INTERNATIONAL STANDARDS FOR THE PERFORMANCE OF RADIATION DETECTION INSTRUMENTS USED IN THE GLOBAL NUCLEAR SECURITY FRAMEWORK

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Abstract

The physical protection of nuclear material is fundamental to nuclear security. Interdicting the illegal movement and transfer of nuclear material is part of the nuclear material physical protection. The instruments for monitoring the illegal movement of nuclear and radioactive material need to have performance characteristics and reliability that will assure that they will do the task of preventing the illegal movement and contraband of nuclear material. The minimum performance requirements that each type of radiation detection instrument must meet are specified in a set of standards. This paper discusses nine IEC (International Electrotechnical Commission) standards that provide the performance requirements for radiation instrumentation used for detection of illicit trafficking of radioactive and nuclear material developed by IEC Sub-committee 45B "Radiation Protection Instrumentation" working group 15. These standards cover the following types of instruments: body-worn (IEC 62401 Ed.2:2017 PRD, IEC 62618 Ed.2: in progress SPRD and IEC 62694 Ed.2: in progress BRD), portable or hand-held (IEC 62327 Ed.2:2017 RID, IEC 62533:2010 GSD and IEC 62534:2010 NSD), portal: IEC 62244 Ed.2:2019 RPM and IEC 62484 Ed.2: in progress SPRM) and vehicle-mounted (IEC 63121: in progress). A standard concerning the format for the data to be output from such instruments, IEC 62755:2012, has been also developed by this working group. The objective of these international standards is to describe the performance requirements and functional criteria along with testing methods for evaluating the performance of the applicable instrumentation. The standards specify the general characteristics, the test procedures, the radiation detection requirements, as well as climatic, mechanical, electromagnetic and electric performance requirements. The main requirements such as gamma/neutron alarms, false alarms, relative intrinsic error, ambient dose equivalent rate, radionuclide identification, over-range, etc. for the different types of instruments are compared. The performance criteria and compliance test methods in these standards are the result of an optimization and consensus among the participating experts from many countries and reflect the positions of the national regulatory agencies, the scientific and technological progress of the industry, the testing laboratories capabilities, end user needs, cost of testing and the field use. These standards provide manufacturers with internationally acceptable requirements and provide consistent test methods for compliance with the stated performance requirements. The connection of these IEC standards with similar ANSI and European (EN) standards is also discussed.

1. INTRODUCTION

1.1. IEC

The International Electrotechnical Commission (IEC) is the world's leading organization that prepares and publishes globally relevant international standards for all electric and electronic devices and systems. It brings together 170 countries (84 Member and 86 Affiliates countries), representing 98% of the world population and 96% of world energy generation. Close to 20 000 experts cooperate on the global IEC platform.

The IEC standards serve as basis for national standardization, as references when drafting international tenders and contracts, and for conformity evaluation of instrumentation. IEC standards are considered by CENELEC (European Committee for Electrotechnical Standardization) for adoption as European standards.

1.2. Subcommittee 45B “Radiation protection instrumentation”

IEC subcommittee 45B "Radiation protection instrumentation" is one of the 207 IEC Technical Committees (TC) and SubCommittees (SC) and prepares standards addressing instrumentation used for:

— the measurement of ionizing radiation in the workplace, to the public, and in the environment for radiation protection purposes;
— illicit trafficking detection of radioactive material and identification of radionuclides;
— and radiation-based security screening.

SC 45B has 20 participating countries, 15 observer countries, 7 working groups (WG) and close to 150 experts from the world leading testing laboratories, governmental agencies, manufacturers and users. The SC has published more than 55 international standards and technical reports since its creation in 1965.

SC 45B has liaisons with ISO/TC85 “Nuclear energy, nuclear technologies, and radiological protection”, IAEA, ICRP, ICRU and other international organizations.

1.3. Working Group 15 and control instrumentation for illicit trafficking of radioactive material

WG 15 of SC 45B develops international standards for illicit trafficking control instrumentation using spectrometry, personal electronic dosimeter and portable dose rate instrumentation. Since its creation in 2002, the WG had 21 meetings and published 10 international standards.

Illicit and inadvertent movement of radioactive materials in the form of radiation sources and contaminated metallurgical scrap has become a problem of increasing importance. Radioactive sources out of regulatory control, so-called “orphan sources”, have frequently caused serious radiation exposures and widespread contamination. Although illicit trafficking in nuclear and other radioactive materials is not a new phenomenon, the concern about a nuclear “black market” has increased in recent years particularly in view of its terrorist potential.

The physical protection of nuclear material is fundamental to nuclear security. Interdicting the illegal movement and transfer of nuclear material is part of the nuclear material physical protection. The instruments for monitoring the illegal movement of nuclear and radioactive material need to have performance characteristics and reliability that will assure that they will intercept the illegal movement and contraband of nuclear material.

In response to the technical policy of the International Atomic Energy Agency (IAEA), the World Customs Organization (WCO) and the International Criminal Police Organization (Interpol) related to the detection and identification of special nuclear materials and security trends, nuclear instrumentation companies are developing and manufacturing radiation instrumentation to assist in the detection of illicit movement of radioactive and special nuclear materials. This type of instrumentation is widely used for security purposes at nuclear facilities, border control checkpoints and international seaports and airports. However, to ensure that instruments performances are reliable and consistent at different locations it is imperative that radiation instrumentation be designed to rigorous specifications based upon agreed performance requirements stated in the international standards.

Previous publications concerning the standardization work of IEC/SC 45B/WG 15 are available in [1] and [2].

2. THE DEVELOPED STANDARDS ON INSTRUMENTATION USED FOR DETECTION OF ILLICIT TRAFFICKING OF RADIOACTIVE MATERIAL

The standards developed by IEC/SC 45B/WG 15 cover the following types of instruments:

— Body-worn:
  - IEC 62401 Ed. 2 (2017) Alarming Personal Radiation Devices (PRD) [3];
  - IEC 62618 Ed. 2 (in progress) Spectroscopy-Based Alarming Personal Radiation Devices (SPRD) [4];
  - IEC 62694 Ed. 2 (in progress) Backpack Based Radiation Detector (BRD) [5];
— Portable or hand-held:
  - IEC 62327 Ed. 2 (2017) Hand-held Radionuclide Identification Devices (RID) [6];

- IEC 62533 (2010) Hand-held highly sensitive Photon Devices (GSD) [7];
- IEC 62534 (2010) Hand-held highly sensitive Neutron Devices (NSD) [8];

— Portal:
- IEC 62244 Ed. 2 (2019) Portal Monitors (RPM) [9];
- IEC 62484 Ed. 2 (in progress) Spectroscopy-Based Portal Monitors (SPRM) [10];

— Vehicle-mounted:
- IEC 63121 (in progress) Vehicle-mounted mobile systems (VMS) [11].

A standard concerning the format for the radiation data to be output for transferring data from such instruments, IEC 62755 (2012) [12], has been also developed by this working group. The standard is written in XML language that. The transferred data in IEC 62755 format is human readable, does not depend on the type of the detection instrument used and does not require any proprietary software. This is of mayor importance in the case of emergency response to a nuclear event. In addition, it allows for these types of instruments to be included in an instrument network that can be composed of diverse types of detection systems (e.g., radiation, chemical, biological, weather).

The first editions of these standards were prepared progressively from 2003 to 2014. Then, revisions have been undertaken in order to harmonize them and to take into account feedback from different testing programs and international projects. Such projects include ITRAP (Illicit Trafficking Radiation Assessment Program), ITRAP+10 and ITRAP+10 phase 2. The ITRAP project was conducted by the IAEA. The ITRAP+10 was initially proposed by the IAEA and later conducted by the European Commission (EC) Joint Research Center (JRC), the United States (US) Department of Homeland Security (DHS) Domestic Nuclear Detection Office (DNDO) and the US Department of Energy.

3. SCOPE OF THE STANDARDS

The scopes of the different standards covering the instrumentation used for the detection of illicit trafficking of radioactive material are shown in the following sections.

3.1. Body-worn

3.1.1. IEC 62401 Ed. 2 PRD

This international standard applies to alarming radiation detection instruments that are pocket-sized, carried on the body and used to detect and indicate the presence and general magnitude of gamma radiation fields. Neutron detection may also be provided.

Personal Radiation Devices (PRDs) alert the user of the presence of a source of radiation that is distinctly above the measured average local background radiation level..

The object of this standard is to describe design and functional criteria along with testing methods for evaluating the performance of the PRDs used for detection of illicit trafficking of radioactive material (e. g., for border radiation monitoring).

This standard does not apply to the ambient or personal dose equivalent rate meters which are covered in IEC 60846-1 [13] or IEC 61526 [14], respectively. If the manufacturer states that the PRD can be used for radiation protection purposes, compliance with IEC 60846-1 or IEC 61526 will be needed.

The 1st edition of the standard was published in 2007 and the 2nd edition was issued in December 2017.

3.1.2. IEC 62618 Ed. 1 SPRD

This international standard applies to Spectroscopy-based (alarming) Personal Radiation Detectors (SPRD) which represent a new instrument category between alarming Personal Radiation Devices (PRD) and Radionuclide Identification Devices (RID). SPRDs are advanced PRDs that can be worn on a belt or in a pocket to alert the wearer of the presence of a radiation source. They are not intended for accurate measurement of personal or ambient dose equivalent (rate). In addition to the features of conventional PRDs, SPRDs provide rapid simultaneous search and identification capability to locate and identify radiation sources. They can discriminate between Naturally Occurring Radioactive Materials (NORM), medical radionuclides, industrial

radioactive sources or Special Nuclear Material (SNM). Because of their limited sensitivity, SPRDs cannot replace RIDs. For first responders, SPRDs are particularly useful due to their small size and weight and radionuclide identification capability.

This standard does not apply to the performance of radiation protection instrumentation which is covered in IEC 61526 [14] and IEC 62401 [3].

The object of this standard is to establish performance requirements, provide examples of acceptable test methods and to specify general characteristics, general test conditions, radiological, environmental, mechanical and electromagnetic characteristics that are used to determine if an instrument meets the requirements of this standard. The results of tests performed provide information to end-users and manufacturers on instrument capability for reliable detection, localization and identification of radiation sources.

Obtaining operating performance that meets or exceeds the specifications as stated in this standard depends upon properly establishing appropriate operating parameters, maintaining calibration, implementing a suitable maintenance program, auditing compliance with quality control requirements and providing proper training for operating personnel.

The first edition of the standard was published in 2013 and a revision has just been started.

3.1.3. IEC 62694 Ed. 1 BRD

This international standard applies to backpack-type radiation detectors (BRDs) that are used for the detection of illicit trafficking of radioactive material. This standard establishes the operational and performance requirements for BRDs. BRDs are portable instruments designed to be worn usually on the back of the user. They may also be used as temporary area monitors in a stand-alone mode.

BRDs detect gamma radiation and may include neutron detection and/or the identification of gamma-ray emitting radionuclides. This standard establishes performance and testing requirements associated with radiation measurements and the expected electrical, mechanical, and environmental conditions while in use.

The standard was published in 2014 and a revision has just been started.

3.2. Portable or hand-held

3.2.1. IEC 62327 Ed. 2 RID

This international standard applies to hand-held instruments used to detect and identify radionuclides and radioactive material, to estimate ambient dose equivalent rate from photon radiation, and optionally, to detect neutron radiation. They are commonly known as radionuclide identification devices or RIDs.

This standard specifies general characteristics, general test procedures, radiation characteristics, as well as electrical, mechanical, safety, and environmental characteristics.

This standard does not cover laboratory type, high-resolution photon spectrometers, or instruments covered by IEC 60846-1 (Portable workplace and environmental meters and monitors) [13], IEC 60846-2 (photon dose (rate) meters) [15] or IEC 61005 (neutron dose equivalent (rate) meters) [16].

The 1st edition of the standard was published in 2006 and the 2nd edition was issued in December 2017.

3.2.2. IEC 62533 Ed. 1 GSD

This international standard applies to hand-held highly sensitive instruments used for the detection and localization of radioactive photon emitting materials. These instruments are designed to detect very small variations above the usual photon background caused mainly by illicit trafficking or inadvertent movement of radioactive material. Compared to pocket devices (see IEC 62401 [3]), these highly sensitive instruments allow the scanning of larger volume items such as vehicles or containers. They may also be used in fixed or temporarily fixed unattended mode to monitor check points or critical areas.

These instruments also provide an indication of the ambient dose equivalent rate from photon radiation. However, this standard does not apply to the performance of radiation protection instrumentation which is covered in IEC 60846 [13] and IEC 61526 [14].

These instruments may provide additional functions as described below without including all features of specialized portable identification devices as defined by IEC 62327 [6]:

— rejecting natural background variation encountered when used in movement;
— sorting alarms of interest from naturally occurring radioactive material (NORM) or medical radionuclides originated alarms;
— provide source categorization data (including limited photon spectra) to a remote location.

The standard was published in 2010.

3.2.3. IEC 62534 Ed. 1 NSD

This international standard applies to hand-held highly sensitive instruments used for the detection and localization of neutron emitting radioactive material. These instruments are designed to detect very small variations in the background that may be caused by illicit trafficking or inadvertent movement of radioactive material. The instrument's high sensitivity allows scanning of larger volume items such as vehicles and containers. These instruments may also be used in fixed or temporally fixed unattended mode to monitor check points or critical areas. Instruments addressed by this standard also provide means to detect photon radiation for personal protection.

This standard does not apply to the performance of radiation protection instrumentation which is covered in IEC 61005 [16] and IEC 61526 [14].

The standard was published in 2010.

3.3. Portal

3.3.1. IEC 62244 Ed. 2 RPM

This international standard defines the performance requirements for installed monitors used for the detection of gamma and neutron radiation emitters. These monitors are commonly known as radiation portal monitors or RPMs. They are used to monitor vehicles, cargo containers, people, or packages and are typically located at national and international border crossings. They may be used at any location where there is a need for this type of monitoring.

IEC 62244 establishes the general, radiological, climatic, mechanical, electric and electromagnetic and documentation requirements and associated test methods.

This standard does not apply to the performance of spectroscopy-based portal monitors covered in IEC 62484 [10].

The 1st edition of the standard was published in 2006 and the publication of the 2nd edition took place in 2019.

3.3.2. IEC 62484 Ed. 2 SRPM

This international standard defines the performance requirements for installed monitors used for the detection and identification of gamma emitters and the detection of neutron radiation emitters. These monitors are commonly known as spectrometric radiation portal monitors or SRPMs. SRPMs are advanced RPMs that in addition to their gamma detection and identification capability they can discriminate between Naturally Occurring Radioactive Materials (NORM), medical radionuclides, industrial radioactive sources or Special Nuclear Material (SNM). They are used to monitor vehicles, cargo containers, people, or packages and are typically used at national and international border crossings and ports of entry. SRPMs may be used at any location where there is a need for this type of monitoring.

This standard establishes the general, radiological, climatic, mechanical, electric and electromagnetic and documentation requirements and associated test methods.

IEC 62484 does not apply to the performance of non-spectroscopic portal monitors covered in IEC 62244 [9].

The 1st edition of the standard was published in 2010 and the publication of the 2nd edition is expected in 2020.

3.4. Vehicle-mounted

3.4.1. IEC 63121 Ed. 1

This international standard applies to vehicle-mounted mobile systems (VMS, also known as mobile systems or mobile monitors) that are used for the detection of illicit trafficking of radioactive materials. These systems may also be used for protection of major public events and for rapid screening of large areas. These mobile monitors consist of one or more radiation detectors mounted in a vehicle, e.g., car or van, which travels predominantly on public roads. This standard does not apply to detection systems mounted in other types of vehicles, e.g., airplanes, helicopters, drones, trains, or boats. Vehicle-mounted detection systems covered by this standard are designed to detect radioactive sources while the vehicle is in motion. They may also be used as stationary monitors that scan stationary or moving objects. Vehicle-mounted mobile systems detect gamma radiation and may include neutron detection and/or identification of gamma-ray emitting radionuclides.

The purpose of this standard is to set minimum requirements for vehicle-mounted mobile systems for the detection of radioactive material. This document establishes general, radiological, climatic, mechanical, electric and electromagnetic, and documentation requirements, and the associated test methods and compliance criteria.

The publication of the standard is expected in early 2020.

3.5. Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials

3.5.2. IEC 62755 Ed. 1

The purpose of this standard is to provide a uniform format for data to be output from radiation measurement instruments used in the detection and identification of illicit trafficking of radioactive materials. The uniform data format enables interpretation of the data without a reference to manufacturer's documentation. The data format is specified in XML language that is human readable and independent of the instrument type and model.

This standard specifies the data format that shall be used for both required and optional data available at the output of radiation measurement instruments that are used for detection of illicit trafficking of radioactive materials. The performance requirements for these types of radiation measurement instruments are described in other standards such as IEC 62401 [3], IEC 62533 [7], IEC 62694 [5], IEC 62244 [9], IEC 62327 [6], IEC 62484 [10] and IEC 62618 [4].

The output consists of measurement data and results of any analysis performed by the radiation measurement instrument.

This standard does not address the instrument control, the data transmission protocols, or the physical media used for the communication of the data.

To ensure the largest interoperability of the radiation instruments and worldwide operations, the technical content (e.g., data elements and attributes, document structure) of this standard matches the ANSI/IEEE N42.42 standard [17].

The standard was published in 2012.

4. PERFORMANCE REQUIREMENTS

4.1. Basic radiation detection requirements (except identification)

The basic radiation detection requirements of the different standards are summarized in Table 1. In most of the cases, there are also other radiation detection requirements as:

- detection of gradually increasing radiation: e.g., the correct detection is tested with slowly moving ^{137}Cs source at the speed of $0.1\ m \cdot s^{-1}$;
- neutron detection alarm (if applicable): e.g., the test is performed with a moderated ^{252}Cf or ^{244}Cm source with an emission rate of $2 \times 10^4\ s^{-1}$ at a distance of 25 cm from the instrument;
- personal protection alarm;

— neutron indication test in the presence of photons.

The standards concerning the portal monitors (RPM and SPRM) have specific requirements for the following types of monitors: pedestrian, road vehicles, rail vehicles (includes rail transported containers) and conveyor.

The progressive revisions of the 9 standards undertaken since 2014 are considering the feedback from the different testing programs which allows making them more consistent across the requirements and methods of test. For example, concerning the PRDs, the gamma alarm is no longer tested statically but using moving sources which is closer to the real operation of the instrument. The 2 levels of background (high and low) needed for the different tests were removed and only one background level (laboratory) remained. Additional details and statistical requirements were included for many tests to clarify and increase their precision. This in turn increases the reproducibility of the test results among different testing laboratories.

TABLE 1. SUMMARY OF SOME OF THE BASIC RADIATION DETECTION REQUIREMENTS

	Max rate of false alarm	Gamma or neutron alarm	Gamma dose rate indication error	Gamma dose rate over-range	Additional tests
PRD	1 alarm in 1 h	≤ 2 s at increase of 0.5 μSv·h^{-1} above background (1)	≤ ±50 % (2)	At 2 times max range	
SPRD	3 alarms in 8 h	≤ 3 s at increase of 0,5 μSv·h^{-1} above background (2)	≤ ±50 % (2)	At 2-10 times max range or 1 mSv·h^{-1}	
BRD	1 alarm in 1 h	≤ 2 s with gamma fluence rate of 4 s^{-1}·cm (1)(3)	≤ ±30 % (2)	At 1.5 times max range	Angular dependence
RID	-	≤ 1 s at increase of 0.5 μSv·h^{-1} above background (4)	≤ ±30 % (2)	At 1.5 times max range	Gamma source localization
GSD	1 alarm in 1 h	≤ 3 s at increase of 0,05 μSv·h^{-1} above background (2)	≤ ±30 % (2)	At 10 times max range or 1 mSv·h^{-1}	
NSD	1 alarm in 1 h	≤ 2 s at exposure from ^{252}Cf to 0.1 n·s^{-1}.cm^{-2}	-	At 10 times max range	
RPM	2 alarms in 10 h	At radiation level greater than a threshold (1)	-	At 1.5 times max range	Warning when backgr. change
SRPM	1 alarm in 10 h	Alarm at radionuclide identification	-	At 1.5 times max range	Warning when backgr. change
VMS	1 alarm in 2 h	At radiation level greater than a threshold (1)	-	At 1.5 times max range	Background effects

(1) Tests with moving sources of ^{241}Am, ^{137}Cs and ^{60}Co, source speed 1.2 m·s^{-1}

(2) Tests with static sources of ^{241}Am, ^{137}Cs and ^{60}Co

(3) Tests at angles between 0° to 90° and 270° to 360°

(4) Tests with moving sources of ^{241}Am, ^{137}Cs and ^{60}Co, source speed 0.5 m·s^{-1}

4.2. Radionuclide identification

Instruments like RID, SPRD, SPRM and VMS shall be able to identify radionuclides and radioactive material. For example, according to IEC 62327 Ed. 2, a RID shall be able to identify the following sources: ^{241}Am, ^{133}Ba, ^{60}Co, ^{137}Cs, ^{67}Ga, ^{131}I, ^{99m}Tc, ^{40}K (KCl or KOH), ^{201}Tl, ^{226}Ra, ^{232}Th, ^{238}U (DU - depleted uranium), ^{235}U (HEU - highly enriched uranium) and ^{239}Pu (WGPu - weapons grade plutonium). This shall be done at an ambient dose equivalent rate of 0.5 μSv·h^{-1} above background measured at the gamma reference point of the RID within an integration time of 1 minute or that stated by the manufacturer, whichever is shorter. There are also requirements for the identification of mixed radioactive materials as ^{131}I + WGPu, NORM (naturally occurring radioactive material) or surrogate, NORM + HEU and NORM + WGPu.

4.3. Climatic, mechanical, electromagnetic and electric requirements

In addition to the radiation detection requirements, all standards have various climatic, mechanical, electromagnetic and electric requirements. The radiation detection instruments discussed in this paper are used in many different environments. They are typically exposed to different temperatures, humidity levels, electromagnetic fields and mechanical stresses such as shock and vibration during normal use. The instrumentation may be worn on the body, handheld, mounted to a vehicle, transported from location to location or installed. To ensure consistency between all SC 45B standards (not only of WG 15), a special standard IEC 62706 Ed. 2 "Radiation protection instrumentation – Recommended climatic, electromagnetic and mechanical performance requirements and methods of tests" [18] was developed that categorizes the different types of instrument (body-worn, handheld, installed, mobile, transportable etc.) and recommends methods of test for the climatic, mechanical and electromagnetic requirements. During the revision of the WG 15 standards, these requirements are taken into account and the standards are being progressively harmonized.

In most of the standards the following tests and requirements are present:

- climatic: ambient temperature, temperature shock, low/high temperature start-up, relative humidity and moisture and dust protection;
- mechanical: drop, vibrations, microphonics/impact and mechanical shock;
- electromagnetic: electrostatic discharge, radio frequency (RF) immunity, radiated emissions, magnetic fields and AC line powered equipment requirements;
- electrical: battery lifetime and power requirements;
- documentation.

5. CONCLUSION

The criteria and compliance test methods in the standards discussed in this paper are the result of an optimization, compromise and consensus among the participating experts from many countries searching for acceptable detection performance that reflects the positions of the national regulatory agencies, scientific and technological progress of the industry, testing laboratories capabilities, end user needs, testing cost and the way the instruments are used in the field.

The object of these international standards is to describe the performance requirements and functional criteria along with testing methods for evaluating the performance of the applicable instrumentation. The standards specify general characteristics, general test procedures, radiation characteristics, as well as climatic, mechanical, electromagnetic and electric characteristics.

These standards provide manufacturers with internationally acceptable requirements and provide consistent test methods for compliance with the stated performance requirements.

The IEC/SC 45B standards for evaluation of the illicit trafficking of radioactive material control instrumentation are used in many countries. They have been transposed by the CENELEC/TC 45B as European EN standards which allows to be referenced and used in different projects and conformity assessment programs as the ITRAP (Illicit Trafficking Radiation Assessment Program).

The US ANSI (American National Standard Institute) standards of the N42 group "Homeland Security Instrumentation" and the IEC/SC 45B/WG15 standards are constantly being harmonized with each other.

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