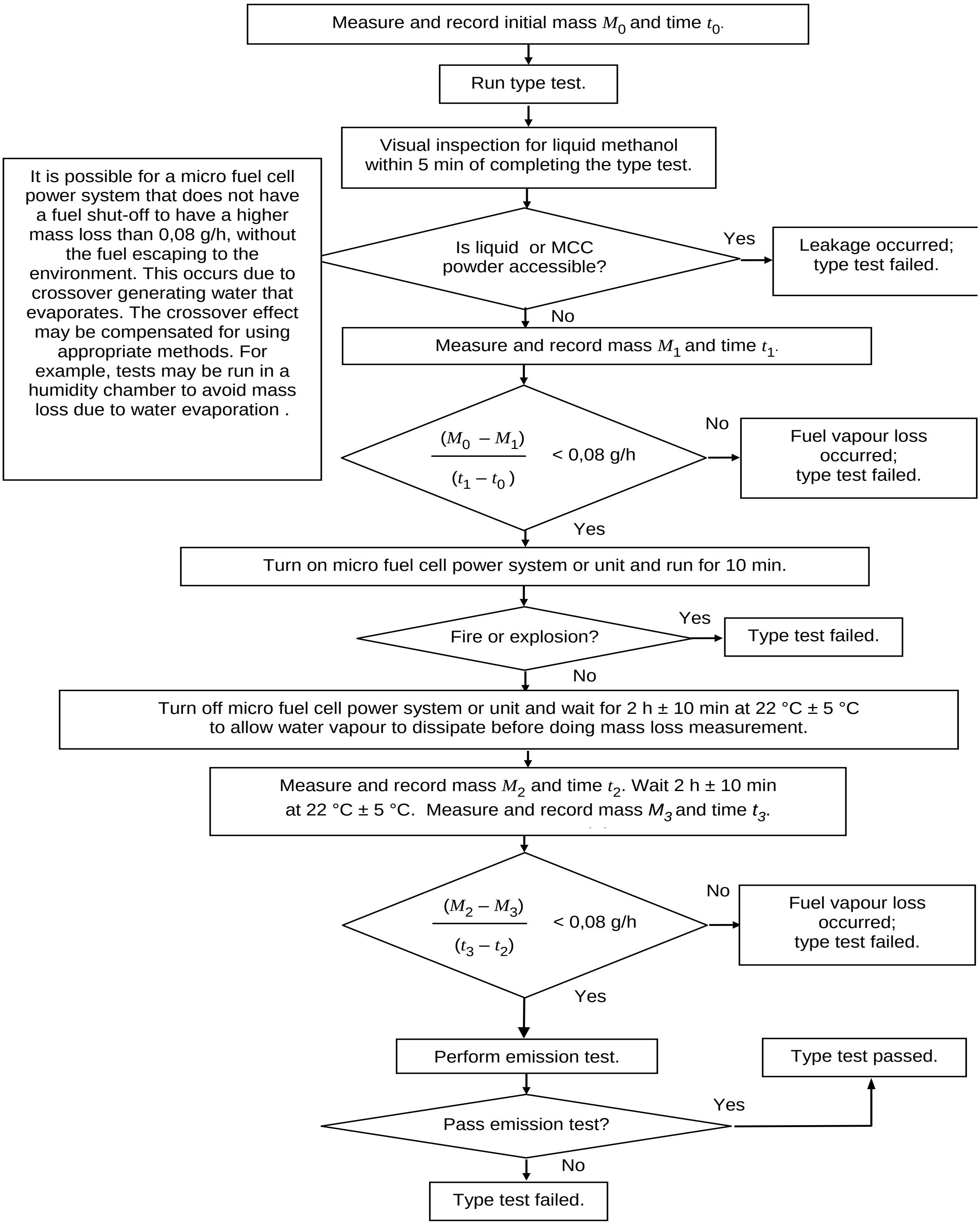


Figure D.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4

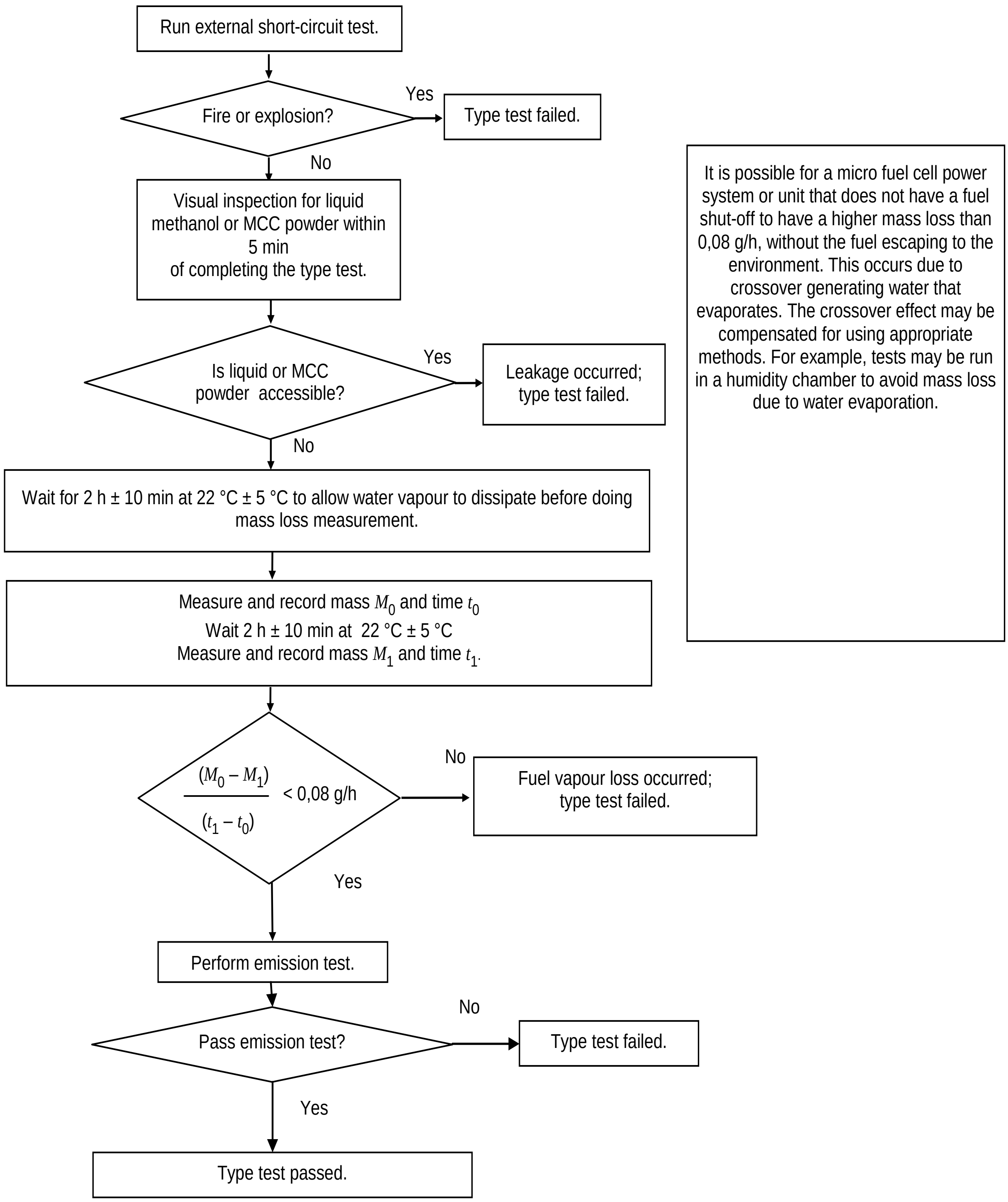


Figure D.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5

D.7.3 Type tests

D.7.3.1 Pressure differential tests

D.7.3.1.1 General

Subclause D.7.3.1 replaces Subclause 7.3.1.

Portions of this test check compliance with Subclause 4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Depending upon which of the two limiting pressure conditions is greater, two options for testing are provided.

a) If 95 kPa internal gauge pressure plus normal working pressure of the fuel cartridge at 22 °C is greater than two times the gauge pressure of the fuel cartridge at 55 °C, either Subclause D.7.3.1.2 or Subclause D.7.3.1.3 may be used to verify compliance with Subclause 4.12.1.2.

b) If two times the gauge pressure of the fuel cartridge at 55 °C is greater than 95 kPa internal gauge pressure plus normal working pressure at 22 °C, subclause D.7.3.1.2 must be used to verify compliance with Subclause 4.12.1.2.

D.7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

   1) Using a suitable fluid medium such as water, pressurize the fuel cartridge body to an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. The pressure rise shall not exceed a rate of 60 kPa/s.

   2) Maintain the maximum pressure for 30 min at laboratory temperature.

   3) Using a suitable fluid medium such as water, pressurize the closed fuel cartridge valve to 95 kPa gauge pressure plus the normal working pressure of the cartridge at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. The pressure rise shall not exceed a rate of 60 kPa/s.

   4) Maintain the maximum pressure for 30 min at laboratory temperature.

d) **Passing criteria:** No accessible liquid test medium leakage and no sudden drop of pressure during the course of the test. Leakage shall be checked visually. Invert the fuel cartridge and the fuel cartridge valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails.

D.7.3.1.3 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   Perform this test in accordance with Figure D.2.

   1) The sample shall be placed in a vacuum chamber and the pressure in the vacuum chamber shall be reduced to 95 kPa below normal atmospheric pressure.

   2) Maintain the vacuum for 30 min.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage, no accessible MCC powder leakage and no fuel vapour loss. See Figure D.2. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

D.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

D.7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex D.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure 6.

   2) Test samples shall be stored at a low external pressure of 68 kPa absolute pressure for 6 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure 6.

   3) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no accessible MCC powder leakage. See Figure 6. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test result is acceptable. During the 6 h test at 68 kPa absolute external pressure the fuel vapour loss shall be less than 0,08 g/h.

D.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex D.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure 7.

   2) Test samples shall be stored at a low external pressure of 11,6 kPa absolute pressure for 1 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure 7, with a fuel vapour loss at 11,6 kPa YES/NO passing

criteria of less than 2,0 g/h on the basis of not exceeding 25 % of the lower flammability limit (LFL).

3) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage and no accessible MCC powder leakage. See Figure 7. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test result is acceptable. During the 1 h test at 11,6 kPa absolute external pressure, the fuel vapour loss shall be less than 2,0 g/h.

D.7.3.2 Vibration test

Subclause D.7.3.2 replaces Subclause 7.3.2.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in D.7.3.1 or a micro fuel cell power system used in D.7.3.1.

b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure D.2 for the fuel cartridge and Figure D.4 for the micro fuel cell power system or unit.

2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage, no accessible MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured based upon Figure D.2 for the fuel cartridge and Figure D.4 for the micro fuel cell power system or unit. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

D.7.3.3 Temperature cycling test

Subclause D.7.3.3 replaces Subclause 7.3.3.

a) **Test sample:** a fuel cartridge used in D.7.3.2, a used fuel cartridge used in D.7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in D.7.3.2 or a micro fuel cell power system used in D.7.3.2.

b) **Purpose:** to simulate the effects of low-temperature and high temperature exposure and the effects of extreme temperature change.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure D.3 for the fuel cartridge and Figure D.4 for the micro fuel cell power system or unit.

   2) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

   3) See Figure 8 for the temperature profile to be used.

   4) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

   5) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

   6) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

   7) The above process is to be done twice.

   8) After 1 h at 22 °C ± 5°C, leakage and fuel vapour loss shall be measured based upon the procedure described in Figure 3 (for fuel cartridge) and Figure 4 (for micro fuel cell power system or unit).

   9) For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No accessible liquid leakage, no accessible MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured based upon Figure D.3 for the fuel cartridge and Figure D.4 for the micro fuel cell power system or unit. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

D.7.3.4 High temperature exposure test

Subclause D.7.3.4 replaces Subclause 7.3.4.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments.

c) **Test procedure:**

   1) Two orientations shall be tested – valve up and valve down.

   2) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

3) Remove the test sample to laboratory temperature.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage, no MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure D.3 for a fuel cartridge. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

D.7.3.5 Drop test

Subclause D.7.3.5 replaces Subclause 7.3.5.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

1) The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

2) The height of the drop shall be:

i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system.

ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge of more than 200 ml.

iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge of up to 200 ml.

3) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

4) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or unit may be used for all four drop orientations, or more than one micro fuel cell power system or unit may be used in subsequent drops, at the discretion of the manufacturer.

5) For all tests, drop orientations shall be:

i) valve up;

ii) valve down;

iii) two other mutually perpendicular orientations.

6) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage, no MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured based upon Figure D.2 for the fuel cartridge and Figure D.4 for the micro fuel cell power system or unit. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable. If the micro fuel cell power system or unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

D.7.3.6 Compressive loading test

Subclause D.7.3.6 replaces Subclause 7.3.6.

D.7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused or used fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

1) The micro fuel cell power system or unit test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

5) Perform emission testing in accordance with 7.3.12 following the compressive loading test.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage, no MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure D.4. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power system over indicating paper in such a way that the valve(s) point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions from micro fuel cell power system or unit shall meet the passing criteria in 7.3.12. If the micro fuel cell power system or unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

D.7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge.

c) **Test procedure:**

1) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage, no MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure D.2. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

D.7.3.7 External short-circuit test

Subclause D.7.3.7 replaces Subclause 7.3.7.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused or used fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

   1) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

   2) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

   3) Perform emission testing in accordance with 7.3.12 after each short-circuit test.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No leakage, no MCC powder leakage and no fuel vapour loss. Leakage and fuel vapour loss shall be measured on the basis of the procedure described in Figure D.5. Leakage shall be checked visually. Remove the fuel cartridge, if present, from the micro fuel cell power system. Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valves point downward toward the indicating paper and look for signs of leakage. If any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

   Exterior surfaces shall not exceed temperatures in Table 2 during or after short circuit testing.

   Emissions shall meet the passing criteria in 7.3.12. If the micro fuel cell power system or unit does not operate but emissions do not exceed the limits of 7.3.12, the emission test is acceptable.

NOTE The external short-circuit test can be done sequentially with the surface, component and exhaust gas temperature test using the same sample.

D.7.3.9 Long-term storage test

Subclause D.7.3.9 replaces Subclause 7.3.9.

D.7.3.9.1 General

Either D.7.3.9.2 (Option 1), D.7.3.9.3 (Option 2) or D.7.3.9.4 (Option 3) may be used.

D.7.3.9.2 Option 1 – Continuous weight measurement

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure D.9):

1) Use a load cell (continuous electronic weight sensing device) designed and calibrated for use at 50 °C inside the temperature chamber.

2) Place the load cell in a temperature chamber at 50 °C ± 2 °C. Place the fuel cartridge on top of the load cell so that all the weight is being applied to the load cell. A fixture may be used to control the position of the fuel cartridge, to ensure all the weight is applied to the load cell.

3) Connect a digital readout to the load cell and collect the data either manually or automatically. The data should be collected with a high degree of confidence to assure that the fuel vapour loss does not exceed 0,08 g/h.

4) Measure and record initial mass M_{initial} and time t_{i}.

5) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

6) If the fuel cartridge still has fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,08 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

7) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,08 g/h.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss, no liquid leakage and no MCC powder leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure D.9. If the fuel cartridge exceeds the 0,08 g/h fuel vapour loss criteria, then the test sample fails the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

D.7.3.9.3 Option 2 – Periodic weight measurements

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure D.9):

1) Place the fuel cartridge in a temperature chamber at 50 °C ± 2 °C. Weight measurements should be collected with a high degree of confidence to determine if the fuel vapour loss does not exceed 0,08 g/h with a minimum of once every three days.

2) Measure and record initial mass M_{initial} and time t_{i}.

3) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

4) The time in which the test samples are removed from the chamber for measurement shall not be included in the time the test sample is to be tested (28 days). Additional time should be added to get the test sample to the test temperature (50 °C ± 2 °C) each time the test sample is removed from the chamber. The test samples should only be stabilised at laboratory temperature if the mass loss will be affected.

5) If the fuel cartridge still has fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,08 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

6) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,08 g/h.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss, no liquid leakage and no MCC powder leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure D.9. If the fuel cartridge exceeds the 0,08 g/h fuel vapour loss criteria, then the test sample fails the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

D.7.3.9.4 Option 3 – One weight measurement

This option is intended for fuel cartridges with very small leak rates.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure D.9):

1) Measure and record initial mass M_{initial} and time t_i.

2) Place the fuel cartridges in a temperature chamber at 50 °C ± 2 °C. After 28 days, the fuel cartridges are removed from the chamber for measurement. The test samples should be stabilised at laboratory temperature if the mass loss will be affected. Then weight measurement is executed.

3) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_f. If the average mass loss rate is less than 0,08 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_f - t_i$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

4) If the fuel cartridge is empty after 28 days, then the type test according to D.7.3.9.2 Option 1 or D.7.3.9.3 Option 2 shall be done.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No fuel vapour loss, no liquid leakage and no MCC powder leakage. Leakage and fuel vapour loss shall be measured based upon the procedure described in Figure D.9. If the fuel cartridge did exceed the 0,08 g/h fuel vapour loss criteria, then the test sample fails the test. Leakage shall be checked visually. Invert the fuel cartridge over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

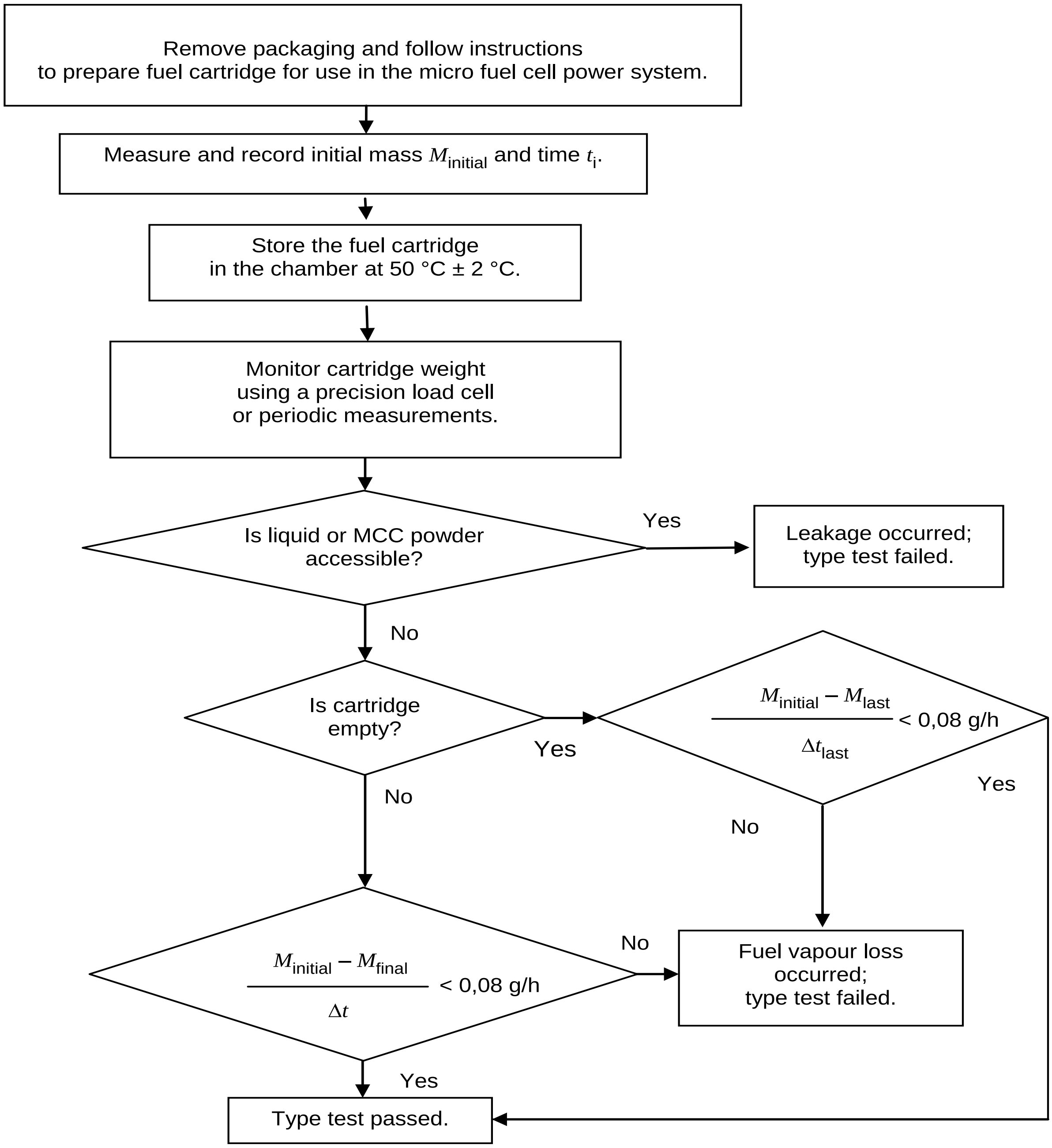


Figure D.9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9

D.7.3.10 High-temperature connection test

Subclause D.7.3.10 replaces Subclause 7.3.10.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage, no fire, no explosion.

c) **Test procedure:**
   1) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.
   2) The micro fuel cell power unit or test fixture with micro fuel cell power unit valve is kept at laboratory temperature.
   3) Remove the test sample from the chamber and connect the fuel cartridge to the micro fuel cell power unit or test fixture with micro fuel cell power unit valve within 5 min of removal from the chamber.
   4) Check for leakage upon connection.
   5) Disconnect the fuel cartridge and check for leakage.

d) **Passing criteria:** No leakage, no MCC powder leakage, no fire or flame, and no explosion. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occurs, this is acceptable. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power unit valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

D.7.3.11 Connection cycling tests

D.7.3.11.1 Fuel cartridge

D.7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused or used insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**
   1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for leakage upon connection.
   2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.
   3) Turn off the micro fuel cell power unit or stop simulated fuel flow.
   4) Disconnect the fuel cartridge and check for leakage.
   5) Repeat this twice more for a total of three connections and disconnections.
   6) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
   7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.
   8) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.
   9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.
   10) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper such that the valve points downward toward the indicating paper and look for signs of leakage.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for leakage.

d) **Passing criteria:** No leakage, no MCC powder leakage, no fire or flame, and no explosion. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit or micro fuel cell power unit valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

D.7.3.11.1.2 Satellite cartridge

Not applicable to this Annex D.

D.7.3.11.2 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused or used fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

   First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

1) Connect the first fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and check for leakage.

5) Repeat this twice more for a total of three connections and disconnections.

6) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

7) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

8) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

9) Connect and disconnect the first fuel cartridge three more times for a total of ten connections and disconnections.

10) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

11) Connect the first fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.

12) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

13) Turn off the micro fuel cell power unit or stop simulated fuel flow.

14) Disconnect the first fuel cartridge and check for leakage.

15) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.

    i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections.

    ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.

    iii) Inversion of the micro fuel cell power unit or the fuel cartridges is not necessary, but, if leakage is found, the test fails.

    iv) Following this ageing, a final unused fuel cartridge will be tested.

16) Connect the final unused fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.

17) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

18) Turn off the micro fuel cell power unit or stop simulated fuel flow.

19) Disconnect the fuel cartridge and check for leakage.

20) Repeat this twice more for a total of three connections and disconnections.

21) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

22) Connect and disconnect the final fuel cartridge four more times for a total of seven connections and disconnections.

23) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

24) Connect and disconnect the final fuel cartridge three more times for a total of ten connections and disconnections.

25) Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage.

26) Connect the fuel cartridge to the micro fuel cell power unit and check for leakage upon connection.

27) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

28) Turn off the micro fuel cell power unit or stop simulated fuel flow.

29) Disconnect the fuel cartridge and check for leakage.

d) **Passing criteria:** No leakage, no MCC powder leakage, no fire or flame, and no explosion. Leakage shall be checked visually. Invert the fuel cartridge and the micro fuel cell power unit over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid or MCC powder leakage is found, the test fails. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit.

Annex E
(normative)

Borohydride micro fuel cell power systems: Class 8 (corrosive) compounds in indirect borohydride fuel cells

E.1 Scope

E.1.2 Fuels and technologies covered by this annex

Annex E covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from Class 8 (corrosive) borohydride formulations as fuel. These systems and units use proton exchange membrane fuel cell technologies. The designs may include fuel processing subsystems to derive hydrogen gas from the borohydride compound fuel.

Figure E.1 replaces Figure 1, and Figures E.13, E.14 and E.15 are additional figures showing micro fuel cell power system block diagrams for use with this annex.

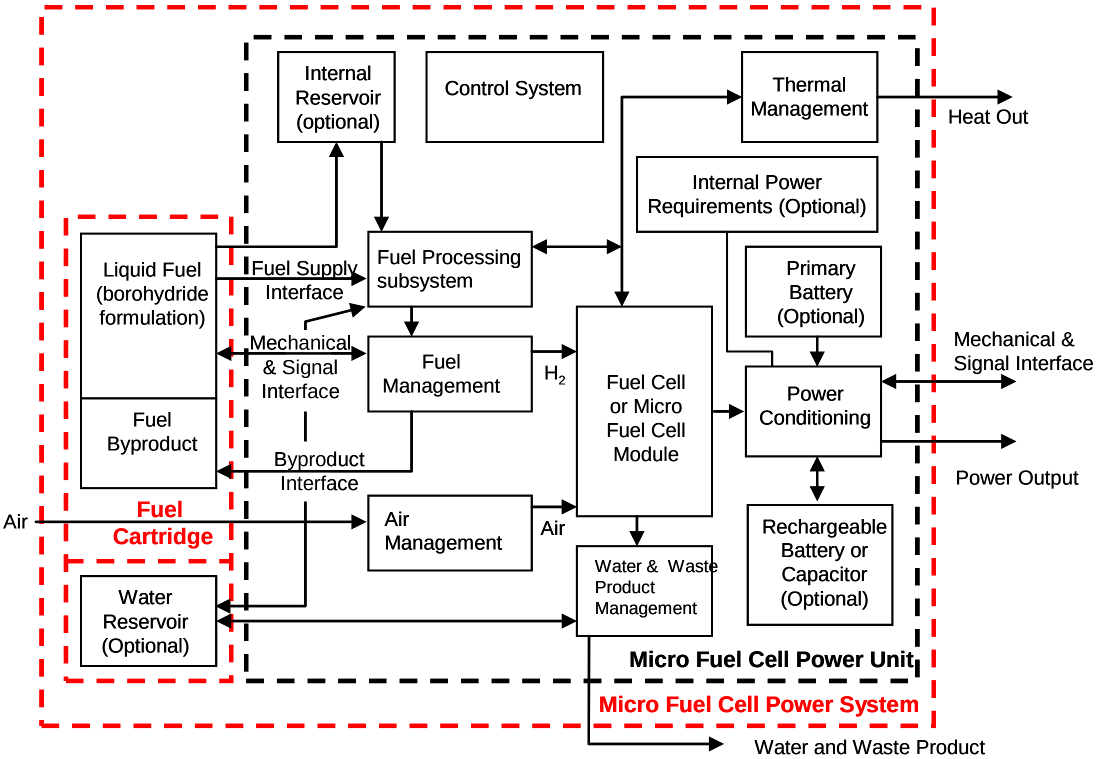


Figure E.1 – Micro fuel cell power system block diagram for liquid Class 8 indirect (corrosive) borohydride compound fuel with onboard fuel processing – Replaces Figure 1

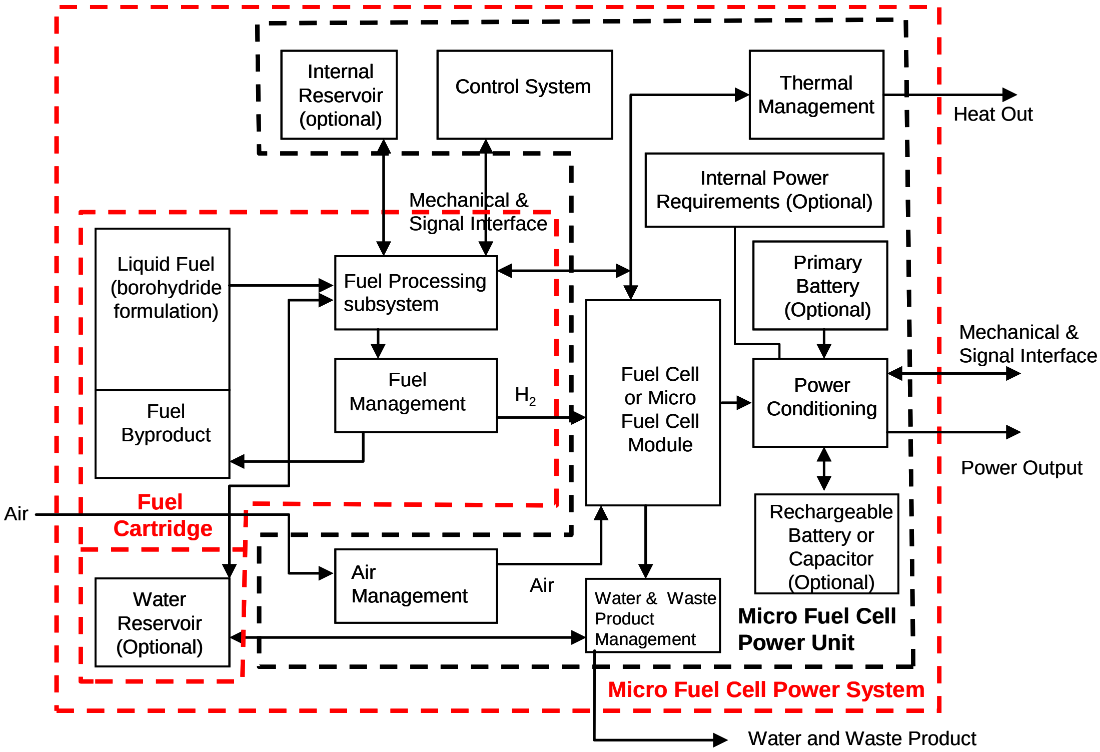


Figure E.13 – Micro fuel cell power system block diagram for liquid Class 8 (corrosive) indirect borohydride compound fuel with fuel cartridge fuel processing

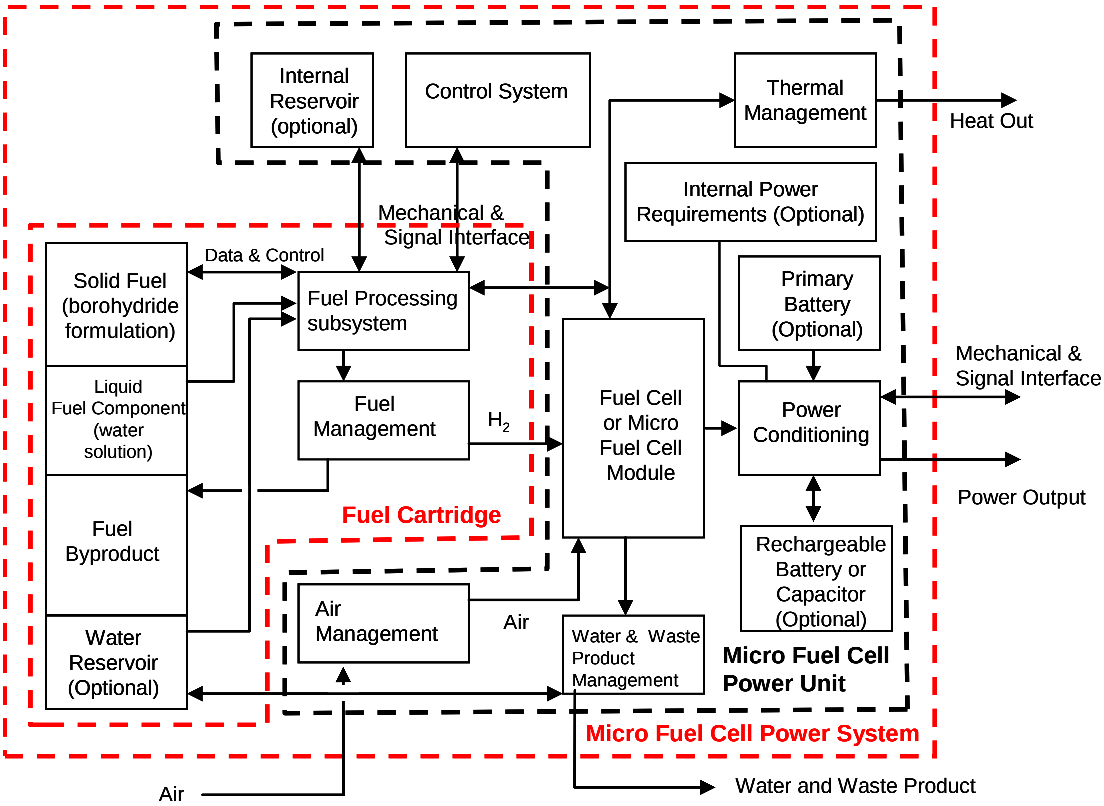


Figure E.14 – Micro fuel cell power system block diagram for solid Class 8 (corrosive) indirect borohydride compound fuel with fuel cartridge fuel processing and cartridge fuel management

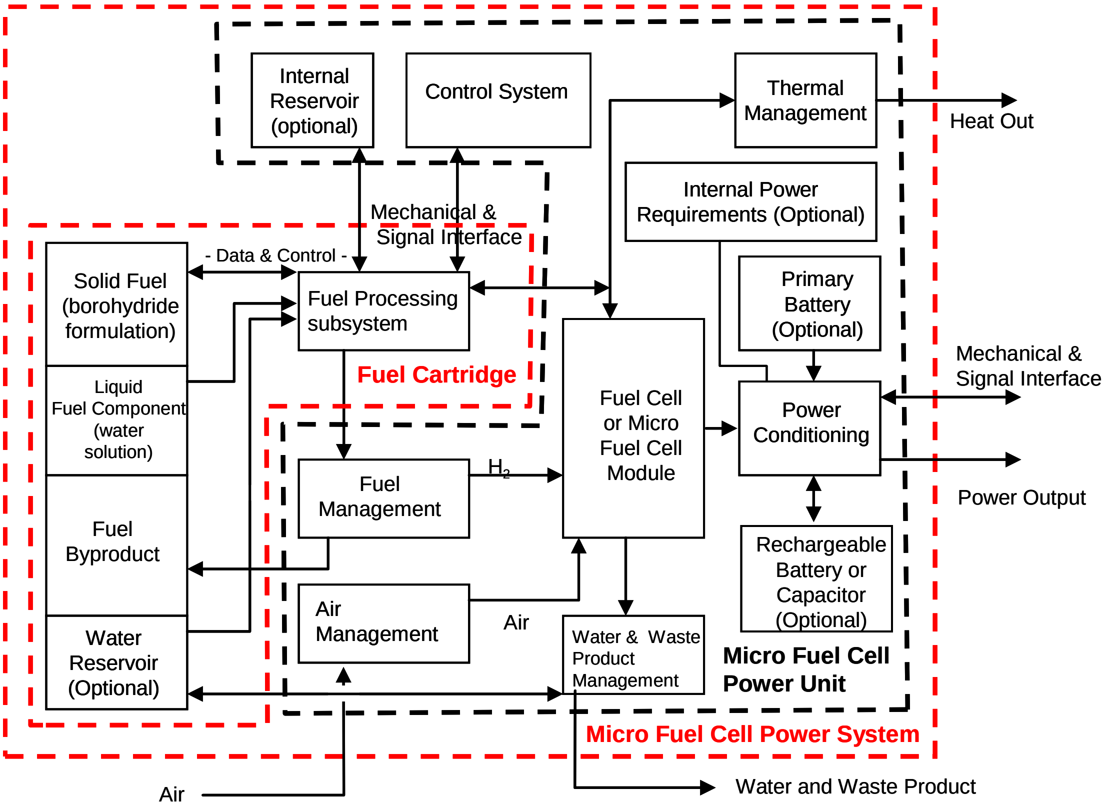


Figure E.15 – Micro fuel cell power system block diagram for solid Class 8 (corrosive) compound fuel with cartridge fuel processing and fuel management internal to the micro fuel cell power unit

E.2 Normative references

In addition to the normative references specified in Clause 2, the following referenced documents are indispensable for the application of this document.

For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16111:2008, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

E.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex E. All terms and conditions in Clause 3 not specifically mentioned here also apply.

E.3.5
fuel
Class 8 (corrosive) formulation of borohydride compounds used to produce electricity indirectly in a micro fuel cell power system

E.3.6
fuel cartridge
removable article that contains fuel and supplies fuel or hydrogen to the micro fuel cell power unit or internal reservoir, not to be refillable by the user

E.3.8
liquid fuel, corrosive
liquid Class 8 (corrosive) formulation of borohydride compounds and one or more alkali metal hydroxides used as fuel for an indirect borohydride micro fuel cell power system

E.3.11
leakage
accessible fuel, hazardous fuel byproducts, electrolyte or hazardous liquid fuel ~~components~~ outside the micro fuel cell power system, micro fuel cell power unit or fuel cartridge~~; hydrogen leakage or impermissible hydrogen gas loss~~ as described in E.7.2.1

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex E in addition to those given in Clause E.3 and in Clause 3.

E.3.37
solid fuel, corrosive
solid Class 8 (corrosive) formulation of borohydride compounds and one or more alkali metal hydroxides used as fuel for an indirect borohydride micro fuel cell power system

E.3.38
indirect borohydride micro fuel cell power system
micro fuel cell power system in which a solid or liquid formulation of borohydride compounds, is processed to produce hydrogen which reacts on an anode of a fuel cell to produce electricity in a micro fuel cell power system

E.3.39
borohydride compounds
sodium or potassium borohydride, or a mixture thereof

E.3.40
liquid fuel component
Class 8 (corrosive), or non-hazardous, water solutions used to produce hydrogen within the fuel processing subsystem

E.3.41
electrolyte
ion conducting membrane used to complete an electric circuit within a fuel cell

E.3.42
fuel byproducts
Class 8 (corrosive), or non-hazardous, compounds produced after hydrogen and/or electricity is produced from fuel

E.3.43
impermissible hydrogen gas loss
hydrogen gas escaping non-operating micro fuel cell power system ~~or~~, micro fuel cell power unit, or fuel cartridge greater than or equal to 0,0032 g/h

E.3.44
accessible fuel, fuel byproducts, electrolyte or liquid fuel components
fuel, fuel byproducts, electrolyte or liquid fuel components that the consumer may come into physical contact with during normal use, reasonably foreseeable misuse, and consumer transportation

E.3.45
fuel processing subsystem
subsystem within the micro fuel cell power unit or fuel cartridge used to produce hydrogen from formulations of borohydride compounds

E.3.46
incompatible materials
materials which are likely to cause a dangerous evolution of heat, or flammable or poisonous gas or vapours if allowed to mix in ways other than those specifically provided for by the micro fuel cell power system design

E.3.47
uncontrolled mixing
mixing of incompatible materials that occurs in ways not specifically provided for by the micro fuel cell power system design

E.3.48
Class 8 (corrosive)
materials which are classified as Class 8: Corrosive Substance under the guidelines of the 15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

E.3.49
non-hazardous
materials which are not subject to guidelines of the 15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

E.3.50
alkali metal hydroxide
hydroxides of sodium, potassium and lithium used in Class 8 (corrosive) solid and liquid fuel formulations

E.3.51
used fuel cartridge
fuel cartridge that that has been put into operation such that at least 45 % of the initial fuel has been utilized and that the operation of the micro fuel cell power system has been halted for at least 1 h

E.3.52
hydrogen leakage
accessible hazardous hydrogen gas outside ~~fuel~~ containment system, including fuel cartridge, fuel management and internal reservoir (see E.7.2.2)

~~**E.3.53**~~
~~**positive pH indication of liquid borohydride fuel and by product**~~
~~a positive indication of the presence of acid (pH less than 3,0) or base (pH greater than 10) on acid base indicator paper attached to the possible leak areas of the micro fuel cell power system during the type test.~~

E.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

E.4.4 Selection of materials

These requirements replace the corresponding requirements of Subclause 4.4.

These requirements of Subclause E.4.4 below apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

E.4.4.1 Micro fuel cell power systems and units are expected to be exposed to a number of environmental conditions over the manufacturer-defined life span of the product such as vibration, shock, varying humidity levels and corrosive environments. Materials employed in the micro fuel cell power system or unit shall be resistant to these environmental conditions. If a micro fuel cell power system or unit is to be used in service where specific environmental conditions are beyond those accounted for in the required tests of this standard, then additional testing shall be performed to verify safety under those environmental conditions.

E.4.4.2 Metallic and non-metallic materials used to construct internal or external parts of the micro fuel cell power system or unit, in particular those exposed directly or indirectly to moisture, fuel and/or byproducts in either a gas or liquid form as well as all parts and materials used to seal or interconnect the same, e.g. welding consumables, shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable under the normal transportation and normal usage conditions within the manufacturer-defined life span of the product and for all test conditions; in particular, they shall be designed to retain their mechanical stability under normal use;

- they shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation;
- the chemical and physical properties necessary for operational safety shall not be significantly affected within the manufacturer-defined life span of the product; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material's corrosion and wear resistance, electrical conductivity, impact strength, ageing resistance, the effects of temperature variations, the effects arising when materials are put together (e.g. galvanic corrosion), and the effects of ultraviolet radiation;
- where conditions of erosion, abrasion, corrosion or other chemical attack may arise, adequate measures shall be taken to
  - minimize that effect by appropriate design, e.g. additional thickness, or by appropriate protection, e.g. use of liners, cladding materials or surface coatings, taking due account of normal use;
  - permit replacement of parts which are most affected;
  - and draw attention, in the manual referred to in Clause 6, to type and frequency of inspection and maintenance measures necessary for continued safe use; where appropriate, it shall be indicated which parts are subject to wear and the criteria for replacement.

E.4.4.3 Elastomeric materials such as gaskets and tubing in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperatures that they are exposed to during normal use. Compliance shall be determined by the following: ISO 188 and ISO 1817.

E.4.4.4 Polymeric materials in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperature they are exposed to during normal use. Compliance shall be determined by ISO 175.

E.4.4.5 Piping systems exposed to hydrogen shall employ materials suitable for exposure to hydrogen, as defined in ISO 16111.

E.4.7 Materials and construction – system

E.4.7.1 *These requirements of Subclause E.4.7 apply to micro fuel cell power systems and units covered by this Annex E. These requirements replace the corresponding requirements of Subclause 4.7.* The maximum quantity of liquid fuel or liquid fuel components stored in the micro fuel cell power unit shall not be more than 1 l. Solid fuel shall not be present in the micro fuel cell power unit.

E.4.7.2 The micro fuel cell power system or unit shall be designed such that an explosion cannot occur even if fuel leaks from or inside the micro fuel cell power system or unit. The design criteria for such means (for example, required ventilation rate) shall be provided by the micro fuel cell power system or unit manufacturer. The means shall be provided either by the micro fuel cell power system or unit manufacturer or by the manufacturer of the device powered by the micro fuel cell power system or unit.

E.4.7.3 Components and materials inside the micro fuel cell power system or unit shall be constructed or shall make use of such materials that propagation of fire and ignition is mitigated. The material flammability shall be such that a sustained fire will not be supported after electrical power and the fuel and oxidant supply have been terminated. This may be demonstrated through the selection of materials meeting FV 0, FV 1 or FV 2 in accordance with IEC 60695-1-1 and IEC 60695-11-10.

E.4.7.4 Micro fuel cell stack membranes are not required to have flammability ratings.

E.4.7.5 Other materials within the micro fuel cell stack which comprise less than 30 % of the total micro fuel cell stack mass are considered to be of limited quantity and are permissible without flammability ratings.

E.4.12 Fuel supply construction

E.4.12.1 Fuel cartridge construction

These requirements of Subclause E.4.12.1 apply to micro fuel cell cartridges covered by this Annex E. These requirements replace the corresponding requirements of Subclause 4.12.1.

Fuel cartridges shall conform to the following requirements.

E.4.12.1.1 There shall be no leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with E.7.3.3 and E.7.3.4.

E.4.12.1.2 There shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Compliance shall be determined by type testing in accordance with E.7.3.1.

E.4.12.1.3 The maximum fuel charge is limited to 1 l for either liquid fuel or liquid fuel components, and 200 g for solid fuel.

E.4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance is checked by E.7.3.11.

E.4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

E.4.12.1.6 A fuel cartridge shall be provided with a means to prevent mis-connection that would result in leakage of fuel when it is installed in a micro fuel cell power system. Compliance is checked by the connection cycling test, E.7.3.11.

E.4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance is checked by the drop test, E.7.3.5, and the connection cycling test, E.7.3.11.

E.4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

E.4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel to leak.

E.4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance is checked by:

- Pressure differential tests, E.7.3.1;
- Vibration test, E.7.3.2;
- Temperature cycling test, E.7.3.3;
- High temperature exposure test, E.7.3.4;
- Drop test, E.7.3.5;
- Compressive loading test, E.7.3.6;
- External short-circuit test, E.7.3.7;
- Long-term storage test, E.7.3.9;
- High-temperature connection test, E.7.3.10;
- Connection cycling tests, E.7.3.11;
- Emission test, E.7.3.12.

E.4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

E.4.12.1.12 In cases where materials (either solid or liquid) are present that are incompatible with either the borohydride fuel or liquid fuel component, the design of the fuel cartridge and micro fuel cell power system shall provide a means for preventing inadvertent or uncontrolled mixing of these materials.

Two independent means for preventing inadvertent or uncontrolled mixing of these materials shall be provided during transportation and storage prior to use. Illustrative examples of these means include but are not limited to: positive activation by the control system; physical removal of an impermeable barrier preventing contact; opening of a normally closed manually controlled valve preventing contact. For at least one of these means for preventing uncontrolled mixing, it shall be necessary for the user to take positive action to remove or deactivate it prior to use.

At least one means for preventing uncontrolled mixing of these materials shall be provided during use and storage after use. This means may include active control by system electronics, subject to the FMEA analysis of 4.2.

E.6 Instructions and warnings for fuel cartridges, micro fuel cell power units, and micro fuel cell power systems

E.6.2 Minimum markings required on the fuel cartridge

These markings replace the markings required by Subclause 6.2.

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE CORROSIVE AND TOXIC, DO NOT DISASSEMBLE.
b) AVOID CONTACT WITH CONTENTS.
c) KEEP AWAY FROM CHILDREN.
d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.
e) DO NOT EXPOSE TO ACIDS, OXIDIZERS, ALCOHOL OR HOUSEHOLD CLEANING PRODUCTS.
f) DO NOT IMMERSE IN WATER OR OTHER LIQUIDS.
g) FOLLOW USAGE INSTRUCTIONS.
h) IN THE CASE OF INGESTION OR INHALATION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.
i) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.
j) COMPOSITION AND AMOUNT OF FUEL.
k) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.
l) MAY CONTAIN FLAMMABLE GAS.

In the case that the contents of the fuel cartridge may be flammable, the marking required under “a)” above shall be changed as follows:

a) CONTENTS ARE FLAMMABLE, CORROSIVE AND TOXIC. DO NOT DISASSEMBLE.

E.6.3 Minimum markings required on the micro fuel cell power system

These markings replace the markings required by Subclause 6.3.

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE CORROSIVE AND TOXIC, DO NOT DISASSEMBLE.
b) AVOID CONTACT WITH CONTENTS.
c) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.
d) DO NOT IMMERSE IN WATER OR OTHER LIQUIDS.
e) FOLLOW USAGE INSTRUCTIONS.
f) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.
g) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

h) COMPOSITION OF FUEL.

i) MAXIMUM CAPACITY OF FUEL IN THE INTERNAL RESERVOIR, IF APPLICABLE

j) TEXT OR MARKING THAT INDICATES THAT THE MICRO FUEL CELL POWER SYSTEM COMPLIES WITH IEC 62282-6-100.

k) MAY CONTAIN FLAMMABLE GAS.

l) ELECTRICAL OUTPUT (VOLTAGE, CURRENT, RATED POWER).

In the case that the contents of the fuel cartridge are corrosive, the marking required under "a)" above shall be changed as follows:

a) CONTENTS ARE WATER-REACTIVE, CORROSIVE AND TOXIC. DO NOT DISASSEMBLE.

In the case that the contents of the fuel cartridge are flammable, the marking required under "a)" above shall be changed as follows:

a) CONTENTS ARE WATER-REACTIVE, CORROSIVE, TOXIC AND FLAMMABLE. DO NOT DISASSEMBLE.

E.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

E.7.1 General

This Subclause E.7.1 replaces Subclause 7.1 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from Class 8 (corrosive) borohydride compounds as fuel.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table E.5 lists the type tests that must be performed. *Table E.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table E.6. *Table E.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table E.5 – List of type tests – Replaces table 5

Test reference	Test item	Test sample
E.7.3.1	Pressure differential tests	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
E.7.3.2	Vibration test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
E.7.3.3	Temperature cycling test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
E.7.3.4	High temperature exposure test	Fuel cartridge Used fuel cartridge
E.7.3.5	Drop test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
E.7.3.6	Compressive loading test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
E.7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface component and exhaust gas temperature test	Micro fuel cell power system or power unit
E.7.3.9	Long-term storage test	Fuel cartridge Used fuel cartridge
E.7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
E.7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
E.7.3.12	Emission test	Micro fuel cell power system or power unit
E.7.3.13	Hydrogen point source gas loss detection test	Micro fuel cell power system or power unit

Table E.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or used, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test.

Test sequence: Tests E.7.3.2 and E.7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests E.7.3.1, E.7.3.2, and E.7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer's discretion if it does not compromise the individual test.

Table E.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is "room temperature" (standard temperature condition, 22 °C ± 5 °C)
Laboratory atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen. The laboratory atmosphere contains not more than 0,008 % hydrogen
Table E.6 replaces Table 6.	

E.7.2 Leakage, hydrogen leakage, and hydrogen gas loss measurement and the measuring procedure

This Subclause E.7.2 replaces Subclause 7.2 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use Class 8 (corrosive) borohydride compounds as fuel.

a) *The leakage measurement shall be executed in principle in accordance with the procedures shown in Figures E.2 through E.5. These figures and their procedures, replace the corresponding figures in Subclause 7.2.*

b) Compliance with the "no leakage", "no hydrogen leakage" and "no impermissible hydrogen gas loss" requirement for all type tests specified in Subclause E.7.3 shall be determined by the leakage measurement procedure of Subclause E.7.2.1, the hydrogen leakage measurement procedure of Subclause E.7.2.2 and the hydrogen gas loss measurement procedure of E.7.3.13 in conjunction with the definition of "leakage" in Subclause E.3.11, "hydrogen leakage" in Subclause E.3.52 and the definition of "impermissible hydrogen gas loss" in Subclause E.3.43, unless otherwise specified.

E.7.2.1 Leakage test and measuring procedures

a) For micro fuel cell power systems, micro fuel cell power units and fuel cartridges containing Class 8 (corrosive) borohydride fuel, the leakage measurement of fuel, fuel byproducts, electrolyte or liquid fuel components shall be done following each type test by performing visual inspection of all possible leak locations. Any drops of fuel, fuel byproducts, electrolyte or liquid fuel component and/or white crystals on the exterior of the micro fuel cell power system or unit or fuel cartridge are indications of leakage. If crystals are accessible, the micro fuel cell power system or unit or fuel cartridge fails the leakage test. As an additional tool for finding fuel, fuel byproducts, electrolyte or liquid fuel component leaks, pH paper, attached to the possible leak areas of the micro fuel cell power system, shall be used to aid in the visual check for leakage. This is an additional requirement in Annex F for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel components. Any existence of a substance with a pH lower than 3,5 or greater than 10,5 is an indication of leakage. See Figure E.2 and Figure E.3. For operational tests, reactant air passages into the micro fuel cell power system and exhaust ports should not be blocked with pH paper.

E.7.2.2 Hydrogen leakage measurement from fuel cartridges and measurement procedures

a) For fuel cartridges containing Class 8 (corrosive) borohydride compounds, the measurement of hydrogen leakage shall be done following each type test using a liquid leak detector (bubble forming) solution or other equivalent means, such as a water immersion test, on all possible leak locations of the fuel cartridge.

b) If bubbles are observed, hydrogen point source gas loss detection testing in accordance with E.7.3.13 shall be performed to ensure no release of hazardous materials to the environment.

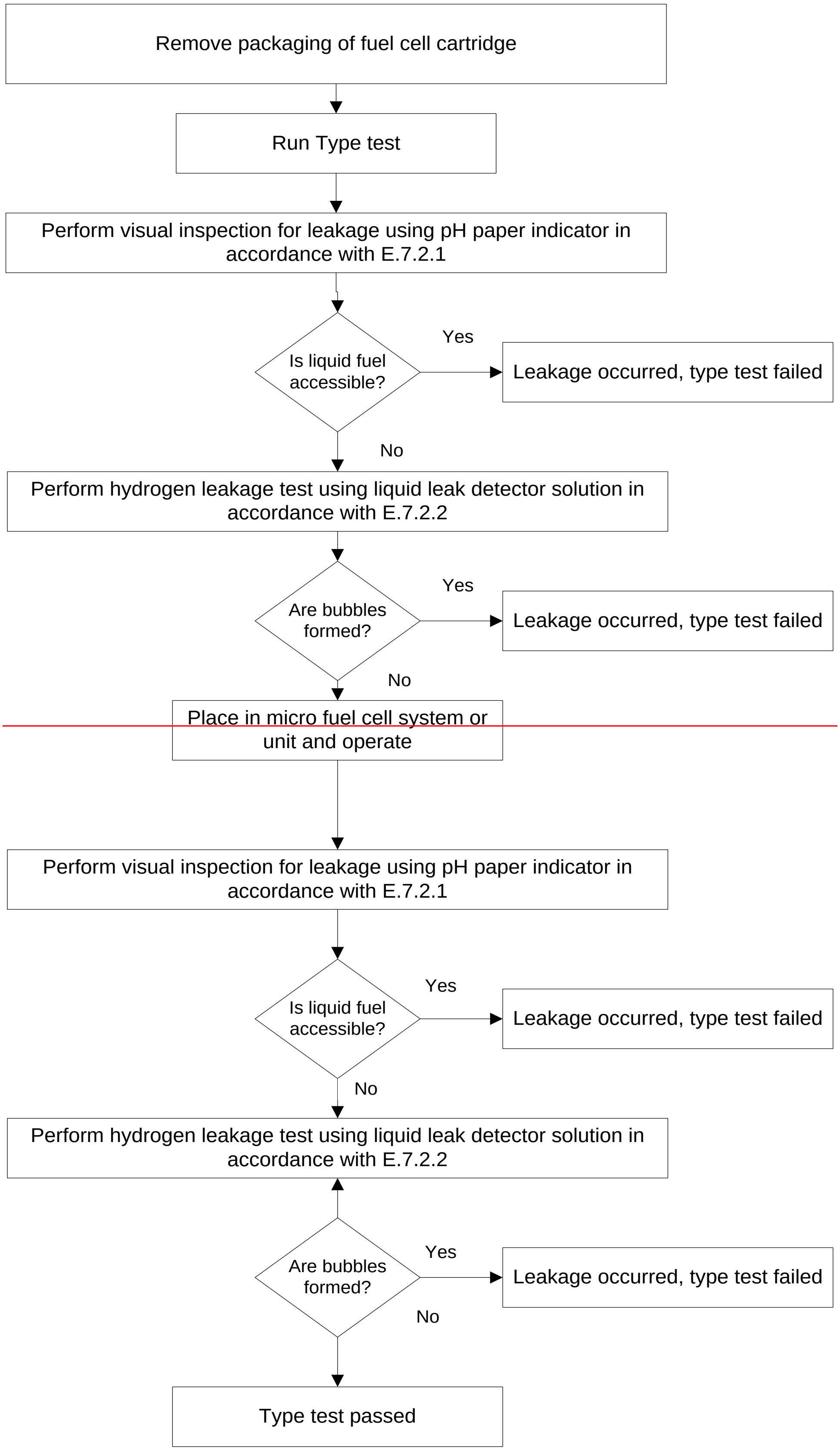
c) If point source testing is performed, hydrogen leakage measurement in accordance with paragraph (a) shall be repeated one hour after completion of the point source test. If bubbles due to hydrogen leakage are observed, the fuel cartridge fails the hydrogen leakage test. See Figure E.2 and Figure E.3.

E.7.2.3 Hydrogen gas loss measurements from micro fuel cell power systems and micro fuel cell power units and measuring procedures

For micro fuel cell power systems, or micro fuel cell power units, following the completion of each type test, the micro fuel cell power system or unit shall be tested for hydrogen gas loss according to Figure E.4 as follows.

a) Perform hydrogen emission testing in accordance with E.7.3.12 with the exception that the micro fuel cell power system or unit shall be off ("DEVICE – OFF"). Hydrogen gas loss shall be less than 0,0032 g/h. If transient emission rates greater than 0,016 g/h are observed during hydrogen emission testing, hydrogen point source gas loss detection testing in accordance with E.7.3.13 ~~is not applicable~~ shall be performed. See Table E.7.

b) Perform hydrogen emission testing in accordance with E.7.3.12 with the micro fuel cell power system or unit turned on ("DEVICE – ON") to test for hydrogen emissions whether or not the micro fuel cell power system or unit is operational. Hydrogen emissions shall be less than 0,8 g/h and hydrogen leakage from any single point leak shall be less than 0,016 g/h. See Table E.7.


Remove packaging of fuel cell cartridge
Run Type test
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Place in micro fuel cell system or unit and operate
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Type test passed

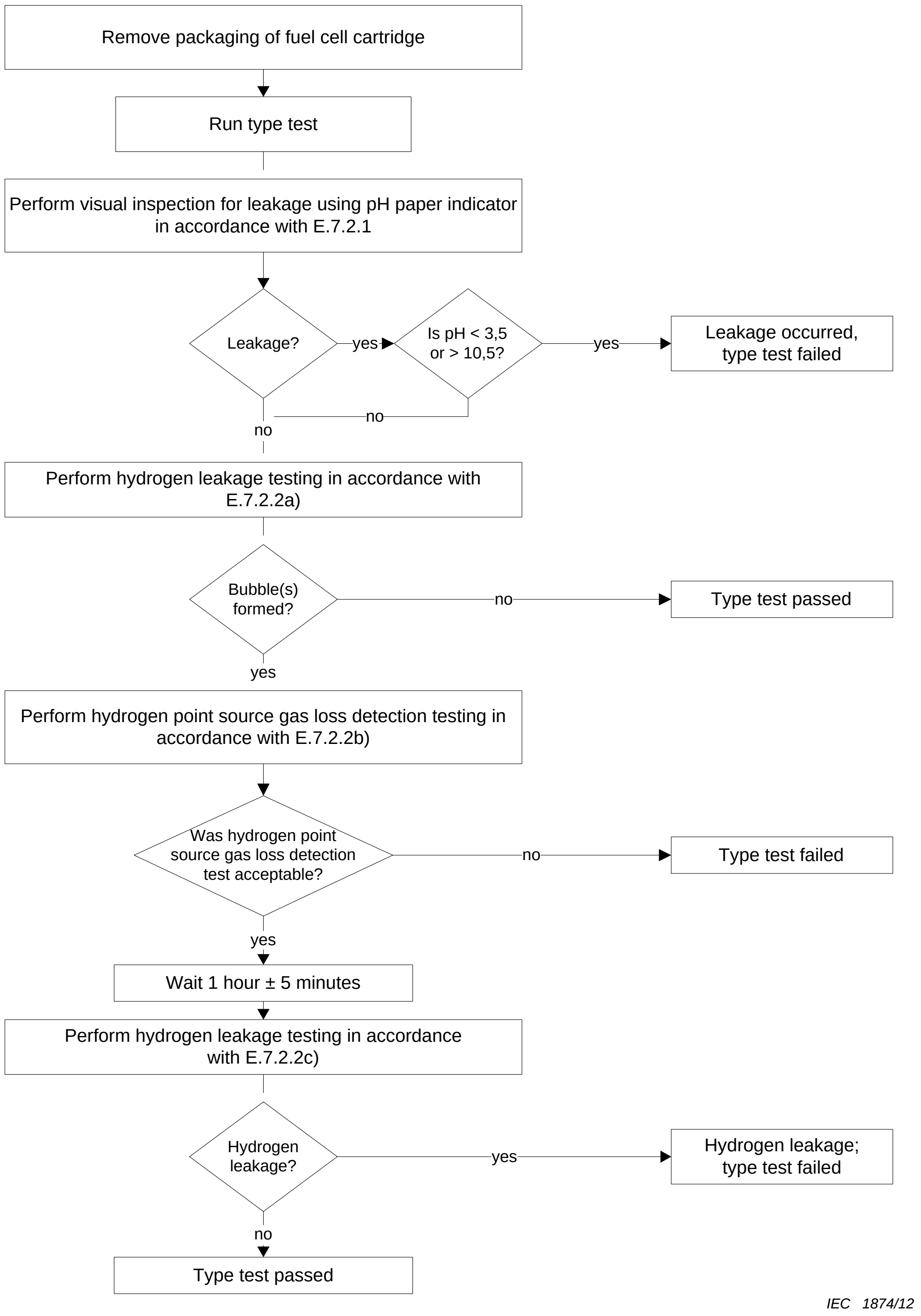
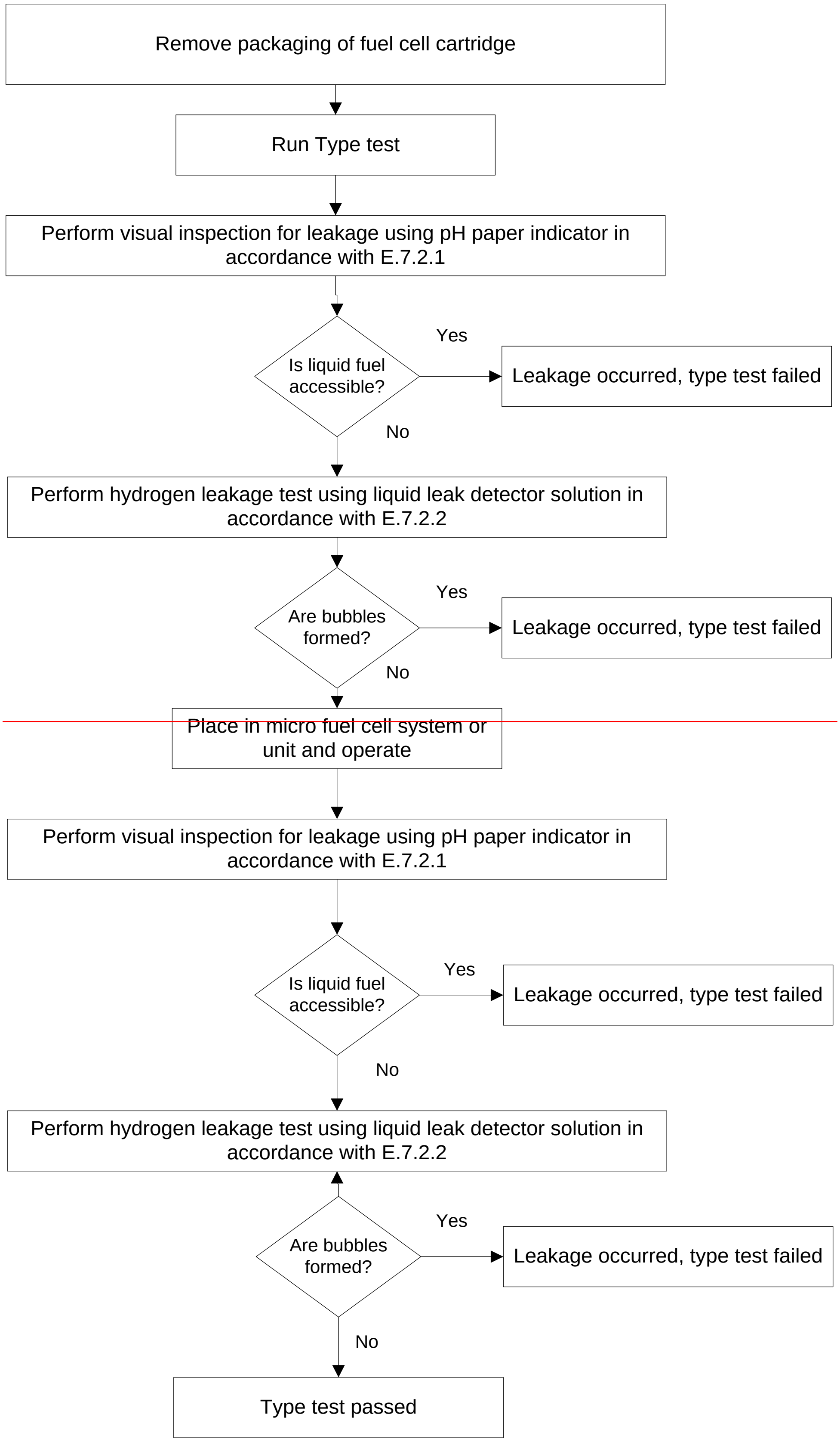


Figure E.2 – Fuel cartridge leakage and hydrogen leakage and test flow chart for vibration, drop, compressive loading – Replaces Figure 2


Remove packaging of fuel cell cartridge
Run Type test
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
~~Place in micro fuel cell system or~~
unit and operate
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Type test passed

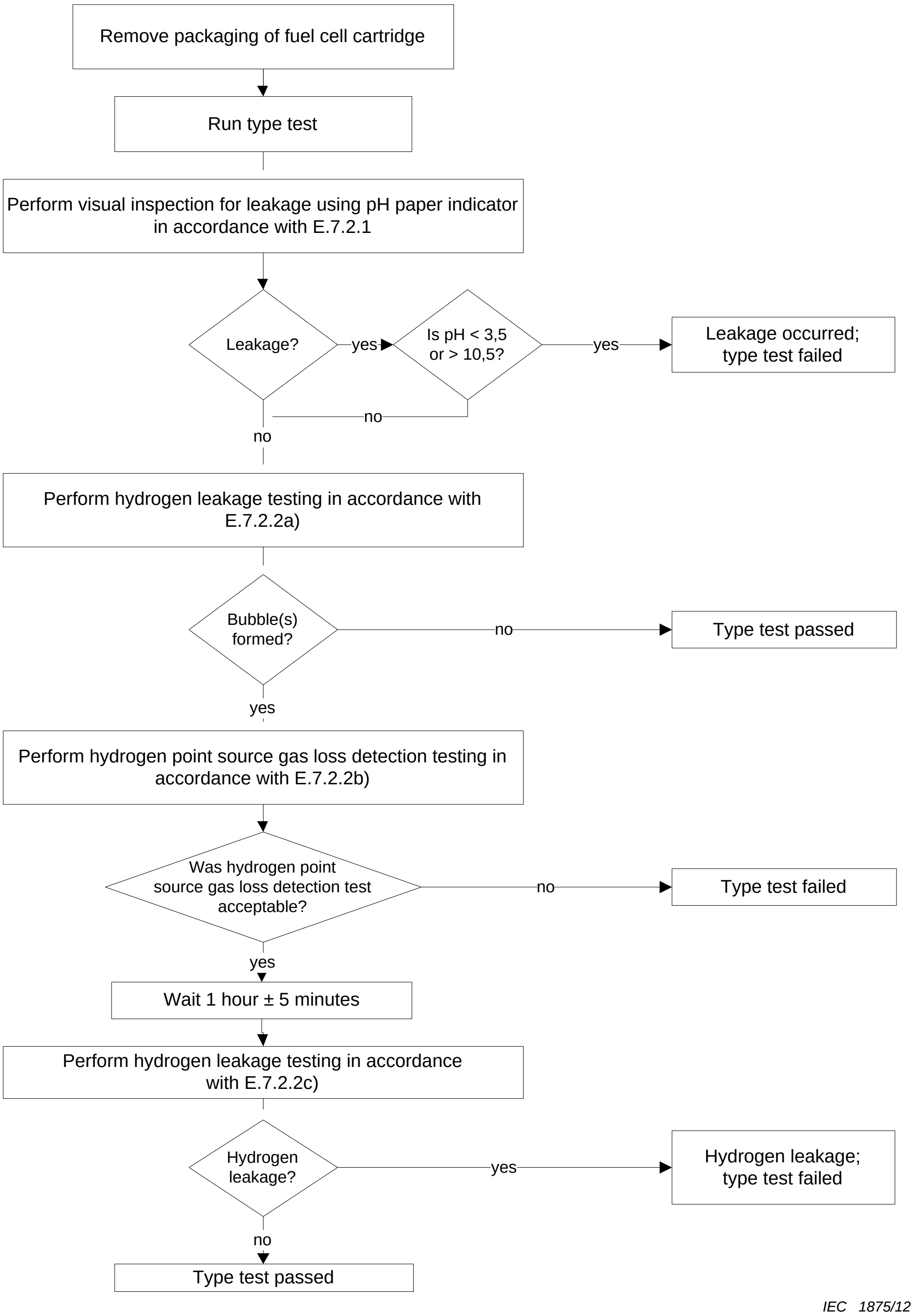
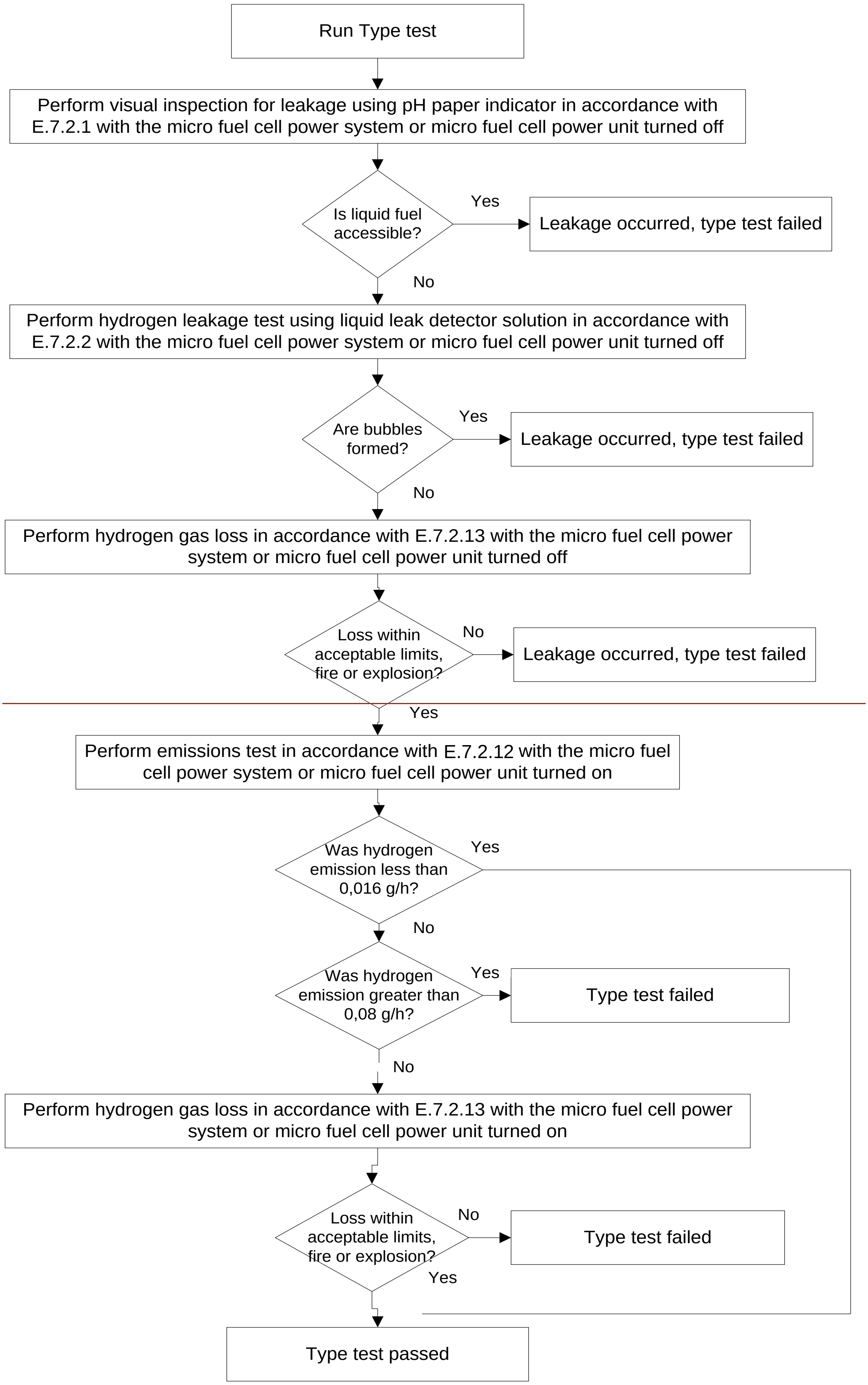


Figure E.3 – Fuel cartridge leakage and ~~mass loss~~ hydrogen leakage test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3


Run Type test
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1 with the micro fuel cell power system or micro fuel cell power unit turned off
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2 with the micro fuel cell power system or micro fuel cell power unit turned off
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Perform hydrogen gas loss in accordance with E.7.2.13 with the micro fuel cell power system or micro fuel cell power unit turned off
Loss within acceptable limits, fire or explosion?
No
Leakage occurred, type test failed
Yes
Perform emissions test in accordance with E.7.2.12 with the micro fuel cell power system or micro fuel cell power unit turned on
Was hydrogen emission less than 0,016 g/h?
Yes
No
Was hydrogen emission greater than 0,08 g/h?
Yes
Type test failed
No
Perform hydrogen gas loss in accordance with E.7.2.13 with the micro fuel cell power system or micro fuel cell power unit turned on
Loss within acceptable limits, fire or explosion?
No
Type test failed
Yes
Type test passed

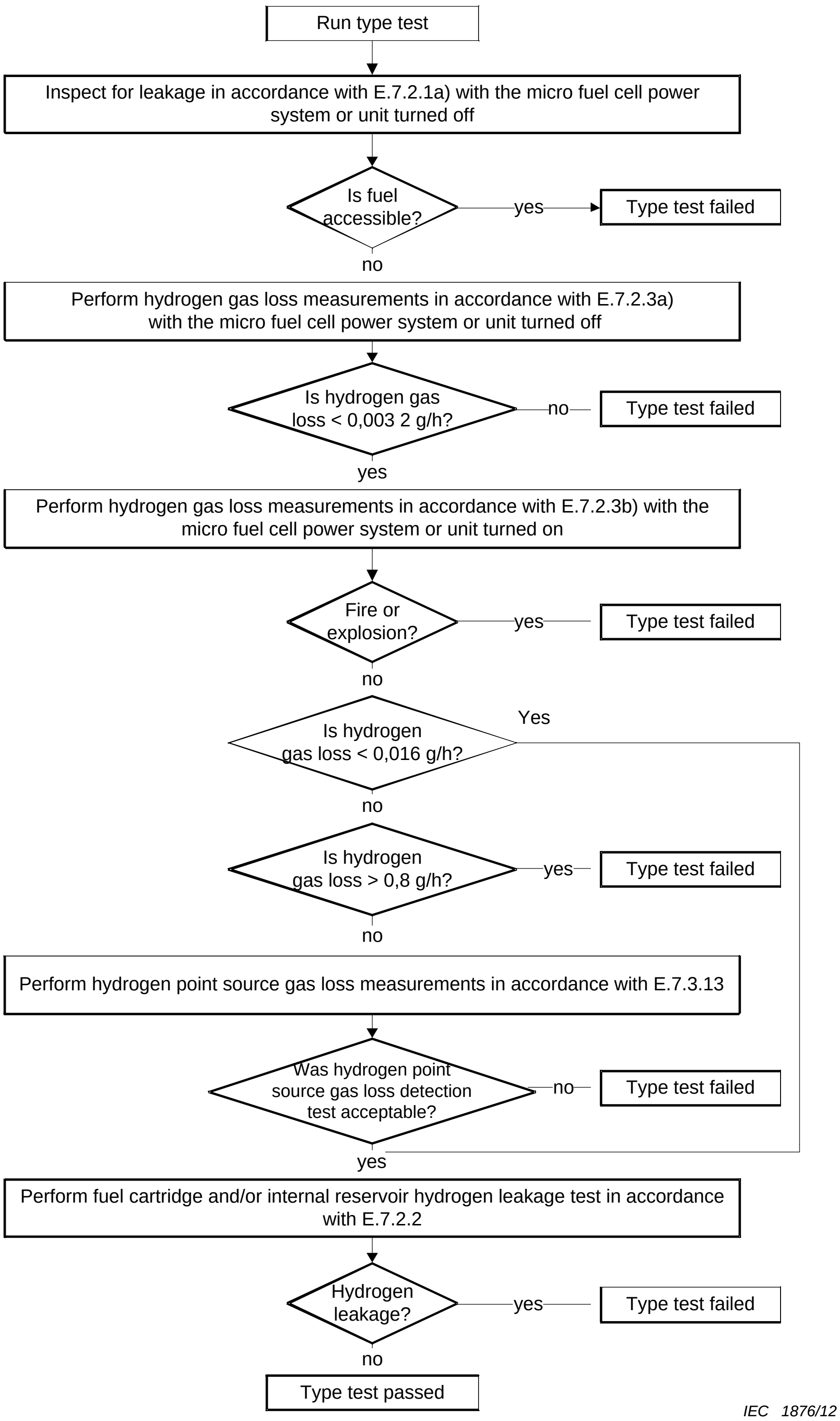
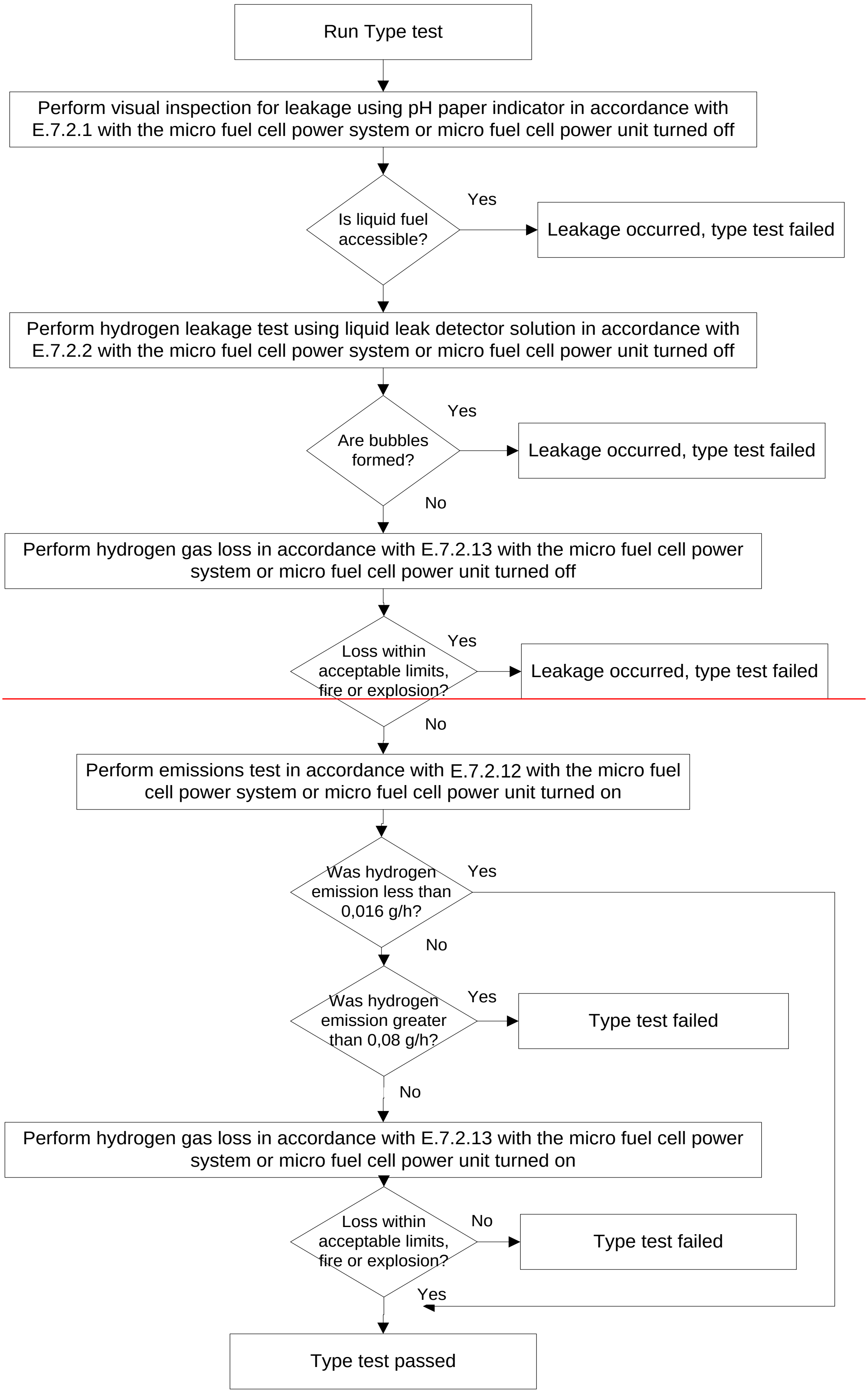


Figure E.4 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4


Run Type test
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1 with the micro fuel cell power system or micro fuel cell power unit turned off
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2 with the micro fuel cell power system or micro fuel cell power unit turned off
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Perform hydrogen gas loss in accordance with E.7.2.13 with the micro fuel cell power system or micro fuel cell power unit turned off
Loss within acceptable limits, fire or explosion?
Yes
Leakage occurred, type test failed
No
Perform emissions test in accordance with E.7.2.12 with the micro fuel cell power system or micro fuel cell power unit turned on
Was hydrogen emission less than 0,016 g/h?
Yes
No
Was hydrogen emission greater than 0,08 g/h?
Yes
Type test failed
No
Perform hydrogen gas loss in accordance with E.7.2.13 with the micro fuel cell power system or micro fuel cell power unit turned on
Loss within acceptable limits, fire or explosion?
No
Type test failed
Yes
Type test passed

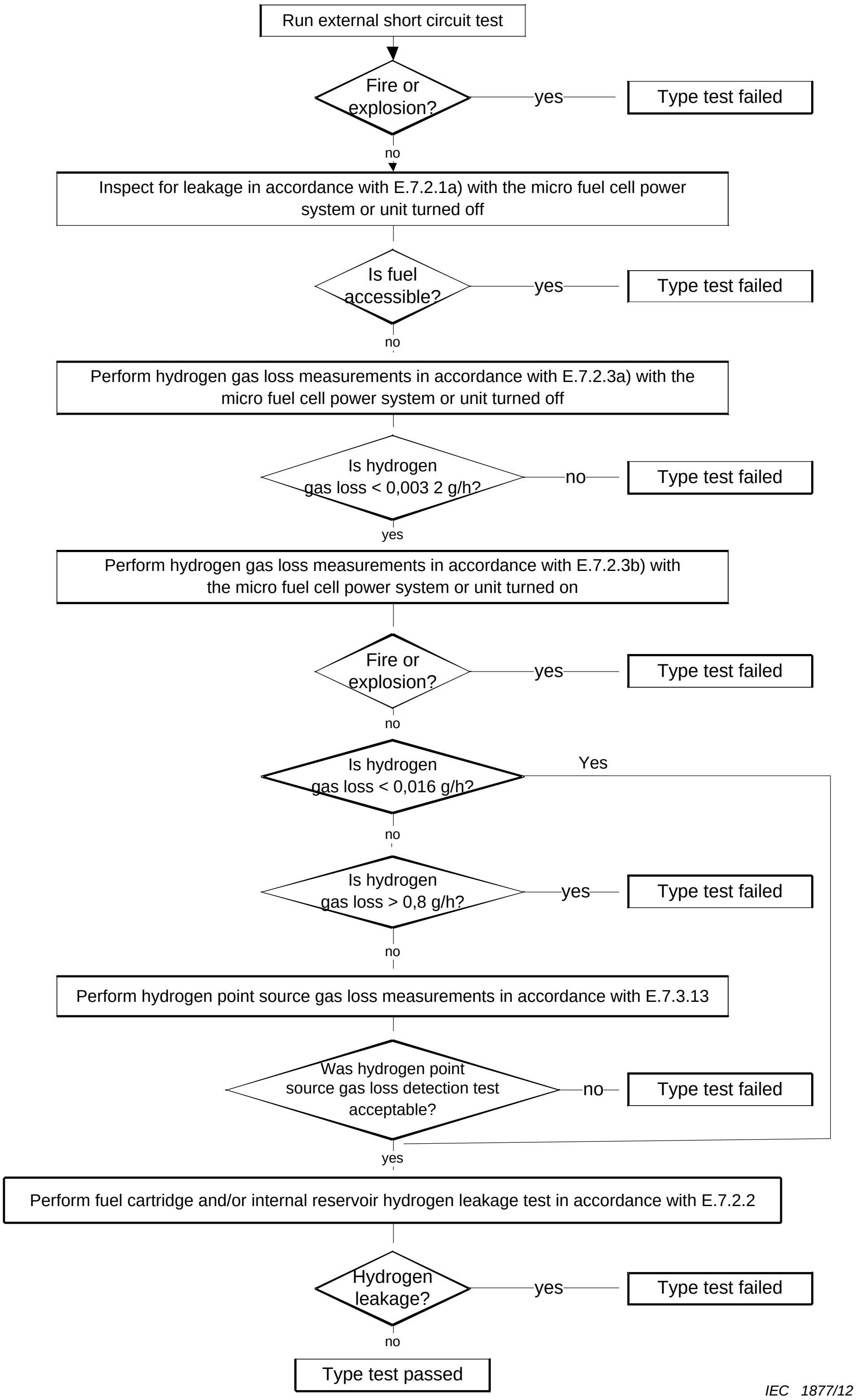


Figure E.5 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for external short-circuit test – Replaces Figure 5

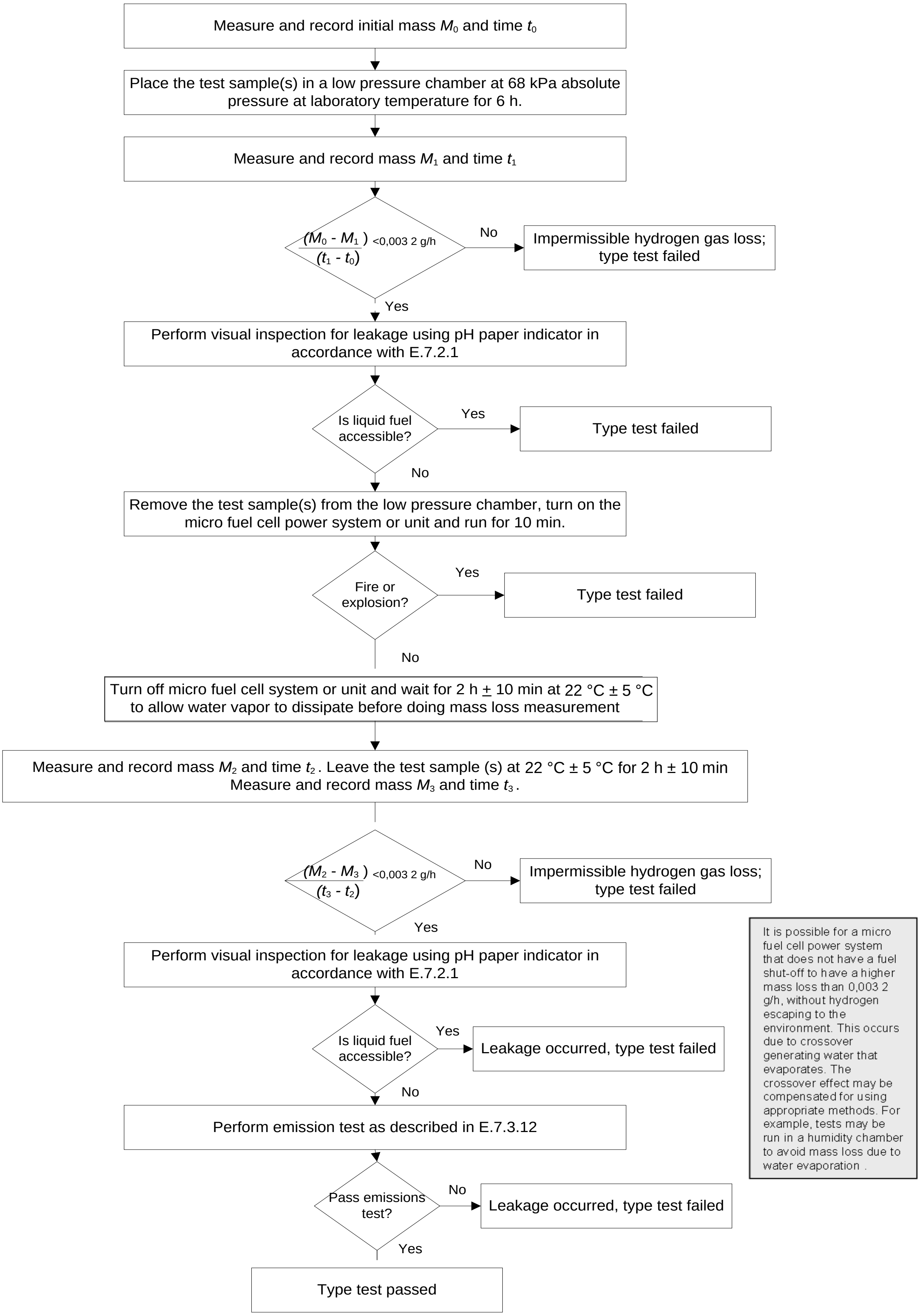


Figure E.6 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6

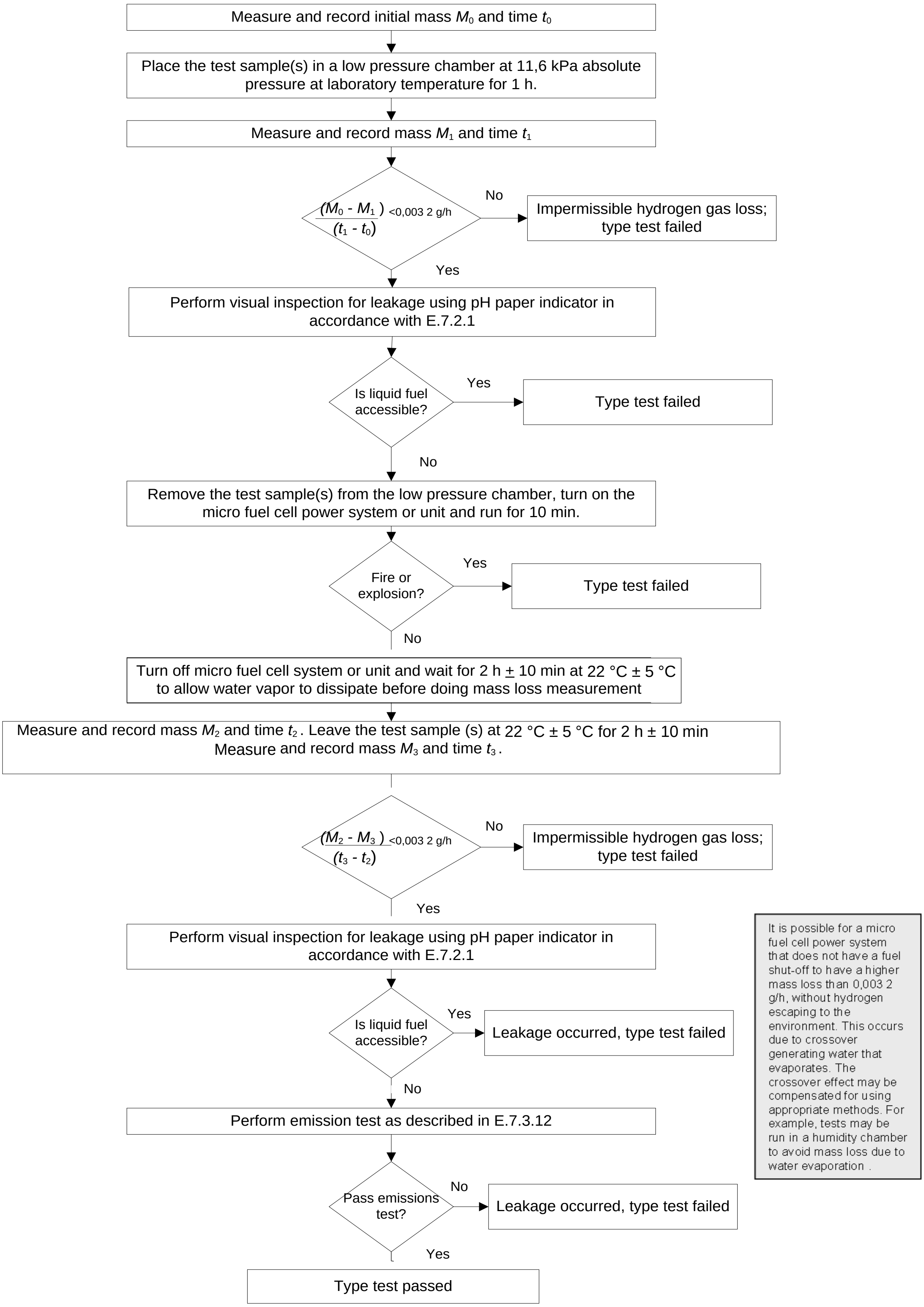


Figure E.7 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7

E.7.3 Type tests

E.7.3.1 Pressure differential tests

E.7.3.1.1 General

Subclause E.7.3.1 replaces Subclause 7.3.1.

Portions of this test check compliance with Subclause E.4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Depending upon which of the two limiting pressure conditions is greater, two options for testing are provided:

a) If 95 kPa internal gauge pressure plus normal working pressure of the fuel cartridge at 22 °C is greater than two times the gauge pressure of the fuel cartridge at 55 °C, either Subclause E.7.3.1.2 or Subclause E.7.3.1.3 may be used to verify compliance with Subclause E.4.12.1.2.

b) If two times the gauge pressure of the fuel cartridge at 55 °C is greater than 95 kPa internal gauge pressure plus normal working pressure at 22 °C, Subclause E.7.3.1.2 must be used to verify compliance with Subclause E.4.12.1.2.

E.7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

   1) Using a suitable fluid medium pressurize the fuel cartridge body to an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. The pressure rise shall not exceed a rate of 60 kPa/s.

   2) Maintain the maximum pressure for 30 min at laboratory temperature.

   3) Using a suitable fluid medium pressurize the closed fuel cartridge valve to 95 kPa gauge pressure plus the normal working pressure of the cartridge at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. The pressure rise shall not exceed a rate of 60 kPa/s.

   4) Maintain the maximum pressure for 30 min at laboratory temperature.

d) **Passing criteria:** no accessible liquid test medium leakage and no sudden drop of pressure during the course of the test. Leakage shall be checked visually. Invert the fuel cartridge and the fuel cartridge valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails.

NOTE Class 8 (corrosive) borohydride fuel will chemically react with water, therefore, water or water-containing substances should not be used as the fluid test medium. Class 8 (corrosive) borohydride fuels have the potential to react with substances other than water, therefore, the chemical reactivity and stability of the particular Class 8 (corrosive) borohydride fuel being tested should be used to guide the selection of a suitable liquid test medium.

E.7.3.1.3 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure E.16.

2) Record the initial mass of the test sample M_0 and starting time t_0. Place the sample in a vacuum chamber and reduce the pressure in the vacuum chamber to 95 kPa below normal atmospheric pressure.

3) Maintain the vacuum for 30 min.

4) Remove the sample from the vacuum chamber and record the final mass M_1 and time t_1. Determine hydrogen gas loss and check for leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel components using visual inspection with pH indicator as described in Subclause E.7.2.1.

5) ~~Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator as described in Subclause E.7.2.1. See Figure E.16.~~ Check for hydrogen leakage as described in E.7.2.2. See Figure E.16.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 for the fuel cartridge and the micro fuel cell power system or unit. Hydrogen gas loss shall meet the requirements of Subclause E.7.2.3 (less than 0,0032 g/h) for the fuel cartridge and micro fuel cell power system or unit. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 ~~after the fuel cartridge is installed in a micro fuel cell power system or unit and operated~~.

E.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

E.7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex E.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

1) Perform this test in accordance with Figure E.6.

2) Test samples shall be stored at a low external pressure of 68 kPa absolute pressure for 6 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure E.6.

3) For the micro fuel cell power system or unit, perform hydrogen gas loss measurements in accordance with E.7.2.3 (including emission testing in accordance with E.7.3.12). See B.7.3.1.3 for alternative methods to measure and calculate impermissible hydrogen gas loss during step 2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in

Subclause E.7.2.1. Hydrogen gas loss shall be determined by the mass loss measurement as shown in Figure E.6. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable.

E.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex E.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figures E.7.

   2) Test samples shall be stored at a low external pressure of 11,6 kPa absolute pressure for 1 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure E.7.

   3) For the micro fuel cell power system or unit, perform hydrogen gas loss measurements in accordance with E.7.2.3 (including emission testing in accordance with E.7.3.12). See B.7.3.1.4 for alternative methods to measure and calculate impermissible hydrogen gas loss during step 2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen gas loss shall be determined by the mass loss measurement as shown in Figure E.7. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable.

E.7.3.2 Vibration test

Subclause E.7.3.2 replaces Subclause 7.3.2 for micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in E.7.3.1 or a micro fuel cell power system used in used in E.7.3.1.

b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure E.2 for the fuel cartridge and Figure E.4 for the micro fuel cell power system or unit.

   2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

   3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

   4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) ~~For the micro fuel cell power system or unit, perform emission testing in accordance with E.7.3.12.~~ Perform the following leakage tests:

   i) For the fuel cartridge, perform leakage tests in accordance with E.7.2.1, hydrogen leakage measurements in accordance with E.7.2.2. See Figure E.2.

   ii) For the micro fuel cell power system or unit, perform visual inspection for leakage using pH paper in accordance with E.7.2.1a, and then perform hydrogen gas loss testing in accordance with E.7.2.3 (including emission testing in accordance with E.7.3.12). See Figure E.4.

   iii) If the micro fuel cell power system or unit contains a fuel cartridge perform hydrogen leakage measurements in accordance with E.7.2.2.

   iv) If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, hydrogen leakage shall be checked following E.7.3.3, in accordance with E.7.3.3 c) 9(iii).

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 for the fuel cartridge and the micro fuel cell power system or unit. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge and micro fuel cell power system or unit. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable.

E.7.3.3 Temperature cycling test

Subclause E.7.3.3 replaces Subclause 7.3.3 for micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

a) **Test sample:** a fuel cartridge used in E.7.3.2, a used fuel cartridge used in E.7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in E.7.3.2 or a micro fuel cell power system used in E.7.3.2.

b) **Purpose:** to simulate the effects of low-temperature and high temperature exposure and the effects of extreme temperature change and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure E.3 for the fuel cartridge and Figure E.4 for the micro fuel cell power system or unit.

   2) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

   3) See Figure E.8 for the temperature profile to be used.

4) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

5) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

6) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

7) The above process is to be done twice.

8) After 1 h at 22 °C ± 5 °C, leakage shall be measured based upon the procedure described in Figure E.3 for fuel cartridge and Figure E.4 for micro fuel cell power system or unit.

9) ~~For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with E.7.3.12.~~ Perform the following leakage tests:

   i) For the fuel cartridge, perform leakage tests in accordance with E.7.2.1, hydrogen leakage measurements in accordance with E.7.2.2. See Figure E.3.

   ii) For the micro fuel cell power system or unit, perform visual inspection for leakage using pH paper in accordance with E.7.2.1a, and then perform hydrogen gas loss testing in accordance with E.7.2.3 (including emission testing in accordance with E.7.3.12). See Figure E.4.

   iii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with E.7.2.2.

~~10) For the fuel cartridge, connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator as described in Subclause E.7.2.1.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1 for the fuel cartridge and the micro fuel cell power system or unit. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge and the micro fuel cell power system or unit. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable.

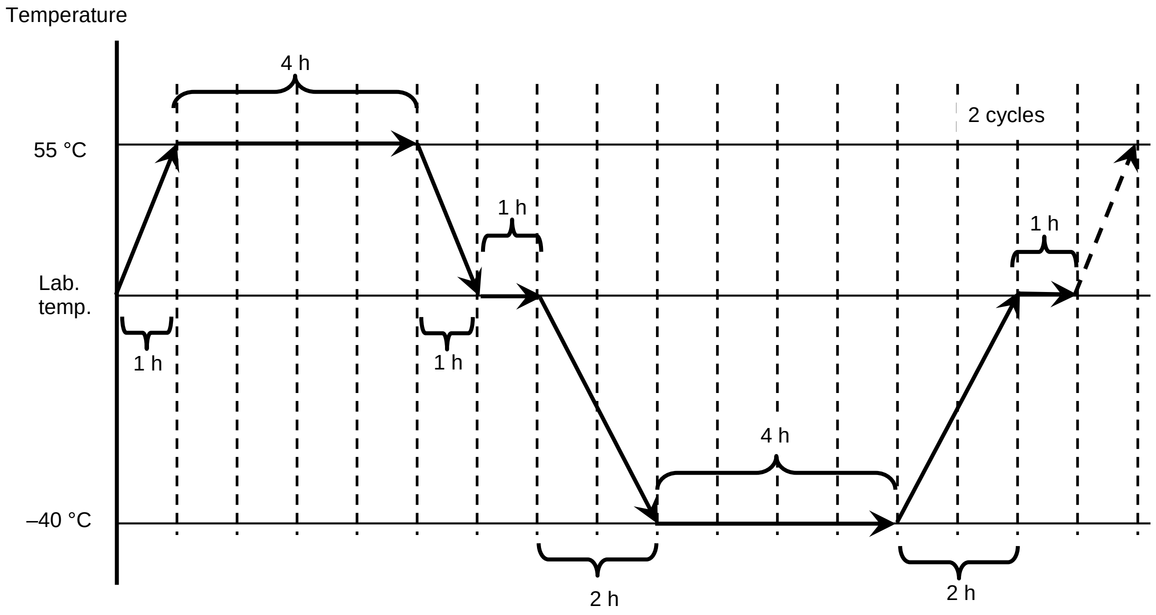


Figure E.8 – Temperature cycling – Replaces Figure 8

E.7.3.4 High temperature exposure test

Subclause E.7.3.4 replaces Subclause 7.3.4 for fuel cartridges covered by this Annex E.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure E.3 for the fuel cartridge.

2) Two orientations shall be tested – valve up and valve down.

3) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

4) Remove the test sample to laboratory temperature. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator test as described in Subclause E.7.2.1. See Figure E.3.

~~5) Connect the fuel cartridge to a micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator test as described in Subclause E.7.2.1. See Figure E.3.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in~~

~~Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually~~ to verify that there is no disturbance to the micro fuel cell power system/unit~~.

E.7.3.5 Drop test

Subclause E.7.3.5 replaces Subclause 7.3.5 for micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure E.2 for the fuel cartridge and Figure E.4 for the micro fuel cell power system or unit.

   2) The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

   3) The height of the drop shall be:

      i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system.

      ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge of more than 200 ml.

      iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge of up to 200 g of solid fuel or up to 200 ml of liquid fuel component.

   4) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

   5) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or unit may be used for all four drop orientations, or more than one micro fuel cell power system or unit may be used in subsequent drops, at the discretion of the manufacturer.

   6) For all tests, drop orientations shall be:

      i) valve up;

      ii) valve down;

      iii) two other mutually perpendicular orientations.

   7) ~~For the fuel cartridge, check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator test as described in Subclause E.7.2.1.~~ Perform the following leakage tests:

      i) For the fuel cartridge, perform leakage tests in accordance with E.7.2.1, hydrogen leakage measurements in accordance with E.7.2.2. See Figure E.2.

      ii) For the micro fuel cell power system or unit, perform visual inspection for leakage using pH paper in accordance with E.7.2.1a, and then perform hydrogen gas loss testing in accordance with E.7.2.3 (including emission testing in accordance with E.7.3.12). See Figure E.4.

      iii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with E.7.2.2.

8) ~~Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator as described in Subclause E.7.2.1. See Figure E.2.~~

9) ~~For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with E.7.3.12.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed)~~ of ~~the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable. If the micro fuel cell power system or unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

E.7.3.6 Compressive loading test

Subclause E.7.3.6 replaces Subclause 7.3.6 for micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

E.7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

1) Perform these tests in accordance with Figure E.4 for the micro fuel cell power system or unit.

2) The micro fuel cell power system or unit test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

3) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

4) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

5) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

6) ~~Perform emission testing in accordance with E.7.3.12 following the compressive loading test.~~ Perform the following leakage tests:

   i) Perform visual inspection for leakage using pH paper in accordance with E.7.2.1a, and then perform hydrogen gas loss testing in accordance with E.7.2.3 (including emission testing in accordance with E.7.3.12). See Figure E.4.

ii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with E.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator ~~as~~ specified in the leakage measurement and test procedure in Subclause E.7.2.1, including after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 ~~for the fuel cartridge~~, including after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable.

E.7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure E.2 for the fuel cartridge.

2) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

3) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

4) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

5) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator as described in Subclause E.7.2.1. See Figure E.2.

~~6) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause E.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator as described in Subclause E.7.2.1. See Figure E.2.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in

Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

E.7.3.7 External short-circuit test

Subclause E.7.3.7 replaces Subclause 7.3.7 for micro fuel cell power systems and units covered by this Annex E.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure E.5 for the micro fuel cell power system or unit.

   2) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

   3) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

   4) Following the short-circuit test, evaluate performance and perform leakage and emissions testing in accordance with Figure E.5.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

   Exterior surfaces shall not exceed the temperatures shown in Table 2 during or after short circuit testing. Emissions shall meet the passing criteria in E.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of E.7.3.12, the emission test is acceptable.

NOTE The external short circuit test can be done sequentially with the surface component and exhaust gas temperature test using the same sample.

E.7.3.9 Long-term storage test

Subclause E.7.3.9 replaces Subclause 7.3.9 for fuel cartridges covered by this Annex E.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure E.9 for fuel cartridges.

2) Record initial mass M_0 and time t_0 and place sample in temperature chamber at 50 °C ± 2 °C with a chamber relative humidity of at least 60 %.

3) The temperature chamber shall be equipped with ventilation and measurement instruments capable of accurately measuring the concentration of hydrogen in the chamber similar to the configuration in Figure E.10.

4) The ventilation flow rate and the hydrogen concentration of interest in the chamber shall be monitored continuously and recorded. See Table E.7. At no time during the test shall the hydrogen concentration in the chamber shall exceed 25 % LFL.

5) The sample shall remain in the chamber at 50 °C ± 2 °C with a chamber relative humidity of at least 60 % for at least 28 days.

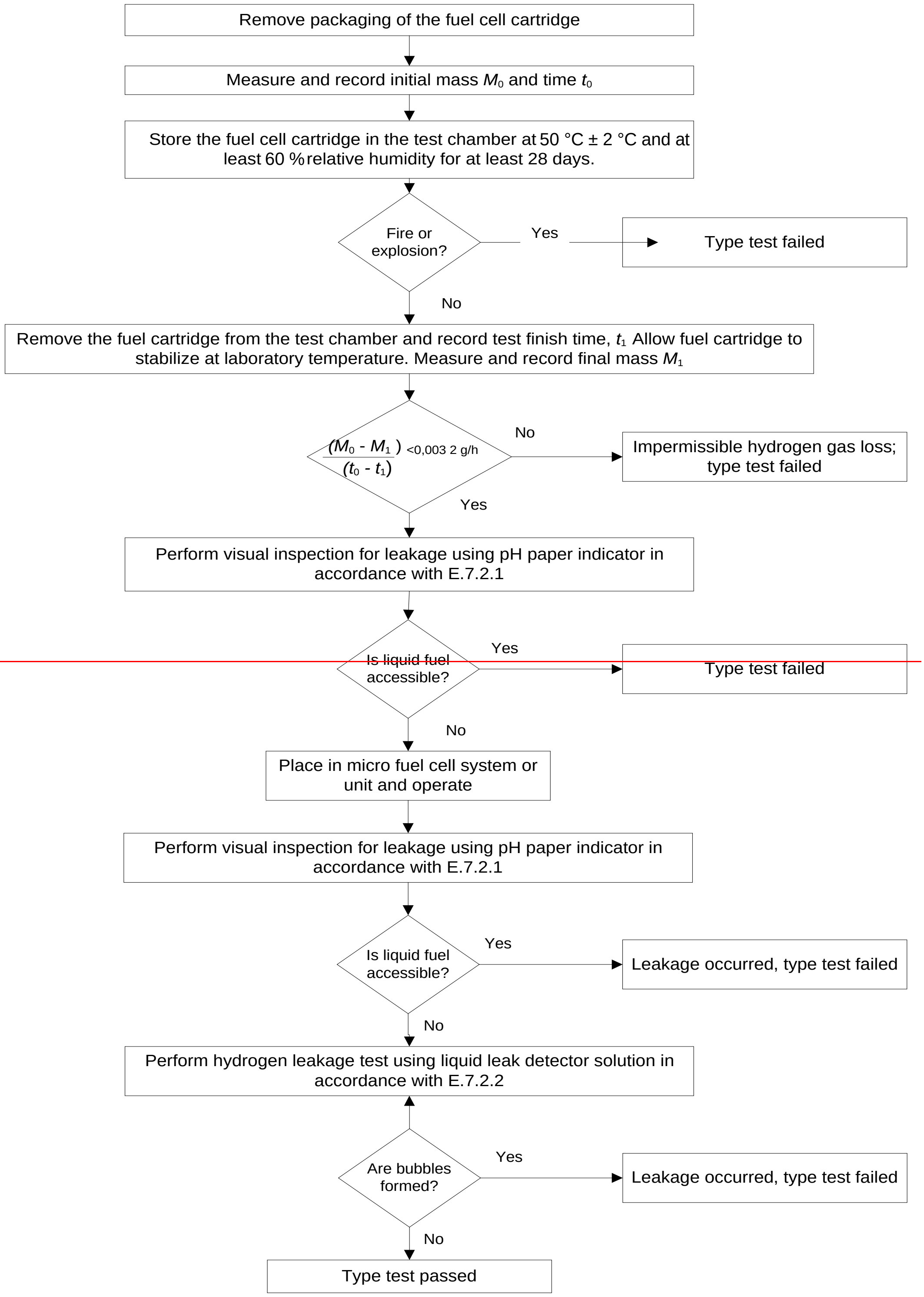
6) At the end of the 28 days, remove the fuel cartridge from the test chamber and record the time the fuel cartridge was removed from the test chamber, t_1. Allow the fuel cartridge to stabilize at laboratory temperature and record the final mass, M_1. Hydrogen gas loss is calculated as follows and shall not exceed 0,0032 g/h:

$$\frac{M_0 - M_1}{t_1 - t_0} < 0{,}0032 \text{ g/h}$$

7) ~~Perform fuel, fuel byproduct, electrolyte and liquid fuel component leakage testing in accordance with Subclause E.7.2.1 for the fuel cartridge. Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for fuel, fuel byproduct, electrolyte, or liquid fuel component leakage using visual inspection with pH indicator test as described in E.7.2.1. See Figure E.9.~~ Perform leakage tests in accordance with E.7.2.1 and hydrogen leakage measurements in accordance with E.7.2.2. See Figure E.9.

8) See B.7.3.9 for alternative methods to measure and calculate impermissible hydrogen gas loss.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen gas loss shall meet the requirements of Subclause E.7.2.3 (less than 0,0032 g/h). The hydrogen concentration in the temperature test chamber shall not exceed 25 % LFL at any time during the test. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 ~~after the fuel cartridge is installed in a micro fuel cell power system or unit and operated~~. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.


Remove packaging of the fuel cell cartridge
Measure and record initial mass M_0 and time t_0
Store the fuel cell cartridge in the test chamber at 50 °C ± 2 °C and at least 60 % relative humidity for at least 28 days.
Fire or explosion?
Yes
Type test failed
No
Remove the fuel cartridge from the test chamber and record test finish time, t_1 Allow fuel cartridge to stabilize at laboratory temperature. Measure and record final mass M_1
$\frac{(M_0 - M_1)}{(t_0 - t_1)}$ <0,003 2 g/h
No
Impermissible hydrogen gas loss; type test failed
Yes
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Type test failed
No
Place in micro fuel cell system or unit and operate
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Type test passed

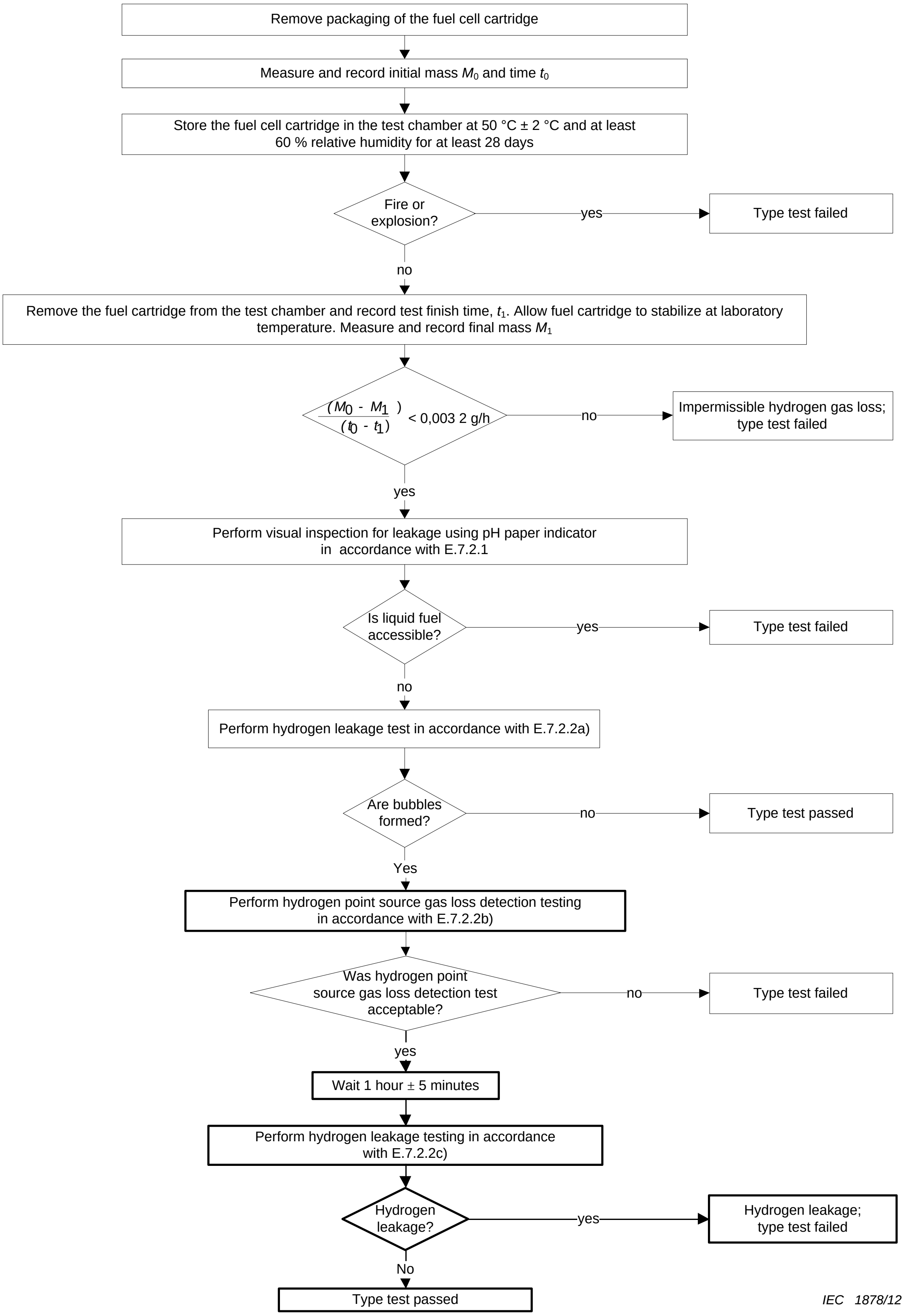


Figure E.9 – Fuel cartridge hydrogen leakage and mass loss test flowchart for long-term storage test – Replaces Figure 9

E.7.3.10 High-temperature connection test

Subclause E.7.3.10 replaces Subclause 7.3.10 for micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure E.2 for fuel cartridges.

   2) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.

   3) The micro fuel cell power unit or test fixture with micro fuel cell power unit valve is kept at laboratory temperature.

   4) Remove the test sample from the chamber and connect the fuel cartridge to the micro fuel cell power unit or test fixture with micro fuel cell power unit valve within 5 min of removal from the chamber.

   5) Check for leakage upon connection and disconnection the fuel cartridge and the micro fuel cell power system or micro fuel cell power unit and perform leakage and hydrogen leakage measurement in accordance with E.7.2.1 and E.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge. ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods.

E.7.3.11 Connection cycling tests

Subclause E.7.3.11 replaces Subclause 7.3.11 for micro fuel cell power systems, units and fuel cartridges covered by this Annex E.

E.7.3.11.1 Fuel cartridge

E.7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused or a used insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as in the leakage test and measurement procedure specified in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in E.7.2.1.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as in specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage specified in the leakage test and measurement procedure specified in Subclause E.7.2.1.

5) Repeat this twice more for a total of three connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in E.7.2.1.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure specified in Subclause E.7.2.1. Hydrogen leakage shall meet the criteria for no hydrogen leakage specified in the leakage test and measurement procedure in Subclause E.7.2.1. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as described in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage as specified in the leakage test and measurement procedure in Subclause E.7.2.1.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure in Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the leakage test and measurement procedure in Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria

for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure in Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

~~14) Connect the fuel cartridge to the micro fuel cell power system or micro fuel cell power unit and perform emission testing in accordance with E.7.3.12 following the connection cycling test.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge; for clarification, it is acceptable to perform the (second) hydrogen leakage test in accordance with E.7.2.2c once, following all 10 connection-disconnection cycles (in step 13), rather than repeat at each connection-disconnection step (e.g. steps 1, 4, 6, 8, 10).~~ Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods.~~ Hydrogen gas loss shall meet the requirements of Subclause E.7.2.3. Emissions must meet passing criteria of E.7.3.12 for operational and non-operating systems.~~

E.7.3.11.1.2 Satellite cartridge

a) **Test sample:** an unused satellite fuel cartridge and an unused micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproduct, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts,

electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1. Initiate or simulate fuel flow.

2) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

3) Repeat this twice more for a total of three connections and disconnections.

4) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

5) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

7) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

9) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and initiate or simulate fuel flow.

10) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and

measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

11) Repeat steps 1 through 10 four more times for a total of 55 cycles, waiting 1 h between each set of 11 cycles.

~~12) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and perform emissions testing as specified in Subclause E.7.3.12 following the cycling test.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 for the fuel cartridge; for clarification, it is acceptable to perform the (second) hydrogen leakage test in accordance with E.7.2.2c after each set of 10 connection-disconnection cycles (in step 10), rather than repeat at each disconnection step (e.g. steps 1, 2, 4, 6, 8). ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. ~~Emissions must meet passing criteria of E.7.3.12 for operational and non-operating systems.~~

E.7.3.11.2 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

1) Connect the first fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and the fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts,

electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

5) Repeat this twice more for a total of three connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

7) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

9) Connect and disconnect the first fuel cartridge three more times for a total of ten connections and disconnections.

10) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

11) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak

detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system the internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

12) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

13) Turn off the micro fuel cell power unit or stop simulated fuel flow.

14) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

15) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.

    i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections.

    ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.

    iii) Inversion of the micro fuel cell power unit or the fuel cartridges is not necessary, but, if leakage is found, the test fails.

    iv) Following this ageing, a final unused fuel cartridge will be tested.

16) Connect the final unused fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and the fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

17) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

18) Turn off the micro fuel cell power unit or stop simulated fuel flow.

19) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive)

borohydride and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

20) Repeat this twice more for a total of three connections and disconnections.

21) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

22) Connect and disconnect the final fuel cartridge four more times for a total of seven connections and disconnections.

23) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

24) Connect and disconnect the final fuel cartridge three more times for a total of ten connections and disconnections.

25) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

26) Connect the fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

27) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

28) Turn off the micro fuel cell power unit or stop simulated fuel flow.

29) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause E.7.2.2 for the fuel cartridge and fuel management system internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause E.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause E.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause E.7.2.1.

30) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and perform hydrogen gas loss testing in accordance with E.7.2.3 (including emissions testing ~~as specified in Subclause~~ in accordance with E.7.3.12) ~~following the cycling test~~. If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with E.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator as specified in the leakage measurement and test procedure in Subclause E.7.2.1, including after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause E.7.2.2 ~~for the fuel cartridge~~, including after the fuel cartridge is installed in a micro fuel cell power system or unit and operated; for clarification, it is acceptable to perform the (second) hydrogen leakage test in accordance with E.7.2.2c after each set of 10 connection-disconnection cycles (in step 14 and step 29), rather than repeat at each connection-disconnection step (e.g. steps 1, 4, 6, 8, 10, 11, 16, 19, 21, 23, 25, and 26). ~~Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator specified in the leakage measurement and test procedure in Subclause E.7.2.1 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause E.7.2.2 after the fuel cartridge is installed in a micro fuel cell power system or unit and operated.~~ Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Emissions must meet passing criteria of E.7.3.12 for operational and non-operating systems.

E.7.3.12 Emission test

This Subclause E.7.3.12 shall replace Subclause 7.3.12 for Class 8 (corrosive) borohydride micro fuel cell power systems or units tested in accordance with Annex E. The included Table E.7, Emission limits, replaces Table 7 in Subclause 7.3.12. Figure E.10 replaces Figure 10 and is identical to Figure 10. Hydrogen emissions are evaluated separately. The procedure for hydrogen emission testing is detailed in Figure E.12, which is to be used as an additional figure when testing is done in accordance with Annex E.

a) **Test sample:** A micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under normal operating conditions, indirect borohydride powered micro fuel cell power system may have emissions. The emissions may be comprised of water or hydrogen, both of which are known not to be toxic. Indirect borohydride micro fuel cell power systems do not normally emit CO, CO_2, formaldehyde or other volatile organic compounds. However, there is a remote possibility that indirect borohydride micro fuel cell power systems utilizing fuels or liquid fuel components containing organic additives may emit CO, CO_2, formaldehyde or other volatile organic compounds under abnormal circumstances. Because this possibility exists, emission limits for CO, CO_2, formaldehyde and volatile organic compounds for micro fuel cell power systems utilizing fuels or liquid fuel components containing organic compounds are imposed by this annex and are listed in Table E.7.

The possibility for hydrogen emissions exists for non-operating indirect borohydride micro fuel sell power systems. Hydrogen emissions testing shall therefore be performed with the micro fuel cell power system off ("DEVICE – OFF") as an additional test. Hydrogen emissions shall be below the allowable 0,0032 g/h with the "DEVICE – OFF" limit given to avoid harmful exposures.

Micro fuel cell power systems emit water vapour and under certain conditions this water vapour can condense. This condensation is not considered an emission or a leak if the pH of the condensate is between 3,5 pH and 10,5 pH.

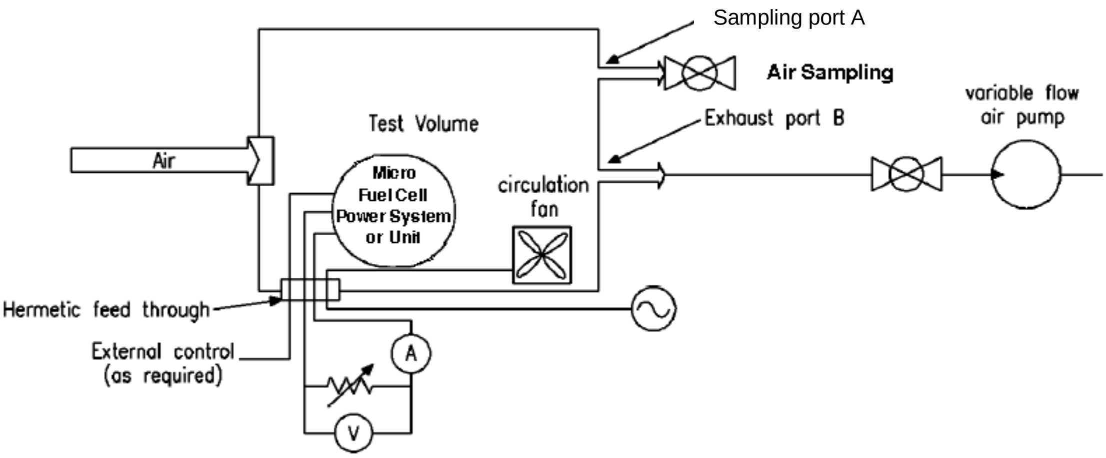


Figure E.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the operational emission test apparatus is shown in Figure E.10. The configuration shown in Figure E.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex E. Emission rate testing in accordance with E.7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex E.

To analyse the hydrogen emissions, a mass spectrometer, gas chromatograph, or other suitable instrument calibrated to measure hydrogen concentration shall be used and connected to sampling port A in Figure E.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer's mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.), additional testing in accordance with E.7.3.12 d) 3) and E.7.3.12 d) 4) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure E.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer's mouth or nose when in use) for emissions concentration limit testing.

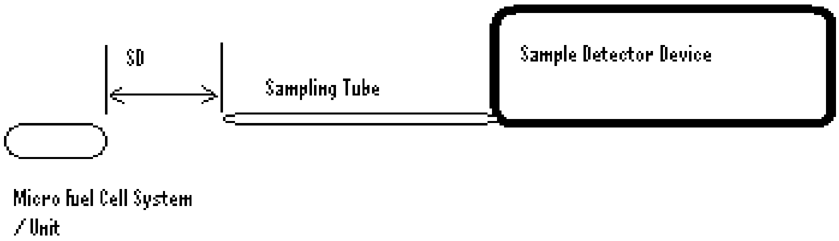


Figure E.11 – Operational emission concentration testing apparatus – Replaces Figure 11

Emission gases might be composed of toxic organic materials such as carbon dioxide, carbon monoxide and formaldehyde, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS) shall be used by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure E.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

The concentration of CO and CO_2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure E.12, which is to be used as an additional figure when testing is done in accordance with Annex E.*

Emission rate sampling tests shall be performed with the micro fuel cell power system or unit on ("DEVICE – ON") follows.

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed with the micro fuel cell power system or unit on ("DEVICE – ON") as follows.

   i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure E.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

   ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

   iii) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure E.10.

   iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure E.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the concentrations of chemical compounds of interest. See Table E.7.

vii) Calculate the emission rate of chemical compounds being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in litres per hour;

F_{S} is the sample flow rate in litres per hour;

C is the concentration in grams per litre.

viii) Compare the maximum measured "DEVICE – ON" emission rate to Table E.7. If the emission rate is not less than the emission rate limit in Table E.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria E.7.3.12 e) 1) i) and E.7.3.12 e) 2) i).

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer’s mouth or nose, the following additional emissions concentration sampling test shall be performed with the micro fuel cell power system or unit on "DEVICE – ON" as follows.

i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power in the large open room while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure E.11. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission concentration test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “ON” position ("DEVICE – ON").

iii) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

iv) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure E.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer's mouth or nose when in use).

v) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

vi) Allow the sample flow rate to stabilise.

vii) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

viii) Record the concentrations of the chemical compounds of interest. See Table E.7.

ix) Compare the maximum measured concentrations to Table E.7. If the emission concentrations are not less than the emission concentration limits in Table E.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria E.7.3.12 e) 2) ii).

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

3) Upon completion of the emissions measurements with both "DEVICE – ON" in accordance with Table E.7, "DEVICE – ON" hydrogen emissions are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure E.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the "on" position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure E.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure E.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the hydrogen concentration.

vii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_\mathrm{P} + F_\mathrm{S}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in litres per hour;

F_S is the sample flow rate in litres per hour;

C is the concentration in grams per litre.

viii) Compare the maximum measured "DEVICE – ON" hydrogen emission rate to Table E.7.

NOTE This is a stabilised concentration measurement.

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

4) Upon completion of the hydrogen emissions measurements with "DEVICE – ON", hydrogen emissions with ("DEVICE – OFF") are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure E.10 for 10 min or until 10 % of the fuel capacity of a full fuel cartridge is used up, whichever is less.

ii) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") and measure the emission rates with the micro fuel cell power system or unit off ("DEVICE – OFF") inside the small test chamber shown in Figure E.10.

iii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iv) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown on Figure E.10.

v) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

vi) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure E.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vii) Record the hydrogen concentration.

viii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_P + F_S) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in litres per hour;

F_S is the sample flow rate in litres per hour;

C is the concentration in grams per litre.

ix) Compare the maximum measured "DEVICE – OFF" hydrogen emission rate to Table E.7.

NOTE This is a stabilised concentration measurement.

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

5) Evaluate the hydrogen emission rate as follows.

i) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and below the allowable 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or unit passes the test and no further testing is necessary.

ii) If the hydrogen emission rate measurement is not below the allowable 0,0032 g/h with the "DEVICE – OFF" and not below the total allowable 0,8 g/h with the "DEVICE – ON", the system or unit fails the test and no further testing is necessary.

iii) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and is below the total allowable 0,8 g/h with the "DEVICE – ON" but is not below 0,016 g/h with the "DEVICE – ON", then proceed with E.7.3.13, hydrogen point source gas loss detection test to verify that no single source of hydrogen exceeds 0,016 g/h.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table E.7 shall be less than the emission rate limit value in Table E.7 when tested in accordance with E.7.3.12 d) 1) for "DEVICE – ON" and E.7.3.12 d) 2) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table E.7 shall be less than the emission rate limit value in Table E.7 when tested in accordance with E.7.3.12 d) 1) for "DEVICE – ON" and E.7.3.12 d) 2) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer's mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall not exceed the emission concentration limit in Table E.7 when tested in accordance with E.7.3.12 d) 3) "DEVICE – ON" and E.7.3.12 d) 4) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

3) Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure E.12, which is to be used as an additional figure when testing is done in accordance with Annex E.* Upon completion of the hydrogen emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table E.7, hydrogen emissions are evaluated as follows.

i) **Passing criteria for non-operating systems:** The hydrogen emission rate shall be less than 0,0032 g/h with the "DEVICE – OFF".

ii) **Passing criteria for operational systems:** If the total hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or micro fuel cell power unit passes the emission test and no further testing is required. If the total hydrogen emission rate is not less than 0,8 g/h with the “DEVICE – ON”, the micro fuel cell power system or unit fails the emission test and no further testing is required. If the Hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", E.7.3.13, hydrogen point source gas loss detection test must be performed with acceptable results to show no more than 0,016 g/h hydrogen leakage from any single point leak.

NOTE 1 The allowable flammable hydrogen emission level that will not support a standing flame is 3 ml/min (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, *Codes and Standards Analysis*, 2001 *(USA)*). The non-flammable hydrogen emissions limit is based on the criteria that hydrogen emission does not build up to more than 25 % of LFL in the reference volume.

NOTE 2 Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

NOTE 3 Carbon dioxide and carbon monoxide vapour emission level limits are based on toxicity effects on humans while the hydrogen emissions level limit is based on the risk of creating a flammable atmosphere in confined spaces and the risk of a potential standing hydrogen flame.

Table E.7 – Emission limits – Replaces Table 7

Emissions	**"DEVICE – ON"** **Concentration limit** [a] based on TWA values for "DEVICE – ON" test condition	**"DEVICE – ON"** **Permissible emissions rate in 10 m^3 ACH volume** [b]	**Impermissible gas loss**[c] **(including "DEVICE – OFF")**
Water	Unlimited for pH between 3,5 and 10,5	Unlimited for pH between 3,5 and 10,5	Unlimited for pH between 3,5 and 10,5
Hydrogen	0,8 g/m^3	0,8 g/h total 0,016 g/h from single point leak[f]	0,003 2 g/h total
Formaldehyde[d]	0,000 1 g/m^3	0,000 6 g/h	0,000 6 g/h
CO	0,029 g/m^3	0,290 g/h	0,290 g/h
CO_2	9 g/m^3	60 g/h[~~c~~e]	60 g/h[e]
Volatile organic carbon compounds[e]	0,000 1 g/m^3	0,000 6 g/h	0,000 6 g/h

~~Table E.7 replaces Table 7.~~

a The concentration limits for CO and CO_2 in this table are the mg/m^3 equivalent of the TWA and STEL exposure limits.

b The "DEVICE – ON" emission rate limit was based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per-person volume is over 20 m^3, so a product of 10 is conservative. A further factor of safety of 10 has been added for hydrogen in this specific case.

c The “impermissible hydrogen gas loss” criteria for non-operating micro fuel cell power systems has been chosen based on a scenario of micro fuel cell power systems in an enclosed space with no ventilation. The space chosen has a volume of 0,28 m^3, or approximately 10 cubic feet. The criterion has been prescribed so that a hydrogen concentration of greater than 25 % LFL is not permitted to develop over a twenty-four hour (24 h) period, if three micro fuel cell power systems are in the enclosed space.

d WHO guideline limit is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The emission limit cannot push the background level above the guideline limit.

~~c~~e A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO 8 h concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

f The allowable flammable hydrogen emission level that will not support a standing flame is 3 standard ml/min, which is equivalent to 0,016 g/h. (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M/N. Swain, Codes and Standards Analysis, 2001 (USA)).

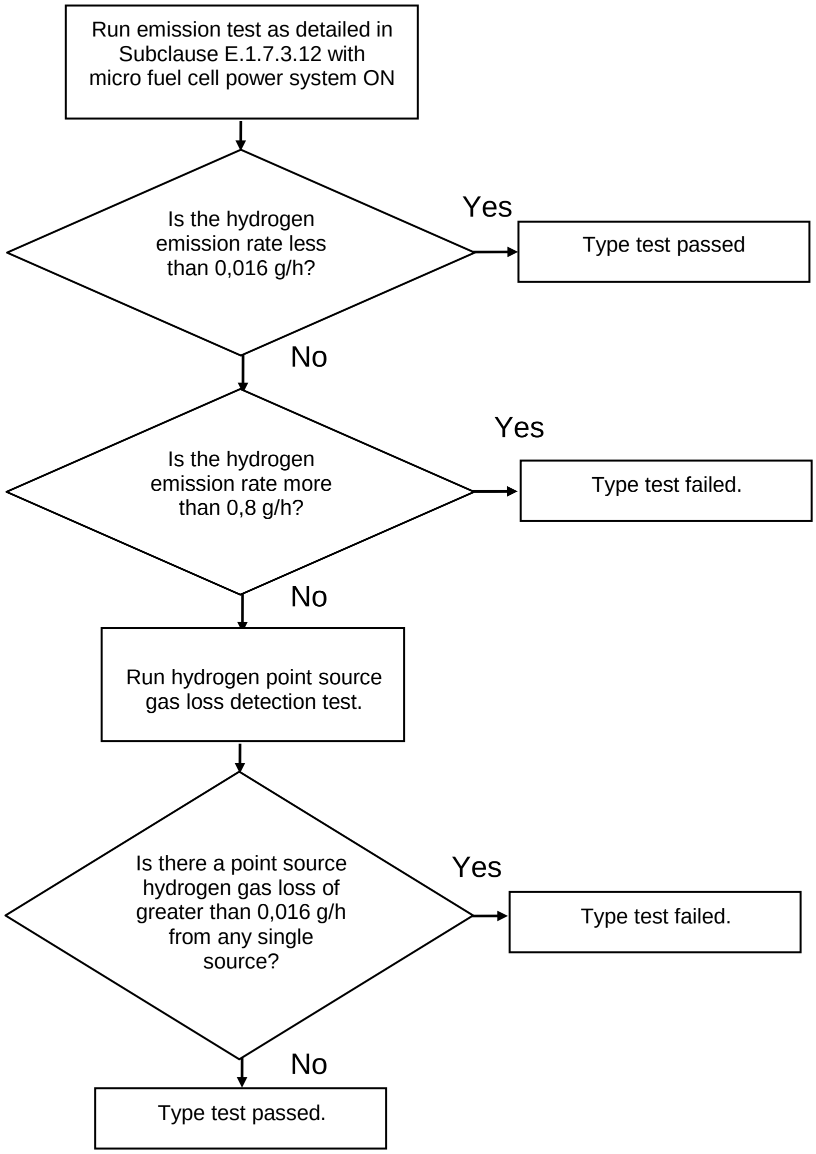
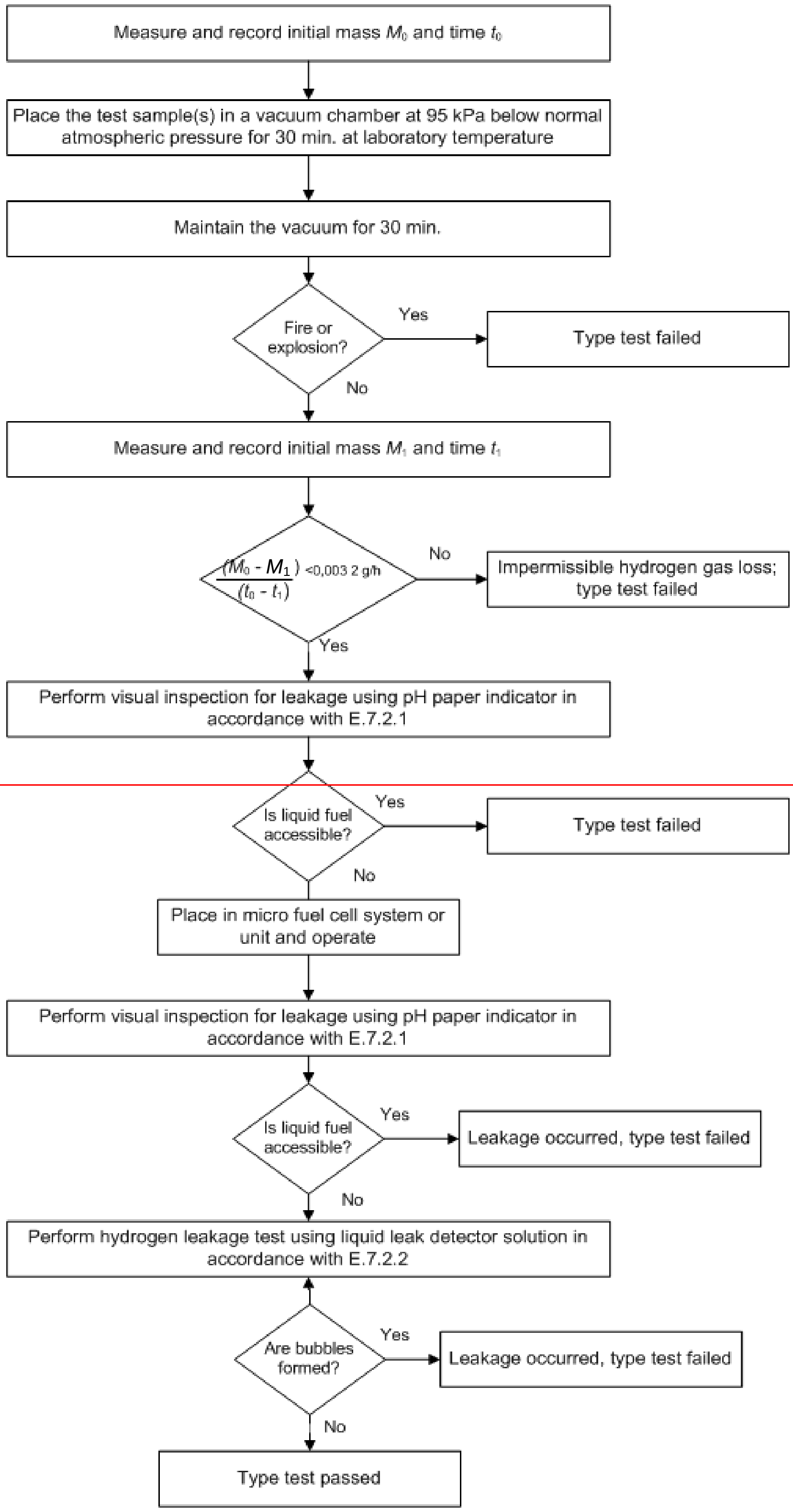


Figure E.12 – Hydrogen emission test procedure for operating micro fuel cell power system – Replaces Figure 12


Measure and record initial mass M_0 and time t_0
Place the test sample(s) in a vacuum chamber at 95 kPa below normal atmospheric pressure for 30 min. at laboratory temperature
Maintain the vacuum for 30 min.
Fire or explosion?
Yes
Type test failed
No
Measure and record initial mass M_1 and time t_1
$\frac{(M_0 - M_1)}{(t_0 - t_1)}$ <0,003 2 g/h
No
Impermissible hydrogen gas loss; type test failed
Yes
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Type test failed
No
Place in micro fuel cell system or unit and operate
Perform visual inspection for leakage using pH paper indicator in accordance with E.7.2.1
Is liquid fuel accessible?
Yes
Leakage occurred, type test failed
No
Perform hydrogen leakage test using liquid leak detector solution in accordance with E.7.2.2
Are bubbles formed?
Yes
Leakage occurred, type test failed
No
Type test passed

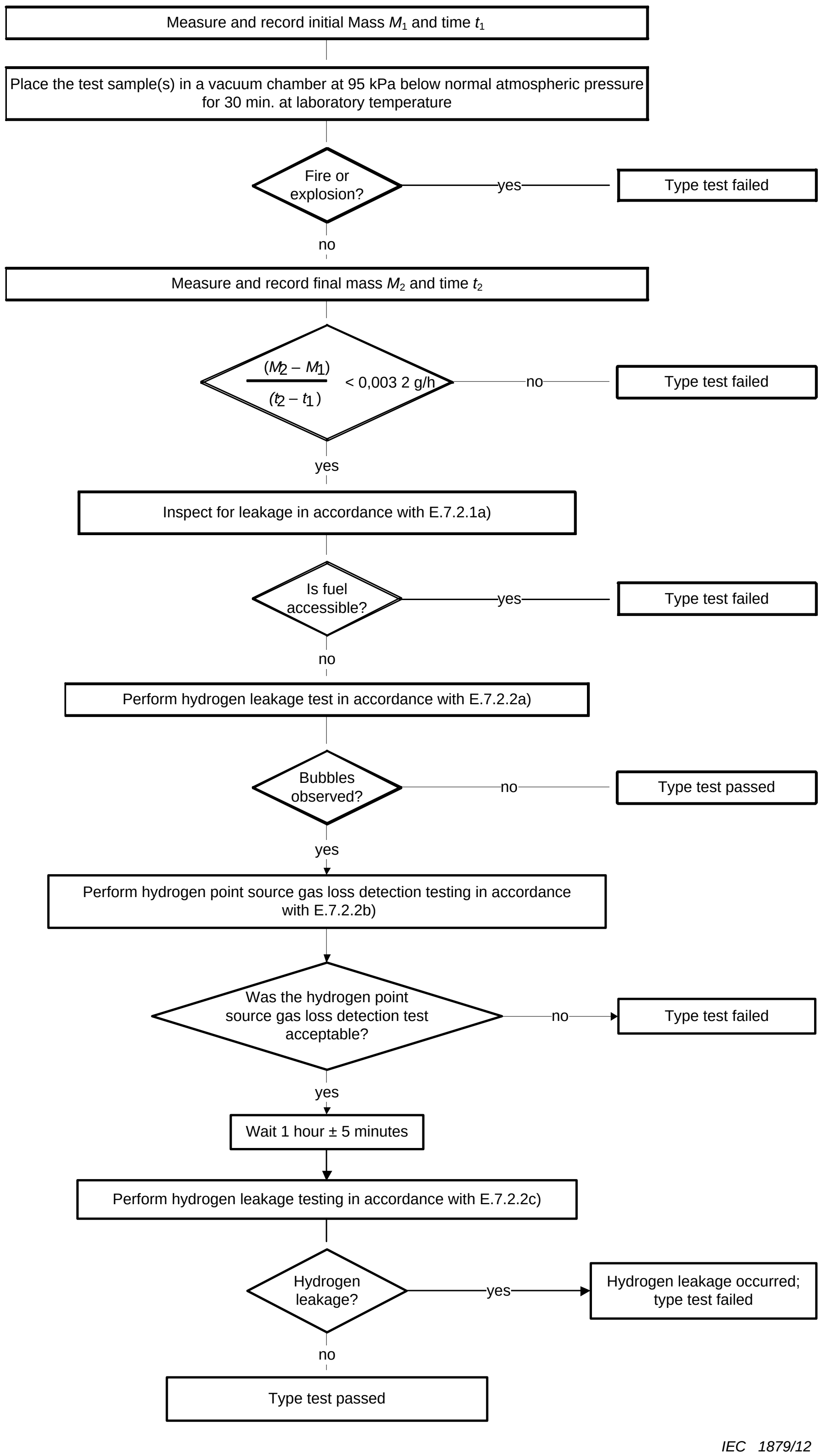


Figure E.16 – Fuel cartridge leakage test flow chart for low external pressure test

E.7.3.13 Hydrogen point source gas loss detection test

The procedure for hydrogen emission testing is detailed in Figure E.12, which is to be used as an additional figure when testing is done in accordance with Annex E. This subclause is additional to the requirements in Clause 7.

This subclause shall be used if required by Subclause E.7.3.12 d) 5) iii) to show compliance with Table F.7, for Class 8 (corrosive) borohydride micro fuel cell power systems and Class 4.3 (water reactive) borohydride micro fuel cell power units. This subclause is required to be performed to meet the passing criteria of Subclause E.7.3.12 e) 3) ii) if the total hydrogen emission rate from an operational Class 8 (corrosive) borohydride micro fuel cell power system or unit is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON".

a) **Test sample:** A micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge or a fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit within the scope of this Annex A, emission of hydrogen shall be maintained at less than the specified values in Table E.7. The hydrogen point source gas loss detection test shall be performed to determine that no single source on the micro fuel cell power system or unit can support a flame in all cases where such compliance cannot be definitively determined by the emission test. Maintaining these limits ensures that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame and ensures an adequate supply of oxygen is maintained in the operating environment

c) **Test apparatus:** The surface of the ~~micro fuel cell power system or unit~~ test sample shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, a hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL. The response of the aforementioned hydrogen detectors is commonly slow, with a response time of many seconds, thus high sweep speeds may cause underestimation of the hydrogen concentration. It is important that the sweep speed shall be slow enough to accurately measure the hydrogen concentration.

d) **Test procedure:**

   1) The micro fuel cell power system or micro fuel cell power unit shall remain turned on ("DEVICE – ON") throughout the duration of the hydrogen point source gas loss detection test.

   2) The testing shall be conducted in a space with no substantial air movement. The measured wind speed 10 cm above the ~~micro fuel cell power system or unit~~ test sample shall not exceed 0,02 m/s. The local concentration of hydrogen diffusion measured in this test is very susceptible to the effect of wind. It is desirable that wind speed anywhere in the test space is as close to zero as possible. Testing in a closed space, such as a glove box or equivalent chamber, is one available method to achieve this requirement.

   3) The surface of the ~~micro fuel cell power system or unit~~ test sample shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

   4) The sensor of the hydrogen detector shall sweep the ~~micro fuel cell power system or unit~~ test sample at a distance no more than 3 mm normal to the surface of the ~~micro fuel cell power system or unit~~ test sample. Consecutive linear sweeps shall not be more than 8 mm apart along the surface of the ~~micro fuel cell power system or unit~~

test sample. The entire surface of the ~~micro fuel cell power system or unit~~ test sample shall be swept in this manner.

5) An effective method for completing these sweeps would be to attach a stand off to the sensor that ensures that a spacing of 3 mm from the ~~micro fuel cell power system or unit~~ test sample is maintained at all times. A pen or other marking utensil attached to the stand off could be used to identify swept areas and ensure that the distance between sweeps does not exceed 8 mm.

6) The sensor should always face directly downward, and the ~~micro fuel cell power system or unit~~ test sample should be moved beneath it such that the surface directly below the sensor is always horizontal.

7) If no points are found where the hydrogen concentration is greater than 25 % LFL, the test is complete and the ~~micro fuel cell power system or unit~~ test sample shall be considered to have passed.

8) When some point source sweeps show a large region of 25 % LFL or greater in the initial linear sweeps, recording the measured concentration values will assist in determining the starting point of secondary spiral sweeps. Point sources are supposed to be where local maximum values exist in the distribution of measured concentration values.

9) If any points are detected to have a hydrogen concentration of 25 % LFL or greater, a second test shall be conducted to ensure that the emission does not exceed 0,016 g/h of pure hydrogen from any single source.

10) The second test shall be performed with the sensor height adjusted to 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample.

11) A spiral sweep shall then be made, originating from the point where the detection of 25 % LFL or greater of hydrogen occurred during the initial linear sweep. The spiral sweep shall have a spacing of 1 mm or less between sweeps, and shall spiral out to a radial distance of at least 4 mm and far enough to detect the maximum hydrogen level from the particular hydrogen source.

12) If the spiral sweep at 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the ~~micro fuel cell power system or unit~~ test sample fails the test. If the spiral sweep does not detect any hydrogen concentrations of 25 % LFL or greater, the ~~micro fuel cell power system or unit~~ test sample passes the test.

e) **Passing criteria:** No gas loss of hydrogen from any single source at greater than 0,016 g/h as indicated by sweep testing. No indications of hydrogen that is 25 % of LFL during the primary sweep testing or no indications of hydrogen that is 25 % of LFL during the secondary sweep testing at 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample. If the spiral sweep at 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the ~~micro fuel cell power system or unit~~ test sample fails the test. See Table E.7.

Annex F
(normative)

Borohydride micro fuel cell power systems: Class 4.3 (water reactive) compounds in indirect borohydride fuel cells

F.1 Scope

F.1.2 Fuels and technologies covered by this annex

Annex F covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from Class 4.3 (water reactive) borohydride compounds as fuel. These systems and units use proton exchange membrane fuel cell technologies. The designs may include fuel processing subsystems to derive hydrogen gas from the borohydride compound fuel.

Figure F.1 replaces Figure 1 and Figure F.12 is an additional figure for this annex showing micro fuel cell power system block diagrams for use with this annex.

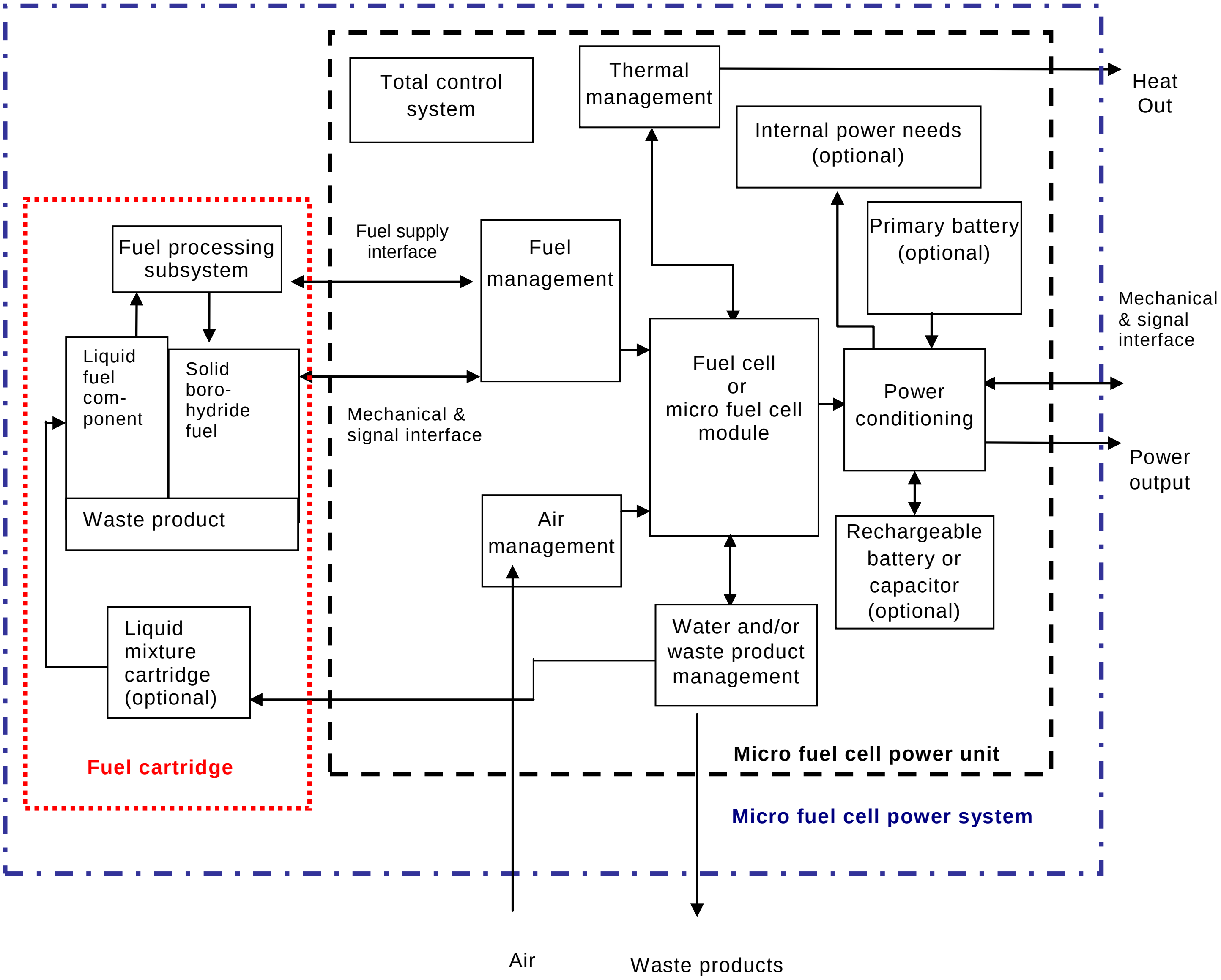


Figure F.1 – Borohydride micro fuel cell power system block diagram for Class 4.3 (water reactive) compound fuel in indirect borohydride fuel cell system; fuel management in micro fuel cell power unit – Replaces Figure 1

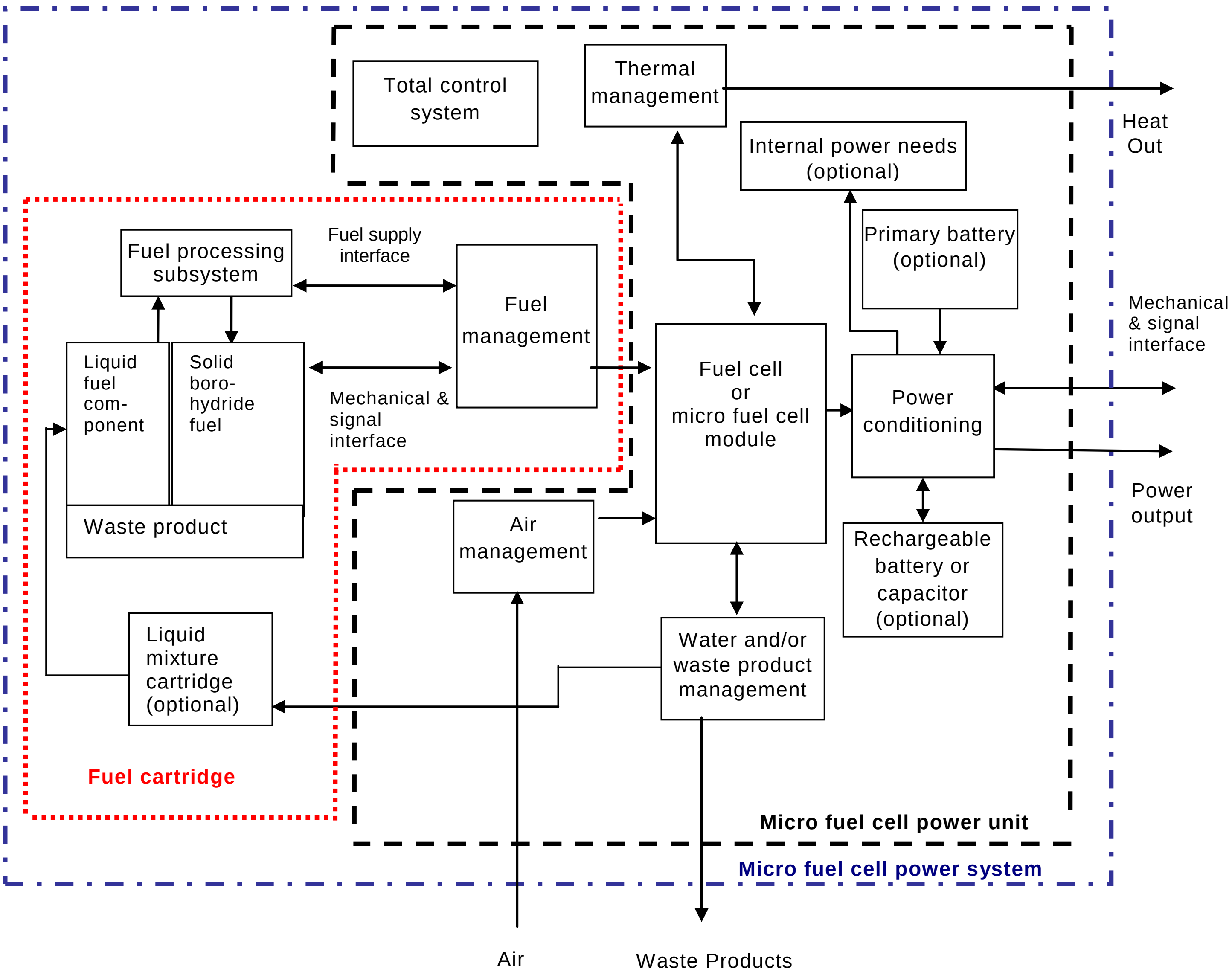


Figure F.12 – Borohydride micro fuel cell power system block diagram for Class 4.3 (water reactive) compound fuel in indirect borohydride fuel cell system; fuel management in fuel cartridge

F.2 Normative references

In addition to the normative references specified in Clause 2, the following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 16111:2008, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

F.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex F. All terms and definitions in Clause 3 not specifically mentioned here also apply.

F.3.5
fuel
Class 4.3 (water reactive) formulation of borohydride compounds used to produce electricity indirectly in a micro fuel cell power system

F.3.6
fuel cartridge
removable article that contains fuel and supplies fuel or hydrogen to the micro fuel cell power unit or internal reservoir, not to be refillable by the user

F.3.8
liquid fuel component
Class 8 (corrosive), or non-hazardous, water solutions containing acids or metal salts as activators, or alcohols as freezing point suppressors

NOTE The water solutions are used to produce hydrogen within the fuel processing subsystem.

F.3.11
leakage
accessible fuel, hazardous fuel byproducts, electrolyte or hazardous liquid fuel~~ components~~ outside the micro fuel cell power system, micro fuel cell power unit or fuel cartridge as described in F.7.2.1~~; hydrogen leakage or impermissible hydrogen gas loss~~

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex F in addition to those given in Clause F.3 and in Clause 3.

F.3.37
solid fuel, water reactive
solid formulation of borohydride compounds used as fuel for an indirect borohydride micro fuel cell power system

The formulation contains at least 70 % borohydride compound and may contain up to 30 % of a non-hazardous activator to facilitate the production of hydrogen.

F.3.38
indirect borohydride fuel cell power system
micro fuel cell power system in which a solid or liquid formulation of borohydride compounds is processed to produce hydrogen which reacts at the anode of a fuel cell to produce electricity in a micro fuel cell power system

F.3.39
borohydride compounds
sodium or potassium borohydride, or a mixture thereof

F.3.40
electrolyte
ion conducting membrane used to complete an electric circuit within a fuel cell

F.3.41
fuel byproducts
Class 8 (corrosive), or non-hazardous compounds produced after hydrogen and/or electricity is produced from fuel

F.3.42
impermissible hydrogen gas loss
hydrogen gas escaping non-operating micro fuel cell power system, ~~or~~ micro fuel cell power unit, or fuel cartridge greater than or equal 0,0032 g/h

F.3.43
accessible fuel, fuel byproducts, electrolyte or liquid fuel components
fuel, fuel byproducts, electrolyte or liquid fuel components that the consumer may come into physical contact with during normal use, reasonably foreseeable misuse, and consumer transportation; or, water reactive components within the fuel cartridge capable of releasing hydrogen if the fuel cartridge is immersed

F.3.44
fuel processing subsystem
subsystem within the micro fuel cell power unit or fuel cartridge used to produce hydrogen from formulations of borohydride compounds

F.3.45
incompatible materials
materials which are likely to cause a dangerous evolution of heat, or flammable or poisonous gas or vapours if allowed to mix in ways other than those specifically provided for by the micro fuel cell power system design

F.3.46
uncontrolled mixing
mixing of incompatible materials that occurs in ways not specifically provided for by the micro fuel cell power system design

F.3.47
Class 4.3 (water reactive)
materials which are classified as Class 4.3: Water Reactive substances under the guidelines of the 15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

F.3.48
non-hazardous
materials which are not subject to guidelines of the 15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

F.3.49
activator
a substance such as a metal salt or acid that facilitates the production of hydrogen from water-reactive borohydride fuel

F.3.50
used fuel cartridge
fuel cartridge that that has been put into operation such that at least 45 % of the initial fuel has been utilized and that the operation of the micro fuel cell power system has been halted for at least 1 h

F.3.51
hydrogen leakage
accessible hazardous hydrogen gas outside ~~fuel~~ containment system, including fuel cartridge ~~and~~, fuel management ~~components~~ and internal reservoir (see F.7.2.2)

F.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

F.4.4 Selection of materials

These requirements replace the corresponding requirements of Subclause 4.4.

These requirements of Subclause F.4.4 apply below to micro fuel cell power systems, units and fuel cartridges covered by this Annex F.

F.4.4.1 Micro fuel cell power systems and units are expected to be exposed to a number of environmental conditions over the manufacturer-defined life span of the product such as vibration, shock, varying humidity levels and corrosive environments. Materials employed in the micro fuel cell power system or unit shall be resistant to these environmental conditions. If a micro fuel cell power system or unit is to be used in service where specific environmental conditions are beyond those accounted for in the required tests of this standard, then additional testing shall be performed to verify safety under those environmental conditions.

F.4.4.2 Metallic and non-metallic materials used to construct internal or external parts of the micro fuel cell power system or unit, in particular those exposed directly or indirectly to moisture, fuel and/or byproducts in either a gas or liquid form as well as all parts and materials used to seal or interconnect the same, e.g. welding consumables, shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable under the normal transportation and normal usage conditions within the manufacturer-defined life span of the product and for all test conditions; in particular, they shall be designed to retain their mechanical stability under normal use;

- they shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation;
- the chemical and physical properties necessary for operational safety shall not be significantly affected within the manufacturer-defined life span of the product; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material’s corrosion and wear resistance, electrical conductivity, impact strength, ageing resistance, the effects of temperature variations, the effects arising when materials are put together (e.g. galvanic corrosion), and the effects of ultraviolet radiation;
- where conditions of erosion, abrasion, corrosion or other chemical attack may arise, adequate measures shall be taken to
  - minimize that effect by appropriate design, e.g. additional thickness, or by appropriate protection, e.g. use of liners, cladding materials or surface coatings, taking due account of normal use;
  - permit replacement of parts which are most affected;
  - and draw attention, in the manual referred to in Clause 6, to type and frequency of inspection and maintenance measures necessary for continued safe use; where appropriate, it shall be indicated which parts are subject to wear and the criteria for replacement.

F.4.4.3 Elastomeric materials such as gaskets and tubing in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperatures that they are exposed to during normal use. Compliance shall be determined by the following: ISO 188 and ISO 1817.

F.4.4.4 Polymeric materials in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperature they are exposed to during normal use. Compliance shall be determined by ISO 175.

F.4.4.5 Piping systems exposed to hydrogen shall employ materials suitable for exposure to hydrogen, as defined in Annex A of ISO 16111.

F.4.7 Materials and construction – system

F.4.7.1 *These requirements of Subclause F.4.7 apply to micro fuel cell power systems and units covered by this Annex F. These requirements replace the corresponding requirements of Subclause 4.7.* The maximum quantity of liquid fuel or liquid fuel components stored in the micro fuel cell power unit shall not be more than 1 l. Solid fuel shall not be present in the micro fuel cell power unit.

F.4.7.2 The micro fuel cell power system or unit shall be designed such that an explosion cannot occur even if fuel or hydrogen leaks from or inside the micro fuel cell power system or unit. The design criteria for such means (for example, required ventilation rate) shall be provided by the micro fuel cell power system or unit manufacturer. The means shall be provided either by the micro fuel cell power system or unit manufacturer or by the manufacturer of the device powered by the micro fuel cell power system or unit.

F.4.7.3 Components and materials inside the micro fuel cell power system or unit shall be constructed or shall make use of such materials that propagation of fire and ignition is mitigated. The material flammability shall be such that a sustained fire will not be supported after electrical power and the fuel and oxidant supply have been terminated. This may be demonstrated through the selection of materials meeting FV 0, FV 1 or FV 2 in accordance with IEC 60695-1-1 and IEC 60695-11-10.

F.4.7.4 Micro fuel cell stack membranes are not required to have flammability ratings.

F.4.7.5 Other materials within the micro fuel cell stack which comprise less than 30 % of the total micro fuel cell stack mass are considered to be of limited quantity and are permissible without flammability ratings.

F.4.12 Fuel supply construction

F.4.12.1 Fuel cartridge construction

These requirements of Subclause F.4.12.1 apply to micro fuel cell power systems and units covered by this Annex F. These requirements replace the corresponding requirements of Subclause 4.12.1.

Fuel cartridges shall conform to the following requirements:

F.4.12.1.1 There shall be no leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with Subclause F.7.3.3 and Subclause F.7.3.4.

F.4.12.1.2 There shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Compliance shall be determined by type testing in accordance with F.7.3.1.

F.4.12.1.3 The maximum fuel charge is limited to 1 l for liquid fuel components, and 200 g for solid fuel.

F.4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel or hydrogen leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance is checked by Subclause F.7.3.11.

F.4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

F.4.12.1.6 A fuel cartridge shall be provided with a means to prevent mis-connection that would result in leakage of fuel or hydrogen when it is installed in a micro fuel cell power system. Compliance is checked by the connection cycling test, Subclause F.7.3.11.

F.4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel or hydrogen when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance is checked by the drop test, Subclause F.7.3.5, and the connection cycling test, subclause F.7.3.11.

F.4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

F.4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel or hydrogen to leak.

F.4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance is checked by:

- pressure differential tests, F.7.3.1;
- vibration test, F.7.3.2;
- temperature cycling test, F.7.3.3;
- high temperature exposure test, F.7.3.4;
- drop test, F.7.3.5;
- compressive loading test, F.7.3.6;
- long-term storage test, F.7.3.9;
- high-temperature connection test, F.7.3.10;
- connection cycling tests, F.7.3.11.

F.4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

F.4.12.1.12 In cases where materials (either solid or liquid) are present that are incompatible with either the borohydride fuel or liquid fuel component, the design of the fuel cartridge and micro fuel cell power system shall provide a means for preventing inadvertent or uncontrolled mixing of these materials.

Two independent means for preventing inadvertent or uncontrolled mixing of these materials shall be provided during transportation and storage prior to use. Illustrative examples of these means include but are not limited to: positive activation by the control system; physical removal of an impermeable barrier preventing contact; opening of a normally closed manually controlled valve preventing contact. For at least one of these means for preventing uncontrolled mixing, it shall be necessary for the user to take positive action to remove or deactivate it prior to use.

At least one means for preventing uncontrolled mixing of these materials shall be provided during use and storage after use. This means may include active control by system electronics, subject to the FMEA analysis of Subclause 4.2.

F.6 Instructions and warnings for fuel cartridges, micro fuel cell power units, and micro fuel cell power systems

F.6.2 Minimum markings required on the fuel cartridge

These markings replace the markings required by Subclause 6.2.

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE WATER-REACTIVE AND TOXIC, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) KEEP AWAY FROM CHILDREN.

d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.

e) DO NOT EXPOSE TO ACIDS, OXIDIZERS, ALCOHOL OR HOUSEHOLD CLEANING PRODUCTS.

f) DO NOT IMMERSE IN WATER OR OTHER LIQUIDS.

g) FOLLOW USAGE INSTRUCTIONS.

h) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

i) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

j) COMPOSITION AND AMOUNT OF FUEL.

k) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.

l) MAY CONTAIN FLAMMABLE GAS.

In the case that the contents of the fuel cartridge are corrosive, the marking required under “a” above shall be changed as follows:

a) CONTENTS ARE WATER-REACTIVE, CORROSIVE AND TOXIC. DO NOT DISASSEMBLE.

In the case that the contents of the fuel cartridge are flammable, the marking required under “a” above shall be changed as follows:

a) CONTENTS ARE WATER-REACTIVE, CORROSIVE, TOXIC AND FLAMMABLE. DO NOT DISASSEMBLE.

F.6.3 Minimum markings required on the micro fuel cell power system

These markings replace the markings required by Subclause 6.3.

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE WATER-REACTIVE AND TOXIC, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.

d) DO NOT IMMERSE IN WATER OR OTHER LIQUIDS.

e) FOLLOW USAGE INSTRUCTIONS.

f) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

g) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

h) COMPOSITION OF FUEL.

i) MAXIMUM CAPACITY OF FUEL IN THE FUEL CARTRIDGE

j) TEXT OR MARKING THAT INDICATES THAT THE MICRO FUEL CELL POWER SYSTEM COMPLIES WITH IEC 62282-6-100.

k) MAY CONTAIN FLAMMABLE GAS.

l) ELECTRICAL OUTPUT (VOLTAGE, CURRENT, RATED POWER).

In the case that the contents of the fuel cartridge are corrosive, the marking required under “a” above shall be changed as follows:

a) CONTENTS ARE WATER-REACTIVE, CORROSIVE AND TOXIC. DO NOT DISASSEMBLE.

In the case that the contents of the fuel cartridge are flammable, the marking required under “a” above shall be changed as follows:

a) CONTENTS ARE WATER-REACTIVE, CORROSIVE, TOXIC AND FLAMMABLE. DO NOT DISASSEMBLE.

F.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

F.7.1 General

This Subclause F.7.1 replaces Subclause 7.1 for this annex when testing borohydride micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use Class 4.3 (water reactive) borohydride as fuel.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table F.5 lists the type tests that must be performed. *Table F.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table F.6. *Table F.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table F.5 – List of type tests – Replaces Table 5

	Test item	Test sample
F.7.3.1	Pressure differential tests	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
F.7.3.2	Vibration test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
F.7.3.3	Temperature cycling test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
F.7.3.4	High temperature exposure test	Fuel cartridge Used fuel cartridge
F.7.3.5	Drop test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
F.7.3.6	Compressive loading test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
F.7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
F.7.3.9	Long-term storage test	Fuel cartridge Used fuel cartridge
F.7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
F.7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
F.7.3.12	Emission test	Micro fuel cell power system or power unit
F.7.3.13	Hydrogen point source gas loss detection test	Micro fuel cell power system or power unit

Table F.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or used, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test.

Test sequence: Tests F.7.3.2 and F.7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests F.7.3.1, F.7.3.2, and F.7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer’s discretion if it does not compromise the individual test.

Table F.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is “room temperature” (standard temperature condition, 22 °C ± 5 °C)
Laboratory atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen. The laboratory atmosphere contains not more than 0,008 % hydrogen
Table F.6 replaces Table 6.	

F.7.2 Leakage, hydrogen leakage, and hydrogen gas loss, and hydrogen emission measurement and the measuring procedure

This Subclause F.7.2 replaces Subclause 7.2 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use Class 4.3 (water reactive) borohydride as fuel.

The leakage measurements shall be executed in principle in accordance with the procedures shown in Figures F.2 through F.5. These figures and their procedures, replace the corresponding figures in Subclause 7.2.

Compliance with the “no leakage”, “no hydrogen leakage” and “no impermissible hydrogen gas loss” requirement for all type tests specified in Subclause F.7.3 shall be determined by the leakage test and measurement procedure of Subclause F.7.2.1, the hydrogen leakage measurement procedure of Subclause F.7.2.2 and the hydrogen gas loss measuring procedure of Subclause F.7.2.3 in conjunction with the definition of “leakage” in Subclause F.3.11, “hydrogen leakage” in Subclause F.3.51, and the definition of “impermissible hydrogen gas loss” in Subclause F.3.42, unless otherwise specified.

F.7.2.1 Leakage test and measurement procedure

a) For micro fuel cell power systems, micro fuel cell power units and fuel cartridges containing Class 4.3 (water reactive) borohydride fuel, the leakage measurement of fuel, fuel byproducts, electrolyte or liquid fuel components shall be done following each type test by performing visual inspection of all possible leak locations. Any drops of fuel, fuel byproducts, electrolyte or liquid fuel component and/or white crystals on the exterior of the micro fuel cell power system or unit or fuel cartridge are indications of leakage. If crystals are accessible, the micro fuel cell power system or unit or fuel cartridge fails the leakage test. As an additional tool for finding fuel, fuel byproducts, electrolyte or liquid fuel component leaks, pH paper, attached to the possible leak areas of the micro fuel cell power system, shall be used to aid in the visual check for leakage. This is an additional requirement in Annex F for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel components. Any existence of a substance with a pH lower than 3,5 or greater than 10,5 is an indication of leakage. See Figure F.2 and Figure F.3. For operational tests, reactant air passages into the micro fuel cell power system and exhaust ports should not be blocked with pH paper.

b) ~~For fuel cell cartridges containing solid, water reactive borohydride fuel, a water immersion test shall be shall be performed following each type test. The entire fuel cartridge containing solid borohydride fuel is immersed in at least one meter of laboratory temperature water for 30 min. If bubbles are observed, the fuel cartridge fails the leakage test. See Figure F.2 and Figure F.3.~~

   1) For fuel cell cartridges containing solid, water reactive borohydride fuel, a water immersion test shall be shall be performed following each type test. The entire fuel cartridge containing solid borohydride fuel is immersed in at least one meter of laboratory temperature water for 30 min.

2) If bubbles are observed, hydrogen point source gas loss detection testing in accordance with F.7.3.13 shall be performed to ensure no release of hazardous material to the environment.

3) If point source testing is performed, the water immersion test of step 1 shall be repeated one hour after completion of the point source test. If bubbles due to leakage are observed, the fuel cartridge fails the leakage test. See Figure F.2 and Figure F.3.

F.7.2.2 Hydrogen leakage measurement from fuel cartridges and/or fuel management systems and measuring procedures

a) For fuel cartridges containing Class 4.3 (water reactive) borohydride, the measurement of hydrogen leakage shall be done following each type test ~~using a liquid leak detector (bubble forming) solution or other equivalent means on all possible leak locations of the fuel cartridge. See Figure F.2 and Figure F.3~~ as follows:

   1) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution or other equivalent means, such as a water immersion test, on all possible leak locations of the fuel cartridge.

   2) If bubbles are observed, hydrogen point source gas loss detection testing in accordance with F.7.3.13 shall be performed to ensure no release of hazardous materials to the environment.

   3) If point source testing is performed, hydrogen leakage measurement in accordance with step 1 shall be repeated one hour after completion of the point source test. If bubbles due to hydrogen leakage are observed, the fuel cartridge fails the hydrogen leakage test. See Figure F.2 and Figure F.3.

   4) Measurement of hydrogen leakage may be performed simultaneously with the leakage test of F.7.2.1.

b) If the fuel cartridge is of the type that is refillable by the manufacturer (automated or by trained technicians), it shall be filled to its rated capacity prior to testing. If the fuel cartridge is not refillable, it shall be tested in the condition in which it completed the type test in question. The fuel cartridge shall be tested for leaks at laboratory temperature. There shall be no leakage from any point on the fuel cartridge.

c) For micro fuel cell power systems or micro fuel cell power units with a fuel management system that contains hydrogen gas above ambient pressure, the measurement of hydrogen leakage shall be done following each type test using a liquid leak detector (bubble forming) solution or other equivalent means on all possible leak locations of the fuel management system. The fuel management system shall be tested for leaks at laboratory temperature. There shall be no leakage from any point on the fuel management system.

d) Both for fuel cartridges containing Class 4.3 (water reactive) borohydride, and for fuel management systems containing hydrogen, no hydrogen leakage is allowed. Testing for hydrogen leakage with a liquid leak detector (bubble forming) solution is acceptable only if no bubbles ~~are found~~ due to hydrogen are observed.

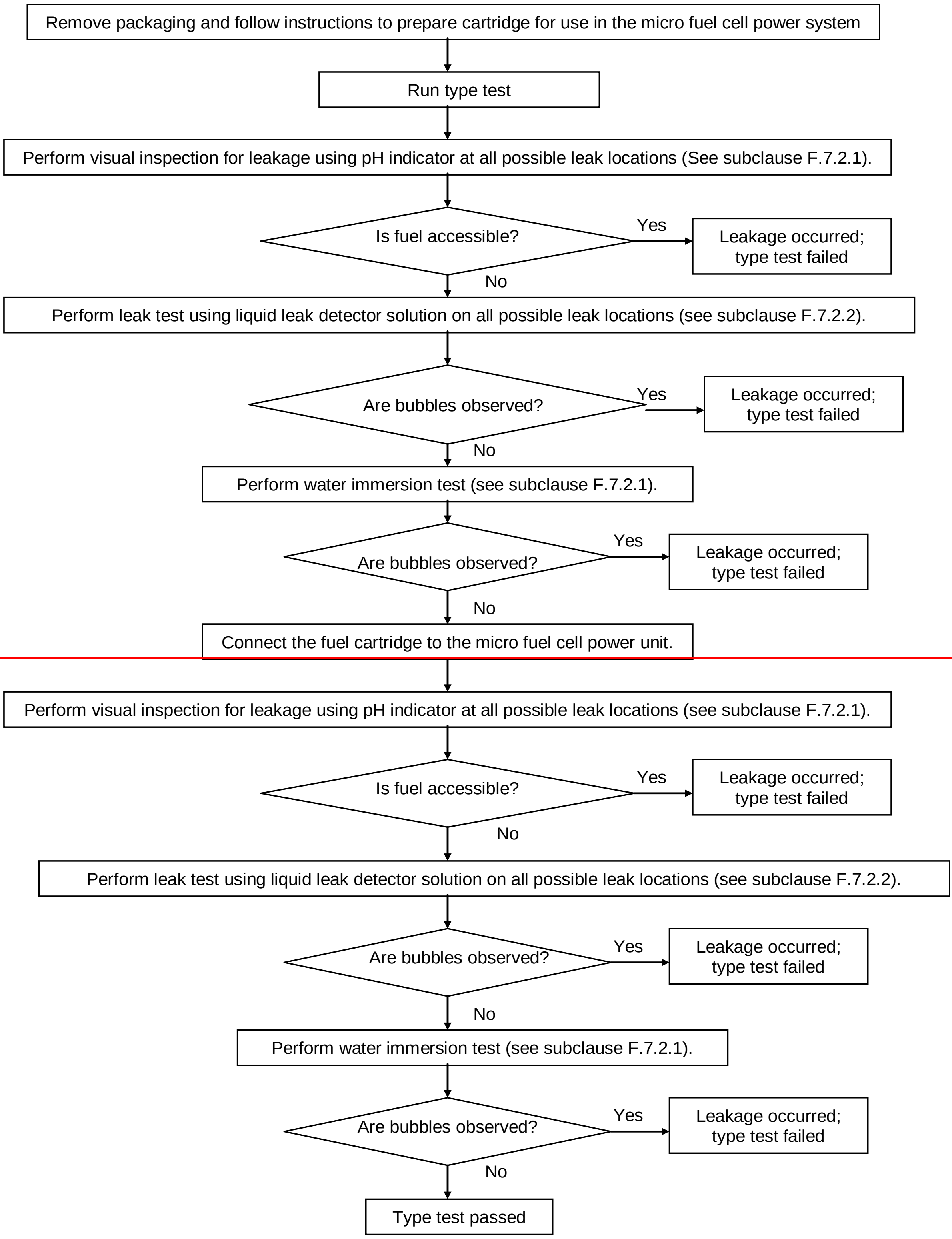
~~NOTE The "no leakage" criteria for fuel cartridges containing Class 4.3 (water reactive) borohydride has been chosen to be consistent with the 15th Edition of the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations; Special Provision 339 for UN 3479, Fuel Cell Cartridge *containing hydrogen in metal hydride*.~~

F.7.2.3 Hydrogen gas loss measurements from micro fuel cell power systems and micro fuel cell power units and measuring procedures

For micro fuel cell power systems, or micro fuel cell power units, following the completion of each type test, the micro fuel cell power system or unit shall be tested for hydrogen gas loss according to Figure F.4 as follows:

a) Perform hydrogen emission testing in accordance with F.7.3.12 with the exception that the micro fuel cell power system or unit shall be off ("DEVICE – OFF"). ~~Hydrogen point source testing in accordance with Subclause F.7.3.13 is not applicable.~~ Hydrogen gas loss shall be less than 0,0032 g/h. If transient emission rates greater than 0,016 g/h are observed during hydrogen emission testing, hydrogen point source gas loss detection testing in accordance with F.7.3.13 shall be performed. See Table F.7.

b) Perform hydrogen emission testing in accordance with Subclause F.7.3.12 with the micro fuel cell power system or unit turned on ("DEVICE – ON") to test for hydrogen emissions whether or not the micro fuel cell power system or unit is operational. Hydrogen emissions shall be less than 0,8 g/h and hydrogen leakage from any single point leak shall be less than 0,016 g/h. See Table F.7.


Remove packaging and follow instructions to prepare cartridge for use in the micro fuel cell power system
Run type test
Perform visual inspection for leakage using pH indicator at all possible leak locations (See subclause F.7.2.1).
Is fuel accessible?
Yes
Leakage occurred; type test failed
No
Perform leak test using liquid leak detector solution on all possible leak locations (see subclause F.7.2.2).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Perform water immersion test (see subclause F.7.2.1).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Connect the fuel cartridge to the micro fuel cell power unit.
Perform visual inspection for leakage using pH indicator at all possible leak locations (see subclause F.7.2.1).
Is fuel accessible?
Yes
Leakage occurred; type test failed
No
Perform leak test using liquid leak detector solution on all possible leak locations (see subclause F.7.2.2).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Perform water immersion test (see subclause F.7.2.1).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Type test passed

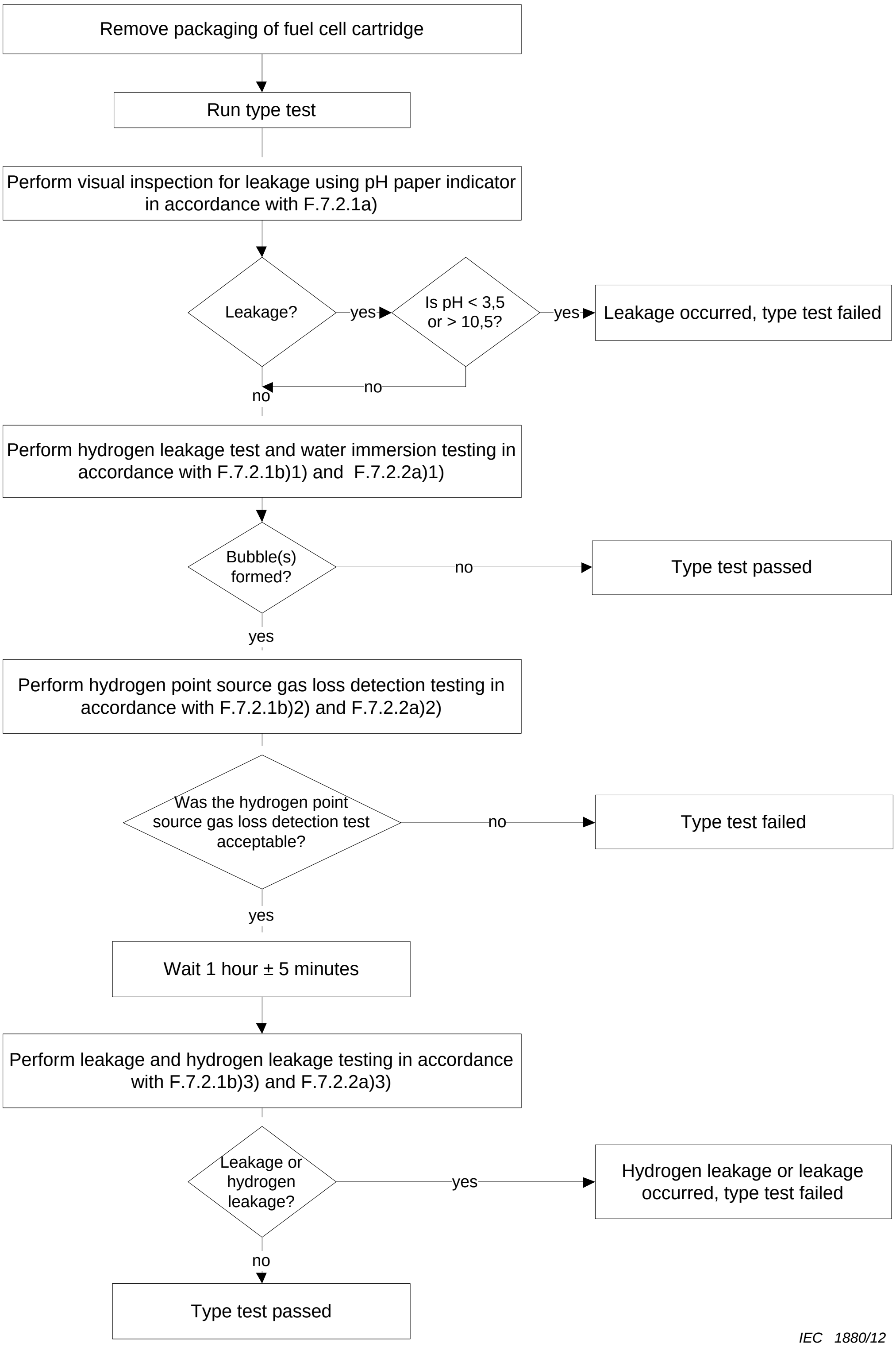
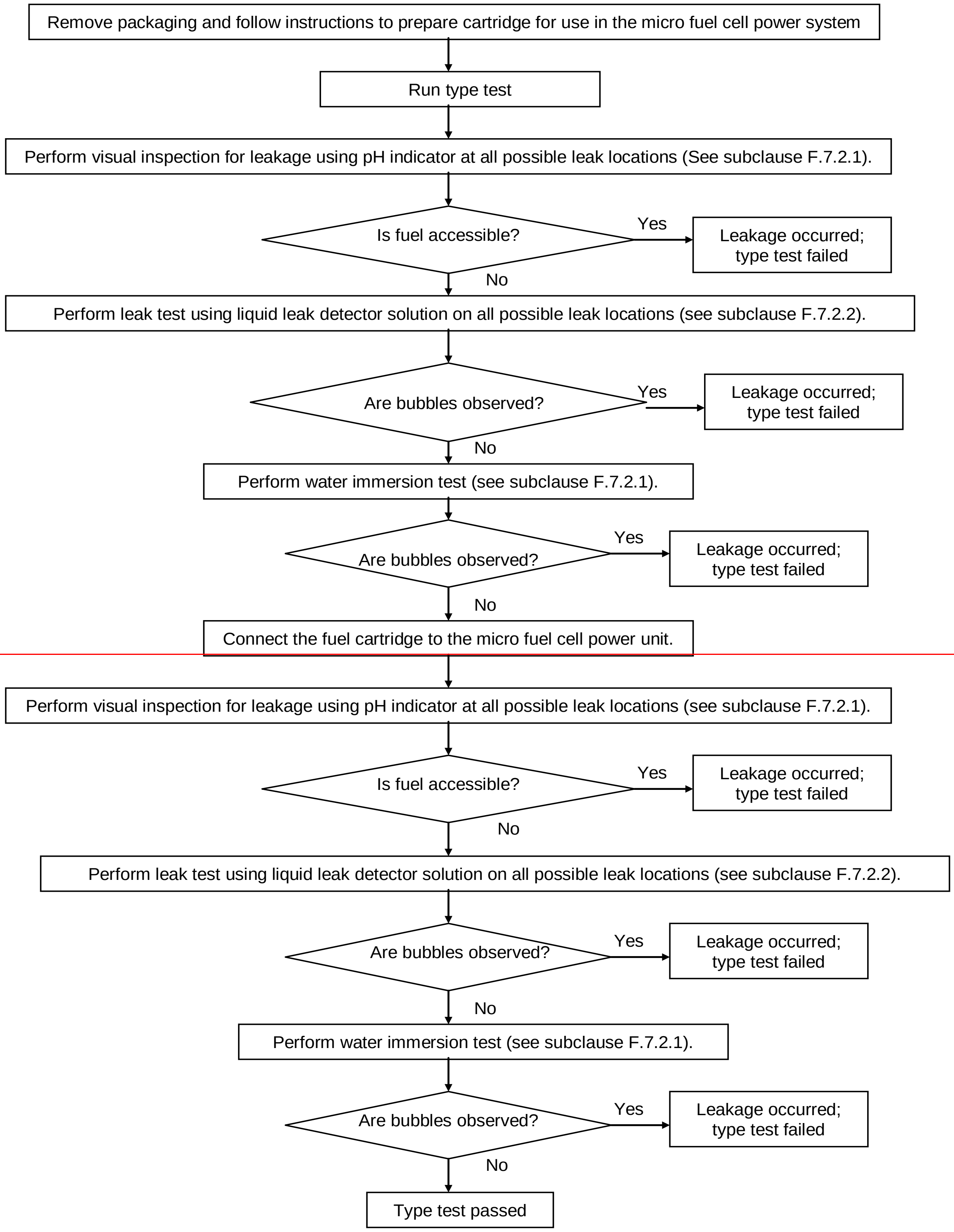


Figure F.2 – Fuel cartridge leakage and hydrogen leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2


Remove packaging and follow instructions to prepare cartridge for use in the micro fuel cell power system
Run type test
Perform visual inspection for leakage using pH indicator at all possible leak locations (See subclause F.7.2.1).
Is fuel accessible?
Yes
Leakage occurred; type test failed
No
Perform leak test using liquid leak detector solution on all possible leak locations (see subclause F.7.2.2).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Perform water immersion test (see subclause F.7.2.1).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Connect the fuel cartridge to the micro fuel cell power unit.
Perform visual inspection for leakage using pH indicator at all possible leak locations (see subclause F.7.2.1).
Is fuel accessible?
Yes
Leakage occurred; type test failed
No
Perform leak test using liquid leak detector solution on all possible leak locations (see subclause F.7.2.2).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Perform water immersion test (see subclause F.7.2.1).
Are bubbles observed?
Yes
Leakage occurred; type test failed
No
Type test passed

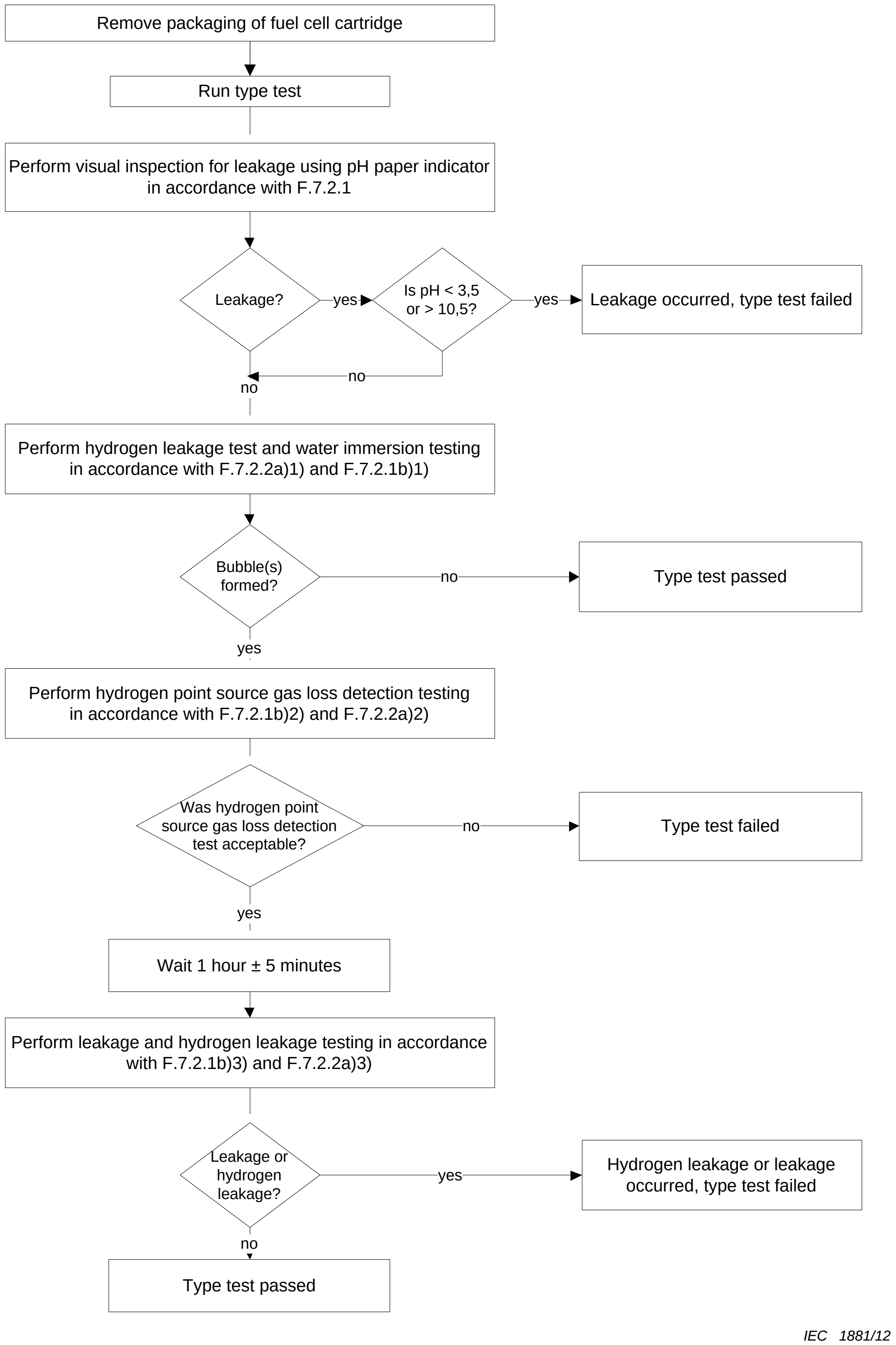
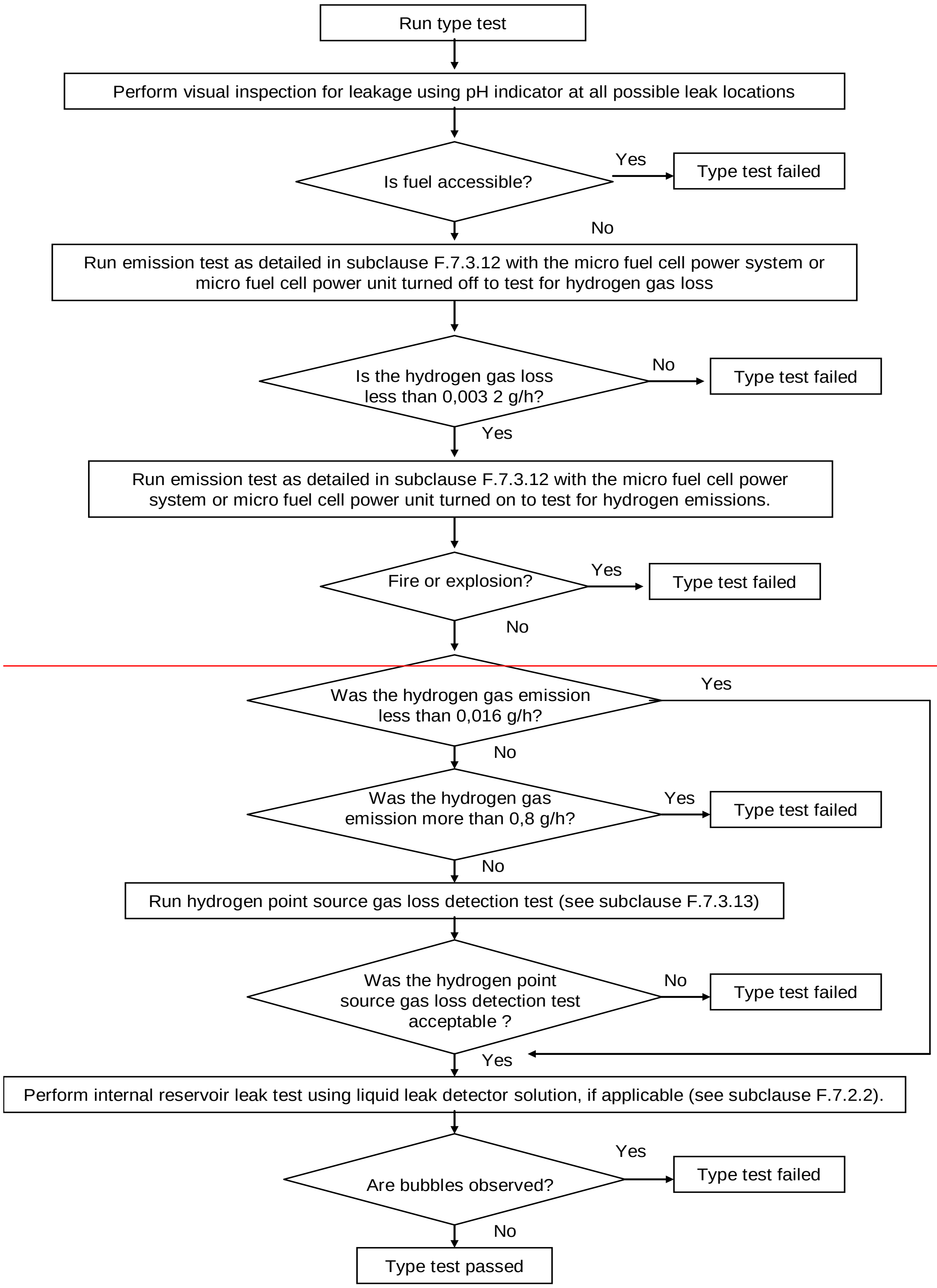


Figure F.3 – Fuel cartridge leakage and ~~mass loss~~ hydrogen leakage test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3


Run type test
Perform visual inspection for leakage using pH indicator at all possible leak locations
Is fuel accessible?
Yes
Type test failed
No
Run emission test as detailed in subclause F.7.3.12 with the micro fuel cell power system or micro fuel cell power unit turned off to test for hydrogen gas loss
Is the hydrogen gas loss less than 0,003 2 g/h?
No
Type test failed
Yes
Run emission test as detailed in subclause F.7.3.12 with the micro fuel cell power system or micro fuel cell power unit turned on to test for hydrogen emissions.
Fire or explosion?
Yes
Type test failed
No
Was the hydrogen gas emission less than 0,016 g/h?
Yes
No
Was the hydrogen gas emission more than 0,8 g/h?
Yes
Type test failed
No
Run hydrogen point source gas loss detection test (see subclause F.7.3.13)
Was the hydrogen point source gas loss detection test acceptable ?
No
Type test failed
Yes
Perform internal reservoir leak test using liquid leak detector solution, if applicable (see subclause F.7.2.2).
Are bubbles observed?
Yes
Type test failed
No
Type test passed

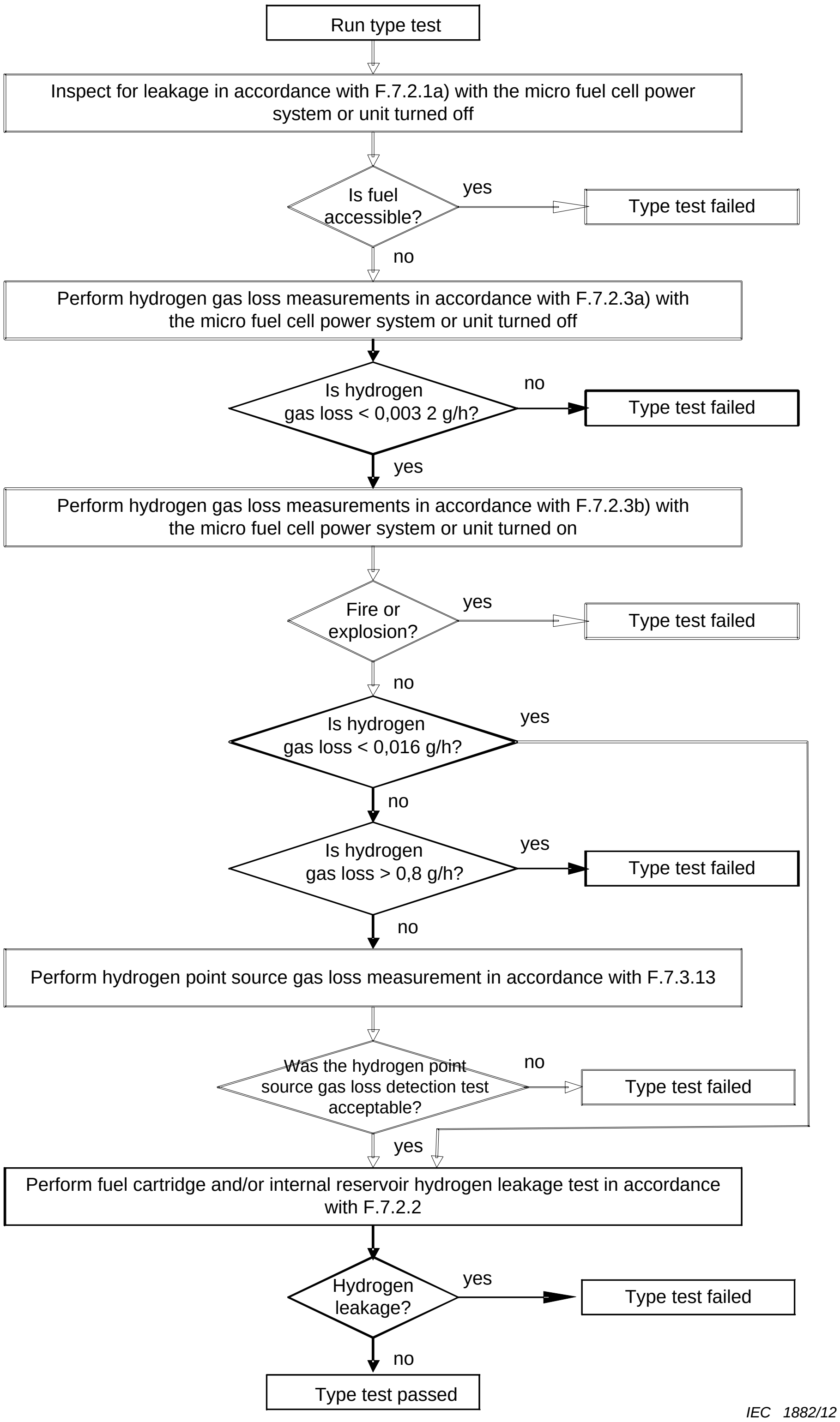
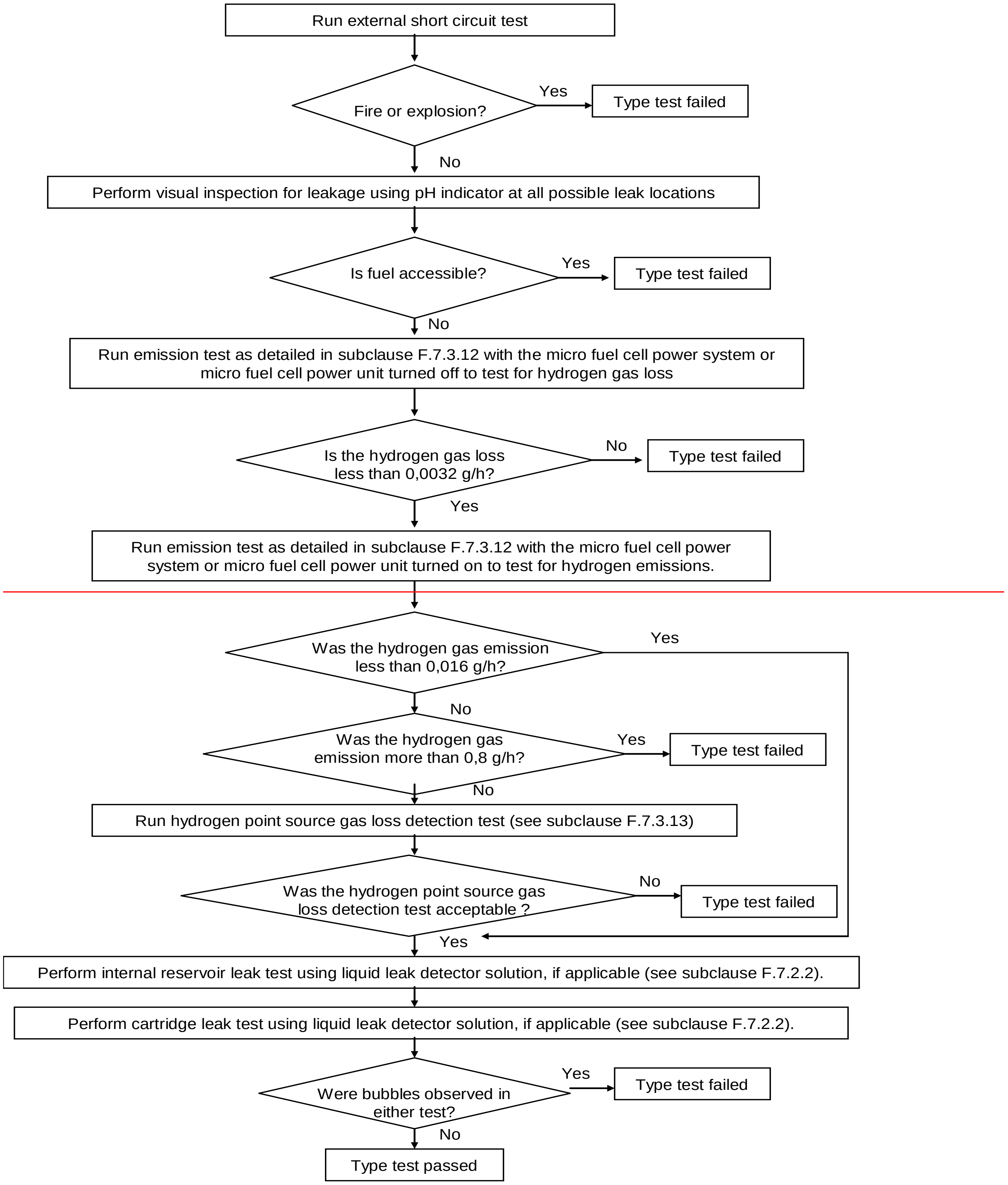


Figure F.4 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4


Run external short circuit test
Fire or explosion?
Yes
Type test failed
No
Perform visual inspection for leakage using pH indicator at all possible leak locations
Is fuel accessible?
Yes
Type test failed
No
Run emission test as detailed in subclause F.7.3.12 with the micro fuel cell power system or micro fuel cell power unit turned off to test for hydrogen gas loss
Is the hydrogen gas loss less than 0,0032 g/h?
No
Type test failed
Yes
Run emission test as detailed in subclause F.7.3.12 with the micro fuel cell power system or micro fuel cell power unit turned on to test for hydrogen emissions.
Was the hydrogen gas emission less than 0,016 g/h?
Yes
No
Was the hydrogen gas emission more than 0,8 g/h?
Yes
Type test failed
No
Run hydrogen point source gas loss detection test (see subclause F.7.3.13)
Was the hydrogen point source gas loss detection test acceptable ?
No
Type test failed
Yes
Perform internal reservoir leak test using liquid leak detector solution, if applicable (see subclause F.7.2.2).
Perform cartridge leak test using liquid leak detector solution, if applicable (see subclause F.7.2.2).
Were bubbles observed in either test?
Yes
Type test failed
No
Type test passed

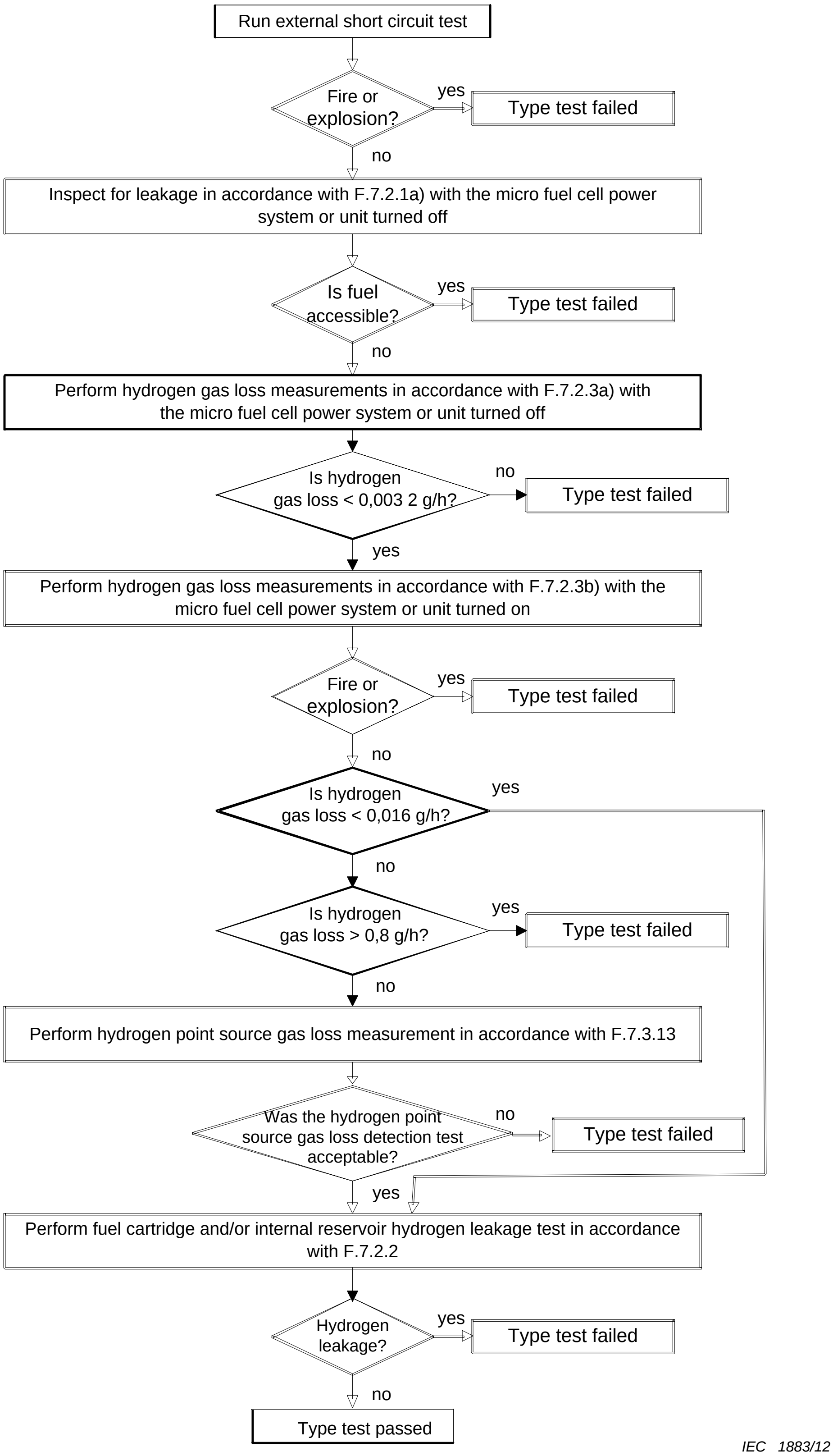


Figure F.5 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for external short-circuit test – Replaces Figure 5

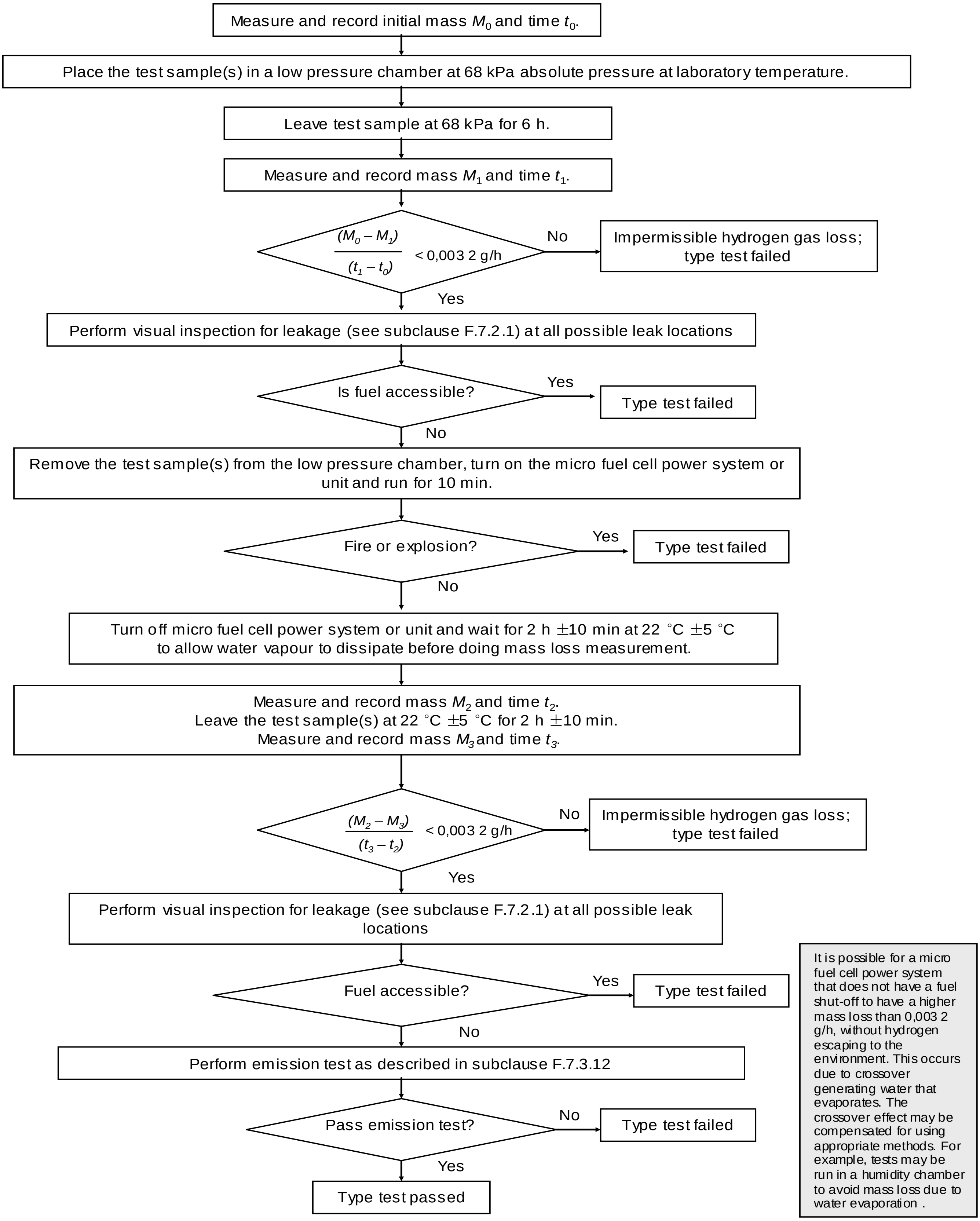


Figure F.6 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6

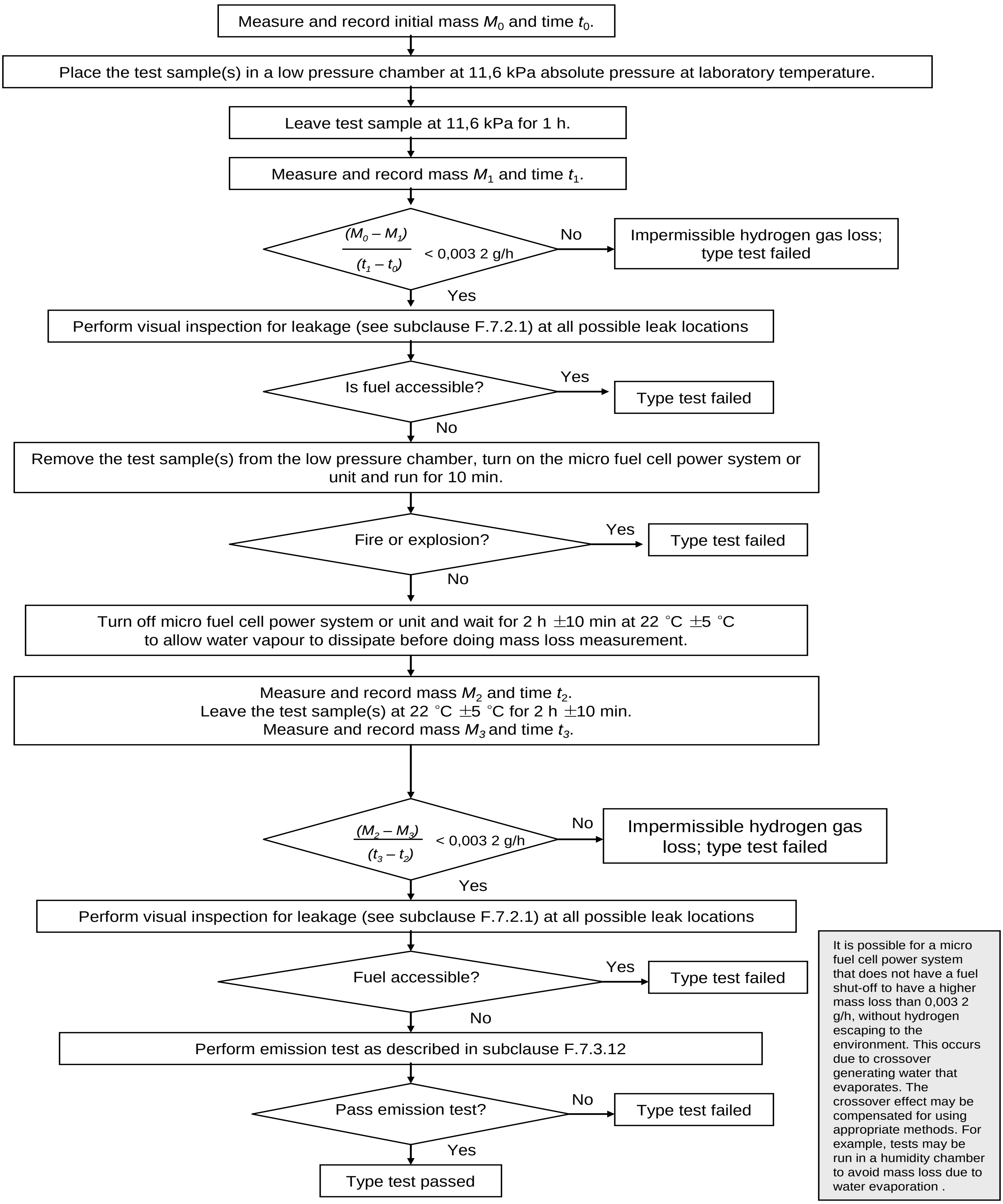


Figure F.7 – Micro fuel cell power system or micro fuel cell power unit leakage and ~~mass~~ hydrogen gas loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7

F.7.3 Type tests

F.7.3.1 Pressure differential tests

F.7.3.1.1 General

Subclause F.7.3.1 replaces Subclause 7.3.1.

Portions of this test check compliance with Subclause 4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Depending upon which of the two limiting pressure conditions is greater, two options for testing are provided.

a) If 95 kPa internal gauge pressure plus normal working pressure of the fuel cartridge at 22 °C is greater than two times the gauge pressure of the fuel cartridge at 55 °C, either Subclause F.7.3.1.2 or subclause F.7.3.1.3 may be used to verify compliance with Subclause 4.12.1.2.

b) If two times the gauge pressure of the fuel cartridge at 55 °C is greater than 95 kPa internal gauge pressure plus normal working pressure at 22 °C, Subclause F.7.3.1.2 must be used to verify compliance with Subclause 4.12.1.2.

F.7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

   1) Using a suitable fluid medium such as mineral oil, pressurize the fuel cartridge body to an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater.
   2) The pressure rise shall not exceed a rate of 60 kPa/s.
   3) Maintain the maximum pressure for 30 min at laboratory temperature.
   4) Using a suitable fluid medium such as mineral oil, pressurize the closed fuel cartridge valve to 95 kPa gauge pressure plus the normal working pressure of the cartridge at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater.
   5) The pressure rise shall not exceed a rate of 60 kPa/s.
   6) Maintain the maximum pressure for 30 min at laboratory temperature.
   7) Perform visual check for leakage of test fluid medium.

d) **Passing criteria:** no accessible liquid test medium leakage and no sudden drop of pressure during the course of the test. Leakage shall be checked visually. Invert the fuel cartridge and the fuel cartridge valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails.

NOTE Class 4.3 (water reactive) borohydride fuel will chemically react with water, therefore, water or water-containing substances should not be used as the fluid test medium. Class 4.3 (water reactive) borohydride fuels have the potential to react with substances other than water, therefore, the chemical reactivity and stability of the particular Class 4.3 (water reactive) borohydride fuel being tested should be used to guide the selection of a suitable liquid test medium.

F.7.3.1.3 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

Perform this test in accordance with Figure F.14. Figure F.14 is a new figure.

1) Record the initial mass of the test sample M_0 and starting time t_0. Place the sample in a vacuum chamber and reduce the pressure in the vacuum chamber to 95 kPa below normal atmospheric pressure.

2) Maintain the vacuum for 30 min.

3) Remove the sample from the vacuum chamber and record the final mass M_1 and time t_1. Determine hydrogen gas loss and check for leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel components using visual inspection with pH indicator and water immersion test as described in Subclause F.7.2.1.

4) ~~Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1. See Figure F.14.~~ Check for hydrogen leakage as described in F.7.2.2. See Figure F.14.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss, no hydrogen leakage and no Class 4.3 (water reactive) fuel or liquid fuel component leakage. See Figure F.14. Hydrogen gas loss shall meet the requirements of Subclause F.7.2.3 (less than 0,0032 g/h). Hydrogen leakage shall meet the no hydrogen leakage requirements~~ (no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator and with the water immersion test as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

F.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

F.7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all Class 4.3 (water reactive) borohydride micro fuel cell power systems and all Class 4.3 (water reactive) borohydride micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

1) Perform this test in accordance with Figure F.6.

2) Test samples shall be stored at a low external pressure of 68 kPa absolute pressure for 6 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure F.6.

3) For the micro fuel cell power system or unit, perform hydrogen gas loss measurements in accordance with F.7.2.3 (including emission testing in accordance with F.7.3.12). See B.7.3.1.3 for alternative methods to measure and calculate impermissible hydrogen gas loss during step 2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel components liquid leakage. See Figure F.6. Remove the fuel cartridge, if present, from the micro fuel cell power system. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Hydrogen gas loss shall be determined by the mass loss measurement as shown in Figure F.6. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of Subclause F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of F.7.3.12, the emission test result is acceptable.

F.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all Class 4.3 (water reactive) borohydride micro fuel cell power systems and all Class 4.3 (water reactive) borohydride micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.
b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.
c) **Test procedure:**
   1) Perform this test in accordance with Figure F.7.
   2) Test samples shall be stored at a low external pressure of 11,6 kPa absolute pressure for 1 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure F.7.
   3) For the micro fuel cell power system or unit, perform hydrogen gas loss measurements in accordance with F.7.2.3 (including emission testing in accordance with F.7.3.12). See B.7.3.1.4 for alternative methods to measure and calculate impermissible hydrogen gas loss during step 2.
d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel components liquid leakage. See Figure F.7. Remove the fuel cartridge, if present, from the micro fuel cell power system. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Hydrogen gas loss shall be determined by the mass loss measurement as shown in Figure F.7. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of Subclause F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of F.7.3.12, the emission test result is acceptable.

F.7.3.2 Vibration test

Subclause F.7.3.2 replaces Subclause 7.3.2.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in Subclause F.7.3.1 or a micro fuel cell power system used in used in Subclause F.7.3.1.
b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.
c) **Test procedure:**
   1) Perform these tests in accordance with Figure F.2 for the fuel cartridge and Figure F.4 for the micro fuel cell power system or unit.
   2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) ~~For the micro fuel cell power system or unit, perform emission testing in accordance with F.7.3.12.~~ Perform the following leakage tests:

   i) For the fuel cartridge, perform leakage tests in accordance with F.7.2.1, hydrogen leakage measurements in accordance with F.7.2.2. See Figure F.2.

   ii) For the micro fuel cell power system or unit, perform visual inspection for leakage using pH paper in accordance with F.7.2.1a), and then perform hydrogen gas loss testing in accordance with F.7.2.3 (including emission testing in accordance with F.7.3.12). See Figure F.4.

   iii) If the micro fuel cell power system or unit contains a fuel cartridge perform hydrogen leakage measurements in accordance with F.7.2.2.

   iv) If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, hydrogen leakage shall be checked following F.7.3.3, in accordance with F.7.3.3 c) 9) iii).

~~7) For the fuel cartridge, check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1.~~

~~8) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of Subclause F.7.3.12, the emission test is acceptable.

F.7.3.3 Temperature cycling test

Subclause F.7.3.3 replaces Subclause 7.3.3.

a) **Test sample:** a fuel cartridge used in Subclause F.7.3.2, a used fuel cartridge used in Subclause F.7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in Subclause F.7.3.2 or a micro fuel cell power system used in Subclause F.7.3.2.

b) **Purpose:** to simulate the effects of low-temperature and high temperature exposure and the effects of extreme temperature change.

c) **Test procedure:**

1) Perform these tests in accordance with Figure F.3 for the fuel cartridge and Figure F.4 for the micro fuel cell power system or unit.

2) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

3) See Figure F.8 for the temperature profile to be used.

4) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

5) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

6) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

7) The above process is to be done twice.

8) After 1 h at 22 °C ± 5°C, leakage shall be measured based upon the procedure described in Figure F.3 (for fuel cartridge) and Figure F.4 (for micro fuel cell power system or unit).

9) ~~For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with F.7.3.12.~~ Perform the following leakage tests:

   i) For the fuel cartridge, perform leakage tests in accordance with F.7.2.1, hydrogen leakage measurements in accordance with F.7.2.2. See Figure F.3.

   ii) For the micro fuel cell power system or unit, perform visual inspection for leakage using pH paper in accordance with F.7.2.1a), and then perform hydrogen gas loss testing in accordance with F.7.2.3 (including emission testing in accordance with F.7.3.12). See Figure F.4.

   iii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with F.7.2.2.

~~10) For the fuel cartridge, connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ (no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in Subclause F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of Subclause F.7.3.12, the emission test is acceptable.

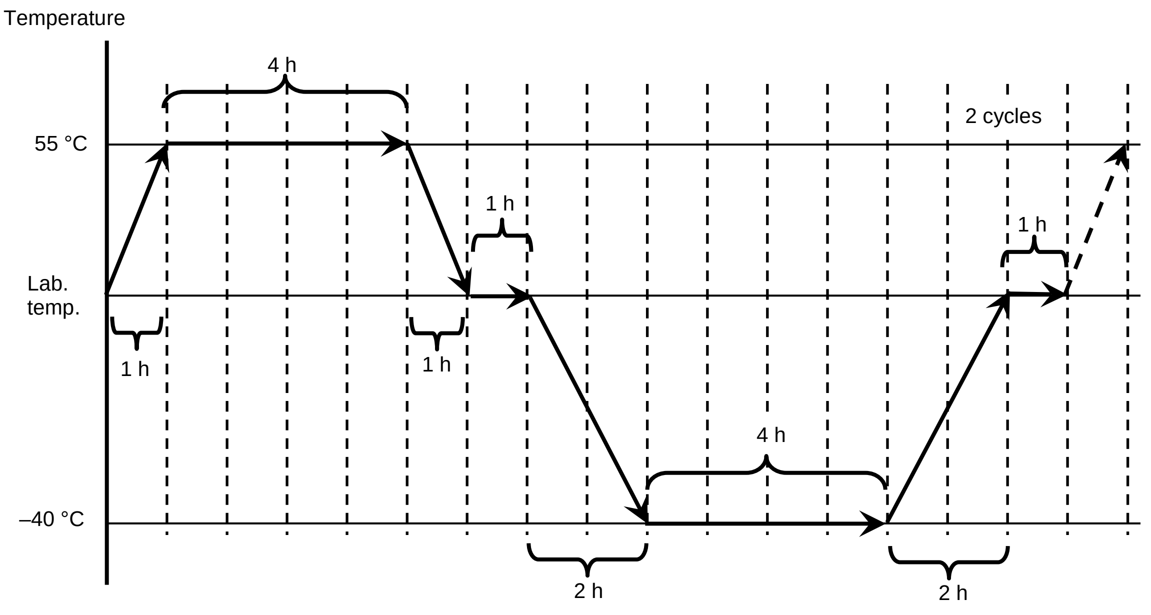


Figure F.8 – Temperature cycling – Replaces Figure 8

F.7.3.4 High temperature exposure test

Subclause F.7.3.4 replaces Subclause 7.3.4.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments.

c) **Test procedure:**

1) Two orientations shall be tested – valve up and valve down.

2) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

3) Remove the test sample to laboratory temperature. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1. See Figure F.3.

~~4) Connect the fuel cartridge to a micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1. See Figure F.3.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ (no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually~~ to verify that there is no disturbance to the micro fuel cell power system/unit~~.

F.7.3.5 Drop test

Subclause F.7.3.5 replaces Subclause 7.3.5.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure F.2 for the fuel cartridge and Figure F.4 for the micro fuel cell power system or unit. The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

   2) The height of the drop shall be:

      i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system.

      ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge of more than 200 g solid fuel or more than 200 ml of liquid fuel component.

      iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge of up to 200 g of solid fuel or up to 200 ml of liquid fuel component.

   3) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

   4) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or unit may be used for all four drop orientations, or more than one micro fuel cell power system or unit may be used in subsequent drops, at the discretion of the manufacturer.

   5) For all tests, drop orientations shall be:

      i) valve up;

      ii) valve down;

      iii) two other mutually perpendicular orientations.

   6) ~~For the fuel cartridge, check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1.~~ Perform the following leakage tests:

      i) For the fuel cartridge, perform leakage tests in accordance with F.7.2.1, hydrogen leakage measurements in accordance with F.7.2.2. See Figure F.2.

      ii) For the micro fuel cell power system or unit, perform visual inspection for leakage using pH paper in accordance with F.7.2.1(a), and then perform hydrogen gas loss testing in accordance with F.7.2.3 (including emission testing in accordance with F.7.3.12). See Figure F.4.

      iii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with F.7.2.2.

   ~~7) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in subclause F.7.2.1. See Figure F.2.~~

   ~~8) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with Subclause F.7.3.12. See Figure F.4.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in Subclause F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of Subclause F.7.3.12, the emission test is acceptable. If the micro fuel cell power system or unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

F.7.3.6 Compressive loading test

Subclause F.7.3.6 replaces Subclause 7.3.6.

F.7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

   1) The micro fuel cell power system or unit test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

   2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

   3) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

   4) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

   5) ~~Perform emission testing in accordance with Subclause F.7.3.12 following the compressive loading test. See Figure F.4.~~ Perform the following leakage tests:

      i) Perform visual inspection for leakage using pH paper in accordance with F.7.2.1(a), and then perform hydrogen gas loss testing in accordance with F.7.2.3 (including emission testing in accordance with F.7.3.12). See Figure F.4.

      ii) If the micro fuel cell power system or unit contains a fuel cartridge or an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with F.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in Subclause F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of Subclause F.7.3.12, the emission test is acceptable.

F.7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge.

c) **Test procedure:**

1) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter.

5) Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1. See Figure F.2.

~~6) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in Subclause F.7.2.2. Check for leakage of fuel, fuel byproducts, electrolyte and liquid fuel components using visual inspection with pH indicator and the water immersion test as described in Subclause F.7.2.1. See Figure F.2.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ (no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

F.7.3.7 External short-circuit test

Subclause F.7.3.7 replaces Subclause 7.3.7.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

1) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

2) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

3) Perform emission testing in accordance with Subclause F.7.3.12 after each short-circuit test. See Figure F.5.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ (no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

Exterior surfaces shall not exceed temperatures in Table 2 during or after short circuit testing.

Emissions shall meet the passing criteria in F.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of Subclause F.7.3.12, the emission test is acceptable.

NOTE The external short circuit test can be done sequentially with the surface component and exhaust gas temperature test using the same sample.

F.7.3.9 Long-term storage test

Subclause F.7.3.9 replaces Subclause 7.3.9 for micro fuel cell power systems, units and fuel cartridges covered by this Annex F.

a) **Test sample:** An unused or a used fuel cartridge

b) **Purpose:** to simulate the effects of long term storage at elevated temperature and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure F.9 for fuel cartridges.

2) Record initial mass M_0 and time t_0 and place sample in temperature chamber at 50 °C ± 2°C with a chamber relative humidity of at least 60 %.

3) The temperature chamber shall be equipped with ventilation and measurement instruments capable of accurately measuring the concentration of hydrogen in the chamber similar to the configuration in Figure F.10.

4) The ventilation flow rate and the hydrogen concentration of interest in the chamber shall be monitored continuously and recorded. See Table F.7. At no time during the test shall the hydrogen concentration in the chamber shall exceed 25 % LFL.

5) The sample shall remain in the chamber at 50 °C ± 2 °C with a chamber relative humidity of at least 60 % for at least 28 days.

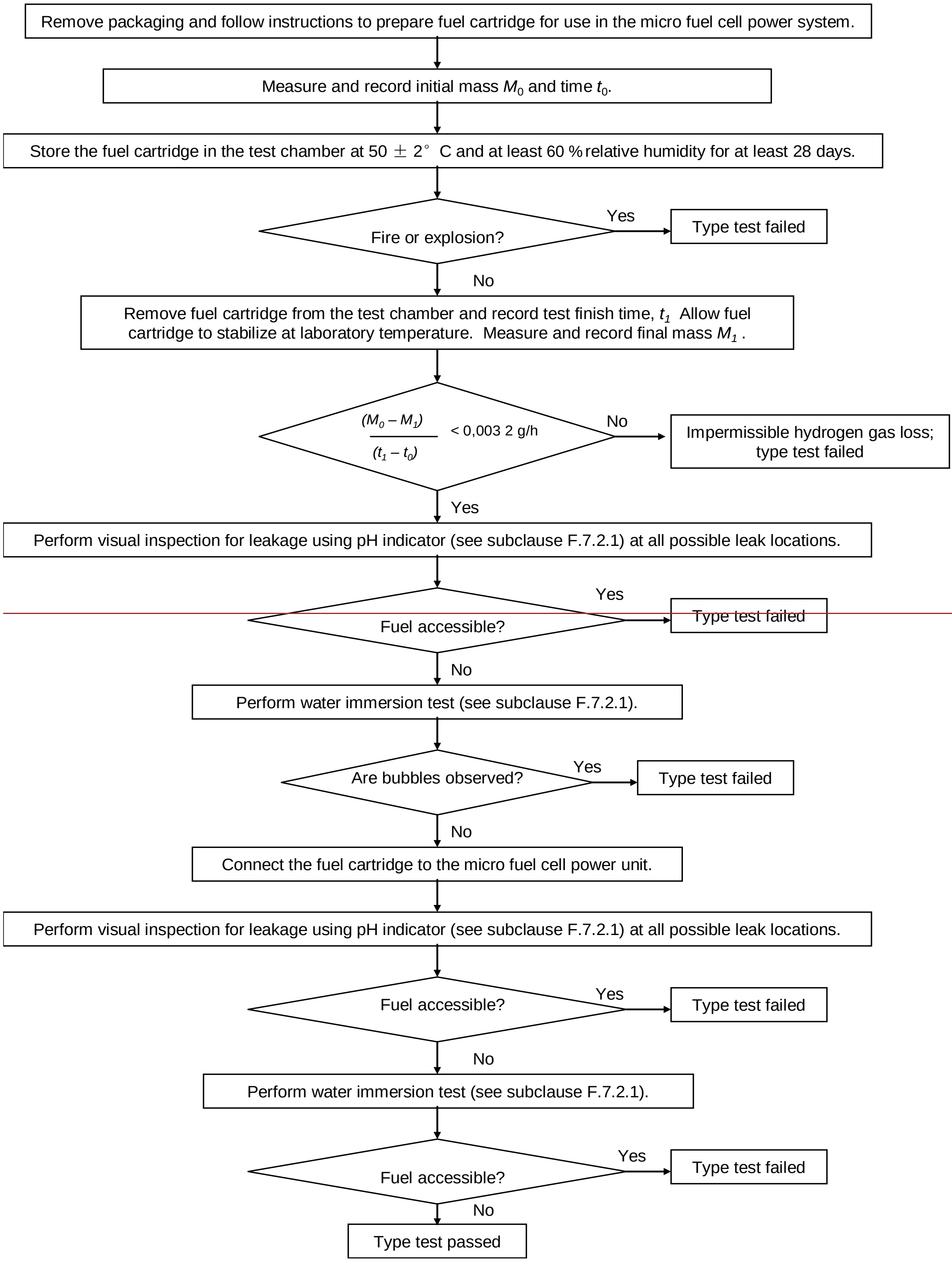
6) At the end of the 28 days, remove the fuel cartridge from the test chamber and record the time the fuel cartridge was removed from the test chamber, t_1. Allow the fuel cartridge to stabilize at laboratory temperature and record the final mass, M_1. Hydrogen gas loss is calculated as follows and shall not exceed 0,0032 g/h:

$$\frac{M_0 - M_1}{t_1 - t_0} < 0{,}0032 \text{ g/h}$$

7) ~~Perform fuel, fuel byproduct, electrolyte and liquid fuel component leakage testing using visual inspection with pH indicator and water immersion test in accordance with Subclause F.7.2.1 for the fuel cartridge.~~ Perform leakage tests in accordance with F.7.2.1 and hydrogen leakage measurements in accordance with F.7.2.2. See Figure F.9.

8) ~~Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for fuel, fuel byproduct, electrolyte, or liquid fuel component leakage using visual inspection with pH indicator and water immersion test as described in F.7.2.1. See Figure F.9.~~ See B.7.3.9 for alternative methods to measure and calculate impermissible hydrogen gas loss.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, or liquid fuel components. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~(no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. The hydrogen concentration in the chamber shall not exceed 25 % LFL at any time during the test. The hydrogen gas loss rate from the cartridge shall not exceed 0,0032 g/h at any time during the test. Fire, flame and explosion shall be checked using cheesecloth, infrared camera, or other suitable methods.


Remove packaging and follow instructions to prepare fuel cartridge for use in the micro fuel cell power system.
Measure and record initial mass M_0 and time t_0.
Store the fuel cartridge in the test chamber at 50 ± 2° C and at least 60 % relative humidity for at least 28 days.
Fire or explosion?
Yes
Type test failed
No
Remove fuel cartridge from the test chamber and record test finish time, t_1 Allow fuel cartridge to stabilize at laboratory temperature. Measure and record final mass M_1 .
$\frac{(M_0 - M_1)}{(t_1 - t_0)}$ < 0,003 2 g/h
No
Impermissible hydrogen gas loss; type test failed
Yes
Perform visual inspection for leakage using pH indicator (see subclause F.7.2.1) at all possible leak locations.
Fuel accessible?
Yes
Type test failed
No
Perform water immersion test (see subclause F.7.2.1).
Are bubbles observed?
Yes
Type test failed
No
Connect the fuel cartridge to the micro fuel cell power unit.
Perform visual inspection for leakage using pH indicator (see subclause F.7.2.1) at all possible leak locations.
Fuel accessible?
Yes
Type test failed
No
Perform water immersion test (see subclause F.7.2.1).
Fuel accessible?
Yes
Type test failed
No
Type test passed

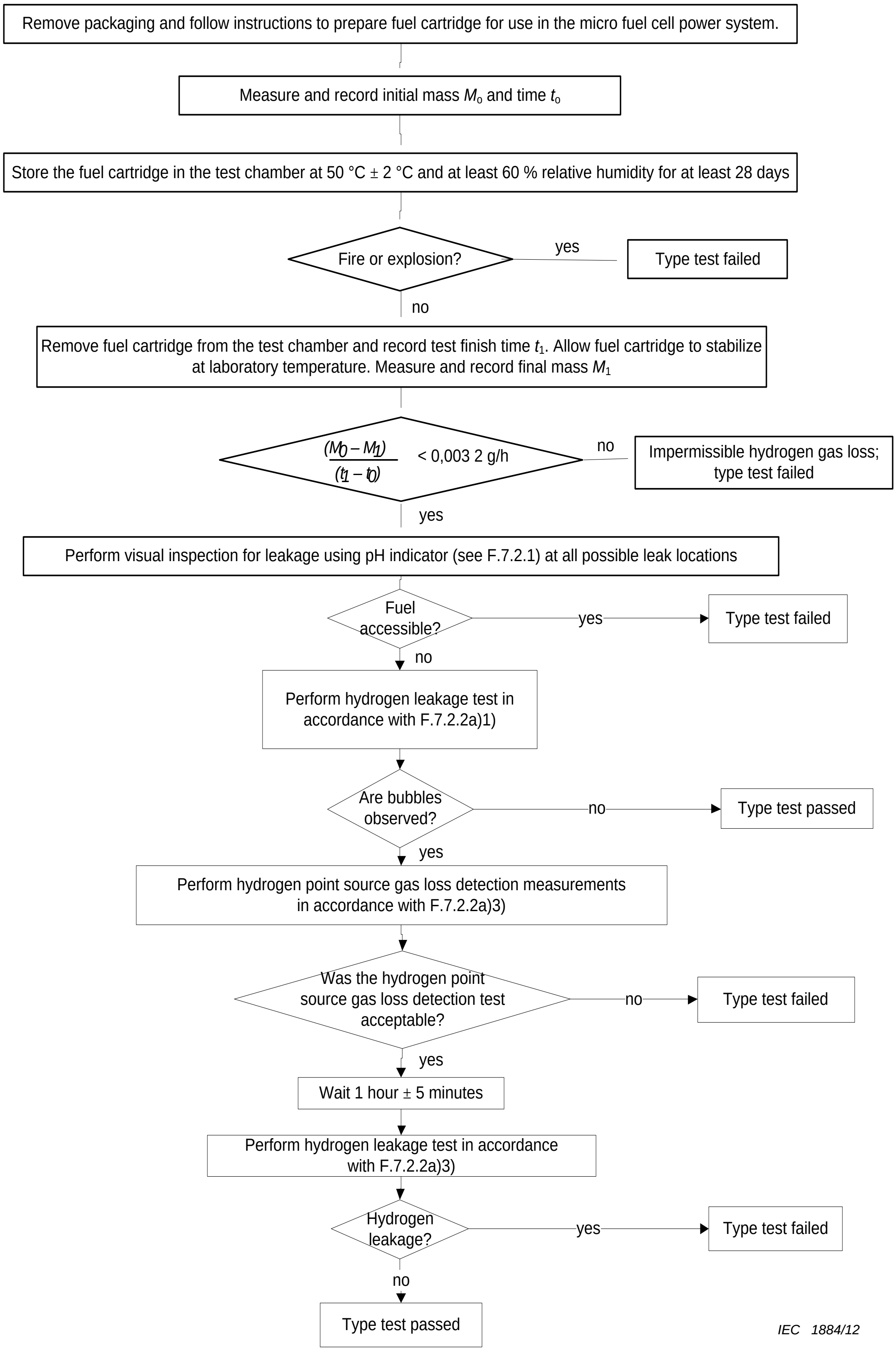


Figure F.9 – Fuel cartridge hydrogen leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9

F.7.3.10 High-temperature connection test

Subclause F.7.3.10 replaces Subclause 7.3.10.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage, no fire, no explosion.

c) **Test procedure:**

   1) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.

   2) The micro fuel cell power unit or test fixture with micro fuel cell power unit valve is kept at laboratory temperature.

   3) Remove the test sample from the chamber and connect the fuel cartridge to the micro fuel cell power unit or test fixture with micro fuel cell power unit valve within 5 min of removal from the chamber.

   4) Check for leakage upon connection. Perform fuel, fuel byproduct, electrolyte and liquid fuel component leakage testing by visual inspection with pH indicator~~ and water immersion test~~ in accordance with Subclause F.7.2.1. Perform hydrogen leakage testing using a liquid leak detector (bubble-forming) in accordance with Subclause F.7.2.2 for the fuel cartridge.

   5) Disconnect the fuel cartridge. Perform fuel, fuel byproduct, electrolyte and liquid fuel component leakage testing by visual inspection with pH indicator and water immersion test in accordance with Subclause F.7.2.1. Perform hydrogen leakage testing using a liquid leak detector (bubble-forming) in accordance with Subclause F.7.2.2 for the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage of Class 4.3 (water reactive) borohydride fuel, fuel by-products, electrolyte or liquid fuel components. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occur, the test is acceptable. Leakage of Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause F.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ (no bubbles formed) of the hydrogen leakage measurement procedure~~ of Subclause F.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually~~ to verify that there is no disturbance to the micro fuel cell power system/unit~~.

F.7.3.11 Connection cycling tests

Subclause F.7.3.11 replaces Subclause 7.3.11 for micro fuel cell power systems, units and fuel cartridges covered by this Annex F.

F.7.3.11.1 Fuel cartridge

F.7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused or a used insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as in the leakage test and measurement procedure specified in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in Subclause F.7.2.1.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as in specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage specified in the leakage test and measurement procedure specified in Subclause F.7.2.1.

5) Repeat this twice more for a total of three connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in Subclause F.7.2.1.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure specified in Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen specified in the leakage test and measurement procedure in Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as described in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage as specified in the leakage test and measurement procedure in Subclause F.7.2.1.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure in Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the leakage test and measurement procedure in Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water

reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure in Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator and water immersion test as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

~~14) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and perform emissions testing as specified in Subclause F.7.3.12.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel component leakage, no impermissible hydrogen gas loss or emissions. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ of the hydrogen leakage measurement procedure (no bubbles)~~ of Subclause F.7.2.2 for the fuel cartridge. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1; for clarification, it is acceptable to perform the (second) hydrogen leakage/water immersion test in accordance with Subclauses F.7.2.2a)3) and F.7.2.1b)3) once, following all 10 connection-disconnection cycles (in step 13), rather than repeat at each disconnection step (e.g. steps 1, 4, 6, 8, 10).~~ Hydrogen gas loss shall meet the requirements of Subclause F.7.2.3. Emissions must meet passing criteria of Subclause F.7.3.12 for operational and non-operating systems.~~

F.7.3.11.1.2 Satellite cartridge

a) **Test sample:** an unused satellite fuel cartridge and an unused micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer’s instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproduct, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1. Initiate or simulate fuel flow.

2) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the

hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

3) Repeat this twice more for a total of three connections and disconnections.

4) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

5) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

7) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

9) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and initiate or simulate fuel flow.

10) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1,

11) Repeat steps 1 through 10 four more times for a total of 55 cycles, waiting 1 h between each set of 11 cycles.

~~12) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and perform emissions testing as specified in Subclause F.7.3.12.~~

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel component leakage, no impermissible hydrogen gas loss or emissions. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen leakage shall meet the no hydrogen leakage requirements~~ of the hydrogen leakage measurement procedure (no bubbles)~~ of Subclause F.7.2.2 for the fuel cartridge. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1; for clarification, it is acceptable to perform the (second) hydrogen leakage/water immersion test in accordance with F.7.2.2a)3) and F.7.2.1b)3) after each set of 10 connection-disconnection cycles (in step 10), rather than repeating at each disconnection step (e.g. steps 1, 2, 4, 6, 8).~~ Hydrogen gas loss shall meet the requirements of Subclause F.7.2.3. Emissions must meet passing criteria of Subclause F.7.3.12 for operational and non-operating systems.~~

F.7.3.11.2 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

1) Connect the first fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and the fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet

the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

5) Repeat this twice more for a total of three connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

7) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

9) Connect and disconnect the first fuel cartridge three more times for a total of ten connections and disconnections.

10) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

11) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

12) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

13) Turn off the micro fuel cell power unit or stop simulated fuel flow.

14) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

15) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.

    i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections.

    ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.

    iii) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. If leakage is found, the test fails.

    iv) Following this ageing, a final unused fuel cartridge will be tested.

16) Connect the final unused fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and the fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

17) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

18) Turn off the micro fuel cell power unit or stop simulated fuel flow.

19) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

20) Repeat this twice more for a total of three connections and disconnections.

21) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

22) Connect and disconnect the final fuel cartridge four more times for a total of seven connections and disconnections.

23) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

24) Connect and disconnect the final fuel cartridge three more times for a total of ten connections and disconnections.

25) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

26) Connect the fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

27) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

28) Turn off the micro fuel cell power unit or stop simulated fuel flow.

29) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause F.7.2.2 for the fuel cartridge and fuel management system, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause F.7.2.2. Check for Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement

procedure in Subclause F.7.2.1. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause F.7.2.1.

30) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and perform hydrogen gas loss testing in accordance with F.7.2.3 (including emission testing ~~as specified in Subclause~~ in accordance with F.7.3.12). If the micro fuel cell power system or unit contains an internal reservoir that contains hydrogen gas above ambient pressure, perform hydrogen leakage measurements in accordance with F.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel component leakage, no impermissible hydrogen gas loss or emissions. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen leakage shall meet the no hydrogen leakage requirements ~~of the hydrogen leakage measurement procedure (no bubbles)~~ of Subclause F.7.2.2 for the fuel cartridge. Class 4.3 (water reactive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause F.7.2.1. Hydrogen gas loss shall meet the requirements of Subclause F.7.2.3. Emissions must meet passing criteria of Subclause F.7.3.12 for operational and non-operating systems. For clarification, it is acceptable to perform the (second) hydrogen leakage/water immersion test in accordance with F.7.2.2a)3) and F.7.2.1b)3) after each set of 10 connection-disconnection cycles (in step 14 and step 29), rather than repeat at each connection-disconnection step (e.g. steps 1, 4, 6, 8, 10, 11, 16, 19, 21, 23, 25, and 26).

F.7.3.12 Emission test

This Subclause F.7.3.12 shall replace Subclause 7.3.12 for Class 4.3 (water reactive) borohydride micro fuel cell power systems or units tested in accordance with Annex F. The included Table F.7, Emission limits, replaces Table 7 in Subclause 7.3.12. Figure F.10 replaces Figure 10 and is identical to Figure 10. Hydrogen emissions are evaluated separately. The procedure for hydrogen emission testing is detailed in Figure F.13, which is to be used as an additional figure when testing is done in accordance with Annex F.

a) **Test sample:** A micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under normal operating conditions, indirect borohydride powered micro fuel cell power systems may have emissions. The emissions may be comprised of water or hydrogen, both of which are known not to be toxic. Indirect borohydride micro fuel cell power systems do not normally emit CO, CO_2, formaldehyde or other volatile organic compounds. However, there is a remote possibility that indirect borohydride micro fuel cell power systems utilizing fuels or liquid fuel components containing organic additives may emit CO, CO_2, formaldehyde, or other volatile organic compounds under abnormal circumstances. Because this possibility exists, emission limits for CO, CO_2, formaldehyde, and volatile organic compounds for micro fuel cell power systems utilizing fuels or liquid fuel components containing organic compounds are imposed by this annex and are listed in Table F.7.

The possibility for hydrogen emissions exists for non-operating indirect borohydride micro fuel sell power systems. Hydrogen emissions testing shall therefore be performed with the micro fuel cell power system off ("DEVICE – OFF") as an additional test. Hydrogen emissions shall be below the allowable 0,0032 g/h with the "DEVICE – OFF" limit given to avoid harmful exposures.

Micro fuel cell power systems emit water vapour and under certain conditions this water vapour can condense. This condensation is not considered an emission or a leak if the pH of the condensate is between 3,5 and 10,5 pH.

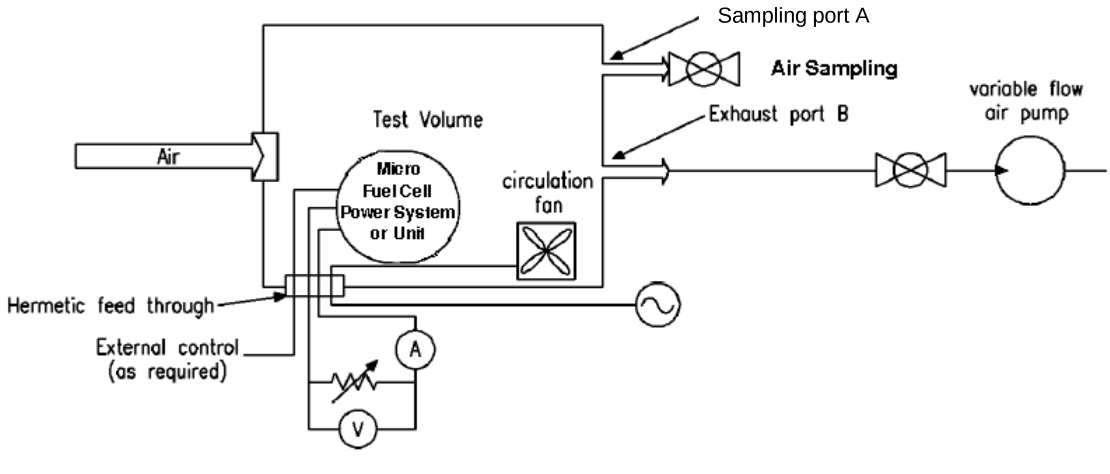


Figure F.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the operational emission test apparatus is shown in Figure F.10. The configuration shown in Figure F.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex F. Emission rate testing in accordance with Subclause F.7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex F.

To analyse the hydrogen emissions, a mass spectrometer, gas chromatograph, or other suitable instrument calibrated to measure hydrogen concentration shall be used and connected to sampling port A in Figure F.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer's mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.), additional testing in accordance with Subclause F.7.3.12 d) 1) and Subclause F.7.3.12 d) 2) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure F.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer's mouth or nose when in use) for emissions concentration limit testing.

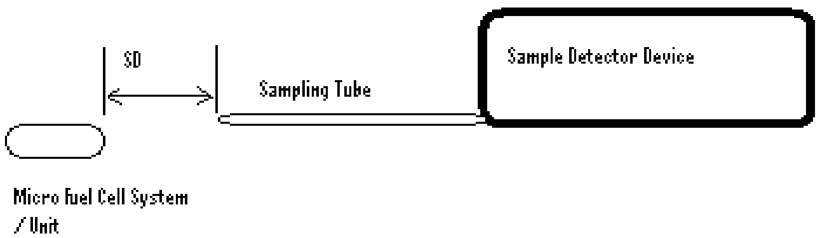


Figure F.11 – Operational emission concentration testing apparatus – Replaces Figure 11

Emission gases might be composed of toxic organic materials such as carbon dioxide, carbon monoxide and formaldehyde, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS) shall be used by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure F.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

The concentration of CO and CO_2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure F.13, which is to be used as an additional figure when testing is done in accordance with Annex F.*

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed with the micro fuel cell power system or unit on ("DEVICE – ON") as follows.

   i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure F.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

   ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

   iii) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure F.10.

   iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

   v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure F.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

   vi) Record the concentrations of chemical compounds of interest. See Table F.7.

   vii) Calculate the emission rate of chemical compounds being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_\text{P} + F_\text{S}) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in standard litres per hour;

F_S is the sample flow rate in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured "DEVICE – ON" emission rate to Table F.7. If the emission rate is not less than the emission rate limit in Table F.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria in Subclause F.7.3.12 e) 1) i) and Subclause F.7.3.12 e) 2) i).

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer's mouth or nose, the following additional emissions concentration sampling test shall be performed with the micro fuel cell power system or unit on "DEVICE – ON" as follows.

i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power in the large open room while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure F.11. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission concentration test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the "ON" position ("DEVICE – ON").

iii) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

iv) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure F.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer's mouth or nose when in use).

v) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

vi) Allow the sample flow rate to stabilise.

vii) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

viii) Record the concentrations of the chemical compounds of interest. See Table F.7.

ix) Compare the maximum measured concentrations to Table F.7. If the emission concentrations are not less than the emission concentration limits in Table F.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria in Subclause F.7.3.12 e) 2) ii).

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

3) Upon completion of the emissions measurements with both "DEVICE – ON" in accordance with Table F.7, “DEVICE – ON” hydrogen emissions are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure F.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure F.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure F.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the hydrogen concentration.

vii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

C is the concentration in grams per standard litre.

viii) Compare the maximum measured "DEVICE – ON" hydrogen emission rate to Table F.7.

NOTE This is a stabilised concentration measurement.

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

4) Upon completion of the hydrogen emissions measurements with "DEVICE – ON", hydrogen emissions with ("DEVICE – OFF") are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure F.10 for 10 min or until 10 % of the fuel capacity of a full fuel cartridge is used up, whichever is less.

ii) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") and measure the emission rates with the micro fuel cell power system or unit off ("DEVICE – OFF") inside the small test chamber shown in Figure F.10.

iii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iv) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown on Figure F.10.

v) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

vi) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure F.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vii) Record the hydrogen concentration.

viii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

C is the concentration in grams per standard litre.

ix) Compare the maximum measured "DEVICE – OFF" hydrogen emission rate to Table F.7.

NOTE This is a stabilised concentration measurement.

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

5) Evaluate the hydrogen emission rate as follows.

   i) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and below the allowable 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or unit passes the test and no further testing is necessary.

   ii) If the hydrogen emission rate measurement is not below the allowable 0,0032 g/h with the "DEVICE – OFF" and not below the total allowable 0,8 g/h with the "DEVICE – ON", the system or unit fails the test and no further testing is necessary.

   iii) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and is below the total allowable 0,08 g/h with the "DEVICE – ON" but is not below 0,016 g/h with the "DEVICE – ON", then proceed with Subclause F.7.3.13, hydrogen point source gas loss detection test to verify that no single source of hydrogen exceeds 0,016 g/h.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

   i) The maximum emission rate for each of the constituents of interest in Table F.7 shall be less than the emission rate limit value in Table F.7 when tested in accordance with Subclause F.7.3.12 d) 1) for "DEVICE – ON" and Subclause F.7.3.12 d) 2) for "DEVICE – ON" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer’s mouth or nose:

   i) The maximum emission rate for each of the constituents of interest in Table F.7 shall be less than the emission rate limit value in Table F.7 when tested in accordance with Subclause F.7.3.12 d) 1) for "DEVICE – ON" and Subclause F.7.3.12 d) 2) for "DEVICE – ON" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

   ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer’s mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall not exceed the emission concentration limit in Table A.7 when tested in accordance with Subclause F.7.3.12 d) 3) "DEVICE – ON" and Subclause F.7.3.12 d) 4) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

3) Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure F.13, which is to be used as an additional figure when testing is done in accordance with Annex F.* Upon completion of the hydrogen emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table F.7, hydrogen emissions are evaluated as follows.

   i) **Passing criteria for non-operating systems:** The hydrogen emission rate shall be less than 0,0032 g/h with the "DEVICE – OFF".

   ii) **Passing criteria for operational systems:** If the total hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or micro fuel cell power unit passes the emission test and no further testing is required. If the total hydrogen emission rate is not less than 0,8 g/h with the “DEVICE – ON”, the micro fuel cell power system or unit fails the emission test and no further testing is required. If the hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", F.7.3.13, hydrogen point source gas loss detection test must be performed with acceptable results to show no more than 0,016 g/h hydrogen leakage from any single point leak.

NOTE 1 The allowable flammable hydrogen emission level that will not support a standing flame is 3 ml/min (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, *Codes and Standards Analysis*, 2001 *(USA)*). The non-flammable hydrogen emissions limit is based on the criteria that hydrogen emission does not build up to more than 25 % of LFL in the reference volume.

NOTE 2 Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

NOTE 3 Carbon dioxide and carbon monoxide vapour emission level limits are based on toxicity effects on humans while the hydrogen emissions level limit is based on the risk of creating a flammable atmosphere in confined spaces and the risk of a potential standing hydrogen flame.

Table F.7 – Emission limits – Replaces Table 7

Emissions	**"DEVICE – ON"** **Concentration limit** [a] based on TWA values for "DEVICE – ON" test condition	**"DEVICE – ON"** **Permissible emissions rate in 10 m^3 ACH volume** [b]	**Impermissible gas loss**[c] **(including "DEVICE – OFF")**
Water	Unlimited for pH between 3,5 and 10,5	Unlimited for pH between 3,5 and 10,5	Unlimited for pH between 3,5 and 10,5
Hydrogen	0,8 g/m^3	0,8 g/h total 0,016 g/h from single point leak[f]	0,0032 g/h total
Formaldehyde[d]	0,000 1 g/m^3	0,000 6 g/h	0,000 6 g/h
CO	0,029 g/m^3	0,290 g/h	0,290 g/h
CO_2	9 g/m^3	60 g/h[~~c~~e]	60 g/h[e]
Volatile organic carbon compounds[e]	0,000 1 g/m^3	0,000 6 g/h	0,000 6 g/h

~~Table F.7 replaces Table 7.~~

a The concentration limits for CO and CO_2 in this table are the mg/m^3 equivalent of the TWA and STEL exposure limits.

b The "DEVICE – ON" emission rate limit was based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is over 20 m^3, so a product of 10 is conservative. A further factor of safety of 10 has been added for hydrogen in this specific case.

c The "impermissible hydrogen gas loss" criteria for non-operating micro fuel cell power systems has been chosen based on a scenario of micro fuel cell power systems in an enclosed space with no ventilation. The space chosen has a volume of 0,28 m^3, or approximately 10 cubic feet. The criterion has been prescribed so that a hydrogen concentration of greater than 25 % LFL is not permitted to develop over a twenty-four hour (24 h) period, if three micro fuel cell power systems are in the enclosed space.

d WHO guideline limit is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The emission limit cannot push the background level above the guideline limit.

~~c~~e A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO 8 h concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

f The allowable flammable hydrogen emission level that will not support a standing flame is 3 standard ml/min, which is equivalent to 0,016 g/h. (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, Codes and Standards Analysis, 2001 (USA)).

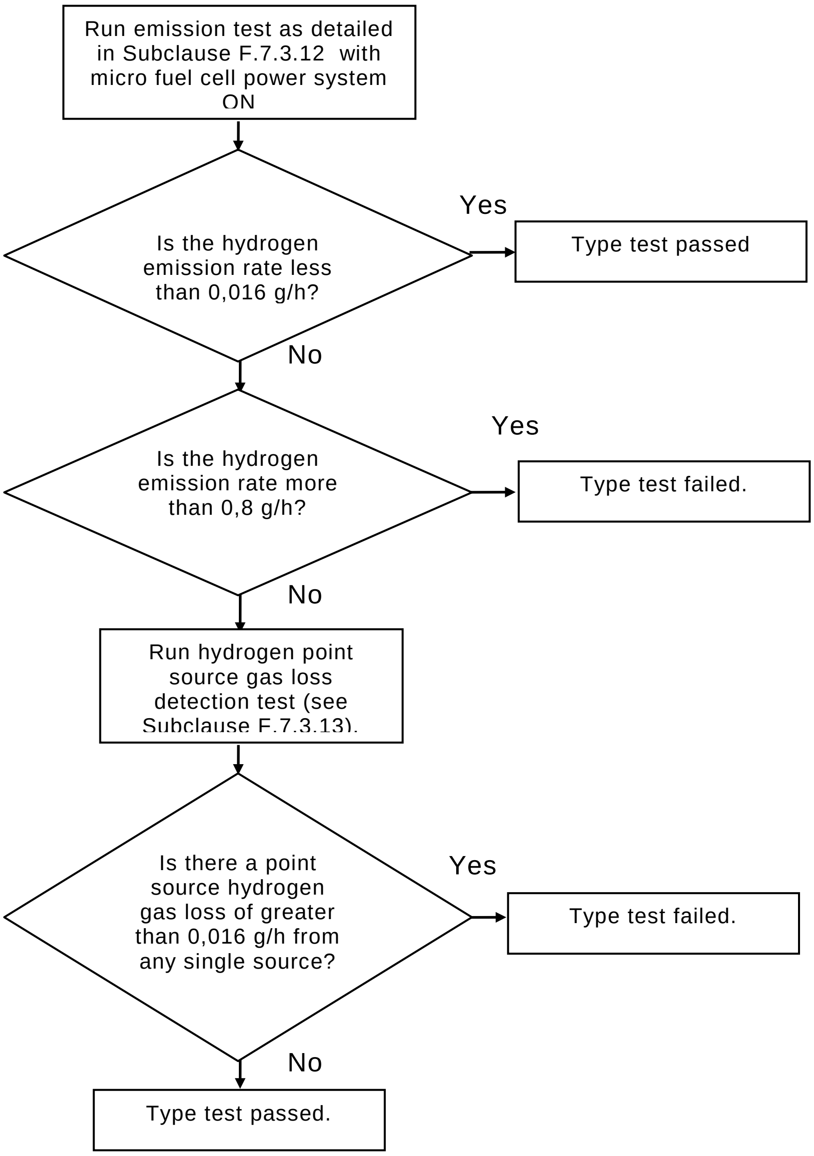
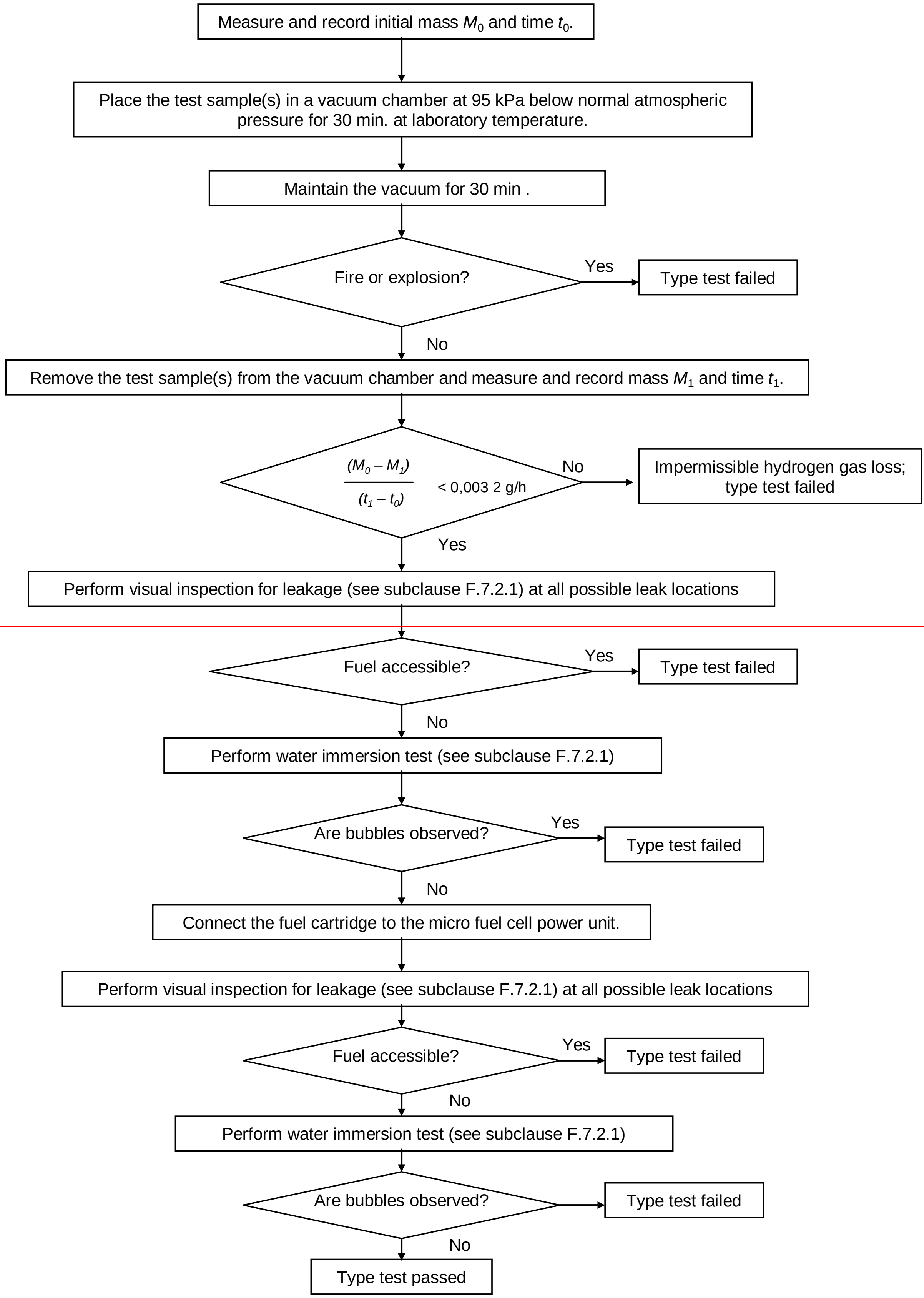


Figure F.13 – Hydrogen emission test procedure for operating micro fuel cell power system


Measure and record initial mass M_0 and time t_0.
Place the test sample(s) in a vacuum chamber at 95 kPa below normal atmospheric pressure for 30 min. at laboratory temperature.
Maintain the vacuum for 30 min .
Fire or explosion?
Yes
Type test failed
No
Remove the test sample(s) from the vacuum chamber and measure and record mass M_1 and time t_1.
$\frac{(M_0 - M_1)}{(t_1 - t_0)}$ < 0,003 2 g/h
No
Impermissible hydrogen gas loss; type test failed
Yes
Perform visual inspection for leakage (see subclause F.7.2.1) at all possible leak locations
Fuel accessible?
Yes
Type test failed
No
Perform water immersion test (see subclause F.7.2.1)
Are bubbles observed?
Yes
Type test failed
No
Connect the fuel cartridge to the micro fuel cell power unit.
Perform visual inspection for leakage (see subclause F.7.2.1) at all possible leak locations
Fuel accessible?
Yes
Type test failed
No
Perform water immersion test (see subclause F.7.2.1)
Are bubbles observed?
Type test failed
No
Type test passed

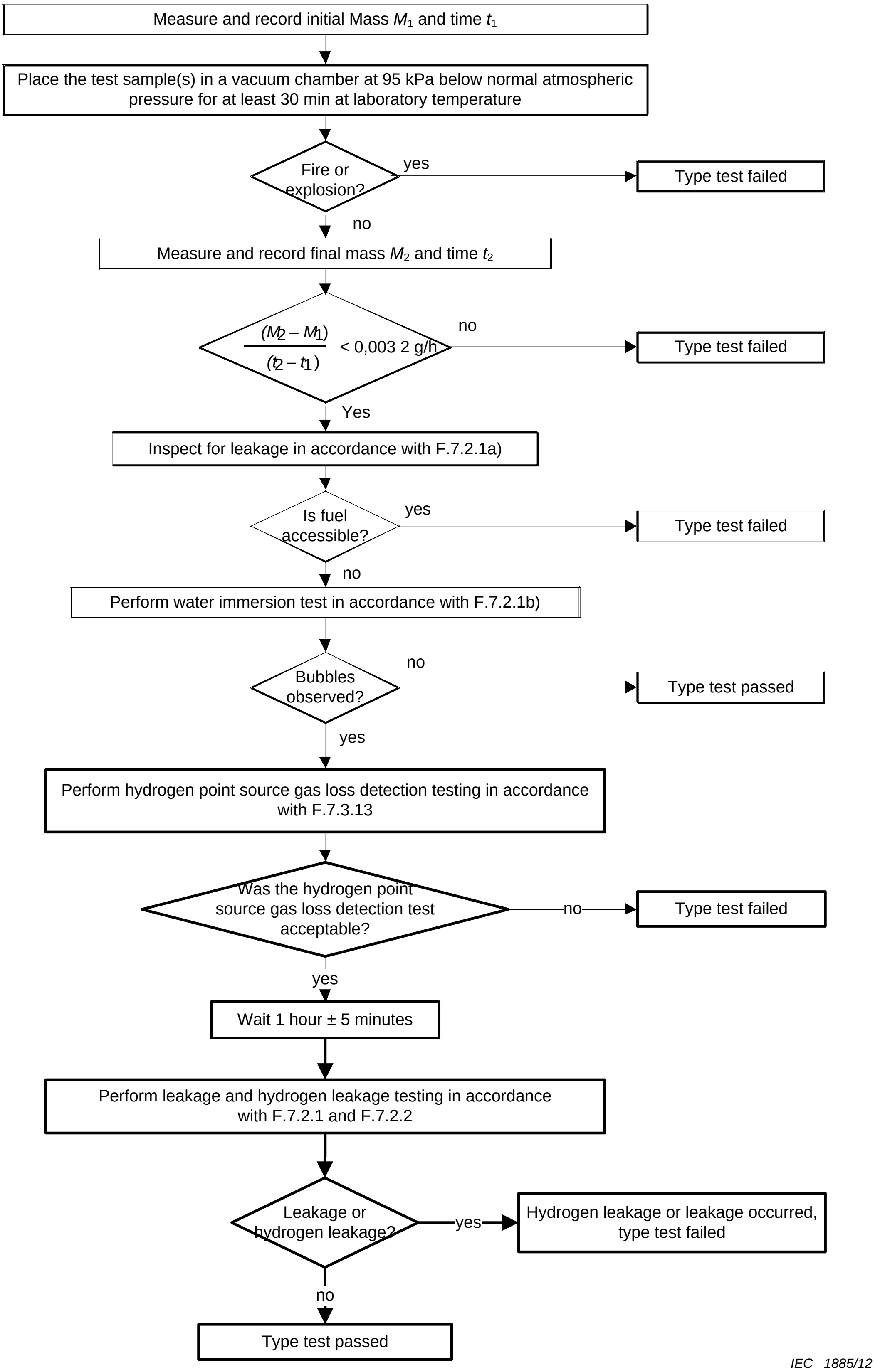


Figure F.14 – Fuel cartridge leakage test flow chart for ~~low~~ external pressure test

F.7.3.13 Hydrogen point source gas loss detection test

The procedure for hydrogen emission testing is detailed in Figure F.13, which is to be used as an additional figure when testing is done in accordance with Annex F. This subclause is additional to the requirements in Clause 7.

This subclause shall be used if required by Subclause F.7.3.12 d) 5) iii) to show compliance with Table F.7, for Class 4.3 (water reactive) borohydride micro fuel cell power systems and Class 4.3 (water reactive) borohydride micro fuel cell power units. This subclause is required to be performed to meet the passing criteria of Subclause F.7.3.12 e) 3) ii) if the total hydrogen emission rate from an operational Class 4.3 (water reactive) borohydride micro fuel cell power system or unit is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON".

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge or a fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit that is fuelled with Class 4.3 (water reactive) borohydride emission of hydrogen shall be maintained at less than the specified values in Table F.7. The hydrogen point source gas loss detection test shall be performed to determine that no single source on the micro fuel cell power system or unit can support a flame in all cases where such compliance cannot be definitively determined by the hydrogen emission test. Maintaining these limits ensures that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame and along with the other emissions testing ensures an adequate supply of oxygen is maintained in the operating environment

c) **Test apparatus:** The surface of the ~~micro fuel cell power system or unit~~ test sample shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, a hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL. The response of the aforementioned hydrogen detectors is commonly slow, with a response time of many seconds, thus high sweep speeds may cause underestimation of the hydrogen concentration. It is important that the sweep speed shall be slow enough to accurately measure the hydrogen concentration.

d) **Test procedure:**

1) The micro fuel cell power system or micro fuel cell power unit shall remain turned on ("DEVICE – ON") throughout the duration of the hydrogen point source gas loss detection test.

2) The testing shall be conducted in a space with no substantial air movement. The measured wind speed 10 cm above the ~~micro fuel cell power system or unit~~ test sample shall not exceed 0,02 m/s. The local concentration of hydrogen diffusion measured in this test is very susceptible to the effect of wind. It is desirable that wind speed anywhere in the test space is as close to zero as possible. Testing in a closed space, such as a glove box or equivalent chamber, is one available method to achieve this requirement.

3) The surface of the ~~micro fuel cell power system or unit~~ test sample shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

4) The sensor of the hydrogen detector shall sweep the ~~micro fuel cell power system or unit~~ test sample at a distance no more than 3 mm normal to the surface of the ~~micro fuel cell power system or unit~~ test sample. Consecutive linear sweeps shall not be more than 8 mm apart along the surface of the ~~micro fuel cell power system or unit~~ test sample. The entire surface of the ~~micro fuel cell power system or unit~~ test sample shall be swept in this manner.

5) An effective method for completing these sweeps would be to attach a stand off to the sensor that ensures that a spacing of 3 mm from the ~~micro fuel cell power system or unit~~ test sample is maintained at all times. A pen or other marking utensil attached to the stand off could be used to identify swept areas and ensure that the distance between sweeps does not exceed 8 mm.

6) The sensor should always face directly downward, and the ~~micro fuel cell power system or unit~~ test sample should be moved beneath it such that the surface directly below the sensor is always horizontal.

7) If no points are found where the hydrogen concentration is greater than 25 % LFL, the test is complete and the ~~micro fuel cell power system or unit~~ test sample shall be considered to have passed.

8) When some point source sweeps show a large region of 25 % LFL or greater in the initial linear sweeps, recording the measured concentration values will assist in determining the starting point of secondary spiral sweeps. Point sources are supposed to be where local maximum values exist in the distribution of measured concentration values.

9) If any points are detected to have a hydrogen concentration of 25 % LFL or greater, a second test shall be conducted to ensure that the emission does not exceed 0,016 g/h of pure hydrogen from any single source.

10) The second test shall be performed with the sensor height adjusted to 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample.

11) A spiral sweep shall then be made, originating from the point where the detection of 25 % LFL or greater of hydrogen occurred during the initial linear sweep. The spiral sweep shall have a spacing of 1 mm or less between sweeps, and shall spiral out to a radial distance of at least 4 mm and far enough to detect the maximum hydrogen level from the particular hydrogen source.

12) If the spiral sweep at 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the ~~micro fuel cell power system or unit~~ test sample fails the test. If the spiral sweep does not detect any hydrogen concentrations of 25 % LFL or greater, the ~~micro fuel cell power system or unit~~ test sample passes the test.

e) **Passing criteria:** No gas loss of hydrogen from any single source at greater than 0,016 g/h as indicated by sweep testing. No indications of hydrogen that is 25 % of LFL during the primary sweep testing or no indications of hydrogen that is 25 % of LFL during the secondary sweep testing at 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample. If the spiral sweep at 6,5 mm above the ~~micro fuel cell power system or unit~~ test sample detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the ~~micro fuel cell power system or unit~~ test sample fails the test. See Table F.7.

Annex G
(normative)

Borohydride micro fuel cell power systems: Class 8 (corrosive) compounds in direct borohydride fuel cells

G.1 Scope

G.1.2 Fuel and technology covered by this annex

Annex G covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges using Class 8 (corrosive) borohydride compound fuels directly.

Figure G.1 replaces Figure 1 showing a direct borohydride micro fuel cell power system block diagram for use with this annex.

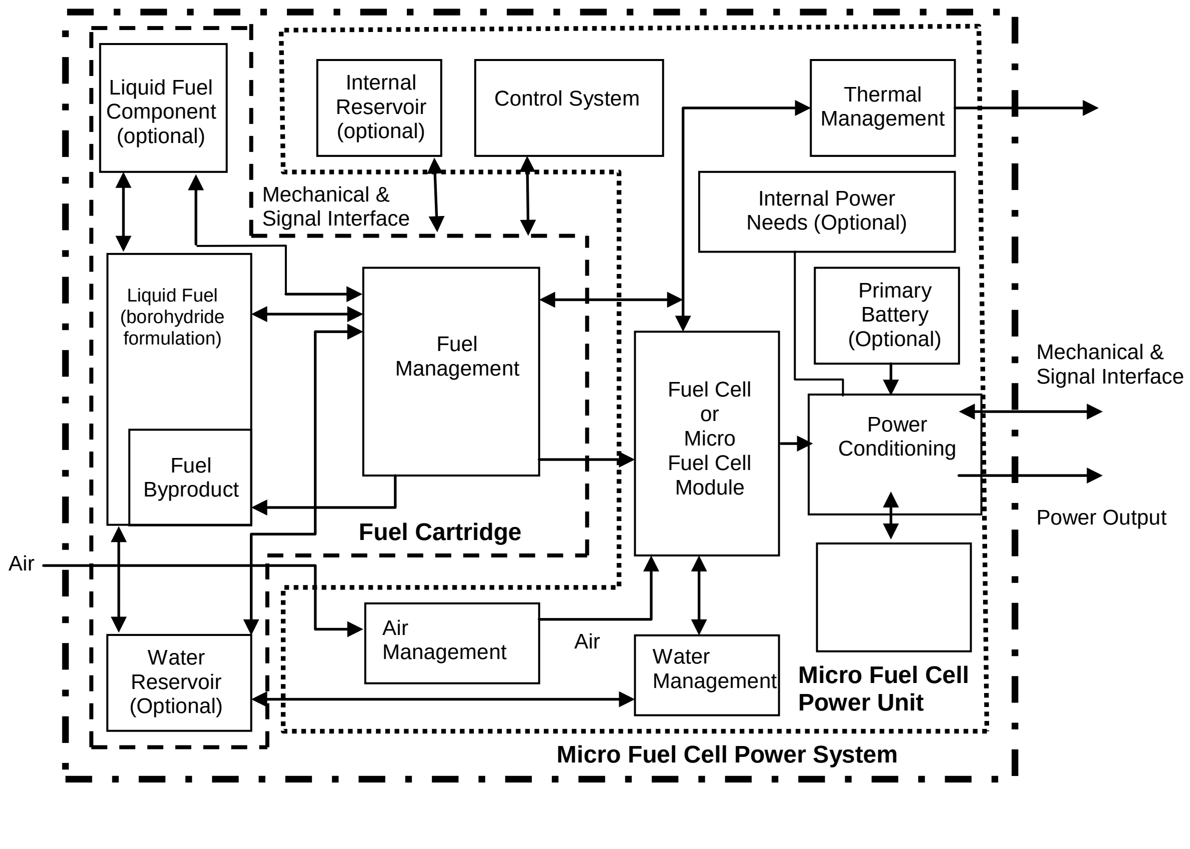


Figure G.1 – Direct borohydride micro fuel cell power system block diagram – Replaces Figure 1

G.1.3 Equivalent level of safety

This subclause replaces Subclause 1.3.

a) The requirements of this standard are not intended to constrain innovation. The manufacturer may consider fuels, materials, designs or constructions not specifically dealt with in this standard. These alternatives should be evaluated as to their ability to yield levels of safety equivalent to those prescribed by this standard.

b) It is understood that all micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall comply with applicable country and local requirements including, but not limited to, those concerning transportation, child-resistance, and storage, where required.

c) The following similarities between methanol and direct borohydride micro fuel cell power systems are provided to enhance understanding of why the direct borohydride requirements mimic methanol requirements with minimal changes.

   1) The similarity in micro fuel cell power system components (see Figure 1 and Figure G.1).

   2) Both types of micro fuel cell power systems use liquid fuels and both micro fuel cell power systems have the “no accessible liquid” criteria for no leakage (see definitions in Clause G.3).

   3) Both types of micro fuel cell power systems may have similar gaseous emissions components and thus shall have similar criteria for measurement and analysis of the emissions, and the same considerations shall be made for emission risk levels.

   4) Formaldehyde and methyl formate emissions seen in methanol micro fuel cell power systems are not present in direct borohydride micro fuel cell power systems.

   5) Hydrogen emissions are possible when sodium or potassium borohydride is in contact with decomposition catalysts with no load on the fuel cell. Properly functioning non-operating micro fuel cell power systems shall have fail-safe mechanisms to prevent fuel flow to the catalysts. Failure modes and effects analysis and related testing shall ensure protection against such failure modes and ensure existence of relevant design mitigations.

   6) Since even with the micro fuel cell power system off, hydrogen may be produced from a direct borohydride fuel cartridge and a micro fuel cell power system, the emission test shall be performed with the micro fuel cell power system off "DEVICE – OFF" as an additional test.

   7) Hydrogen and water vapour are possible emissions from an operational "DEVICE – ON" micro fuel cell power system.

   8) Sodium and potassium borohydride fuels are non-flammable; thus warning statements for the product related to fuel flammability do not apply to direct borohydride micro fuel cell power system products.

G.2 Normative references

In addition to the normative references specified in Clause 2, the following normative documents are indispensable for the application of this document.

ISO 16111, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

G.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex G. All terms and conditions in Clause 3 not specifically mentioned here also apply.

G.3.5
fuel
Class 8 (corrosive) formulation of borohydride compounds used to produce electricity directly in a micro fuel cell power system

G.3.7
direct borohydride micro fuel cell power system
micro fuel cell power system in which a liquid formulation of borohydride compounds chemically reacts on an anode of a fuel cell to produce electricity in a micro fuel cell power system

G.3.8
liquid fuel, corrosive
materials which are classified as Class 8: corrosive substances under the guidelines of the 15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

Liquid formulation of borohydride compounds used as fuel for a direct borohydride micro fuel cell power system.

G.3.11
leakage
accessible fuel, fuel by-products, electrolyte or liquid fuel components outside the micro fuel cell power system or fuel cartridge; hydrogen leakage or impermissible hydrogen gas loss

The additional terms and their definitions below are needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex G in addition to those given in Clause 3.

G.3.37
borohydride compounds
sodium or potassium borohydride, or a mixture thereof

G.3.38
liquid fuel component
Class 8 (corrosive), or non-hazardous, water solutions used to produce hydrogen within the fuel processing subsystem

G.3.39
electrolyte
corrosive (alkaline) compound solution or ion conducting membrane used to complete an electric circuit within a fuel cell

G.3.40
fuel byproducts
Class 8 (corrosive), or non-hazardous compounds produced after hydrogen and/or electricity is produced from fuel

G.3.41
impermissible hydrogen gas loss
hydrogen gas escaping non-operating micro fuel cell power system or micro fuel cell power unit greater than or equal to 0,0032 g/h

G.3.42
accessible fuel, fuel byproducts, electrolyte or liquid fuel components
fuel, fuel byproducts, electrolyte or liquid fuel components that the consumer may come into physical contact with during normal use, reasonably foreseeable misuse, and consumer transportation

G.3.43
Class 8 (corrosive)
materials which are classified as Class 8: Corrosive Substance under the guidelines of the 15^{th} edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

G.3.44
non-hazardous
materials which are not subject to guidelines of the 15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

G.3.45
alkali metal hydroxide
hydroxides of sodium, potassium and lithium used in Class 8 (corrosive) liquid fuels

G.3.46
used fuel cartridge
fuel cartridge that that has been put into operation such that at least 45 % of the initial fuel has been utilized and that the operation of the micro fuel cell power system has been halted for at least 1 h

G.3.47
hydrogen leakage
hydrogen gas outside fuel containment system, including fuel cartridge, fuel management and internal reservoir, if applicable (see G.7.2.2)

G.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

G.4.4 Selection of materials

These requirements replace the corresponding requirements of Subclause 4.4.

These requirements of Subclause G.4.4, below, apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

G.4.4.1 Micro fuel cell power systems and units are expected to be exposed to a number of environmental conditions over the manufacturer-defined life span of the product such as vibration, shock, varying humidity levels and corrosive environments. Materials employed in the micro fuel cell power system or unit shall be resistant to these environmental conditions. If a micro fuel cell power system or unit is to be used in service where specific environmental conditions are beyond those accounted for in the required tests of this standard, then additional testing shall be performed to verify safety under those environmental conditions.

G.4.4.2 Metallic and non-metallic materials used to construct internal or external parts of the micro fuel cell power system or unit, in particular those exposed directly or indirectly to moisture, fuel and/or byproducts in either a gas or liquid form as well as all parts and materials used to seal or interconnect the same, e.g. welding consumables, shall be suitable for all physical, chemical and thermal conditions which are reasonably foreseeable under the normal transportation and normal usage conditions within the manufacturer-defined life span of the product and for all test conditions; in particular, they shall be designed to retain their mechanical stability under normal use;

- they shall be sufficiently resistant to the chemical and physical action of the fluids that they contain and to environmental degradation;
- the chemical and physical properties necessary for operational safety shall not be significantly affected within the manufacturer-defined life span of the product; specifically, when selecting materials and manufacturing methods, due account shall be taken of the material’s corrosion and wear resistance, electrical conductivity, impact strength, ageing resistance, the effects of temperature variations, the effects arising when materials are put together (e.g. galvanic corrosion), and the effects of ultraviolet radiation;
- where conditions of erosion, abrasion, corrosion or other chemical attack may arise, adequate measures shall be taken to

- minimize that effect by appropriate design, e.g. additional thickness, or by appropriate protection, e.g. use of liners, cladding materials or surface coatings, taking due account of normal use;
- permit replacement of parts which are most affected;
- and draw attention, in the manual referred to in Clause 6, to type and frequency of inspection and maintenance measures necessary for continued safe use; where appropriate, it shall be indicated which parts are subject to wear and the criteria for replacement.

• Fuel containing parts, such as piping systems, shall employ materials suitable for exposure to hydrogen, as defined in 5.2 of ISO 16111. Annex A of ISO 16111 details material compatibility for hydrogen service.

G.4.4.3 Elastomeric materials such as gaskets and tubing in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperatures that they are exposed to during normal use. Compliance shall be determined by the following: ISO 188.

G.4.4.4 Polymeric materials in contact with fuels shall be resistant to deterioration when in contact with those fuels and shall be suitable for the temperature they are exposed to during normal use. Compliance shall be determined by ISO 175.

G.4.4.5 Piping systems exposed to hydrogen shall employ materials suitable for exposure to hydrogen, as defined in Annex A of ISO 16111.

G.4.7 Materials and construction – system

These requirements of Subclause G.4.7 apply to micro fuel cell power systems and units covered by this Annex G. These requirements replace the corresponding requirements of Subclause 4.7.

G.4.7.1 The maximum quantity of liquid fuel or liquid fuel components stored in the micro fuel cell power unit shall not exceed 1 l.

G.4.7.2 The micro fuel cell power system or unit shall be designed such that an explosion cannot occur even if fuel leaks from or inside the micro fuel cell power system or unit. The design criteria for such means (for example, required ventilation rate) shall be provided by the micro fuel cell power system or unit manufacturer. The means shall be provided either by the micro fuel cell power system or unit manufacturer or by the manufacturer of the device powered by the micro fuel cell power system or unit.

G.4.7.3 Components and materials inside the micro fuel cell power system or unit shall be constructed or shall make use of such materials that propagation of fire and ignition is mitigated. The material flammability shall be such that a sustained fire will not be supported after electrical power and the fuel and oxidant supply have been terminated. This may be demonstrated through the selection of materials meeting FV 0, FV 1 or FV 2 in accordance with IEC 60695-1-1 and IEC 60695-11-10.

G.4.7.4 Micro fuel cell stack membranes are not required to have flammability ratings.

G.4.7.5 Other materials within the micro fuel cell stack which comprise less than 30 % of the total micro fuel cell stack mass are considered to be of limited quantity and are permissible without flammability ratings.

G.4.12 Fuel supply construction

G.4.12.1 Fuel cartridge construction

These requirements replace the corresponding requirements of Subclause 4.12.1. Fuel cartridges shall conform to the following requirements.

These requirements apply to micro fuel cell power systems and units covered by this Annex G.

G.4.12.1.1 There shall be no leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with 7.3.3 and 7.3.4.

G.4.12.1.2 There shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Compliance shall be determined by type testing in accordance with 7.3.1.

G.4.12.1.3 The maximum quantity of fuel charge is limited to 1 l for either liquid fuel or liquid fuel components.

G.4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance is checked by 7.3.11.

G.4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

G.4.12.1.6 A fuel cartridge shall be provided with a means to prevent mis-connection that would result in leakage of fuel when it is installed in a micro fuel cell power system. Compliance is checked by the connection cycling test, 7.3.11.

G.4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance is checked by the drop test, 7.3.5, and the connection cycling test, 7.3.11.

G.4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

G.4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel to leak.

G.4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance is checked by:

- pressure differential tests, G.7.3.1;
- vibration test, G.7.3.2;
- temperature cycling test, G.7.3.3;
- high temperature exposure test, G.7.3.4;
- drop test, G.7.3.5;

- compressive loading test, G.7.3.6;
- long-term storage test, G.7.3.9;
- high-temperature connection test, G.7.3.10;
- connection cycling tests, G.7.3.11.

G.4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

G.4.12.2 Fuel cartridge fill requirement

This requirement replaces the corresponding requirement of Subclause 4.12.2:

This requirement applies to micro fuel cell power systems and units covered by this Annex G.

The fuel cartridge design and fuel fill amount shall allow fuel expansion without leakage to a fuel cartridge temperature of 70 °C in the case of the fuel cartridge alone and when the fuel cartridge is constrained by the micro fuel cell power system or a comparable test fixture.

G.6 Instructions and warnings for fuel cartridges, micro fuel cell power units, and micro fuel cell power systems

These markings replace the markings required by Subclause 6.2.

G.6.1 Minimum markings required on the fuel cartridge

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE CORROSIVE AND TOXIC, DO NOT DISASSEMBLE.
b) AVOID CONTACT WITH CONTENTS.
c) KEEP AWAY FROM CHILDREN.
d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.
e) DO NOT EXPOSE TO ACIDS, OXIDIZERS, ALCOHOL OR HOUSEHOLD CLEANING PRODUCTS.
f) FOLLOW USAGE INSTRUCTIONS.
g) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.
h) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.
i) COMPOSITION AND AMOUNT OF FUEL.
j) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.

In the case that the contents of the fuel cartridge may be flammable, the marking required under “a)” above shall be changed as follows:

a) CONTENTS ARE FLAMMABLE, CORROSIVE AND TOXIC. DO NOT DISASSEMBLE.

G.6.2 Minimum markings on the micro fuel cell power system

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE CORROSIVE AND TOXIC, DO NOT DISASSEMBLE.

b) AVOID CONTACT WITH CONTENTS.

c) KEEP AWAY FROM CHILDREN.

d) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES.

e) DO NOT EXPOSE FUEL CARTRIDGE TO ACIDS, OXIDIZERS, ALCOHOL OR HOUSEHOLD CLEANING PRODUCTS.

f) FOLLOW USAGE INSTRUCTIONS.

g) IN THE CASE OF INGESTION OF FUEL OR CONTACT WITH THE EYES, SEEK MEDICAL ATTENTION.

h) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

i) COMPOSITION OF FUEL.

j) MAXIMUM CAPACITY OF FUEL IN THE INTERNAL RESERVOIR, IF APPLICABLE.

k) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.

l) ELECTRICAL OUTPUT (VOLTAGE, CURRENT, RATED POWER)

In the case that the contents of the fuel cartridge may be flammable, the marking required under “a)” above shall be changed as follows:

a) CONTENTS ARE FLAMMABLE, CORROSIVE AND TOXIC. DO NOT DISASSEMBLE.

G.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

G.7.1 General

This Subclause G.7.1 replaces Subclause 7.1 for this annex when testing borohydride micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use Class 8 (corrosive) borohydride as fuel.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table G.5 lists the type tests that must be performed. *Table G.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table G.6. *Table G.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table G.5 – List of type tests – Replaces Table 5

	Test item	Test sample
G.7.3.1	Pressure differential tests	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
G.7.3.2	Vibration test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
G.7.3.3	Temperature cycling test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
G.7.3.4	High temperature exposure test	Fuel cartridge Used fuel cartridge
G.7.3.5	Drop test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
G.7.3.6	Compressive loading test	Fuel cartridge Used fuel cartridge Micro fuel cell power system or power unit
G.7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
G.7.3.9	Long-term storage test	Fuel cartridge Used fuel cartridge
G. 7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
G.7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit Used fuel cartridge and micro fuel cell power unit
G.7.3.12	Emission test	Micro fuel cell power system or power unit
G.7.3.13	Hydrogen point source gas loss detection test	Micro fuel cell power system or power unit

Table G.5 replaces Table 5.

Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or used, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test.

Test sequence: Tests G.7.3.2 and G.7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests G.7.3.1, G.7.3.2, and G.7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units.

Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer's discretion if it does not compromise the individual test.

Table G.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is "room temperature" (standard temperature condition, 22 °C ± 5 °C)
Laboratory atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen. The laboratory atmosphere contains not more than 0,008 % hydrogen
Table G.6 replaces Table 6.	

G.7.2 Leakage, hydrogen leakage, and hydrogen gas loss, and hydrogen emission measurement and the measuring procedure

This Subclause G.7.2 replaces Subclause 7.2 for this annex when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use Class 8 (corrosive) borohydride as fuel.

The leakage measurements shall be executed in principle in accordance with the procedures shown in Figures G.2 through G.5. These figures and their procedures, replace the corresponding figures in Subclause 7.2.

Compliance with the "no leakage", "no hydrogen leakage" and "no impermissible hydrogen gas loss" requirement for all type tests specified in Subclause G.7.3 shall be determined by the leakage test and measurement procedure of subclause G.7.2.1, the hydrogen leakage measurement procedure of Subclause G.7.2.2 and the hydrogen gas loss measuring procedure of Subclause G.7.2.3 in conjunction with the definitions of "leakage" in Subclause G.3.11, "hydrogen leakage" in Subclause G.3.47, and the definition of "impermissible hydrogen gas loss" in Subclause G.3.41, unless otherwise specified.

G.7.2.1 Leakage test and measurement procedure

a) For micro fuel cell power systems, micro fuel cell power units and fuel cartridges containing Class 8 (corrosive) borohydride fuel, the leakage measurement of fuel, fuel byproducts, electrolyte or liquid fuel components shall be done following each type test by performing visual inspection of all possible leak locations. Any drops of fuel, fuel byproducts, electrolyte or liquid fuel component and/or white crystals on the exterior of the micro fuel cell power system or unit or fuel cartridge are indications of leakage. If crystals are accessible, the micro fuel cell power system or unit or fuel cartridge fails the leakage test. As an additional tool for finding fuel, fuel byproducts, electrolyte or liquid fuel component leaks, pH paper, attached to the possible leak areas of the micro fuel cell power system, shall be used to aid in the visual check for leakage. This is an additional requirement in Annex G for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel components. Any existence of a substance with a pH lower than 3,5 or greater than 10,5 is an indication of leakage. See Figure G.2 and Figure G.3. For operational tests, reactant air passages into the micro fuel cell power system and exhaust ports should not be blocked with pH paper.

b) For fuel cell cartridges containing solid, corrosive borohydride fuel, a water immersion test shall be shall be performed following each type test. The entire fuel cartridge containing solid borohydride fuel is immersed in at least one meter of laboratory temperature water for 30 min. If bubbles are observed, the fuel cartridge fails the leakage test. See Figure G.2 and Figure G.3.

G.7.2.2 Hydrogen leakage measurement from fuel cartridges, fuel management systems and internal reservoirs, if applicable, and measuring procedures

a) For fuel cartridges containing Class 8 (corrosive) borohydride, the measurement of hydrogen leakage shall be done following each type test using a liquid leak detector (bubble forming) solution or other equivalent means on all possible leak locations of the fuel cartridge. See Figure G.2 and Figure G.3.

b) If the fuel cartridge is of the type that is refillable by the manufacturer (automated or by trained technicians), it shall be filled to its rated capacity prior to testing. If the fuel cartridge is not refillable, it shall be tested in the condition in which it completed the type test in question. The fuel cartridge shall be tested for leaks at laboratory temperature. There shall be no leakage from any point on the fuel cartridge.

c) For micro fuel cell power systems or micro fuel cell power units with an internal reservoir, if applicable, a fuel management system that contains hydrogen gas above ambient pressure, the measurement of hydrogen leakage shall be done following each type test using a liquid leak detector (bubble forming) solution or other equivalent means on all possible leak locations of the fuel management system and internal reservoir, if applicable. The fuel management system and internal reservoir, if applicable shall be tested for leaks at laboratory temperature. There shall be no leakage from any point on the fuel management system and internal reservoir, if applicable

d) Both for fuel cartridges containing Class 8 (corrosive) borohydride, and for fuel management systems containing hydrogen, no hydrogen leakage is allowed. Testing for hydrogen leakage with a liquid leak detector (bubble forming) solution is acceptable only if no bubbles are found.

NOTE The “no leakage” criteria for fuel cartridges containing Class 8 (corrosive) borohydride has been chosen to be consistent with the 15th Edition of the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations; Special Provision 339 for UN 3479, Fuel Cell Cartridge *containing hydrogen in metal hydride*.

G.7.2.3 Hydrogen gas loss measurements from micro fuel cell power systems and micro fuel cell power units and measuring procedures

For micro fuel cell power systems, or micro fuel cell power units, following the completion of each type test, the micro fuel cell power system or unit shall be tested for hydrogen gas loss according to Figure G.4 as follows:

a) Perform hydrogen emission testing in accordance with G.7.3.12 with the exception that the micro fuel cell power system or unit shall be off ("DEVICE – OFF"). Hydrogen point source testing in accordance with G.7.3.13 is not applicable. Hydrogen gas loss shall be less than 0,0032 g/h.

b) Perform hydrogen emission testing in accordance with G.7.3.12 with the micro fuel cell power system or unit turned on ("DEVICE – ON") to test for hydrogen emissions whether or not the micro fuel cell power system or unit is operational. Hydrogen emissions shall be less than 0,8 g/h.

c) If hydrogen emissions in accordance with G.7.3.12 with the micro fuel cell power system or unit turned on ("DEVICE – ON") in step G.7.3.12.e) 3) ii) were greater than 0,016 g/h, perform the hydrogen point source gas loss detection test in accordance with G.7.3.13. If the micro fuel cell power system or unit fails the hydrogen point source gas loss detection test in accordance with G.7.3.13, the micro fuel cell power system or unit fails the type test and no further testing is necessary.

d) Perform leak testing on the fuel management system and internal reservoir, if applicable, using a liquid leak detector (bubble forming) solution, if a fuel management system or internal reservoir containing hydrogen is used. No leakage is allowed from the fuel management system and internal reservoir, if applicable.

e) Total hydrogen emissions from an operational system shall be less than 0,8 g/h and hydrogen leakage from any single point leak shall be less than 0,016 g/h. See Table G.7.

f) Total hydrogen gas loss from a non-operating system shall be less than 0,0032 g/h. See Table G.7.

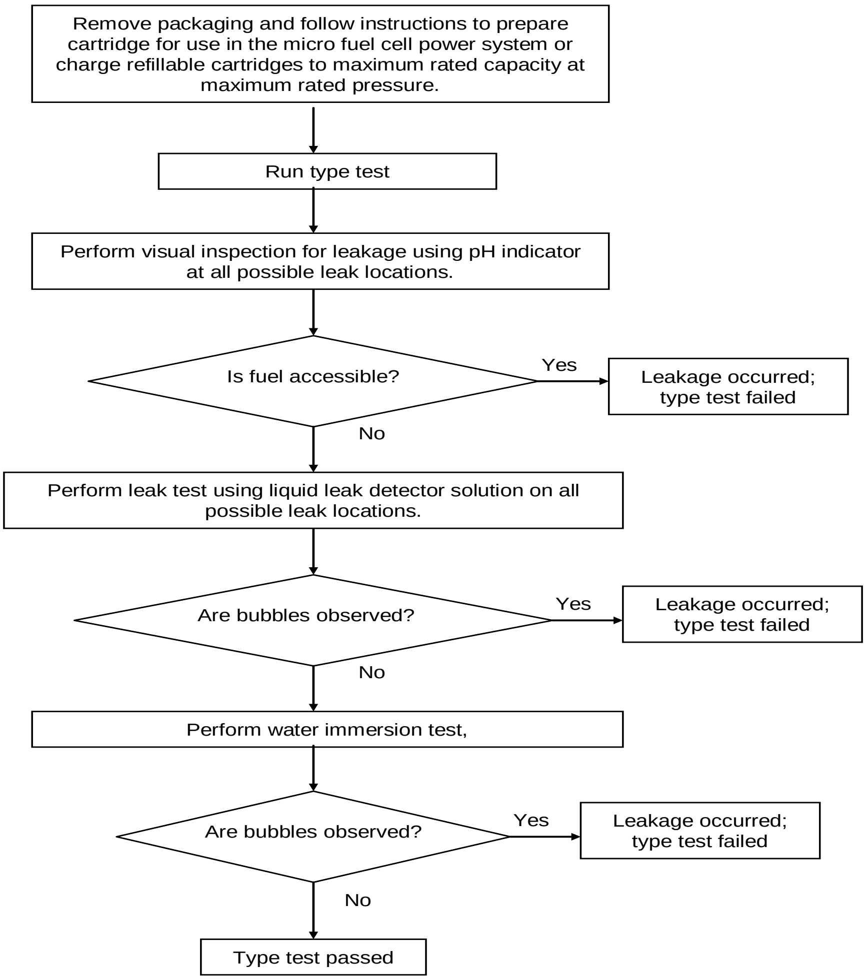


Figure G.2 – Fuel cartridge leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests – Replaces Figure 2

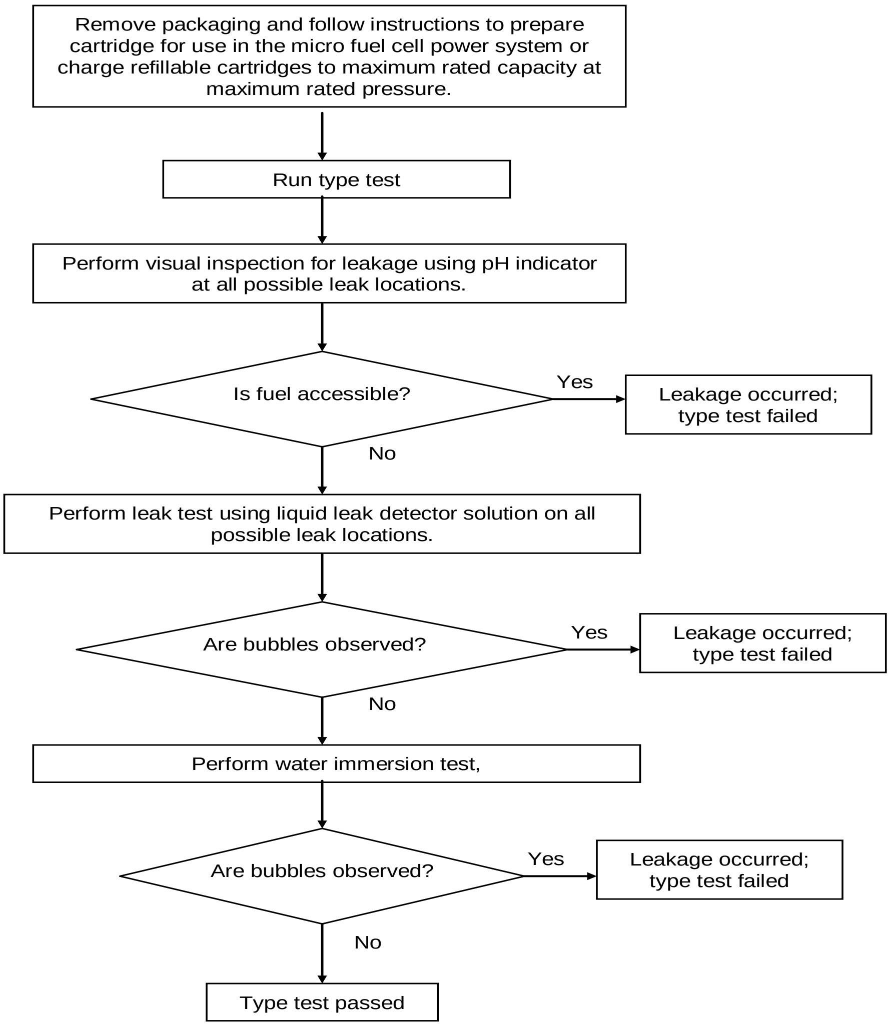


Figure G.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3

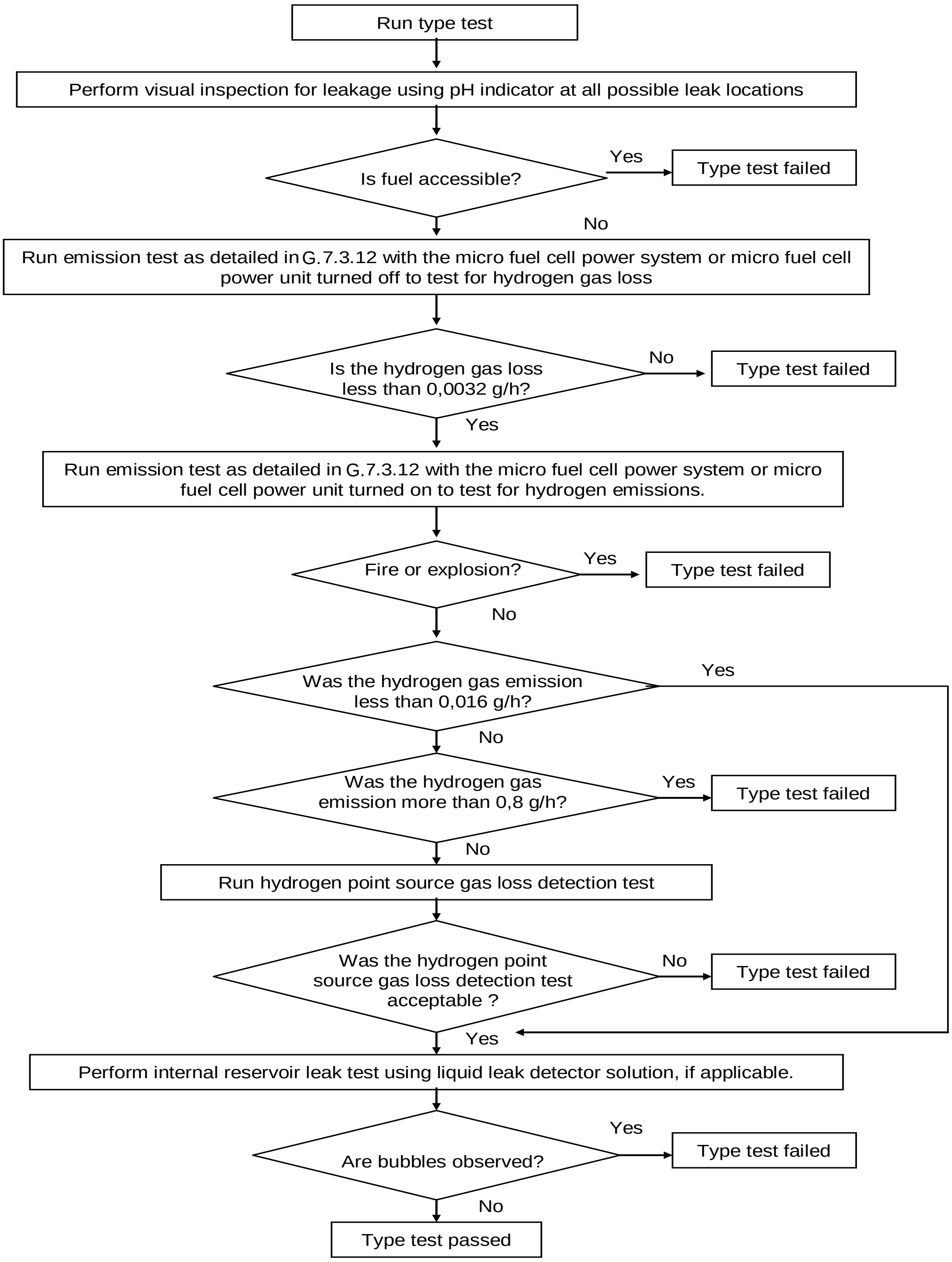


Figure G.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss flow chart for pressure differential, vibration, temperature cycling, drop, and compressive loading tests – Replaces Figure 4

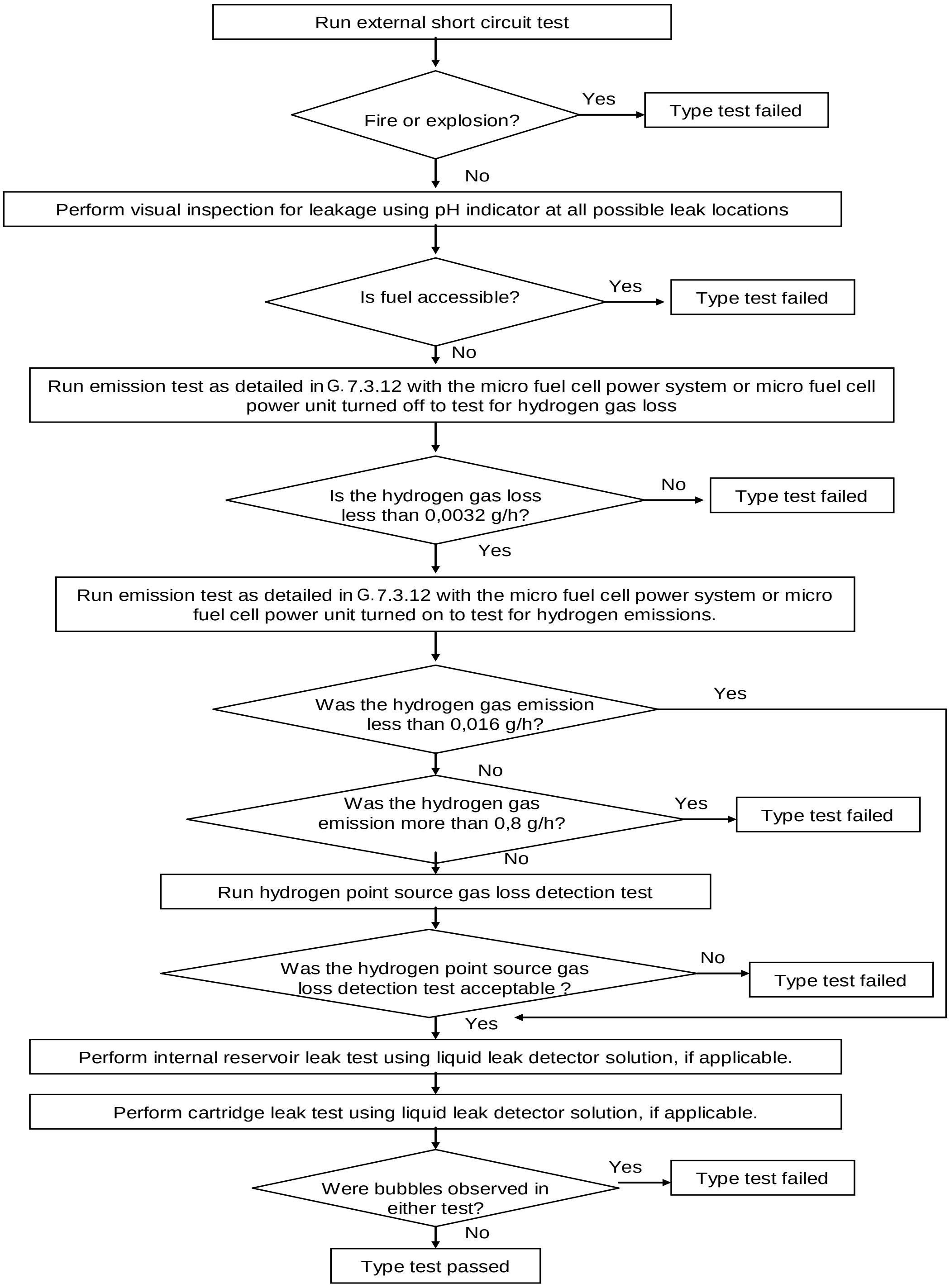


Figure G.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5

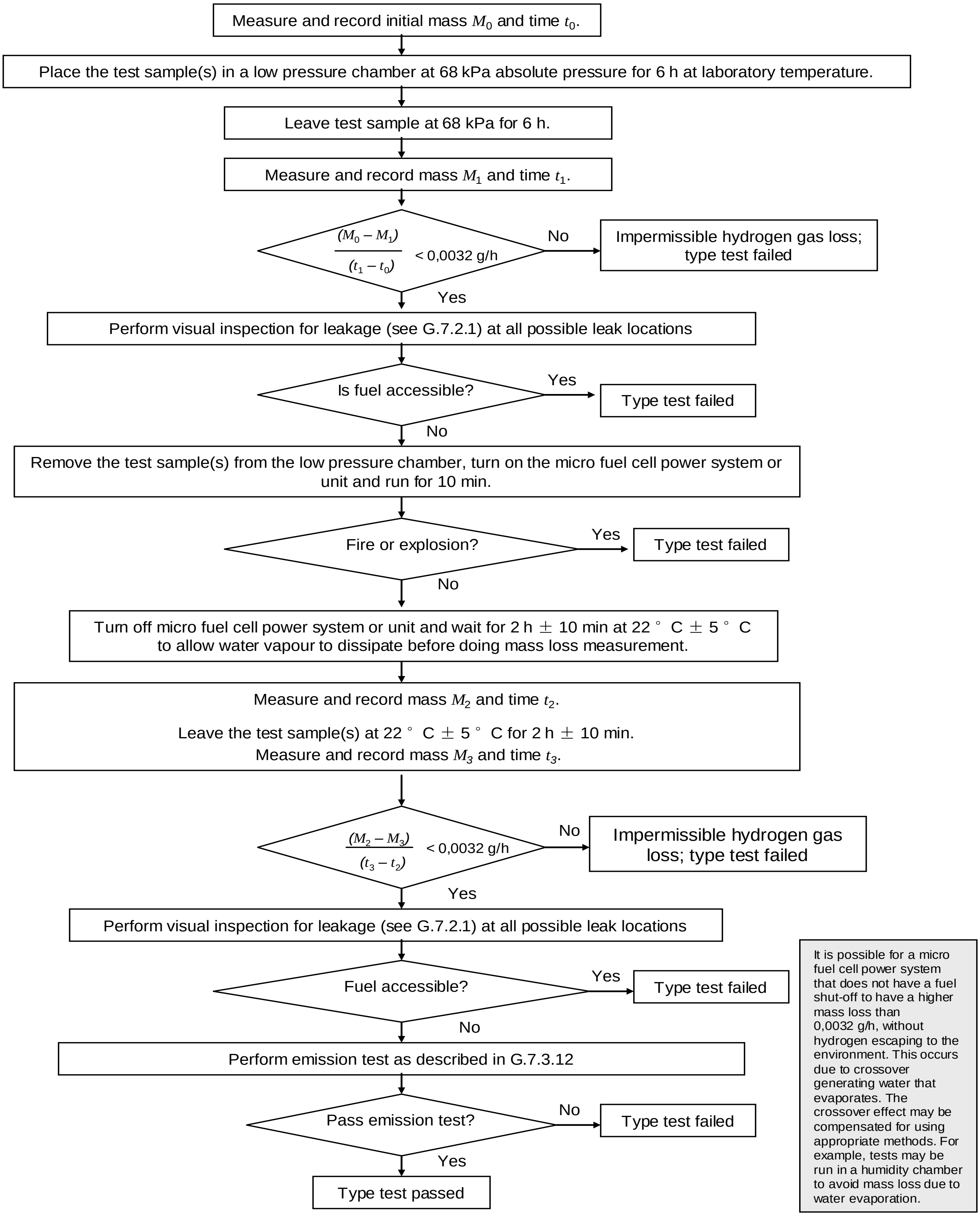


Figure G.6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6

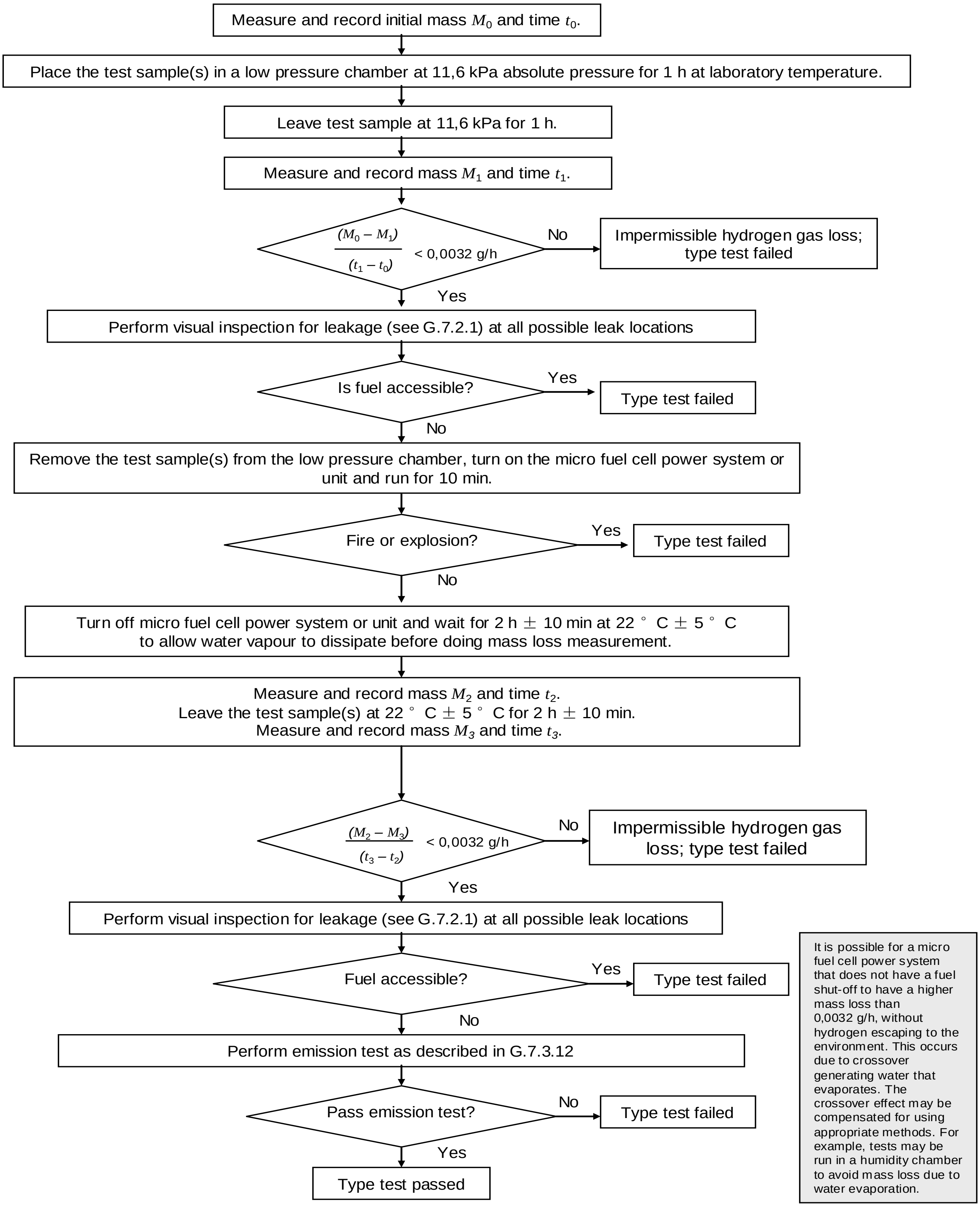


Figure G.7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7

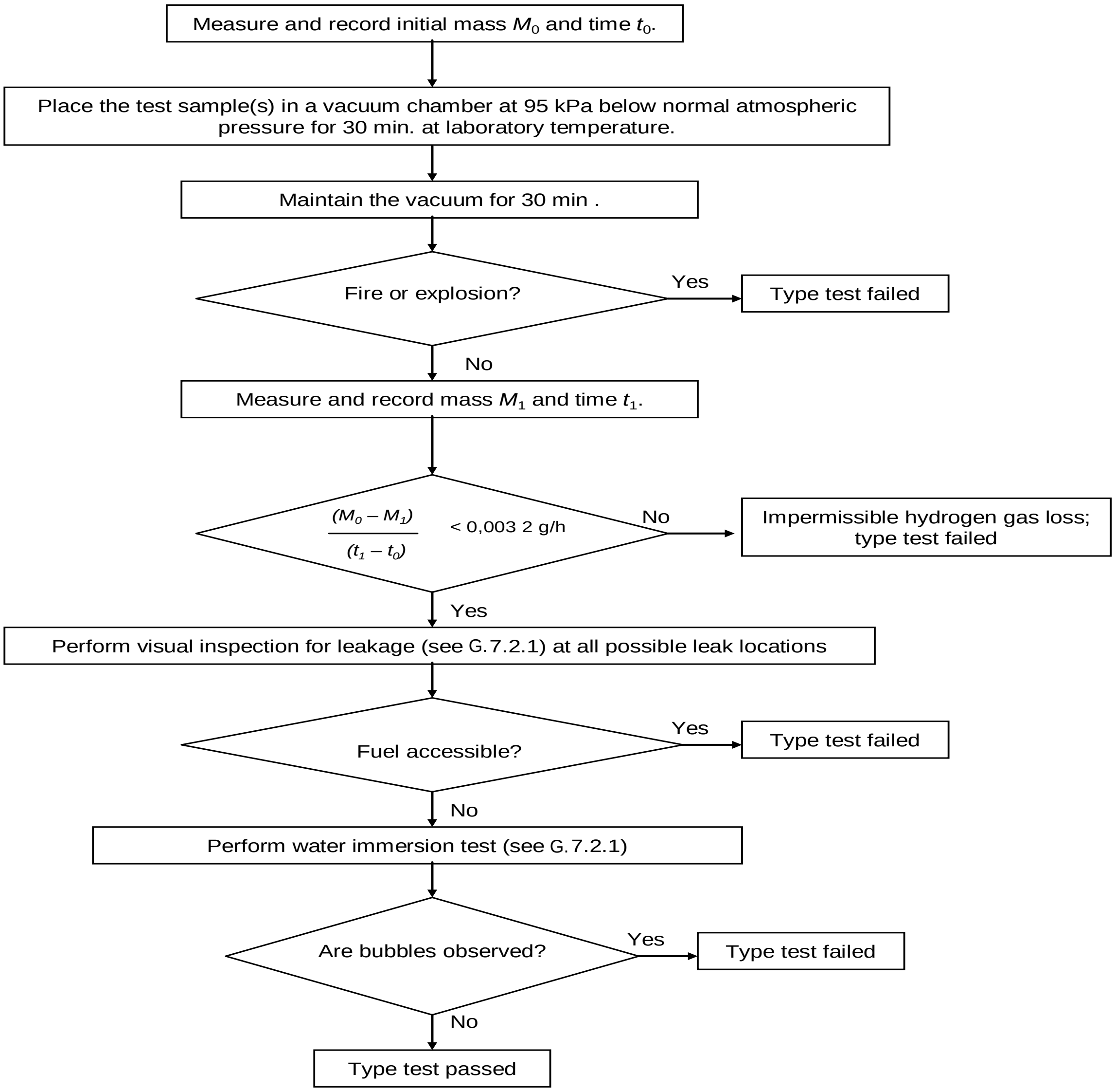


Figure G.13 – Fuel cartridge leakage test flow chart for low external pressure test

G.7.3 Type tests

G.7.3.1 Pressure differential tests

G.7.3.1.1 General

Subclause G.7.3.1 replaces Subclause 7.3.1.

Portions of this test check compliance with Subclause 4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater. Depending upon which of the two limiting pressure conditions is greater, two options for testing are provided:

a) If 95 kPa internal gauge pressure plus normal working pressure of the fuel cartridge at 22 °C is greater than two times the gauge pressure of the fuel cartridge at 55 °C, either Subclause G.7.3.1.2 or subclause G.7.3.1.3 may be used to verify compliance with Subclause 4.12.1.2.

b) If two times the gauge pressure of the fuel cartridge at 55 °C is greater than 95 kPa internal gauge pressure plus normal working pressure at 22 °C, Subclause G.7.3.1.2 must be used to verify compliance with Subclause 4.12.1.2.

G.7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

   1) Using a suitable fluid medium such as mineral oil, pressurize the fuel cartridge body to an internal pressure of 95 kPa internal gauge pressure plus normal working pressure at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater.

   2) The pressure rise shall not exceed a rate of 60 kPa/s.

   3) Maintain the maximum pressure for 30 min at laboratory temperature.

   4) Using a suitable fluid medium such as mineral oil, pressurize the closed fuel cartridge valve to 95 kPa gauge pressure plus the normal working pressure of the cartridge at 22 °C or two times the gauge pressure of the fuel cartridge at 55 °C, whichever is greater.

   5) The pressure rise shall not exceed a rate of 60 kPa/s.

   6) Maintain the maximum pressure for 30 min at laboratory temperature.

d) **Passing criteria:** No accessible liquid test medium leakage and no sudden drop of pressure during the course of the test. Leakage shall be checked visually. Invert the fuel cartridge and the fuel cartridge valve over indicating paper in such a way that the valve points downward toward the indicating paper and look for signs of leakage; if any accessible liquid leakage is found, the test fails.

NOTE Class 8 (corrosive) borohydride fuel will chemically react with water, therefore, water or water-containing substances should not be used as the fluid test medium. Class 8 (corrosive) borohydride fuels have the potential to react with substances other than water, therefore, the chemical reactivity and stability of the particular Class 8 (corrosive) borohydride fuel being tested should be used to guide the selection of a suitable liquid test medium.

G.7.3.1.3 Fuel cartridge low external pressure test

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure G.13.

   2) The sample shall be placed in a vacuum chamber and the pressure in the vacuum chamber shall be reduced to 95 kPa below normal atmospheric pressure.

   3) Maintain the vacuum for 30 min.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no Class 8 (corrosive) fuel or liquid fuel component leakage. See Figure G.2. Hydrogen gas loss shall meet the requirements of Subclause G.7.2.3 (less than 0,0032 g/h). Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

G.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

G.7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all Class 8 (corrosive) borohydride micro fuel cell power systems and all Class 8 (corrosive) borohydride micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure G.6.

   2) Test samples shall be stored at a low external pressure of 68 kPa absolute pressure for 6 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure G.6.

   3) For the micro fuel cell power system or unit, perform emission testing in accordance with G.7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel components liquid leakage. See Figure G.6. Remove the fuel cartridge, if present, from the micro fuel cell power system. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Hydrogen gas loss shall be determined by the mass loss measurement as shown in Figure G.7. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of G.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test result is acceptable.

G.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all Class 8 (corrosive) borohydride micro fuel cell power systems and all Class 8 (corrosive) borohydride micro fuel cell power units.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure G.7.

   2) Test samples shall be stored at a low external pressure of 11,6 kPa absolute pressure for 1 h at laboratory temperature. Leakage shall be measured on the basis of the procedure described in Figure G.7.

   3) For the micro fuel cell power system or unit, perform emission testing in accordance with G.7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel components liquid leakage. See Figure G.7. Remove the fuel cartridge, if present, from the micro fuel cell power system / unit. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Hydrogen gas loss shall be determined by the mass loss measurement as shown in Figure G.7. Fire or flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emission testing shall meet the passing criteria of G.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test result is acceptable.

G.7.3.2 Vibration test

Subclause G.7.3.2 replaces Subclause 7.3.2 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in G.7.3.1 or a micro fuel cell power system used in used in G.7.3.1.

b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure G.2 for the fuel cartridge and Figure G.4 for the micro fuel cell power system or unit.

2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) For the micro fuel cell power system or unit, perform emission testing in accordance with 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit Emissions shall meet the passing criteria in G.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test is acceptable.

G.7.3.3 Temperature cycling test

Subclause G.7.3.3 replaces Subclause 7.3.3 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** a fuel cartridge used in G.7.3.2, a used fuel cartridge used in G.7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in G.7.3.2 or a micro fuel cell power system used in G.7.3.2.

b) **Purpose:** to simulate the effects of low-temperature and high temperature exposure and the effects of extreme temperature change.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure G.3 for the fuel cartridge and Figure G.4 for the micro fuel cell power system or unit.

   2) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

   3) See Figure G.8 for the temperature profile to be used.

   4) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

   5) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

   6) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

   7) The above process is to be done twice.

   8) After 1 h at 22 °C ± 5°C, leakage and fuel vapour loss shall be measured based upon the procedure described in Figure G.3 (for fuel cartridge) and Figure G.4 (for micro fuel cell power system or unit).

   9) For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with G.7.3.12.

   10) For an internal reservoir, if applicable, perform hydrogen leakage measurement testing, in accordance with G.7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in G.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test is acceptable.

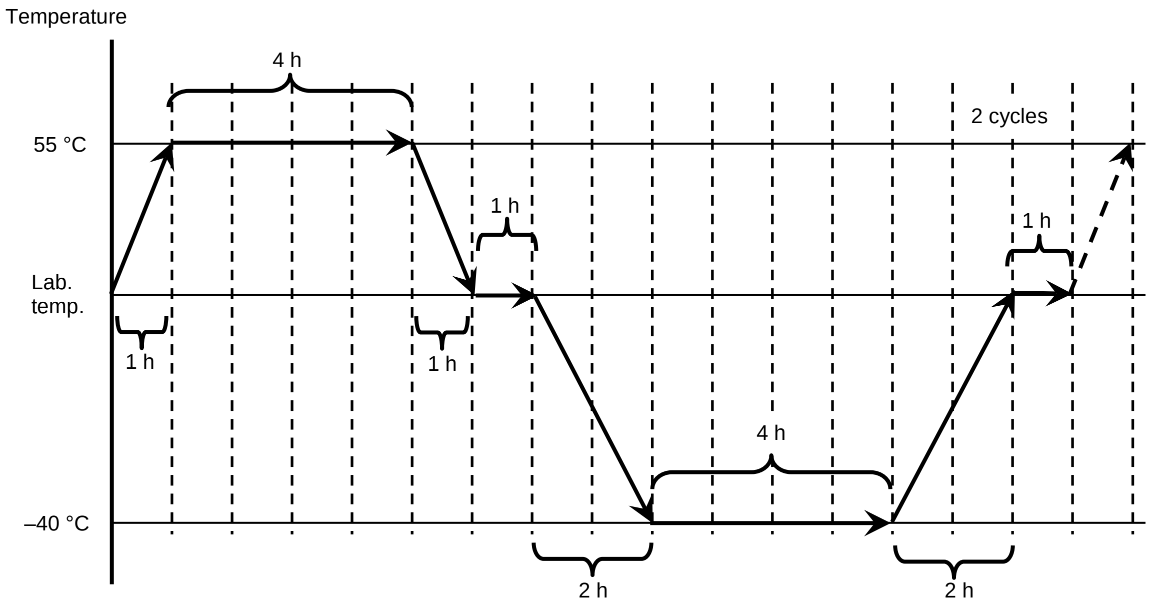


Figure G.8 – Temperature cycling – Replaces Figure 8

G.7.3.4 High temperature exposure test

Subclause G.7.3.4 replaces Subclause 7.3.4 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments.

c) **Test procedure:**

 1) Two orientations shall be tested – valve up and valve down.

 2) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

 3) Remove the test sample to laboratory temperature.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

G.7.3.5 Drop test

Subclause G.7.3.5 replaces Subclause 7.3.5 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** an unused fuel cartridge, a used fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

1) The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

2) The height of the drop shall be:

i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system;

ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge of more than 200 g solid fuel or more than 200 ml of liquid fuel component;

iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge of up to 200 g of solid fuel or up to 200 ml of liquid fuel component.

3) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

4) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or unit may be used for all four drop orientations, or more than one micro fuel cell power system or unit may be used in subsequent drops, at the discretion of the manufacturer.

5) For all tests, drop orientations shall be:

i) valve up;

ii) valve down;

iii) two other mutually perpendicular orientations.

6) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with G.7.3.12.

7) For an internal reservoir, if applicable, perform hydrogen leakage measurement testing, in accordance with G.7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in G.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test is acceptable. If the micro fuel cell power system or unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

G.7.3.6 Compressive loading test

Subclause G.7.3.6 replaces Subclause 7.3.6 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

G.7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

1) The micro fuel cell power system or unit test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

5) Perform emission testing in accordance with G.7.3.12 following the compressive loading test.

6) For an internal reservoir, if applicable, perform hydrogen leakage measurement testing, in accordance with G.7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit. Emissions shall meet the passing criteria in G.7.3.12. If the micro fuel cell power system/unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test is acceptable.

G.7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge.

c) **Test procedure:**

1) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

3) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

4) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

G.7.3.7 External short-circuit test

Subclause G.7.3.7 replaces Subclause 7.3.7 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

   1) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

   2) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

   3) Perform emission testing in accordance with G.7.3.12 after each short-circuit test.

   4) For an internal reservoir, if applicable, perform hydrogen leakage measurement testing, in accordance with G.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

   Exterior surfaces shall not exceed temperatures in Table 2 during or after short circuit testing.

   Emissions shall meet the passing criteria in G.7.3.12. If the micro fuel cell power system or unit does not operate but emissions do not exceed the limits of G.7.3.12, the emission test is acceptable.

NOTE The external short-circuit test can be done sequentially with the surface, component and exhaust gas temperature test using the same sample.

G.7.3.9 Long-term storage test

Subclause G.7.3.9 replaces Subclause 7.3.9 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** an unused or a used fuel cartridge.

b) **Purpose:** to simulate the effects of long term storage at elevated temperature and ensure no leakage.

c) **Test procedure:**

   1) Perform these tests in accordance with Figure G.9 for fuel cartridges.

   2) Record initial mass M_0 and time t_0 and place sample in temperature chamber at 50 °C ± 2 °C with a chamber relative humidity of at least 60 %.

   3) The temperature chamber shall be equipped with ventilation and measurement instruments capable of accurately measuring the concentration of hydrogen in the chamber similar to the configuration in Figure G.10.

   4) The ventilation flow rate and the hydrogen concentration of interest in the chamber shall be monitored continuously and recorded. See Table G.7. At no time during the test shall the hydrogen concentration in the chamber shall exceed 25 % LFL.

5) The sample shall remain in the chamber at 50 °C ± 2 °C with a chamber relative humidity of at least 60 % for at least 28 days.

6) At the end of the 28 days, remove the fuel cartridge from the test chamber and record the time the fuel cartridge was removed from the test chamber, t_1. Allow the fuel cartridge to stabilize at laboratory temperature and record the final mass, M_1. Hydrogen gas loss is calculated as follows and shall not exceed 0,0032 g/h:

$$\frac{M_0 - M_1}{t_1 - t_0} < \quad 0{,}0032 \text{ g/h}$$

7) Perform fuel, fuel byproduct, electrolyte and liquid fuel component leakage testing using visual inspection with pH indicator and water immersion test in accordance with Subclause G.7.2.1 for the fuel cartridge.

8) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power system. Check for fuel, fuel byproduct, electrolyte, or liquid fuel component leakage using visual inspection with pH indicator and water immersion test as described in G.7.2.1. See Figure G.9.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, or liquid fuel components. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge. The hydrogen concentration in the chamber shall not exceed 25 % LFL at any time during the test. The hydrogen gas loss rate from the cartridge shall not exceed 0,0032 g/h at any time during the test. Fire, flame and explosion shall be checked using cheesecloth, infrared camera, or other suitable methods.

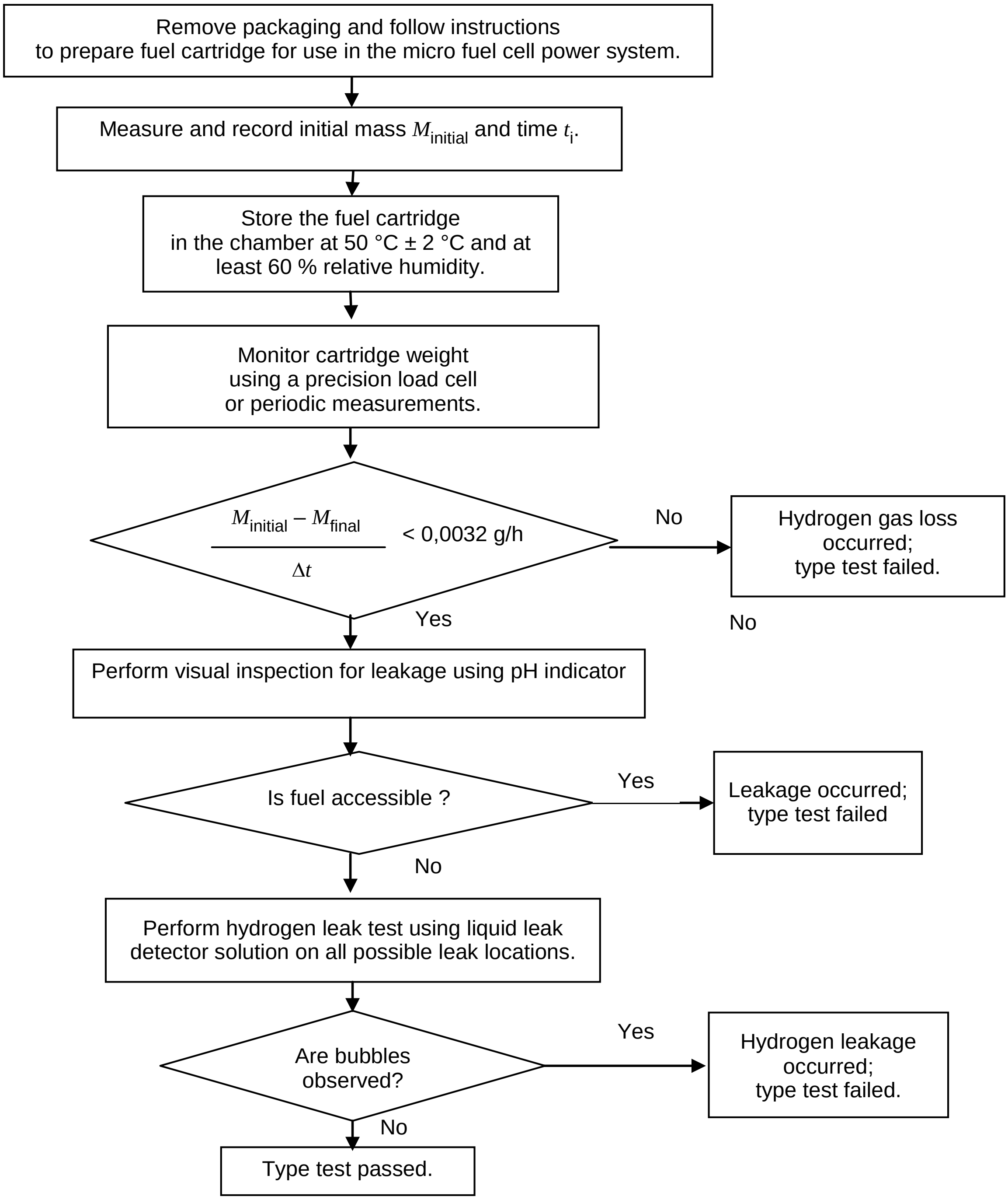


Figure G.9 – Fuel cartridge hydrogen leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9

G.7.3.10 High-temperature connection test

Subclause G.7.3.10 replaces Subclause 7.3.10 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

a) **Test sample:** an unused fuel cartridge or a used fuel cartridge and a micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage, no fire, no explosion.

c) **Test procedure:**

   1) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.

   2) The micro fuel cell power unit or test fixture with micro fuel cell power unit valve is kept at laboratory temperature.

   3) Remove the test sample from the chamber and connect the fuel cartridge to the micro fuel cell power unit or test fixture with micro fuel cell power unit valve within 5 min of removal from the chamber.

   4) Check for leakage upon connection.

   5) Disconnect the fuel cartridge and check for leakage.

   6) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with G.7.3.12.

   7) For an internal reservoir, if applicable, perform hydrogen leakage measurement testing, in accordance with G.7.2.2.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel by-products, electrolyte of liquid fuel components. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occurs, this is acceptable. Leakage of Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte, and liquid fuel components shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in Subclause G.7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system/unit.

G.7.3.11 Connection cycling tests

Subclause G.7.3.11 replaces Subclause 7.3.11 for micro fuel cell power systems, units and fuel cartridges covered by this Annex G.

G.7.3.11.1 Fuel cartridge

G.7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused or a used insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

   1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as in the leakage test and measurement procedure specified in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts,

electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in G.7.2.1.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as in specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage specified in the leakage test and measurement procedure specified in Subclause G.7.2.1.

5) Repeat this twice more for a total of three connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in G.7.2.1.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure specified in Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen specified in the leakage test and measurement procedure in Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as described in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage as specified in the leakage test and measurement procedure in Subclause G.7.2.1.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure in Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the leakage test and measurement procedure in Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the leakage test and measurement procedure in Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and

measurement procedure in Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel component leakage, no impermissible hydrogen gas loss or emissions. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen leakage shall meet the no hydrogen leakage requirements of the hydrogen leakage measurement procedure (no bubbles) of Subclause G.7.2.2 for the fuel cartridge. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Hydrogen gas loss shall meet the requirements of Subclause G.7.2.3. Emissions must meet passing criteria of Subclause G.7.3.12 for operational and non-operating systems.

G.7.3.11.1.2 Satellite cartridge

a) **Test sample:** an unused satellite fuel cartridge and an unused micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer’s instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve. Check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproduct, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1. Initiate or simulate fuel flow.

2) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

3) Repeat this twice more for a total of three connections and disconnections.

4) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria

for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

5) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

7) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

9) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and initiate or simulate fuel flow.

10) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

11) Repeat steps 1 through 10 four more times for a total of 55 cycles, waiting 1 h between each set of 11 cycles.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel component leakage, no impermissible hydrogen gas loss or emissions. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen leakage shall meet the no hydrogen leakage requirements of the hydrogen leakage measurement procedure (no bubbles) of Subclause G.7.2.2 for the fuel cartridge. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Hydrogen gas loss shall meet the requirements of Subclause G.7.2.3. Emissions must meet passing criteria of G.7.3.12 for operational and non-operating systems.

G.7.3.11.1.3 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

   First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

   1) Connect the first fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

   2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

   3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

   4) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

   5) Repeat this twice more for a total of three connections and disconnections.

   6) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

7) Connect and disconnect the first fuel cartridge four more times for a total of seven connections and disconnections.

8) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

9) Connect and disconnect the first fuel cartridge three more times for a total of ten connections and disconnections.

10) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

11) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

12) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

13) Turn off the micro fuel cell power unit or stop simulated fuel flow.

14) Disconnect the first fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

15) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.

i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections.

ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.

iii) Inversion of the micro fuel cell power unit or the fuel cartridges is not necessary, but, if leakage is found, the test fails.

iv) Following this ageing, a final unused fuel cartridge will be tested.

16) Connect the final unused fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

17) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

18) Turn off the micro fuel cell power unit or stop simulated fuel flow.

19) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

20) Repeat this twice more for a total of three connections and disconnections.

21) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

22) Connect and disconnect the final fuel cartridge four more times for a total of seven connections and disconnections.

23) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for

no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

24) Connect and disconnect the final fuel cartridge three more times for a total of ten connections and disconnections.

25) Check for hydrogen leakage using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

26) Connect the fuel cartridge to the micro fuel cell power unit and check for hydrogen leakage upon connection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

27) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

28) Turn off the micro fuel cell power unit or stop simulated fuel flow.

29) Disconnect the fuel cartridge and check for hydrogen leakage upon disconnection using a liquid leak detector (bubble forming) solution in accordance with the hydrogen leakage measurement procedure of Subclause G.7.2.2 for the fuel cartridge, the fuel management system and internal reservoir, if applicable. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of Subclause G.7.2.2. Check for Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause G.7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte or liquid fuel component leakage, no impermissible hydrogen gas loss or emissions. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually. Hydrogen leakage shall meet the no hydrogen leakage requirements of the hydrogen leakage measurement procedure (no bubbles) of Subclause G.7.2.2 for the fuel cartridge and internal reservoir, if applicable. Class 8 (corrosive) borohydride fuel, fuel byproducts, electrolyte and liquid fuel component leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause G.7.2.1. Hydrogen gas loss shall meet the requirements of Subclause G.7.2.3. Emissions must meet passing criteria of G.7.3.12 for operational and non-operating systems.

G.7.3.12 Emission test

This Subclause G.7.3.12 shall replace Subclause 7.3.12 for Class 8 (corrosive) borohydride micro fuel cell power systems or units tested in accordance with Annex G. The included Table G.7, Emission limits, replaces Table 7 in Subclause 7.3.12. Figure G.10 replaces Figure 10 and is identical to Figure 10. Hydrogen emissions are evaluated separately. The procedure for hydrogen emission testing is detailed in Figure G.12, which is to be used as an additional figure when testing is done in accordance with Annex G.

a) **Test sample:** A micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under normal operating conditions, indirect borohydride powered micro fuel cell power systems may have emissions. The emissions may be comprised of water or hydrogen, both of which are known not to be toxic. Indirect borohydride micro fuel cell power systems do not normally emit CO, CO_2, formaldehyde or other volatile organic compounds. However, there is a remote possibility that indirect borohydride micro fuel cell power systems utilizing fuels or liquid fuel components containing organic additives may emit CO, CO_2, formaldehyde, or other volatile organic compounds under abnormal circumstances. Because this possibility exists, emission limits for CO, CO_2, formaldehyde, and volatile organic compounds for micro fuel cell power systems utilizing fuels or liquid fuel components containing organic compounds are imposed by this annex and are listed in Table G.7.

   Micro fuel cell power systems emit water vapour and under certain conditions this water vapour can condense. This condensation is not considered an emission or a leak if the pH of the condensate is between 3,5 pH and 10,5 pH.

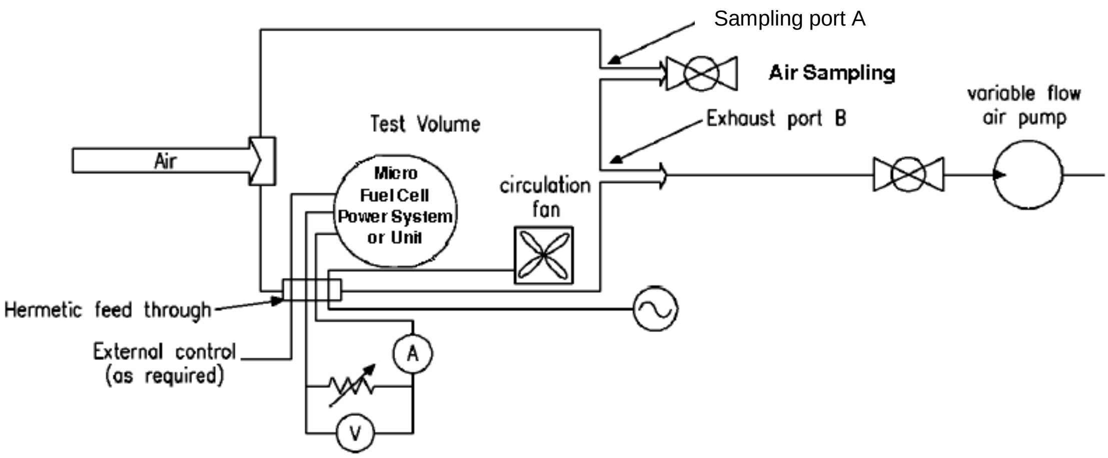


Figure G.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the operational emission test apparatus is shown in Figure G.10. The configuration shown in Figure G.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex G. Emission rate testing in accordance with G.7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex G.

   To analyse the hydrogen emissions, a mass spectrometer, gas chromatograph, or other suitable instrument calibrated to measure hydrogen concentration shall be used and connected to sampling port A in Figure A.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer's mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.), additional testing in accordance with G.7.3.12 d) 3) and G.7.3.12 d) 4) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure G.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer's mouth or nose when in use) for emissions concentration limit testing.

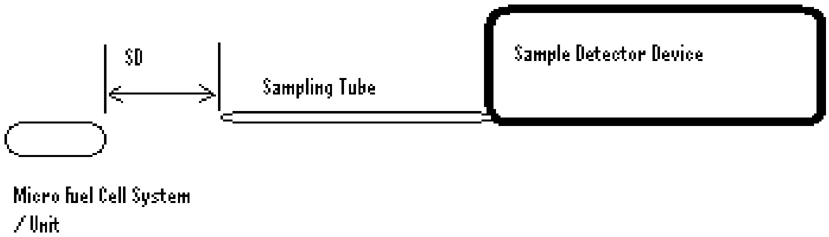


Figure G.11 – Operational emission concentration testing apparatus – Replaces Figure 11

Emission gases might be composed of toxic organic materials such as carbon dioxide, carbon monoxide and formaldehyde, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS) shall be used by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure G.10. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments.

A hydrogen detector calibrated for the zero-to-one-percent mass concentration hydrogen range can be used to measure the hydrogen concentration.

The concentration of CO and CO_2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure G.12, which is to be used as an additional figure when testing is done in accordance with Annex G.*

Emission rate sampling tests shall be performed both with the micro fuel cell power system or unit on ("DEVICE – ON") and with the micro fuel cell power system or unit off ("DEVICE – OFF") as follows.

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed with the micro fuel cell power system or unit on ("DEVICE – ON") as follows.

   i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure G.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure G.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure G.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the concentrations of chemical compounds of interest. See Table G.7.

vii) Calculate the emission rate of chemical compounds being emitted by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_{\text{P}} + F_{\text{S}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in litres per hour;

F_{S} is the sample flow rate in litres per hour;

C is the concentration in grams per litre.

viii) Compare the maximum measured "DEVICE – ON" emission rate to Table G.7. If the emission rate is not less than the emission rate limit in Table G.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria G.7.3.12 e) 1) i) and G.7.3.12 e) 2) i).

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer’s mouth or nose, the following additional emissions concentration sampling test shall be performed with the micro fuel cell power system or unit on "DEVICE – ON" as follows.

i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling system do not contribute emissions (that is, contaminants) to the test. Prior to testing, a system check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

ii) Operate the micro fuel cell power system or micro fuel cell power unit at rated power in the large open room while sampling the emission concentrations using the operational emission concentration testing apparatus shown in Figure G.11. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission concentration test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “ON” position ("DEVICE – ON").

iii) Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

iv) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure G.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer’s mouth or nose when in use).

v) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

vi) Allow the sample flow rate to stabilise.

vii) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

viii) Record the concentrations of the chemical compounds of interest. See Table G.7.

ix) Compare the maximum measured concentrations to Table G.7. If the emission concentrations are not less than the emission concentration limits in Table G.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria G.7.3.12 e) 2) ii).

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

3) Upon completion of the emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table G.7, “DEVICE – ON” hydrogen emissions are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure G.10. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “on” position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure G.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure G.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vi) Record the hydrogen concentration.

vii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in litres per hour;

F_{S} is the sample flow rate in litres per hour;

C is the concentration in grams per litre.

viii) Compare the maximum measured "DEVICE – ON" hydrogen emission rate to Table G.7.

NOTE This is a stabilised concentration measurement.

ix) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

4) Upon completion of the hydrogen emissions measurements with "DEVICE – ON", hydrogen emissions with ("DEVICE – OFF") are evaluated as follows.

i) Operate the micro fuel cell power system or micro fuel cell power unit at rated power inside the small test chamber shown in Figure G.10 for 10 min or until 10 % of the fuel capacity of a full fuel cartridge is used up, whichever is less.

ii) Turn the micro fuel cell power system or unit off ("DEVICE – OFF") and measure the emission rates with the micro fuel cell power system or unit off ("DEVICE – OFF") inside the small test chamber shown in Figure G.10.

iii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iv) Gaseous hydrogen emissions from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown on Figure G.10.

v) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

vi) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure G.10, while simultaneously measuring and recording the variable flow air pump flow rate and measuring and recording the sample flow rate through air sampling port A.

vii) Record the hydrogen concentration.

viii) Calculate the emission rate of hydrogen being emitted by multiplying the maximum stabilized concentration of hydrogen by the simultaneous total air flow through the system. The total air flow through the system is determined by adding the steady-state variable flow air pump flow rate through the system to the simultaneous sample flow rate. See below:

$$ER = (F_P + F_S) \times C$$

where

ER is the emission rate in grams per hour;

F_P is the variable flow air pump flow rate in litres per hour;

F_S is the sample flow rate in litres per hour;

C is the concentration in grams per litre.

ix) Compare the maximum measured "DEVICE – OFF" hydrogen emission rate to Table G.7.

NOTE This is a stabilised concentration measurement.

x) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

5) Evaluate the hydrogen emission rate as follows.

i) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and below the allowable 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or unit passes the test and no further testing is necessary.

ii) If the hydrogen emission rate measurement is not below the allowable 0,0032 g/h with the "DEVICE – OFF" and not below the total allowable 0,8 g/h with the "DEVICE – ON", the system or unit fails the test and no further testing is necessary.

iii) If the hydrogen emission rate measurement is below the allowable 0,0032 g/h with the "DEVICE – OFF" and is below the total allowable 0,08 g/h with the "DEVICE – ON" but is not below 0,016 g/h with the "DEVICE – ON", then proceed with B.7.3.13, hydrogen point source gas loss detection test to verify that no single source of hydrogen exceeds 0,016 g/h.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

i) The maximum emission rate for each of the constituents of interest in Table G.7 shall be less than the emission rate limit value in Table G.7 when tested in accordance with G.7.3.12 d) 1) for "DEVICE – ON". If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer’s mouth or nose:

   i) The maximum emission rate for each of the constituents of interest in Table G.7 shall be less than the emission rate limit value in Table G.7 when tested in accordance with G.7.3.12 d) 1) for "DEVICE – ON" and G.7.3.12 d) 2) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

   ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer’s mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall not exceed the emission concentration limit in Table G.7 when tested in accordance with G.7.3.12 d) 3) "DEVICE – ON" and G.7.3.12 d) 4) for "DEVICE – OFF" testing respectively. If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

3) Hydrogen emissions are evaluated separately. *The procedure for hydrogen emission testing is detailed in Figure G.12, which is to be used as an additional figure when testing is done in accordance with Annex G.* Upon completion of the hydrogen emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table G.7, hydrogen emissions are evaluated as follows.

   i) **Passing criteria for non-operating systems:** The hydrogen emission rate shall be less than 0,0032 g/h with the "DEVICE – OFF".

   ii) **Passing criteria for operational systems:** If the total hydrogen emission rate is less than 0,016 g/h with the "DEVICE – ON", the micro fuel cell power system or micro fuel cell power unit passes the emission test and no further testing is required. If the total hydrogen emission rate is not less than 0,8 g/h with the “DEVICE – ON”, the micro fuel cell power system or unit fails the emission test and no further testing is required. If the hydrogen emission rate is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON", G.7.3.13, hydrogen point source gas loss detection test must be performed with acceptable results to show no more than 0,016 g/h hydrogen leakage from any single point leak.

NOTE 1 The allowable flammable hydrogen emission level that will not support a standing flame is 3 ml/min (Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535; M.R. Swain and M.N. Swain, *Codes and Standards Analysis*, 2001 *(USA)*). The non-flammable hydrogen emissions limit is based on the criteria that hydrogen emission does not build up to more than 25 % of LFL in the reference volume.

NOTE 2 Hydrogen is defined as a simple asphyxiant but for this risk to exist, oxygen levels have to fall less than 18 % at normal atmospheric pressure. Hydrogen related flammability risk arises at hydrogen-in-air concentrations greater than 4 %, while the asphyxiant risk arises at hydrogen-in-air concentrations greater than 12 %. Therefore, the flammability limits are used in defining the limits for hydrogen emissions.

NOTE 3 Carbon dioxide and carbon monoxide vapour emission level limits are based on toxicity effects on humans while the hydrogen emissions level limit is based on the risk of creating a flammable atmosphere in confined spaces and the risk of a potential standing hydrogen flame.

Table G.7 – Emission limits – Replaces Table 7

Emissions	"DEVICE – ON" Concentration limit [a] based on TWA values for "DEVICE – ON" test condition	"DEVICE – ON" Permissible emissions rate in 10 m^3 ACH volume [b]
Water	Unlimited for pH between 3,5 and 10,5	Unlimited for pH between 3,5 and 10,5
Hydrogen	0,8 g/m^3	0,8 g/h total 0,016 g/h from single point leak
Formaldehyde[d]	0,000 1 g/m^3	0,000 6 g/h
CO	0,029 g/m^3	0,290 g/h
CO_2	9 g/m^3	60 g/h[c]
Volatile organic carbon compounds	0,000 1 g/m^3	0,000 6 g/h

Table G.7 replaces Table 7.

[a] The concentration limits for CO and CO_2 in this table are the mg/m^3 equivalent of the TWA and STEL exposure limits.

[b] The "DEVICE – ON" emission rate limit was based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH) because it covers the reasonably foreseeable environments where micro fuel cell power systems will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is over 20 m^3, so a product of 10 is conservative.

[c] A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO eight-hour concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

[d] WHO guideline limit is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The emission limit cannot push the background level above the guideline limit.

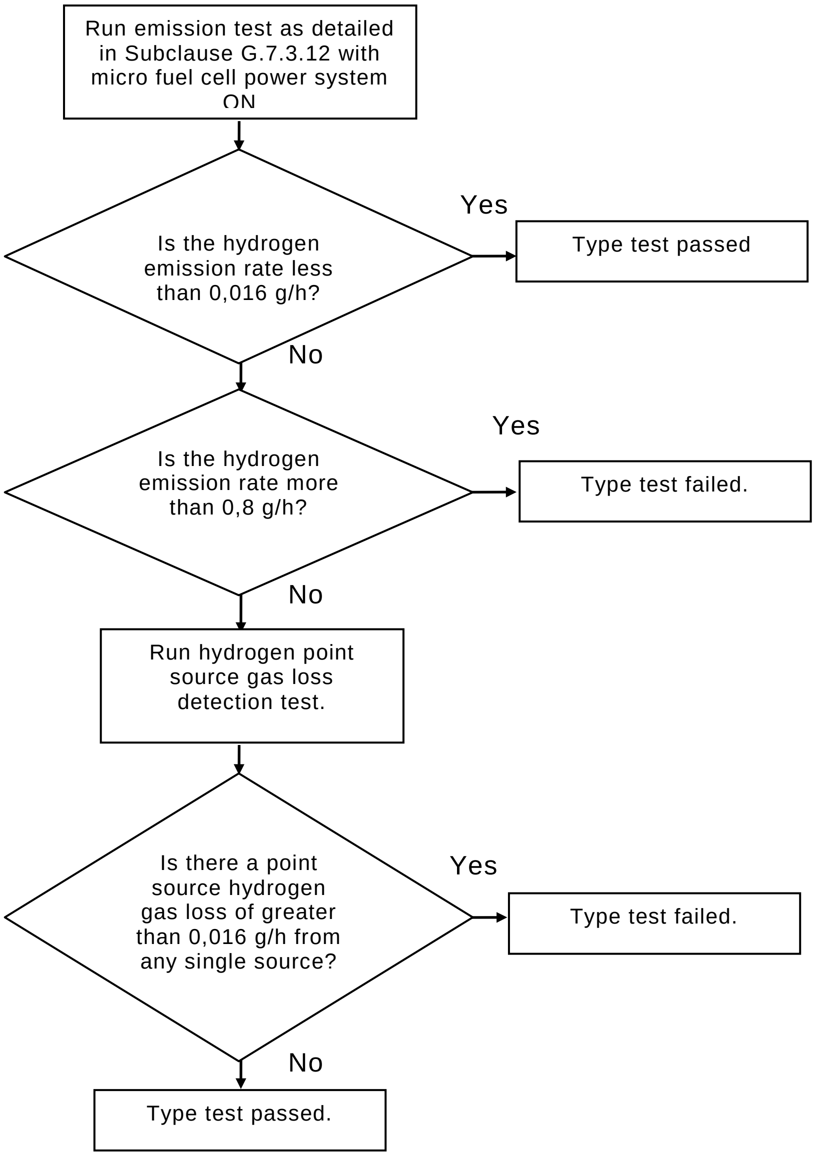


Figure G.12 – Hydrogen emission test procedure for operating micro fuel cell power system

G.7.3.13 Hydrogen point source gas loss detection test

The procedure for hydrogen emission testing is detailed in Figure G.12, which is to be used as an additional figure when testing is done in accordance with Annex G.

This subclause shall be used if required by subclause G.7.3.12 e) 3) ii) to show compliance with Table G.7, for Class 8 (corrosive) borohydride micro fuel cell power systems and Class 8 (corrosive) borohydride micro fuel cell power units. This subclause is required to be performed to meet the passing criteria of Subclause G.7.3.12 e) 3) ii) if the total hydrogen emission rate from an operational Class 8 (corrosive) borohydride micro fuel cell power system or unit is less than 0,8 g/h but more than 0,016 g/h with the "DEVICE – ON". This subclause is additional to the requirements in Clause 7.

a) **Test sample:** A micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or a micro fuel cell power unit – that is fuelled with Class 8 (corrosive) borohydride – emission of hydrogen shall be maintained at less than the specified values in Table G.7. The hydrogen point source gas loss detection test shall be performed to determine that no single source on the micro fuel cell power system or unit can support a flame in all cases where such compliance cannot be definitively determined by the hydrogen emission test. Maintaining these limits ensures that, in addition to not permitting a flammable concentration to build up in the reference volume, there is no gas loss of hydrogen from the specimen that could support a flame and along with the other emissions testing ensures an adequate supply of oxygen is maintained in the operating environment.

c) **Test apparatus:** The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, a hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL. The response of the aforementioned hydrogen detectors is commonly slow, with a response time of many seconds, thus high sweep speeds may cause underestimation of the hydrogen concentration. It is important that the sweep speed shall be slow enough to accurately measure the hydrogen concentration.

d) **Test procedure:**

1) The micro fuel cell power system or micro fuel cell power unit shall remain turned on ("DEVICE – ON") throughout the duration of the hydrogen point source gas loss detection test.

2) The testing shall be conducted in a space with no substantial air movement. The measured wind speed 10 cm above the micro fuel cell power system or unit shall not exceed 0,02 m/s. The local concentration of hydrogen diffusion measured in this test is very susceptible to the effect of wind. It is desirable that wind speed anywhere in the test space is as close to zero as possible. Testing in a closed space, such as a glove box or equivalent chamber, is one available method to achieve this requirement.

3) The surface of the micro fuel cell power system or unit shall be systematically swept with a point source hydrogen detector. This hydrogen detector may be either a mass spectrometer, hand-held hydrogen detector, or other instrument suitable for measuring small quantities of hydrogen from a point source that is at least as accurate, if not more so, than the aforementioned instruments. The hydrogen detector shall be tuned to detect a level of hydrogen that is at 25 % of LFL.

4) The sensor of the hydrogen detector shall sweep the micro fuel cell power system or unit at a distance no more than 3 mm normal to the surface of the micro fuel cell power system or unit. Consecutive linear sweeps shall not be more than 8 mm apart along the surface of the micro fuel cell power system or unit. The entire surface of the micro fuel cell power system or unit shall be swept in this manner.

5) An effective method for completing these sweeps would be to attach a stand off to the sensor that ensures that a spacing of 3 mm from the micro fuel cell power system or unit is maintained at all times. A pen or other marking utensil attached to the stand off could be used to identify swept areas and ensure that the distance between sweeps does not exceed 8 mm.

6) The sensor should always face directly downward, and the micro fuel cell power system or unit should be moved beneath it such that the surface directly below the sensor is always horizontal.

7) If no points are found where the hydrogen concentration is greater than 25 % LFL, the test is complete and the micro fuel cell power system or unit shall be considered to have passed.

8) When some point source sweeps show a large region of 25 % LFL or greater in the initial linear sweeps, recording the measured concentration values will assist in determining the starting point of secondary spiral sweeps. Point sources are supposed to be where local maximum values exist in the distribution of measured concentration values.

9) If any points are detected to have a hydrogen concentration of 25 % LFL or greater, a second test shall be conducted to ensure that the emission does not exceed 0,016 g/h of pure hydrogen from any single source.

10) The second test shall be performed with the sensor height adjusted to 6,5 mm above the micro fuel cell power system or unit.

11) A spiral sweep shall then be made, originating from the point where the detection of 25 % LFL or greater of hydrogen occurred during the initial linear sweep. The spiral sweep shall have a spacing of 1 mm or less between sweeps, and shall spiral out to a radial distance of at least 4 mm and far enough to detect the maximum hydrogen level from the particular hydrogen source.

12) If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. If the spiral sweep does not detect any hydrogen concentrations of 25 % LFL or greater, the micro fuel cell power system or unit passes the test.

e) **Passing criteria:** No gas loss of hydrogen from any single source at greater than 0,016 g/h as indicated by sweep testing. No indications of hydrogen that is 25 % of LFL during the primary sweep testing or no indications of hydrogen that is 25 % of LFL during the secondary sweep testing at 6,5 mm above the micro fuel cell power system or unit. If the spiral sweep at 6,5 mm above the micro fuel cell power system or unit detects a maximum concentration of hydrogen that is 25 % of LFL or greater, the micro fuel cell power system or unit fails the test. See Table G.7.

Annex H
(normative)

Butane solid oxide micro fuel cell power systems

H.1 Scope

H.1.2 Fuels and technologies covered

Annex H covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use butane and butane/propane mixtures – consisting of at least 75 % butane by mass – as fuel. These systems and units use solid oxide fuel cell technologies.

Figure H.1 replaces Figure 1 showing a butane solid oxide micro fuel cell power system block diagram for use with this annex.

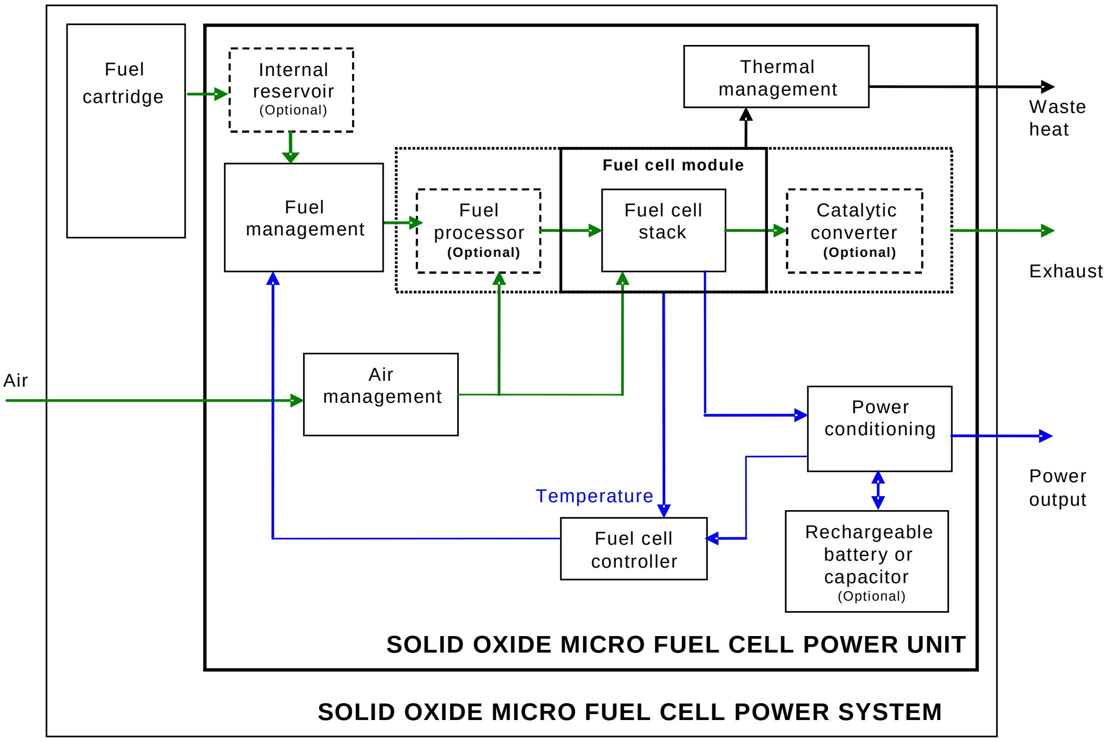


Figure H.1 – Butane solid oxide micro fuel cell power system block diagram – Replaces Figure 1

H.3 Terms and definitions

The terms and definitions below replace those corresponding terms and definitions in Clause 3 for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex H. All terms and definitions in Clause 3 not specifically mentioned here also apply.

H.3.5
fuel
butane and butane/propane mixtures comprising at least 75 % butane by mass

H.3.7
hazardous liquid fuel
not applicable for this Annex H

H.3.11
leakage
impermissible leakage as defined in H.3.37

H.3.18
no accessible liquid
not applicable for this Annex H

H.3.19
no fuel vapour loss
no impermissible leakage as defined in H.3.37

H.3.26
waste cartridge
not applicable for this Annex H

H.3.27
water cartridge
not applicable for this Annex H

The additional term and definition below is needed for micro fuel cell power systems, micro fuel cell power units and fuel cartridges covered by this Annex H in addition to those given in Clause H.3 and in Clause 3.

H.3.37
impermissible leakage
a release of fuel in excess of 0,045 g/h from a non-operating micro fuel cell power system or fuel cartridge

In addition, no impermissible leakage shall mean fuel cartridges are bubble-tight as confirmed by the water bath test described in this annex. For micro fuel cell power systems, no impermissible leakage shall also mean compliance with the emission test limits specified in this annex.

H.4 Materials and construction of micro fuel cell power systems, micro fuel cell power units and fuel cartridges

H.4.1 General

These requirements apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex H. These requirements replace the corresponding requirements of Subclause 4.1.

a) Compliance with the requirements of Clause H.4 shall be verified during the review of the safety FMEA and/or during type tests specified in Clause H.7.

b) The micro fuel cell power unit, when coupled to the fuel cartridge, shall be designed and constructed to avoid any credible risk of leakage, fire or explosion posed by the micro fuel cell power system itself or gases, vapours, liquids or other substances produced or used by the micro fuel cell power system.

c) To prevent a fire or explosion hazard within the micro fuel cell power system, the manufacturer shall eliminate potential ignition source(s) within areas where fuel is present (or can be potentially released).

d) Flammable, toxic or corrosive materials shall be kept within a closed containment system such as within fuel piping, in a reservoir, a fuel cartridge or similar enclosure.

H.4.2 FMEA / hazard analysis

These requirements apply to micro fuel cell power systems, units and fuel cartridges covered by this Annex H. These requirements replace the corresponding requirements of Subclause 4.2.

H.4.2.1 A failure modes and effects analysis (FMEA) or equivalent reliability analysis shall be conducted by the manufacturer to identify faults which can have safety related consequences and the design features that serve to mitigate those faults. The analysis shall include failures that may result in leakage. Failures related to refilling of non-user refillable fuel cartridges, if anticipated by the manufacturer or trained technicians, shall be considered.

H.4.2.2 Guidance can be found in the following informative references: IEC 61025, and IEC 60812.

H.4.2.3 It shall be the responsibility of the manufacturer to ensure that any emission from the micro fuel cell power system does not result in harmful or dangerous effects on the user or others during normal use, reasonably foreseeable misuse, and consumer transportation.

H.4.2.4 The FMEA shall include consideration of the effects of the micro fuel cell power system and cartridges being exposed to fire.

H.4.12 Fuel supply construction

H.4.12.1 Fuel cartridge construction

These requirements apply to micro fuel cell power systems and units covered by this Annex H. These requirements replace the corresponding requirements of Subclause 4.12.1.

Fuel cartridges shall conform to the following requirements:

H.4.12.1.1 There shall be no leakage from the fuel cartridge in the temperature range of –40 °C to +70 °C. Compliance shall be determined by type testing in accordance with H.7.3.3 and H.7.3.4.

H.4.12.1.2 There shall be no leakage from the fuel cartridge at an internal pressure of two times the gauge pressure of the fuel cartridge at 55 °C. Compliance shall be determined by type testing in accordance with H.7.3.1.

H.4.12.1.3 Maximum fuel volume in the fuel cartridge shall not exceed 1 l.

H.4.12.1.4 For normal use, reasonably foreseeable misuse, and consumer transportation of a fuel cartridge with a micro fuel cell power unit by a consumer, means to prevent fuel leakage prior to, during, and after connection or transfer of fuel to the micro fuel cell power unit shall be provided. Compliance is checked by H.7.3.11.

H.4.12.1.5 A fuel cartridge shall be resistant to corrosion in its usage environment.

H.4.12.1.6 A fuel cartridge shall be provided with a means to prevent misconnection that would result in leakage of fuel when it is installed in a micro fuel cell power system. Compliance is checked by the connection cycling test, H.7.3.11.

H.4.12.1.7 Fuel supply connectors provided on the fuel cartridge shall have a construction that prevents the leakage of fuel when not attached to a micro fuel cell power unit during normal usage, reasonably foreseeable misuse, and consumer transportation. Compliance is checked by the drop test, H.7.3.5, and the connection cycling test, H.7.3.11.

H.4.12.1.8 In the case where a pressure release valve or similar means is provided, such pressure release valve shall satisfy the performance requirement for each type test. This valve shall pass all type tests with no leakage.

H.4.12.1.9 The structure at the connection to the fuel cartridge shall not allow fuel to leak.

H.4.12.1.10 A fuel cartridge, including the fuel cartridge interface to the micro fuel cell power unit, including the valve, shall have a construction sufficient to withstand normal use and reasonably foreseeable misuse generated by vibration, heat, pressure, being dropped or otherwise subject to a mechanical shock etc. Compliance is checked by:

- pressure differential tests, H.7.3.1;
- vibration test, H.7.3.2;
- temperature cycling test, H.7.3.3;
- high temperature exposure test, H.7.3.4;
- drop test, H.7.3.5;
- compressive loading test, H.7.3.6;
- long-term storage test, H.7.3.9;
- high-temperature connection test, H.7.3.10;
- connection cycling tests, H.7.3.11.

H.4.12.1.11 The fuel cartridge valves shall operate as intended without the use of tools and without excessive force needed to connect or disconnect.

H.4.12.1.12 Fuel cartridges containing in excess of 120 ml of fuel will be designed to provide a controlled release of fuel in the case of exposure to fire. This may be accomplished through either a thermally sensitive or pressure sensitive feature. This may be integrally incorporated into the fuel cartridges, such as through a portion of the fuel cartridge having a designed weakness that will vent at an appropriate pressure or temperature.

H.4.12.1.13 Fuel cartridges in excess of 200 ml shall be fire tested in accordance with H.7.3.15.

H.4.12.2 Fuel cartridge fill requirement

These requirements apply to micro fuel cell power systems and units covered by this Annex H. These requirements replace the corresponding requirements of Subclause 4.12.2.

Fuel cartridges shall conform to the following requirements.

The fuel cartridge design and fuel fill amount shall allow fuel expansion without leakage to a fuel cartridge temperature of 70 °C in the case of the fuel cartridge alone and when the fuel cartridge is constrained by the micro fuel cell power system or a comparable test fixture.

H.6 Instructions and warnings for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

H.6.2 Minimum markings required on the fuel cartridge

These markings replace the markings required by Subclause 6.2.

As a minimum, the following shall be marked on the fuel cartridge.

a) CONTENTS ARE FLAMMABLE, DO NOT DISASSEMBLE.

b) KEEP AWAY FROM CHILDREN.

c) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES OR IGNITION SOURCES.

d) FOLLOW USAGE INSTRUCTIONS.

e) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

f) COMPOSITION AND AMOUNT OF FUEL.

g) TEXT OR MARKING THAT INDICATES THAT THE FUEL CARTRIDGE COMPLIES WITH IEC 62282-6-100.

H.6.3 Minimum markings required on the micro fuel cell power system

These markings replace the markings required by Subclause 6.3.

In addition, as a minimum, the following shall also be marked on the micro fuel cell power system to show:

a) CONTENTS ARE FLAMMABLE, DO NOT DISASSEMBLE.

b) DO NOT EXPOSE TO TEMPERATURES ABOVE 50 °C OR OPEN FLAMES OR IGNITION SOURCES.

d) FOLLOW USAGE INSTRUCTIONS.

e) TRADE MARK AND/OR MANUFACTURER NAME, MODEL DESIGNATION AND TRACEABILITY REQUIRED BY THE MANUFACTURER.

g) COMPOSITION OF FUEL.

h) MAXIMUM CAPACITY OF FUEL IN THE INTERNAL RESERVOIR, IF APPLICABLE.

i) TEXT OR MARKING THAT INDICATES THAT THE MICRO FUEL CELL POWER SYSTEM COMPLIES WITH IEC 62282-6-100.

j) ELECTRICAL OUTPUT (VOLTAGE, CURRENT, RATED POWER).

H.7 Type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges

H.7.1 General

This Clause H.7 replaces Clause 7 for this annex H when testing micro fuel cell power systems, micro fuel cell power units and fuel cartridges that use butane and butane/propane mixtures as fuel.

a) The type tests for micro fuel cell power systems, micro fuel cell power units and fuel cartridges shall provide that these micro fuel cell power systems, units and fuel cartridges are safe for normal use.

b) Table H.5 lists the type tests that shall be performed. *Table H.5 replaces Table 5.*

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by Table H.6. *Table H.6 replaces Table 6.*

d) The micro fuel cell power system, power unit and/or fuel cartridge shall be conditioned at a standard laboratory temperature of 22 °C ± 5 °C for a minimum of 3 h prior to each test being performed.

e) Warning: These type tests use procedures that may result in harm if adequate precautions are not taken. Tests should only be performed by qualified and experienced technicians using adequate protection.

Table H.5 – List of type tests – Replaces Table 5

Test reference	Test item	Test sample
H.7.3.1	Pressure differential tests	Fuel cartridge Fuel cartridge valve Micro fuel cell power system or power unit
H.7.3.2	Vibration test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
H.7.3.3	Temperature cycling test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
H.7.3.4	High temperature exposure test	Fuel cartridge Partially filled fuel cartridge
H.7.3.5	Drop test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
H.7.3.6	Compressive loading test	Fuel cartridge Partially filled fuel cartridge Micro fuel cell power system or power unit
H.7.3.7	External short-circuit test	Micro fuel cell power system or power unit
7.3.8	Surface, component and exhaust gas temperature test	Micro fuel cell power system or power unit
H.7.3.9	Long-term storage test	Fuel cartridge Partially filled fuel cartridge
H.7.3.10	High-temperature connection test	Fuel cartridge and micro fuel cell power unit Partially filled fuel cartridge and micro fuel cell power unit
H.7.3.11	Connection cycling test	Fuel cartridge and micro fuel cell power unit
H.7.3.12	Emission test	Micro fuel cell power system or power unit
H.7.3.13	High temperature shutdown test	Micro fuel cell power system or power unit
H.7.3.14	High temperature operation test	Micro fuel cell power system or power unit
Table H.5 replaces Table 5. Test sample: The quantity of the sample shall be a minimum of six (6) fuel cartridges, either unused or partially filled, as specified by the individual tests above, or a minimum of three (3) micro fuel cell power systems or units for each type test. Test sequence: Tests H.7.3.2 and H.7.3.3 shall be conducted sequentially for testing the same fuel cartridges. Tests H.7.3.1, H.7.3.2, and H.7.3.3 shall be done sequentially for testing the same micro fuel cell power systems or power units. Reuse of samples: Fuel cartridges and micro fuel cell power systems or units may be re-used at the manufacturer’s discretion if it does not compromise the individual test.		

Table H.6 – Laboratory standard conditions – Replaces Table 6

Item	Condition
Laboratory temperature	Laboratory temperature is "room temperature" (standard temperature condition, 22 °C ± 5 °C)
Laboratory room atmosphere; for micro fuel cell power system and micro fuel cell power unit testing only.	The laboratory atmosphere contains not more than 0,2 % carbon dioxide and not more than 0,002 % carbon monoxide. The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen.

H.7.2 Leakage measurement of fuel and the measuring procedure

The leakage measurement of butane or butane/propane mixture fuel shall be executed in principle in accordance with the procedure shown in Figures H.2 through H.7 and H.9 respectively. Any exceptions will be noted in the various subclauses.

If fuel cartridges are made of a material that can absorb and release moisture which could affect the accuracy of mass loss measurements, an empty fuel cartridge may optionally be subject to the type tests along with the test fuel cartridges and any weight change in the empty fuel cartridge used to correct the measurement of the test fuel cartridge.

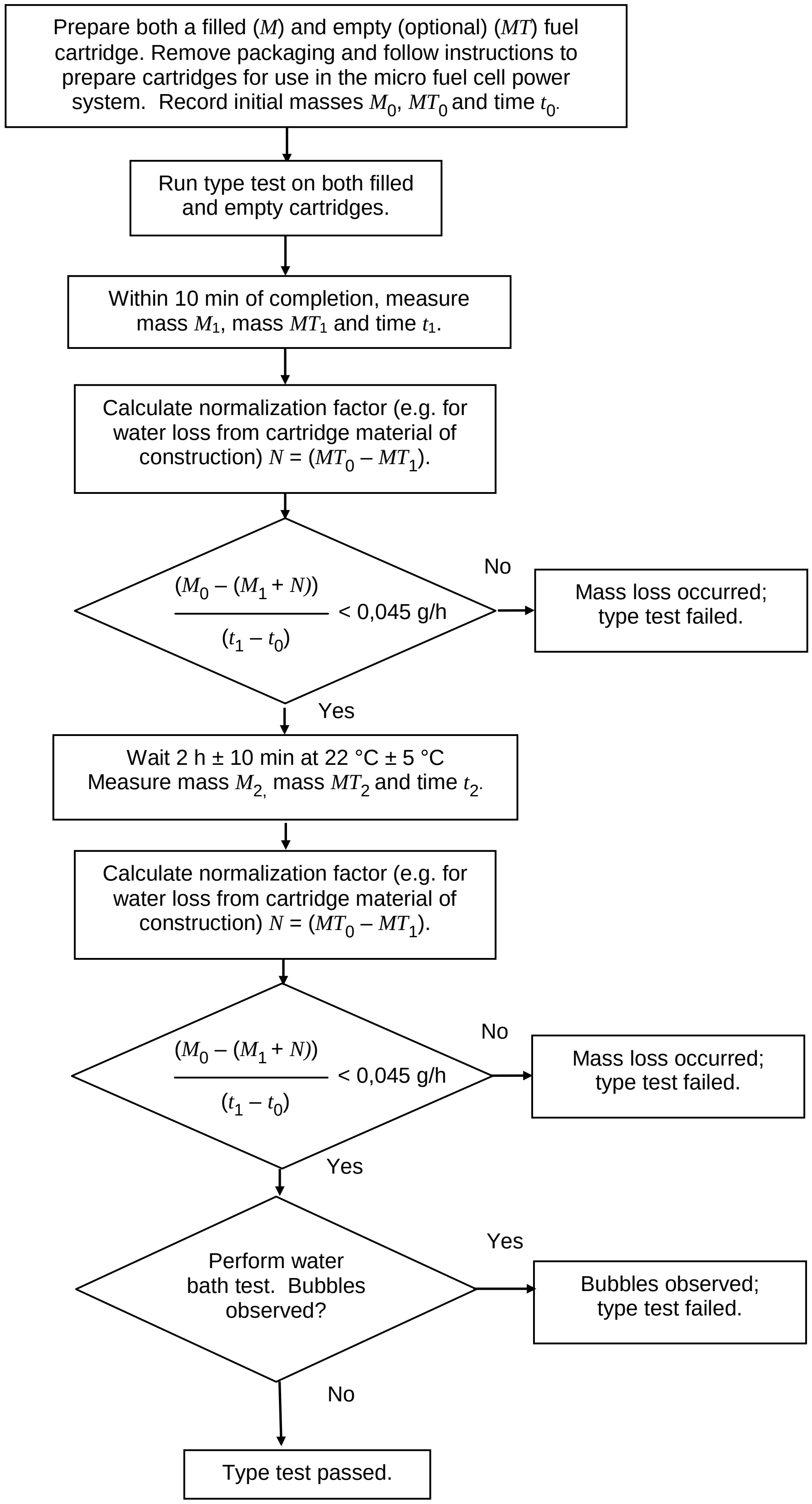


Figure H.2 – Fuel cartridge leakage and mass loss test flow chart for vibration, drop and compressive loading tests – Replaces Figure 2

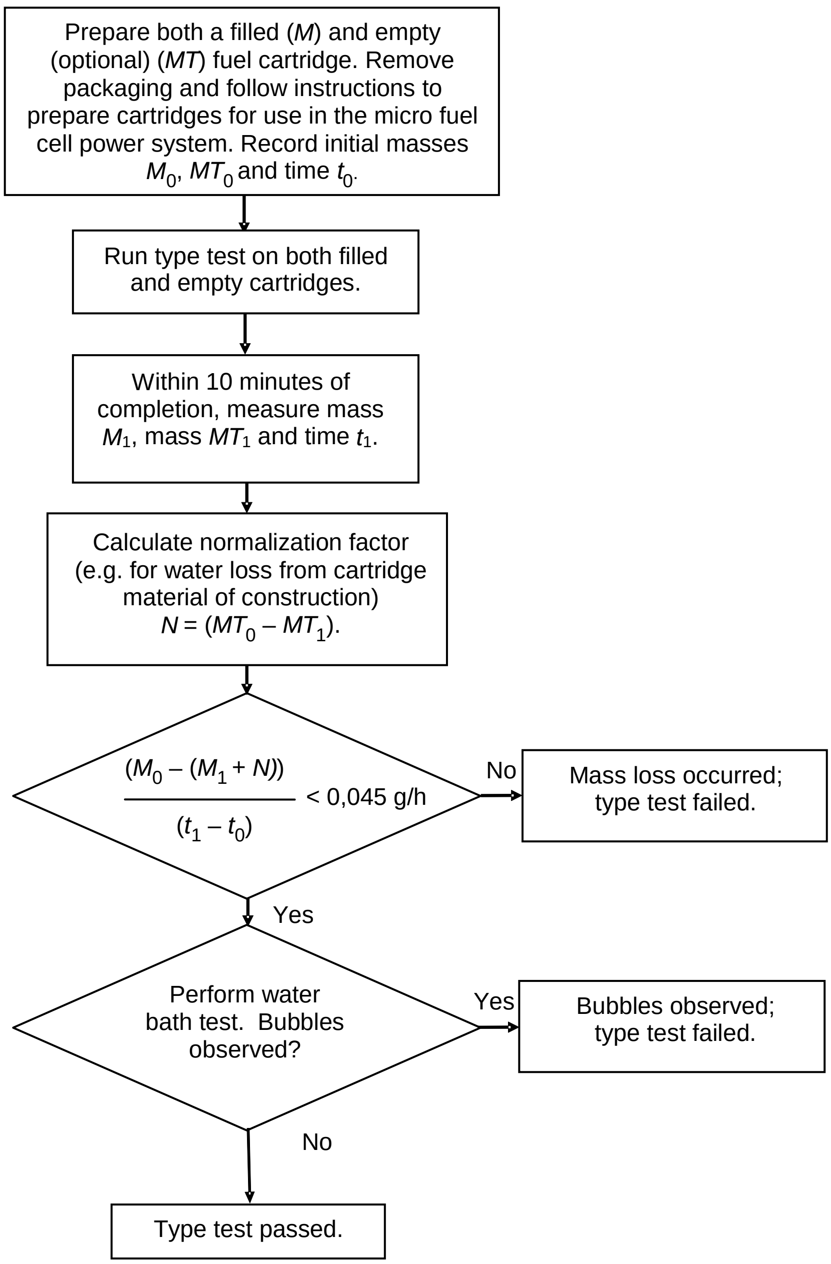


Figure H.3 – Fuel cartridge leakage and mass loss test flow chart for temperature cycling test and high temperature exposure test – Replaces Figure 3

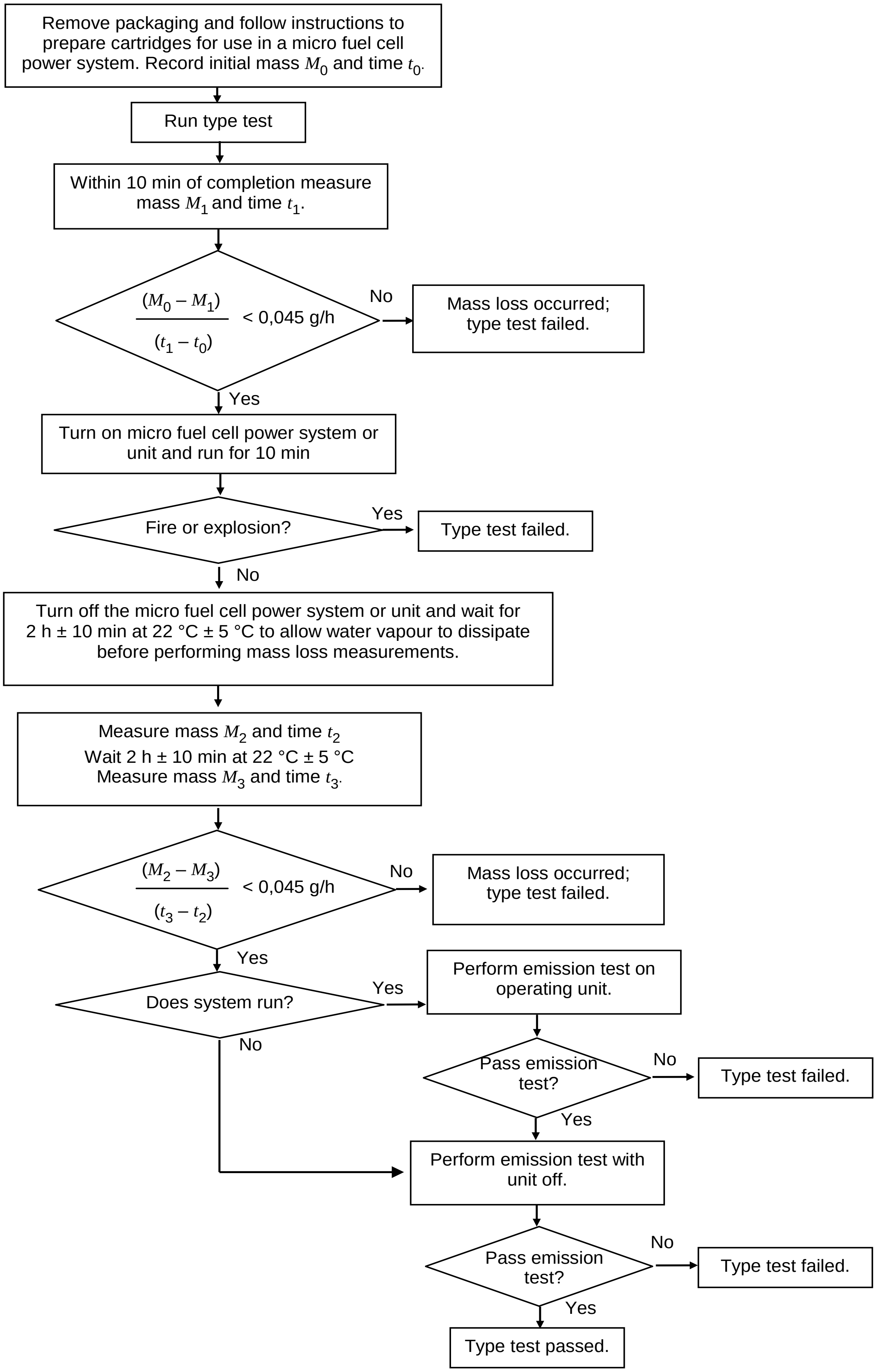


Figure H.4 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for pressure differential, vibration, temperature cycling, drop and compressive loading tests – Replaces Figure 4

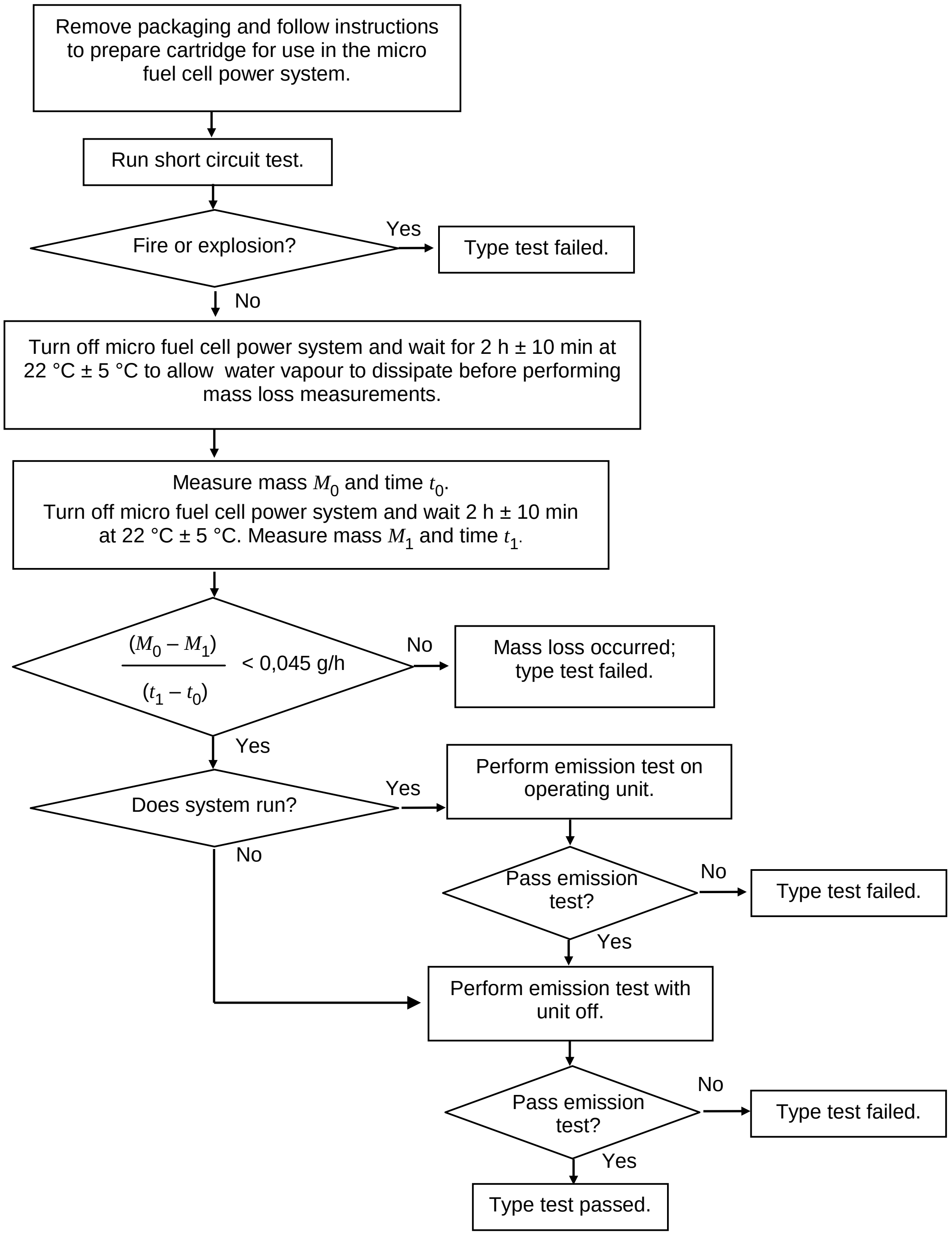


Figure H.5 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for external short-circuit test – Replaces Figure 5

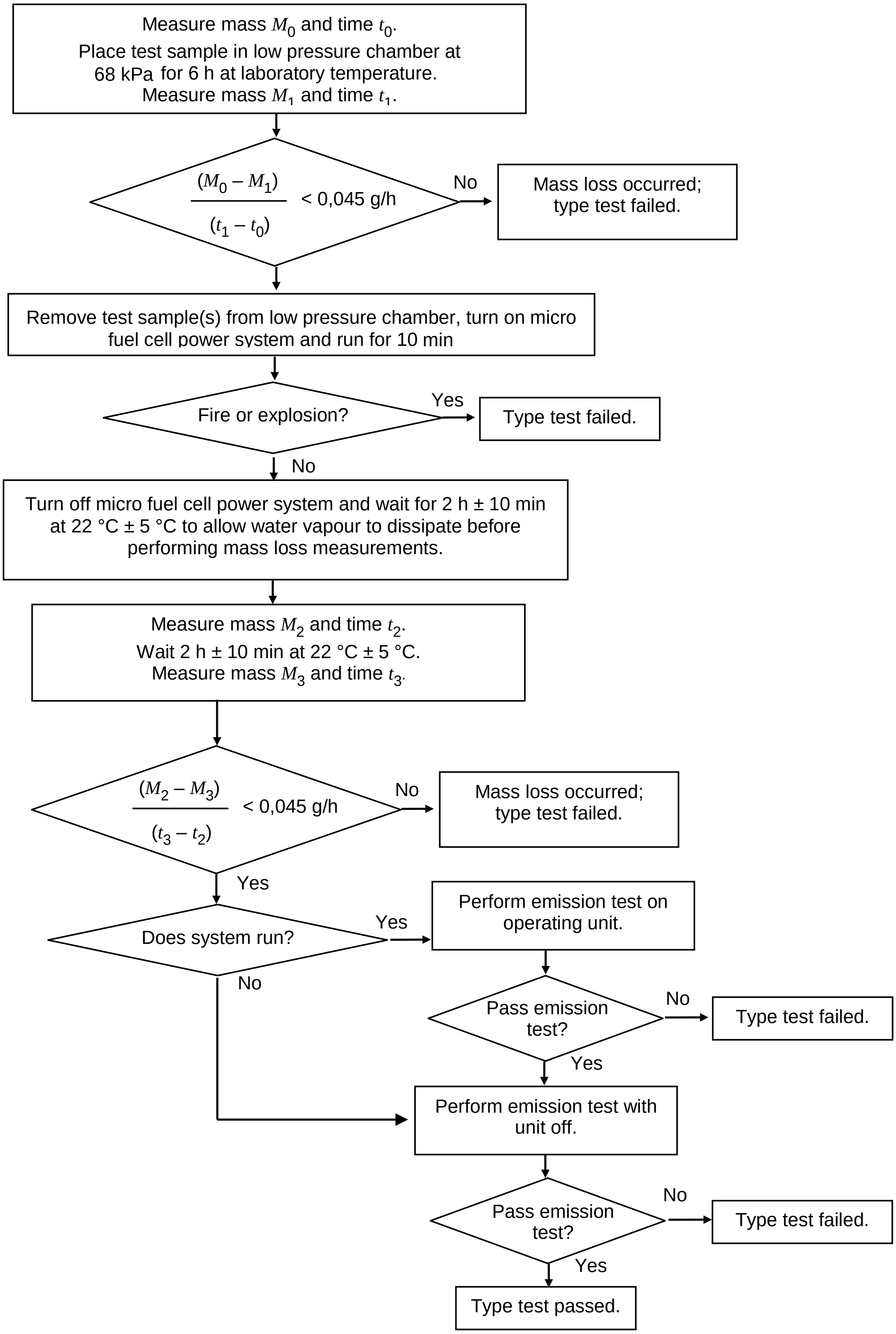


Figure H.6 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 68 kPa low external pressure test – Replaces Figure 6

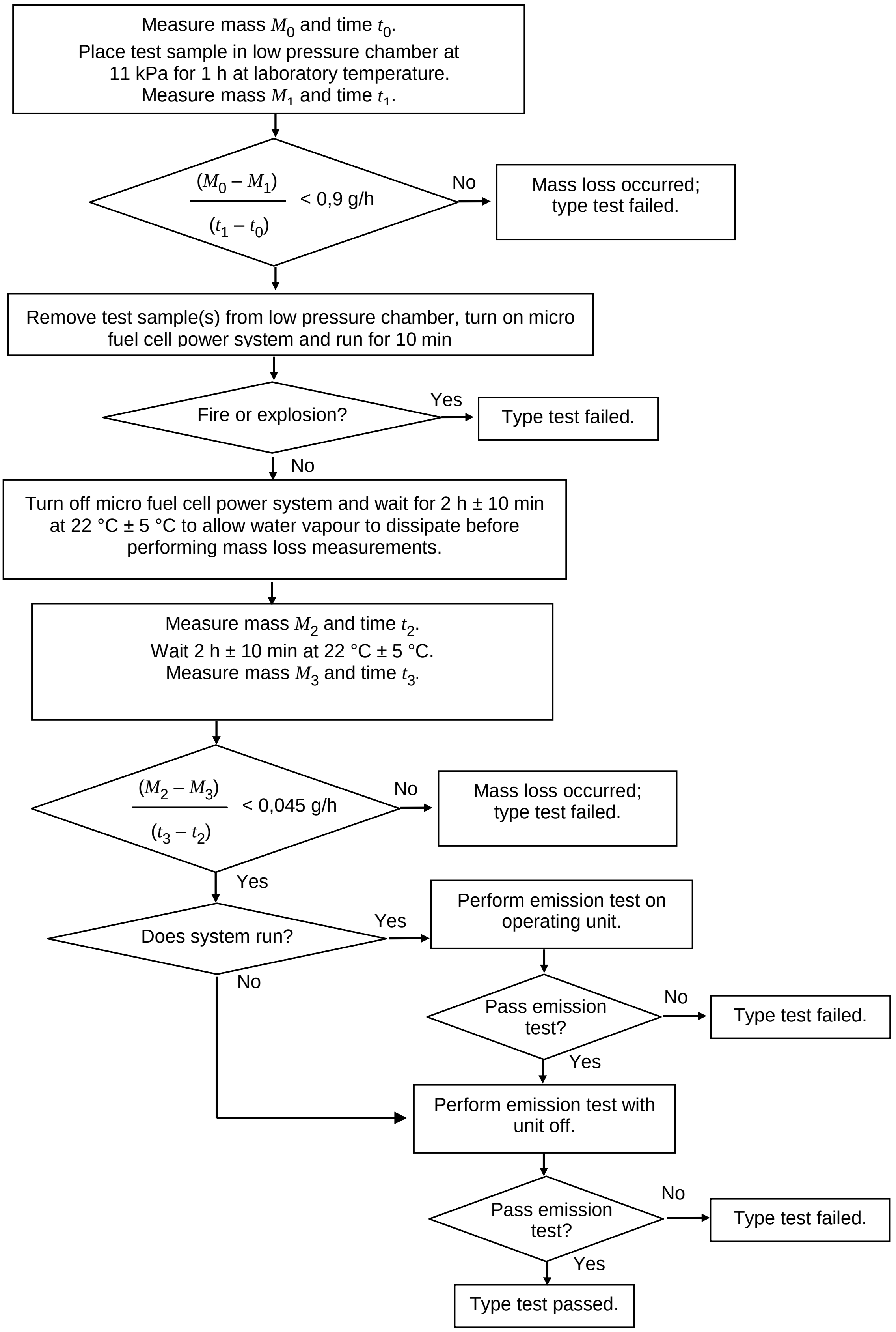


Figure H.7 – Micro fuel cell power system or micro fuel cell power unit leakage and mass loss test flow chart for 11,6 kPa low external pressure test – Replaces Figure 7

H.7.3 Type tests

H.7.3.1 Pressure differential tests

H.7.3.1.1 General

Portions of this test check compliance with Subclause H.4.12.1.2 to verify that there shall be no leakage from the fuel cartridge at an internal pressure of two times the gauge pressure of the fuel cartridge at 55 °C.

H.7.3.1.2 Fuel cartridge internal pressurization test

Either H.7.3.1.2.1 (Option 1), H.7.3.1.2.2 (Option 2) or H.7.3.1.2.3 (Option 3) may be used.

H.7.3.1.2.1 Option 1 – Mass flow measurement

a) **Test sample:** a fuel cartridge body and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

For the internal pressurization test mass flow measurement, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

1) Using a suitable fluid medium such as butane, air, nitrogen, or similar gas, pressurize the fuel cartridge body to an internal pressure of twice the vapour pressure of the fuel at 55 °C. A flow sensor suitable for measuring the impermissible leakage rate shall be placed in line with the pressurizing medium. The pressure rise shall not exceed a rate of 60 kPa/s.

2) Maintain the maximum pressure for 30 min at laboratory temperature.

3) Using a suitable fluid medium such as butane, air, nitrogen, or similar gas, pressurize the closed fuel cartridge valve to a pressure of twice the vapour pressure of the fuel at 55 °C. A flow sensor suitable for measuring the impermissible leakage rate shall be placed in line with the pressurizing medium. The pressure rise shall not exceed a rate of 60 kPa/s.

4) Maintain the maximum pressure for 30 min at laboratory temperature.

5) If an alternative reference gas is used for the pressurizing fluid media, the measured leak rate shall be normalized to an equivalent butane leakage rate.

See below:

$$LR_{\mathrm{Beq}} = D_{\mathrm{B}} \times FR_{\mathrm{RG}} \times \frac{V_{\mathrm{RG}}}{V_{\mathrm{B}}}$$

where

LR_{Beq} is the butane equivalent leakage rate in grams per hour;

D_{B} is the density of butane gas at standard laboratory conditions in grams per cubic meter;

FR_{RG} is the reference gas flow rate in cubic meters per hour;

V_{RG} is the viscosity of the reference gas;

V_{B} is the viscosity of butane gas.

d) **Passing criteria:** No impermissible leakage or sudden loss of pressure. Mass loss shall be less than 0,045 g/h of butane or equivalent.

H.7.3.1.2.2 Option 2 – Mass emission rate measurement

a) **Test sample:** a fuel cartridge body and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test apparatus:** An example of the mass emission rate testing apparatus is shown in Figure H.10.

d) **Test procedure:**

For the internal pressurization test mass flow measurement, both the fuel cartridge body and the fuel cartridge valve must be pressurized, but may be tested either separately or concurrently.

1) Place the fuel cartridge body and a fuel cartridge valve inside the small test chamber shown in Figure H.10.
2) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.
3) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.
4) Using a suitable reference gas medium such as helium, hydrogen, carbon dioxide, or other detectable gas, pressurize the fuel cartridge body and the fuel cartridge valve to an internal pressure of twice the vapour pressure of the fuel at 55 °C. The pressure rise shall not exceed a rate of 60 kPa/s.
5) Maintain the pressure for 30 min at laboratory temperature.
6) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure H.10, while simultaneously measuring and recording the flow through the test chamber. The flow through the test chamber can be computed from the sum of the variable flow air pump flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber.
7) Record the concentrations of the reference gas media and calculate the emission rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

or

$$ER = (F_{\mathrm{i}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

8) Compute the mass equivalent leakage rate of butane using the density and viscosity of the reference gas and of butane.

See below:

$$ER_{\mathrm{Beq}} = ER_{\mathrm{RG}} \times \frac{D_{\mathrm{B}}}{D_{\mathrm{RG}}} \times \frac{V_{\mathrm{RG}}}{V_{\mathrm{B}}}$$

where

ER_{Beq} is the butane equivalent emission rate in grams per hour;

ER_{RG} is the reference gas emission rate as calculated above;

D_{B} is the density of butane gas at standard laboratory conditions;

D_{RG} is the density of the reference gas at standard laboratory conditions;

V_{RG} is the viscosity of the reference gas;

V_{B} is the viscosity of butane gas.

e) **Passing criteria:** No impermissible leakage or sudden loss of pressure. Mass loss shall be less than 0,045 g/h of butane or equivalent.

H.7.3.1.2.3 Option 3 – Immersion test

a) **Test sample:** a fuel cartridge body and a fuel cartridge valve.

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage.

c) **Test procedure:**

For the internal pressurization test, the fuel cartridge body and the fuel cartridge valve shall be tested separately.

1) Using a suitable fluid medium such as butane, air, nitrogen, or similar gas, pressurize the fuel cartridge body to an internal pressure of twice the vapour pressure of the fuel at 55 °C. The pressure rise shall not exceed a rate of 60 kPa/s.
2) Maintain the maximum pressure for 30 min at laboratory temperature.
3) While maintaining pressure, place the fuel cartridge body in a room temperature water bath and verify that the cartridge body is bubble tight.
4) Using a suitable fluid medium such as butane, air, nitrogen, or similar gas, pressurize the closed fuel cartridge valve to a pressure of twice the vapour pressure of the fuel at 55 °C. The pressure rise shall not exceed a rate of 60 kPa/s.
5) Maintain the maximum pressure for 30 min at laboratory temperature.
6) While maintaining pressure, place the fuel cartridge valve in a room temperature water bath and verify that the fuel cartridge valve is bubble tight.

d) **Passing criteria:** No bubbles, impermissible leakage or sudden loss of pressure. Fuel cartridge body and fuel cartridge valve shall be bubble tight.

H.7.3.1.3 Fuel cartridge low external pressure test

This subclause of the main body is not applicable to this Annex H, as twice the vapour pressure of the Annex H fuel will always exceed a gauge pressure of 95 kPa plus the normal cartridge working pressure at 22 °C, making this test unsuitable as an alternative to the fuel cartridge internal pressurization test.

H.7.3.1.4 Micro fuel cell power system or micro fuel cell power unit pressure differential tests

H.7.3.1.4.1 Micro fuel cell power system or micro fuel cell power unit 68 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex H.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   1) Perform this test in accordance with Figure H.6.

   2) Place test sample in low pressure chamber and reduce pressure to 68 kPa.

   3) Allow the test sample to remain at 68 kPa for 6 h at laboratory temperature.

   4) Return the chamber to atmospheric pressure and remove test sample from chamber.

   5) Leakage shall be measured on the basis of the procedure described in Figure H.6.

   6) Perform emission testing in accordance with H.7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.6 and shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. The emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but the emission does not exceed the limits of H.7.3.12, the emission test is acceptable.

H.7.3.1.4.2 Micro fuel cell power system or micro fuel cell power unit 11,6 kPa low external pressure test

This test is required for all micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex H.

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system.

b) **Purpose:** to simulate the effects of high internal pressure or low external pressure and ensure no leakage.

c) **Test procedure:**

   Perform this test in accordance with Figure H.7.

   1) Place test sample in low pressure chamber and reduce pressure to 11 kPa.

   2) Allow the test sample to remain at 11 kPa for 1 h at laboratory temperature.

   3) Return the chamber to atmospheric pressure and remove test sample from chamber.

   4) Leakage shall be measured on the basis of the procedure described in Figure H.7.

   5) Perform emission testing in accordance with H.7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.7 and shall be less than 0,9 g/h while at 11 kPa and less than 0,045 g/h the remainder of the test. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. The emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but the emission does not exceed the limits of H.7.3.12, the emission test is acceptable.

H.7.3.2 Vibration test

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in H.7.3.1 or a micro fuel cell power system used in H.7.3.1.

b) **Purpose:** to simulate the effects of normal transportation vibration and ensure no leakage.

c) **Test procedure:**

1) Perform these tests in accordance with Figure H.2 for the fuel cartridge and Figure H.4 for the micro fuel cell power system or micro fuel cell power unit.

2) The test sample shall be firmly secured to the platform of the vibration machine without distorting the sample in such a manner as to properly transmit the vibration.

3) The vibration shall be a sinusoidal waveform with a logarithmic sweep between 7 Hz and 200 Hz and back to 7 Hz traversed in 15 min.

4) This cycle shall be repeated 12 times for a total of 3 h for each of three mutually perpendicular mounting positions of the test samples.

5) The logarithmic frequency sweep is as follows: from 7 Hz a peak acceleration of 1 g_n is maintained until 18 Hz is reached. The amplitude is then maintained at 0,8 mm (1,6 mm total excursion) and the frequency increased until a peak acceleration of 8 g_n occurs (approximately 50 Hz). A peak acceleration of 8 g_n is then maintained until the frequency is increased to 200 Hz.

6) For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with H.7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage and fuel vapour loss shall be measured based upon Figure H.2 for the fuel cartridge and Figure H.4 for the micro fuel cell power system or micro fuel cell power unit. Leakage shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. The emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but the emission does not exceed the limits of H.7.3.12, the emission test is acceptable.

H.7.3.3 Temperature cycling test

a) **Test sample:** a fuel cartridge used in H.7.3.2, a partially filled fuel cartridge used in H.7.3.2, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications used in H.7.3.2 or a micro fuel cell power system used in H.7.3.2.

b) **Purpose:** to simulate the effects of low-temperature and high temperature exposure and the effects of extreme temperature change.

c) **Test procedure:**

1) Perform these tests in accordance with Figure H.3 for the fuel cartridge and Figure H.4 for the micro fuel cell power system or micro fuel cell power unit.

2) For a fuel cartridge, two fuel cartridge orientations shall be tested – valve up and valve down. For a micro fuel cell power system or a micro fuel cell power unit, only one orientation needs to be tested.

3) See Figure H.8 for the temperature profile to be used.

4) Place the test sample in a temperature-controlled test chamber and increase the chamber temperature from laboratory temperature to 55 °C ± 2 °C in 1 h ± 5 min and keep it at 55 °C ± 2 °C for a minimum of 4 h.

5) Decrease the chamber temperature to 22 °C ± 5 °C in 1 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min, then decrease the chamber temperature to –40 °C ± 5 °C in 2 h ± 5 min and keep it at –40 °C ± 5 °C for a minimum of 4 h.

6) Increase the chamber temperature to 22 °C ± 5 °C in 2 h ± 5 min and keep it at 22 °C ± 5 °C for 1 h ± 5 min.

7) The above process is to be done twice.

8) Upon completion of the second cycle, leakage and fuel vapour loss shall be measured based upon the procedure described in Figure H.3 (for fuel cartridge) and Figure H.4 (for micro fuel cell power system or micro fuel cell power unit).

9) For the micro fuel cell power system or micro fuel cell power unit, perform emission testing in accordance with H.7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage and fuel vapour loss shall be measured based upon Figure H.3 for the fuel cartridge and Figure H.4 for the micro fuel cell power system or micro fuel cell power unit. Leakage shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. The emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but the emission does not exceed the limits of H.7.3.12, the emission test is acceptable.

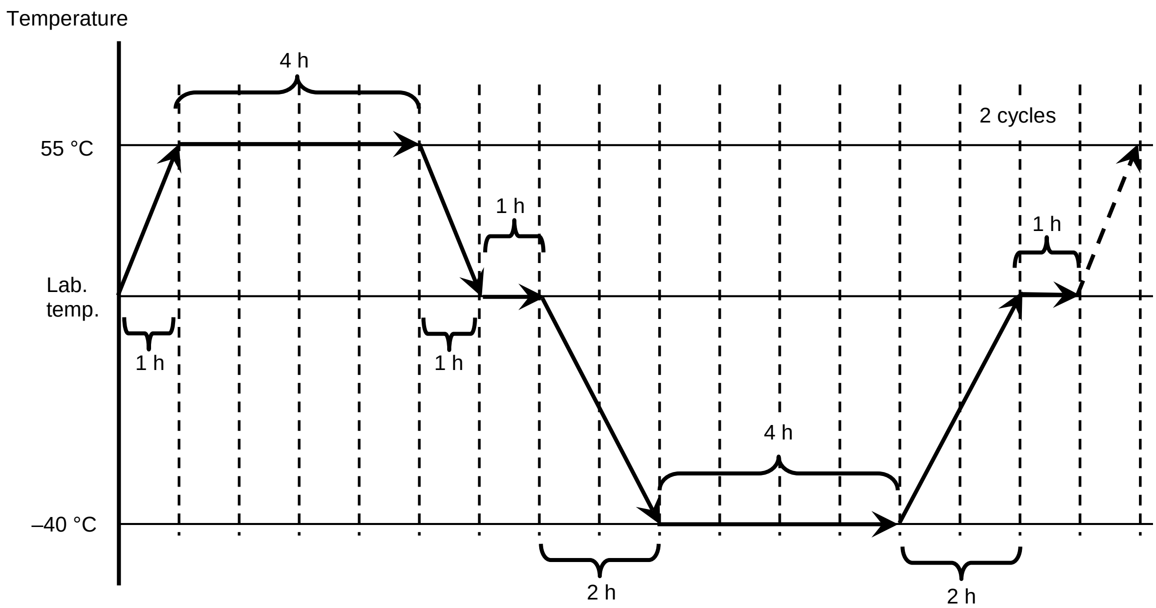


Figure H.8 – Temperature cycling – Replaces Figure 8

H.7.3.4 High temperature exposure test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of a fuel cartridge left in high temperature environments.

c) **Test procedure:**

1) Two orientations shall be tested – valve up and valve down.

2) Place the test sample in a temperature controlled test chamber that is at a temperature of 70 °C ± 2 °C and allow chamber temperature to recover to 70 °C ± 2 °C and maintain that temperature for at least 4 h with the sample in the chamber.

3) Remove the test sample to laboratory temperature.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.3 and shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the fuel cartridge. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.5 Drop test

a) **Test sample:** an unused fuel cartridge, a partially filled fuel cartridge, a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an inadvertent drop and ensure no leakage.

c) **Test procedure:**

1) The test sample shall be dropped on a horizontal surface that consists of hardwood at least 13 mm thick, mounted on two layers of plywood each 18 mm to 20 mm thick, all supported on a concrete or equivalent non-resilient floor from a predetermined height.

2) The height of the drop shall be:

i) 1 200 mm ± 10 mm: in the case of a micro fuel cell power unit and/or a micro fuel cell power system.

ii) 1 500 mm ± 10 mm: in the case of a fuel cartridge of more than 200 ml.

iii) 1 800 mm ± 10 mm: in the case of a fuel cartridge of up to 200 ml.

3) For the fuel cartridge tests, the drop test shall be carried out in four drop orientations with the same sample.

4) For the micro fuel cell power unit or the micro fuel cell power system, one micro fuel cell power system or micro fuel cell power unit may be used for all four drop orientations, or more than one micro fuel cell power system or micro fuel cell power unit may be used in subsequent drops, at the discretion of the manufacturer.

5) For all tests, drop orientations shall be:

i) valve up;

ii) valve down;

iii) two other mutually perpendicular orientations.

6) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with H.7.3.12.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage and fuel vapour loss shall be measured based upon Figure H.2 for the fuel cartridge and Figure H.4 for the micro fuel cell power system or micro fuel cell power unit. Leakage shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. The emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but the emission does not exceed the limits of H.7.3.12, the emission test is acceptable. If the micro fuel cell power system or micro fuel cell power unit is still operational, protective circuitry specified by the FMEA as part of the safety systems shall still be fully functional. There shall be no exposure of hazardous parts.

H.7.3.6 Compressive loading test

H.7.3.6.1 Micro fuel cell power system or micro fuel cell power unit

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the micro fuel cell power unit, or micro fuel cell power system.

c) **Test procedure:**

   1) The micro fuel cell power system or micro fuel cell power unit test sample shall be placed between two flat hardwood blocks approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 245 N ± 9,8 N.

   2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

   3) A compressive force of 245 N ± 9,8 N shall be applied to the stationary sample for 5 s.

   4) The test shall be carried out in three mutually perpendicular orientations as a rule. If the sample would not stand on its own, it does not need to be tested in that orientation.

   5) Perform emission testing in accordance with H.7.3.12 following the compressive loading test.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage and fuel vapour loss shall be measured based upon Figure H.2 for the fuel cartridge and Figure H.4 for the micro fuel cell power system or micro fuel cell power unit. Leakage shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. Emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but emission does not exceed the limits of H.7.3.12, the emission test is acceptable.

H.7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of the forces reasonably encountered due to something heavy being placed on the fuel cartridge.

c) **Test procedure:**

   1) The fuel cartridge test sample shall be placed between two flat hardwood blocks of approximately 254 mm (10 inches) long, 101,6 mm (4 inches) wide and 12,7 mm (1/2 inch) thick equipped with suitable force applicator(s) capable of exerting a compressive force on the sample of 981 N ± 9,8 N.

   2) A compressive force shall be applied to the sample gradually at a rate of less than or equal to 12,7 mm/min (1/2 inch/min).

   3) A compressive force of 981 N ± 9,8 N shall be applied to the stationary sample for 5 s.

   4) Fuel cartridge orientations shall be selected on the basis of likely stable resting positions when accidentally dropped (e.g. those orientations having the lowest centres of gravity with respect to the resting surface). It is acceptable to test only one surface of a prismatic fuel cartridge that is sufficiently cubic and the curved surface of a cylindrical fuel cartridge with a longitudinal axis length longer than twice the diameter.

d) **Passing criteria**: No fire or flame at any time, no explosion at any time and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.2 and shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the fuel cartridge. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.7 External short-circuit test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** to simulate the effects of an external short-circuit.

c) **Test procedure:**

   1) External short-circuit testing shall be done separately on both operating [DEVICE ON] and non-operating [DEVICE OFF] micro fuel cell power systems or micro fuel cell power units respectively.

   2) Each test sample shall be short-circuited by connecting the positive and negative terminals of the micro fuel cell power system or micro fuel cell power unit with wire having a maximum resistance load of 0,1 Ω for at least 5 min.

   3) Perform emission testing in accordance with 7.3.12 after each short-circuit test.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time, and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.5 and shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Perform emission testing on the micro fuel cell power system or micro fuel cell power unit with the micro fuel cell power unit both on and off. Emission shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but emission does not exceed the limits of H.7.3.12, the emission test is acceptable. Exterior surfaces shall not exceed temperatures in Table 2 during or after short circuit testing.

NOTE The external short-circuit test can be done sequentially with the surface, component and exhaust gas temperature test using the same sample.

H.7.3.9 Long-term storage test

H.7.3.9.1 General

Either H.7.3.9.2 (Option 1), H.7.3.9.3 (Option 2) or H.7.3.9.4 (Option 3) may be used.

H.7.3.9.2 Option 1 – continuous weight measurement

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure H.9):

1) Use a load cell (continuous electronic weight sensing device) designed and calibrated for use at 50 °C inside the temperature chamber.

2) Place the load cell in a temperature chamber at 50 °C ± 2 °C. Place the fuel cartridge on top of the load cell so that all the weight is being applied to the load cell. A fixture may be used to control the position of the fuel cartridge, to ensure all the weight is applied to the load cell.

3) Connect a digital readout to the load cell and collect the data either manually or automatically. The data should be collected with a high degree of confidence to assure that the fuel vapour loss is less than 0,045 g/h.

4) Measure and record initial mass M_{initial} and time t_i.

5) The sample shall remain in the temperature test chamber at 50 °C ± 2 °C for at least 28 days.

6) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_f. If the average mass loss rate is less than 0,045 g/h, then the test sample passes the test for fuel vapour loss.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

   ii) $\Delta t = t_f - t_i$ = 28 days × 24 h/day = 672 h.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{final} = the final mass of the fuel cartridge.

7) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,045 g/h.

   i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

   ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

   iii) M_{initial} = the initial mass of the fuel cartridge.

   iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire at any time, no explosion at any time and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.9 and shall be less than 0,045 g/h. Flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the fuel cartridge. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.9.3 Option 2 – periodic weight measurements

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure H.9):

1) Measure and record initial mass M_{initial} and time t_{i}.

2) Place the fuel cartridge in a temperature chamber at 50 °C ± 2 °C. Weight measurements should be collected with a high degree of confidence to determine if the fuel vapour loss is less than 0,045 g/h with a minimum of once every three days.

3) The time in which the test samples are removed from the chamber for measurement shall not be included in the time the test sample is to be tested (28 days). Additional time should be added to get the test sample to the test temperature (50 °C ± 2 °C) each time the test sample is removed from the chamber. The test samples should only be stabilised at laboratory temperature if the mass loss will be affected.

4) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,045 g/h, then the test sample passes the test for fuel vapour loss.

i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

iii) M_{initial} = the initial mass of the fuel cartridge.

iv) M_{final} = the final mass of the fuel cartridge.

5) If the fuel cartridge is empty prior to the end of the test, the mass loss rate shall be calculated based on the elapsed time at the last measured data point (Δt_{last}) and the final mass (M_{last}) at the last measured data point before the fuel cartridge became empty. The test is passed if the fuel vapour loss is less than 0,045 g/h.

i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{last}}}{\Delta t_{\text{last}}}$

ii) Δt_{last} = the elapsed time period between the initial weight measurement taken at the start of the test and the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

iii) M_{initial} = the initial mass of the fuel cartridge.

iv) M_{last} = the last weight measurement taken when liquid fuel still remained in the fuel cartridge.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.9 and shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the fuel cartridge. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.9.4 Option 3 – One weight measurement

This option is intended for fuel cartridges with very small leak rates.

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge.

b) **Purpose:** to simulate the effects of long-term storage at elevated temperature and ensure no leakage.

c) **Test procedure** (See Figure 9):

1) Measure and record initial mass M_{initial} and time t_{i}.

2) Place the fuel cartridges in a temperature chamber at 50 °C ± 2 °C. After 28 days, the fuel cartridges are removed from the chamber for measurement. The test samples should be stabilised at laboratory temperature if the mass loss will be affected. Then weight measurement is executed.

3) If the fuel cartridge still has liquid fuel in the test sample at the end of the test, calculate the fuel vapour loss by dividing the mass loss by the number of hours that the test sample was in the chamber. Within five minutes of completing the test, measure and record mass M_{final} and record time t_{f}. If the average mass loss rate is less than 0,045 g/h, then the test sample passes the test for fuel vapour loss.

i) Fuel vapour loss $= \dfrac{M_{\text{initial}} - M_{\text{final}}}{\Delta t}$

ii) $\Delta t = t_{\text{f}} - t_{\text{i}}$ = 28 days × 24 h/day = 672 h.

iii) M_{initial} = the initial mass of the fuel cartridge.

iv) M_{final} = the final mass of the fuel cartridge.

4) If the fuel cartridge is empty after 28 days, then the type test according to H.7.3.9.2 Option 1 or H.7.3.9.3 Option 2 shall be done.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time and no impermissible leakage. Leakage shall be measured on the basis of the procedure described in Figure H.9 and shall be less than 0,045 g/h. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the fuel cartridge. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

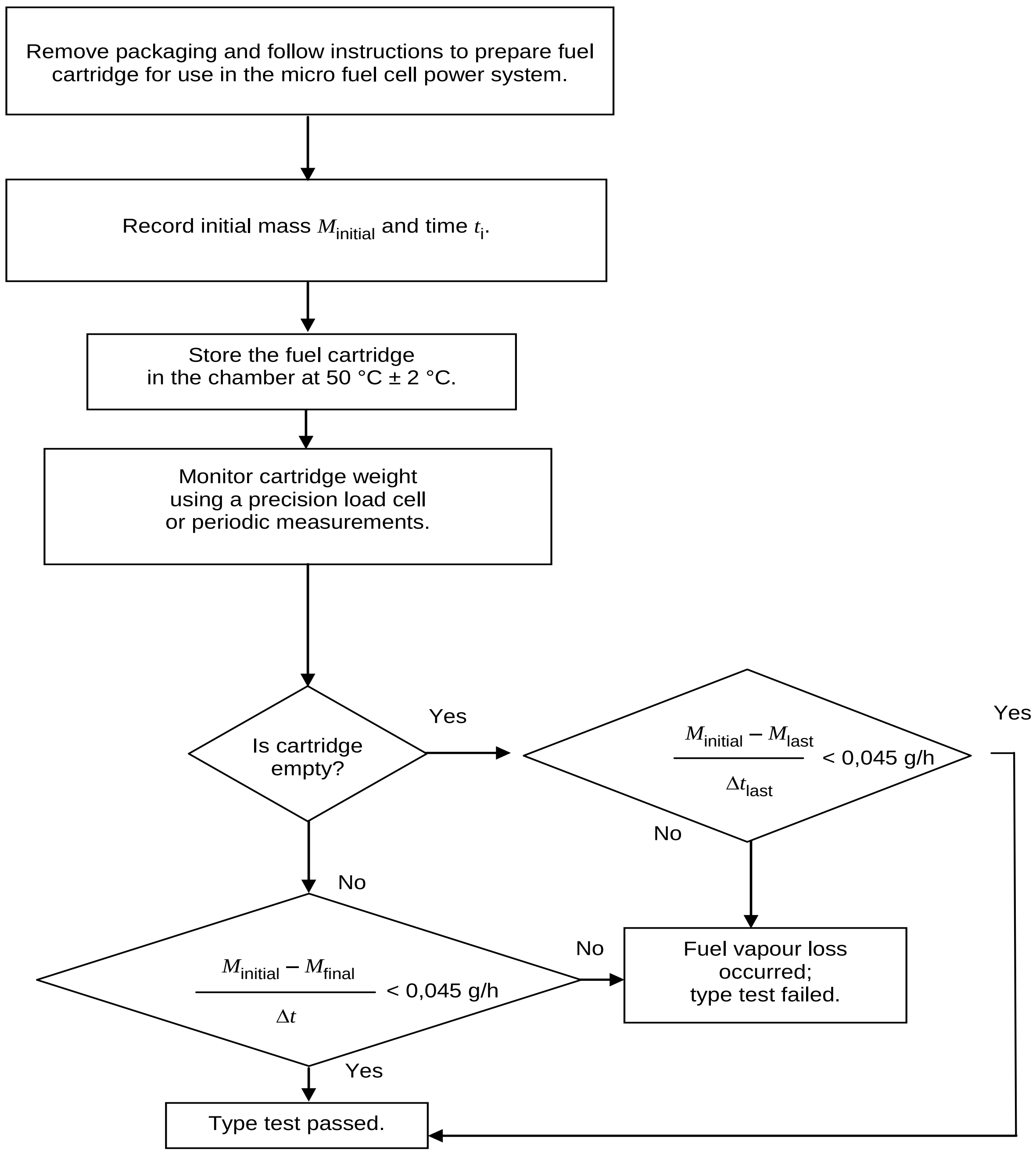


Figure H.9 – Fuel cartridge leakage and mass loss test flow chart for long-term storage test – Replaces Figure 9

H.7.3.10 High-temperature connection test

a) **Test sample:** an unused fuel cartridge or a partially filled fuel cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve with the fuel cartridge at an elevated temperature and ensure no leakage, no fire, no explosion.

c) **Test procedure:**

   1) Place the fuel cartridge test sample into a temperature-controlled test chamber that is at a temperature of 50 °C ± 2 °C for at least 4 h.

   2) The micro fuel cell power unit or test fixture with a micro fuel cell power unit valve is kept at laboratory temperature. If the micro fuel cell power unit or test fixture has an internal reservoir, it should be filled prior to connection with the test sample in order to prevent fill volume from being a source of error in the leakage measurement.

   3) Remove the test sample from the chamber and, within 5 min of removal from the chamber, weigh test sample and connect the fuel cartridge to the micro fuel cell power unit or test fixture with a micro fuel cell power unit valve.

   4) Disconnect the fuel cartridge and weigh. The maximum acceptable mass loss is 0,045 g.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occurs, this is acceptable. Leakage shall be determined by the difference in mass before and after the connection cycle. Mass loss shall be less than 0,045 g. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit or cartridge. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.11 Connection cycling test

H.7.3.11.1 Fuel cartridge

H.7.3.11.1.1 Insert cartridge, exterior cartridge or attached cartridge

a) **Test sample:** an unused insert cartridge, exterior cartridge or attached cartridge and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions or a suitable test fixture with a micro fuel cell power unit valve and fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

   1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve and check for leakage upon connection.

   2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

   3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

   4) Disconnect the fuel cartridge and measure the mass of the cartridge.

   5) Connect and disconnect the cartridge for a total of three connections and disconnections.

6) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is greater than 0,9 g, the fuel cartridge fails the type test.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Weigh the fuel cartridge and record the mass.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is greater than 0,9 g, the fuel cartridge fails the type test.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for leakage by subjecting the cartridge to a water bath test.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. Leakage shall be determined by the difference in mass before and after the connection cycle. Mass loss shall be less than 0,9 g over three connection cycles. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the cartridge, micro fuel cell power unit or test fixture. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.11.1.2 Satellite cartridge

a) **Test sample:** an unused satellite fuel cartridge and an unused micro fuel cell power unit or a suitable test fixture with a micro fuel cell power unit valve fuelled in accordance with the manufacturer’s instructions. The test fixture shall have a configuration representative of the micro fuel cell power unit geometry and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the micro fuel cell power unit and ensure no leakage.

c) **Test procedure:**

1) Connect the fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and measure the mass of the cartridge.

5) Connect and disconnect the cartridge for a total of three more connections and disconnections.

6) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is equal to or greater than 0,9 g, the fuel cartridge fails the type test.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Weigh the fuel cartridge and record the mass.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is equal to or greater than 0,9 g, the fuel cartridge fails the type test.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) Disconnect the fuel cartridge and check for leakage by subjecting the cartridge to a water bath test.

14) Repeat steps 5 through 13 four more times for a total of 55 cycles, waiting 1 h between each set of 11 cycles.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. Leakage shall be determined by the difference in mass before and after the connection cycle. Mass loss shall be less than 0,9 g over three connection cycles. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the cartridge, micro fuel cell power unit or test fixture. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.11.3 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges and an additional 98 fuel cartridges or suitable test fixtures with fuel cartridge valves and a micro fuel cell power unit fuelled in accordance with the manufacturer's instructions. The test fixture shall have a configuration representative of the fuel cartridge valve geometry and material and shall have the ability to simulate fuel flow.

b) **Purpose:** to simulate the effects of mating and un-mating of the fuel cartridge to the fuel cell power unit and ensure no leakage both at initial use and after suitable ageing of the micro fuel cell power unit connection.

First fuel cartridge (#1) and final fuel cartridge (#100) are inspected; the other 980 cycles are only to age the micro fuel cell power unit.

In the case of a micro fuel cell power unit using satellite cartridge, it shall be tested according to the following procedure by simulating fuel flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

1) Connect the first fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve.

2) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

3) Turn off the micro fuel cell power unit or stop simulated fuel flow.

4) Disconnect the fuel cartridge and measure the mass of the cartridge.

5) Connect and disconnect the cartridge for a total of three more connections and disconnections.

6) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is equal to or greater than 0,9 g, the fuel cartridge fails the type test.

7) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

8) Weigh the fuel cartridge and record the mass.

9) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

10) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is equal to or greater than 0,9 g, the fuel cartridge fails the type test.

11) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

12) Turn off the micro fuel cell power unit or stop simulated fuel flow.

13) In order to age the micro fuel cell power unit fuel cartridge connection, perform the following steps.

    i) Using either fuel cartridges or a suitable test fixture with fuel cartridge valves, cycle the micro fuel cell power unit fuel cartridge connection for a total of 980 connections and disconnections. Cartridges or valves may be changed every 10 or more cycles.

    ii) Simulate fuel flow after each set of 50 connection-disconnection cycles.

    iii) Mass loss does not need to be checked during the aging process, but if obvious leakage is noted, the test fails.

    iv) Following this ageing, a final unused fuel cartridge will be tested.

14) Connect the final fuel cartridge to the micro fuel cell power unit or micro fuel cell power unit valve.

15) Operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

16) Turn off the micro fuel cell power unit or stop simulated fuel flow.

17) Disconnect the fuel cartridge and measure the mass of the cartridge.

18) Connect and disconnect the cartridge for a total of three more connections and disconnections.

19) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is equal to or greater than 0,9 g, the fuel cartridge fails the type test.

20) Connect and disconnect the fuel cartridge four more times for a total of seven connections and disconnections.

21) Weigh the fuel cartridge and record the mass.

22) Connect and disconnect the fuel cartridge three more times for a total of ten connections and disconnections.

23) Weigh the fuel cartridge and calculate the mass loss during the three connect-disconnect cycles. If the accumulated mass loss is equal to or greater than 0,9 g, the fuel cartridge fails the type test.

24) Connect fuel cartridge and operate the micro fuel cell power unit or otherwise simulate fuel flow for at least 1 min.

25) Turn off the micro fuel cell power unit or stop simulated fuel flow.

26) Disconnect the fuel cartridge and check for leakage by subjecting the cartridge to a water bath test.

d) **Passing criteria:** No leakage, no fire or flame, and no explosion. Leakage shall be determined by the difference in mass before and after the connection cycle. Mass loss shall be less than 0,9 g over three connection cycles. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power unit. Cartridge shall be subjected to a water bath test and shall be bubble-tight. The temperature of the water bath and the duration of the test shall be such that the internal pressure in the cartridge reaches that which would be reached at 55 °C. No leakage or permanent deformation may occur, except that a plastic cartridge may be deformed through softening provided that it does not leak.

H.7.3.12 Emission test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** Under operating conditions (or attempted operating conditions) of a micro fuel cell power system or micro fuel cell power unit, emission of carbon monoxide (CO), carbon dioxide (CO_2) and organic compounds such as butane, formaldehyde, and other materials listed in Table H.7 shall be maintained at less than the specified values. Maintaining these limits not only prevents inadvisable exposure but also ensures that an adequate supply of oxygen is maintained in the operating environment.

The “DEVICE-OFF” emission test is performed solely to assure there is no impermissible leakage of fuel. Butane solid oxide micro fuel cell power units must be operating at temperature in order to generate reaction-based emissions, which are evaluated in the “DEVICE ON” emission test.

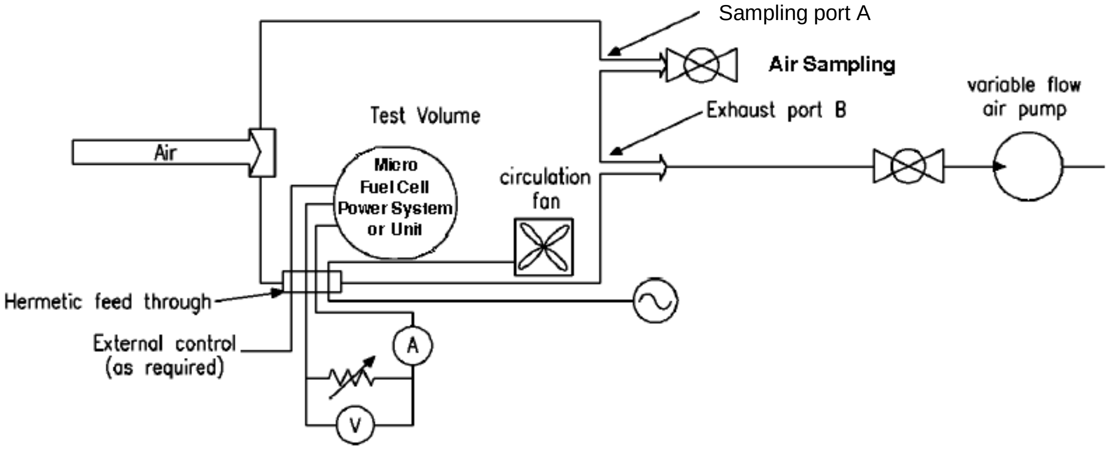


Figure H.10 – Operational emission rate testing apparatus – Replaces Figure 10

c) **Test apparatus:** An example of the emission rate testing apparatus is shown in Figure H.10. The configuration shown in Figure H.10 is for emission rate testing of all micro fuel cell power systems or units tested in accordance with this Annex H. Emission rate testing in accordance with H.7.3.12 d) 1) is required for all types of micro fuel cell power systems and micro fuel cell power units tested in accordance with this Annex H.

For micro fuel cell power systems or units that are intended to be used in close proximity to a consumer’s mouth or nose (such as micro fuel cell power systems or units used to power cell phones, handheld games, etc.), additional testing in accordance with H.7.3.12 d) 2) is required to verify that emission concentrations in the vicinity of a user's mouth or nose are kept within appropriate limits. This emission concentration testing shall be done in a large open room using a different emission concentration testing apparatus. An example of the operational emission concentration testing apparatus is shown in Figure H.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell power system or unit to a consumer’s mouth or nose when in use) for emission concentration limit testing.

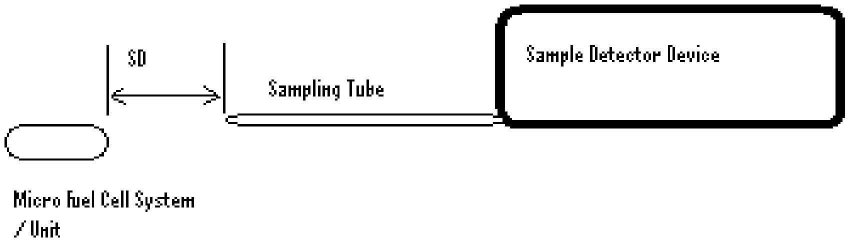


Figure H.11 – Operational emission concentration testing apparatus

Emission gases might be composed of toxic organic materials such as methanol, formaldehyde, formic acid and methyl formate, which are potentially exhausted from a micro fuel cell power system or a micro fuel cell power unit.

To analyse these organic materials, a gas chromatograph with a flame ionization detector (GC/FID) or with a mass spectrometer (GC/MS), a high-performance liquid chromatography (HPLC) system, a visible absorption spectrophotometer (VAS), or an ultraviolet visible absorption spectrophotometer (UV-VAS) shall be used either by absorbing emission gas to a sorbent tube fixed to sampling port A of the test chamber or directly to an analyzer through sampling port A in Figure H.10. However, the use of other instruments is allowed, provided that the performance for this measurement is sufficient to accurately determine compliance with the emission limits.

The concentration of CO and CO2 gas can be measured by a non-dispersive infrared absorption analyzer. These analytical instruments shall comply with ISO 16000-3, ISO 16000-6 and ISO 16017-1. However, the use of other instruments is allowed, provided that the performance for this measurement is equivalent to that of the above-mentioned instruments using the above mentioned standards.

d) **Test procedure:**

1) For all micro fuel cell power systems and units – both those intended to be used in close proximity to a consumer's mouth or nose and those not intended to be used in close proximity to a consumer's mouth or nose – the following emission rate sampling test shall be performed.

i) Place the micro fuel cell power system or micro fuel cell power unit inside the small test chamber shown in Figure H.10, with the unit on and operating at rated power. If the micro fuel cell power system or unit is no longer operational due to a type test, the emission test shall be performed with the micro fuel cell power system or unit fully fuelled and the power switch in the “ON” position ("DEVICE – ON").

ii) The small test chamber shall be supplied with clean air. The supply of air into the test volume should be from a known purity source. If bottled air is not used, the use of blanks to determine background concentration levels should be considered to avoid false non-compliant results.

iii) Gaseous emission from the micro fuel cell power system or unit shall be sampled at the outlet of the small test chamber, at air sampling port A shown in Figure H.10.

iv) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

v) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure H.10, while simultaneously measuring and recording the flow through the test chamber. The flow through the test chamber can be computed from the sum of the variable flow air pump flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber.

vi) Record the concentrations of the chemical compounds of interest for the “unit on” emission criteria. See Table H.7.

vii) Turn the unit off, opening and closing the chamber as necessary. Allow the micro fuel cell power unit to complete any shut down cycle and transition to its full OFF state.

viii) Allow the test chamber variable flow air pump air flow, circulation fan flow and sample flow rate to stabilise.

ix) Sample and record the gaseous contents of the test chamber through air sampling port A shown in Figure H.10, while simultaneously measuring and recording the flow through the test chamber. The flow through the test chamber can be computed from the sum of the variable flow air pump flow rate and the sample flow rate through air sampling port A or by measuring the inlet flow rate to the test chamber.

x) Record the concentrations of the chemical compounds of interest for the “unit off” emission criteria. See Table H.7.

xi) Calculate the emission rate of chemical compounds of interest by multiplying the maximum stabilized concentration of each constituent by the simultaneous total air flow through the chamber. The total air flow through the chamber is determined by adding the steady-state variable flow air pump flow rate through the chamber to the simultaneous sample flow rate or by measuring the inlet air flow rate.

NOTE The total air flow into the chamber is equal to the sum of the air flow rates out of the chamber. Therefore, the air flow rate at the inlet of the chamber is equal to the air flow rate at the outlet of the chamber plus the sampling flow rate. The two values both represent the total air flow rate through the chamber, and either may be used to calculate the emission rate.

See below:

$$ER = (F_{\mathrm{P}} + F_{\mathrm{S}}) \times C$$

or

$$ER = (F_{\mathrm{i}}) \times C$$

where

ER is the emission rate in grams per hour;

F_{P} is the variable flow air pump flow rate in standard litres per hour;

F_{S} is the sample flow rate in standard litres per hour;

F_{i} is the air flow rate at the inlet of the chamber in standard litres per hour;

C is the concentration in grams per standard litre.

xii) Compare the maximum measured emission rate to Table H.7. If the emission rate is not less than the emission rate limit in Table H.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria H.7.3.12 e) 1) i) and H.7.3.12 e) 2) i).

xiii) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

2) For micro fuel cell power systems and units that are intended to be used in close proximity to a consumer's mouth or nose, the following additional emission concentration sampling test shall be performed. This test only need be performed with the unit on, as leakage rate with the unit off is assessed under Subclause H.7.3.12 1) and the associated emission limit does not present a hazard to humans.

   i) Emission rate testing of micro fuel cell power systems or units shall be done in a large open room. It is the intent of this test to approximate and to measure the expected emission concentrations near a person's mouth or nose in still air. A mannequin or other mock-up may be used to improve the accuracy of the test. The air in the room shall be sampled prior to testing to ensure accuracy and to avoid false non-compliant results. Be careful to ensure that materials in the room or in the sampling apparatus do not contribute emissions (that is, contaminants) to the test. Prior to testing, a check for contamination without the micro fuel cell power system or unit in place is recommended to avoid false non-compliant results. Air changes in the room shall be kept to a minimum corresponding to normal residential or commercial designs (e.g. less than one air change per hour). Take care not to disturb the sampling area with extraneous air flows.

   ii) Gaseous emission concentrations from the micro fuel cell power system or unit shall be sampled using the operational emission concentration testing apparatus shown in Figure H.11. For emission concentration testing, the air sampling tube shall extend to a separation distance (SD) from the micro fuel cell power system or micro fuel cell power unit that is representative of the breathing zone of a consumer (the distance from the micro fuel cell system or unit to a consumer's mouth or nose when in use).

   iii) The sampling rate for the close proximity emission concentration measurements shall be 5 l per minute, which represents the breathing rate of an adult human being.

   iv) Allow the sample flow rate to stabilize.

   v) Sample and record the fuel cell power system or unit gaseous emissions that occur at a distance that is representative of the breathing zone of a consumer.

   vi) Record the concentrations of the chemical compounds of interest. See Table H.7.

   vii) Compare the maximum measured concentrations to Table H.7. If the emission concentrations are not less than the emission concentration limits in Table H.7, the micro fuel cell power system or unit fails the test and no further testing is required. See passing criteria H.7.3.12 e) 2) ii).

   viii) Emission measurements shall be averaged over a certain time duration which is representative of the normal operation of the micro fuel cell power system or unit and the equipment that it powers (i.e. one fuel cartridge worth of operation). The test does not need to be measured continuously, providing that the initial start-up, at least 3 h of operation, and the end of the fuel cartridge are measured. If the fuel cartridge does not last for 3 h, the entire fuel cartridge duration shall be measured continuously.

e) **Passing criteria:**

1) For micro fuel cell power systems and micro fuel cell power units not intended to be used in close proximity to a consumer's mouth or nose:

   i) The maximum emission rate for each of the constituents of interest in Table H.7 shall be less than the emission rate limit value in Table H.7 when tested in accordance with H.7.3.12 d) 1). If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

2) For micro fuel cell power systems and micro fuel cell power units to be used in close proximity to a consumer's mouth or nose:

   i) The maximum emission rate for each of the constituents of interest in Table H.7 shall be less than the emission rate limit value in Table H.7 when tested in accordance with H.7.3.12 d) 1). If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

ii) For micro fuel cell power systems and micro fuel cell power units intended to be used in close proximity to a consumer's mouth or nose; in addition to meeting the emission rate limit above, the maximum emission concentration for each of the constituents of interest shall be less than the emission concentration limit in Table H.7 when tested in accordance with H.7.3.12 d) 2). If the micro fuel cell power system or unit does not operate, or shuts down in a safe manner prior to exceeding a limit, the test is acceptable.

Table H.7 – Emission Limits – Replaces Table 7

	"DEVICE – ON" Concentration limit [a]	"DEVICE – OFF" Emission rate limit [c]	"DEVICE – ON" Emission rate limit [b]
Butane[g]	1,9 g/m^3	0,045 g/h	0,9 g/h
CO	0,029 g/m^3	N/A	0,290 g/h
CO_2	9 g/m^3	N/A	60 g/h [d]
Formic acid	0,009 g/m^3	N/A	0,09 g/h
Formaldehyde [e]	0,000 1 g/m^3	N/A	0,000 6 g/h
Hydrogen [f]	N/A	N/A	0,016 g/h
Methyl formate	0,245 g/m^3	N/A	2,45 g/h
NO	0,031 g/m^3	N/A	0,31 g/h
NO_2	0,005 7 g/m^3	N/A	0,57 g/h

[a] The concentration limits in this table are in units of g/m^3 and are the equivalent of the TWA exposure limits expressed in ppmv, as shown in Table H.8. Concentration limits are not tested with the device off, as the leakage rate with the unit off is assessed under Subclause H.7.3.12 1) and the associated emission limit does not present an inhalation hazard to humans.

[b] The "DEVICE – ON" emission rate limit is based on 10 m^3 ACH, selected as the product of the reference volume times the air changes per hour (ACH), as this represents the reasonably foreseeable environments where micro fuel cell power systems or units will be used. The interior space in a small car and the minimum volume per person on commercial aircraft is at 1 m^3. The minimum ACH used on passenger aircraft is 10 and the lowest ventilation setting in cars is 10 ACH. Homes and offices may have ACH levels as low as 0,5 but the per person volume is over 20 m^3, so a product of 10 is conservative.

[c] The "DEVICE – OFF" emission test is performed solely to assure there is no impermissible leakage of fuel. Butane solid oxide micro fuel cell power units must be operating at temperature in order to generate reaction-based emissions, which are evaluated in the "device – on" emission test.

[d] A seated human adult has a CO_2 emission rate of 30 g/h. The fuel cell plus human adult emission rates are limited such that the CO_2 concentration does not reach the WHO eight-hour concentration limit of 9 g/m^3. In an environment with 10 m^3 ACH, this limits the contribution from the fuel cell to 60 g/h.

[e] WHO guideline limit for formaldehyde is 0,000 1 g/m^3. Background levels are 0,000 03 g/m^3. The fuel cell emission cannot push the background level above the guideline limit.

[f] The operating hydrogen emission rate of 0,016 g/h equates to the highest leak rate that will not support a flame and is less than the 0,8 g/h leak rate necessary to achieve a 25 % LFL in a 1 cubic meter chamber with 1 air change per hour.

[g] The operating butane emission rate of 0,9 g/h equates to the highest leak rate that will not support a flame and is less than the 1,9 g/h leak rate necessary to achieve the TLV limit of 800 ppm in a 1 cubic meter chamber with 1 air change per hour. The non-operating butane leakage criteria have been chosen based on a scenario of micro fuel cell power systems or units in an enclosed space with no ventilation. The space chosen has a volume of 0,28 m^3, or approximately 10 cubic feet. The criterion has been prescribed so that a butane concentration of greater than 25 % LFL is not permitted to develop over a twenty-four hour (24 h) period, if three micro fuel cell power systems are in the enclosed space.

Table H.8 – Occupational exposure limits

	TWA exposure limit (TWA – time weighted average over 8 h of operation)
Butane	< 800 ppmv
CO	< 25 ppmv
CO_2	< 5 000 ppmv
Formic acid	< 5 ppmv
Formaldehyde	< 0,08 ppmv
Hydrogen	N/A
Methyl formate	< 100 ppmv
NO	< 25 ppmv
NO_2	< 3 ppmv

H.7.3.13 High temperature shutdown test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with the manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** To verify that the micro fuel cell power unit initiates a shutdown sequence within a reasonable time period if the SOFC stack reaches an abnormal high temperature. If the micro fuel cell power unit fails to operate normally after testing one of these components, a different unit may be used for testing the remaining components. If any combination of components is integrated into an isothermal module, those components may be tested concurrently.

c) **Test procedure:**

1) While the micro fuel cell power unit is operating at its rated output, use the manufacturer's specified method to set the SOFC stack to a temperature 20 °C above the maximum operating temperature.

2) Verify that the micro fuel cell power system shutdown sequence is initiated either prior to the test component reaching or within 5 s of reaching the elevated temperature set point.

3) If the micro fuel cell power unit does not contain a high temperature reformer, or if the reformer is in the same thermal module as the SOFC stack, proceed to step 5. Otherwise, while the micro fuel cell power unit is operating at its rated output, use the manufacturer's specified method to set the reformer to a temperature 20 °C above the maximum operating temperature.

4) Verify that the micro fuel cell power system shutdown sequence is initiated either prior to the test component reaching or within 5 s of reaching the elevated temperature set point.

5) If the micro fuel cell power unit does not contain a high temperature catalytic converter, or if the catalytic converter is in the same thermal module as the SOFC stack, the test is complete. Otherwise, while the micro fuel cell power unit is operating at its rated output, use the manufacturer's specified method to set the catalytic converter to a temperature 20 °C above the maximum operating temperature.

6) Verify that the micro fuel cell power system shutdown sequence is initiated either prior to the test component reaching or within 5 s of reaching the elevated temperature set point.

d) **Passing criteria:** The micro fuel cell power unit shutdown sequence shall initiate before reaching, or no later than 5 s after reaching, the elevated temperature set point.

H.7.3.14 High temperature operation test

a) **Test sample:** a micro fuel cell power unit fuelled in accordance with the manufacturer's specifications or a micro fuel cell power system with unused fuel cartridge.

b) **Purpose:** To verify that the micro fuel cell power unit operates safely if the SOFC stack is at a temperature of 30 °C above the maximum operating temperature. If the micro fuel cell power unit contains a reformer, or catalytic converter, these components shall also be tested. If the micro fuel cell power unit fails to operate normally after testing one of these components, a different unit may be used for testing the remaining components. If any combination of components is integrated into an isothermal module, those components may be tested concurrently.

c) **Test procedure:**

   1) Use manufacturer's specified method to disable the automatic shutdown mechanism described in H.7.3.13. Set the SOFC stack temperature at 30 °C above the maximum specified operating temperature.

   2) Run the micro fuel cell power unit at full load as specified by the manufacturer for 1 h at this elevated temperature. The micro fuel cell power unit is not required to deliver the rated load or function normally, as a result of the elevated temperature.

   3) Perform emission testing in accordance with H.7.3.12 with the unit on and off.

   4) If the micro fuel cell power unit does not contain a high temperature reformer or if the reformer is in the same thermal module as the SOFC stack, proceed to step 7. Otherwise, use the manufacturer's specified method to disable the automatic shutdown mechanism described in H.7.3.13. Set the reformer temperature at 30 °C above the maximum specified operating temperature.

   5) Run the micro fuel cell power unit at full load as specified by the manufacturer for 1 h at this elevated temperature. The micro fuel cell power unit is not required to deliver the rated load or function normally, as a result of the elevated temperature.

   6) Perform emission testing in accordance with H.7.3.12 with the unit on and off.

   7) If the micro fuel cell power unit does not contain a high temperature catalytic converter, or if the catalytic converter is in the same thermal module as the SOFC stack, the test is complete. Otherwise, use the manufacturer's specified method to disable the automatic shutdown mechanism described in H.7.3.13. Set the catalytic converter temperature at 30 °C above the maximum specified operating temperature.

   8) Run the micro fuel cell power unit at full load as specified by the manufacturer for 1 h at this elevated temperature. The micro fuel cell power unit is not required to deliver the rated load or function normally, as a result of the elevated temperature.

   9) Perform emission testing in accordance with H.7.3.12 with the unit on and off.

d) **Passing criteria:** No fire or flame at any time, no explosion at any time. Fire and flame shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually to verify that there is no disturbance to the micro fuel cell power system or micro fuel cell power unit. Micro fuel cell power system or micro fuel cell power unit shall be emission tested with the micro fuel cell power unit both on and off and shall meet the acceptance criteria in H.7.3.12. If the micro fuel cell power unit does not operate but the emission does not exceed the limits of H.7.3.12, the emission test is acceptable.

H.7.3.15 Fire test

a) **Test sample:** an unused fuel cartridge.

b) **Purpose:** Fire testing shall be performed on all new fuel cartridge designs with a butane capacity of over 200 ml. The test is to demonstrate that the fire protection system, such as pressure relief devices (PRD) and/or integral thermal insulation will prevent the uncontrolled venting of the fuel cartridge under the specified fire conditions.

Any significant change to the design, for example changes in: diameter, length, or PRD shall necessitate repeating the fire testing. Exception: A manufacturer can use data and engineering calculations, based on previous fire testing results on existing designs, to show that a new design does not require fire testing.

Precautions shall be taken to insure safety of personnel and property during fire testing in the event that fuel cartridge rupture occurs.

c) **Test procedure:**

1) Fuel cartridges shall be filled to rated capacity with butane. The fuel cartridges tested shall be representative of production cartridges.

2) Temperature and pressure of the fuel cartridge shall be monitored remotely and recorded at intervals of every 15 s or less. Where practical, a manual valve shall be installed to allow venting of the fuel cartridge in the event of a test equipment or micro fuel cell power system malfunction.

In addition to the pressure and temperature readings, the following information shall also be recorded for each test, as applicable:

i) fuel cartridge manufacturer;

ii) fuel cartridge part or model number;

iii) unique fuel cartridge identifier;

iv) PRD location and orientation;

v) date of test;

vi) fuel cartridge pressure in MPa;

vii) fuel cartridge orientation (vertical, horizontal or inverted);

viii) laboratory temperature;

ix) estimated wind condition/direction;

x) names of witnesses;

xi) time of activation of pressure relief device; and

xii) elapsed time to completion of the test.

Exception: For fuel cartridge designs that preclude monitoring pressure during the fire test, a statement of justification for not monitoring pressure during the fire test shall be given, a means for determining activation of the PRD shall be provided and additional safety precautions shall be taken to safely carry out the fire test.

3) Fire tests shall be conducted on at least three fuel cartridges in each orientation of intended use and/or transportation. For fuel cartridge designs for which the orientation of use and transportation are not specified, at least three fuel cartridges shall be fire tested in at least the vertical and horizontal orientation.

Fuel cartridges shall be subjected to a heat source over their entire width. For fuel cartridges less than or equal to 0,30 m in length, a temperature-indicating device shall be installed within 0,05 m of, but not in contact with, the fuel cartridge surface near each end. For fuel cartridges longer than 0,30 m, install a temperature indicating device at each end and one at the midpoint. Temperature-indicating devices are permitted to be inserted into small metallic blocks (less than 0,025 m per side).

4) The fuel cartridges shall be tested either by direct (bonfire) or indirect (chimney) flame impingement methods. The fire source shall totally engulf the test apparatus described above. Any fuel may be used for the fire source provided it supplies uniform heat sufficient to maintain the specified test temperatures for a minimum of 20 min or until the fuel cartridge is vented. The selection of a fuel should take into consideration air pollution concerns. The arrangement of the fire shall be recorded in sufficient detail to ensure that the rate of heat input to the fuel cartridge is reproducible.

   i) Direct flame impingement

      Sufficient fuel shall be supplied to ensure a burn time of at least 20 min. The fuel cartridge shall be placed in the test orientation with the fuel cartridge at least 0,100 m above the fuel or at a sufficiently greater height to ensure total flame engulfment. Metallic shielding shall be used to prevent direct flame impingement on tank valves, fittings, and/or pressure relief devices. The metallic shielding shall not be in direct contact with the specified fire protection system (pressure relief devices or tank valve).

   ii) Indirect flame impingement

      The fuel cartridge shall be placed in a test apparatus that is designed to contain the test subject and provide a controlled and reproducible rate of heat input without localized overheating. The apparatus can be constructed of any suitable material capable of withstanding the test environment. The fire source shall be installed to provide heat to the chimney and test specimen in a uniform manner.

      Immediately following ignition, the fire shall produce a flame entirely engulfing the test apparatus. The temperature of at least one temperature-indicating device shall indicate a temperature of at least 590 °C within 5 min of ignition. One temperature-indicating device shall maintain an average temperature of at least 590 °C for the duration of the test.

d) **Passing criteria:**

1) The fuel cartridge design is deemed to have passed the test if, for all valid tests, either of the following criteria is met in the same manner.

   i) The internal pressure vents to zero gauge pressure in a controlled manner as intended by the fuel cartridge design.

   ii) The fuel cartridge withstands the fire for a minimum of 20 min without venting.

2) Any failure or inconsistency of the fire or heat source during a test shall invalidate the result, and a re-test shall be required. Any venting through or failure of the shell, a valve, fitting or tubing during the test that is not part of the intended protection system shall invalidate the result and a re-test shall be required.

Bibliography

IEC 62282-5-1, *Fuel cell technologies – Part 5-1: Portable fuel cell power systems – Safety*

IEC 61025, *Fault tree analysis (TA)*

IEC 60812, *Analysis techniques for system reliability – Procedure for failure mode and effects analysis (FMEA)*

ISO/TR 15916:2004, *Basic considerations for the safety of hydrogen systems*

15th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

Sax's Dangerous Properties of Industrial Materials 11th Edition

SWAIN, M.R. and SWAIN, M.N. Codes and Standards Analysis. Proceedings of the 2001 DOE Program Review; NREL/CP-570-30535, 2001.

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

3, rue de Varembé
PO Box 131
CH-1211 Geneva 20
Switzerland

Tel: + 41 22 919 02 11
Fax: + 41 22 919 03 00
info@iec.ch
www.iec.ch