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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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Foreword

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The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

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ISO 22188 was prepared by Technical Committee ISO/TC 85, *Nuclear energy*, Subcommittee SC 2, *Radiation protection*.

Introduction

Inadvertent movement and illicit trafficking in radioactive materials[1)] are not a new phenomenon. However, concern has increased remarkably in the last decade. A few percent of these incidents involve so-called “special nuclear materials”, which may be used for nuclear weapons and therefore cause a threat of nuclear proliferation. The vast majority of these incidents, however, involve radioactive sources, low-enriched, natural and depleted uranium, which are not usable for weapons. In the case of inadvertent movements, there have been instances in which loss of control over radioactive materials has led to serious, even fatal, consequences to persons. Examples include unintentional incorporation of radioactive materials into recycled steel, recovery of lost radioactive sources by unsuspecting individuals, and deliberate purloining of radioactive material.

The potential radiological hazard to workers, the general public and the environment, caused by such radioactive materials adds an additional threat to inadvertent movement and illicit trafficking, so both the proliferation threat and the radiological hazard shall be considered. Detection of radioactive materials at border crossings as well as inside countries, i.e. at check points, is therefore an important issue.

This International Standard addresses both the procedural aspects of detecting radioactive materials as well as the minimum requirements regarding instrumentation used in the process. The procedural aspects cover the techniques to search, locate and possibly identify radioactive substances and may be summarized under response activities. Guidelines for appropriate training programs might also be considered a relevant aspect. Instruments used in the process might comprise stationary monitors, portable or hand-held detectors’ and these need to be characterized with respect to minimum requirements in order to make the recommended procedures applicable. Based on the results of an extensive testing program on such detection systems, undertaken in cooperation with the International Atomic Energy Agency (IAEA), test procedures are recommended for routine operation (to ensure operability of equipment) and also for acceptance testing (to verify minimum requirements).

It is assumed that such an International Standard will allow more efficient use and operation of existing equipment, will enhance communication across borders and encourage activities to detect and counteract illicit trafficking in radioactive materials. The benefits thus gained contribute towards the efforts in counter-proliferation and radiation protection. On the contrary, a lack of standardization will delay implementation of intended activities, specifically because certain questions (e.g. investigation level, action threshold) shall be agreed upon internationally. Technical documents published by the IAEA in this subject area are a first step in recommending justifiable and agreed specifications and procedures, see [2], [3] and [4].

1) Since nuclear materials are also radioactive, in this International Standard the term “radioactive materials” always includes nuclear materials.

Monitoring for inadvertent movement and illicit trafficking of radioactive material

1 Scope

This International Standard 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 (e.g. 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 International Standard, 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 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 may be done at the borders of a state.

This International Standard is applicable to regulatory authorities seeking guidance on implementation of action plans to combat illicit trafficking, to law enforcement agencies (e.g. border guards) to obtain guidelines on recommended monitoring procedures, and to equipment manufacturers in order to understand minimum requirements derived from operational necessities according to this International Standard.

NOTE The general term “dose” refers to ambient dose equivalent if not stated otherwise in this International Standard.

2 Normative references

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

IEC 60038, *IEC standard voltages*

IEC 60846, *Radiation protection instrumentation — Ambient and/or directional dose equivalent (rate) meters and/or monitors for beta, X and gamma radiation*

IEC 60068-2-1, *Environmental testing — Part 2: Tests — Tests A: Cold*

IEC 60068-2-2, *Environmental testing — Part 2: Tests — Tests B: Dry heat*

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

3 Terms and definitions

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

3.1
control of radioactive materials
act of maintaining cognizant supervision by proper authorities over the production, use, storage, transport and disposal of radioactive materials

3.2
detection
discovery on the basis of measurements and interpretation of results of a case of inadvertent movement or illicit trafficking

3.3
detection limit
quantity which specifies the minimum sample contribution which can be detected with a given probability of error using the measuring procedure in question

3.4
false-alarm rate
rate of alarms which are not caused by a radioactive source under the specified background conditions

3.5
illicit trafficking
any intentional unauthorized movement of radioactive materials as defined in this International Standard, particularly across national borders, for subsequent illegal sale, use, storage or further transfer

3.6
inadvertent movement
any unintentional unauthorized receipt, possession, use or transfer of radioactive materials as defined in this International Standard

3.7
investigation level
quantity of radiation intensity (expressed as dose rate or equivalent) established by agreement, defined as the nominal radiation level at which an alarm is triggered and consequent investigation of individuals, vehicles or goods shall be established

NOTE This term is synonymous with (nominal) alarm level or (nominal) alarm-threshold setting and shall not be confused either with instrument-related alarm-threshold setting (see A.3) or with the detection limit.

3.8
monitoring
measurement of dose or contamination for reasons related to the assessment or control of exposure to radiation or radioactive substances, and the interpretation of the results

3.9
non-proliferation
broad term used in international agreements in relation to limiting the availability of nuclear material and thus reducing the capability for production of nuclear weapons

3.10
physical protection
measures for the protection of radioactive materials designed to prevent any unauthorized removal or sabotage

3.11
regulatory authority
authority or authorities designated or otherwise recognized by a government for regulatory purposes in connection with protection and safety

3.12
response
ratio of the indicated value to the conventional true value

NOTE "Value" may be ambient dose equivalent rate or another, monitor-specific signal, sufficiently proportional to radiation intensity.

3.13
safeguards
verification system within the framework of international non-proliferation policy, applied to the peaceful uses of nuclear energy and intended to maintain stringent control over nuclear material

3.14
special nuclear material SNM
highly enriched uranium and all forms of plutonium, see [5]

4 Monitoring instruments

4.1 Pocket-type instruments

4.1.1 General

Small gamma radiation detectors, which are roughly the size of a message pager, can be worn on a belt or carried in a pocket for hands-free operation and quietly alert the operator to the presence of radioactive materials. Because of their small size, these instruments are ideally suited for use by individual law enforcement officers and first responders to a radiation alarm, without requiring extensive training.

A pocket-type instrument is a small, lightweight, robust device which will alert the wearer to radiation levels above background from gamma and X radiation. A solid-state detector is most frequently used in the instrument to ensure the required sensitivity. It shall be maintenance free, of rugged construction, weather resistant and battery operated with adequate operation time of at least 12 h. There shall be an indication on battery condition. The alarm-threshold should be pre-adjusted before issuance to the officer, to account for the natural background radiation at the particular location. A pocket-type instrument should be able to produce three types of alarms, a visual (light), audible (tone), and vibrating (silent) alarm, when the radiation intensity exceeds the alarm-threshold. For covert operation, disabling of the audible alarm should be possible. The audible tone should change as a function of dose rate. A display should provide a simple (luminescent) indication, which is proportional to dose rate. This indication serves two purposes, radiation safety, i.e. to warn the officer of greater radiation levels, and as a search tool for locating radiation sources.

4.1.2 Operation

A pocket-type instrument should be worn on the body, pocket, belt or similar location. A self-testing feature should verify proper operation of the instrument before usage. False-alarms, i.e. alarms without radioactive materials present, will occur occasionally due to the fluctuations in background. When the alarm-threshold is set properly, e.g. about three times the natural background level, false-alarms should occur not more than once per day. Radiation triggering innocent alarms may be detected on an occasional basis. This is due to the fact that many objects contain small quantities of radioactive material such as natural thorium or uranium.

4.1.3 Calibration and routine checking

Like most radiation detectors, it is recommended that calibration be once a year by a qualified individual or maintenance facility.

A pocket-type instrument should be checked, on a daily basis 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.

4.1.4 Minimum requirements and test methods

4.1.4.1 Alarm-threshold

The system should provide adjustable threshold levels.

The alarm shall continue to operate in saturation conditions at high dose rates.

The instrument shall clearly indicate an alarm condition. If an alarm has been triggered, the indication shall continue for a specified minimum period which is not shorter than 5 s.

If the instrument provides an audible alarm, this shall be in excess of 85 dB at 30 cm.

4.1.4.2 Sensitivity for gamma radiation

Where the dose rate exceeds the investigation level of 1 μSv/h for a period of 2 s or more, an alarm shall be activated with a probability greater than 99 %. For background dose rates up to 0,2 μSv/h, the false-alarm rate shall be less on average than 2 in a 12 h period.

NOTE One method to verify these minimum requirements can be found in D.2.2.

4.1.4.3 Sensitivity for neutron radiation

If the instrument provides neutron detection capability, the detector shall alarm when exposed to a neutron flux emitted from a ^{252}Cf source of 0,01 μg (approximately 20 000 n/s) for a duration of 10 s, at 0,25 m distance, when the gamma radiation is shielded to less than 1 %. The probability of detecting this alarm condition shall be 50 %. The false-alarm rate shall be less on average than 6 in a 1 h period.

NOTE 1 The neutron dose rate corresponding to the irradiation conditions mentioned above would approximately be in the order of 3 μSv/h.

NOTE 2 One method to verify these minimum requirements can be found in D.3.1.

4.1.4.4 Uncertainty of dose rate indication

If the system provides a quantitative dose rate indication, this indication shall be in accordance with IEC 61526.

4.1.4.5 Environmental conditions

The instrument shall meet the minimum requirements in a temperature range of − 15 °C to + 45 °C and a relative humidity of at least 95 %, for non-condensing conditions.

NOTE One method to verify these minimum requirements can be found in D.4.1.

4.1.4.6 Mechanical and electromagnetic properties

See IEC 61526.

4.2 Hand-held instruments

4.2.1 General

Hand-held radiation monitors are small, battery-powered, instruments that measure the ambient background level and then calculate an alarm-threshold. They may contain microprocessors. Thus, these instruments can compensate for variations in the background level when turned on, or on command. These monitors continuously make short measurements of the radiation level and compare the results to the alarm-threshold. The hand-held monitors can effectively search pedestrians, packages, cargo, and motor vehicles. The hand-held monitor shall be maintenance free, of rugged construction, weather resistant and battery operated with an adequate operation time of at least 12 h. There shall be an indication of the battery condition.

The most significant difference between the hand-held and fixed installed monitors is the human factor that strongly influences the ability of a hand-held instrument to detect radioactive materials in the field. Training is therefore of vital importance. If the officer does not move the monitor in close proximity to any radioactive material that is present, it may not be detected.

The small hand-held instrument can be placed nearer to the radioactive material where the dose rate will be higher, thus yielding high sensitivity to radiation signature. To achieve that sensitivity, officers shall be trained in the proper technique to conduct effective searches, and the training shall be repeated periodically. These instruments should also have the capability to measure dose rate for radiation safety purposes.

4.2.2 Operation

Hand-held monitors are small radiation detection instruments that can be used as either the primary search device or as a second-stage search device for fixed stationary monitors. The monitor should be equipped with an audible alarm to enable the officer to perform the search without watching the device. For search applications, the instrument should have a handle that makes it easy to hold and it should weigh less than approximately 2 kg. The instrument should preferably use a solid state gamma detector. Neutron sensitivity would also be a desirable feature. The capability to distinguish between gamma and neutron alarms is preferable. These instruments shall make measurements on short time scales of approximately 1 s so that they can be used to scan quickly the surfaces of packages, pedestrians, vehicles and cargo. The instruments shall facilitate the localisation of radiation sources by either providing automatic reset of an alarm condition and/or a frequency dependence of the alarm indication on dose rate.

4.2.3 Calibration and routine testing

As for most radiation detectors, it is recommended that calibration be carried out once a year by a qualified individual or maintenance facility.

A hand-held instrument should be checked, on a daily basis 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.

4.2.4 Minimum requirements and test methods

4.2.4.1 Alarm-threshold

The system should provide adjustable threshold levels.

The alarm shall continue to operate in saturation conditions of high dose rates.

The instrument shall clearly indicate an alarm condition. If an alarm has been triggered and the actual dose rate falls below the alarm-threshold, the alarm indication shall be automatically and quickly reset.

If the instrument provides an audible alarm, this shall be in excess of 85 dB in 30 cm.

4.2.4.2 Sensitivity for gamma radiation

Where the dose rate exceeds the investigation level of 0,4 μSv/h for a period of 3 s or more, an alarm shall be activated with a probability greater than 90 %. For background dose rates up to 0,2 μSv/h, the false-alarm rate shall be less on average than 6 in a 1 h period.

NOTE 1 It is desirable that the instruments' response is faster for higher dose rates.

NOTE 2 One method to verify these minimum requirements can be found in D.2.4.

4.2.4.3 Sensitivity for neutron radiation

If the instrument provides neutron detection capability, the detector shall alarm when exposed to a neutron flux emitted from a ^{252}Cf source of 0,01 μg (approximately 20 000 n/s) for a duration of 10 s, at 0,25 m distance, when the gamma radiation is shielded to less than 1 %. The probability of detecting this alarm condition shall be 50 %. The false-alarm rate shall be less on average than 6 in a 1 h period.

NOTE 1 The neutron dose rate corresponding to the irradiation conditions mentioned above would approximately be in the order of 3 μSv/h.

NOTE 2 One method to verify these minimum requirements can be found in D.3.1.

4.2.4.4 Uncertainty of dose rate indication

If the system provides a dose rate indication, this indication shall be in accordance with IEC 60846.

4.2.4.5 Environmental conditions

The instrument shall meet the minimum requirements listed above in a temperature range of − 15 °C to + 45 °C and with a relative humidity of at least 95 %, for non-condensing conditions.

NOTE One method to verify these minimum requirements can be found in D.4.2.

4.2.4.6 Mechanical and electromagnetic properties

Shock-proofing of the instrument is desirable.

See IEC 60846.

4.3 Installed instruments

4.3.1 General

Installed radiation vehicle and pedestrian 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. The use of suitable occupancy sensors is essential for achieving the required low false-alarm rate.

Preferably, gamma and neutron radiation levels should be measured and indicated separately. These monitors automatically search pedestrians or vehicles as they pass through the monitor. These monitors continuously measure the background radiation level and may adjust the alarm-threshold to maintain a constant false-alarm rate.

4.3.2 Operation

4.3.2.1 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. The effectiveness of fixed installed instruments is strongly dependent on its ability to measure the radiation intensity over the entire search area. 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 manning the inspection point. Independent indication of gamma and neutron alarms should be provided.

NOTE The majority of detection will be the result of naturally occurring radioactive materials (e.g. fertilisers, specific varieties of pottery) or out-patients from nuclear medicine departments, see Annex E.

4.3.2.2 Pedestrian monitors

Pedestrian monitors may be installed as single- or dual-sided monitors. Barriers shall be installed to restrict the pedestrian traffic so that passage is within 1,0 m of the monitor. Where pedestrian traffic corridors are larger than 1 m, dual-sided monitors should be installed. The monitor 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 instrument 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 systems which can be used to easily identify the presence of shielding material.

4.3.2.3 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 two-sided monitors are effective in detecting abnormal radiation levels in shipments of metals for recycling, they are much less effective in detecting illicitly trafficked radioactive materials 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 instrument should be placed where the speed of the vehicle is controlled and reduced.

For passenger vehicles, one-sided monitors are acceptable if the maximum passage width is limited to 3 m or less.

For large trucks and buses, two-sided monitors are required and the maximum distance between pillars should be less than 4,5 m (this is dependent on the maximum width of the vehicle to be scanned).

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 vehicle should not be allowed to stop while passing through the monitor. 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 assembly may cause degradation of the assembly or alarm activation.

4.3.3 Calibration and routine testing

The automatic portal monitor shall be calibrated and tested periodically.

Automatic portal monitors should be checked daily with small radioactive 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.

It is recommended that the equipment be inspected and functionally tested once a year by a qualified individual or maintenance facility.

4.3.4 Minimum requirements

4.3.4.1 Sensitivity for gamma radiation

Where the dose rate exceeds the investigation level of 0,3 μSv/h at the reference point of the instrument for a period of 1 s or more and when the monitoring area is occupied, an alarm shall be activated with a probability greater than 99 %. For background dose rates up to 0,2 μSv/h, the false-alarm rate shall be less on average than 1 in 1 000 occupancies.

NOTE 1 Background compensation may be necessary for truck and bus monitoring.

NOTE 2 One method to verify these minimum requirements can be found in D.2.3.

4.3.4.2 Sensitivity for neutron radiation

If neutron detection capability is required, the detector shall trigger alarm when exposed to a neutron flux emitted from a ^{252}Cf source of 0,01 μg (approximately 20 000 n/s) for a duration of 5 s, at 2 m distance, when the gamma radiation is shielded to less than 1 %. The probability of detecting this alarm condition shall be 99 %.

It is recommended that installed systems also have neutron detection capability. If this is the case, the false-alarm rate stated in 4.3.4.1 applies also for the combined system. The neutron dose rate corresponding to the irradiation conditions mentioned above would approximately be in the order of 0.05 μSv/h.

NOTE One method to verify these minimum requirements can be found in D.3.2.

4.3.4.3 Environmental conditions

The monitor shall be able to operate over an ambient temperature range from − 25 °C to + 40 °C, although higher temperatures may occur in enclosed cabinets, especially detector component cabinets. Because of the possibility of these higher temperatures, the test shall be performed over the temperature range from − 25 °C to + 55 °C (see IEC 60068-2-1 and IEC 60068-2-2, respectively). Acceptable operation is indicated by a less than 20 % change in detector count rate with that measured at + 20 °C.

The use of devices to control temperature within individual assemblies is acceptable.

Mains-operated assemblies shall be designed to operate from single phase a.c. supply voltage in one of the following categories in accordance with IEC 60038.

— Series I: 230 V.

— Series II: 120 V and/or 240 V.

The assemblies shall be capable of operating from mains with a supply voltage tolerance of + 10 % to − 15 % and a supply frequency of 47 Hz to 51 Hz in those countries where the frequency is 50 Hz, or 57 Hz to 61 Hz in those countries where the frequency is 60 Hz.

4.3.4.4 Protection of the housing

Additional barriers shall be placed adjacent to the equipment to avoid accidental damage.

4.4 Radionuclide identifiers

4.4.1 General

Radionuclide identification devices are hand-held, battery-powered instruments used for field radionuclide identification by non-experts. The instrument should provide self-calibration based on a (preferably internal) calibration source. The identification of a gamma emitter follows after the detection of an alarm (e.g., by a border monitor or a radiation pager) and the localization of the source, using a portable gamma-search tool. 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.

Most of the radionuclides encountered at borders can be identified by instruments capable of identifying gamma energy peaks between 60 keV and at least 1,5 MeV.

A precise and stable energy calibration which does not change with time, as a function of temperature, battery voltage or count rate is essential for reliable radionuclide identification.

4.4.2 Operation

A low number of radionuclides/gamma lines in a library makes is easier for the software to reach a high detection rate. Compilation, editing, optimizing and testing of the radionuclide libraries used is essential and should be carefully done by the developer or an experienced expert user.

Radionuclides shall be categorized as nuclear materials, industrial radionuclides, medical radionuclides and naturally occurring radioactive materials (NORM), for example:

a) nuclear materials: ^{233}U, ^{235}U, ^{239}Pu, ^{241}Pu;

b) industrial radionuclides: ^{60}Co, ^{137}Cs, ^{192}Ir, ^{226}Ra, ^{241}Am, ^{238}Pu;

c) medical radionuclides: ^{18}F, ^{57}Co, ^{67}Ga, ^{99m}Tc, ^{201}Tl, ^{123}I, ^{125}I, ^{131}I, ^{111}In, ^{192}Ir;

d) naturally occurring radioactive materials (NORM): ^{40}K, ^{226}Ra, ^{232}Th, ^{238}U.

4.4.3 Minimum requirements

4.4.3.1 Radionuclide identification

After energy calibration, the following radionuclides, producing a gamma radiation dose rate at the detector of about 0,5 µSv/h above background shall be identified: ^{57}Co, ^{60}Co, ^{40}K, ^{137}Cs, ^{241}Am.

NOTE Whereas the identification and/or categorization of these radionuclides is a concern, it is also important to ensure the absence of certain radionuclides in the presence of others.

The manufacturer shall state the radionuclides that the instrument can identify and their category.

4.4.3.2 Sensitivity for gamma radiation

If the instrument provides gamma detection capability, the following requirement applies.

Where the dose rate exceeds the investigation level of 0,4 µSv/h for a period of 3 s or more, an alarm shall be activated with a probability greater than 90 %. For background dose rates up to 0,2 µSv/h, the false-alarm rate shall be less on average than 6 in a 1 h period.

NOTE 1 It is desirable that the instrument response is faster for higher dose rates.

NOTE 2 One method to verify these minimum requirements can be found in D.2.4.

4.4.3.3 Sensitivity for neutron radiation

If the instrument provides neutron detection capability, the detector shall alarm when exposed to a neutron flux emitted from a ^{252}Cf source of 0,01 µg (approximately 20 000 n/s) for a duration of 10 s, at 0,25 m distance, when the gamma radiation is shielded to less than 1 %. The probability of detecting this alarm condition shall be 50 %. The false-alarm rate shall be less on average than 6 in a 1 h period.

NOTE 1 The neutron dose rate corresponding to the irradiation conditions mentioned above would approximately be in the order of 3 µSv/h.

NOTE 2 One method to verify these minimum requirements can be found in D.3.1.

4.4.3.4 Environmental conditions

The instrument shall meet the minimum requirements listed above in a temperature range of − 15 °C to + 45 °C and a relative humidity of at least 95 %, for non-condensing conditions.

NOTE One method to verify these minimum requirements can be found in D.4.2.

Annex A
(informative)

Background information

A.1 Strategy for detection

The process leading to the detection of inadvertent movement or illicit trafficking of radioactive materials can be illustrated by the flow diagram in Figure A.1. It has the following main steps:

a) strategic evaluation of the need for border monitoring;

b) selection of instruments;

c) determination of investigation levels;

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

e) evaluation of radioactive material found.

These provide an outline for the various clauses of this International Standard.

This International Standard primarily covers radiological monitoring at borders from a technical and operational viewpoint. A decision as to whether, when or where to establish radiological monitoring at borders should be the result of the development of a comprehensive national strategy for regaining control over radioactive materials.

One of the key factors in the development of a national strategy is the threat analysis. By evaluating historical, political, social, 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 worthwhile 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 border monitoring will be put in place more for political, or public peace-of-mind reasons than because of a rational need based on a significant threat.

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

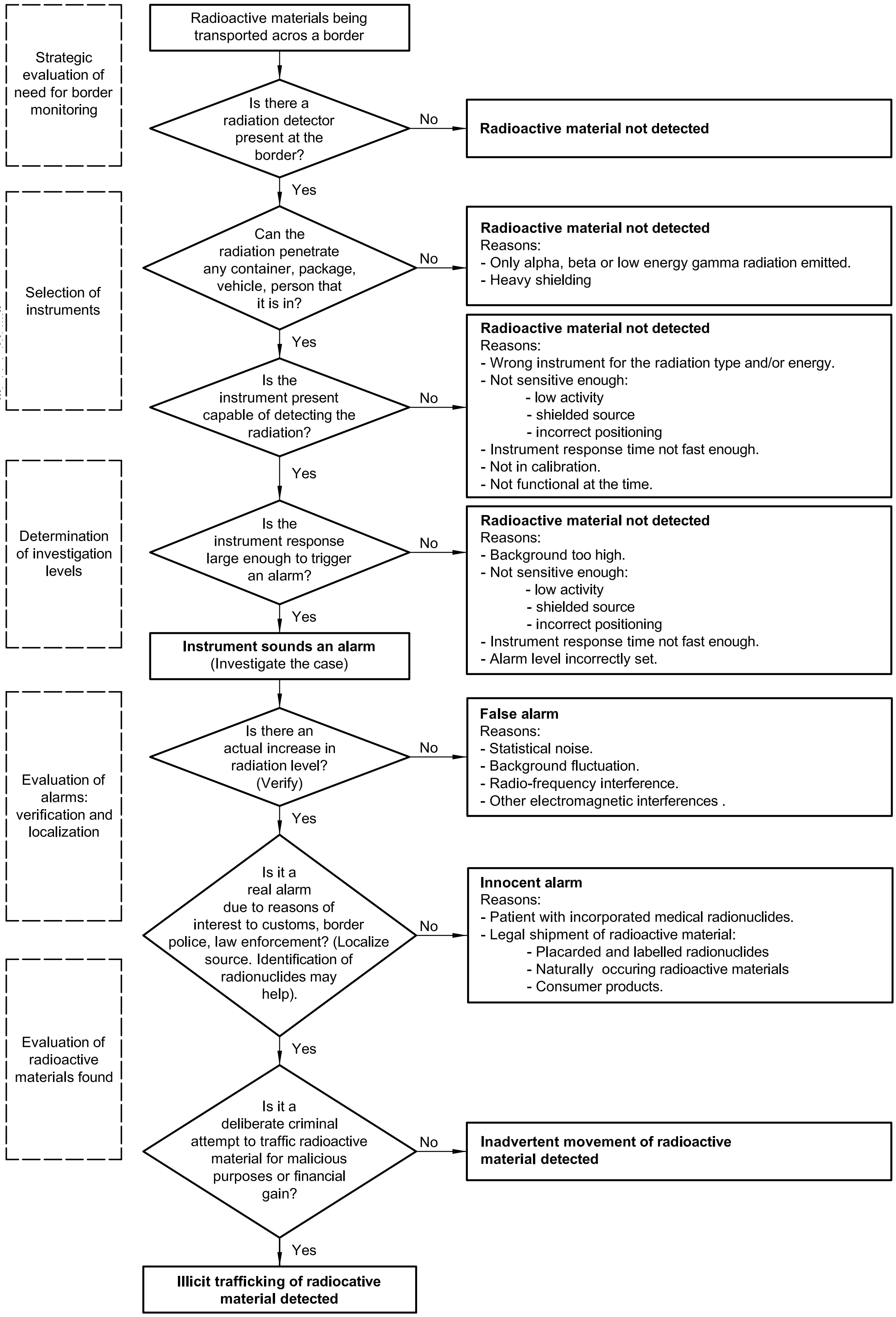


Figure A.1 — Flowchart for the detection of inadvertent movement or illicit trafficking

A.2 False alarms

“Real alarms” are caused by the presence of illicit radioactive or nuclear materials. “False alarms” are due to two different reasons. First, the statistical fluctuations of the background radiation intensity and the inherent (electronic) noise level of the instrument may cause false-alarms. Second, nuisance alarms may also be caused by an actual increase in the radiation intensity as a result of the presence of naturally-occurring radioactive materials (NORM), medical radionuclides administered to patients, and legal shipments of radioactive sources. These alarms can be called “innocent alarms.” The monitoring equipment 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.

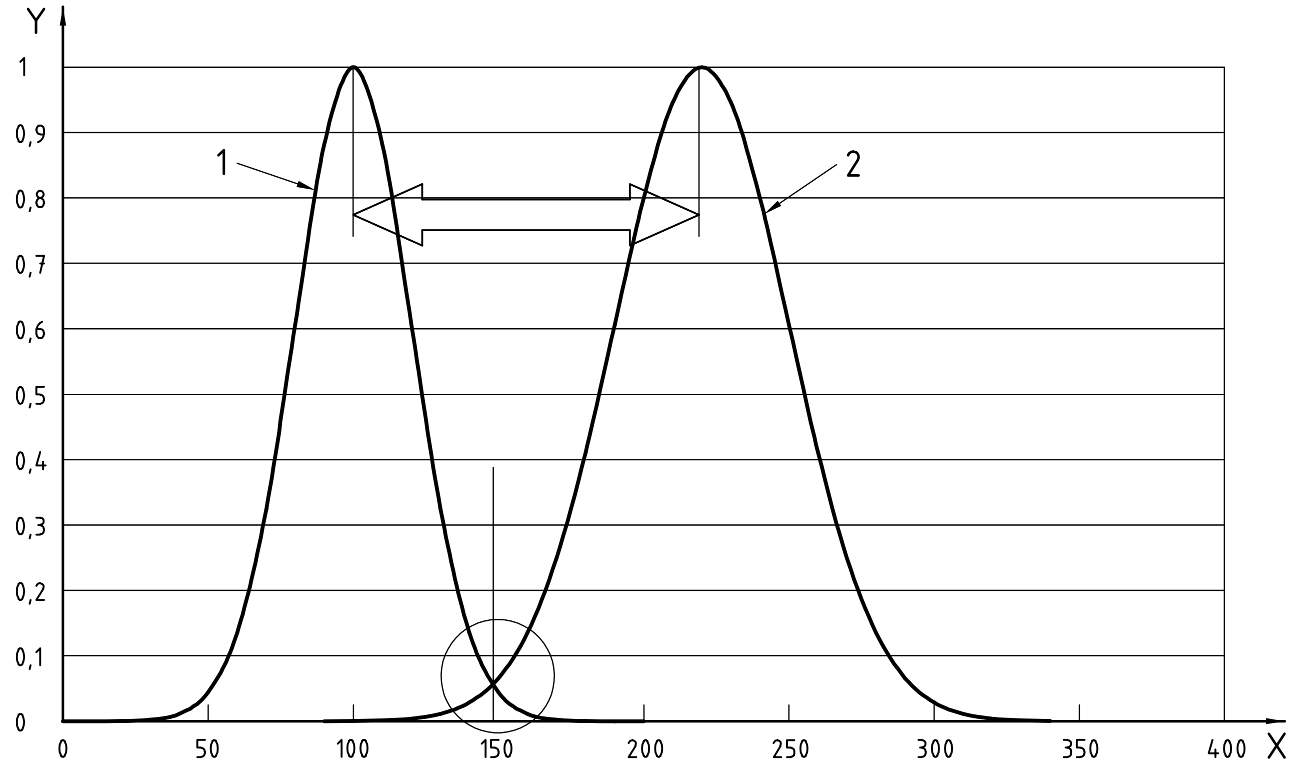
For example, in airline passenger or pedestrian border-crossing environments, the most common radioactive sources likely to be encountered are medical out-patients who have recently received radioactive radionuclides for diagnosis or treatment. Although the radioactive agents used (e.g., iodine for thyroid treatment, thallium for heart stress tests) are generally short-lived, individuals can remain detectable for days or weeks from the residual radioactive materials. 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 in shielding containers, even of high activity, may not be detected at borders without unloading the vehicle, a procedure generally ruled out at borders. Highly sensitive monitoring systems necessarily cause frequent alarms due to innocent radioactive materials, such as naturally occurring radioactivity, e.g. in fertilizers, 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.

A.3 Selection of an investigation level

An “investigation 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 investigation 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 multiple of the standard deviation of the background count rate. This cannot be generally stated, especially if the sensitivity of the detector is low. However, the investigation level chosen shall be set beyond the detection limit of the instrument to make detection possible.

First of all, it shall be understood that the instrument alarm-threshold shall be set considerably below the nominal investigation 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 3 σ below the desired level in order to catch 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.2.



Key

1 background

2 radiation source

X Arbitrary units.

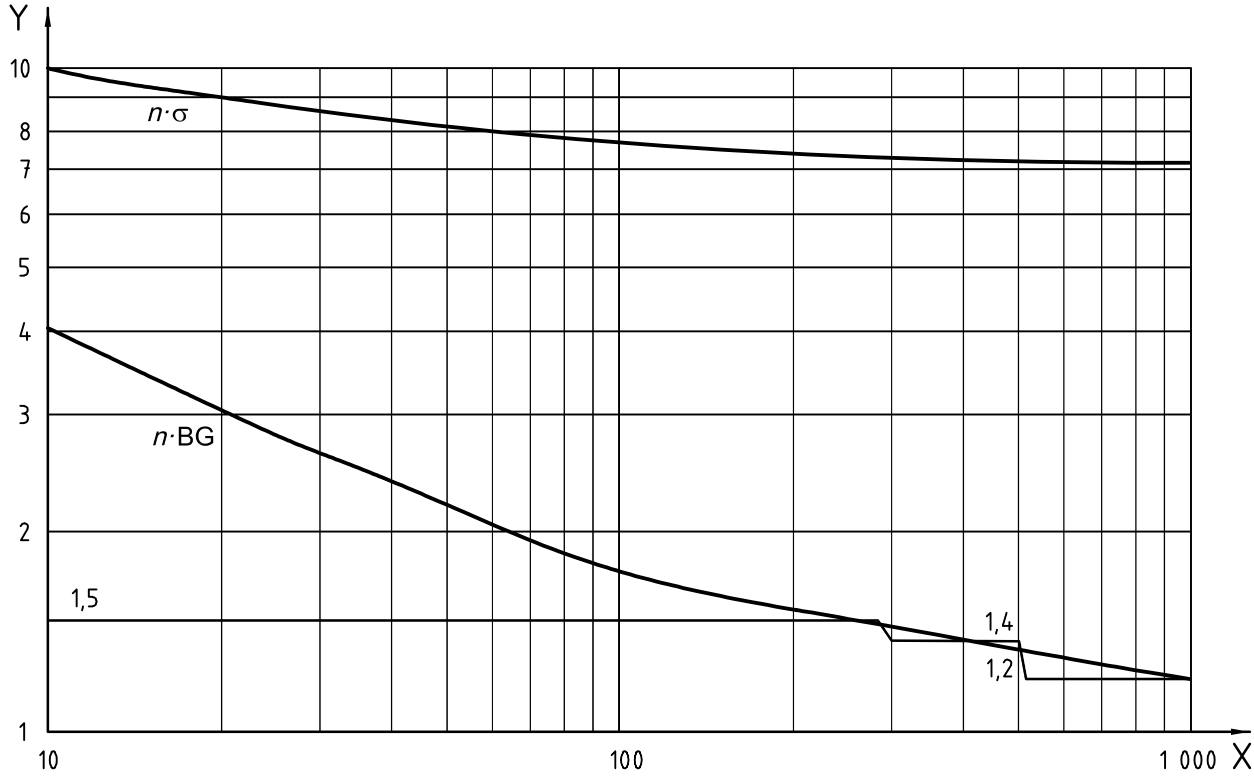
Y Arbitrary units.

Figure A.2 — Overlapping signals from background and radiation source

Recommendations for an optimized investigation level can be derived from results obtained from a large scale pilot study on border monitoring systems, the Illicit Trafficking Radiation Detection Assessment Program (ITRAP). As discussed above, a compromise shall be reached in establishing a practical alarm-threshold so that illicitly trafficked radioactive or nuclear materials may be detected yet provide an acceptably low false-alarm rate. “Innocent” radioactive materials will also trigger the alarms, but the subsequent investigation should disclose this and allow continued movement of the individual or goods.

In the following discussion, the desired investigation level or instrument setting will be 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 characteristic. Real monitors will 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.3 relates the background count rate (abscissa) of large monitoring systems with the lowest possible choice of ‘nominal investigation 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 investigation level in this example. The step function characterises the requirement of monitoring at 50 %, 40 % or 20 % above average background.



Key

X Background count rate (counts per second).

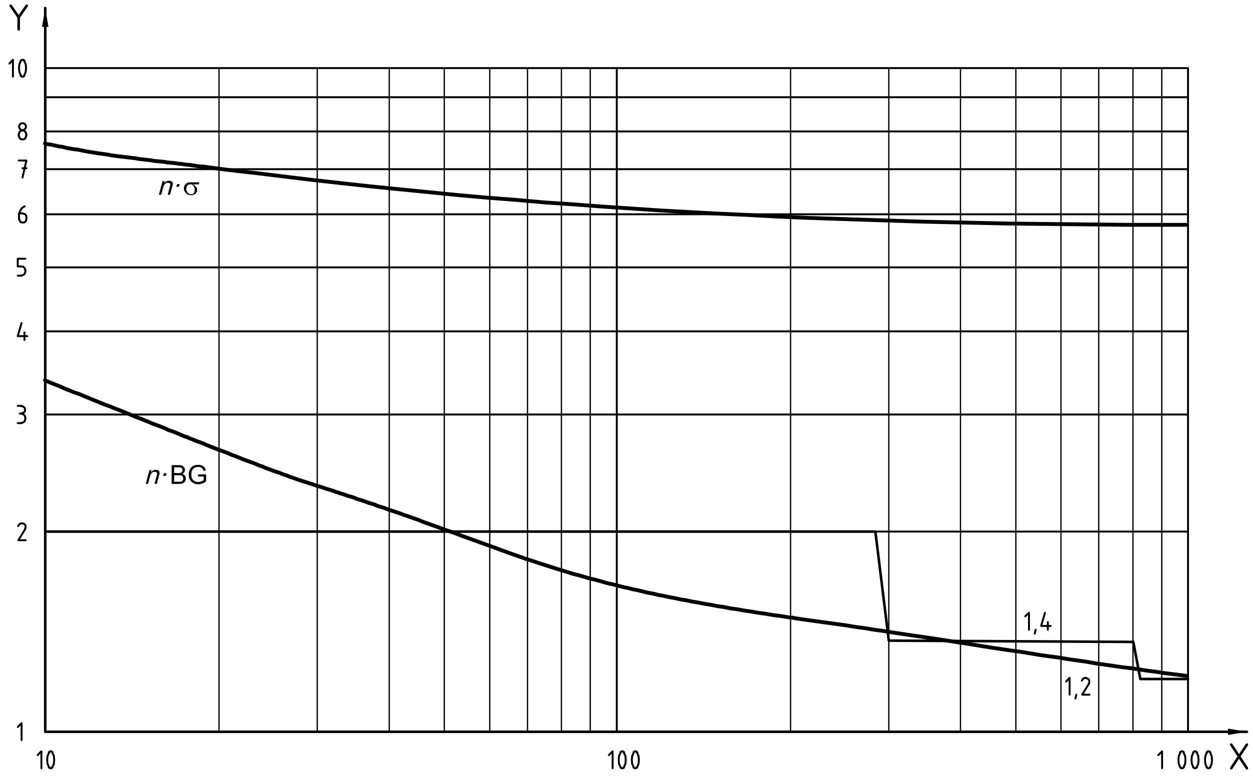
Y Level setting expressed in multiples of background (BG) or sigma (σ).

Figure A.3 — Nominal investigation level setting as a function of background count rate for false-alarm rate 1:10 000 and detection probability 99,9 %

Preliminary results from the ITRAP field tests for truck monitoring indicate that an investigation level of at least 7 σ natural background (corresponding to 1,2 times the natural background at a normal background count rate of 1 000 s^{-1}), is needed to meet the minimum requirements for the false-alarm rate for fixed installed systems. If the investigation level is raised to 1,4 times the background, in addition to fulfilling the false-alarm rate requirements, the frequency of innocent alarms can be decreased approximately by a factor of ten. For example, a truck lane handling some 1 000 trucks per day would see innocent alarms reduced from 10 per day to 1 per day, corresponding to an innocent alarm rate of 1 % per truck to 0,1 % per truck.

For monitoring of pedestrians or cars, where innocent alarms should be caused by medical radionuclides only and are generally not so frequent, a lower investigation level of 1,2 times the natural background is recommended.

The diagram represented in figure A.4 is based on the values adopted in this International Standard for installed systems, namely a detection probability of 99 % (corresponding to 2,5 σ) and a false-alarm rate of less than 1 in 1 000 (corresponding to 3 σ). Consequently, an investigation level of at least 5,5 σ to 6 σ natural background is needed to meet the specifications. The step function characterises the requirement of monitoring at 100 %, 40 % or 20 % above average background.



Key

X Background count rate (counts per second).

Y Level setting expressed in multiples of background (BG) or sigma (σ).

Figure A.4 — Nominal investigation level setting as a function of background count rate for false-alarm rate 1:1 000 and detection probability 99 %

Annex B
(informative)

Radiation monitoring at checkpoints

B.1 General

This annex offers guidance on the selection of instrumentation for deployment at borders (including all locations where goods or individuals may enter a state), and also offers guidance on their use under field conditions where there are operational constraints. It should be noted that the advice refers to radiological detection of radioactive materials, and does not focus on radiological protection issues. The protection of the individuals involved also needs to be considered; however, experience has shown that the likelihood of significant radiological hazards is small.

There are some important points that need to be emphasized at the beginning.

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

b) Secondly, not all instruments detect all types and energies of radiation and therefore, decisions shall be made as to what radioactive materials might be expected and what it is desired to detect. For example, if a State assesses that the relevant threat is from nuclear materials, specialized neutron detection instrumentation will be needed. If this is not considered a threat, then more basic gamma radiation detection instrumentation will probably suffice. Alternatively, both can be installed and set to alarm independently. Detecting a neutron radiation source is a strong indication of the presence of nuclear materials, because significant neutron sources do not exist as naturally occurring radioactive materials or as radioactive materials used in medicine.

c) Thirdly, even if the correct instrument is in place, there are still several reasons why it might not be capable of detecting radiation from radioactive materials crossing the border. A listing of some reasons is given below.

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

   — The instrument response-time characteristics are too slow for the speed at which the instrument and the source pass each other.

   — The instrument might be out of calibration far enough to change its response.

   — The instrument might not be functional at the time.

Within the current subject, instruments of interest can be divided into three categories.

— **Pocket-type instruments** are small, lightweight instruments used to detect the presence of radioactive materials and to inform the investigator about radiation levels.

— **Hand-held instruments** usually have greater sensitivity and can be used to detect, locate or (for some types of instrument) identify radioactive materials. Such instruments may also be useful for making more accurate dose rate measurement in order to determine radiation safety requirements.

— **Fixed installed, automatic instruments** are designed to be installed in checkpoints, such as at road and rail border crossings, airports or seaports. Such instruments can provide high sensitivity monitoring of a continuous flow of persons, vehicles, luggage, packages, and cargo, whilst minimizing interference with the flow of traffic.

B.2 Selection of instruments

B.2.1 Uses of instruments

There are several uses of radiological monitoring instruments that are relevant to this International Standard. Each of these will be a factor in the selection of an appropriate instrument. These purposes can be summarized as follows.

a) **Detection**: An instrument is needed to give an alarm if a certain radiation level is exceeded. Knowledge about the specific radiation level is not necessarily required.

b) **Verification**: Once an alarm has been given, it is necessary to verify that it is a genuine alarm. Use of a different instrument is one way of doing this.

c) **Localization**: A real alarm necessitates searching for and localizing the origin of the radiation. In this instance, it is important to determine the radiation level for radiation safety purposes.

d) **Identification**: Determination of the radiation type and energy will often enable the radionuclide to be identified. This will help in assessing the nature of the event.

B.2.2 Detection

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 three types of instruments in B.2.1 can be used.

Where the traffic of goods, vehicles or people can be funnelled into narrow confines known as "nodal points", fixed, installed, automatic instruments are the preferred option.

Pocket-type and hand-held instruments are particularly useful where operations are conducted in widely dispersed areas such as airports or seaports. For example, pocket-type instruments can be issued to and worn by every law enforcement officer on duty.

Hand-held instruments provide greater sensitivity of detection compared to pocket-type instruments, but they are heavier and usually more expensive. Hand-held instruments are mostly used for detection, in targeted search situations of specified consignments, perhaps when a suspicion of illicit trafficking already exists based on intelligence reports.

B.2.3 Verification

Each detection needs to be verified to exclude false-alarms. Verification involves repeating the measurement process to confirm the initial indication of a radiation field. For pocket-type and hand-held instruments, this would normally involve repeating the examination of the vehicle or person. For fixed installed instruments, it may mean that the vehicle needs to be recirculated through the installation to obtain a repeat measurement. Verification is best done with a different instrument than that used for detection, but it could be done with the same instrument. Under certain conditions, such as when recirculation is not practicable, it may require a different type of instrument to be used.

B.2.4 Localization

Once the detection is verified, the origin of the radiation signal shall be localized. For this purpose, pocket-type 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 the officers and the public. To do this, instruments with dose rate indication are essential.

B.2.5 Identification

Once the origin of the signal is located, it is normally useful to identify the specific radionuclide 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.

Primary identification at border crossings typically requires special hand-held instruments applying gamma spectroscopic techniques to identify the radionuclide. If such equipment is not available, additional expert assistance may be necessary.

Some instrumentation available today combines several of the above-mentioned tasks into one unit.

B.3 Verification of alarms

B.3.1 Categories of alarms

Figure A.1 illustrates the steps involved in the use of radiation monitoring instrumentation for detection of inadvertent movement or illicit trafficking of radioactive materials. Its purpose is to illustrate the process, identify many of the reasons why radioactive materials may not be detected and to introduce the terminology used when discussing alarms.

There are three main types of alarms of primary interest:

- false-alarms;
- innocent alarms;
- real alarms.

False-alarms are caused by the normal, statistical fluctuations of the background radiation intensities and the inherent, electronic noise levels of the instrument. False-alarms can also be caused by nearby radio-frequency interference.

For the purpose of this International Standard, innocent alarms are those that result from an actual increase in radiation level, but for reasons that are not due to inadvertent movement or illicit trafficking of radioactive materials. There are a multitude of potential causes for innocent alarms. It is expected that the majority of actual alarms at borders will be innocent alarms resulting from the presence of medical radionuclides administered to patients, naturally occurring radioactive materials (NORM), and other legal shipments of radioactive materials.

As an example, in airline passenger or pedestrian border-crossing environments, the most common radioactive sources likely to be encountered are people who have recently received radionuclides for medical diagnosis or treatment. Although the radioactive agents used (e.g., iodine for thyroid treatment, or thallium for heart stress tests) are generally short-lived, residual radioactive materials may be detectable for days or weeks after the medical procedure. There is a significant probability of encountering such patients among the travelling public.

Measurement conditions at borders are essentially different from those in nuclear facilities, recycling or disposal facilities. Large traffic volumes crossing major borders limits the time available for detection and multiple checks are usually impractical. Even high activity radioactive sources in shielding containers may not be detected at borders without unloading the vehicle, and such a procedure is not routinely practicable. Highly sensitive monitoring systems necessarily cause more frequent false-alarms or innocent alarms due to such sources as naturally occurring radioactivity in fertilizers or in scale in pipes used in the oil industry. The ITRAP study identified four categories of transported goods that caused innocent alarms, with the highest frequency of 10 alarms per day coming from industrial products and raw material.

The relevant authorities of States determine the limits of allowable activity concentrations, for naturally occurring substances. 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.

The final category of alarms, real alarms, are defined here as being ones that

a) are caused by an actual increase in the radiation intensity, and

b) result from the inadvertent movement or illicit trafficking of radioactive materials.

Making the latter determination normally involves further evaluation of the situation.

Verifying an initial alarm usually involves repeating the measurement under the same conditions and/or using another instrument. A similar response is a good indication that there is a measurable actual increase in radiation levels.

B.3.2 Pocket-type and hand-held instruments

Once a radioactive emitter has been detected, the same or a different instrument can also be used for verification. If an alarm is triggered again, verification is clear, and further investigation is required.

B.3.3 Monitoring of pedestrians and their luggage

A pedestrian causing a portal monitor alarm to be triggered can be passed through the monitor a second time to see if the alarm recurs. If the alarm recurs, it is recommended that the person be separated from any items being carried and that further investigations be made.

A radiation dose rate survey of the person and the person's belongings using a hand-held or pocket-type instrument should be undertaken. If the radiation level is greater than 0,1 mSv/h at 1 m distance, the support of professional radiation safety assistance is recommended. The value of 0,1 mSv/h at 1 m has been selected in view of the fact that this is the limit for legal transport of radioactive materials as detailed in [1].

If the radiation level is below 0,1 mSv/h, a surface scan of the individual and their belongings can be performed using a hand-held radiation monitor. Advice on search techniques is given in Annex C.

If the source of the radiation is determined to be located in one of the carried items, consideration may be given to X-raying the item to determine whether significant gamma shielding is present or not. However, if local assessment suggests that there is a significant probability of trafficking associated with terrorist activity, consideration should be given to other potential hazards. In particular, there may be the possibility of explosive devices being detonated by the action of the X-radiation.

When the source of the radiation has been located, it is useful to identify its energy and thereby determine the radionuclide(s) involved.

If, at any point in the investigation, an alarm is confirmed by any neutron-detection instrumentation, it is strongly recommended that professional radiation safety assistance be requested.

The recommended response measures to be applied when radioactive materials have been detected are described in more detail in [4].

B.3.4 Monitoring of vehicles

When the passage of a vehicle through a fixed installed radiation monitor results in an alarm condition, it will normally be necessary to remove the vehicle from the flow of traffic for further investigation.

Remembering the possibility that the alarm could be caused by residual medical radionuclides, it is useful to ensure that the driver and passengers are removed from the vehicle and scanned separately. At this point, a radiation dose rate survey of the individuals and the vehicle can be performed. As previously described, if the radiation level is greater than 0,1 mSv/h at 1 m, it is recommended that professional radiation safety assistance be requested.

If the radiation level is below 0,1 mSv/h, a surface scan of the vehicle, the driver, passengers or other individuals can be performed using a hand-held radiation monitor according to the search technique given in Annex C.

If, at any point in the investigation, a neutron alarm is confirmed, it is recommended that professional radiation safety assistance be requested. When the source of the radiation has been located, it is useful to identify it as discussed later.

As already mentioned, for truck traffic and cargo containers, the most frequent alarms will be innocent alarms caused by large quantities of naturally occurring radioactive material. For example, large shipments of fertilizer, agricultural produce, tobacco products, some mining ores, porcelain, and timber have been known to cause alarms. However, it should be noted that these radiation signatures are uniformly distributed through the load and therefore, are different from the usually more localized signature of individual sources or trafficked radioactive material.

The recommended response measures are described in more detail in [4].

B.4 Response

B.4.1 Recommendations

B.4.1.1 Control of radioactive materials

Radioactive materials may be considered to be under control when cognisant supervision is maintained by the designated authority over the production, use, storage, transport and disposal of the radioactive materials. Any circumstances, which result in loss of control of radioactive materials, should be treated as an incidence of illicit trafficking until the contrary is proved. More details are given in [2].

B.4.1.2 Situations requiring response

It is anticipated that response measures will either be reactive or proactive, depending upon the circumstances of each incident. In general terms, discovery or disclosure of inadvertent movement or illicit trafficking will require an immediate reactive response while intelligence-based reports of a similar nature will require a proactive response.

A reactive response will be required in the following circumstances:

— through radiation monitoring, a detection of the unauthorized or uncontrolled presence or movement of radioactive or nuclear materials;

— notification of radioactive or nuclear materials having been found in an unauthorized location;

— notification about an object suspected of containing radioactive or nuclear materials;

— notification about an incident involving, or suspected of involving, radioactive or nuclear materials, and where illicit activity is indicated; and

- a discovery of a discrepancy between a customs declaration form and the corresponding shipment of radioactive materials.

NOTE 1 Detection means a conclusion based on measurements and the interpretation that there is a real case of Inadvertent movement of or illicit trafficking.

NOTE 2 Notification is meant to include both formal and casual elements, whether through written reports, oral statements, telephone conversations, and similar communications.

A proactive response will be required in the following circumstances:

- notification about the detection of instances of non-compliance with transport regulations;
- discrepancies found in the inventory of radioactive materials, and
- notification about the inadvertent movement of or illicit movement of radioactive or nuclear materials.

B.4.1.3 Scale of response

An assessment of previous incidents has shown diverse situations ranging from inadvertent or illicit possession of small quantities of radioactive materials, which were relatively harmless, to the possession and trafficking in weapons-grade nuclear materials, which may pose a serious security threat. Irrespective of the severity of the incident, the overriding considerations will be

- to minimize any potential health hazards,
- to bring the radioactive or nuclear materials under appropriate control, and
- to investigate, gather evidence and prosecute offenders.

The scale of the response should be geared to the severity of the individual situation. In cases where there is no significant health hazard, security implication or proliferation threat, front-line officers and the routine response mechanisms of their respective agencies can deal with an incident simply yet effectively.

In a serious incident, there will be a need for a more elaborate response mechanism and the scale of the response will increase. It is therefore appropriate to consider a flexible approach, which can move from the immediate operational requirements into a tactical response mechanism and, on very rare occasions, to a strategic level if the need arises.

B.4.2 Operational response

B.4.2.1 Alarms

States are developing their respective monitoring programmes and deploying radiation detection equipment at locations such as border-crossing points, ports and airports. This equipment will provide an alarm when increased levels of radiation are encountered. More information concerning monitoring equipment, its operational characteristics, and alarms is contained in [3].

B.4.2.2 First information

This section therefore details the immediate response mechanisms to be adopted upon an alarm, which could be from a installed, hand-held or pocket-type radiation monitor. There are other ways in which a First Information Report may be received by a responding agency, such as Intelligence Reports, but in many situations, the use of radiation detection equipment will provide either the first information or confirmation that radioactive materials are present.

An alarm activation should trigger an alert whereby personnel at the scene are made aware of a potentially hazardous situation. The alert process should also result in the Duty Supervisor of the responding agency being informed of the incident and assuming initial command and control functions.

B.4.2.3 Safety considerations

Irrespective of the scale of the incident, response personnel shall always be aware that there may be hazards associated with an incident involving radioactive or nuclear materials. In such cases, the safety of response personnel and the general public is of paramount importance. Response personnel shall be familiar with safety procedures and the measures which can be adopted to mitigate health hazards.

In the unlikely event that a situation arises whereby there are injured individuals at the scene, who may have been contaminated by radioactive materials or exposed to radiation, casualty handling at the scene could be necessary.

B.4.2.4 Actions by the first responder to an alarm

It is assumed that response personnel at the scene will be equipped with radiation detection equipment. This equipment should enable the First Responder to assess the radiological hazard by measurement of the dose rate, and to locate and identify the source. When an alarm is activated as a result of a radiation monitoring programme, the First Responder should report the circumstances of the alarm activation to the Duty Supervisor, giving as much information as is immediately available. The Duty Supervisor should then take action to verify the alarm.

B.4.2.5 Verification procedures

To verify that the alarm is genuine and to confirm the presence of radiation, the First Responder should use a second set of radiation detection equipment. For instance, if a static portal alarm is activated, the First Responder could utilise a radiation pager, hand-held survey meter or some other radiation detection equipment to verify the presence of radiation. If the initial alarm cannot be verified by a second instrument, it may be assumed that the first indication was a false-alarm. If the presence of radiation is confirmed by the verification process, action should then be taken to assess the radiological hazard.

B.4.2.6 Methods to access radiological hazards

To assess the radiological hazard at the scene of an incident, hand-held dose rate meters (survey meters) shall be used. While locating a source, radiological safety is one aspect to be considered, as determined by the dose rate measurement.

B.4.2.7 Location of the radioactive source

The First Responder should act to establish the location of the radioactive material. At this stage, it is sufficient to determine the general location of the source without knowing its exact location. For example, it would be acceptable to determine that the source was confined to a piece of luggage or a vehicle or to something like a large commercial container, where the materials could be isolated if the situation proved to be hazardous. The location of the radioactive material could be determined without opening the item which contains the material. The usual safety and security aspects relevant to response to weapons incidents (e.g., bombs, incendiary devices) apply.

Until such time as a full radiological assessment is made, response personnel shall take precautions to avoid contact with radioactive sources. Although it may not be possible to avoid exposure from external radiation, it should be noted that skin contamination, inhalation and ingestion of radioactive substances may also pose health hazards. Response personnel should therefore avoid eating, drinking and smoking in the immediate area until it is ascertained that they have not been contaminated with radioactive materials.

B.4.2.8 Initial radiological hazard assessment

Having identified the general location of the source, the First Responder may approach the source using a dose rate meter to determine the extent of the radiological hazard and to observe the situation close to the source.

If the First Responder encounters any of the following conditions, the scene should be considered dangerous:

— a reading in excess of 0,1 mSv/h at a distance of 1 m or further from the item containing the source;

NOTE 1 This reading is equivalent to the upper dose limit at 1 m distance from a package used for the legal transport of radioactive materials (transport index 10), as detailed in reference [1].

— any indication that there is neutron radiation present; or

NOTE 2 The presence of neutrons suggests that fissionable or fertile radioactive materials or nuclear materials are present.

— any indication that the packaging or container of the radioactive source has been ruptured or damaged, or that radioactive materials are loose or have been spilled.

In such a situation, the First Responder should primarily ensure the safety of individuals in the vicinity, the isolation of the source and the notification of the situation to the duty supervisor. He should then withdraw to a safe distance from the source.

The level of 0,1 mSv/h at a distance of 1 m has been chosen assuming that the First Responder will be this close to the source for only a brief time. Lower levels may be set according to national regulations.

An assessment of previous incidents has shown that the majority are of a minor nature with little or no radiological hazard. These can be dealt with at an operational level without the necessity to activate a Tactical Response or an Emergency Response Plan.

B.4.2.9 Identification

If it has been established that there are no significant radiological health hazards associated with an incident, the next action of front-line officers should be to identify the radioactive source. At this stage, it is possible that the suspect source may be identified as an innocent source. If that occurs, front-line officers should record the details and terminate their response.

B.4.2.10 Illicit trafficking

If it is determined that it is a case of illicit trafficking, the First Responder should consider the gathering of evidence at the scene to support a future criminal prosecution. If it is ascertained that the radioactive materials are nuclear materials, those materials shall be seized, contained securely under constant surveillance by guards, and the relevant competent authorities notified immediately.

To ascertain if there are any circumstances which indicate inadvertent or illicit activity, it should be noted that, in nearly all cases of legal transportation of radioactive materials, the persons responsible for the shipments should be in possession of authentic documentation to support the transportation. The materials should be labelled and packaged in accordance with the regulations governing the transportation of radioactive materials and, most importantly, the radiation levels should be within the acceptable levels for the transportation of such materials. It should also be noted that specific regulations exist for the physical protection of nuclear materials.

NOTE See references [1] and [11].

It therefore follows that the lack of documentation, incorrect labelling, inadequate packaging, levels of radiation above the acceptable levels, or radiation levels significantly different from those specified in the documentation should be treated as suspicious and an indicator of illicit activity.

If the materials are confirmed to be of an illicit nature, but not hazardous, front-line officers should seize the items and arrange temporary storage.

If it is ascertained that the radioactive materials arise from an innocent source, such as medically administered radionuclides, natural radiation not exceeding accepted levels or legal shipments of radioactive materials, then front-line officers should record details of the incident and terminate the response procedures.

B.4.2.11 Incident investigation

In all incidents of illicit trafficking in or inadvertent movement of radioactive materials, it will be necessary to conduct an investigation into the circumstances of the case. However, it is accepted that there may not be a requirement for a prolonged or detailed investigation into minor incidents, particularly so if the source of the materials can be identified and there are no further matters of concern arising from the incident.

B.4.2.12 Legal process

Depending upon national legislation, and the circumstances of the incident, it may be necessary to prosecute certain individuals. As a consequence, the investigation procedures should then be geared to the legal requirements of the judicial process of the State involved. It should be noted that, in certain countries, there are different regulations and legal requirements governing nuclear materials, as opposed to other radioactive substances and investigators shall take due cognisance of the local situation.

In order to corroborate the legal process, an expert opinion may be required to verify the presence, quantity and nature of the radioactive material, as well as other details, such as the degree of danger caused by the incident.

B.4.2.13 Notification to the duty supervisor

The First Responder at the scene should observe and report the situation to the Duty Supervisor. From initial observations at the scene, the First Responder should, in addition to standard routine information also be able to provide the following information relating to the radiological assessment:

— measurements taken during the initial radiological assessment;

— the presence of packages bearing radiation warning symbols;

— the type of packaging of the radioactive materials;

— the condition of the packaging and whether the packaging appears to be damaged or breached;

— any labelling or other information to indicate the nature of the suspect materials.

B.4.2.14 Expert advice

The use of radiation detection equipment requires specialized training and technical knowledge. In the event that front-line officers are unable to conduct an initial radiological hazard assessment, or deem 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] and should be contained in the State's Tactical Response Plan. This individual should automatically be deployed to the scene if a dangerous radiological 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.

B.4.2.15 Incident level

The Duty Supervisor should consider the scale of the incident and initiate a tactical response if it is deemed necessary. If the situation is one which comes within the scope of a dangerous radiological incident, the Duty

Supervisor should activate a Tactical Response Plan if he has authority to do so, or, if necessary, seek authorization from a pre-designated senior officer.

Annex C
(informative)

Search techniques

C.1 General search preparation

Clearly the verification of an alarm and the searching for the radioactive material can be one continuous process even though they are discussed separately in this document. Each of them involves a radiation survey with a portable instrument. It should be noted that this section only describes the general principles of searching, since individual instruments vary in their features.

Since the presence of radiation is not detectable by our human senses, it is important to check the operability of any instrument before its use. Manufacturer's suggested procedures should be used. Typically they will involve a battery check and a response check to a small radioactive source. In addition, the average background radiation level needs to be noted. All of this preparation is best undertaken away from the intended search area. Initial functional checks and background measurement are reliable only if they are performed in a representative normal background. This is especially important for some modern instruments that measure the ambient background level and automatically adjust alarm-thresholds. These checks would normally only take 10 s to 30 s, and the search may then be started.

Regardless of the hand-held search instrument used, including pocket-type instruments, the effectiveness of the procedure depends on the quality of the search technique. Different techniques are recommended below for searching pedestrians, packages, vehicles or cargo.

When searching, automated instruments may occasionally indicate very brief signals above the alarm-threshold. This is because instruments of this type continuously measure the radiation field in very short counting-time intervals. Most of the measured values are near the background level, but a few may exceed the alarm-threshold due to statistical effects of counting. Therefore, single alarms during the scanning process are not significant. Significant alarms are those that are multiple and reproducible.

To conduct a thorough, effective search, the monitor shall be scanned over the surface of the individual, package or vehicle. When the instrument senses a radiation level that is significantly above background, it will indicate this in some way, depending on its design features. Many modern instruments alarm with a series of "beeps". This allows the user to concentrate on the search instead of watching a meter face.

It is important that, during scanning, the instrument is maintained at a close distance to the surface (approximately 5 cm to 10 cm) without making contact. In addition, instruments are typically more sensitive if they are moved slowly over an area. However, there is a trade-off with the length of time that a survey might take. A reasonable guide would be to move the detector, or its probe at about 20 cm/s.

The nearer that a monitor comes to a radioactive source, the greater the radiation intensity and the easier it is to find the material. To localise the radioactive material, the user should follow the direction of increasing intensity, that is, more frequent beeps until the maximum level is found. A rapidly varying dose rate as the instrument is moved would be an indicator of an individual radiation source. On the other hand, a small change in an elevated reading would indicate a larger volume of material such as a naturally radioactive bulk ore shipment.

C.2 Pedestrian search

It is recommended that a pedestrian carrying bags or packages be separated from these items before searching so that they may be searched independently.

To perform a reasonable radiation search of an individual, will typically take about 20 s to 30 s. This is enough time to search the individual’s front, back and sides if the speed and distance guide given below is used.

The following systematic search pattern is recommended. Starting near one foot, continue up one side of the body to the head, then scan down the other side. Then ask the individual to make a quarter turn and repeat the pattern on the front and back. A scan from head to foot will take about 4 s to 5 s. Hence, each up and down scan will take about 8 s to 10 s. Turning takes a few more seconds, giving a total of about 20 s. These timings are considered to be the minimum, but will enable a reasonable search when a large number of people need to be scanned.

C.3 Package and cargo search

It is important that the items people commonly carry, such as briefcases, purses, packages and luggage are searched as a separate procedure from the search of the individual. This will help to ensure that a systematic and complete search is achieved. Each item is best searched by passing the monitor over its surface at a rate similar to that used on people.

Where legal powers allow law enforcement officers to do so, it is useful to ask the person to open large items for a visual search. It is recommended that bulky, heavy objects be assessed and searched if it is considered that they may be radiation shields.

If a package is sealed and cannot be opened for a visual search, a slower external search of all accessible sides with the instrument will increase the probability of detecting any radioactive material that may be inside.

Law-enforcement officers need to think broadly about all risks when searching for nuclear or other radioactive material. For example, the package could also contain explosive or other hazardous material and may need to be handled with appropriate caution.

C.4 Motor vehicle search

C.4.1 General

Motor vehicles are more challenging to search than people or packages. The search is a much longer procedure, due to the materials and complexity of the structure of the vehicle, and the need to search people in the vehicle and any items carried by them as separately.

Although instrumentation is essential in these searches, it is important to remember that a visual search is also a key part of the search process. Large, heavy containers merit very careful scans with the monitor as they may be shielding radioactive material contained within. More careful scans usually mean moving the instrument probe slower and keeping it closer to the object of interest.

In addition, large heavy structures can shield the path of gamma radiation and block their passage, just as objects in the path of light create a shadow. It follows that it is important to look for shields that are in the path of any radiation that may be originating from behind the item, rather than within it. Effective shielding materials include thick metal, brick and concrete, and for neutrons, substantial quantities of polythene, plastic or water.

C.4.2 Search of personnel and their effects

It is recommended that the occupants be searched as well as the vehicle. A systematic and complete search of the occupants can only be achieved if the occupants disembark from the vehicle, and stand away from it, and the procedure described in C.2 is followed. Similarly, belongings such as briefcases, purses or packages need to be surveyed as in C.3.

C.4.3 Hood area search

A search under the vehicle's hood can be achieved by moving the monitor within 15 cm of all surfaces that can be reached, including the hood itself.

C.4.4 Trunk and interior search

A search of the vehicle's trunk and interior can be performed if a systematic approach is taken. Enter through each door and search around every object and surface within reach. Scan unlikely places, such as the dashboard, sun-visor, headliner area, floor, and under the seats. Search the space behind the rear seat. Search the cargo areas in trucks. Areas that cannot be reached on the inside may be able to be searched from outside the vehicle.

It may be useful to note that glass is a less effective shield than metal, and so it could be more appropriate to search at windows than parts of the metal structure. It is recommended that the aim should be to keep the monitor within 10 cm of every surface. Extra time taken when searching a vehicle improves the probability of detecting any radioactive material that may be present.

C.4.5 Exterior search

It is recommended that a search of the outside of a vehicle includes checking under frame rails and bumpers as well as the wheel wells in front and behind the tyres.

C.4.6 Truck beds

It is recommended that the bed of trucks be searched, even if it appears to be empty. This is because a container of radioactive material may be attached to the under-surface.

C.4.7 Large trucks

Large vehicles, such as step vans, flatbed trucks, dump trucks, garbage trucks, and many other large trucks present a particular challenge. In fact, the ITRAP study even concluded that detailed searching of large trucks with hand-held instruments is not practical. It recommended a more sophisticated fixed installation system for such search purposes. Nevertheless a hand-held instrument search of some areas of the vehicle can still be achieved. It is helpful to have a stepladder or step-stool to reach high places. Alternatively, a detector could have its cable extended and then be attached to the end of a long pole. A search of accessible spaces can be augmented by a search of the exterior of any inaccessible spaces.

Annex D
(informative)

Recommended test methods

D.1 General

The following compilation of test methods is provided for informative purposes.

D.2 Sensitivity for gamma radiation

D.2.1 General

The requirement for the alarm probability should be tested with ^{241}Am, ^{137}Cs and ^{60}Co in a gamma energy range from 60 keV to 1,3 MeV.

For the purpose of testing, the following arrangement should be used depending on the category of instrument.

D.2.2 Pocket-type instrument

The unit shall be exposed to a dose rate resulting in a uniform field encompassing the instrument and of duration 2 s. An alarm should ensue. After approximately 1 min, to allow resetting of the alarm and return to background conditions, the exposure shall be repeated.

The 99 % detection probability shall be verified by one of two methods.

a) At least 1 000 exposure cycles at a nominal alarm-threshold of 1 µSv/h shall result in no more than 10 failures (i.e. unregistered alarms).

b) The manufacturer provides documentation stating that the following requirements are satisfied:

- detailed specification of the instrument alarm-threshold setting, which shall be set for the purpose of this test approximately 2,5 σ below the nominal alarm-threshold of 1 µSv/h (e.g. 0,7 µSv/h);

- information on statistical variation of the instrument response at nominal alarm-threshold setting (i.e. 1 µSv/h), based on at least 100 evaluations of similar instruments, and specification of average σ for this type of instrument at the nominal alarm-threshold;

- verification that the instrument alarm-threshold setting complies with the requirement to be at least 2,5 σ below the nominal alarm-threshold (99 % one-sided probability corresponds to 2,33 σ under Gaussian assumptions);

- there shall be 30 consecutive exposure cycles with a uniform dose rate corresponding to the instrument alarm-threshold setting (e.g. 0,7 µSv/h) with at least 16 detections (not more than 14 unregistered alarms), corresponding to 50 % detection probability at 50 % confidence level.

The verification of the requirement for the false-alarm rate should be tested by the following test method. The equipment shall be operated in an elevated background dose rate (^{137}Cs) of 0,2 µSv/h ± 10 % for a minimum of four 12 h periods and a maximum of 14 12 h periods. If, at any time after four 12 h periods the false-alarm rate is less than 2 per 12-h-period, the equipment shall be deemed to pass the test. If, after 14 12 h periods, 28 or more alarms are given, the equipment has failed the test.

D.2.3 Installed instruments

The equipment shall be operated in an elevated background dose rate (^{137}Cs) of 0,2 µSv/h ± 10 %. The unit shall be exposed to dose rate pulses resulting from a source at least 3 m away and of duration 1 s, yielding a total dose rate at the reference point of the detector of 0,3 µSv/h. An alarm should ensue. After approximately 1 min, to allow resetting of the alarm and return to background conditions, the exposure shall be repeated.

The 99 % detection probability shall be verified by one of two methods.

a) At least 1 000 exposure cycles at a nominal alarm-threshold of 0,3 µSv/h shall not result in more than 10 failures (i.e. unregistered alarms);

b) The manufacturer provides documentation stating that the following requirements are satisfied:

— detailed specification of the instrument alarm-threshold setting, which shall be set for the purposes of this test approximately 2,5 σ below the nominal alarm-threshold of 0,3 µSv/h (e.g. 0,27 µSv/h);

— information on statistical variation of the instrument response at nominal alarm-threshold setting (i.e. 0,3 µSv/h), based on at least 100 evaluations of similar instruments, and specification of average σ for this type of instrument at the nominal alarm-threshold;

— verification that the instrument alarm-threshold setting complies with the requirement to be at least 2,5 σ below the nominal alarm-threshold (99 % one-sided probability corresponds to 2,33 σ under Gaussian assumptions);

— the equipment shall be operated in an elevated background dose rate (^{137}Cs) of 0,2 µSv/h ± 10 %. The unit shall be exposed to 30 consecutive dose rate pulses resulting from a source at least 3 m away and of duration 1 s, yielding a cumulative dose rate at the reference point of the detector corresponding to the instrument alarm-threshold setting (e.g. 0,27 µSv/h) with at least 16 detection (not more than 14 unregistered alarms), corresponding to 50 % detection probability at 50 % confidence level.

The requirement for the alarm probability shall be fulfilled where the increase in dose rate is due to gamma radiation of ^{241}Am, ^{137}Cs and ^{60}Co in a gamma energy range from 60 keV to 1,3 MeV.

The variation in response along the detector shall be determined by moving a ^{241}Am source from floor level (0 m) to 2 m for pedestrian and car monitors and from 0,7 m to 4 m for truck and bus monitors parallel to the detector at a distance of 20 cm for pedestrian monitors and 50 cm for vehicle monitors from the detector. Readings shall be taken every 10 cm. No response shall be less than 25 % of the maximum response.

The verification of the requirement for the false-alarm rate shall be tested by the following test method. The manufacturer shall demonstrate theoretically that the required false-alarm rate is achievable but, with a test of at least 100 consecutive occupancies, there shall be no false-alarm.

NOTE The occupancies can be simulated by electronically activating the occupancy sensor.

D.2.4 Hand-held instruments and radionuclide identifiers

The unit shall be exposed to a dose rate resulting in an uniform field encompassing the instrument and of duration 3 s. An alarm should ensue. After approximately 1 min to allow resetting of the alarm and return to background conditions, the exposure shall be repeated.

The 90 % detection probability shall be verified by one of two methods.

a) At least 100 exposure cycles at a nominal alarm-threshold of 0,4 µSv/h shall result in no more than 10 failures (i.e. unregistered alarms).

b) The manufacturer provides documentation stating that the following requirements are satisfied:

- detailed specification of the instrument alarm-threshold setting, which shall be set for the purpose of this test at approximately 1,4 σ below the nominal alarm-threshold of 0,4 μSv/h (e.g. 0,3 μSv/h);
- information on statistical variation of the instrument response at nominal alarm-threshold setting (i.e. 0,4 μSv/h), based on at least 100 evaluations of similar instruments, and specification of average σ for this type of instruments at the nominal alarm-threshold;
- verification that the instrument alarm-threshold setting complies with the requirement to be at least 1,4 σ below the nominal alarm-threshold (90 % one-sided probability corresponds to 1,281 6 σ under Gaussian assumptions);
- there shall be 30 consecutive exposure cycles with a uniform dose rate corresponding to the instrument alarm-threshold setting (e.g. 0,3 μSv/h) with at least 16 detections (not more than 14 unregistered alarms), corresponding to 50 % detection probability at 50 % confidence level.

The verification of the requirement for the false-alarm rate shall be tested by the following test method. The equipment shall be operated in an elevated background dose rate (^{137}Cs) of 0,2 μSv/h ± 10 % for a minimum of four 1 h periods and a maximum of 14 1 h periods. If, at any time after four 1 h periods, the false-alarm rate is less than 6 per 1 h period, the equipment shall be deemed to pass the test. If, after 14 1 h periods, 84 or more alarms are given, the equipment has failed the test.

D.3 Sensitivity for neutron radiation

D.3.1 Pocket-type instruments, hand-held instruments and radionuclide identifiers

The 50 % detection probability should be verified by the following arrangement. 30 consecutive exposure cycles with the gamma-shielded ^{252}Cf source equivalent 0,01 μg at 0,25 m distance for a duration of 10 s with at least 16 detections (not more than 14 unregistered alarms).

The verification of the requirement for the false-alarm rate should be tested by the following test method. The equipment shall be operated in an elevated background dose rate (^{137}Cs) of 0,2 μSv/h ± 10 % for a minimum of four 1 h periods and a maximum of 14 1 h periods. If, at any time after four 1 h periods, the false-alarm rate is less than 6 per 1 h period, the equipment shall be deemed to pass the test. If, after 14 1 h periods, 84 or more alarms are given, the equipment has failed the test.

D.3.2 Installed instruments

The 99 % detection probability shall be verified by the following arrangement. At least 1 000 exposure cycles with the gamma-shielded ^{252}Cf source equivalent 0,01 μg at 2 m distance for a duration of 5 s and not more than 10 failures (i.e. unregistered alarms).

D.4 Environmental conditions

D.4.1 Pocket-type instruments

D.4.1.1 Warning assemblies with no indication of dose rate

In the case of warning assemblies with no indication of dose rate, the following test should be performed.

The warning assembly shall be placed in an environmental chamber and exposed to a dose rate of 0,2 μSv/h, and with the temperature set to 45 °C for a period of 4 h; no more than two alarms shall occur. Where the alarm condition locks, it shall be reset as soon as it occurs. After the period of 4 h is complete the assembly shall be exposed to a dose rate of 1 μSv/h for a period of 15 min with the temperature remaining at 45 °C; the alarm shall operate continuously. At the end of this period, the temperature shall be decreased to – 15 °C; the alarm shall continue and shall also continue for a period of at least 15 min after the temperature has stabilized between – 10 °C and – 15 °C. The dose rate at the assembly shall be reduced to 0,2 µSv/h. If necessary the alarm shall be reset. No more than two alarms shall occur during the next 4 h. Any locked alarms shall be immediately reset. The assembly shall be removed from the environmental chamber, no more than one alarm shall occur in the next hour.

D.4.1.2 Assemblies with indication of dose rate

If the device has a dose rate indication, the dosemeter shall be exposed to a reference source providing a sufficient indication under standard test conditions for the test to be carried out.

a) Then the temperature shall be maintained at each of its extreme values for at least 4 h, and the indication of the dosemeter measured during the last 30 min of this period. The limits of variation of indication shall be within ± 10 %.

b) The dosemeter shall be placed in a temperature of 20 °C ± 2 °C and allowed to stabilize for a minimum of 60 min. The dosemeter shall be exposed in a reproducible geometry to the reference source of sufficient intensity to minimize the effect of statistical fluctuations of the dosemeter readings and to produce an indication in approximately the middle of the second least significant order of magnitude of the effective range of measurement. The mean dosemeter reading shall be determined after a sufficient number of readings have been taken. The dosemeter and the source shall be removed from this environment and placed directly into an environmental chamber such that the same exposure geometry is established and the temperature near the dosemeter is maintained between 45 °C and 50 °C. This procedure shall be performed in less than 5 min. The mean dosemeter reading shall be determined at this point, and then every 15 min for 2 h. If the dosemeter does not fail the test within the first hour, data do not need to be taken during the second hour; however, the dosemeter should remain in this environment during the period required to reach temperature stabilization. The dosemeter and source shall be removed from the environmental chamber and returned to the first environment such that the same exposure geometry is established and the temperature near the dosemeter is 20 °C ± 2 °C. This procedure shall be performed in less than 5 min. The mean dosemeter reading shall be determined at this point and then every 15 min for 2 h. If the dosemeter does not fail within the first hour, data do not need to be taken during the second hour; however, the dosemeter should remain in this environment during the period required to reach temperature stabilization.

The test shall be repeated with the temperature inside the environmental chamber maintained between – 10 °C and – 15 °C.

D.4.2 Hand-held instruments and radionuclide identifiers

See D.4.1.2.

Annex E
(informative)

Examples of naturally occurring radioactive materials

One of the reasons for alarms in border monitoring are radionuclides occurring in nature. The most frequently naturally occurring radionuclides are ^{40}K, U-nat (^{226}Ra) and Th-nat (^{232}Th) in equilibrium with its daughter products.

Table E.1 — Frequently observed materials containing naturally occurring radionuclides

Substance	Approximate activity concentration Bq/kg		
	^{40}K	^{226}Ra	^{232}Th
Fertilizers	40 — 8 000	20 — 1 000	20 — 30
Granite	60 — 2 000	30 — 500	17 — 310
Adobe	300 — 2 000	20 — 90	32 — 200
Slate	500 — 1 000	30 — 70	40 — 70
Sandstone	40 — 1 000	20 — 70	20 — 70
Marble	40 — 200	4 — 40	2 — 100
Feldspar	2 000 — 4 000	40 — 100	70 — 200
Monazite sand	40 — 70	30 — 1 000	50 — 3 000
Concrete	50 — 1 600	20 — 500	20 — 70
Cement	< 40 — 700	10 — 330	10 — 200

Additional substances that might contain radioactive materials are

— thoriated tungsten welding electrodes,

— refractory materials,

— irradiated gem stones (natural base material containing artificial radionuclides),

— camera lenses,

— polishing powder,

— thoriated glasses,

— coloured ceramic glazes,

— incandescent gas mantles,

— bananas, marihuana (containing ^{40}K).

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