INTERNATIONAL STANDARD

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Second edition
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Monitoring for inadvertent movement and illicit trafficking of radioactive material

Surveillance des mouvements non déclarés et des trafics illicites de matière radioactive

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ISO copyright office
CP 401 • Ch. de Blandonnet 8
CH-1214 Vernier, Geneva
Phone: +41 22 749 01 11
Email: copyright@iso.org
Website: www.iso.org

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO document should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

ISO draws attention to the possibility that the implementation of this document may involve the use of (a) patent(s). ISO takes no position concerning the evidence, validity or applicability of any claimed patent rights in respect thereof. As of the date of publication of this document, ISO had not received notice of (a) patent(s) which may be required to implement this document. However, implementers are cautioned that this may not represent the latest information, which may be obtained from the patent database available at www.iso.org/patents. ISO shall not be held responsible for identifying any or all such patent rights.

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 85, *Nuclear energy, nuclear technologies and radiological protection,* Subcommittee SC 2, *Radiological protection*.

This second edition cancels and replaces the first edition (ISO 22188:2004), which has been technically revised.

The main changes are as follows:

— Update of the introduction, considering the continuous development of technology.

— Update of Clause 2.

— There were 14 terms and definitions listed in the first edition (ISO 22188:2004). According to related standards and IAEA technical documents,

  — the following terms have been deleted: 3.1 control of radioactive material, 3.9 non-proliferation, 3.10 physical protection, 3.12 response, 3.13 safeguards and 3.14 special nuclear material;

  — the following terms have been added: 3.1 check source, 3.2 competent authority, 3.3 computer security, 3.9 nuclear material, 3.10 radioactive contamination, 3.11 radioactive material, 3.12 radiological monitoring, 3.13 radionuclide, 3.15 threat, 3.16 threat assessment and 3.17 threshold level. Terms and definitions count updated to 17.

— According to the standard's title, "instruments" in the title of Clause 4 was deleted. Originally, there were 4 types of instruments categorized in the first edition (ISO 22188:2004); they were pocket-type instruments, hand-held instruments, installed instruments and radionuclide identifiers. In this second edition, the kinds of devices are updated to 7. Individually, they are personal radiation devices, hand-held instruments, hand-held radionuclide identification devices, installed radiation portal monitors, mobile systems, backpack-type radiation detectors, active interrogation and imaging systems. For each instrument the general characteristics, operation, calibration and routine testing, minimum performance requirements and test methods are presented. References to the IEC standards covering the performance requirements for these types of instruments were added and the requirements listed in this document were removed.

— This document primarily covers radiological monitoring at borders from a technical and operational viewpoint. Whether, when or where to establish radiological monitoring at borders should be the result of a comprehensive national regulatory strategy for radioactive material control. Therefore, the training requirements for border agents, inspectors and first responders have been added (see 4.2).

— Radiation monitoring systems, particularly those which are networked, connected to the internet or use cloud services, are vulnerable to a range of cyber threats. The computer security of these systems seeks to maintain the integrity, accessibility, authenticity and, where required, the confidentiality of data and instrument control. Guidance from national authorities for computer security should be sought by end-users for maintaining business continuity and reliability of radiation monitoring services and systems. A new Clause 6 has been added to deal with this issue.

— Parts of Annex A, and all of Annex B and Annex C were integrated into the text of Clauses 4 and 5 of the revised document. Annex D was eliminated and references to applicable IEC standards were given for performance requirements and test methods. Annex A was rewritten and simplified as Alarms and threshold levels. A new Annex B was added to list the possible trafficked devices and radionuclides. Examples of naturally occurring radioactive material remain as Annex C.

— Update of the Bibliography.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The International Atomic Energy Agency (IAEA) Incident and Trafficking Database (ITDB) system has been recording incidents of inadvertent movement and illicit trafficking of nuclear and other radioactive materials since 1995. Although the numbers of reported incidents fluctuate over time, those related to trafficking or malicious use remain a concern. A small number of these reported incidents involve seizures of potentially weapons-usable nuclear material, but the majority involve unauthorized activities including stolen or missing radioactive material and the detection of contaminated manufactured goods. Examples include unintentional incorporation of radioactive materials into recycled steel, handling of lost radioactive sources by unsuspecting individuals, and deliberate theft of radioactive material.

The potential radiological hazard to workers, the general public and the environment caused by misappropriated radioactive materials adds an additional threat to inadvertent movement and illicit trafficking. There have been instances in which loss of control over radioactive materials has led to serious, even fatal, consequences. Detection of radioactive materials at border crossings as well as maritime ports, airports and inside countries, for example at check points, is therefore an important issue.

This document addresses the procedural aspects of detecting radioactive materials. The procedural aspects cover the techniques to search, locate and possibly identify radioactive substances. Guidelines for appropriate training programs and maintenance of equipment are also considered a relevant aspect. Instruments used in the process are characterized with respect to minimum requirements in order to make the recommended procedures applicable. These include personal radiation devices, hand-held instruments, hand-held radionuclide identification devices, installed radiation portal monitors, backpack-type radiation detectors, mobile systems, active interrogation, and imaging systems. Specifications for the minimum performance requirements and test methods for instrumentation are covered by other existing standards, which are listed in the normative references clause.

Due to advances continually being made in the field of border radiation monitoring equipment, it is assumed that it can represent a consensus on the minimum specifications presently achievable. It is assumed that this document will allow more efficient use and operation of existing equipment, enhance communication across borders, and encourage activities to detect and counteract inadvertent movement and illicit trafficking of radioactive materials. The benefits thus gained contribute towards the efforts to counter nuclear weapons proliferation and increase radiation protection. A lack of standardization can delay implementation of intended activities, specifically if certain parameters, for example threshold level, are not agreed upon internationally. Technical documents published by the IAEA in this subject area provide a set of technical specification that can be used in design testing, qualifying and purchasing border radiation monitoring equipment, they are the basis for recommending justifiable and agreed specifications and procedures, see References [1], [2], [3], [4], [5], [6] and [7].

Monitoring for inadvertent movement and illicit trafficking of radioactive material

1 Scope

This document specifies methods and means of monitoring for inadvertent movement and illicit trafficking of radioactive material. It provides guidelines on the use of both stationary and portable, for example hand-held, instruments to monitor for radiation signatures from radioactive material. Emphasis is placed on the operational aspects, i.e., requirements derived for monitoring of traffic and commodities mainly at border-crossing facilities. Although the term border is used repeatedly in this document, it is meant to apply not only to international land borders but also maritime ports, airports, and similar locations where goods or individuals are being checked. This document does not specifically address the issue of detection of radioactive materials at recycling facilities, although it is recognized that transboundary movement of metals for recycling occurs, and that monitoring of scrap metals might be done at the borders of a state.

This document is applicable to

— regulatory bodies and other competent authorities seeking guidance on implementation of action plans to combat illicit trafficking,

— law enforcement agencies, for example border guards, to obtain guidelines on recommended monitoring procedures,

— equipment manufacturers in order to understand minimum requirements derived from operational necessities according to this document, and

— end-users of radiation detection equipment applicable to this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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 60325, *Radiation protection instrumentation — Alpha, beta and alpha/beta (beta energy > 60keV) contamination meters and monitors*

IEC 61526, *Radiation protection instrumentation — Measurement of personal dose equivalents $H_p(10)$ and $H_p(0,07)$ for X, gamma, neutron and beta radiations – Direct reading personal dose equivalent meters*

IEC 62244, *Radiation protection instrumentation — Installed radiation portal monitors (RPMs) for the detection of illicit trafficking of radioactive and nuclear materials*

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

IEC 62387, *Radiation protection instrumentation — Dosimetry systems with integrating passive detectors for individual, workplace and environmental monitoring of photon and beta radiation*

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

IEC 62484, *Radiation protection instrumentation — Spectrometric radiation portal monitors (SRPMs) 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 Detectors (SPRD) for the 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*

IEC 62945, *Radiation protection instrumentation — Measuring the imaging performance of X-ray computed tomography (CT) security screening systems*

IEC 62963, *Radiation protection instrumentation — X-ray computed tomography (CT) inspection systems of bottled/canned liquids*

IEC 63085, *Radiation protection instrumentation — System of spectral identification of liquids in transparent and semitransparent container (Raman systems)*

IEC 63121, *Radiation protection instrumentation — Vehicle-mounted mobile systems for the detection of illicit trafficking of radioactive materials*

3 Terms and definitions

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

ISO and IEC maintain terminology databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at https://www.electropedia.org/

3.1
check source
radioactive source, not necessarily calibrated, used to confirm the continuing satisfactory operation of an instrument designed to detect photonic or particulate radiation

3.2
competent authority
any body or authority designated or otherwise recognized as such for any purpose in connection with the transport regulations

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

Note 1 to entry: This term is used only with reference to the Transport Regulations for consistency with terminology used in the wider field of regulation of the transport of dangerous goods. Otherwise, the more general term regulatory body should be used, with which competent authority is essentially synonymous.

3.3
computer security
particular aspect of information security that is concerned with the protection of computer-based systems against compromise

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

3.4
detection
discovery of the presence of radioactive material on the basis of measurements and interpretation of results

3.5
detection limit
smallest true value of the measurand which ensures a specified probability of being detectable by the measurement procedure

[SOURCE: ISO 12749-1: 2020, 3.4.11]

3.6
false-alarm rate
rate of alarms which are not caused by a radioactive source under the specified background conditions

3.7
illicit trafficking
any intentional unauthorized movement of radioactive materials, particularly across national borders, for subsequent illegal sale, use, storage or further transfer

3.8
inadvertent movement
any unintentional unauthorized receipt, possession, use or transfer of radioactive materials

3.9
nuclear material
plutonium except that with isotopic concentration exceeding 80 % in ^{238}Pu; ^{233}U; 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

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

3.10
radioactive contamination
radioactive substances on surfaces, or within solids, liquids or gases (including the human body), where their presence is unintended or undesirable, or the process giving rise to their presence in such places

[SOURCE: ISO 12749-1: 2020, 3.3.4]

3.11
radioactive material
material designated in national law or by a regulatory body as being subject to regulatory control because of its radioactivity

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

Note 1 to entry: This is the "regulatory" meaning of radioactive, and should not be confused with the "scientific" meaning of radioactive.

Note 2 to entry: The term radioactive substance is also used to indicate that the "scientific" meaning of radioactive is intended, rather than the "regulatory" meaning of radioactive suggested by the term radioactive material.

3.12
radiological monitoring
radiation monitoring
measurement of dose, dose rate or activity for reasons relating to the assessment or control of exposure to radiation or exposure due to radioactive substances, and the interpretation of the results

[SOURCE: ISO 12749-1: 2020, 3.3.5]

Note 1 to entry: The general term "dose" refers to ambient dose equivalent if not stated otherwise in this document.

3.13
radionuclide
nuclide which is in an unstable state due to excess of internal energy and which will attain a stable state by emitting radiation

Note 1 to entry: Radionuclides are either naturally occurring radionuclides, such as ^{40}K, ^{235}U, ^{238}U, ^{232}Th and their radioactive decay products or produced by activation or other artificial means.

[SOURCE: ISO 12749-1: 2020, 3.1.8]

3.14
regulatory body
authority or system of authorities designated by the government of a State as having legal authority for conducting the regulatory process, including issuing authorizations, and thereby regulating nuclear, radiation, radioactive waste and transport safety

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

3.15
threat
person or group of persons with motivation, intention and capability to commit a malicious act

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

3.16
threat assessment
evaluation of the *threat* (3.15), based on available intelligence, law enforcement, and open source information, that describes the motivation, intentions, and capabilities of these threats

[SOURCE: IAEA Nuclear Safety and Security Glossary: 2022(interim) edition. Vienna: IAEA, 2022. 248 p]

3.17
threshold level
level of some measurable (or otherwise assessable) quantity such that, if that level is exceeded, something happens.

[SOURCE: IAEA Nuclear Security glossary: 2020 edition, draft. Vienna: IAEA, 2020. 60 p]

Note 1 to entry: The threshold level for a detection instrument is a level of the measured quantity (for example, of dose rate) that, if exceeded, triggers the instrument to generate an alarm. Such a threshold level is set by the user of the instrument at the lowest level that might indicate some form of malicious act.

4 Monitoring

4.1 Overview

The process for detection of inadvertent movement or illicit trafficking of radioactive material is illustrated by the flowchart in Figure 1. This provides an outline for the various clauses of this document. It has the following main steps:

a) strategic evaluation of the need for border monitoring;

b) selection of instruments;

c) determination of threshold levels;

d) evaluation of alarms, by verification and localization of the radioactive material;

e) evaluation of radioactive material found.

This document primarily covers radiological monitoring at borders from a technical and operational viewpoint. The decisions regarding whether, when, or where to establish radiological monitoring at borders should result in a comprehensive national regulatory strategy for radioactive materials control.

One of the key factors in the development of a national strategy is threat assessment. By evaluating historical, political, sociological, economic and geographic factors, a State can come to a reasonable assessment as to the potential, or threat of illicit trafficking or inadvertent movement of radioactive materials across its borders. For some countries, at certain border locations, monitoring may be regarded as a necessary component of their overall strategy. For many others, the potential problem is so low that it would not be considered sufficiently cost-beneficial to implement border monitoring. However, it is recognized that sometimes radiological monitoring at borders is put in place more for political, or public peace-of-mind reasons rather than a rational need based on a significant threat.

Should it be determined that border monitoring is needed, the results of the strategic analysis also helps in the determination of the types of instruments to be used and where they should be deployed. The monitoring process is most effective if it is conducted at locations that have the greatest potential for identifying and intercepting illicit trafficking or inadvertent movement of radioactive material. In general terms, these are “control points” or “nodal points” where the flow of people, vehicle movement or freight converges. These locations may already be control points for other purposes, such as weigh-stations or customs.

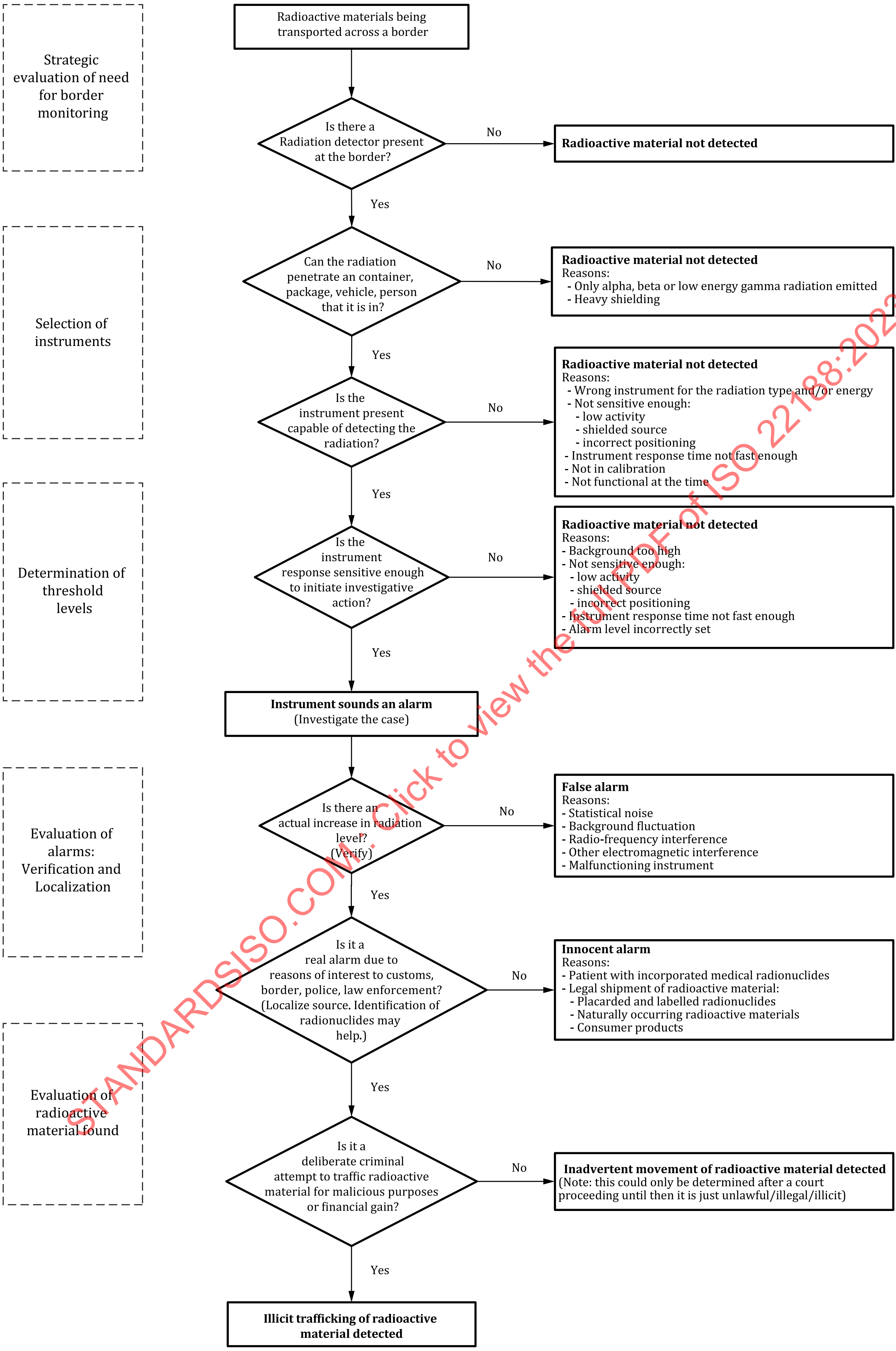


Figure 1 — Flowchart for detection of inadvertent movement or illicit trafficking of radioactive material

4.2 Training requirements for border agents, inspectors and first responders

It is recommended that the agencies in charge of performing the monitoring for inadvertent movement or illicit trafficking of radioactive material develop an operating procedure or tactical response plan that describes the roles and responsibilities of the personnel involved in these activities. In addition, a description of the type of response that the personnel follow based on the instruments' measurement results may also be part of the operating procedure. Training may be required to ensure that the operating procedures are followed and that the users of instruments understand the functionality and limitations of the instrumentation.

The monitoring and detection of inadvertent movement or illicit trafficking of radioactive materials requires specialized training and basic technical knowledge. In the event that front-line officers are unable to conduct an initial radiological hazard assessment, or recognize that they require assistance, they should inform their duty supervisor. This individual should contact a pre-designated radiological advisor. Suggested duties of the radiological advisor are listed in Reference [4] Annex III, and should be contained in the State's tactical response plan. This individual should automatically be deployed to the scene if inadvertent movement or illicit trafficking of radioactive material incident is encountered. However, it is appropriate to seek advice from the radiological advisor on the management of routine incidents when there is any doubt or ambiguity in making the initial hazard assessment.

To minimize the potential for harmful radiation exposure and/or a serious incident, border agents, inspectors and first responders tasked with the monitoring and detection of radioactive materials should, as a minimum, have basic requisite training consisting of but not limited to

a) basic concepts on physics and types of radiation,

b) radioactivity and radiation hazards,

c) general awareness/familiarization as per Reference [1] subclause 313(a),

d) radiation protection and safety as per Reference [1] subclause 313(c),

e) radiation monitoring processes, detection and measurement skills, including theory of operation for instruments on hand, routine checking (testing), maintenance, etc.,

f) risk and situation assessment, and

g) response to a radiation alarm.

Training shall be provided by an accredited individual; and shall be updated as required over the period of employment. Personnel should receive a certificate, or record of training, upon successful completion. Records of training shall be retained by the employer for the duration of the trainee's employment, or as required by regulatory authorities.

4.3 Monitoring instruments

4.3.1 General

There are different types of instruments that can be used for monitoring and detection of inadvertent movement and illicit trafficking of radioactive material, these include

a) personal radiation devices,

b) hand-held instruments,

c) hand-held radionuclide identification devices (RIDs),

d) installed radiation portal monitors with or without spectrometry capabilities (SRPMs or RPMs) ,

e) backpack-type radiation detectors (BRDs),

f) mobile systems,

g) active interrogation, and

h) imaging systems.

As for most radiation detectors, manufacturers' recommendations should be followed. The general climatic, electromagnetic and mechanical performance requirements and methods of tests requirements can address from Reference [8]. The data format used in the detection of illicit trafficking of radioactive material should refer to Reference [9]. The guidance and recommendations for radiation sources used in illicit trafficking detection are described in Reference [10].

Generally, the instrument is not used for routine measurements, and while some instrument manufacturers provide recommendations for periodic calibrations, general guidance on appropriate performance maintenance is lacking. Annual laboratory calibration intervals may not be practical or appropriate for monitoring and detection of inadvertent movement and illicit trafficking of radioactive material that are not covered by regulations. It is typically recommended that instrument calibration be carried out annually by a qualified individual or maintenance facility. The period of calibration can be adjusted based on the instrument performance and the user capabilities. (See Reference [11] [12] [13] [14] [15] [16]).

The general characteristics, applications, requirements, and operation for each type of instruments are listed in the subclauses below.

4.3.2 Personal radiation devices

4.3.2.1 General characteristics

These devices are small, lightweight devices used to detect the presence of radioactive material and to inform the user about radiation levels. These devices, roughly the size of a mobile phone, which can be worn on a belt or carried in a pocket for hands-free operation and alert the operator to the presence of radioactive materials. Because of their small size, these devices are ideally suited for use by individual law or border enforcement officers and first responders, for example front-line officer, fire fighters, without requiring extensive training. Some of these devices can also provide radionuclide identification capabilities.

There are different types of personal radiation devices. Even if similar in appearance these devices are required to meet different types of requirements. These may include

a) personal radiation detectors (PRDs),

b) spectroscopy-based personal radiation detectors (SPRDs),

c) electronic personal dosimeters (EPDs),

d) extended range personal radiation detectors (ER-PRDs), and

e) personal emergency radiation detectors (PERDs).

A PRD is a small, lightweight, robust device, which alerts the wearer to radiation levels above background from gamma-ray and X-ray radiation, and in some cases for neutrons. The SPRDs have the same capabilities as the PRDs, but in addition have radionuclide identification capabilities. EPDs are designed to be worn on workers in planned radiation exposure situations to measure the individual dose. The ER-PRDs are dual detector instruments that extend the measurement range of a PRD without losing the low dose rate sensitivity. PERDs are designed to measure the individual dose. These devices can display radiation dose and dose rate. Its alarm function can work if the dose or dose rate exceeds a pre-set threshold and can be used as a tool for responder dose monitoring.

4.3.2.2 Operation

PRDs, ER-PRDs and SPRDs are commonly used for monitoring for inadvertent movement and illicit trafficking of radioactive materials. PRDs should be worn on the body, ideally the torso, in a pocket, on a lanyard or belt or similar secured method. A self-testing feature should verify proper operation of the instrument (including battery charge level) before usage. False alarms, i.e. alarms without radioactive materials present, occur occasionally due to the fluctuations in background. When the alarm-threshold is set properly, false alarms should occur not more than once per day. There is always a trade-off between detection sensitivity and false alarms. Radiation triggering innocent alarms may be detected on an occasional basis. This is due to the fact that many objects including, for example foodstuffs, dinnerware, tiles, concrete, fertilizer, ice melt, sand, cat litter, etc., contain small quantities of radioactive material such as potassium, radium, thorium or uranium. Also, persons who have undergone radiation therapy or diagnosis may be sources of radiation. In some cases when the treatment or test was recently carried out, the levels of radiation can be high.

4.3.2.3 Calibration and routine checking

Most personal radiation devices go through a self-checking routine when turned on. For its continued ability to detect radiation, a personal radiation device should be checked on a daily basis or prior to use, if possible. Functionality tests may be performed on these devices to assure proper response. This may be done by placing the instrument near a low activity radioactive check source or naturally occurring radioactive materials (NORM) (see Annex C) and observing its response to the radiation. Manufacturers' recommendations should be followed. Appropriate check sources (see Reference [14]), with sufficient output to produce a significant reading on the instruments used, are very useful.

Like most radiation detectors, it is recommended that EPDs be regularly calibrated (as required by the national regulatory authority).

4.3.2.4 Minimum performance requirements and test methods

PRDs shall meet the performance requirements described in IEC 62401, SPRDs in IEC 62618 and EPDs in IEC 61526 and IEC 62387. These documents also describe the associated test methods.

4.3.3 Hand-held instruments

4.3.3.1 General characteristics

Hand-held instruments provide greater sensitivity of detection compared to PRDs, but they are heavier and usually more expensive. For example, they would be chosen

a) when a suspicion of illicit trafficking already exists based on intelligence reports,

b) to localize a source,

c) to measure the dose rate, and

d) to identify the radionuclide.

Hand-held instruments are small, battery-powered radiation detection instruments that measure the ambient background level and then calculate an alarm-threshold based on a sigma level above background. Thus, these instruments can compensate for variations in the background level when turned on, or on command. These instruments continuously make short time measurements of the radiation level and compare the results to the alarm-threshold. The hand-held instruments can effectively search pedestrians, packages, cargo, and motor vehicles at a close distance. These instruments can alert the user to unexpected levels of radiation present in the background.

The most significant difference between the hand-held instruments and installed portal monitors is the human factor that strongly influences the ability of a hand-held instrument to detect radioactive materials in the field when placed at a close distance and moved at a slow speed. If the officer does not move the instrument at a slow enough speed and in close enough proximity to any radioactive material that is present, it may not be detected.

The hand-held instruments can be placed nearer to the radioactive material where the dose rate is higher, thus yielding higher sensitivity to the radiation signature. To achieve that sensitivity, border agents, inspectors and first responders shall be trained in the proper technique to conduct effective searches, and the training should be repeated periodically.

Hand-held instruments are designed to measure one or more of photon, alpha, beta or neutron radiations. For interdiction and detection activities, the most common type is the hand-held instruments with gamma detection capabilities, and in some cases with neutron detection. Hand-held instruments with alpha and beta detectors are mostly used for detection of radioactive contamination. These may be used by agencies to clear people or packages that are potentially contaminated with radioactive materials.

4.3.3.2 Operation

Hand-held instruments can be used either as the primary search instruments or as second-stage search instruments for installed radiation portal monitors. This type of instruments is used to facilitate the localisation of radiation sources by providing an alarm and/or a frequency dependent alarm indication on dose rate or count rate.

4.3.3.3 Calibration and routine testing

A hand-held instrument should be source checked daily or prior to use, if possible, for its continued ability to detect radiation. This may be done by placement of the instrument near a radiation check source and observing a repeatable radiation level.

Like most radiation detectors that provide dose rate measurements, it is recommended that these instruments be calibrated periodically (as required by the national regulatory authority).

4.3.3.4 Minimum performance requirements and test methods

Hand-held instruments shall meet the performance requirements of one of the following standards:

— contamination meters covered by IEC 60325;

— highly sensitive gamma detectors covered by IEC 62533;

— highly sensitive neutron detectors covered by IEC 62534.

These documents also describe the associated test methods.

4.3.4 Hand-held radionuclide identification devices (RIDs)

4.3.4.1 General characteristics

RIDs are hand-held, battery-powered devices used for in field radionuclide identification of radioactive materials by non-experts. These instruments provide self-calibration and gain stabilization based on an internal or external source (e.g. ^{137}Cs, ^{40}K).

Most of the radionuclides encountered at borders can be identified by instruments capable of identifying gamma-ray energy peaks between 60 keV and at least 1,5 MeV (in most cases a maximum range of 3 MeV is recommended for the identification of ^{232}U or ^{232}Th). These devices use scintillator or solid-state detectors (such as sodium iodine (NaI(Tl)), high purity germanium (HPGe), etc.) to discriminate different gamma-ray energies emitted by radioactive nuclides (i.e. radionuclides).

These devices can provide a radiation exposure or dose rate display, as they are equipped with several detectors that may include a Geiger-Muller (GM) tube. Some of these devices are also equipped with a neutron detector.

A library of common radionuclides (and in some cases the number of gamma-ray lines for a given radionuclide) stored within the RID's CPU allows the devices to identify the radionuclides found with a high level confidence. Compilation, editing, optimizing and testing of the radionuclide libraries used are essential and should be carefully programmed by the developer or an expert user. The radionuclide library should be tailored to the radionuclides commonly encountered at a given location. These devices provide a message when radiation is detected, the radionuclide is not in the library, or when the counting statistics are poor.

For the purpose of this document, the term radioactive materials may be used in reference to nuclear materials, industrial radionuclides, medical radionuclides and NORMs, for example

a) Nuclear materials: ^{233}U, ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu,

b) Industrial radionuclides: ^{57}Co, ^{60}Co, ^{75}Se, ^{90}Sr, ^{133}Ba, ^{137}Cs, ^{152}Eu, ^{192}Ir, ^{203}Hg, ^{226}Ra, ^{241}Am, ^{238}Pu, ^{252}Cf,

c) Medical radionuclides: ^{18}F, ^{22}Na, ^{51}Cr, ^{67}Ga, ^{99}Mo, ^{99m}Tc, ^{103}Pt, ^{201}Tl, ^{123}I, ^{125}I, ^{131}I, ^{133}Xe, ^{111}In, ^{166}Ho, ^{192}Ir, ^{211}At, ^{223}Ra, ^{225}Ac, and

d) NORMs: ^{40}K, ^{226}Ra, ^{232}Th, ^{238}U and their decay products. (See Annex C).

4.3.4.2 Operation

These devices can alert the user to unexpected levels of radiation present in the ambient background. Meanwhile, the ability to identify radionuclides makes them useful in response to control requirements. In most cases the identification of a gamma-ray emitter takes place after the detection of a radioactive material, for example by an alarm produced by a radiation portal monitor or a personal radiation device, and the localization of the source for which the RIDs (or a different type of detector) may be used. Therefore, it is assumed that the identification can, in most cases, be done from a close distance (if the dose rate allows this) and that sufficient time is available for this investigation.

For reducing the number of false identifications, the RIDs require having an up-to-date background measurement at the measurement location. Therefore, if the measurement location is changed, a new background needs to be acquired to reduce the probability of obtaining false identifications.

4.3.4.3 Calibration and routine testing

For optimal performance the energy calibration and background checks should be performed as prompted by the devices or by manufacturer specifications.

It is recommended that the energy calibration is checked if the device is exposed to changes in temperature or when the device is turned off for an extended period of time. The background should be updated when prompted by the instrument or when the instrument is moved to a different location.

4.3.4.4 Minimum performance requirements and test methods

Hand-held radionuclide identification devices shall meet the performance requirements described in IEC 62327. This document also describes the associated test methods.

4.3.5 Installed radiation portal monitors

4.3.5.1 General characteristics

Installed radiation portal monitors are designed to detect the presence of radioactive material automatically by comparing the gamma and/or neutron intensity, while the monitor is occupied, to the continuously updated background radiation level, which is measured (and updated) while the monitor is unoccupied.

Gamma and neutron radiation levels are indicated separately. These monitors automatically search pedestrians, packages or vehicles as they pass through the monitors. These monitors continuously measure the background radiation level and may adjust the alarm-threshold to maintain a constant false-alarm rate. These monitors may also have radionuclide identification capabilities.

In some cases, high throughput pedestrian and package monitors may not require occupancy sensors for proper operation.

RPMs are sometimes used in combination with imaging devices, for example X-ray or gamma-ray imaging machines, metal detectors or active interrogation systems. In these cases, RPMs should be placed at a distance from imaging devices because of the risk of interference from the photons produced by these devices. The throughput of a RPM may be higher than a screening lane using an X-ray imaging system or metal detection), if so, a RPM could be placed ahead of the screening lanes at a check point covering one or several lanes.

4.3.5.2 Operation

4.3.5.2.1 General

A fixed installed radiation portal monitor is only as effective as the “check point” where it is installed. The monitors shall be installed such that all the pedestrians, vehicles, and cargo traffic are forced to pass through the monitors at a controlled speed. There should be sufficient shielding or distance, in order to minimize false alarms resulting from pedestrians or objects waiting in the same or adjacent line to be screened. The effectiveness of fixed installed monitors is strongly dependent on its ability to measure the radiation activity over the entire object being searched. It further requires that inspection officers promptly respond to alarms. These alarms may be remotely observed. Alarm indications should be in clear view of the officers staffing the inspection point. Monitors that discriminate NORMs and medical sources from all other types of radiation can reduce the number of alarms and minimize additional screening at the inspection point.

NOTE The majority of detection is the result of NORMs, for example fertilisers, specific varieties of pottery, sand, etc., or outpatients from nuclear medicine departments. (See Annex B).

4.3.5.2.2 Pedestrian monitors

Pedestrian monitors may be installed as single-sided or dual-sided monitors. Barriers may be installed to restrict the pedestrian traffic so that passage is within 1,0 m of the monitor or the distance specified by the manufacturer. Where pedestrian traffic corridors are larger than 1,0 m, it is recommended that dual-sided monitors are installed. The monitors should be placed away from heavy doors, which can cause excess false alarms, since effective shielding by the doors may lead to increased fluctuations in the radiation background. The occupancy sensor shall be positioned so that it is only triggered when the monitor is occupied and not by individuals walking in the vicinity of the monitor. Because of the possibility of gamma shielding in luggage and packages, the monitors are most effective when they are used in combination with metal-detection equipment or X-ray imaging systems, which can be used to easily identify the presence of shielding metal or other type material (depending on the technology used).

4.3.5.2.3 Vehicle monitors

Using fixed installed radiation monitors to search vehicles for radiation sources is complicated by the inherent shielding caused by the vehicle structure. While simple dual-sided monitors are effective in detecting abnormal radiation levels in shipments of metals for recycling, they may be less effective in detecting inadvertent movement or illicitly trafficking radioactive material when that material is purposely concealed.

Barriers, which do not obstruct the view of the monitor, should be installed to protect the monitor from being damaged by the vehicles. Since the sensitivity of the monitor is strongly dependent on monitoring time, the monitors should be placed where the speed of the vehicle is controlled and reduced.

For passenger vehicles, single-sided monitors are acceptable. For large trucks and buses, dual-sided monitors are required. The maximum distance between pillars is dependent on the maximum width of the vehicle to be scanned and the facility blueprint.

The speed of the vehicle shall be monitored, and where the vehicle's speed exceeds that for effective monitoring, a specific alarm shall be given. The occupancy sensor shall be positioned so that it is only triggered when the monitoring system is occupied and not by other traffic in the vicinity.

Detection assemblies should be mounted using methods that prevent or minimize the transfer of vibration transients caused by passing vehicles. Vibration transients that transfer to the detection assemblies may cause degradation of the assemblies or alarm activation.

4.3.5.2.4 Calibration and routine testing

The installed radiation portal monitors should be checked daily with check sources to verify that they can detect radiation intensity increases and corresponding alarms can be triggered. Self-diagnostic check facilities should be included to cover as many functions as practicable, and where these facilities indicate the possibility of malfunction, an external alarm shall be given.

Degradation of the detectors' response may occur when exposed to temperature and humidity fluctuations over an extended period of time. Periodic calibrations should be helpful in order to determine the detectors response degradation.

4.3.5.3 Minimum performance requirements and test methods

Installed radiation portal monitors shall meet the performance requirements described in IEC 62244 and IEC 62484. These documents also describe the associated test methods.

4.3.6 Mobile systems

4.3.6.1 General characteristics

Mobile systems may be mounted in different platforms, these include:

a) vehicle-mounted systems – These systems consist of one or more radiation detectors mounted in a vehicle (i.e. car or van), which travels predominantly on roads. Vehicle-mounted mobile systems detect gamma radiation and may include neutron detection and/or identification of gamma-ray emitting radionuclides. These systems can be used to monitor areas in proximity to roads, or other areas, the vehicle traverses, or can be used to provide a temporary static checkpoint where the vehicle remains stationary.

b) boat-mounted systems – These systems consist of one or more radiation detectors mounted in a boat or small ship which travels on water. Boat-mounted systems can detect gamma radiation and may include neutron detection and/or identification of gamma-ray emitting radionuclides. They can be used for boats passing each other or when boats are standing next to each other (e.g. in boarding activities).

c) aerial-mounted systems – These systems consist of one or more radiation detectors mounted on a small plane, helicopter or unmanned aerial vehicle (UAV). Aerial-mounted systems can detect gamma radiation and may include neutron detection and/or radionuclide identification devices. These systems can be used to cover large areas in the search for radioactive materials.

4.3.6.2 Operation

Particular fields of application for these systems include the protection of major public events, rapid screening or scanning of large areas and responding to a radiological event.

Aerial systems may be limited to certain applications due to the large distances between the source of radiation and the detectors.

4.3.6.3 Calibration and routine testing

As for most radiation detectors, it is recommended that calibration is performed based on manufacturer specifications or other applicable standards.

4.3.6.4 Minimum performance requirements and test methods

Vehicle-mounted mobile systems shall meet the performance requirements described in IEC 63121. This document also describes the associated test methods. Aerial and boat-mounted systems are not yet covered by the IEC standards.

4.3.7 Backpack-type radiation detectors

4.3.7.1 General characteristics

These types of detectors can incorporate larger volume gamma detectors, for example plastic, NaI(Tl), CsI, $LaBr_3$(Ce), compared to PRDs, and some have neutron detection and radionuclide identification capabilities. Some detectors provide directionality information, location information and can communicate and transmit data to a central control system. These systems can be used to monitor areas accessible to a user on foot or used to provide a temporary static checkpoint where the user remains stationary.

4.3.7.2 Operation

Particular fields of application for these systems include the protection of major public events and rapid screening of large areas.

4.3.7.3 Calibration and routine testing

As for most radiation detectors, it is recommended that calibration is performed based on manufacturer specifications or other applicable standards.

4.3.7.4 Minimum performance requirements and test methods

Backpack-type radiation detectors shall meet the performance requirements described in IEC 62694. This document also describes the associated test methods.

4.3.8 Active interrogation and imaging systems

4.3.8.1 General characteristics

In addition to the passive instruments described above, there are active interrogation and imaging systems that may be used in combination with the passive instruments in order to determine the presence of radioactive materials and other illegal items. These systems may include:

a) Imaging body scanners. These systems are mainly used at airports to screen people going through the check points. They can be based on X-ray backscatter or millimetre-wave and microwave technology;

b) X-ray computed tomography (CT) security-screening systems. These systems are mainly used to screen check-in luggage at airports;

c) Cabinet X-ray machines. These systems are mainly used to screen carry-on luggage at airports;

d) Active interrogation systems. These systems probe a sample with neutron or photon sources, radiography, and cosmic muon tomography to determine the presence of certain radioactive materials. The main role of active-interrogation systems is to detect the presence of nuclear material inside an object by observing the radiation emitted by that object when it has been exposed to known sources of external radiation;

e) Vehicle X-ray, gamma-ray imaging systems, often used at maritime ports.

4.3.8.2 Minimum performance requirements and test methods

Active interrogation and imaging systems shall meet the performance requirements described in IEC 62945, IEC 62963 and IEC 63085. These documents also describe the associated test methods.

5 Radiation monitoring at checkpoints

5.1 General

Once a decision has been made to perform border monitoring, as well as where to perform it and for what to look for, the next step is to select an instrument to detect any abnormal radiation level. For this purpose, any of the types of instruments in 4.3.2 through 4.3.8 can be used.

Personal radiation devices, hand-held instruments, and backpack-type radiation detectors are particularly useful where operations are conducted in small and mid-size areas such as airports or stadiums. For example, personal radiation devices can be issued to and worn by every law enforcement officer on duty.

Hand-held instruments provide greater sensitivity of detection compared to personal radiation devices, but they are heavier and usually more expensive (as in the case of RIDs). Hand-held instruments are mostly used in targeted search of specified consignments, e.g. when suspicion of inadvertent movement or illicit trafficking of radioactive material already exists based on intelligence.

Where the traffic of goods, vehicles, packages, or people can be funnelled into narrow confines (known as “nodal or check points”) fixed, installed radiation portal monitors are the preferred option. Under these conditions, imaging systems can also be used.

Mobile systems may be driven around larger areas where containers or packages are placed in holding locations such as seaports. These systems can also be used to scan cities where major events take place.

Aerial and boat-mounted systems may be used to screen wide areas at different locations depending on the type of areas that need to be searched.

5.2 Important considerations

There are a number of factors that impact successful detection of radioactive material:

a) In order to detect radioactive material, the radiation that it emits shall be able to penetrate any container, package, vehicle or person that the radioactive material is in. Practically, this means that pure alpha emitters and low energy beta emitting radionuclides, as well as some low energy gamma-ray emitting radionuclides, are not detected. In addition, heavy shielding around any radioactive material may reduce radiation levels outside the container to below detectable levels.

b) Not all instruments can detect all types and energies of radiation. Therefore, decisions shall be made as to what radioactive materials might be expected and are desired to detect. For example, manufactured sources used in nuclear medicine and industry (such as nuclear density gauges) may be legally shipped but could be mislabelled or carried outside the specified container. If a State determines that the relevant threat is from nuclear material, e.g. potentially containing fissile materials, neutron detection instruments are needed. If this is not considered as a threat, then more basic instruments for gamma or beta/gamma radiation detection are probably sufficient. Alternatively, each type of instrument can be installed and set to alarm independently. Significant neutron sources do not exist as NORMs, so detecting a neutron radiation source is still a strong indication of the presence of nuclear materials or sealed neutron sources (e.g. ^{241}Am-Be, ^{252}Cf).

c) Even if the correct instrument is in place, there are still reasons why it might not be possible to detect and prevent radioactive materials from crossing the border. For example:

— the instrument response-time characteristics are too slow for the speed in which the object is being scanned (e.g. the speed at which the instrument and the source pass each other);

— the instrument is not sensitive enough because the source is of low radioactivity, shielded or too far away.

5.3 Verification

Each detection should be verified to exclude false alarms (see Annex A). Verification involves repeating the measurement process to confirm the initial indication of a radiation field. For personal radiation devices and hand-held instruments, this would normally involve repeating the examination of the vehicle, object, or person. For installed radiation portal monitors, it may mean that the vehicle needs to be recirculated through the monitor to obtain a repeat measurement or a secondary station equipped with another installed radiation portal monitor or a different type of instrument such as a hand-held instrument. Verification is best performed with a different instrument than that used for detection, but if needed the same instrument can be used.

5.4 Localization

After the detection is verified, the origin of the radiation shall be localized. For this purpose, personal radiation devices or hand-held instruments are needed. At this point, a radiation safety assessment may be required in order to determine the appropriate response and to ensure the safety of personnel and the public. To do this, count rate and calibrated dose rate monitors are essential.

5.5 Identification

Once the origin of the radiation is located, it is normally useful to identify the specific radionuclide, or radionuclides, involved. This is because it impacts the safety considerations, as well as the subsequent scale of response to the discovery of the radioactive material. Identification of the radionuclide helps to categorize the nature of the event. It may also provide some information about the former use and ownership of the material. These data can be used later for enforcement purposes by the national regulatory authority.

5.6 Search techniques, operational response and follow-up

Standard operating procedures pertaining to search techniques, operational response and follow-up shall be prepared as mandated by a responsible regulatory agency in the jurisdiction of use.

6 Cyber assurance for monitoring instruments

6.1 General

Radiation monitoring systems, particularly those which are computer-based, networked, connected to the internet or use cloud services, are vulnerable to a range of computer security threats. Intentional computer security threats to radiation monitoring systems can be categorized into:

a) digital theft and malicious use of sensitive information, for example ransomware, espionage, resulting in compromised confidentiality;

b) cyber sabotage to disable or impair measurement, control and communication functions, for example distributed denial of service attacks, resulting in compromised availability;

c) compromise the reliability or trustworthiness of monitoring in combination with other modes of attack, for example blended cyber-physical attacks, resulting in compromised integrity;

d) spoofing of data to create false alarm, resulting in compromised authenticity.

6.2 Risk-based good practice

The cyber assurance of these systems seeks to maintain the integrity, availability, authenticity, and, where required, the confidentiality, of data and instrument control. Guidance from national authorities for computer security should be sought by end-users for maintaining business continuity and reliability of radiation monitoring services and systems. The ISO/IEC 27000 series and IAEA NSS.17 provide good practice guidance on information security management and technologies.

End-users should ensure effective risk-based procedures, processes and technologies to prevent, protect and respond to cyber threats and attacks. These include:

a) computer security measures shall be designed and implemented in a graded approach to meet threats outlined in a regularly updated cyber threat assessment or design basis threat;

b) protecting and maintaining radiation monitoring instrumentation that is networked or connected to the internet through a programme of computer security hygiene and software security patching;

c) protecting digital communication and controlling of radiation monitoring instrumentation and associated centralised control or screening areas;

d) computer security of physical protection assets, including radiation monitoring systems, should be integrated with security.

6.3 Operational aspects

Some corresponding operational methods can be adopted to ensure the cyber assurance of the monitoring instruments. These include:

a) Secure digital access: Authenticity and privilege of user access may be ensured through a credential system including a secure password policy and/or use of biometrics. Access privilege levels and user accounts shall be managed and maintained in a timely manner.

b) Secure communication: End-users may ensure confidentiality through best practice cryptography in data communication, including radiation monitoring data, on a network or over the internet.

c) Data minimisation: Instruments should allow end-users to control and turn off recording or sending of data from the instrument, for example user information, data from a camera or global navigation satellite system (GNSS) chip, if not needed.

d) Secure storage of sensitive information and physical accessibility to information transmission infrastructure: Information in persistent storage should be secured physically and digitally. Physical and digital access attack surfaces shall be minimised and protected.

e) Software updates and security patching: Instrumentation vendors and manufacturers shall detail the duration and extent of software support services including vulnerability reporting, software patching and updates.

Annex A
(informative)

Alarms and threshold levels

A.1 Real and false alarms

“Real alarms” are caused by the presence of radioactive or nuclear materials. Various factors can produce “alarms,” such as

— statistical fluctuations of the background radiation intensity and the inherent (electronic) noise level of the instrument – false alarms,

— electromagnetic interference (EMI) – false alarms, and

— actual increase in the radiation intensity as a result of the presence of NORMs, technically enhanced NORMs (TENORMs), medical radionuclides administered to patients, and legal shipments of radioactive sources – innocent alarms.

NOTE In this situation, the monitoring instrument is doing what it is supposed to be doing, that is, detecting increases in the ambient background level of radiation, but the increase has a reason, the presence of radioactive materials.

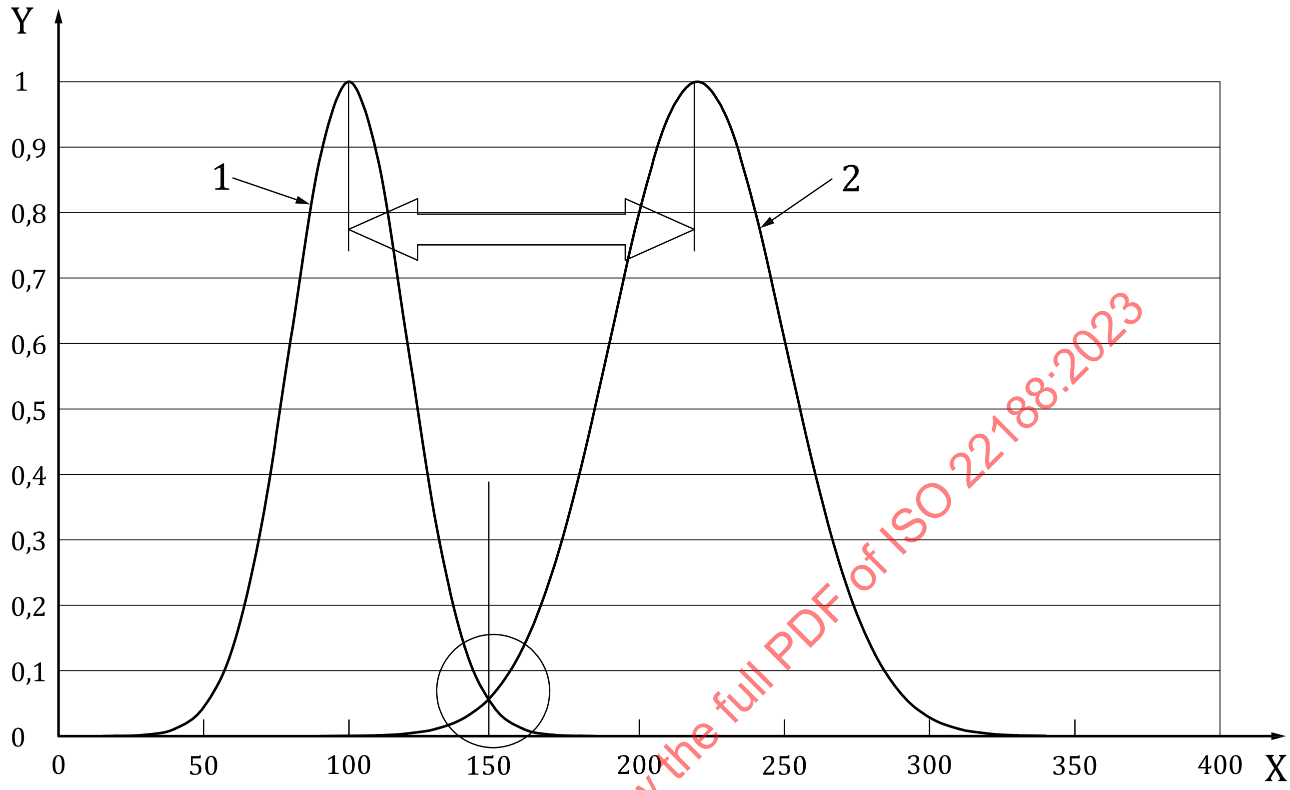
For example, in airline passengers or pedestrian border-crossing environments, the most common radioactive sources likely to be encountered are medical outpatients who have been recently administered a radionuclide for diagnosis or treatment. Although the radioactive agents used, for example iodine-131 for thyroid treatment, technetium-99m or thallium-201 for heart stress tests, are generally short-lived, residual radioactive materials in individuals can remain detectable for days or weeks. There is a significant probability of encountering such patients among the travelling public.

Measurement conditions at borders are essentially different from that in nuclear facilities or recycling or disposal facilities. Large traffic volumes crossing major borders limits the time available for detection, and multiple checks are usually impractical. Radioactive sources, even of high activity, in shielding containers may not be detected at borders without unloading the vehicle, a procedure generally ruled out at borders. Highly sensitive monitoring systems necessarily cause frequent innocent alarms due to NORM, for example in fertilizers, TENORM, for example scale in pipes used in the oil industry, or medical radionuclides. Frequent false alarms at a border or other high-traffic-volume monitoring location would render the monitoring system useless in practice. Therefore, a compromise between excessive false-alarm rate and unacceptably low sensitivity shall be made. Spectrometric devices using nuclide identification help to reduce the number of innocent alarms.

A.2 Selection of a threshold level

A “threshold level” is defined here as the nominal radiation level at which an alarm is triggered, and consequent investigation of individuals, vehicles or goods should be established. A particular threshold level is realized by the alarm-threshold setting of a monitoring instrument. The alarm-threshold can be expressed in terms of multiples of background, or as a coverage interval of the standard deviation of the background count rate, or as an absolute value of count rate or dose rate. This cannot be generally stated, especially if the sensitivity of the detector is low. However, the threshold level chosen shall be set beyond the detection limit of the instrument to make detection possible. Alarms may also be based on criteria other than count rate or dose rate, such as nuclide identification, which is not regarded here.

The instrument alarm-threshold shall be set considerably below the nominal threshold level chosen to allow for statistical variation. To achieve 99,9 % detection probability and assuming the idealized case of Gaussian distribution, the instrument threshold shall be set at least at 3σ below the desired level to detect all those events that fall statistically on the "low side." On the other hand, the instrument setting shall stay safely away from values too close to background, see Figure A.1.



Key

X arbitrary units

Y arbitrary units

1 background

2 radiation source

Figure A.1 — Overlapping signals from background and radiation source

Recommendations for an optimized threshold level can be derived from the large-scale pilot study on border monitoring systems, as presented in the Illicit Trafficking Radiation Detection Assessment Program (ITRAP). As discussed above, a compromise shall be reached in establishing a practical alarm-threshold so that inadvertent movement and illicit trafficking of radioactive materials may be detected yet provide an acceptably low false-alarm rate. The subsequent investigation should disclose innocent alarms and allow continued movement of the individuals or goods.

In the following discussion, the desired threshold level or instrument setting is expressed as multiples of background (in count rate or dose rate) or in multiples n of background standard deviation, σ. It shall be recognized that these considerations apply for an idealized system with Gaussian characteristics. Real monitors tend to perform less well, depending on design characteristics such as electronic noise or averaging algorithms employed. The idealized case may serve as a general guideline, whereas individual monitor performance characteristics shall be verified by rigorous testing.

The diagram represented in Figure A.2 relates the background count rate (abscissa) of large monitoring systems with the lowest possible choice of 'nominal threshold level' in terms of multiples n of background standard deviation (upper curve) and multiples of background count rate BG (lower curve) under the requirements of a false-alarm rate of less than 1:10 000 and a detection probability of 99,9 %. The instrument alarm-threshold should be set at 3 σ below the desired threshold level in this example. The step function characterizes the requirements of monitoring at 50 %, 40 % or 20 % above average background.

