IEC TR 62971

Edition 1.0 2015-10

TECHNICAL REPORT

colour inside

Radiation instrumentation – Radiation sources used in illicit trafficking detection standards – Guidance and recommendations

IEC TR 62971:2015-10(en)

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INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

ICS 13.280

ISBN 978-2-8322-2958-3

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INTERNATIONAL ELECTROTECHNICAL COMMISSION

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RADIATION INSTRUMENTATION – RADIATION SOURCES USED IN ILLICIT TRAFFICKING DETECTION STANDARDS – GUIDANCE AND RECOMMENDATIONS

FOREWORD

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IEC TR 62971, which is a technical report, has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation.

The text of this technical report is based on the following documents:

Enquiry draft	Report on voting
45B/817/DTR	45B/821/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

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

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

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- withdrawn,
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RADIATION INSTRUMENTATION – RADIATION SOURCES USED IN ILLICIT TRAFFICKING DETECTION STANDARDS – GUIDANCE AND RECOMMENDATIONS

1 Scope

This Technical Report (TR) provides guidance and recommendations regarding the availability and use of radiation sources that are needed when testing and evaluating instruments used for the detection of illicit trafficking of radioactive material. The relevant standards are listed in 4.1. Guidance includes the use of surrogate or replacement radioactive materials that could be more easily obtained.

The object of this Technical Report is to provide guidance to instrument manufacturers, users, and testing organisations as to the selection and possible use of radiation sources, source surrogates and source simulation tools when testing and evaluating an instrument's ability to detect and identify illicit trafficking of radioactive material.

2 Normative references

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

IEC 60050-395, *International Electrotechnical Vocabulary – Part 395: Nuclear instrumentation: Physical phenomena, basic concepts, instruments, systems, equipment and detectors*

3 Terms and definitions, abbreviations and symbols

3.1 Terms and definitions

For the purposes of this document, the following terms and definitions, as well as those given in IEC 60050-395 apply.

3.1.1
nuclear material
plutonium, except that with isotopic concentration exceeding 80 % in plutonium-238; uranium-233; uranium enriched in the isotope 235 or 233; uranium containing the mixture of isotopes as occurring in nature other than in the form of ore or ore-residue; any material containing one or more of the foregoing

Note 1 to entry: Additional details regarding source composition can be found in 4.3.

[SOURCE: IAEA-TECDOC-1311-September 2002]

3.2 Abbreviations and symbols

DD Deuterium-Deuterium

DU Depleted Uranium

HEU Highly Enriched Uranium

IAEA International Atomic Energy Agency

NIST National Institute of Standards and Technology

NORM Naturally Occurring Radioactive Material

Np Neptunium

PMMA Poly methyl methacrylate

Pu Plutonium

RGPu Reactor Grade Plutonium

NM Nuclear Material

WGPu Weapons Grade Plutonium

4 Background

4.1 List of relevant standards

The following standards are currently relevant to this Technical Report. Each standard contains requirements for photon and neutron radiation emitting sources including those requirements for NM.

– IEC 62244, *Radiation protection instrumentation – Installed radiation monitors for the detection of radioactive and special nuclear materials at national borders*

– IEC 62327, *Radiation protection instrumentation – Hand-held instruments for the detection and identification of radionuclides and for the indication of ambient dose equivalent rate from photon radiation*

– IEC 62401, *Radiation protection instrumentation – Alarming personal radiation devices (PRD) for detection of illicit trafficking of radioactive material*

– IEC 62484, *Radiation protection instrumentation – Spectroscopy-based portal monitors used for the detection and identification of illicit trafficking of radioactive material*

– IEC 62533, *Radiation protection instrumentation – Highly sensitive hand-held instruments for photon detection of radioactive material*

– IEC 62534, *Radiation protection instrumentation – Highly sensitive hand-held instruments for neutron detection of radioactive material*

– IEC 62618, *Radiation protection instrumentation – Spectroscopy-based alarming Personal Radiation Devices (SPRD) for detection of illicit trafficking of radioactive material*

– IEC 62694, *Radiation protection instrumentation – Backpack-type radiation detector (BRD) for the detection of illicit trafficking of radioactive material*

4.2 Source suppliers

Several radioactive sources are required for testing to IEC standards. Many sources are commercially available for purchase. It is up to each individual organization to identify the manufacturer or supplier based on their specific needs.

4.3 Nuclear Material (NM) sources and materials of interest

At the time of publication, the materials of interest include:

– Depleted Uranium (DU),

– Highly Enriched Uranium (HEU),

– Reactor Grade Plutonium (RGPu), and

– Weapons Grade Plutonium (WGPu).

Due to the availability of DU for testing, it will not be addressed in this Technical Report.

For IEC efforts, HEU has an enrichment of greater than 90 % ^{235}U and DU of no more than 0,4 % ^{235}U. RGPu is defined as containing more than 12 % ^{240}Pu, and WGPu having no more than 6 % ^{240}Pu and not less than 12 % ^{239}Pu.

Standardized test sources containing NM are sealed sources that are characterized by mass, isotope content, geometric shape (e.g., spherical), and age. The characterization should include chemical elements, not just radionuclides.

^{237}Np, ^{232}U, ^{233}U have been discussed as a possible material of interest, but due to very limited availability they will not be addressed further in this Tehcnical Report.

4.4 Neutron sources

Based on the materials of interest to be detected, a fission spectrum source is required at an emission rate of 20 000 neutrons per second. Therefore, each applicable standard requires the use of a ^{252}Cf source having an activity of approximately 185 kBq.

Neutron sources with higher emission rates such as those used for dosimetry or dosemeter calibration (i.e., radiation protection instrument calibration) will produce more scattered neutrons because the source to detector distance must be increased to maintain the same fluence rate produced by the recommended source. Therefore, the use of a neutron source with much higher emission rates is not recommended for illicit trafficking detection instrumentation.

4.5 Surrogate materials and efforts

4.5.1 Materials

– **HEU**

  HEU sources are required to produce the radiation test field for spectrometric or identification type instruments. The amount of ^{235}U depends on the requirements in the standard and instrument being tested. Because the main photon energy of ^{235}U is 186 keV, most emissions come from the surface of the source to a depth of approximately 1 mm (based on the 95 % infinite thickness emission rate). As a result, the quantity of a surrogate source can be reduced and still have the same emission as a much larger mass. Surrogate HEU sources have been developed in the form of sealed stainless steel capsules containing porous graphite cylinders saturated with HEU oxide and in the form of thin wall hollow HEU spheres.

– **Uranium**

  Uranyl acetate may be used as a check source to verify uranium identification capabilities. The chemical compound can be purchased as a powder although there are many different options as to its composition. Uranyl acetate consists of ^{238}U and ^{235}U at 0,3 % to 0,4 % enrichment depending on the manufacturer. Uranyl acetate is a toxic material.

– **Plutonium radiation surrogate**

  A self-contained source of gamma-ray and neutron radiation suitable for use as a radiation source surrogate for WGPu has been developed (See Bibliography: US Patent 7,655,935 B1, Feb 2, 2010). The surrogate source, which does not contain NM, was designed to produce a radiation spectrum similar to that of WGPu over an energy range from 59 keV to 2 614 keV. This WGPu surrogate also emits neutrons having fluxes commensurate with gamma radiation intensities employed. The surrogate source consists of ^{133}Ba, ^{252}Cf, ^{137}Cs, ^{153}Gd, ^{57}Co, ^{155}Eu, ^{177m}Lu, ^{113}Sn, ^{228}Th, ^{95}Zr in an assembly. Further details are available in the referenced patent. This source is relevant for testing the identification capabilities of instruments with an energy resolution that is no better than 5 %.

– **Use of plated sources for handheld detection systems**

  Sources made from the plating of ^{239}Pu or ^{235}U to a substrate were investigated as possible surrogates for larger sources that are used to test the identification function of handheld devices. The investigation determined that the amount of material required may not be feasible for plated sources.

– **Neutron source**

The currently accepted emission intensity for ^{252}Cf is 20 000 neutrons per second is used by the relevant standards.

Due to the short half-life of ^{252}Cf (2,65 y), there has been much discussion in the standards community regarding the use of ^{241}Am-Be as a replacement. The use of bare ^{241}Am-Be when testing illicit trafficking radiation detection systems that were built with moderation included is not appropriate since the monitors were designed specifically for detection of fission spectrum sources. Additional moderation would be required to ensure that the neutrons impinging on the detector are similar to that from a fission spectra point source.

Figure 1 shows an ^{241}Am-Be spectrum plotted in Lethargy format normalized to one source neutron. The spectrum is taken from ISO 8529-1:2001. For Lethargy plots, when the energy axis is logarithmic and the ordinate axis is linear (as shown in Figure1), the area between any two energies is directly proportional to the number of neutrons emitted by the source between those energies.

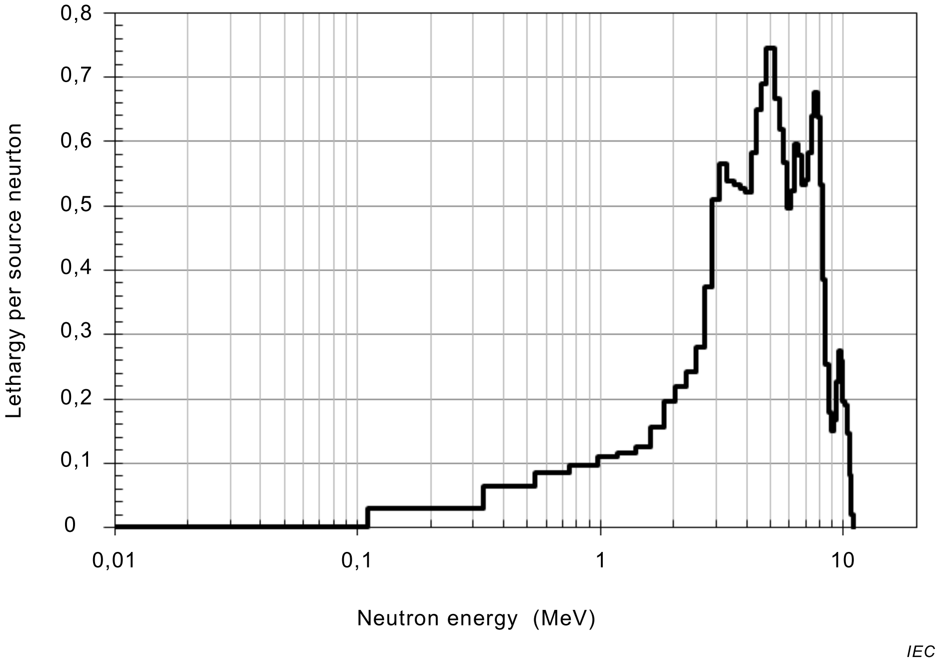

Figure 1 – ^{241}Am-Be energy distribution

It is not currently possible to manufacture neutron sources from ^{241}Am-Be that provide an acceptable fission neutron spectrum. Further investigation is needed to determine if it is possible to manufacture sources for the purpose of providing an alternative for ^{252}Cf.

Another possible source of fission spectrum neutrons is ^{244}Cm. This radionuclide has an 18 year half-life which is much longer than that of ^{252}Cf. Manufacturing safety and availability of ^{244}Cm makes this a less effective neutron source.

Another possible surrogate is through the use of a deuterium-deuterium (DD) generator that produces 2,5 MeV neutrons, which might be shaped by various shields to give a suitable spectrum. This would be expensive, and there would need to be a way to verify reproducibility in output. It is therefore not recommended as a surrogate neutron source.

^{241}Americium-Boron is also being investigated as a possible surrogate for ^{252}Cf due to the similar neutron spectra.

4.5.2 Efforts

– **Semi-empirical method for performance evaluation of detection and radionuclide identification**

A semi-empirical (derived from experiment and observation rather than theory) performance appraisal method to analyze the performance of radionuclide identification software has been developed. This spectral injection technique is based on the analysis of randomized raw instrument measured spectra. The raw spectra are obtained from the high quality spectral measurement of actual sources. The process creates synthetic spectra for injection into the instrument–specific analysis software. The method also allows the use of synthetic spectra if raw spectra are not available.

This method provides a means to evaluate analysis software performance and to complement testing with actual sources. This method does not include the detector and associated electronics. Future IEC 62957-1, *Radiation instrumentation – Semi-empirical method for performance evaluation of detection and radionuclide identification – Part 1: Performance evaluation of instruments featuring radionuclide identification in static mode,* is being developed for this technique.

– **Neutron field measurement**

Typically, a neutron source is moderated by the surrounding material as well as the surface below the source or detector. These moderating materials include air, the container holding the source (e.g., vehicle, shipping container), and road or ground surface and moisture level within those surfaces. Measurements and model/calculations have shown that surrounding a ^{252}Cf source with high density polyethylene having a thickness of 3 cm to 4 cm is most representative of the operational environment.

4.5.3 Simulated gamma spectra versus real spectra

Simulated spectra are sometimes used to verify the functionality of instruments used to identify radionuclides. Some of the advantages of using simulated spectra include reduced time and budget required to make predictions of instrument response under different test conditions. An example of the use of simulated spectra could be the characterization of an instrument's response to sources that are shielded or masked by different types of materials. An actual experiment may be unaffordable due to the large possible number of combinations and test cases.

The disadvantage of simulations is that it is difficult to produce spectra as obtained in an actual measurement. Simulations require the knowledge of many parameters, such as detector dimensions, detector efficiency, source encapsulation, source activity, materials surrounding the detector and source that might be unknown to the user. Therefore, software validation is required to understand the limitations of the simulation.

4.5.4 Use of Naturally Occurring Radioactive Material (NORM)

In several IEC standards, NORM is used to verify the identification response of spectrometric instruments. The use of bulk or large quantities of NORM for standardized, routine testing is difficult due to non-reproducible isotopic composition between different NORMs and handling of bulk material during testing. To address this, a surrogate NORM was developed that makes use of ^{226}Ra and ^{232}Th (or ^{232}U) point sources surrounded by approximately 9 cm of polymethyl methacrylate (PMMA). The PMMA increases the Compton contribution and reduces the x-rays and low energy gamma-rays in the energy spectrum making it appear as bulk material (See Bibliography: Measurements for the Development of a Simulated Naturally Occurring Radioactive Material, *Journal of Research of the National Institute of Standards and Technolog*y, Volume 117 (2012)). The described configuration does not include ^{40}K nor does it create a reduction in the measured radiation field that may be caused by bulk material. The need to include ^{40}K should be determined prior to using the surrogate NORM material for testing.

Another possible surrogate NORM source is known as the "KUTH field verifier". This product was developed for the oil well logging industry as an aid in the calibration of down-hole gamma-ray spectroscopy tools. The device consists of ^{40}K, natural U, and ^{232}Th. Both the natural U and ^{232}Th are in secular equilibrium. No additional information is available.

5 General requirements

5.1 NM

Table 1 contains a list of the NM sources currently used in IEC standards. Source strengths are typically given as a mass quantity for a given shape and material type (metal or oxide). The surface areas shown for HEU and DU are based on the center cross-section of a sphere for the stated mass.

NOTE In IEC 62327, the source strength for testing is based on an ambient dose equivalent rate of 0,5 μSv h^{-1} (± 30 %).

Table 1 – IEC NM

Sources	Quantity (± 20 %)
DU	4,5 kg (46 cm^2)
HEU	237 g (6,5 cm^2)
RGPu	1,4 g
WGPu	15 g
^{252}Cf	2×10^4 neutrons s^{-1}

For Pu (RGPu and WGPu), the amount of ^{241}Am (ingrowth from the decay of ^{241}Pu) varies widely for different Pu sources. There is a need to limit the amount of low energy gamma-ray emissions from ^{241}Am to ensure that test results are comparable when tests are performed using different Pu sources. In order to provide comparable results, the net count rate of the 60 keV line from the ^{241}Am is reduced to be no more than 10 times greater than that of the net count rate from the 414 keV line for ^{239}Pu. For example, if the count rate from the 414 keV line is 100 counts per second then the count rate from the 60 keV line is less than or equal to 1 000 counts per second. This ratio is based on spectral measurements made of various Pu sources. Copper with more than 99 % purity or Cadmium may be used as shielding material to reduce the 60 keV emissions. Any dose rate measurements should be made after the Pu source is surrounded by the material used to shield ^{241}Am.

Current applicable IEC standards require the use of RGPu and WGPu to verify an instrument's ability to identify radionuclides. Figure 2 shows a comparison between RGPu and WGPu spectra obtained using a sodium-iodide-based (NaI(Tl)) spectrometric instrument. There are differences between the spectra which may allow an instrument to identify the plutonium enrichment, but this level of identification is not required in the relevant standards. It is therefore suggested that only one Pu material be required for testing purposes. Current availability indicates that WGPu be the required NM.

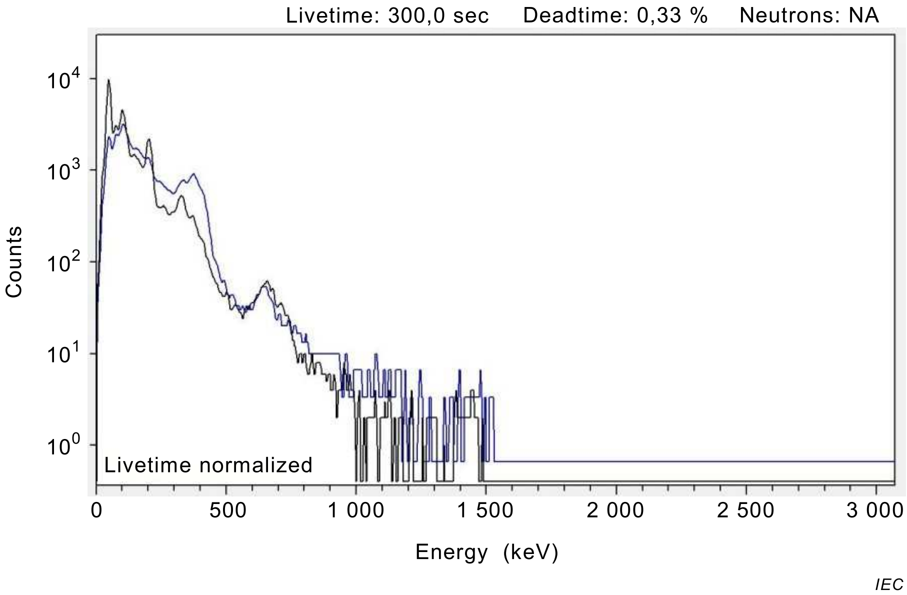

Figure 2 – Low resolution RGPu (blue trace) and WGPu spectra comparison

5.2 Metals or oxides

Test results have indicated that the difference between spectra from a metal and those from an oxide is such that it would not prevent a typical spectrometric instrument from identifying the material. Oxides are typically easier to obtain but may be more difficult to identify due to the presence of lower energy photons from scattering within the material.

5.3 Spheres or plates

NMs have a high density. Most emissions come from the surface of the source to a depth dependent on the photon energy. For example, the depth for 185 keV is approximately 1 mm (based on the 95 % infinite thickness emission rate), 5,6 mm for 400 keV, and 20,8 mm for 1 MeV. As a result, plates may be used instead of solid spheres. For plates, the quantity of NM can be reduced and still have the same emission rate as the solid sphere of much greater mass.

5.4 Source encapsulation

Sealed sources are ideal for these types of applications. Several sources were designed specifically for testing against standards using stainless steel encapsulations (See Bibliography: NIST Technical Note, *Gamma-ray emitting test sources for portal monitors used for homeland security*).

Due to the short half-life of medical sources, stainless steel encapsulation may not be practical. The use of epoxies to make a solid source for handling purposes is recommended.

The physical design of the encapsulation should take into consideration mechanical requirements, safety, and physical leakage. Several sources used in IEC standards require specific construction due to their use and potential for damage.

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