# IEC/PAS 62282-6-150

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# PUBLICLY AVAILABLE SPECIFICATION

## PRE-STANDARD

colour inside

**Fuel cell technologies –**
**Part 6-150: Micro fuel cell power systems – Safety – Water reactive (UN Division 4.3) compounds in indirect PEM fuel cells**

IEC/PAS 62282-6-150:2011(E)

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# FUEL CELL TECHNOLOGIES –

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IEC-PAS 62282-6-150 has been processed by IEC technical committee 105: Fuel cell technologies.

| The text of this PAS is based on the following document: | This PAS was approved for publication by the P-members of the committee concerned as indicated in the following document |
|---|---|
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| 105/309/PAS | 105/321/RVD |

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# FUEL CELL TECHNOLOGIES –

## Part 6-150: Micro fuel cell power systems – Safety – Water reactive (UN Division 4.3) compounds in indirect PEM fuel cells

## 1 Scope

### 1.1 General

a) This consumer safety PAS covers micro fuel cell power systems using hydrogen produced from the reaction of an aqueous solution with solid UN Division 4.3 (water-reactive) compounds in indirect PEM fuel cell systems 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 PAS establishes requirements for micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from the reaction of an aqueous solution with solid UN Division 4.3 (water-reactive) compounds for use in indirect PEM fuel cell systems 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 PAS 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 PAS.

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) This PAS covers micro fuel cell power systems, micro fuel cell power units and fuel cartridges using hydrogen produced from the reaction of an aqueous solution with solid UN Division 4.3 (water reactive) solid compounds as fuel. These systems and units use polymer electrolyte membrane fuel cell technologies. The designs may include fuel processing subsystems to derive hydrogen gas from the water-reactive solid fuel.

b) Micro fuel cell power system block diagrams for covered systems are shown in Figures 1.1 and 1.2.

c) All portions of this PAS apply to micro fuel cell power systems, micro fuel cell power units and fuel cartridges as defined in 1.1 above.

Clauses 1 through 7 of this PAS parallel the general safety requirements given in IEC 62282-6-100, considered relevant to micro fuel cell systems of all types and further includes requirements specific to water reactive solid fuels as included in Annex F of IEC 62282-6-100:2010.

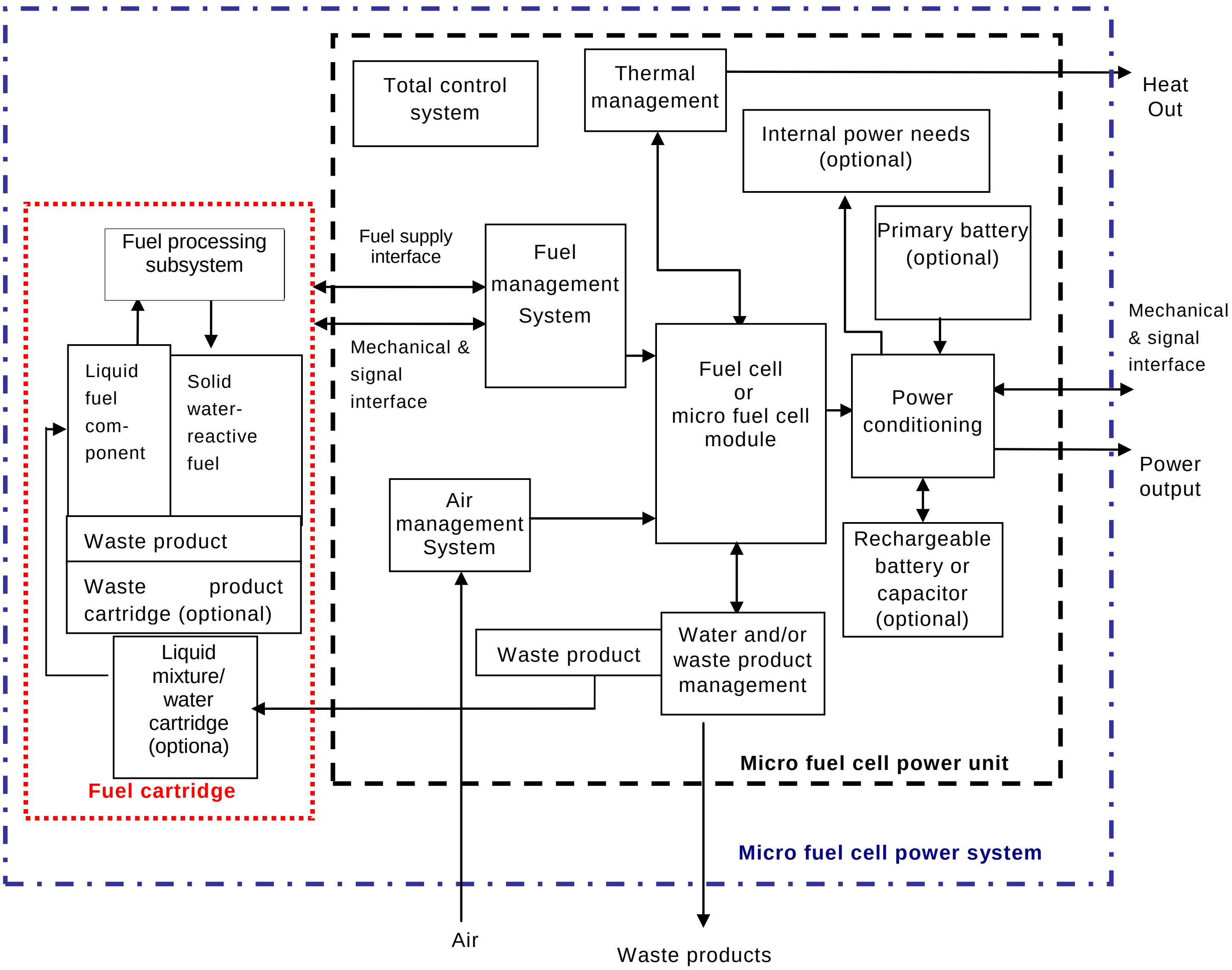


**Figure 1.1 – Micro fuel cell power system block diagram for UN Division 4.3 (water reactive) compound fuel in indirect PEM fuel cell system – Fuel management system in micro fuel cell power unit**

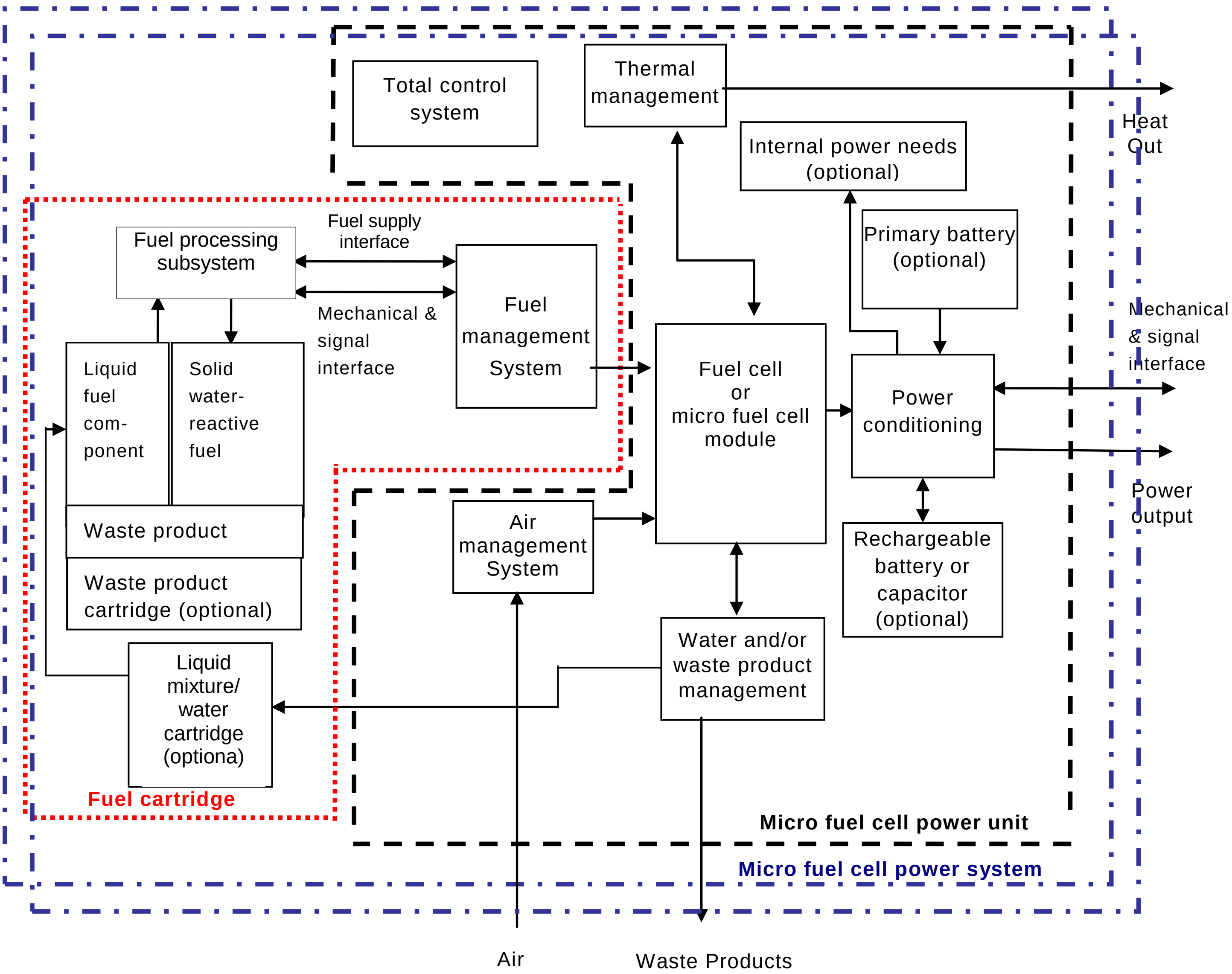


**Figure 1.2 – Micro fuel cell power system block diagram for UN Division 4.3 (water reactive) compound fuel in indirect PEM fuel cell system – Fuel management system in fuel cartridge**

### 1.3 Equivalent level of safety

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

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, *Explosive atmospheres – Part 15: Equipment protection by type of protection "n"*

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 60695-1-10: *Fire hazard testing – Part 1-10: Guidance for assessing the fire hazard of electrotechnical products – General guidelines*

IEC 60695-1-11: *Fire hazard testing – Part 1-11: Guidance for assessing the fire hazard of electrotechnical products – Fire hazard assessment*

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 60730-1:2010, *Automatic electrical controls for household and similar use – Part 1: General requirements*

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

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

IEC 62133, *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, *Safety of primary and secondary lithium cells and batteries during transport*

ISO 175, *Plastics – Methods of test for the 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*

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 – Sampling and analysis of volatile organic compounds by sorbent tube/thermal desorption/capillary gas chromatography – Part 1: Pumped sampling*

ISO 16111:2008, *Transportable gas storage devices – Hydrogen absorbed in reversible metal hydride*

*United Nations Recommendations on the Transport of Dangerous Goods – Model Regulations; Sixteenth revised edition*

*United Nations Recommendations on the Transport of Dangerous Goods – Manual of Tests and Criteria; Fifth revised edition*

## 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**
UN Division 4.3 (water-reactive) solid formulation of compounds comprising constituents selected from the following group used as fuel for an indirect PEM micro fuel cell power system:

> (water reactive) mixtures, alloys, compounds or chemical hydrides of the following materials: sodium, magnesium, borohydride compounds, silicon, silicon dioxide, iron, nickel, cobalt.

The formulation may contain a non-hazardous activator to facilitate the production of hydrogen.

Only UN Division 4.3 (water reactive) solid compounds which solely evolve hydrogen gas upon contact with water (or non-hazardous aqueous solutions) shall be permitted. Compounds with a subsidiary hazard risk, or which are not permitted to be transported by air according to the ICAO Technical Instructions, shall not be permitted under this PAS.

**3.6**
**fuel cartridge**
removable article that contains fuel and supplies hydrogen 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**
liquid fuel component with a pH $< 3,5$ or $> 10,5$

**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 fuel management system that stores hydrogen and cannot be removed

**3.11**
**leakage**
accessible fuel, hazardous fuel byproducts or hazardous liquid fuel outside the micro fuel cell power system, micro fuel cell power unit, 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 or other cartridges (optional).

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

**3.19**
**no fuel vapour loss**
not applicable

**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 utilized fuel cartridge**
fuel cartridge that has been put into operation such that approximately 45 % – 55 % 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

**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 hydrogen 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 the manufacturer or by trained technicians

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

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

**3.27**
**water cartridge/liquid mixture**
cartridge that is filled with water or liquid fuel component

**3.28**
**fuel management system**
optional components used to control fuel or hydrogen properties (e.g. concentration, flow rate, purity, temperature, humidity or pressure) or aspects of hydrogen generation to support micro

fuel cell power system operation, including management and/or storage of generated hydrogen gas (e.g. via storage in and release from an internal reservoir), if applicable

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

**3.29**
**air management system**
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

NOTE Not all systems will include all functions. Some systems may 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

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

**3.31**
**primary battery**
non-rechargeable battery

**3.32**
**fuel cell**
electrochemical device that converts the energy of the chemical reaction between hydrogen or hydrogen rich gases 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

**3.37**
**indirect PEM fuel cell power system**
micro fuel cell power system in which a solid formulation of water-reactive 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

**3.38**
**borohydride compounds**
sodium or potassium borohydride, or a mixture thereof

**3.39**
**electrolyte**
ion conducting membrane used to complete an electric circuit within a fuel cell

**3.40**
**fuel byproducts**
Class 8 (corrosive), or non-hazardous compounds produced during the generation of hydrogen and/or electricity from solid water reactive fuel; fuel byproducts shall not have any subsidiary risks.

**3.41**
**impermissible hydrogen gas loss**
hydrogen gas escaping fuel cartridge, non-operating micro fuel cell power system, or micro fuel cell power unit greater than or equal 0,003 2 g/h

**3.42**
**accessible fuel, hazardous fuel byproducts or hazardous liquid fuel components**
fuel, hazardous fuel byproducts or hazardous 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

**3.43**
**fuel processing subsystem**
subsystem within the fuel cartridge used to produce hydrogen from formulations of water-reactive compounds

**3.44**
**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

**3.45**
**uncontrolled mixing**
mixing of incompatible materials that occurs in ways not specifically provided for by the micro fuel cell power system design

**3.46**
**UN Division 4.3 (water reactive)**
materials which in contact with water emit flammable gases and are classified as UN Division 4.3: Water Reactive substances under the guidelines of the 16th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations when tested in accordance with the UN Manual of Tests and Criteria for the Classification of Dangerous Goods

**3.47**
**non-hazardous**
materials which are not classified as dangerous goods subject to guidelines of the 16th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations

NOTE For clarification, a mixture or substance is not subject to the Model Regulations only if the hazard characteristics of the mixture or substance are such that they do not meet the criteria for classification for any class as a dangerous good, as identified in the UN Model Regulations and the UN Manual of Tests and Criteria for the Classification of Dangerous Goods. The UN Model Regulations and Manual of Tests and Criteria may be found online at:

http://www.unece.org/trans/danger/publi/unrec/rev16/16files_e.html and
http://www.unece.org/trans/danger/publi/manual/Rev4/ManRev4-files_e.html, respectively;

5th edition currently only available in print

**3.48**
**activator**
substance such as a metal salt or acid that facilitates the production of hydrogen from water-reactive fuel

**3.49**
**hydrogen leakage**
hydrogen gas outside hydrogen containment system, including fuel cartridge and fuel management system (see 7.2.2)

**3.50**
**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. Corrosive solutions may not have a subsidiary risk.

**3.51**
**Class 8 (corrosive)**
materials which are classified as Class 8: Corrosive substances under the guidelines of the 16th edition of the UN Recommendations on the Transport of Dangerous Goods, Model Regulations when tested in accordance with the UN Manual of Tests and Criteria for the Classification of Dangerous Goods

**3.52**
**hazardous fuel byproduct**
fuel by-product with a pH $< 3,5$ or $> 10,5$

# 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 or hydrogen 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 or hydrogen 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 and IEC 60812.

**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 PAS, 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.

**4.4.5** Piping systems exposed to hydrogen shall employ materials suitable for exposure to hydrogen, as defined in Annex A of ISO 16111:2008.

### 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, consumer transportation and storage 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, reasonably foreseeable misuse, consumer transportation and storage.

**4.6.3** The valves shall have means to prevent leakage through normal use, reasonably foreseeable misuse, consumer transportation, 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 leakage. Compliance shall be checked using test probe 11 of IEC 61032 and a force of 9,8 N.

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

### 4.7 Materials and construction – System

**4.7.1** The maximum quantity of 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.

**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.

**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 V-0, V-1 or V-2 in accordance with IEC 60695-1-10, IEC 60695-1-11 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 or hydrogen 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 or hydrogen, 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, normal use, reasonably foreseeable misuse, consumer transport and storage 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<br>Test A.2 of IEC 60950-1:2005, or<br>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<br>Test A.2 of IEC 60950-1:2005, or<br>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<br>HB75 (IEC 60695-11-10) for thickness < 3 mm, or<br>HBF (foamed) (ISO 9772), or<br>550 °C glow wire test of IEC 60695-2-11, or<br>see 4.9.3 for exceptions |
| Inside the fire enclosure | Components and parts including mechanical and electrical enclosures | V-2, or<br>HF-2 (foamed) (ISO 9772), or<br>Test A.2 of IEC 60950-1:2005, or<br>Relevant IEC component standards, or<br>see 4.9.4 for exceptions |
| Any location | Air filter assemblies | V-2 (IEC 60695-11-10), or<br>HF-2 (foamed) (ISO 9772), or<br>Test A.2 of IEC 60950-1:2005, or<br>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.

NOTE In this case, the term “fuel” is used in its generic sense, not as defined in 3.5.

**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.

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 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 for liquid fuel components, and 200 g for solid fuel.

**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 leakage or hydrogen leakage prior to, during, and after connection or transfer of hydrogen 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 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 leakage 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 leakage.

**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.

**4.12.1.12** In cases where materials (either solid or liquid) are present that are incompatible with either the water-reactive solid 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.

### 4.12.2 Fuel cartridge fill requirement

The fuel cartridge design and fuel fill amount shall allow fuel or hydrogen 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.

## 4.13 Protection against mechanical hazards

### 4.13.1 Piping and tubing other than fuel or hydrogen lines

Requirements are listed below for the construction of piping, tubing and fittings – other than fuel or hydrogen 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 designed to withstand freezing and corrosion, and avoid breakage. Compliance is determined by 7.3.3 and 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<br>°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<br>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 60730-1:2010, 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 × $V_{oc}$ |
| 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 / $V_{oc}$ |

| | | | |
|---|---|---|---|
| $30 < V_{oc} \leq 60$ | | | $\leq 100 / V_{oc}$ |

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 60730-1:2010.

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 impermissible hydrogen gas 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 or hydrogen 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 or hydrogen 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 or hydrogen 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) that communicates the intended safe transportation, use, storage, maintenance and disposal of the product.

### 6.2 Minimum markings required on the fuel cartridge

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

a) CONTENTS ARE WATER-REACTIVE, 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 PAS 62282-6-150.

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. 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 AND FLAMMABLE. DO NOT DISASSEMBLE.

### 6.3 Minimum markings required on the micro fuel cell power system or micro fuel cell power unit

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

a) CONTENTS ARE WATER-REACTIVE, 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 PAS 62282-6-150.

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.

### 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 PAS 62282-6-150;

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.

c) Unless otherwise explicitly prescribed elsewhere in this clause, laboratory conditions are specified by 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 to ensure safety of equipment and personnel during testing.

**Table 5 – List of type tests**

| Test reference | Test item | Test sample |
|---|---|---|
| 7.3.1 | Pressure differential tests | Fuel cartridge<br>Partially utilized fuel cartridge<br>Micro fuel cell power system or power unit |
| 7.3.2 | Vibration test | Fuel cartridge<br>Partially utilized fuel cartridge<br>Micro fuel cell power system or power unit |
| 7.3.3 | Temperature cycling test | Fuel cartridge<br>Partially utilized fuel cartridge<br>Micro fuel cell power system or power unit |
| 7.3.4 | High temperature exposure test | Fuel cartridge<br>Partially utilized fuel cartridge |
| 7.3.5 | Drop test | Fuel cartridge<br>Partially utilized fuel cartridge<br>Micro fuel cell power system or power unit |
| 7.3.6 | Compressive loading test | Fuel cartridge<br>Partially utilized fuel cartridge<br>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<br>Partially utilized fuel cartridge |
| 7.3.10 | High-temperature connection test | Fuel cartridge and micro fuel cell power unit<br>Partially utilized 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 |
| 7.3.13 | Hydrogen point source gas loss detection 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 utilized, 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.

**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.<br>The laboratory atmosphere contains at least 18 % oxygen but not more than 21 % oxygen. |

### 7.2 Leakage, hydrogen leakage, and hydrogen gas loss, and hydrogen emission measurement and the measuring procedures

*The leakage measurements shall be executed in principle in accordance with the procedures shown in Figures 2 through 7, 9 and 13.*

Compliance with the "no leakage", "no hydrogen leakage" and "no impermissible hydrogen gas loss" requirement for all type tests specified in 7.3 shall be determined by the leakage test and measurement procedure of 7.2.1, the hydrogen leakage measurement procedure of 7.2.2 and the hydrogen gas loss measuring procedure of 7.2.3 in conjunction with the definition of "leakage" in 3.11, "hydrogen leakage" in 3.51, and the definition of "impermissible hydrogen gas loss" in 3.42, unless otherwise specified.

#### 7.2.1 Leakage test and measuring procedure

a) For micro fuel cell power systems, micro fuel cell power units and fuel cartridges containing UN Division 4.3 (water reactive) solid fuel, the leakage measurement shall be done following each type test by performing visual inspection of all possible leak locations. Any drops of fuel, hazardous fuel byproducts, or hazardous liquid fuel component and/or solid deposits on the exterior of the micro fuel cell power system or unit or fuel cartridge are indications of leakage. If solid deposits are accessible, the micro fuel cell power system or unit or fuel cartridge fails the leakage test. As an additional tool for finding leakage, 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. Any existence of a substance with a pH lower than 3,5 or greater than 10,5 is an indication of leakage. See Figure 2 and Figure 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 water-reactive solid fuel, a water immersion test shall be performed following each type test. The entire fuel cartridge containing water-reactive solid 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 2 and Figure 3.

#### 7.2.2 Hydrogen leakage measurement from fuel cartridges and/or fuel management systems and measuring procedure

a) For fuel cartridges containing UN Division 4.3 (water reactive) solid fuel, 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 2 and Figure 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 hydrogen 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 hydrogen leakage from any point on the fuel management system.

d) Both for fuel cartridges containing UN Division 4.3 (water reactive) solid fuel, 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 hydrogen leakage" criteria for fuel cartridges containing UN Division 4.3 (water reactive) solid-fuel has been chosen to be consistent with the 16th Edition of the United Nations Recommendations on the Transport of Dangerous Goods, Model Regulations; Special Provision 328 for UN 3476, Fuel cell cartridge *containing water reactive substances*.

#### 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 4 through 7 as follows:

a) Perform hydrogen emission testing in accordance with 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 7.3.13 is not applicable. Hydrogen gas loss shall be less than 0,003 2 g/h. See Table 7.

b) Perform hydrogen emission testing in accordance with 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 7.

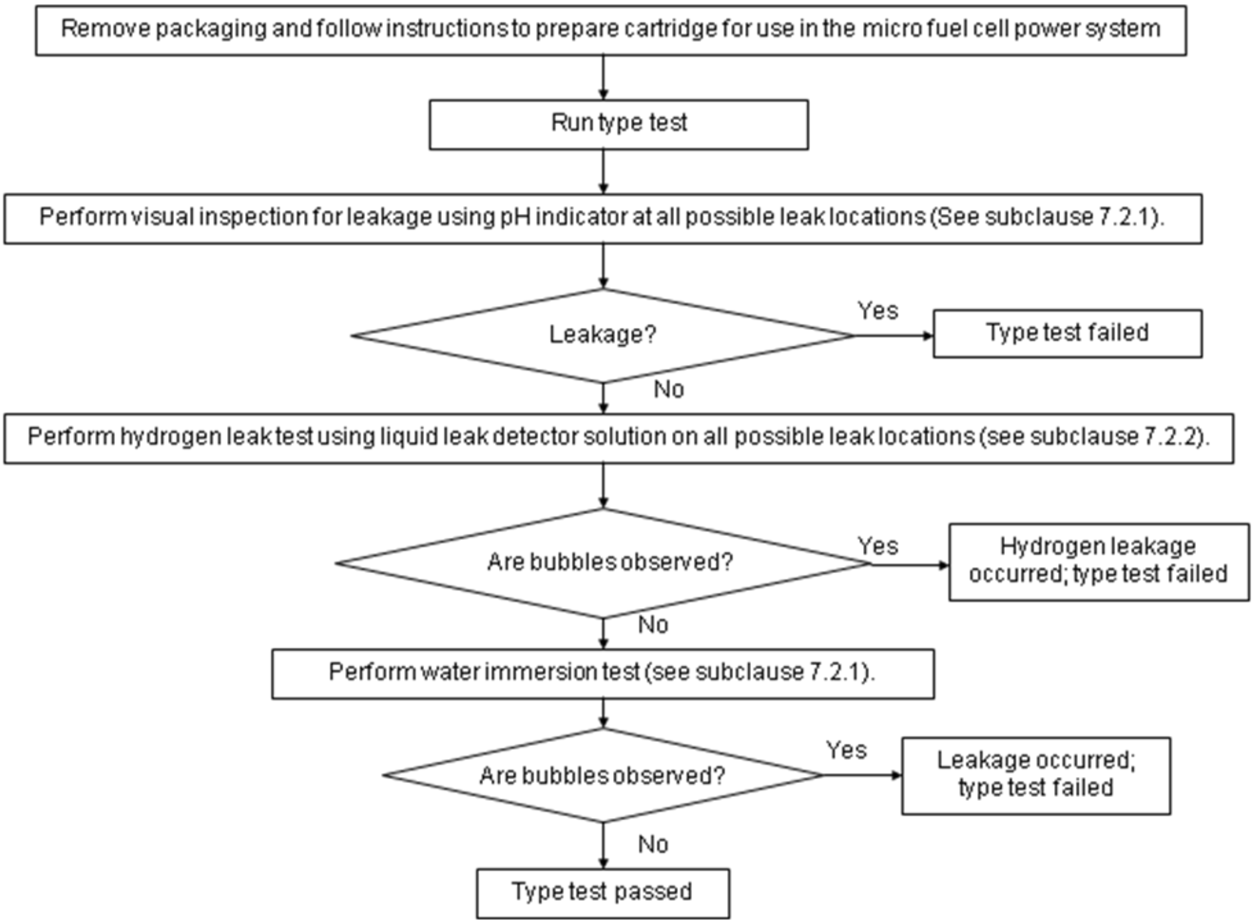


**Figure 2 – Fuel cartridge leakage test flow chart for pressure differential, vibration, drop, and compressive loading tests**

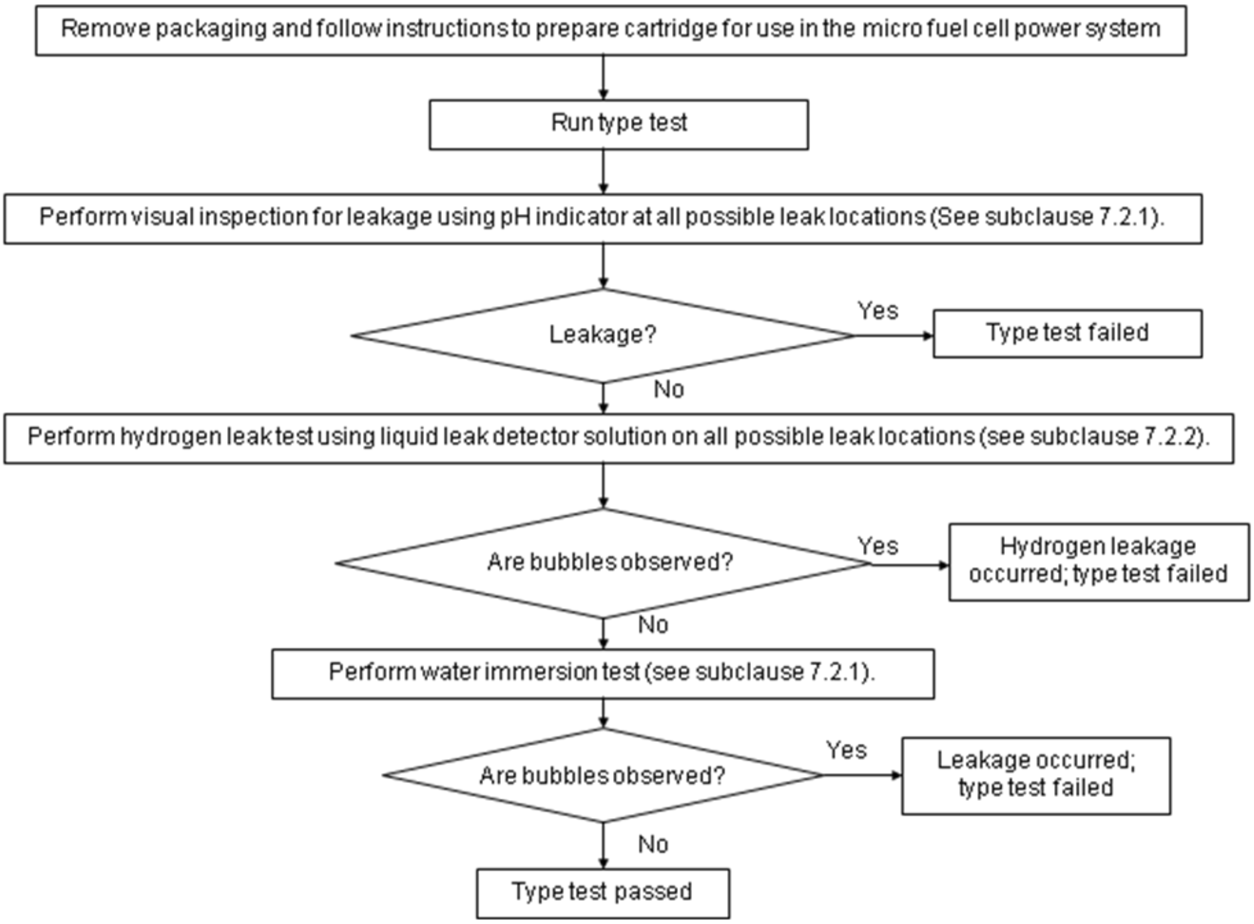


**Figure 3 – Fuel cartridge leakage test flow chart for temperature cycling test and high temperature exposure test**

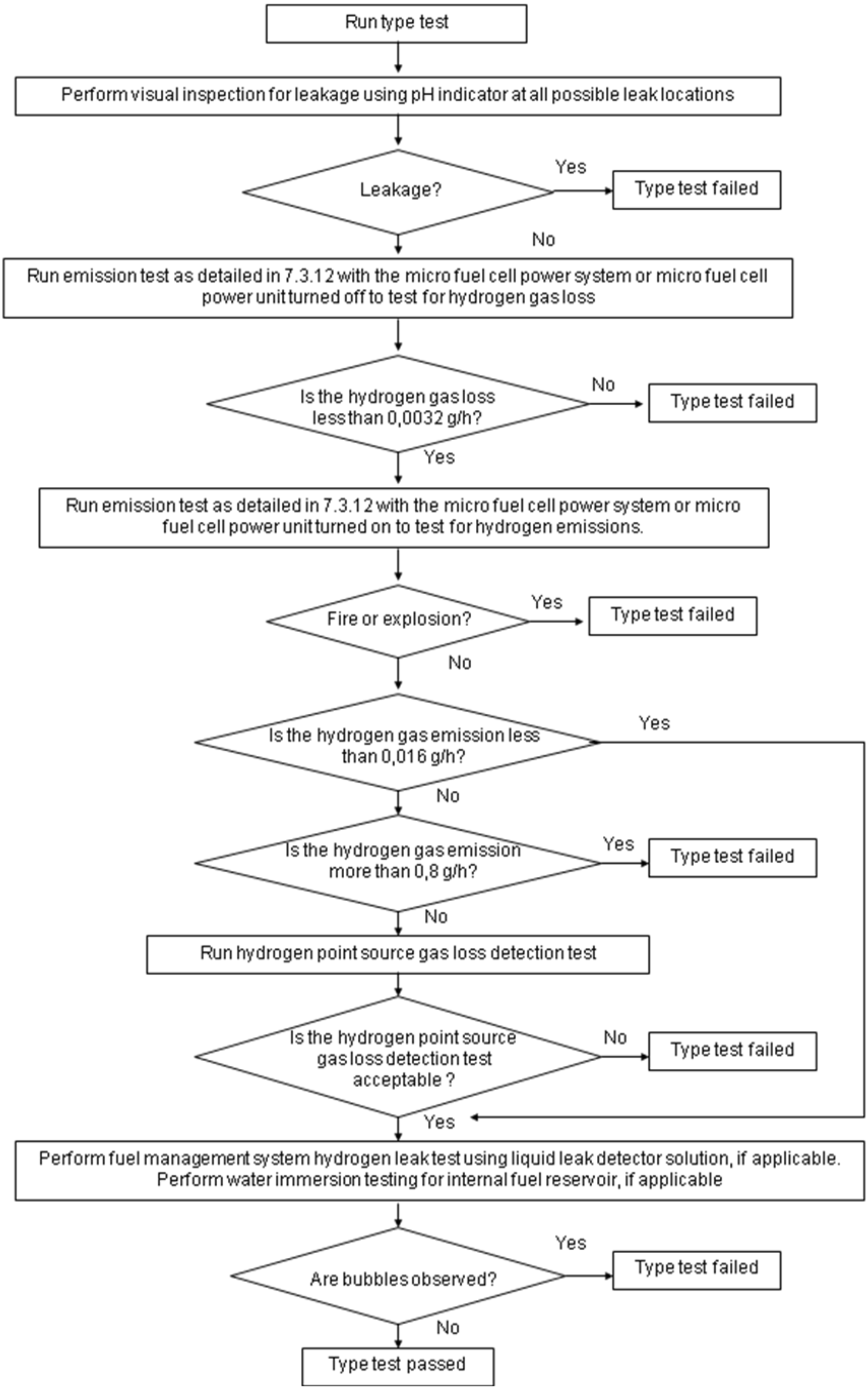


**Figure 4 – Micro fuel cell power system or micro fuel cell power unit leakage and hydrogen gas loss test flow chart for vibration, temperature cycling, drop and compressive loading tests**

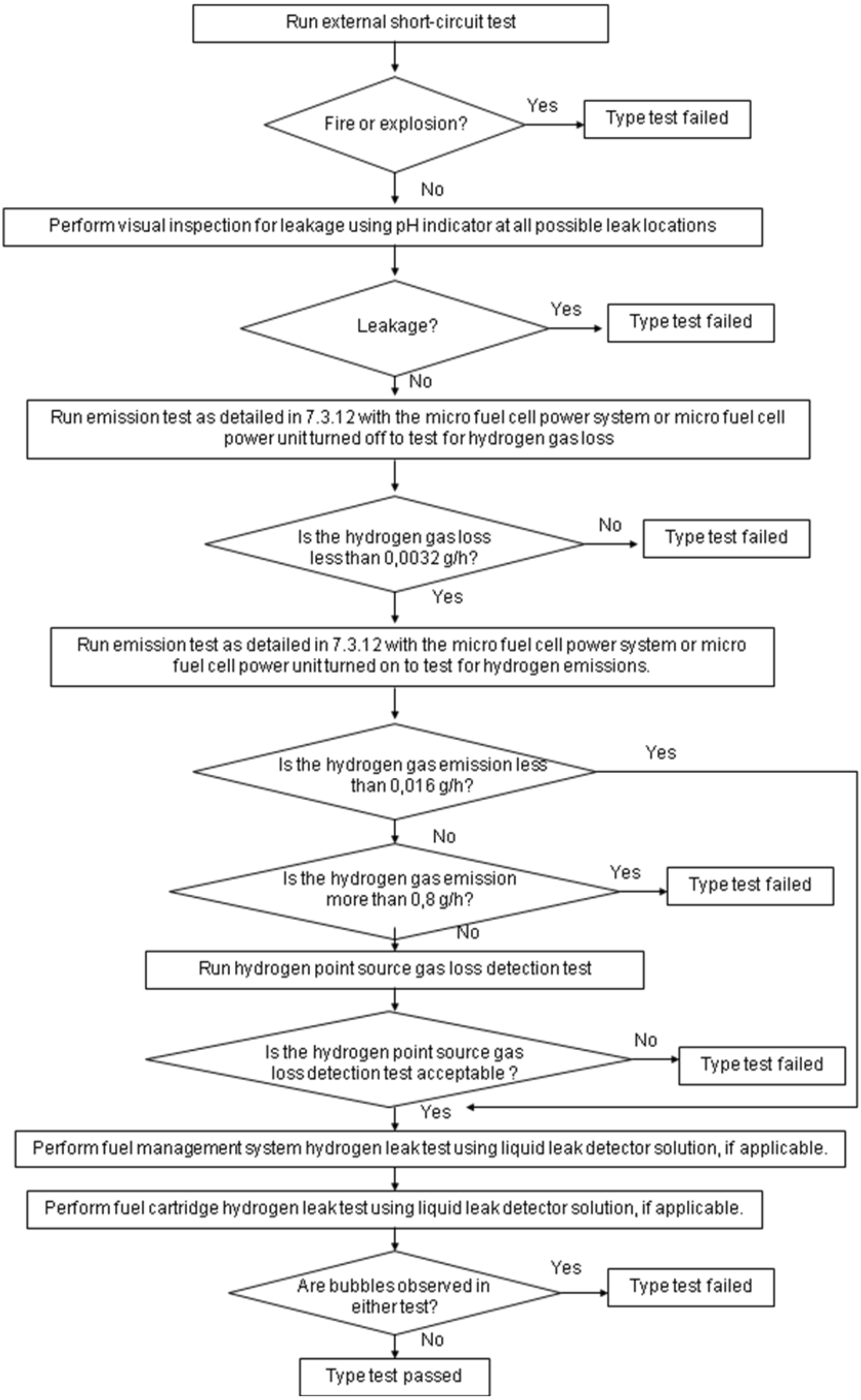


**Figure 5 – Micro fuel cell power system or micro fuel cell power unit leakage and hydrogen gas loss test flow chart for external short-circuit test**

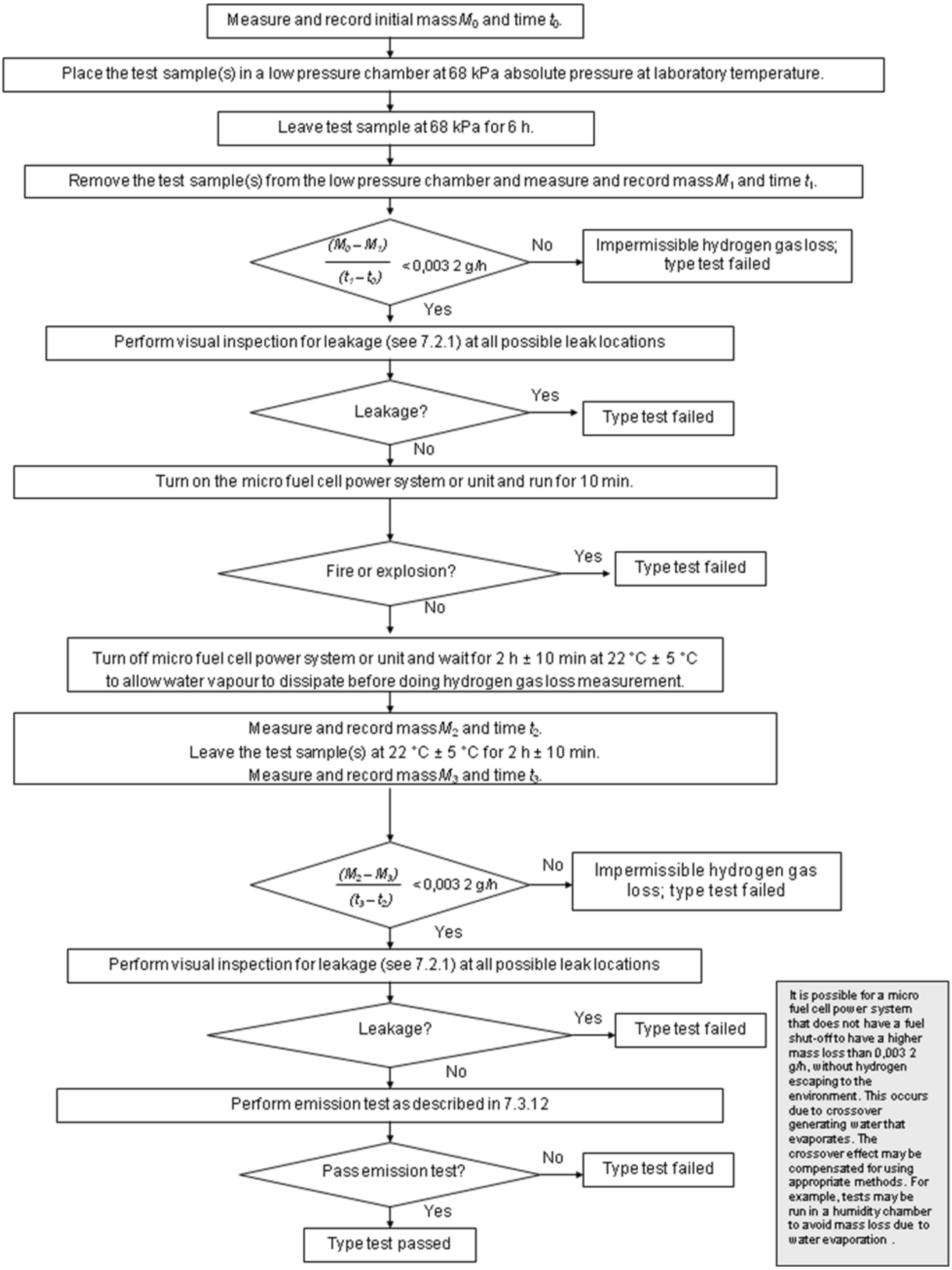


**Figure 6 – Micro fuel cell power system or micro fuel cell power unit leakage and hydrogen gas loss test flow chart for 68 kPa low external pressure test**

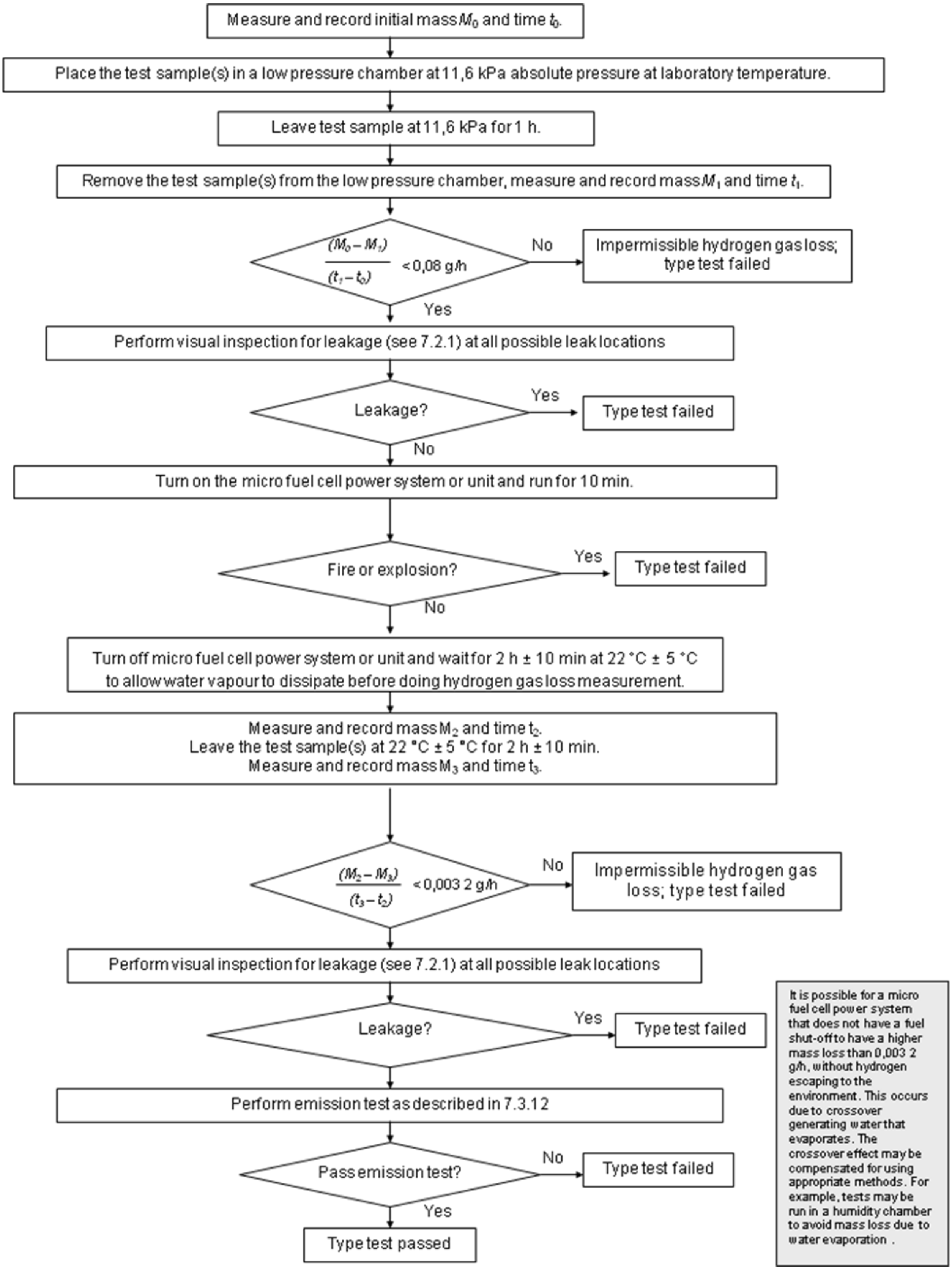


**Figure 7 – Micro fuel cell power system or micro fuel cell power unit leakage and hydrogen gas loss test flow chart for 11,6 kPa low external pressure test**

### 7.3 Type tests

#### 7.3.1 Pressure differential tests

##### 7.3.1.1 General

The first portions of this test ensures compliance with 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 7.3.1.2 or 7.3.1.3 may be used to verify compliance with 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, 7.3.1.2 shall be used to verify compliance with 4.12.1.2.

The second portion of this test ensures that there shall be no leakage from micro fuel cell power system or micro fuel cell power unit at a low external pressure of 68 kPa and 11,6 kPa external absolute pressure.

##### 7.3.1.2 Fuel cartridge internal pressurization test

a) **Test sample:** an unused fuel cartridge or a partially utilized 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. 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 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. 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 fluid 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 UN Division 4.3 (water reactive) solid fuel will chemically react with water, therefore, water or water-containing substances should not be used as the fluid test medium. UN Division 4.3 (water reactive) solid fuels have the potential to react with substances other than water, therefore, the chemical reactivity and stability of the particular UN Division 4.3 (water reactive) solid fuel being tested should be used to guide the selection of a suitable fluid test medium.

#### 7.3.1.3 Fuel cartridge low external pressure test

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

b) **Purpose:** to simulate the effects of high internal fuel cartridge pressure and ensure no leakage, hydrogen leakage or impermissible hydrogen gas loss.

c) **Test procedure:**

Perform this test in accordance with Figure 13.

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 using visual inspection with pH indicator and water immersion test as described in 7.2.1.

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 leakage. See Figure 13. Hydrogen gas loss shall meet the requirements of 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 7.2.2 for the fuel cartridge. Leakage shall be tested visually with pH indicator and with the water immersion test as specified in the leakage test and measurement procedure in 7.2.1. 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

There are two options for measuring leakage in the pressure differential test procedures; one is based on monitoring hydrogen concentration, the other is a simple mass loss measurement. Either of the two options may be employed in the pressure differential test, according to their applicability.

**Method 1:** Hydrogen concentration measurement

**Method 2:** Simple mass loss (if technique is applicable)

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 and no impermissible hydrogen gas loss.

c) **Test procedure:**

1) Store test sample at a low external pressure of 68 kPa absolute pressure for at least 6 h at laboratory temperature.

2) Measure leakage in accordance with Method 1 or Method 2, as prescribed below.

3) Following the pressure differential test, remove the test sample from the vacuum chamber and perform emission testing in accordance with 7.3.12.

Either of the following two methods may be used to satisfy step 2), above:

Method 1 – Hydrogen concentration measurement:

i) Test samples shall be stored in a sealed vacuum chamber at a low external pressure of 68 kPa absolute pressure for 6 h.

NOTE 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.

ii) 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:

$$C_{pv} = \frac{\dfrac{HLR \times t}{2 \times 1{,}00794\ {}^{g}/_{mol}} \times 22{,}4\ {}^{l}/_{mol}}{V} \times 100 = \frac{\dfrac{0{,}0032\ {}^{g}/_{h} \times 6\ h}{2 \times 1{,}00794\ {}^{g}/_{mol}} \times 22{,}4\ {}^{l}/_{mol}}{V} \times 100 = \frac{0{,}21 l}{V} \times 100$$

where

$C_{pv}$ is the hydrogen concentration in % by volume that would result from a hydrogen gas loss rate of 0,003 2 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 0,003 2 g/h;

$t$ is the duration of the test, in this case, 6 h;

or simplified to:

$$C_{pv} = \frac{0{,}21 l}{V} \times 100$$

where

$C_{pv}$ is the hydrogen concentration in % by volume that would result from a hydrogen gas loss rate of 0,003 2 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 0,003 2 g/h hydrogen gas loss and fails the test.

iii) At the end of the 6 h 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 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.

iv) Compare the measured hydrogen concentration in the vacuum chamber to the hydrogen concentration that would result from a hydrogen gas loss rate of 0,003 2 g/h calculated above.

v) The hydrogen gas loss rate shall be less than the impermissible hydrogen gas loss limit of 0,003 2 g/h in accordance with 3.41 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 0,003 2 g/h. If the hydrogen concentration in the vacuum chamber is less than the hydrogen concentration $C_{pv}$ calculated in ii) above, then the test sample passes the test for hydrogen gas loss.

Method 2 – Simple mass measurement:

i) Leakage shall be measured on the basis of the procedure described in Figure 6.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no leakage. See Figure 6. Remove the fuel cartridge, if present, from the micro fuel cell power system. Leakage shall be tested visually as specified in the leakage test and measurement procedure in 7.2.1. Hydrogen gas loss shall be determined by the hydrogen gas loss measurement as shown in Figure 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 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.

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

There are two options for measuring leakage in the pressure differential test procedures; one is based on monitoring hydrogen concentration, the other is a simple mass loss measurement. Either of the two options may be employed in the pressure differential test, according to their applicability.

**Method 1:** Hydrogen concentration measurement

**Method 2:** Simple mass loss (if technique is applicable)

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 and no impermissible hydrogen gas loss.

c) **Test procedure:**

1) Store test sample at a low external pressure of 11,6 kPa absolute pressure for at least 1 h at laboratory temperature.

2) Measure leakage in accordance with Method 1 or Method 2, as prescribed below.

3) Following the pressure differential test, remove the test sample from the vacuum chamber and perform emission testing in accordance with 7.3.12.

Method 1 – Hydrogen concentration measurement:

i) Test samples shall be stored in a sealed vacuum chamber at a low external pressure of 11,6 kPa absolute pressure for 1 h.

NOTE 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.

ii) 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:

$$C_{\mathrm{pv}} = \frac{\dfrac{HLR \times t}{2 \times 1{,}00794\ \mathrm{g/mol}} \times 22{,}4\ \mathrm{l/mol}}{V} \times 100 = \frac{\dfrac{0{,}08\ \mathrm{g/h} \times 1\mathrm{h}}{2 \times 1{,}00794\ \mathrm{g/mol}} \times 22{,}4\ \mathrm{l/mol}}{V} \times 100 = \frac{0{,}9\mathrm{l}}{V} \times 100$$

where

$C_{\mathrm{pv}}$ 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.

iii) 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.

iv) 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 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.

v) 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 above.

vi) 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 ii) above, then the test sample passes the test for hydrogen gas loss.

Method 2 – Simple mass measurement:

i) Leakage shall be measured on the basis of the procedure described in Figure 7.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no leakage. See Figure 7. Remove the fuel cartridge, if present, from the micro fuel cell power system. Leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Hydrogen gas loss shall be determined by the hydrogen gas loss measurement as shown in Figure 7. 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. 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 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.

### 7.3.2 Vibration test

a) **Test sample:** an unused fuel cartridge, a partially utilized 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.

7) For the fuel cartridge, check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in 7.2.2. Check for leakage using visual inspection with pH indicator and the water immersion test as described in 7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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 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 utilized 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 hydrogen gas 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.

10) For the fuel cartridge, check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in 7.2.2. Check for leakage using visual inspection with pH indicator and the water immersion test as described in 7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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 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.

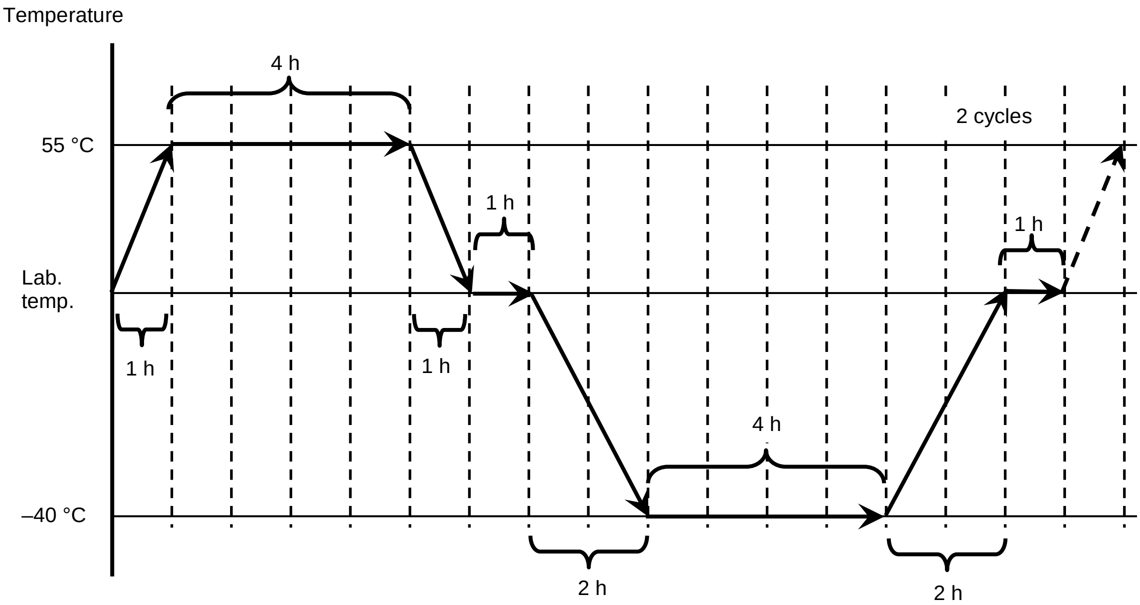


**Figure 8 – Temperature cycling**

### 7.3.4 High temperature exposure test

a) **Test sample:** an unused fuel cartridge or a partially utilized 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 7.2.2. Check for leakage using visual inspection with pH indicator and the water immersion test as described in 7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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.

### 7.3.5 Drop test

a) **Test sample:** an unused fuel cartridge, a partially utilized 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 the fuel cartridge, check for hydrogen leakage using liquid leak detector (bubble-forming) solution as described in 7.2.2. Check for leakage using visual inspection with pH indicator and the water immersion test as described in 7.2.1.

   7) For micro fuel cell power system or micro fuel cell power unit tests, perform emission testing in accordance with 7.3.12. See Figure 4.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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 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. See Figure 4.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test when applicable as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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 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.

#### 7.3.6.2 Fuel cartridge

a) **Test sample:** an unused fuel cartridge or a partially utilized 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 7.2.2. Check for leakage using visual inspection with pH indicator and the water immersion test as described in 7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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.

### 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 hydrogen leakage. No leakage. Leakage shall be determined visually using pH indicator and with the water immersion test when applicable as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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 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 emissions 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 stabilize 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

There are four options for the long-term storage test procedure; two are based on monitoring hydrogen concentration, one is a simple mass loss measurement and one is a periodic mass loss measurement. Any of the four options may be employed in the long-term storage test, as applicable.

**Method 1:** Continuous hydrogen concentration measurement

**Method 2:** Controlled flow hydrogen concentration measurement

**Method 3:** Simple mass measurement (if technique is applicable)

**Method 4:** Periodic mass measurement (if technique is applicable)

a) **Test sample:** An unused or a partially utilized 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 9.

2) Apparatus shall be a temperature test chamber capable of maintaining an internal temperature of 50 °C ± 2 °C. The test chamber shall be equipped with sampling and monitoring instruments capable of accurately measuring air flow through the test chamber and hydrogen concentration in the test chamber, with a configuration similar to that shown in Figure 10. 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.

3) 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.

4) Place sample in temperature chamber at 50 °C ± 2°C with a chamber relative humidity of at least 60 %. The sample shall remain in the chamber 50 °C ± 2°C for at least 28 days.

NOTE 1 For Methods 1 and 2, the hydrogen concentration and the air flow rate through the test chamber shall be monitored continuously. At no time during the test shall the hydrogen concentration in the chamber shall exceed 25 % LFL.

5) Monitor hydrogen concentration continuously and/or measure cartridge mass according to Method 1, 2, 3 or 4, as prescribed below.

6) Perform leakage testing in accordance with 7.2.1 for the fuel cartridge using visual inspection with pH indicator and water immersion test. Perform hydrogen leakage testing in accordance with 7.2.2 using a liquid leak detector at all possible leak locations. If the fuel cartridge is empty of hydrogen at the end of 28 days, refill the cartridge (or pressurize using suitable inert gas) to rated charging pressure according to manufacturer's instructions prior to executing the hydrogen leakage measurement.

Any of the following four methods may be used to satisfy step (5), above:

Method 1 – Continuous hydrogen concentration measurement:

i) Hydrogen gas loss shall be sampled continuously at the outlet of the small test chamber, at air sampling port 'A' (see Figure 10).

ii) Sample and record the gaseous contents of the test chamber through the air sampling port 'A' (see Figure 10), while simultaneously measuring and recording the total air flow through the test chamber (computed from the sum of the outlet air flow rate and the air flow through port A, or be measuring the inlet flow rate to the test chamber).

iii) 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 of 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 hydrogen gas loss rate.

iv) See below:

$$HLR = (F_0 + F_S) \times C$$

or

$$HLR = (F_i) \times C$$

where

$HLR$ is the hydrogen gas loss rate in grams per hour;

$F_0$ is the outlet air flow rate in standard litres per hour;

$F_t$ 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; and

$C$ is the concentration of hydrogen in grams per standard litre.

Method 2 – Controlled flow hydrogen concentration measurement:

i) The air flow rate shall be controlled such that a hydrogen gas loss rate from the cartridge of 0,003 2 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:

$$F_t = \frac{HLR \times SV}{C} = \frac{0{,}0032\ ^{g}/_{h} \times \left(\frac{22{,}4\ g/mol}{2 \times 1{,}00794\ g/mol}\right)}{0{,}25 \times 4\%} = 3{,}56\ ^{l}/_{h}$$

$$F_t = \frac{HLR \times SV}{C} = \frac{0{,}0032\ ^{g}/_{h} \times \left(\frac{22{,}4\ L/mol}{2 \times 1{,}00794\ g/mol}\right)}{0{,}25 \times 0{,}04} = 3{,}56\ ^{l}/_{h}$$

where

$HLR$ is the hydrogen gas loss rate in grams per hour;

$F_S$ 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; and

0,04 is the lower flammability limit of hydrogen.

Method 3 – Simple mass measurement:

i) Record initial mass $M_{\text{initial}}$ and time $t_{\text{initial}}$.

ii) At the end of the 28 days, remove the fuel cartridges from the test chamber for measurement. The test samples should be stabilized at a laboratory temperature if the mass loss will be affected.

iii) Within five minutes of completing the test, measure and record mass $M_{\text{final}}$ and record time $t_{\text{final}}$. 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 $(M_{\text{initial}} - M_{final})$ divided by the elapsed time $(t_{\text{final}} - t_{initial})$ according to the following formula:

$$\frac{M_{\text{initial}} - M_{\text{final}}}{\Delta t} = \text{hydrogen mass loss rate,}$$

where

$\Delta t = t_{\text{final}} - t_{\text{initial}}$ = 28 d × 24 h/d = 672 h;

$M_{\text{initial}}$ = the initial mass of the fuel cartridge; and

$M_{\text{final}}$ = the final mass of the fuel cartridge.

iv) If the hydrogen mass loss rate is less than 0,003 2 g/h, then the test sample passes the test for hydrogen gas loss.

v) If the fuel cartridge no long contains hydrogen after 28 days, then the type test according to either Method 1, Method 2 or Method 4 shall be performed.

Method 4 – Periodic cartridge mass loss:

i) Collect weight measurements 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.

ii) Record initial mass $M_{\text{initial}}$ and time $t_{\text{initial}}$.

iii) 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.

iv) 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 $M_{\text{final}}$ and record time $t_{\text{final}}$.Calculate hydrogen mass loss rate using the difference in mass $(M_{\text{initial}} - M_{final})$ divided by the elapsed time $(t_{\text{final}} - t_{initial})$ according to the following formula:

$$\frac{M_{\text{initial}} - M_{\text{final}}}{\Delta t} = \text{hydrogen mass loss rate,}$$

where

$\Delta t = t_{\text{final}} - t_{\text{initial}}$ = 28 d × 24 h/d = 672 h;

$M_{\text{initial}}$ = the initial mass of the fuel cartridge; and

$M_{\text{final}}$ = the final mass of the fuel cartridge.

v) If the hydrogen mass loss rate is less than 0,003 2 g/h, then the test sample passes the test for hydrogen gas loss.

vi) If the fuel cartridge contains no more fuel 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 $(t_{\text{last}})$ and the final mass $(M_{\text{last}})$ at the last measured data point before the fuel cartridge became empty. If the hydrogen mass loss rate is less than 0,003 2 g/h, then the test sample passes the test for hydrogen gas loss.

$$\frac{M_{\text{initial}} - M_{\text{last}}}{\Delta t} = \text{hydrogen mass loss rate,}$$

where

$\Delta t = t_{\text{last}} - t_{\text{initial}}$;

$M_{\text{last}}$ is the last weight measurement taken when fuel still remained in the cartridge; and

$t_{\text{last}}$ is the time corresponding to the measurement of $M_{\text{last}}$

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No impermissible hydrogen gas loss and no leakage. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. The hydrogen gas loss rate from the cartridge shall be less than 0,003 2 g/h as measured by any of the four methods. Fire, flame and explosion shall be checked using cheesecloth, infrared camera, or other suitable methods. Explosion shall be checked visually.

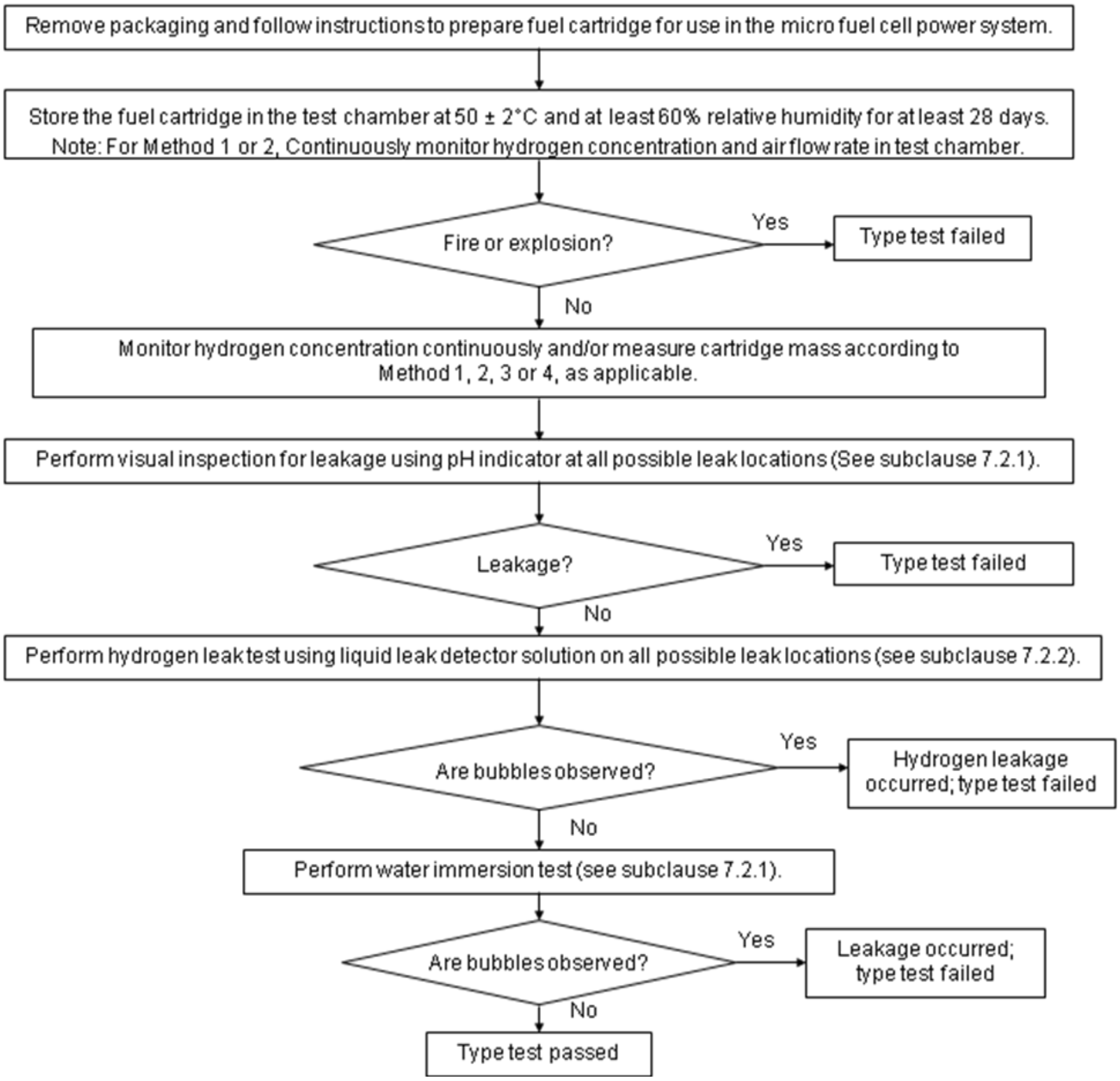


**Figure 9 – Fuel cartridge leakage and hydrogen gas loss test flow chart for long-term storage test.**

### 7.3.10 High temperature connection test

a) **Test sample:** an unused fuel cartridge or a partially utilized 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 valve using a micro fuel cell power unit or a suitable test fixture 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 leakage testing by visual inspection with pH indicator and water immersion test in accordance with Subclause 7.2.1. Perform

hydrogen leakage testing using a liquid leak detector (bubble-forming) in accordance with 7.2.2 for the fuel cartridge.

5) Disconnect the fuel cartridge. Perform leakage testing by visual inspection with pH indicator and water immersion test in accordance with 7.2.1. Perform hydrogen leakage testing using a liquid leak detector (bubble-forming) in accordance with 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. If, using normal force, the fuel cartridge cannot be connected, and no leakage, no fire, and no explosion occur, this is acceptable. Leakage shall be determined visually using pH indicator and with the water immersion test as specified in the leakage measurement and test procedure in 7.2.1. Hydrogen leakage shall meet the no hydrogen leakage requirements (no bubbles formed) of the hydrogen leakage measurement procedure of 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.

### 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 hydrogen 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 and no hydrogen 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage upon connection using visual inspection with pH indicator as in the leakage test and measurement procedure specified in 7.2.1. Leakage shall meet the criteria for no leakage found in 7.2.1.

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

3) Turn off the micro fuel cell power unit or stop simulated hydrogen 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in 7.2.2. Check for leakage using visual inspection with pH indicator as in specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage specified in the leakage test and measurement procedure specified in 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in 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 hydrogen leakage test and measurement procedure specified in Subclause 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen specified in the leakage test and measurement procedure in 7.2.2. Check leakage using visual inspection with pH indicator as described in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage as specified in the leakage test and measurement procedure in 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 hydrogen leakage test and measurement procedure in Subclause 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the leakage test and measurement procedure in 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

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

12) Turn off the micro fuel cell power unit or stop simulated hydrogen 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 hydrogen leakage test and measurement procedure in 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage as specified in the leakage test and measurement procedure in 7.2.2. Check for upon connection using visual inspection with pH indicator and water immersion test as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no leakage. 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 7.2.2 for the fuel cartridge. Leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in 7.2.1.

#### 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 hydrogen 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 no impermissible hydrogen gas loss and no hydrogen 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1. Initiate or simulate hydrogen 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

5) Connect and disconnect the first unused 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 hydrogen 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 7.2.2. Hydrogen leakage shall meet the criteria for no hydrogen leakage found in the hydrogen leakage measurement procedure of 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 7.3.12.

d) **Passing criteria:** No fire or flame at any time. No explosion at any time. No hydrogen leakage, no 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 7.2.2 for the fuel cartridge. Leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in Subclause 7.2.1. Hydrogen gas loss shall meet the requirements of 7.2.3. must meet passing criteria of 7.3.12 for operational and non-operating systems.

#### 7.3.11.2 Micro fuel cell power unit

a) **Test sample:** a minimum of two unused fuel cartridges which are named as the first unused fuel cartridge and a final unused fuel cartridge, respectively 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 hydrogen 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 unused fuel cartridge (#1) and final unused 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 hydrogen flow between the satellite cartridge and the micro fuel cell power unit.

c) **Test procedure:**

   1) Connect the first 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 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 7.2.2. Check for leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in Subclause 7.2.1.

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

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

   4) Disconnect the first unused 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 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 7.2.2. Check for leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

   7) Connect and disconnect the first unused 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

9) Connect and disconnect the first unused 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 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 7.2.2. Check for leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

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

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

14) Disconnect the first unused 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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) Operate the system or simulate system operation 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

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

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

19) Disconnect the final unused 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 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 7.2.2. Check leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.
22) Connect and disconnect the final unused 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.
24) Connect and disconnect the final unused 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 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 7.2.2. Check for leakage using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.
26) 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 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 7.2.2. Check for leakage upon connection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.
27) Operate the micro fuel cell power unit or otherwise simulate hydrogen flow for at least 1 min.
28) Turn off the micro fuel cell power unit or stop simulated hydrogen flow.
29) Disconnect the final unused 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 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 7.2.2. Check for leakage upon disconnection using visual inspection with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Leakage shall

meet the criteria for no leakage found in the leakage test and measurement procedure in 7.2.1.

30) For the micro fuel cell power system or micro fuel cell power unit, perform hydrogen gas loss measurement in accordance with 7.2.3 (this includes 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 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 7.2.2 for the fuel cartridge. Leakage shall be tested visually with pH indicator as specified in the leakage test and measurement procedure in 7.2.1. Hydrogen gas loss shall meet the requirements of 7.2.3. Emissions must meet passing criteria of 7.3.12 for operational and non-operating systems.

### 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 normal operating conditions, indirect water-reactive solid fuel 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 water-reactive solid fuel 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 water-reactive solid fuel 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 and are listed in Table 7.

The possibility for hydrogen emissions exists for non-operating indirect water-reactive solid fuel micro fuel cell 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.

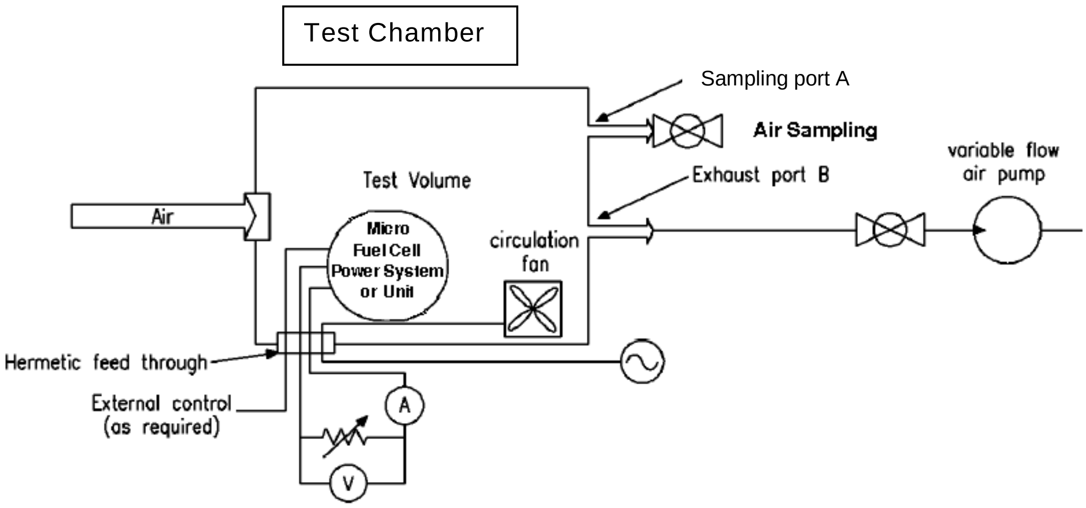


**Figure 10 – Operational emission rate testing apparatus**

c) **Test apparatus:** An example of the operational emission test 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 tested in accordance with this PAS 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 tested in accordance with this PAS.

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 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 7.3.12 d) 1) and 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.

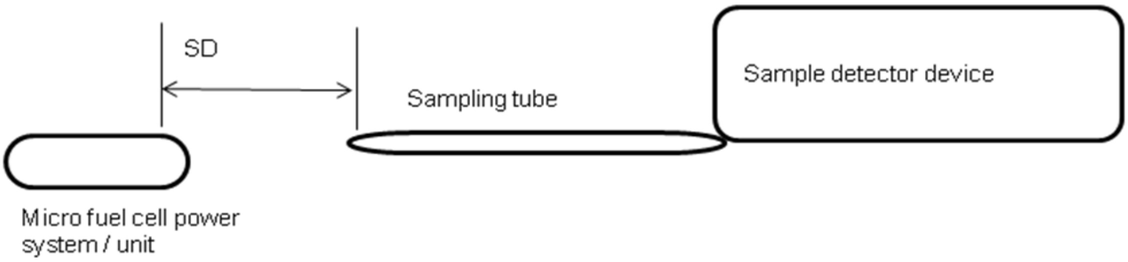


**Figure 11 – Operational emission concentration testing apparatus**

Emission gases might be composed of toxic organic materials such as 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 analyser 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.

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 12.

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 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 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 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 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;

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

$F_\mathrm{S}$ 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 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 in 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 with the micro fuel cell power system or unit on "DEVICE – ON" as follows.

i) Emission concentration 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 ("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 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 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 in 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 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 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 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 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:

$$ER = (F_P + F_S) \times C$$

where

$ER$ is the emission rate in grams per hour;

$F_P$ is the variable flow air pump flow rate in 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 7.

NOTE This is a stabilized 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 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 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 in 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 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 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 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 Subclause 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 7 shall be less than or equal to the emission rate limit value in Table 7 when tested in accordance with 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 7 shall be less than or equal to the emission rate limit value in Table 7 when tested in accordance with Subclause 7.3.12 d) 1) for "DEVICE – ON" and 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 7 when tested in accordance with 7.3.12 d) 2) "DEVICE – ON" and 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 12. Upon completion of the hydrogen emissions measurements with both "DEVICE – ON" and "DEVICE – OFF" in accordance with Table 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", 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 7 – Emission limits**

| **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]** | **Non-operating system 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<br>0,016 g/h from single point leak | 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[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 |

[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] 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

[e] A seated human adult has a $CO_2$ emission rate of 30 g/h. The micro fuel cell power system or unit 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 micro fuel cell power system or unit to 60 g/h.

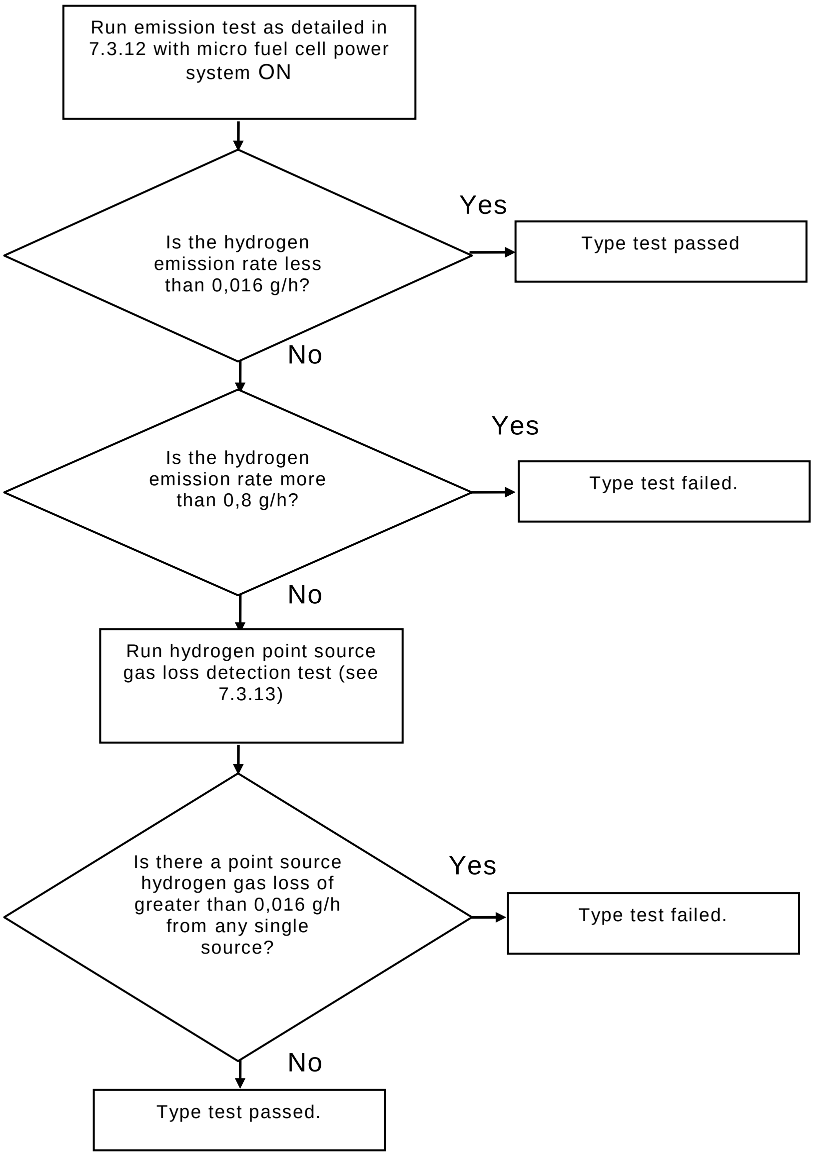


**Figure 12 – Hydrogen emission test procedure for operating micro fuel cell power system**

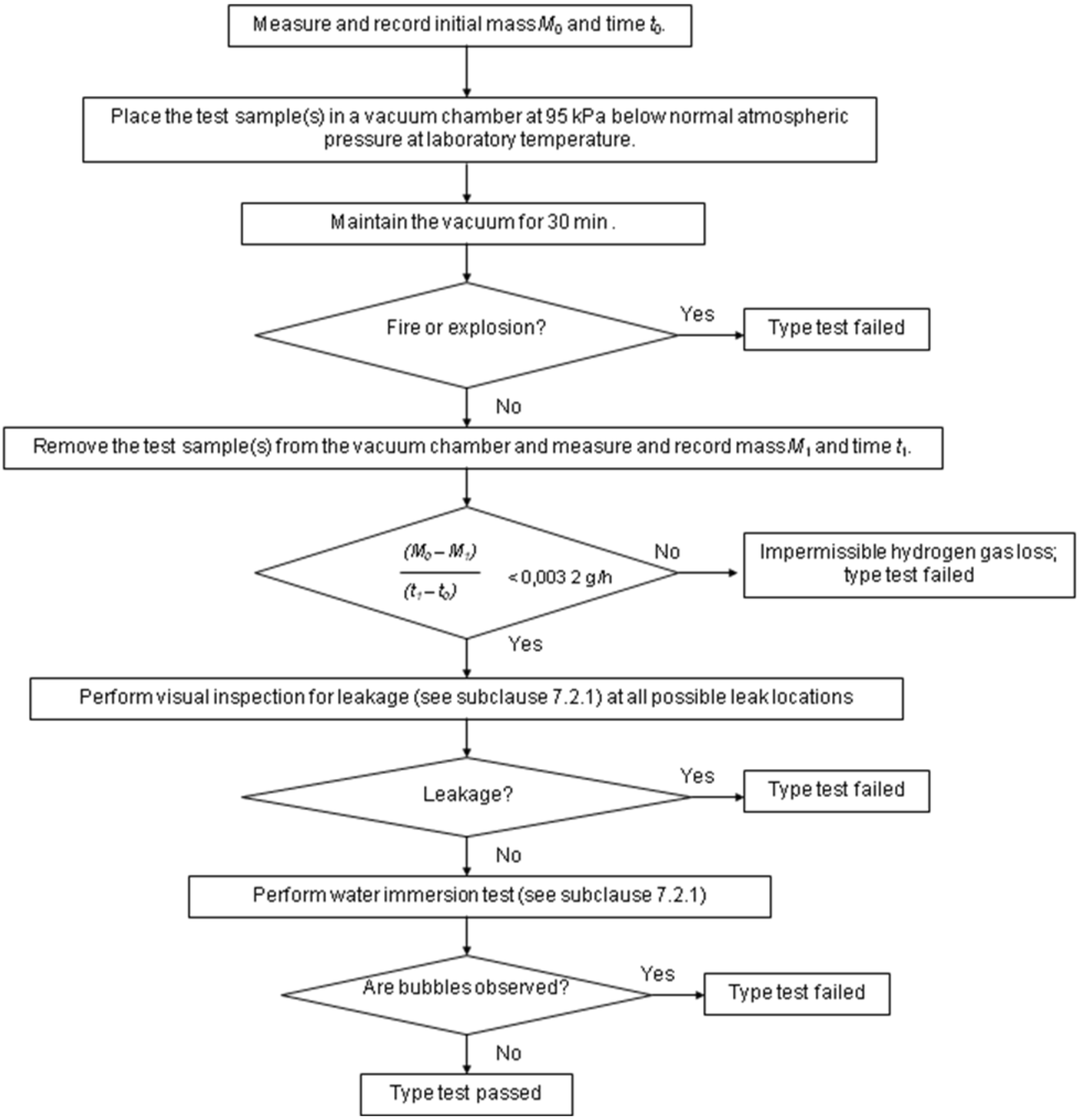


**Figure 13 – Fuel cartridge leakage test flow chart for low external pressure test**

### 7.3.13 Hydrogen point source gas loss detection test

The procedure for hydrogen emission testing is detailed in Figure 12. This subclause shall be used if required by 7.3.12 d) 5) iii) to show compliance with Table 7, for UN Division 4.3 (water reactive) solid fuel micro fuel cell power systems and UN Division 4.3 (water reactive) solid fuel micro fuel cell power units. This subclause is required to be performed to meet the passing criteria of 7.3.12 e) 3) ii) if the total hydrogen emission rate from an operational UN Division 4.3 (water reactive) solid fuel 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 that is fuelled with Division 4.3 (water reactive) solid fuel emission of hydrogen shall be maintained at less than the specified values in Table 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 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 standoff 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 standoff 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 7.

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