IAEA Nuclear Security Series No. 1

Technical Guidance

Reference Manual

Technical and Functional Specifications for Border Monitoring Equipment

IAEA

International Atomic Energy Agency

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TECHNICAL AND FUNCTIONAL SPECIFICATIONS FOR BORDER MONITORING EQUIPMENT

REFERENCE MANUAL

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IAEA NUCLEAR SECURITY SERIES No. 1

TECHNICAL GUIDANCE

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REFERENCE MANUAL

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FOREWORD

Illicit trafficking of nuclear and other radioactive material has been an issue of concern since the first seizures in the early 1990s. By the end of 2004 Member States had confirmed 540 cases, while about another 500 remain unconfirmed. Most of the confirmed cases have a criminal dimension, even if they were not for known terrorist purposes. The attacks of September 2001 in the USA dramatically emphasized the requirement for the enhanced control and security of nuclear and other radioactive material. In response to a resolution by the IAEA General Conference in September 2002 the IAEA has adopted an integrated approach to protection against nuclear terrorism. This brings together IAEA activities concerned with the physical protection of nuclear material and nuclear installations, nuclear material accountancy, detection and response to illicit nuclear trafficking, the security and safety of radioactive sources, emergency response measures — including pre-emergency measures in Member States and at the IAEA — and the promotion of State adherence to relevant international instruments.

States have the responsibility for combating illicit trafficking and the inadvertent movements of radioactive material. The IAEA cooperates with Member States and other international organizations in joint efforts to prevent incidents of illicit trafficking and inadvertent movements and to harmonize policies and measures by providing relevant advice through a range of technical assistance and documents. In this context the IAEA issued a group of three technical documents, co-sponsored by the World Customs Organization, Europol and Interpol, on the inadvertent movement and illicit trafficking of radioactive material. The first is Prevention of the Inadvertent Movement and Illicit Trafficking of Radioactive Material (IAEA-TECDOC-1311), the second is called Detection of Radioactive Material at Borders (IAEA-TECDOC-1312) and the third is Response to Events Involving the Inadvertent Movement or Illicit Trafficking of Radioactive Material (IAEA-TECDOC-1313).

The present publication provides a set of technical specifications that can be used in design testing, qualifying and purchasing border radiation monitoring equipment. Due to advances continually being made in the field of border radiation monitoring equipment they represent a consensus on the minimum specifications presently achievable. This report is based on work undertaken through an IAEA Coordinated Research Project (CRP) on Improvement of Technical Measures to Detect and Respond to Illicit Trafficking of Nuclear and other Radioactive Material. It includes contributions from the participants in the research coordination and technical meetings held in December 2003 and October 2004. Other relevant national and international standards were taken into account. The work undertaken by

the participants in the CRP and other contributors to this endeavour is gratefully acknowledged.

The preparation of this publication in the IAEA Nuclear Security Series has involved extensive consultations with Member States. As a final step, the draft was circulated to all Member States to solicit further comments and suggestions before publication. The IAEA officer responsible for this publication was R. Arlt of the Division of Technical Support, Department of Safeguards.

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1. INTRODUCTION

1.1. BACKGROUND

The development of the specifications for border radiation monitoring equipment originates with an illicit trafficking radiation detection assessment programme (ITRAP) pilot study in February 2000 [1], and a project to test border radiation monitoring systems jointly conducted by the IAEA and the Austrian Research Centre Seibersdorf during the years 1997–2000. The project was funded by the Austrian Government and co-sponsored by the IAEA, the World Customs Organization and Interpol. The ITRAP minimum requirements evolved from numerous project meetings and IAEA Technical Committee meetings with representatives of over 30 Member States. Twenty-nine manufacturers of border monitoring equipment from nine countries participated in the laboratory and field tests. During the ITRAP test period extensive discussions based on test results led to significant revisions of the original version of this publication. The following milestones mark the further evolution of the specifications:

(a) Workshop on Border Monitoring Equipment, Los Alamos, NM, USA, April 1999
(b) Workshop on Border Monitoring Equipment, Vienna, Austria, January 2002
(c) Research Coordination Meeting, Vienna, Austria, April 2002
(d) Consultants Meeting, Vienna, Austria, March 2003
(e) Workshop, EU Joint Research Centre, Ispra, Italy, April 2003
(f) Research Coordination and Technical Meeting, Vienna, Austria, December 2003
(g) Research Coordination Meeting, Sochi, Russian Federation, October 2004.

The present publication is the final set of minimum specifications produced after comprehensive internal and external reviews of draft versions. It includes comments from previous draft versions, the results of additional tests, updated sections on the suppression of innocent/nuisance alarms, and revised tables.

1.2. OBJECTIVE AND SCOPE

The purpose of these specifications is deployment rather than just testing. That is, the system parameters discussed here can be used as specifications for how the equipment will actually be deployed for border security applications rather than only for use during intercomparisons of equipment from various manufacturers. For this reason, some system parameters given here may differ from national or international standards [2–6] that are generally intended as test standards for such equipment comparisons. Since technical improvements take place rapidly the specified performance parameters are understood to be minimum parameters. This publication can also be used by Member States either in testing border radiation equipment for conformity with the standards or in equipment procurement.

2. CATEGORIES AND CHARACTERISTICS OF INSTRUMENTS

As described in Ref. [7], instruments for use by front line law enforcement officers to detect and characterize radioactive material at borders or inside countries can be divided into the following categories:

(a) Fixed radiation portal monitors (RPMs);
(b) Personal radiation detectors (PRDs);
(c) Hand held radionuclide identification devices (RIDs);
(d) Hand held neutron search detectors (NSDs).

Fixed RPMs are designed to be used at checkpoints such as those at road and rail border crossings, airports or seaports to detect the presence of gamma and neutron radiation and alert the officer to the presence of radioactive and nuclear material. RPM instruments are the preferred option where the traffic of goods, vehicles or people can be funnelled into narrow confines, known as nodal or choke points, because of their inherent greater sensitivity over hand held or PRDs. They can provide high sensitivity monitoring of a continuous flow of persons, vehicles, luggage, packages, mail and cargo, while minimizing interference with the flow of traffic. Technical specifications distinguish between pedestrian and vehicle monitors. Any installation of automated portal monitors should be supported by additional PRDs and multipurpose hand held

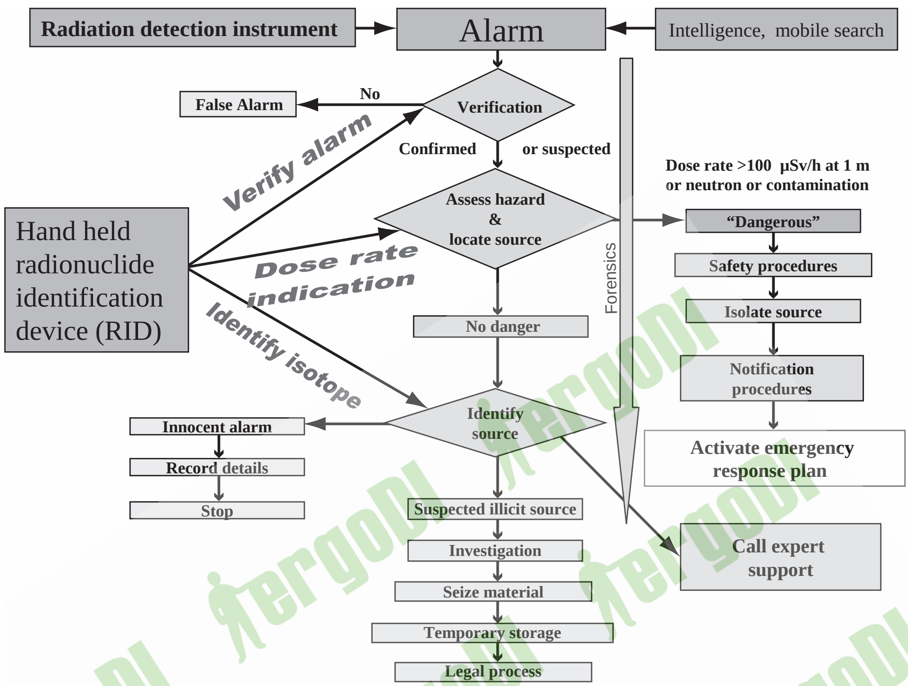

FIG. 1. Generic response scheme.

instruments for the personal radiation safety of the front line officers, verification of alarms, localization of the source and identification of the radionuclide. The derived information is used by the first responder to determine the adequate level of response (operational, tactical or strategic), which depends on the type of radiation (gamma/neutron), dose rate, surface contamination and radionuclide type. An example of a generic response scheme is given in Fig. 1.

Personal radiation detectors are small, automated, lightweight radiation monitors worn on the body, used to detect the presence of or to search for gamma and neutron radiation and to alert the user to the presence of radioactive and nuclear material and to warn of significant radiation levels. These instruments are particularly useful as personal radiation protection detectors or when patrolling large areas with few or no choke points, such as airports or seaports. PRDs can be issued to and worn by every law enforcement officer on duty and are ideally suited for use by first responders to a radiation alarm because of their small size. In addition, they do not require extensive training to operate. Another advantage is their inherent mobility, which allows closer approach to a suspected radiation source when this is safe.

Hand held RIDs[1] are used to detect, locate and identify radioactive and nuclear material and simultaneously provide sufficiently accurate gamma dose rate measurement to ensure radiation safety during the location and identification of the radioactive material. These instruments have a greater sensitivity than PRDs, but they are heavier and more expensive. Most of these instruments, apart from spectrometric gamma detectors, are equipped with a neutron sensor and some of them use a detachable alpha/beta detector to check for surface contamination. Hand held RIDs are mostly used for detection in targeted search situations and for identification of the radionuclide(s) causing an alarm. For example, they are used to:

(1) Verify an alarm triggered by fixed installed detectors or PRDs;
(2) Localize the source;
(3) Check the gamma dose rate and give the neutron count rate in counts per second (counts/s) and approximate dose rate;
(4) Identify the radionuclide;
(5) Perform specialized tasks such as assessment of the source strength, measurement of the ^{235}U enrichment in a well defined measurement geometry.

Hand held NSDs are designed for high neutron detection sensitivity combined with limited size and weight to allow for hand held operation for a sufficiently long time. Their purpose is to detect and locate neutron emitting radioactive material. They were introduced to complement RIDs, which often have limited neutron detection sensitivity. In addition, it may be necessary to check for contamination by measuring alpha and beta radiation, either using an external probe connected to the multipurpose instrument or a separate contamination monitor.

Additional types of specialized, fixed, automated portal monitors include scrap monitors, container crane monitors for seaports and conveyor belt monitors (e.g. for monitoring cargo or luggage in airports or for monitoring

[1] Hand held gamma search instruments are designed for high gamma detection sensitivity to detect and locate radioactive material emitting gamma radiation. Although such instruments are still in use they can be replaced by modern multipurpose hand held RIDs. Presently available RIDs using NaI or CsI scintillation detectors for searching and gamma spectrometry have gamma detection sensitivity comparable to conventional hand held gamma search instruments, usually based on plastic scintillators. It is therefore preferable to use RIDs instead of hand held gamma search instruments, since RIDs can also be used for identification of radioactive material as well as for radiation safety measurements.

mail). Other related instruments are mobile for airborne or car borne radiation surveys or briefcase type, hand carried systems which are used on special occasions. At present, not enough practical experience is available to derive specifications for such specialized systems. However, in the framework of the CRP on Improvement of Technical Measures to Detect and Respond to Illicit Trafficking of Nuclear and other Radioactive Material, some of these instruments will be discussed to initiate more technical work which may later be used as a basis for technical and functional specifications of these specialized systems.

Other instruments that are not covered here are the devices used by expert responders, who move to the scene if the isotope cannot be identified with a RID in a serious trafficking incident or where there is danger of a radiological attack. These responders are equipped with more sophisticated instruments such as portable gamma spectrometers with medium and high resolution detectors, coincidence neutron detection systems, health physics instrumentation, portable X ray imagers and air samplers.

All instruments must comply with national and international electrical safety standards. For fixed installed systems, because of their weight, mechanically safe installation is an additional requirement.

The purpose of these categories of instruments can therefore be summarized as:

(i) Detection and verification: An instrument needs to activate an alarm only if a minimum radiation level is exceeded. This radiation level is related to the background count rate. Once an alarm has alerted law enforcement officers of the possible presence of radioactive material, its genuineness must be verified. This is done by repeating the measurement of the possible source with the same instrument or by using a different instrument, such as a PRD or hand held instrument.

(ii) Assessment and localization: A verified alarm necessitates searching for and localizing the origin of the radiation. As this is done it is important to make a radiological assessment for radiation safety purposes and to determine the appropriate level of response. PRDs, RIDs and NSDs are used.

(iii) Identification: Measurement of the gamma spectrum will often enable the radionuclide to be identified. This information is essential to categorize the nature of the event and determine further response, particularly to distinguish between innocent/nuisance alarms and those caused by illicit radioactive material, and to trigger a high level alert if nuclear material is detected. RIDs and spectral portal monitors are used.

3. GENERAL COMMENTS ON TEST PROCEDURES

To ensure reproducibility of results and validity of comparisons between systems being considered, all verifications of detection equipment performance should be carried out under the following standard reference test conditions unless stated otherwise:

(a) Environmental conditions should be within the ranges of 20°C ± 10% (temperature), 50–75% relative humidity, and 70–106 kPa (normal) atmospheric pressure.
(b) The vicinity of walls, ceilings, etc. should not have a significant influence (±10%) on the results of verification. This requirement is especially important for neutron efficiency and sensitivity verification.
(c) Computer controlled devices such as trolleys or occupancy sensor interrupters can be used. However, this is a less realistic testing condition, making actual passage through tests using sources in vehicles generally more desirable.
(d) All devices to be verified should be equipped to allow automated computer control during a long term test period (such as false alarm rate (FAR)). Access to all raw data such as counts/s should be possible.
(e) Wherever practical the confidence level for the result of the tests should be 95% and the probability of detection should be not less than 80%.
(f) The monitors to be verified should be tuned or adjusted prior to the tests. No adjustments are allowed during the test procedure.

Where nuclear material sources are specified for sensitivity testing surrogate sources can be substituted. The surrogate for weapons grade plutonium (WGPu) is ^{133}Ba (0.12 MBq is approximately equivalent to 1 g WGPu), and for high enriched uranium (HEU) it is ^{57}Co. The relation of the source activity to HEU mass depends on the enrichment, chemical form, density and container dimensions. One MBq ^{57}Co corresponds to about 50 g HEU oxide powder enriched to greater than 90% in a cylindrical aluminium container with a wall thickness of 4 mm. The shape and density of the source must be quoted wherever a quantity of uranium oxide or plutonium oxide is used in the document. Oxide densities can vary by as much as a factor of 5 and these densities affect the self-absorption properties of the material. Since the goal of using these quantities is to specify an emission rate, quoting the amount of material without shape and density leaves an uncertainty of a factor of 5 to 10 in the emission rate. Numerical dose rate values in this publication are the ambient dose equivalent rates and are given in units of μSv·h^{-1} or mSv·h^{-1}.

4. FIXED RPMS

4.1. APPLICATIONS

Modern, fixed RPMs are designed to detect the presence of radioactive material being carried by pedestrians or transported in vehicles. The RPM systems operate by measuring the gamma and/or neutron radiation level while a person or vehicle occupies the detection area. The RPM then compares this level to an alarm threshold that is usually affected by the background radiation level that has been measured previously and updated while the search area was unoccupied. To achieve the required sensitivities the systems often take the suppression of the background caused by a heavy vehicle into account. In addition, coincidence counting with photomultipliers viewing the same scintilator can be used to reduce the energy threshold at low energies.

The RPM should function correctly in both pass-through and wait-in operation modes, depending on the operational requirements and technical needs. Pass-through operation refers to a vehicle in continuous motion through the portal system. Wait-in operation refers to a vehicle that stops temporarily in the portal system, such as due to stop-and-go traffic. Hardware and software must support both modes of operation.

4.2. CHARACTERISTICS

RPMs typically consist of an array of detectors in one or more vertical pillars with associated electronics plus occupancy sensors, allowing unambiguous distinction of vehicles and personnel, so that the instrument knows when to monitor the vehicle or pedestrian as they pass through and when to update the background radiation level and alarm threshold. Systems are often equipped with video cameras to record the item which caused the alarm. Both gamma and neutron detection is essential to find Pu, which can easily be shielded for its gamma radiation. It is essential that the portal monitor report both neutron and gamma alarms independently and concurrently if present. Because instrument sensitivity is strongly dependent on distance, it is important to get the person or vehicle as close as practically possible to the detector array. Therefore the highest efficiency is achieved if the monitors are installed so that all the pedestrians, vehicles, and cargo traffic are forced to pass close by or between monitors. Careful consideration should, therefore, be given to selecting the optimum location to install RPMs so they can be most effective. Hard X ray or gamma imaging can also be used to detect high density shielding, which may be used to reduce the detectable gamma rays emerging from the object to be monitored.

The efficiency of RPMs is also strongly dependent on their ability to measure the radiation intensity over the search area of interest. Therefore, when installing the monitor it is important that the detector be positioned so that it has an unobstructed view of the search area. However, the instrument should also be protected from mechanical damage. Alarm indications — separate for neutrons and gammas — should be clearly visible to the officers staffing the inspection point, and officers responding to alarms will need to be trained in the appropriate response procedures. Modern systems often include a connection to a local area network if several stations are installed at a border crossing point, e.g. a large airport. All data can be concentrated in a central data collection computer in the duty room, which can have a secure, remote link to the customs headquarters. It is recognized that much work is currently being undertaken in the application of RPM for pedestrian and vehicular use. Systems are commercially available which offer simple to very complex technological solutions to the problem. Some systems, for instance, provide positional data of the source location within the monitored space. In addition, it is recognized that there are emerging technologies such as the use of algorithms to flag naturally occurring radioactive material (NORM) or medical isotopes in persons. An innocent/nuisance alarm is a genuine radiation alarm caused by a source that is not illicit, such as NORM, or a passenger who has recently undergone a nuclear medical procedure.

The procedure to be used for testing the portal monitors against this specification should be as follows. First the system should be tested for its FAR at a prescribed threshold, determining its sensitivity. If the FAR requirement is met the system then should be tested for its alarm sensitivity. The specification is met if both tests are successfully passed. The goal is to achieve maximum sensitivity, especially in the low energy region related to nuclear material, at an acceptably low level of false alarms.

The RPM software must separately generate gamma ray and neutron alarms using specific alarm algorithms and parameters. The software must support a method for automated adjustment of the gamma ray and neutron alarm thresholds without interfering with ongoing operation of the RPM. The software should have a user interface that allows the user to choose which alarm parameters and method will be employed in a given configuration. The software should make all alarm information available and annunciate alarms visually and acoustically, separately for neutrons and gammas.

The RPM should incorporate a methodology for fault alarms based on low or high background values for either the gamma or the neutron channels. To achieve the required sensitivities, RPMs may use proprietary algorithms to take into account the reduction of the gamma background due to the presence of a loaded truck in the search area. The RPM system should include the ability to store raw and processed data from the system on an internal or external computer. The data format used should be non-proprietary and fully disclosed. There should be no artificial upper limit on the gamma energy sensitivity below 2.7 MeV.

4.3. RADIATION PORTAL MONITOR

4.3.1. Pedestrian monitors

Pedestrian monitors are designed to detect the presence of radioactive material being carried by pedestrians as they pass between or near radiation detectors. Pedestrian monitors can be designed as single or dual detector pillar systems. Barriers should be installed to restrict the pedestrian traffic so that each person passes within at least 1.5 m of a pillar. Where pedestrian traffic corridors are larger than 1.5 m dual pillars should be installed. It is important to place the detector away from heavy doors, which can cause excess false alarms. This is because shielding by the doors can lead to increased fluctuations in the radiation background. In addition, it is important to position the occupancy sensor so that it is triggered only when the monitor is physically occupied and not by individuals walking near the monitor. The possible presence of shielding in luggage and packages may mean that the monitors are most effective when they are used in combination with metal detection systems or X ray machines, which can be used to easily identify the presence of shielding material. When used in combination with X ray machines, special care should be taken to shield the X rays from being detected by the portal monitor. To reduce the sensitivity, the sides of the gamma detector not viewing the source should be shielded.

The portal system parameters must be fixed for the entire test period. Systems can have a method for the indication of medical radionuclides (which may trigger an innocent/nuisance alarm). If this method is to be used the system should also meet the performance criteria of a standard pedestrian monitor using gross gamma and neutron detectors and, in addition, flag medical isotopes as described below. It is assumed that if such an indication occurs appropriate follow-up action (secondary screening inspection using a RID) can be undertaken to prevent a possible attempt to mask the illegal transfer of other radioactive substances. All the measurements described below are performed for complete single or dual detector pillar systems.

False alarm rate

For pedestrian monitors the FAR is the number of alarms (neutron or gamma) per specified number of passages of a pedestrian through the monitor which are not triggered by radiation sources but by other causes such as statistical variations in the measurement process, i.e. counting statistics, variations in natural background intensity or instrument malfunction. The susceptibility of an instrument to statistical variations and hence its FAR is directly related to its detection sensitivity and correction of the natural background instability. It is therefore necessary to test for the FAR before testing for detection sensitivity. As guidance for deployment, the gamma or the neutron FAR should not be more than 1 per 10 000 passages. Calculations show that this requirement is met if the alarm threshold is set at least four sigma above the standard background (when the normal approximation of Poisson statistics is valid).

Test method:

False alarm rates can be tested automatically during extended periods by triggering the occupancy signal to simulate a passage and storing the number of occupancy signals and alarms. In the automated mode the occupancy signal should be on for a duration of 1 s and off for the next 2 s, allowing a 30 s break after every 30 cycles for automatic background update. The minimum number of tests should be 30 000, which can be conducted in an automatic mode in less than 36 h. The criterion is met at the 95% confidence level if no false alarms are registered. For 100 000 tests the number of false alarms must be not more than five at a 95% confidence level, as shown in Annex II.

Note that the absence of a person in the monitor during a simulated passage raises the gamma FAR slightly (by about 2%) because the person's body slightly lowers the background radiation intensity during monitoring. Therefore, the result of the simulated testing can be considered a worst case condition.

Search region and variation in sensitivity

For all pedestrian monitors the search region should cover at least the following ranges, as shown in Fig. 2:

(a) Vertical: 0–2 m;
(b) Horizontal: 1.5 m for a single pillar or 3 m for a dual pillar.

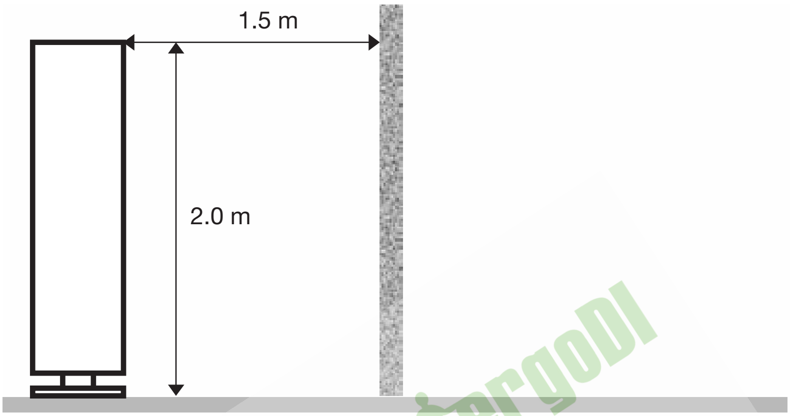

FIG. 2. Search region for a pedestrian monitor.

The variation in sensitivity over the search region observed for gamma rays and neutrons versus height at 1.5 m horizontally from a pillar should be less than ±50%.

Test method:

Any variation in the sensitivity of the search region should be tested by placing one of the unshielded sources listed below at 1.5 m from a pillar at heights of 0, 0.5, 1.0, 1.5, 2.0 m above ground and taking the corresponding counts/s from the detector above background counts/s. The statistical accuracy of the data should be at least ±10%. The sources intended for the measurements are ^{57}Co and ^{137}Cs of at least 1 MBq activity and a ^{252}Cf standard neutron source configuration emitting at least 12 000 n·s^{-1}.

Results of the measurements should be plotted as an array of radionuclides versus the corresponding height at which the measurement for each source can be found. It is required that the variation in counts/s observed for each source versus height should be less than ±50%.

Sensitivity to gamma radiation

The pedestrian monitor must meet both the static and dynamic test requirements. Because dynamic tests are more time consuming and expensive than static tests it is recommended that the dynamic tests be performed only after the static tests have been successfully passed. Current technology systems should not have difficulties passing these static test requirements. It should also be realized that for changes in local background the resulting variation in sensitivity will be proportional to the square root of the background variation.

Static detection efficiency test:

For a point gamma source 1.5 m from the monitor surface area midpoint the following minimum absolute detection efficiency requirements must be met. The efficiency column below is the total net count rate above background per MBq for the monitoring system (i.e. the sum of the count rates for two detector pillars where two are used). Actual detection sensitivity depends on the local background count rate. For a FAR requirement of 1/10 000 the minimum net count rate must be at least four times ('sigma multiplier'[2]) higher than the square root of the background for a 50% detection probability. Higher detection probability requires a higher sigma multiplier. The last column in Table 1 represents the sigma multiplier at a background count rate of

TABLE 1. STATIC DETECTION EFFICIENCY

Source	Primary energies (keV)	Efficiency (net counts/s/ MBq)	Dose rate at 1.5 m ($nSv\cdot h^{-1}$ per MBq)	Efficiency (net counts/s per $nSv\cdot h^{-1}$)	Minimum sigma multiplier
^{241}Am	60	180	2.3	78	8
^{57}Co	122, 136	700	9.3	75	32
^{137}Cs	662	800	42	19	38
^{60}Co	1173, 1333	1500	160	9.4	70
^{133}Ba	31, 356, 81, 302	1400	23	61	64
HEU oxide powder	X rays, 186	>1000 counts/s/100 g	11/100 g	>100	
WGPu oxide pellet (6 g)	X rays, 400, 600	>650 counts/s/6 g >150 counts/s/6 g in 1 cm steel	13/6 g 3/6 g in 1 cm steel	>50	

[2] The sigma multiplier is the ratio of the net signal count rate above background divided by the square root of the background count rate.

500 counts/s and listed detection efficiency. The shape and density of uranium oxide or plutonium oxide sources must be quoted.

Dynamic test:

This test is intended to verify the overall system performance for gamma detection. At standard background the test is carried out with a 1 MBq activity ^{137}Cs source (±30%) and a 1 MBq ^{57}Co source (±30%) activity. To obtain the required 80% detection probability at a 95% confidence level the threshold value for this test must be set 2.0 'sigma multiplier' units lower (two square roots of background count rate lower than total 'source + background' count rate).[3]

The probability of detection should be tested by pedestrians walking through the monitor 1.5 m from a pillar at an average speed of 1.2 $m \cdot s^{-1}$, carrying the source at a height of 1 m above ground. An interruption between a reasonable number of passages should be provided to allow the monitor to update the background. The required detection probability (80% at a 95% confidence level) is confirmed if at least 45 alarms are triggered in 50 passages.

Sensitivity to neutron radiation

The pedestrian monitor should respond appropriately to neutrons in both static and dynamic testing.

Static detection efficiency test:

For a ^{252}Cf standard neutron source of 12 000 neutrons per second ($n \cdot s^{-1}$) (±30%) emission at 1.5 m from the reference point of the detector surface, the net count rate (background subtracted) must be not less than 12 counts/s (±30%).

Dynamic test:

This test is intended to verify the overall system performance for neutron detection. The probability of detection should be tested by either a person pulling a rolling suitcase containing a ^{252}Cf standard neutron source

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[3] This requirement should be compatible with a FAR of 1/10 000, i.e. the net count rate from the test source should provide at least a 6.0 'sigma multiplier' coefficient at a given background count rate.

configuration at a distance of 1 m from the person to minimize the influence of the body albedo, or by a trolley transporting a standard neutron source configuration through the portal. The source, emitting 12 000 $n \cdot s^{-1}$ (±30%), which corresponds to about 200 g of WGPu, should be transported through the monitor at a distance of 1.5 m from a pillar with an average speed of 1.2 $m \cdot s^{-1}$ at a height of 1.0 m above ground. An interruption between a reasonable number of passages should be provided to allow the monitor to update the background. The required detection probability (80% at a 95% confidence level) is confirmed if at least 45 neutron alarms are triggered for 50 passages.

Gamma sensitivity of neutron detectors

The pedestrian monitor must not trigger a neutron alarm when exposed to a ^{60}Co gamma ray source producing a dose rate at the reference point of the neutron detector of 100 $\mu Sv \cdot h^{-1}$ (±30%) at a minimum of 1 m distance.

Test method:

Insensitivity of neutron detectors to gamma rays should be tested by a ^{60}Co gamma ray source which produces a dose rate at the neutron detector equal to 100 $\mu Sv \cdot h^{-1}$ (±30%), for example a 280 MBq source placed at a distance from the reference point of the detector of 1 m. Insensitivity of neutron detectors to gamma rays is confirmed if no neutron alarms are triggered in 60 successive tests.

Indication of innocent/nuisance alarms due to medical radionuclides

Experience has shown that a relatively large number of innocent/ nuisance gamma alarms are observed at airports and other border crossing points due to radiopharmaceuticals in passengers. Real time gamma spectrometry using highly sensitive spectral gamma detectors and fast radionuclide identification can be used as an option to indicate innocent/ nuisance alarms through the identification of the radionuclide(s) causing an alarm while the passenger with luggage passes through the monitor. The system should function as follows: any gross gamma alarm of the gamma counter of the portal monitor is flagged as a ‘green’ alarm when a medical radionuclide is simultaneously identified by the spectrometric channel. In this case the user may decide that the gamma alarm is not to be followed up (provided the dose rate is below a certain limit).

Depending on the prevailing threat level a green alarm may not be followed up immediately. However, the alarm and the corresponding gamma spectra should be recorded for later review by experts in any case. The medical radionuclides of greatest interest due to their frequency of use are ^{201}Tl, ^{99m}Tc, ^{131}I, ^{111}In, and ^{65}Ga.

It should be noted that the most important requirement for such a device is to identify — with a high detection rate and within seconds — medical radionuclides. Moreover, no other radionuclides should be misinterpreted as medical (flagged green). The identification of all other radionuclides is desirable but may not be achieved due to the short measurement time. Where other radionuclides or a non-identified gamma source, triggering an alarm, are detected (as the device does not fully replace a RID), a follow-up measurement with an RID is required.

The general requirements for spectral radiation monitors should be similar to the standard gross gamma/neutron pedestrian monitors described previously. In this section only the real time gamma spectrometer feature used for the decision making process is specified. Either one or two pillar configurations can be employed. The distance between the detector pillar and the pedestrian should not exceed 1.5 m. In contrast to the specifications for RIDs, emphasis is put on the detection of low energy, unshielded gamma emitters on the background of scattered gamma rays. It is assumed — if there were an attempt to smuggle a shielded source — that persons and luggage have passed metal detection systems which would have indicated the presence of shielding material.

The gamma channel should be able to detect and properly identify any unshielded gamma emitting radionuclide, which exposes the spectral gamma detector with a dose rate at the detector of 0.05–0.25 μSv·h^{-1} (depending on the energy of the emitted gamma rays, 0.05 μSv·h^{-1} for 60 keV, 0.15 μSv·h^{-1} up to 662 keV and 0.25 μSv·h^{-1} for higher energies) above the natural background level at a walking speed of up to about 1.2 m·s^{-1}. The spectrometer should also detect nuclear material causing a dose rate of 0.1 μSv·h^{-1} at the detector surface (e.g. 10 g of 1 mm Cd shielded low burnup PuO_2 at a distance of 1 m), concealed by a medical radionuclide up to a dose rate at the reference point of the detector of 1 μSv·h^{-1}. To fulfil these requirements a single, large volume NaI detector can be used. A multichannel analyser (MCA) that can collect and process gamma spectra for decision making in 1 s intervals is recommended.

A ‘red’ alarm should be given:

(a) If the dose rate/count rate is above a preset limit.
(b) If any radionuclide other than medical ones is identified.
(c) If a radiation alarm was detected but the radionuclide was not identified.

The user should be able to configure the alarm's output: red/green lights and/or corresponding audio signals (separate signals for neutron alarm). A remote transmission of the list of alarms and the associated gamma spectra should be possible. It should also be possible to use the system in conjunction with a radiation triggered video camera.

In the expert mode the list of identified radionuclides and a full MCA display should be shown on the screen. It should be possible for an expert to use the software for off-line viewing and evaluation of the recorded alarm spectra and to export the data for external processing. The data should be in the ASCII format [8] and the file format should be documented.

As to the spectrometric channel, similar requirements apply as to the gamma spectrometer of a RID (integral non-linearity of the energy scale less than 1% from 0.06 to 1 MeV and less than 2% above, stabilization assuring temperature stability of less than 0.1% per °C over the temperature range of +10°C to +35°C, energy resolution for ^{137}Cs less than 9%, sufficiently fast gamma spectrometer with minimized high rate peak shift (less than 1% for 10 μSv·h^{-1} of ^{137}Cs at the detector surface) to pass the test described below.

Since the dose rate at the detector can cover a wide range the system should have a large dynamic count rate range. Medical radionuclides must still be identified if a passing person with a medical radionuclide causes a peak dose rate of up to 50 μSv·h^{-1} at the detector. Before the spectrometer becomes saturated, enough undistorted information should be collected during the data acquisition phase to identify the radionuclide.

Detection probability test:

Pass an unshielded medical source of ^{131}I producing a dose rate of 0.15 μSv·h^{-1} (±30%) (about 2.5 MBq at a distance of 1 m) above background along the detector with a speed of 1.2 m·s^{-1} at a height of 1 m above ground. Check whether the system's gamma counter has triggered an alarm and whether the gamma spectrometer identified the alarm properly as a medical alarm, flagging the gamma alarm of the monitor as a green alarm. The requirement is met if 90% of the cases are identified.

Pass unshielded nuclear material and industrial isotopes (^{133}Ba, ^{57}Co and 1 mm Cd filtered low burnup and high burnup Pu, and separately, HEU of well documented chemical and physical composition and shape), producing a dose rate of 0.15 and 10 μSv·h^{-1} (±30%) above background along the detector with a speed of 1.2 m·s^{-1} at a height of 1 m above ground. Check the alarm indication of the monitor. In none of 100 passes should a green alarm occur, only a red alarm showing the isotope.

Detection of radionuclide mixtures test:

Repeat the test described above by adding samples of 1 mm Cd filtered low burnup Pu, and separately, HEU oxide producing 0.15 $\mu Sv \cdot h^{-1}$ above background at the detector surface. Check whether a red alarm is still being triggered, correctly identifying the radionuclides combined with a medical source emitting 1 $\mu Sv \cdot h^{-1}$ (±30%) at the reference point of the detector (about 10 MBq ^{131}I at a distance of 0.2 m). The requirement is met if at least 45 alarms are triggered in 50 passages.

Dose rate overload test:

Move a Pu (or ^{133}Ba) sample, producing a peak dose rate of 50 $\mu Sv \cdot h^{-1}$ at the detector surface, with a speed of 1.2 $m \cdot s^{-1}$ horizontally along the detector. Check whether the radionuclide is properly identified before the spectrometer becomes saturated. Standard test procedures for gamma spectrometers should be used to check the hardware performance (energy resolution, peak shifts with temperature and count rate, precision of the energy calibration).

4.3.2. Vehicle and rail monitors

Vehicle monitors

The inherent shielding of the vehicle structure and its components complicates the use of fixed installed radiation monitors to detect radiation sources in vehicles. While standard truck bed monitors can be effective in detecting abnormal radiation levels in shipments of metal for recycling, they are much less effective in detecting radioactive material when that material is deliberately concealed. Monitors specially designed to detect illicit traffic of radioactive sources are more effective than common monitors for scrap contamination because they typically have detectors positioned to view more of the vehicle, while scrap monitors typically view only the truck bed.

The vehicle portal monitor should be double sided (two pillars) and symmetric. The sensitivity of detection depends upon the proximity of the detector to the source and the speed of the vehicle. The maximum recommended distance between pillars is 6 m, depending on the width of the vehicle to be scanned. It is important that barriers that do not obstruct the view of the monitor be installed to protect the monitor from being accidentally damaged by vehicles. Detectors should monitor one lane only. Vehicle portals may be of a car or truck type (including buses), differing in the height of the search region.

Since the sensitivity of the monitor is also strongly dependent on monitoring time the instrument needs to be placed where the speed of the vehicle is controlled and reduced. Instruments vary in their capabilities but it is recommended that the speed of the vehicle not exceed 8 $km \cdot h^{-1}$, although in some situations a higher speed of up to 30 $km \cdot h^{-1}$ may be required to maintain the flow of traffic. For higher speed requirements, the sensitivity of the detectors has to be increased accordingly.

The portal system parameters must be fixed for the entire test protocol. Systems can have a method for rejecting NORM. If this method is used it must be used for all aspects of this specification.

It is essential that the occupancy sensor be of the type suitable for the particular application and be positioned so that it is triggered only when the monitoring portal is occupied and is not triggered by other traffic in the vicinity.

Rail monitors

Automatic rail radiation monitors are effective tools for preventing the illicit movement of radioactive material across international borders. The monitors determine the presence of radioactive material by detecting gamma rays and neutrons emitted from the radioactive material. They should be specifically designed to detect the neutrons and low energy gamma rays characteristic of nuclear material. Rail monitors are essentially the same as vehicle monitors except that they should monitor a region that may be wider and higher than required for vehicle monitoring.

The monitors must consist of at least two detector pillars positioned on opposite sides of a train passageway. The monitors must be capable of determining and indicating separate neutron and gamma alarms. To limit the nuisance alarm rate the monitors should be capable of continuously updating the natural background intensity, except when occupied. They should be equipped with occupancy sensors. For monitoring trains, the occupancy sensor must be capable of not losing occupancy for the entire length of the train, including the space between cars and the presence of flatcars. Identification of each car of the train that produces an alarm is required.

For both rail and truck monitors the automated indication of innocent alarms connected with NORM can considerably reduce the workload of front line officers. Recently, spectrometric systems with NaI or even electrically cooled HPGe detectors have been under development for vehicle and rail monitors as well. In contrast with the spectral pedestrian monitors described in Section 4.3.11, where mainly medical isotopes with low energy gamma lines need to be identified, the task is more difficult for spectral rail and truck monitors. High energy gamma lines of ^{40}K, ^{232}Th and ^{226}Ra need to be detected in seconds and large arrays of spectral gamma detectors are needed. Once more operational experience becomes available it will be included in a future update to this publication.

False alarm rate: For vehicle monitors the FAR is the number of alarms (neutron or gamma) per specified number of passages of a vehicle through the monitor which are not caused by radiation sources (including NORM). These alarms are triggered by other causes such as statistical variations in the measurement process, i.e. counting statistics or variations in natural background intensity (but not instrument malfunction, which should be eliminated). The susceptibility of an instrument to statistical variations — and hence its FAR — is directly related to its detection sensitivity and natural background rate. It is therefore necessary to test for the FAR before testing for detection sensitivity. As guidance for deployment the gamma or neutron FAR during operation should not be more than 1 per 10 000 passages. Neutron alarms of fixed installed systems are particularly critical, normally requiring a special response. False neutron alarms can be introduced by microphonics, strong gamma sources and electromagnetic interference (EMI).

Test method:

FARs can be tested automatically during an extended period by triggering the occupancy signal by simulating a passage and storing the number of occupancy signals and alarms. In the test mode the occupancy signal should be on for the duration of 3 s and off for the next 2 s, allowing a 30 s break after every 30 cycles for automatic background update. The minimum number of tests should be 30 000, which can be conducted in less than 36 h in an automatic mode. The criterion is met at a 95% confidence level if no false alarms are registered. For 100 000 tests the number of false alarms should be not more than 5 at a 95% confidence level, as shown in Annex II.

Note that the absence of a vehicle in the monitor during a simulated passage raises the gamma FAR slightly because the vehicle would lower the background radiation intensity during monitoring (by up to about 20%). So the result of the simulated testing can be considered to be the worst case condition.

Search region and variation in sensitivity: To ensure that the monitor can meet the specified sensitivity regardless of the vehicle's inherent shielding the monitor should consist of at least two pillars symmetrically spaced on either side of the vehicle. Each pillar should contain evenly spaced detectors to monitor the search region between the pillars uniformly. Using current technology it is recommended that the gamma ray detectors in each pillar should be large plastic scintillators and neutron detection should be ^{3}He tube

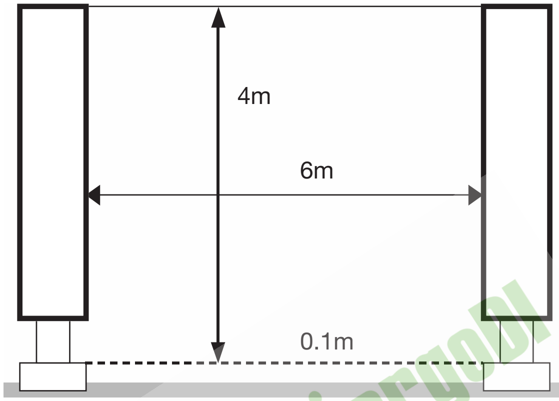

FIG. 3. Search region for truck portals.

based. The gamma detectors should be gamma shielded on the three larger surfaces, which do not face the vehicle.

For all vehicle monitors (cars, trucks and buses) the search region should cover at least a:

(a) Vertical range for truck portals: 0.1–4 m, see Fig. 3;
(b) Vertical for car portals: 0–3 m;
(c) Horizontal (aperture between two detectors) for truck/bus monitors up to 6 m.

The variation in sensitivity observed for gamma rays and neutrons versus height on the centre line should be less than ±50%.

Rail monitors should be tested by passing the sources at a height of 1.5 m, such that the distance of closest approach is no less than 3.1 m. From a level of 0.25–4 m above the track the sensitivity variation should be no greater than ±50%.

Test method:

The variation in the sensitivity of the search region is defined by placing one of the unshielded sources listed below in the middle of the search region (i.e. 3 m from either pillar) at heights of 0.1, 1, 2, 3, 4 m (3 m maximum for car portals) above ground and recording the corresponding counts/s from the detector above background counts/s. The statistical accuracy of the data should be at least ±10%. The sources intended for the measurements are ^{57}Co and ^{137}Cs of at least 1.0 MBq activity and a ^{252}Cf standard neutron source configuration of at least 12 000 n·s^{-1}.

Measurement results should be plotted as an array of radionuclides versus the corresponding height at which the variation in sensitivity for a given source can be found. The variation in counts/s for each source versus height should be less than ±50%.

Sensitivity to gamma radiation: The vehicle monitor must meet both the static and dynamic test requirements. Because dynamic tests are more time consuming and expensive than the static tests it is recommended that they be performed only after the static tests have been passed successfully. Current technology systems should not have any difficulties passing these static test requirements. Also, it should be realized that for changes in local background the resulting variation in sensitivity will be proportional to the square root of the background variation.

Static detection efficiency test:

For a point source 3 m from the monitor surface area midpoint the following minimum absolute detection efficiency requirements must be met. The efficiency column below is the total net count rate above background per MBq for the monitoring system (i.e. the sum of the count rates for the two detector pillars in systems using two pillars). Actual detection sensitivity depends on the local background count rates. At a FAR requirement of 1/10 000 (4.4.2) the minimum net count rates must be at least four times ('sigma multiplier'[4]) higher than the square root of the backgrounds for a 50% detection probability. A higher detection probability requires a higher sigma multiplier. The last column in Table 2 represents the sigma multiplier at 2500 background count rates and listed detection efficiency.

Dynamic test:

This test is intended to verify the overall system performance for gamma detection. At standard background, the test is carried out with a 1 MBq (±30%) activity ^{137}Cs source and a 1 MBq (±30%) activity ^{57}Co source. To obtain the required 80% detection probability at a 95% confidence level the threshold value for this test should be set at 2.0 'sigma multiplier' units lower (two square roots of background count rates lower than total 'source + background' count rates).[5]

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[4] The sigma multiplier is the ratio of the net signal count rate above background divided by the square root of the background count rate.

TABLE 2. STATIC DETECTION EFFICIENCY

Source	Primary energies (keV)	Efficiency (net counts/ s/MBq)	Dose rate at 3 m ($nSv\cdot h^{-1}$/MBq)	Efficiency (net counts/s/ $nSv\cdot h^{-1}$)	Minimum sigma multiplier
^{241}Am	60	200	0.6	330	4
^{57}Co	122, 136	800	2.3	350	16
^{137}Cs	662	900	10.6	85	18
^{60}Co	1173, 1333	1900	40	48	38
^{133}Ba	31, 356, 81, 302	1600	5.8	275	32
HEU oxide powder	X rays, 186	>1200 counts/ s/100 g	3 $nSv\cdot h^{-1}$/100 g 0.2 $nSv\cdot h^{-1}$/4 g	>400	
WGPu oxide pellet	X rays, 400, 600	>600 counts/ s/6 g	3 $nSv\cdot h^{-1}$/ 6 g	>200	

The probability of detection is tested by a bare source passing along the centre line (3 m) of the portal at a height of 1 m, at an average speed of 8 $km\cdot h^{-1}$ (±30%)$^{-1}$. An interruption between a reasonable number of passages should be provided to allow the monitor to update the background. The required detection probability (80% at 95% confidence level) is confirmed if at least 45 alarms are triggered for 50 passages.

Sensitivity to neutron radiation: The vehicle monitor should respond appropriately to neutrons in both static and dynamic testing.

Static detection efficiency test:

A ^{252}Cf standard neutron source configuration of 12 000 $n\cdot s^{-1}$ (±30%) intensity at 3 m from the detector sensitive surface must produce a net count rate of at least 8 counts/s (±30%) per pillar.

[5] This requirement should be compatible with a FAR of 1/10 000, i.e. the net count rate from the test source should provide at least a 6.5 'sigma multiplier" coefficient at a given background count rate.

Dynamic test with moving source:

This test is intended to verify the overall performance of the system. The detection probability should be tested by using a ^{252}Cf standard neutron source configuration emitting 12 000 n·s^{-1} (±30%), which is approximately equivalent to 200 g WGPu, passing along the centre line of the portal at a height of 1 m, with an average speed of 8 km·h^{-1} (±30%). An interruption between a reasonable number of passages should be provided to allow the monitor to update the background. The required detection probability (80% at a 95% confidence level) is confirmed if at least 45 alarms are triggered for 50 passages.

Gamma sensitivity of neutron detectors: The vehicle monitor must not trigger a neutron alarm when exposed to a ^{60}Co gamma ray source producing a dose rate at the reference point of the neutron detectors of 100 μSv·h^{-1} (±30%).

Test method:

The insensitivity of neutron detectors to gamma rays should be tested by a ^{60}Co gamma ray source producing a dose rate at the detector of 100 μSv·h^{-1} (±30%), for example a 300 MBq source being placed at a distance of 1 m from the reference point of the neutron detector. Insensitivity of neutron detectors to gamma rays is confirmed if no neutron alarms are triggered in 60 successive tests.

Suppression of innocent/nuisance alarms due to NORM material: In most border monitoring applications many vehicles contain NORM such as ^{232}Th, ^{226}Ra, ^{40}K, natural U in industrial material such as ceramic tiles, fertilizer, cat litter, porcelain toilets, etc. These generate innocent/nuisance alarms. Such alarms cause significant operational issues as all portal alarms should be fully investigated.

As an option to resolve these issues the portal systems can include the ability to identify such material (such as using a spectroscopic technique on the plastic scintillation detectors) and to apply a different (higher) alarm threshold to NORM or flagging these alarms as NORM alarms. This alarm threshold should be set to a level suiting local operating conditions to automatically reject such NORM if below the NORM alarm threshold. From an operational view, material identified as NORM should not trigger an alarm but should indicate that innocent/nuisance (NORM or medical) material is present. Any such NORM rejection algorithm must not diminish the ability of the portal system to alarm on otherwise detectable nuclear material. All tests of this specification must be made with this method enabled if it is to be used.

Systems employing such technology should store raw data from all analysed vehicles for a reasonable period (minimum of 30 days) to permit experts to independently analyse the raw data to ensure that an acceptable level of NORM alarm rejection has occurred.

Test method:

The vehicle monitor should trigger a gamma alarm flagged as NORM, when NORM (^{40}K and ^{232}Th) producing a gamma dose rate above a background of 0.1 μSv·h^{-1} (±30%) at a distance of 1.0 m from a detector pillar is passed through the system on the centre line of the portal at a height of 1 m at a speed of 8 km·h^{-1} (±30%). Nevertheless, the vehicle monitor should trigger a gamma alarm when the gamma dose rate produced by NORM exceeds this value.

Rejection probability test: The test procedure should be carried out using fertilizers containing ^{40}K. For this test the amount of fertilizer required is about 250 kg if the fertilizer contains 40% K. The probability of rejection should be tested by a source passing along the centre line of the portal at a height of 1 m, with an average speed of 8 km·h^{-1} (±30%). The test passages should be repeated with sufficient interruption between each passage to allow the monitor to update the background. Rejection probability is confirmed if no more than five alarms are triggered in 50 passages.

Detection probability test: The test should be carried out with ^{40}K plus ^{137}Cs. The recommended ^{137}Cs activity is 30 kBq (3 nSv·h^{-1} at 1 m). The probability of detection should be tested by passing a source along the centre line of the portal at a height of 1 m, with an average speed of 8 km·h^{-1}, varying by no more than 1 km·h^{-1}. The test passages should be repeated with sufficient interruption between each passage to allow the monitor to update the background. Detection probability is confirmed if at least 45 gamma alarms are triggered in 50 passages.

4.4. COMMON TECHNICAL AND FUNCTIONAL REQUIREMENTS

The following requirements and test methods are applicable to pedestrian, vehicle and rail monitors.

4.4.1. Overload characteristics

For gamma rates giving a dose rate greater than 100 μSv·h^{-1} at the surface of the detection assembly the monitor must stay in alarm and remain so during such exposure when it occurs during a monitoring cycle.

The manufacturer should state the time taken by the monitor to return to a non-alarm condition after the dose rate is returned to background. This should not be more than 1 min.

Test method:

With the monitor operating in a stable natural background, note the background count rate and then initiate a counting cycle. Simultaneously, increase the ambient background using a ^{137}Cs source by a minimum of 100 $\mu Sv \cdot h^{-1}$ (e.g. 100 MBq at 0.3 m) as measured at the surface of a detection assembly. The monitor should alarm and remain in alarm until the radiation field is reduced to the pre-test level. After 1 min, the monitor must perform normally.

4.4.2. Operational availability

Vehicle monitors should be available at least 99% of the time, i.e. less than four days out of service per year, and provide an operational lifetime of more than 10 a. It is understood that this parameter is difficult to test. The 'mean time to repair' is also an important parameter. This is more a question as to the availability of spare parts and maintenance support. This should be a part of the agreement with the supplier. The reliability of a system can be significantly improved if regular recalibration and preventive maintenance are done.

4.4.3. Occupancy sensor requirements

The occupancy (or presence) sensor is a device signalling the presence of an item (vehicle or pedestrian) in the specified place. The occupancy (or presence) sensors must operate reliably under all expected weather conditions where used, including rain, snow or fog, and for all types of expected vehicle passages.

Test method:

A test must be developed to ensure that the occupancy sensor operates reliably. The test must be based on the type of sensor used to detect occupancy or initiate a count cycle. The test must consist of 1000 consecutive occupancies and 99.9% reliability is required for acceptance.

4.5. ENVIRONMENTAL AND ELECTRICAL REQUIREMENTS

The following sections relate to performance parameters for common temperature, humidity and mains power operating requirements and test methods applicable to pedestrian, vehicle and rail monitors.

4.5.1. Ambient climate

Pedestrian and vehicle monitors should be weather proofed and designed for permanent outdoor operation, taking account of the realities of the particular climate at the location of the instruments. The instruments should not vary by more than 15% in a temperature range of –20°C to +50°C and a relative humidity of 100% at +35°C, in non-condensing conditions. Depending on climatic conditions at the point of installation, performance tests at temperatures down to –35°C may be necessary. The environment enclosure of the systems should conform to National Electrical Manufacturers Association Standard 250, 2003 for enclosure type 4X or equivalent for weather and corrosion [9].

Test method: temperature:

Parts of the system that are intended for installation in a controlled environment should be excluded from this test. This test should normally be carried out in an environmental chamber. In general it is not necessary to control the humidity of the air in the chamber unless the monitor is particularly sensitive to changes in humidity. Humidity levels should be low enough to prevent condensation (less than 50%). The rate of change for temperature must not exceed 10°C per hour. For this test the detector assembly must be switched on and exposed to the reference ^{137}Cs gamma and neutron ^{252}Cf radiation.

The temperature must be maintained at each of its extreme values for a minimum of 16 h and the count rate of the assembly measured every 60 min during this period. The limits of variation of indications should be within ±15% of the readings at +20°C.

Test method: humidity:

Parts of the system that are intended for installation in a controlled environment should be excluded from this test. The test must be carried out at a constant temperature of +35°C using an environmental chamber. For this test the detector enclosure must be switched on and exposed to the reference ^{137}Cs

gamma and neutron ^{252}Cf radiation. The humidity must be maintained at its extreme values for a minimum of ten days and the count rates of the assembly noted every 8 h during this period. The permitted variation in the indications of less than ±15% is in addition to the permitted variations due to temperature alone. Following exposure each assembly should be inspected for corrosion or other humidity caused effects. There should be no observable effects from the exposure.

4.5.2. Mains power operation

It is essential that all instruments be connected to an uninterruptible power supply to accommodate power failures during a specified time interval (not less than 2 h). Systems must be designed to operate from single phase AC supply voltage in one of the following categories, in accordance with Ref. [10]:

- Series I: 230 V;
- Series II: 120 and/or 240 V.

The systems must be capable of operating from mains with a supply voltage tolerance of +10% to –5% and a supply frequency of 47–51 Hz or 57–61 Hz. The readings must not vary by more than ±10% over the variations of these voltages and frequencies.

Test method:

Place a ^{137}Cs source adjacent to the detection enclosure. With the voltage supply at its nominal value determine and record the mean reading from each detector. Take sufficient readings with the supply voltage 10% above the nominal value and sufficient readings with the supply voltage 5% below the nominal value. The mean values should not differ by more than 10% from those obtained with nominal supply voltage. These tests should be repeated, but instead of changing the voltage the frequency should be changed from:

(a) 47 Hz, and the readings at these frequencies should not vary by more than the values stated above compared to the readings at 50 Hz, or
(b) 57 Hz–61 Hz and the readings at these frequencies should not vary by more than the values stated above compared to the readings at 60 Hz.

The above tests should be repeated using a ^{252}Cf neutron source.

4.6. ELECTROMAGNETIC INTERFERENCE REQUIREMENTS

The following electromagnetic tests are applicable to pedestrian, vehicle and rail monitors.

4.6.1. External magnetic fields

The manufacturer should provide a warning if an assembly may be influenced by the presence of external magnetic fields. This should be stated in the instruction manual.

Test method:

This should be subject to agreement between the manufacturer and the purchaser. The following is provided as a recommendation only:

(a) Set the magnetic field intensity for continuous fields to 30 A/m at a frequency of 50 or 60 Hz;
(b) Expose the assembly to at least two orientations (0° and 90°) relative to the field lines.

Note that 1 A/m is equivalent to a free space induction of 1.26 mT.

Compliance should be checked by recording count rates from each detector and by monitoring the operational status during exposure. The count rate should not vary by more than 15% of the rate under standard test conditions. There should be no change in the operational status.

4.6.2. Radiated electromagnetic fields

The maximum spurious variation in the count rates from the detectors (both transient and permanent) due to electromagnetic fields should be less than 15% of the rate under standard test conditions. No alarms or other outputs should be activated when the monitor is exposed to the field.

Test method:

Compliance with the performance requirements should be checked by recording detector count rates and operating settings with and without the presence of the radiofrequency (RF) field around the monitor. (For the purpose of this and subsequent tests the monitor can be reduced to a single detector assembly with simulations of the operational functions, where more than one would normally be used.)

The field strength should be 10 V/m over the frequency range from 20 MHz to 1 GHz in steps of 1% (severity level 3 as described in IEC 61000-4-3) [11]. The test can be performed using a field strength of 20 V/m to reduce the number of measurements needed to show compliance with this requirement. If any change in count rate greater than 5% of the count rate under standard test conditions is observed additional tests between ±5% around the frequency of susceptibility in steps of 1% with a field strength of 10 V/m should be carried out with the monitor in all three orientations. There should be no change in the operational setting at any frequency.

4.6.3. Conducted disturbances induced by bursts and RFs

The maximum spurious variation in the count rate from the detectors (both transient and permanent) due to conducted disturbances induced by bursts [12, 13] and RFs should be less than 15% of the rate under standard test conditions. No alarms or other outputs should be activated when the assembly is exposed to the field.

The test applies to devices used in the presence of RF transmitters in the frequency range of 150 kHz to 80 MHz. Monitors that do not have at least one conducting cable (mains supply, signal line or earth connection) are excluded.

Test method:

Perform the following operations both with and without the presence of conducted disturbances induced by bursts (IEC 61000-4-4) [12] and conducted disturbances induced by RF fields (IEC 61000-4-6) [13] (the severity level should be level 3 in both cases), and with and without the presence of radiation sources.

Compliance should be checked by recording count rates from each detector channel and by monitoring the operational status during exposure. The count rate should not vary by more than 15% of the rate under standard test conditions. There should be no change in the operational status.

4.6.4. Surges and oscillatory waves

The tests apply to mains-operated devices. The maximum spurious indications (both transient and permanent) of the display or data output due to surges or oscillatory waves must be less than 15% of the count rates under standard test conditions. No alarms or other outputs should be activated.

Test method:

Connect the mains supply terminal to the pulse generator by means of a coupling/decoupling network in accordance with IEC 61000-4-5 [14] and IEC 61000-4-12 [15] (the severity level should be level 3) and carry out the following operations with and without the presence of radiation sources:

(a) Ten pulses should be applied to the device with a minimum time between surges of one min;
(b) Each pulse should consist of a combination wave (1.2/50 μsec–8/20 μsec) at an intensity of 2 kV;
(c) Ring wave pulses should be no more than 2 kV.

Compliance should be checked by recording count rates from each detector channel and by monitoring the operational status during exposure. The count rates should not vary by more than 15% of the rate under standard test conditions. There should be no change in the operational status.

4.6.5. Electrostatic discharge

The maximum spurious indications (both transient and permanent) at the display or data output due to electrostatic discharge (ESD) should be less than 15% of the rate under standard test conditions. No alarms or other outputs should be activated when the device is exposed to the discharges.

Test method:

User accessible components must be placed close to a suitable discharge test generator as described in IEC 61000-4-2 [16], and the following operations are performed with and without the presence of radiation sources.

(a) Set the assembly to perform a measurement.
(b) Discharge at least five times to those various external parts of the complete monitor which may be touched by the operator.
(c) For assemblies with conductive surfaces and coupling planes, the contact discharge method must be used as described in Ref. [16]. The ESD must be equivalent to that from a capacitor of 150 pF charged to a voltage of 6 kV and discharged through a resistor of 330 Ω (severity level 3).
(d) When assemblies with insulated surfaces are tested, the air discharge method with a voltage of 8 kV (severity level 3) must be used.

Compliance should be checked by recording count rates from each detector channel and by monitoring the operational status during exposure. The count rates should not vary by more than 15% of the rate under standard test conditions. There should be no change in the operational status.

4.7. MECHANICAL REQUIREMENTS

Components used outdoors near pedestrian traffic will not be exposed to mechanical environments such as shock and vibration other than when shipped to the location. Monitors designed for vehicles and trains, unless mounted onto other handling devices such as cranes, will most likely be exposed to minimal shock and vibration environments. The following requirements are therefore only for monitors used while mounted on other devices such as cranes. Detection assemblies mounted on cranes will have special requirements that are not addressed in this publication.

4.7.1. Mechanical shocks

Detection assemblies should be able to withstand, without affecting their performance, mechanical shocks (half-sine) from all directions at an acceleration of 300 $m \cdot s^{-2}$ over a time interval of 6 ms. During the test the assembly should be operating. After exposure the detection assembly must be inspected for loose or broken components. No alarms or other changes should occur during the vibration exposure. The indication of the monitor should not vary more than 15% from a corresponding set of reference readings.

Test method:

The detection assembly should be exposed to a ^{137}Cs source having sufficient intensity to minimize the effect of statistical fluctuations such as a radioactive source defined in Section 3.5 at a distance of 50 cm from the reference point. The count rates given by the equipment should be recorded. The mean corresponding reading should be determined.

The detection assembly should be subjected to harmonic loadings of 0.5 gn whose frequency gradually increases from 10 Hz to 33 Hz and decreases from 33 Hz to 10 Hz in each of three orthogonal directions (a 1 min cycle is recommended) [17]. The mean readings should be determined and recorded during the vibration.

In addition, the detector assembly should be subjected to harmonic loadings of 2 gn for 15 min in each of three orthogonal directions at one or more frequencies in each of the following ranges: 10–21 Hz and 22–33 Hz. However, if any mechanical resonance is found in the above test the test frequency should be chosen among the resonance frequencies. After each 15 min vibration interval the mean reading should be determined in the same exposure geometry as used initially and compared to the corresponding pre-vibration set of readings. The equipment should be inspected and the physical condition documented.

5. PERSONAL RADIATION DETECTORS

5.1. APPLICATION

Personal radiation detectors, which are similar in size to a message pager or mobile phone, can be worn on a belt or in a pocket for automated, hands free operation for alerting the user, or hand held for searching close to a suspect item. They are much more sensitive than personal dosimeters, which are used for more precise dose rate and dose measurements. They may also be used as improvised, automated radiation monitors, using their capability to alarm and retain these records for later review and retrieval in the memory. To determine the location of the radiation source the alarm indication should reset automatically when the radiation is no longer present.

5.2. CHARACTERISTICS

Current technology provides both gamma and neutron/gamma PRDs. Although in some applications neutron detection is not required, the present technical specifications mainly consider PRDs capable of detecting both gamma and neutron radiation.

To reach the highest neutron detection efficiency the PRD should be worn near the body to utilize the additional moderation it provides. PRDs can be used in ‘silent mode’ to warn the operator of the presence of radioactive material without alerting other persons in the area. PRDs are ideally suited for use by individual officers and first responders to a radiation alarm. Because they are small in size and lightweight, PRDs can be brought close to the radiation source, partially compensating for their lower detector volume and sensitivity compared to RPMs. However, it should be noted that well shielded sources hidden in vehicles are likely to be invisible to any level of portable radiation detection instruments and can only be detected by very large and highly sensitive fixed installed portal monitors. If mounted on a pole PRDs can reach the upper part of a truck. At extremely low temperatures they can be thermally isolated and warmed up from time to time, e.g. by putting them in the pocket, to keep them operational. Finally, they do not require extensive training to operate.

Since these instruments are relatively inexpensive and small enough to be worn on the belt or in a pocket it is recommended that each officer be routinely equipped with a PRD while on duty. PRDs have low power consumption so that they may be used continuously. Another advantage of these instruments is their inherent mobility, which allows closer approach to a suspected radiation source when this is safe. The use of pocket type radiation detectors worn by personnel in the course of their regular duties can represent a 'moving curtain' that can be very flexible compared to fixed, installed instruments when choke points are not feasible, and thus cover a wide variety of possible traffic routes. Note, however, that it may be difficult to localize the source of a radiation alarm in a crowd. An additional application is their use in a timer/counter mode when the radiation is measured during an extended time interval to obtain better statistics. If a suspicious item with a weak radiation field needs to be checked it can be measured for a long period, leading to an increase of the detection sensitivity by orders of magnitude.

PRDs should have a memory that can integrate the accumulated gamma and neutron dose (not replacing, however, personal dosimeters as a legal requirement). Some PRDs also record a time distribution of radiation alarms — a very desirable feature to document the result of a radiation search or automated monitoring operation.

Although PRDs can be made with one of several different types of gamma radiation detectors, currently only scintillation detectors are considered sensitive enough for this application. In view of the fact that detection of neutron radiation is crucial for radiation safety considerations as well as for detection of nuclear material, PRDs providing gamma and neutron detection are also considered here. The instrument's display should provide simple acoustic and visual indications, which should be proportional to the count rate and different for gamma and neutron radiation. This indicates to the user any changes in radiation levels and can also be used as a search tool for locating radiation sources when more sensitive instruments are not available. The alarm threshold (sigma multiplier) should be pre-set before being issued to field officers and be capable of compensating for background changes when switched on or by pressing a button. In practice, the signal from the source should be independent of the local background. Setting a constant alarm threshold (e.g. fixed count rate) makes the absolute instrument sensitivity dependent on the local background level, which is not desirable. A feature that is desirable for law enforcement is the possibility of integrating neutron and gamma counts over an extended time, e.g. overnight, to increase the sensitivity to check a weak source.

There are two possibilities for response in case of an alarm. Either the alarm remains on until the user acknowledges it manually — to go into the search mode afterwards, or the device allows automatic search when an alarm has been detected. It is up to the user to choose the preferred option.

5.3. ESSENTIAL AND DESIRABLE FUNCTIONAL FEATURES

The following features are considered essential and desirable for the proper usability of PRDs.

5.3.1. Essential features

(a) Simple to operate for non-expert users;
(b) Fully automatic, unattended continuous operation for at least 400 h without the need for any adjustment or for frequent operational checks;
(c) Gamma and neutron radiation alarms with separate visual, acoustic and silent indications;
(d) Gamma dose rate indication, energy compensated and indication of neutron counts and optional dose rate (calibrated to fast ^{252}Cf emitted neutrons), selectable;
(e) Integrating measurement mode, indicating gamma counts, neutron counts, errors and time;
(f) Increasing repetition rate (not pitch) of beep tone with increasing radiation signal for eyes free searching and adjustable volume to cover the large variations in human hearing sensitivity and noise level;
(g) Silent (inaudible) alarms for covert operation, such as vibrating alarm;
(h) Safety alarm (high dose rate) with pre-settable level (restricted access);
(i) Small, rugged packaging, shock resistant and waterproof;
(j) Indication of battery status.

5.3.2. Desirable features

(a) Setting of essential operational parameters should be protected and only be settable by the appropriate authority, e.g. via external PC to avoid incorrect adjustment;

(b) An external docking station should be provided for charging and possible data retrieval for multiple units;

(c) All alarms should be recorded with a time stamp in the memory to permit supervisors to cross-check and ensure correct investigation.

5.4. TECHNICAL AND FUNCTIONAL PERFORMANCE SPECIFICATIONS AND TESTING

5.4.1. False alarm rate

For PRDs the FAR is the number of alarms per unit of time which are not caused by radiation sources but by other causes such as statistical variations in the measurement process, i.e. counting statistics, variations in natural background intensity (not corrected for) or instrument susceptibility to electronic noise, microphonics or EMI. The susceptibility of an instrument to statistical variations and hence its FAR is directly related to its sensitivity. It is therefore recommended to test for the FAR before testing for detection sensitivity. The FAR for either gamma rays or neutrons during operation should not be more than 1 per 60 min at a 1–2 s sampling time and a 95% confidence level.

Test method:

The instrument should not trigger more than two false alarms (1 neutron and 1 gamma) within the continuous search mode for a period of 1 h at a 95% confidence level. The test should be performed by automated real time counting of the optical, acoustic or hard wired alarm signals.

5.4.2. Sensitivity to gamma radiation

The PRD must trigger a gamma alarm when a gamma source producing a dose rate of 0.5 μSv·h^{-1} (±30%) at the reference point of the detector is passed through with a speed of 0.5 m·s^{-1} in standard background conditions. This requirement must be fulfilled in the continuous gamma ray energy range of 60 keV–1.33 MeV.

Test method:

This test must be carried out in steps by subsequent performance of the test with each of the following sources, ^{241}Am, ^{137}Cs, ^{60}Co and standard nuclear material sources if available. The recommended activities or masses, creating 0.5 μSv·h^{-1} at the reference point of the detector when passing at a distance of 0.4 m, are ^{241}Am (20 MBq), ^{137}Cs (1.0 MBq), ^{60}Co (0.25 MBq), WGPu (10 g Pu metal), and HEU (100 g HEU oxide). In each group the dose rate produced by the source at a distance of 0.4 m from the reference point of the detector should be measured with an accuracy better than ±30% and properly adjusted to the corresponding value.

The probability of detection should be tested by an automated trolley passing near the PRD at a distance of 0.4 m at the closest approach between the source and the detector at an average speed of 0.5 m·s^{-1}, carrying one of the sources mentioned above. Detection probability is confirmed if at least 45 gamma alarms are triggered in 50 passages with each type of source. Gamma and neutron alarms must be clearly distinguishable.

5.4.3. Sensitivity to neutron radiation

The PRD should trigger a neutron alarm when exposed to a ^{252}Cf standard neutron source configuration emitting 20 000 n·s^{-1} (approximately 0.01 μg or 0.2 MBq) moving with a speed of 0.5 m·s^{-1} at a distance of closest approach between the source and a PRD of 10 cm. The instrument should fulfil this condition when worn on the body or tested on a standard ICRU phantom [18] of 30 cm × 30 cm × 15 cm made from polymethylmethacrylic (PMMA).

Test method:

The instrument must be mounted centred on the front side of a standard 30 cm × 30 cm × 15 cm ICRU phantom [18] made from PMMA. The probability of detection should be tested by an automated trolley passing the reference point of the PRD at a 10 cm distance of closest approach between the source and the reference point of the detector at an average speed of 0.5 m·s^{-1}. Detection probability is confirmed if at least 45 neutron alarms are triggered for 50 passages.

5.4.4. Gamma sensitivity of the neutron detector

The instrument should not trigger a neutron alarm when exposed to a ^{60}Co gamma ray source producing a dose rate at the neutron detector of not less than 100 μSv·h^{-1} (±30%), for example a 300 MBq ^{60}Co source placed at a distance of about 1 m from the reference point of the detector.

Note that this dose rate has been chosen as the highest value permissible for law enforcement at a 1 m distance according to the recommendations of the

IAEA for operational response [19]. It is also the highest permissible dose rate at a 1 m distance (transport index 10) according to the IAEA Transport Regulations [20].

Test method:

Insensitivity of the neutron channel of the instrument to gamma rays should be tested by exposing the PRD to a ^{60}Co (300 MBq) gamma ray source to produce a dose rate of 100 μSv·h^{-1} (±30%) at a distance of 1 m. Insensitivity of neutron detectors to gamma rays is confirmed if no more than one neutron alarm is triggered during a 10 min exposure.

5.4.5. Alarm settings

The instrument must provide different visual/acoustic/silent (vibration) signals for alarm, i.e. detection of increased radiation levels, and safety alarm, i.e. high radiation levels which require immediate radiation safety measures such as withdrawing from the vicinity of the source. Adjustable threshold levels for both types of neutron and gamma alarms using a protected method of setting alarm thresholds, e.g. via external PC, should be provided. The approximate dose rate corresponding to the alarm threshold levels should be shown by the display on request. Alarms should be both visual and acoustic. A selection of silent alarms (e.g. vibration) must be provided. All alarms should be recorded with a time stamp. While the safety alarm threshold is set in absolute ambient equivalent dose rate values or in absolute count rates, the normal radiation detection alarm is usually set as a number of sigma multipliers above the background value (see footnotes 2 and 3).

5.4.6. Audible indication rate for searching (‘alarm rate’)

To facilitate the location of sources the audible repetition rate (alert or beep rate), but not pitch, must be proportional to the intensity of radiation.

5.4.7. Gamma dose rate indication

The uncertainty of the ambient dose equivalent rate indication in the range of 0.1 μSv·h^{-1} up to 10 μSv·h^{-1} should be within ±50% in the continuous photon energy range from 60 to 1330 keV at the nominal direction of incidence, which should be displayed on the device. For dose rates above 50 μSv·h^{-1} and up to at least 10 mSv·h^{-1}, an overload indication alarm should be given.

Test method:

The instrument must be mounted centred on the front side of a standard ICRU phantom [18] and exposed to ^{241}Am, ^{137}Cs, and ^{60}Co sources producing a dose rate of 0.1 μSv·h^{-1}, 1.0 μSv·h^{-1} and 50 μSv·h^{-1}, each ±30% at the reference point of the instrument in the nominal direction of incidence, as stated by the manufacturer. The dose rate indication should not deviate more than ±50% from the expected dose rate value, which is measured independently by a reference instrument with an accuracy better than ±15%.

To test the overload indication the instrument should be exposed to a dose rate of 10 mSv·h^{-1} with ^{60}Co (e.g. 300 MBq at 10 cm) for a duration of 100 s, and it should be verified that the overload indication is on. One minute after returning to a dose rate of less than 50 μSv·h^{-1} the dose rate indication should be within ±50% of the expected value.

5.4.8. Physical dimensions

The instrument should preferably be worn on the belt like a mobile telephone without being inconveniently large or heavy. The outside dimensions should be no more than 200 mm × 100 mm × 50 mm and the weight should be less than 400 g.

5.4.9. Battery life

Each instrument must operate on standard rechargeable or non-rechargeable batteries. With new or fully charged batteries of the type recommended by the manufacturer the battery life must be greater than 400 h under no alarm conditions. Under continuous alarm conditions the battery lifetime should be greater than 3 h. The PRD should have a low battery indication.

Test method:

The actual battery life with rechargeable batteries should be measured under alarm conditions and non-alarm conditions in the search mode. The test is passed if the instrument remains operational for at least 400 h with only a few alarms triggered and for at least 3 h under alarm conditions at room temperature (20°C ± 2°C). Alternatively, the measured power consumption and battery capacity can be used to estimate the battery life.

5.4.10. Environmental and EMI

The instrument should meet the same requirements as formulated in the next section dealing with RIDs, as dealt with in Sections 6.4.10–6.4.27.

5.4.11. Ruggedness

The PRD should be resistant to vibration, shock and moisture. The detailed requirements and test descriptions are given in Sections 6.4.25–6.4.27.

6. HAND HELD RIDS

6.1. APPLICATION

Modern multipurpose RIDs which detect gamma and neutron radiation are available. These instruments can be used for searching and localization of radioactive sources and simultaneously for gamma dose rate measurements for radiation safety purposes and indication of neutron count rate and/or dose rate. However, these instruments are not intended for use as legal dosimeters, which may also be required.[6] Furthermore, these instruments can be operated as gamma spectrometers to identify certain user defined radionuclides. For this purpose the gamma radiation spectra are compared with gamma lines or reference spectra of frequently observed radionuclides, and identified if statistically significant agreement is observed. Some instruments also have an external, detachable alpha/beta surface contamination monitor.

6.2. CHARACTERISTICS

To qualify as a RID, its gamma spectrometer must have the following minimum features:

[6] If the RID gives the ambient equivalent dose rate values but is not certified for legal usage as a legal dose rate metre, this should be noted in the instrument's manual or directly on the instrument

(a) Measurement of a gamma spectrum (not only in a few regions of interest);
(b) Internal processing of the spectrum to determine energy, area of gamma lines and/or the spectrum shape;
(c) Decision logic which evaluates either the whole spectrum or the list of gamma energies/intensities found, against a library of radionuclides (either gamma spectra or a look-up table consisting of energies and intensities);
(d) Use of decision making filters to properly assign gamma lines with similar energies but emitted by different isotopes, taking into account the measured peak areas, and to properly identify mixtures of radionuclides and shielded samples which produce gamma spectra with a high level of scattered gamma rays and an alteration of the observed intensities.

Hand held instruments can be used as either the primary search (detection) device to effectively search pedestrians, packages, cargo, and motor vehicles with a great deal of flexibility to locate the radiation source or as a secondary search device for verification of alarms obtained with fixed installed or PRDs. Their neutron detection sensitivity, however, is often not sufficient to localize a weak neutron source. In this case, if a special high sensitivity hand held neutron search/monitor device is not available the long period timer/counter mode should be available to at least detect the presence of a weak neutron field. Modern instruments are required to have a computer link, which can be used to transfer the spectra to a notebook, e.g. for remote transmission to an expert team. It is essential that the instrument be equipped with a selectable audible signal indicator or optional 'silent' alarm function (e.g. vibrator) to enable the user to perform the search without watching the display. The audio and visual indications need to be clearly distinct for gamma and neutron radiation. Many of the characteristics in the search mode should be similar to those of PRDs.

For effective searching the instrument should be self-contained (no external detectors or cabling, except surface contamination monitor), rugged, and should weigh less than 3 kg. It should have a comfortable, ergonomically designed carrying handle to allow for extended, single handed operation for long periods with protective gloves.

An essential requirement to achieve good performance with regard to radionuclide identification is the use of a low activity radioactive source to stabilize the energy response to the system (or the use of a stable detector, e.g. CdZnTe). If a different method of stabilization is used, e.g. by light emitting diodes (LED), a radioactive check source should still be used periodically to verify proper energy calibration. The device can also use the ^{40}K radiation of the environment or that of a substance provided with the instrument containing ^{40}K.

6.3. ESSENTIAL FUNCTIONAL FEATURES

The following features are considered essential for the proper usability of multipurpose RIDs.

6.3.1. Generic requirements

(a) Single handed operation — also with protective gloves;
(b) Simultaneous gamma and neutron detection;
(c) Selectable safety dose rate alarm levels (restricted access);
(d) Timer/counter mode for neutron and gamma channels to enhance detection efficiency;
(e) Rugged design for outdoor use in a wide range of temperature and humidity;
(f) Sufficient battery life for at least 8 h;
(g) Automatic (easy) and manual (expert) mode of operation, switch protected;
(h) Operational parameter settings: non-critical parameters in easy mode, critical parameters in expert mode (with restricted access) and mostly via computer link; selected parameters saved on exit; all parameters resettable to factory defaults;
(i) Minimum buttons to operate the device;
(j) Easy decontamination (smooth surface, not absorbant or retentive of radioactive material);
(k) Indication of the reference points on the detector casing (point with the highest counting efficiency if directed towards the test source);
(l) Suitable documentation for the users such as an operating manual, technical service and maintenance manual, list of spectra parts, troubleshooting, short checklist procedure and instrument training material;
(m) Battery backed up real time clock and memory.

6.3.2. Detector

(a) Multiple detectors for simultaneous measurement of gamma and neutrons integrated in one instrument case (no switching), except for an external alpha/beta detector if supplied;

(b) Highly sensitive spectral gamma detector, e.g. NaI, CsI, LaCl-3;
(c) Neutron detector effectively suppressing gamma signals;
(d) High dose rate range gross gamma detector.

6.3.3. Display and visual indications

(a) Adequate display size, well readable under field conditions and temperature extremes, illuminated with user settable display light-on time with always-on option, automated contrast adjustment depending on temperature;
(b) Capability for multilanguage support of the user interface;
(c) Energy compensated gamma dose rate indication in various modes of operation, neutron dose rate for specified neutron spectrum;
(d) Gamma and neutron counts/s with error over selected measurement time (timer/counter mode); indication of accumulated dose;
(e) Dose rate indication in units of $\mu Sv \cdot h^{-1}$ (or $mrem \cdot h^{-1}$) only, not in $nSv \cdot h^{-1}$;
(f) Auto scaling for graphic indication of count rate (e.g. bar graph, strip chart for searching);
(g) Upon startup, diagnostic messages displaying proper functioning, date and time, battery status, hardware and software version and instrument ID, stabilization messages;
(h) Adjustable threshold levels for the gamma (dose rate) and neutron (count rate/dose rate) safety alarms (absolute values); default values: 100 $\mu Sv \cdot h^{-1}$;
(i) Over range indication for dose rates greater than 10 $mSv \cdot h^{-1}$ with acoustic alarm;
(j) Indication of remaining battery life or capacity when using recommended batteries;
(k) Indication of charging process;
(l) Three ways to set parameters: non-protected in the easy mode, protected in the expert mode and through the PC support software.

6.3.4. Display indications during radionuclide identification

(a) Spectrum display with cursor functions (only in expert mode).
(b) Dead time or maximum count rate indication.
(c) Time left until processing of spectrum (countdown) if used in a fixed time mode.
(d) Indication that device is busy with processing of the spectrum.
(e) Display of results in easy mode, including radionuclide and category, unknown radionuclide, or weak signal. It is recommended to have an

indication of the confidence of the identification; ability to continue the measurement even if a result is shown.

(f) Ability to stop a measurement, showing the result if available.

(g) Ability to save the spectrum.

6.3.5. Acoustic signals

(a) Different search audio signals for gamma and neutron counts;

(b) Increasing frequency (not pitch) of audio rate proportional to gamma count rate;

(c) Single 'beeps' for neutron counts;

(d) Acoustic dose rate alarms if a specified level is exceeded;

(e) Visual and acoustic low battery alarm;

(f) Silent alarm capability (e.g. vibration), complemented by screen message.

6.3.6. Spectrometer amplifier/MCA requirements

(a) At least 1000 analog to digital conversion (ADC) channels, energy range 30–3000 keV;

(b) Stabilization of energy response (e.g. temperature sensor, LED, weak radioactive check source, preferably NORM);

(c) Linearization of the energy scale for scintillation detectors;

(d) Energy precision: Less than 1% deviation of measured gamma line energies from true in the range 30 keV–1 MeV and less than 2% in the range 1 MeV–3 MeV; differential non-linearity of ADC less than 1%;

(e) Operation without manual re-stabilization for at least 8 h in a temperature range of 20°C ± 2°C with a scintillation detector and for at least one week with a CdZnTe detector;

(f) Maximum throughput in memory 20 k counts/s;

(g) Count rate shift less than 1% for dose rates up to 50 μSv·h^{-1} (^{137}Cs);

(h) Pileup rejecter, pole zero adjustment and baseline restorer or equivalent;

(i) ADC and amplifier dead time correction;

(j) Memory for at least 100 spectra of 1000 channels each;

(k) User friendly PC support software for use by experts with easy to use transfer option for use by trained officers;

(l) Response to sudden temperature gradients, tolerating temperature changes from room temperature to +50°C and –20°C (one manual re-stabilization allowed if used for more then 1 h);

(m) Automatic spectra saving in automated (easy) mode.

6.3.7. Internal memory and PC link

(a) Data format ASCII and documented [8];
(b) PC link using standard communication interface and cables (e.g. RS232, USB, splash water protected port);
(c) Storage for at least 1000 measured alarm values in search mode (date and time, signal size);
(d) Information in data file also including relevant set-up and diagnostics data and measurement results.

6.3.8. Power supply

(a) Rechargeable and non-rechargeable, standard size battery (to be used if internal battery is dead or charger is not available), warning indication if non-rechargeable batteries are used;
(b) Set-up parameters, data and date–time setting not to be lost if main battery is completely discharged or is being replaced;
(c) Auto voltage sensing, worldwide usable AC adapter/charger, car battery adapter;
(d) Automatic change to trickle charge if left on mains power, not overloading the battery;
(e) Charging and fully charged indication on display;
(f) Charging possible during operation;
(g) Charging time (to reach 90% of capacity), less than battery discharge time, when instrument is turned off.

6.4. TECHNICAL AND FUNCTIONAL PERFORMANCE SPECIFICATIONS AND TESTING

6.4.1. Gamma energy range

To properly identify the full list of radionuclides given in section 6.4.18 the gamma energy range will extend from 30 keV (^{137}Cs X rays detectable) to 3 MeV.

Test method:

The gamma energy range of the detector at 30 keV and 3 MeV is to be tested by analysing the spectra of the 32 keV X rays of ^{137}Cs and the 2.614 MeV gamma rays of a ^{232}Th source. The X rays and gamma peaks are to be fully captured in the ADC range.

6.4.2. Sensitivity to gamma radiation in search mode

To find radioactive sources, even when they are shielded or located some distance from the instrument, a selectable acoustic gamma alarm signal must be triggered when the ambient dose equivalent rate is increased by 0.05 μSv·h^{-1} at the detector reference point for the duration of 1 s above standard background. The probability of triggering this alarm is to be better than 90%. The detection probability of 80% is verified with a confidence level of at least 95%, when at least 87 detections are made for 100 exposures. The instrument should fulfil these performance characteristics in a gamma energy range from 30 keV to 1.33 MeV.

At a distance of 0.5 m from the detector reference point the ambient dose equivalent rate of 0.05 μSv·h^{-1} corresponds to 2.5 MBq of ^{241}Am, 0.6 MBq of ^{57}Co, 0.13 MBq of ^{137}Cs, 0.035 MBq of ^{60}Co, and 0.24 MBq of ^{133}Ba. Limited experimental data for nuclear material show that a level of 0.05 μSv·h^{-1} at a distance of 0.5 m is produced by a HEU metal sphere of 350 g or by a Cd shielded high density 2.5 g sintered oxide pellet of WGPu.

Test method:

The test must be performed with ^{137}Cs. In the search mode the alarm should appear within 1 s after the signal exceeds the alarm threshold value and disappear within 1 s after the radiation signal decreases below threshold. Take at least 100 measurements by exposing the instrument to a dose rate of 0.05 μSv·h^{-1} of ^{137}Cs above the background at the detector reference point for 1 s each, and record how frequently the acoustic signal has been triggered. The detection probability of 80% is verified with a confidence level of 95% when at least 87 detections are made for 100 exposures.

6.4.3. Test of the hardware performance of the RID gamma spectrometer

The following describes the requirements and tests for the amplifier and MCA in the RID.

Peak shift and broadening as a function of count rate

During isotopic identification there should be an indication of the upper permissible count rate/dead time. This test is to check that any deterioration of the spectrometer performance remains within specified limits to ensure that radionuclide identification performs well at high count rates. The maximum throughput in memory at this upper count rate limit will also be measured. The following sources with sufficient activity to reach the upper count rate limit of the present generation RIDs should be used: ^{241}Am, ^{137}Cs and ^{60}Co.

Expose the detector with each source at a dose rate of 1 μSv·h^{-1} and 50 μSv·h^{-1}. Determine (in per cent relative to the value at 1 μSv·h^{-1}) the peak shift and broadening for the upper limit. The peak shift at the upper limit should be less than 1%. The peak broadening for a detector with a normal resolution of less than 8% for ^{137}Cs should be less than 10%. The maximum throughput in memory should be at least 20 k counts/s.

Peak stabilization warmup

The instrument should be powered on from a cold start and the calibration procedure recommended by the manufacturer should be completed. The peak location of the ^{137}Cs peak should be measured every two minutes. The peak location after the warmup time specified by the vendor should be compared with the nominal value of 662 keV. At the end of the warmup time the difference should be less than 1%.

Long term peak drift at room temperature

The instrument should be powered on from a cold start and the calibration procedure recommended by the manufacturer should be completed. The instrument should be maintained at room temperature (20°C ± 2°C). The peak location of the ^{137}Cs should be measured every hour for at least 8 h (without manual re-stabilization). The maximum peak drift of the ^{137}Cs peak should not exceed ±1%.

Peak stability with changing temperature

The instrument should be exposed in a temperature chamber at room temperature (20°C). The instrument should be powered on from a cold start and the calibration procedure and warmup time recommended by the vendor should be completed. The peak location of the ^{137}Cs peak should be measured and verified to be within ±1% of the nominal value. The temperature should then be lowered to –20°C and later increased to +50°C. Without manual restabilization the peak shift and broadening should be measured after 1 h at each temperature extreme. The peak shift should be less than 1% and the peak broadening should be less than 10%.

Check of the efficiency of the pileup rejector (PUR)

This test checks to what extent the PUR is capable of suppressing spurious gamma peaks, caused by pulse pileup, in a spectrum. A ^{137}Cs source (with a 1 mm Cd filter) is advanced to the detector until a count rate of 20 kcounts/s is reached. Measure, with a statistical error of <10%, the ratio of the pileup pulses above 700 keV in the spectrum relative to the number of pulses in the 662 keV peak. This ratio must be less than 0.05. Repeat this measurement for a ^{241}Am source, causing a count rate of 20 kcounts/s on the NaI detector. Measure, with a statistical error of <10%, the ratio of the pileup pulses above 70 keV in the spectrum relative to the number of pulses in the 60 keV peak.

Check of the precision of the energy calibration

This test checks the energy calibration of the instrument and the effectiveness of the correction on non-linearities, covering the specified energy range of the gamma spectrometer from 30 keV–3 MeV. Using the peak centroid function of the instrument, or if not available the cursor, determine the gamma energy of gamma peaks in the range from 32 keV (^{137}Cs X rays) to 2642 keV (^{232}Th). The maximum deviation between the measured and true values must be less than 1% in the range of 30 keV–1 MeV and less than 2% in the range of 1 MeV–3 MeV.

6.4.4. Sensitivity to neutron radiation

The instrument should give a neutron alarm when exposed to a neutron flux emitted from a ^{252}Cf standard neutron source configuration emitting 20 000 n·s^{-1} (±30%) (~0.01 μg), for a duration of 5 s at a distance of 0.20 m from the detector when the gamma radiation is shielded to less than 1%. The probability of triggering a neutron alarm should be better than 80%, i.e. no more than 4 failures in 100 exposures.

Note that the specified neutron sensitivity is sufficient for radiation safety purposes only and to confirm the presence of neutrons, but not for locating neutron sources in the field, except if the position of the source has already been nearly determined, e.g. by a portal monitor. For effective neutron source location a more sensitive neutron detector would be required, which might not fit into a hand held multipurpose RID and is to be designed as a stand-alone device. This neutron searching device (see below) should provide much higher neutron sensitivity than the value stated above.

Test method:

The probability of detection should be tested by exposing the reference point of the instrument at least 100 times to the neutron flux emitted from a ^{252}Cf standard neutron source of 20 000 n·s^{-1} (±30%) (~0.01 μg) for a duration of 5 s at a distance of 0.20 m from the reference point of the detector. A detection probability of 90% is verified at a confidence level of 95% when at least 87 detections are made for 100 exposures.

Note that the neutron detection sensitivity of a hand held device depends strongly on the moderation. The test should therefore be performed in a non-reflective situation, e.g. on a thin steel plate without additional moderation of the source. If an instrument is delivered with an external moderator this can be used.

To test the long term stability of the neutron counter, the count rate of a test source in a fixed geometry should be determined, using the timer/counter mode at least 10 times in 24 h with a statistical error of <1%. The deviations should be within statistical limits.

6.4.5. Gamma sensitivity of neutron detector

The instrument should not trigger a neutron alarm when exposed to a ^{60}Co gamma ray source producing a dose rate at the neutron detector reference point of not less than 100 μSv·h^{-1} (±30%), placed at a distance of at least 1 m from the reference point of the detector.

Note that this dose rate has been chosen as the highest value permissible for law enforcement personnel at a 1 m distance according to IAEA recommendations for operational response [19]. It is also the highest permissible dose rate (transport index 10) according to the IAEA Transport Regulations [20].

Test method:

The insensitivity of the instrument to gamma rays should be tested by exposing the RID to a ^{60}Co (300 MBq at 1 m) gamma ray source to produce a dose rate of 100 μSv·h^{-1} (±30%) at the neutron detector reference point. Insensitivity of neutron detectors to gamma rays is verified if no more than one additional neutron alarm is triggered during 1 h.

Note that this test and the false neutron alarm rate test should be performed prior to the neutron sensitivity test. The result of this test should also be used to verify that the ^{252}Cf used in Section 6.4.7 does not cause false neutron pulses due to the gamma sensitivity of the neutron detector.

6.4.6. Safety alarm setting

The instrument should provide threshold levels for the gamma (dose rate) and neutron (count rate or dose rate) safety alarms (absolute values), adjustable within the range of the gamma/neutron dose rates and neutron counts/s range. The dose rate corresponding to the gamma/neutron threshold level should be displayed on the dose rate screen. Alarms should be both visual and acoustic.

6.4.7. Gamma dose rate indication

The instrument must be capable of measuring ambient dose equivalent rates of up to 10 mSv·h^{-1} with an uncertainty of less than ±50% at the detector reference point in the continuous energy range of 60 keV–1.33 MeV with a frontal direction of incidence. When the dose rate is increased gradually from 100 μSv·h^{-1} the device should not indicate zero dose rate for more than 1 s when switching from the NaI based rate reading to the GM counter based reading and back.

Test method:

The instrument should be exposed to ^{241}Am, ^{137}Cs and ^{60}Co sources, each producing a dose rate of 1 μSv·h^{-1}, 100 μSv·h^{-1} and 1 mSv·h^{-1} at the reference point of the instrument, as stated by the manufacturer, in frontal direction of incidence. In addition, the instrument should be exposed to ^{60}Co at a dose rate of 10 mSv·h^{-1} (300 MBq at 10 cm). No dose rate reading should deviate more than ±50% from the expected dose rate value measured with a calibrated, traceable gamma dose rate meter. There should be no discontinuity in the dose rate indication over the complete specified range. This also applies to the safety alarm settings and threshold levels described in Section 6.4.6.

To verify that the energy calibration of the instrument is not affected by a high gamma dose rate, a source of ^{241}Am should be properly identified in accordance with the test procedure set forth in Section 6.4.18 within 1 min after a 1 min exposure to a ^{60}Co source with a dose rate of 10 mSv·h^{-1}. When the dose rate indication switches from NaI to GM based values, a zero value should not be shown for more than 1 s with the GM counter directed towards the gamma source.

6.4.8. Over range indication

The instrument must provide an over range indication or continuous alarm at dose rates that are beyond its measuring range of 10 mSv·h^{-1} up to a dose rate of 1 Sv·h^{-1} applied for 1 min.

Test method:

The instrument should be exposed to a ^{60}Co source producing a dose rate of approximately 1 Sv·h^{-1} at the detector reference point for 10 min. The instrument's over range indication should remain on.

6.4.9. False alarm rate for gamma and neutron radiation

At standard gamma and neutron background, the FAR should be less than one per minute for gamma alarms and less than one per hour for neutron alarms at a 95% confidence level. The dwell time should be 1 s.

Test method:

At standard gamma and neutron background the total number of gamma alarms during 10 min should be less than five for a 95% confidence level and the total number of neutron alarms should be less than 5 in 8 h for a 95% confidence level.

6.4.10. Environmental requirements

The instrument must meet the performance specifications listed above in the temperature range of –20°C to +50°C and at a non-condensing relative humidity of 90% at 35°C. For certain geographical areas more extreme conditions could apply. Special, more expensive device options should be available upon request.

6.4.11. Temperature shock

The instrument must be fully functional within 1 h of exposure to rapid temperature changes from 20°C to –20°C, from –20°C to 20°C, from 20°C to 50°C, and from 50°C to 20°C, with each change being reached in less than 5 min. The instrument must provide an indication if it is not fully functional.

Test method:

Place the instrument in an environmental chamber and allow it to stabilize at 20°C, then perform a simultaneous radionuclide identification of ^{241}Am and ^{60}Co placed in a location that provides a dose rate of 0.5 μSv·h^{-1} from each source at the reference point of the detector. The instrument and radioactive sources should then be exposed to temperatures of 50°C (±2°C), 20°C (±2°C) and –20°C (±2°C), with the temperature change being made in less than 5 min. No manual restabilization should be allowed.

The instrument should be observed continuously. Every 15 min, simultaneous radionuclide identification should be performed as stated previously and a series of dose rate readings should be recorded. Radionuclide identification should not be done if the instrument indicates that it is not functional. After 1 h the instrument should correctly identify each radionuclide in nine out of ten trials. In addition, the mean indicated gamma dose rate from each temperature extreme should be within ±30% of the mean dose rate obtained at 20°C.

6.4.12. Electrostatic discharge

The instrument must function properly after exposure to ESD at intensities of up to 6 kV for contact and 8 kV for air.

Test method:

To evaluate an instrument's immunity to ESD the 'contact discharge' technique for conductive surfaces and coupling planes and the 'air discharge' technique for insulating surfaces should be used. Discharge points should be selected based on user accessibility.

There should be ten discharges per discharge point with a 1 s recovery time between each discharge. The maximum intensity of each discharge is based on the technique used, 6 kV for contact and 8 kV for air discharge. The instrument should be able to perform a simultaneous radionuclide identification of ^{241}Am and ^{60}Co placed in a location that provides a dose rate of 0.5 μSv·h^{-1} from each at the detector after exposure to the ESD test. No alarms or false identifications should occur during exposure to each discharge.

6.4.13. Radiofrequency

The instrument should not be affected by RF fields over the frequency range of 20–1000 MHz and 1400–2000 MHz at an intensity of 10 volts per metre

(V/m). The indicated dose equivalent rate should remain within ±30% of the reading with no discharge applied.

Test method:

Place the instrument in an RF controlled environment and expose it to an RF field of 20 V/m measured without an instrument present in the irradiation area over a frequency range of 20–1000 MHz and 1400–2000 MHz that is 80% amplitude modulated with a 1 kHz sine wave. The test should be performed using an automated sweep at a frequency change rate not greater than 1% of the fundamental. Note that 20 V/m is selected to reduce test time by permitting tests in one orientation.

If susceptibilities are indicated by substantial changes in the displayed dose rate or other operational changes such as alarm activation, perform a simultaneous radionuclide identification of ^{241}Am and ^{60}Co placed in a location that provides a dose rate of 0.5 μSv·h^{-1} from each source at the detector at those frequencies. No alarms or other spurious indications should occur and there should be no change in radionuclide identification. The indicated dose rate should remain within ±30% of the initial indicated value throughout the RF exposure.

6.4.14. Radiated emissions

Radiation protection instrumentation can be used in many different areas. RF emissions from an instrument should not be high enough to interfere with other equipment located in the area of use. The emission limits when measured at 3 m are shown in Table 3.

TABLE 3. EMISSION LIMITS

Emission frequency range (MHz)	Field strength (μV/m)
30–88	100
88–216	150
216–960	200
Above 960	500

Test method:

Place the instrument in a shielded room or chamber, as appropriate. Place an antenna 3 m from the assembly. With the instrument off collect a background spectrum using a bandwidth of 50 kHz. Switch the instrument on and perform an RF scan. Repeat the test with the instrument performing radionuclide identification. The measured emission should be less than those in Table 3.

6.4.15. Conducted immunity

The instrument should not be affected by RF fields that can be conducted onto the instrument through an external conducting cable. Instruments that do not have at least one external conducting cable are excluded.

Test method:

Place ^{241}Am and ^{60}Co sources in a location that provides a dose rate of 0.5 μSv·h^{-1} from each source at the detector and expose the instrument to a conducted RF field over the frequency range of 150 kHz–80 MHz at an intensity of 140 dB (μV) 80% amplitude modulated with a 1 kHz sine wave. The test should be carried out using an automated sweep at a frequency change rate not greater than 1% of the fundamental. If susceptibilities are indicated by substantial changes in the displayed dose rate or other operational changes such as alarm activation, perform simultaneous radionuclide identification at those frequencies. No alarms or other spurious indications should occur and there should be no change in radionuclide identification. The indicated dose rate should remain within ±30% of the initial indicated value throughout the RF exposure.

6.4.16. Magnetic fields

The instrument should be fully functional when exposed to DC magnetic fields in two orientations relative to a 10 G magnetic field.

Test method:

Place ^{241}Am and ^{60}Co sources in a location that provides a dose rate of 0.5 μSv·h^{-1} from each source at the detector and expose the instrument to a 10 G magnetic field. If susceptibilities are indicated by substantial changes in the displayed dose rate or other operational changes such as alarm activation, perform radionuclide identification. No alarms or other outputs should be activated and there should be no change in simultaneous correct radionuclide identification.

6.4.17. Battery life

The instruments need to operate on standard rechargeable and non-rechargeable batteries. With fully charged (rechargeable) or new (non-rechargeable) batteries of the type recommended by the manufacturer, the battery life should be greater than 8 h under no alarm conditions. Under continuous alarm conditions the battery lifetime should be greater than 3 h. An indicator for the remaining battery capacity must be provided.

Test method:

The current consumption in both non-alarm and continuous alarm conditions should be measured. The resulting battery life should be calculated based on the measured capacity of well conditioned and charged batteries at room temperature (20°C ± 2°C). In addition, at least one test to measure the instrument's actual battery lifetime under alarm (audio + vibration + visual) and non-alarm conditions should be performed. The battery life at the lowest specified temperature (–20°C) should also be measured and should not be less than 6 h.

6.4.18. Radionuclide identification

Most of the radionuclides likely to be encountered at borders should be identified by instruments capable of identifying spectra consisting of gamma ray energy peaks between 30 keV and at least 3 MeV. The radionuclides of greatest interest and those most likely to be encountered are listed below in order of increasing isotopic number. Radionuclides should be identified by the individual radionuclide and the relevant category, i.e. nuclear, medical, industrial and NORM. For uranium, plutonium and radioactive iodine it is sufficient to display the element and category in the easy mode only. Multipurpose RID should be capable of identifying all radionuclides listed below, which should not be considered all-inclusive.

Note that radionuclide identification under realistic conditions at the border may present more stringent requirements than those shown below (shielded sources in vehicles, high background of scattered gamma rays, nuclear material masked by other radionuclides, etc.). The users may require identification of nuclear material and other radioactive sources in a wide range of realistic cases, including:

(a) U and Pu in lead and steel containers;
(b) Nuclear material of different physical and chemical compositions ranging from thin metallic samples to infinitely thick samples with high and low U and Pu concentrations;
(c) Fast identification of weakly active NORM to quickly identify an innocent/nuisance alarm (fertilizer, tiles, etc.);
(d) Identification of a weak nuclear material signal on a high background of masking NORM or industrial radionuclides;
(e) No false positive alarms involving the indication of U or Pu;
(f) Reliable radionuclide identification over a wide range of environmental and count rate conditions;
(g) Non-ambiguous display messages informing the non-expert in gamma spectrometry of the result of an analysis;
(h) Addressing the needs of first responders to a radiological dispersion device alarm (extended list of radionuclides, high count rate operation, shielded sample).

Radionuclides to be identified

(a) Nuclear material: ^{233}U, ^{235}U, ^{238}U , also recycled (covering HEU, LEU, NU, DU), ^{237}Np, ^{239}Pu (ranging from reactor to weapons grade);
(b) Medical radionuclides: ^{18}F, ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{125}I[7], ^{131}I, ^{133}Xe, ^{201}Tl, ^{51}Cr, ^{103}Pd;
(c) Industrial radionuclides: ^{57}Co, ^{75}Se, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{241}Am, ^{152}Eu;
(d) NORM: ^{40}K (fertilizer, cat litter, tiles, ceramics), ^{226}Ra (in equilibrium with daughters), ^{232}Th and decay products[8], and ^{238}U in natural U and its decay products (e.g. in Fiestaware® or coloured glass);
(e) Bremsstrahlung (e.g. ^{90}Sr/^{90}Y) should not be misidentified as gamma radiation from one of the listed radionuclides and preferably be identified as 'bremsstrahlung';

[7] This isotope may not be identifiable by all devices since its main lines have an energy of only about 27 keV.

[8] The high energy gamma lines of ^{232}Th and ^{228}Th at 2614 keV are also an attribute of recycled uranium. A differentiation between ^{228}Th originating from ^{232}Th decay and that from ^{233}U or ^{232}U decay is desirable.

(f) Neutron capture gamma rays in polyethylene should be identified as 'neutron capture gammas'.

In automatic (easy) mode the system should:

(1) If any uranium radionuclide is detected, display: 'nuclear — uranium';
(2) If any plutonium radionuclide is detected, display: 'nuclear — plutonium';
(3) If ^{232}Th + daughters are detected, display: 'NORM — Th';
(4) If ^{18}F is detected, display 'annihilation gamma rays';
(5) If iodide isotope is detected, display 'medical — I';
(6) If ^{241}Am is detected, display 'industrial — Am'; Pu may be present.

In manual (expert) mode the system should:

(i) If uranium radionuclide is detected, display 'DU, NU, LEU, HEU' and whether the material is recycled.
(ii) If plutonium radionuclide is detected, display 'reactor grade' or 'weapons grade' Pu. The presence of neutrons should be recognized by software and should be used to identify Pu. Expert users should assess any impact on spectrum/enrichment caused by the presence of absorbers.
(iii) If ^{232}Th + daughters are detected, display: 'NORM — Th' and whether ^{228}Th originated from ^{232}Th or from the decay of ^{233}U or ^{232}U.
(iv) For iodide isotopes, give the mass numbers and display, e.g. 'medical — I'.

Since the probability of observing particular radionuclides at different types of border crossings such as land borders, airports and seaports varies, it is useful to be aware that for pedestrian or car border crossings and airports, medical radionuclides from recently discharged patients are the most likely to be encountered. This radioactive material can either be localized or distributed throughout the body, depending on the kind of treatment.

Naturally occurring radionuclides such as ^{40}K, ^{226}Ra, ^{232}Th and ^{238}U are most likely to be detected when large quantities of material are transported, i.e. at seaports, on trains, and in truck traffic at land borders.

Test method:

The instrument must be set up according to the manufacturer's instructions. The ambient dose equivalent rate at the detector reference point from each source, unshielded or shielded, should be 0.5 μSv·h^{-1} (±30%) above background and the background spectrum should be recorded. The test should consist of 100 trials for each radionuclide. The performance is acceptable when the instrument correctly identifies the radionuclide in 87 out of 100 trials. The following time requirements are to be met:

(a) Unshielded in 1 min;
(b) Steel shielded within 2 min;
(c) Lead shielded samples within 10 min;
(d) NORM samples up to 10 min;
(e) Nuclear material ^{233}U, ^{235}U, ^{238}U (ranging from depleted U to high enriched U), ^{237}Np, Pu (ranging from weapons to reactor grade of all ages and chemical, physical compositions and shape);
(f) Medical radionuclides: ^{18}F (PET), ^{67}Ga, ^{99m}Tc, ^{111}In, ^{123}I, ^{125}I, ^{131}I, ^{133}Xe, ^{201}Tl, ^{51}Cr, ^{103}Pd;
(g) Industrial radionuclides: ^{57}Co, ^{75}Se, ^{60}Co, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{241}Am, ^{152}Eu;
(h) NORM: ^{40}K, ^{226}Ra (in equilibrium with daughters), ^{232}Th and decay products, ^{238}U in natural U and decay products;
(i) Unshielded: ^{40}K, ^{57}Co, ^{60}Co, ^{67}Ga, ^{99m}Tc, ^{125}I, ^{131}I, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{201}Tl, ^{226}Ra, ^{232}Th, ^{233}U, U, Pu (^{241}Am suppressed with a Cd filter), ^{241}Am;
(j) Behind 5 mm steel shielding: ^{40}K, ^{57}Co, ^{60}Co, ^{67}Ga, ^{99m}Tc, ^{125}I, ^{131}I, ^{133}Ba, ^{137}Cs, ^{192}Ir, ^{201}Tl, ^{226}Ra, ^{232}Th, ^{233}U, ^{235}U, ^{238}U, Pu, ^{241}Am, ^{75}Se, ^{152}Eu;
(k) Behind 10 mm lead shielding: Pu, ^{238}U (depleted and low enriched Uranium, $< 20\%$).

In addition, it is desirable to include a categorization of Bremsstrahlung sources: ^{90}Sr/^{90}Y. Note that some isotopes may have industrial/medical applications. In this case they should be flagged as 'industrial' to be on the safe side. Some NORM isotopes may also have industrial applications. It is up to the responsible officer to consult experts if the source strength/dose rate does not match typical NORM values.

The normalization of the test conditions to a constant dose rate on the detector surface makes it easier to pass the test for low energy gamma emitters because of their higher number of gammas per dose rate unit. At higher energies, however, the density of gamma lines per energy interval is much lower and identification is easier.

Test method: mixtures:

The instrument must be set up according to the manufacturer's instructions. The following isotopic combinations must be identified within 2 min (unshielded) at 0.5 μSv·h^{-1} (±30%) above background measured at the detector reference point from each radionuclide. The measurements should be made with two sources irradiating the detector at the same time for 2 min.

— ^{137}Cs + U (natural and HEU);
— ^{131}I + U (natural and HEU);
— ^{131}I + WGPu;
— ^{57}Co + U (natural and HEU);
— ^{133}Ba + WGPu;
— ^{226}Ra + ^{232}Th.

6.4.19. Increase gamma background requirement

The instrument must be able to identify the radionuclide of interest in the presence of an increased gamma background from natural thorium and ^{40}K.

Test method:

Expose the instrument to a natural thorium and ^{40}K gamma dose rate (fertilizer) measured at the detector of 0.5 μSv·h^{-1}. Place a HEU sample at a location that provides an increase of 0.5 μSv·h^{-1} at the detector. The instrument must be able to identify the radionuclide of interest (HEU) within 2 min. The test should consist of 50 trials and the performance is acceptable when the instrument correctly identifies the radionuclide of interest in 45 out of 50 consecutive trials. The test should be repeated using ^{60}Co as the radionuclide of interest. If only a weak ^{40}K source is available the test should be performed with an increased measurement time for the ^{40}K exposure relative to that of the other radionuclides.

6.4.20. Interfering ionizing radiation (beta) requirement

The instrument should identify a radionuclide of interest when exposed to the radiation emitted from a shielded pure beta emitting radionuclide.

Test method:

Expose the instrument to a 5 mm steel shielded beta emitter (^{32}P or ^{90}Sr/^{90}Y). The photon (X rays, Bremsstrahlung, etc.) radiation should be 0.5 μSv·h^{-1} at the detector reference point. Expose the instrument to a 0.5 μSv·h^{-1} ^{137}Cs gamma dose rate. The test should consist of 50 individual trials and is acceptable when the instrument correctly identifies ^{137}Cs in 45 of 50 consecutive trials.

Remove the ^{137}Cs source and with the instrument exposed only to the shielded beta emitter, perform identification. The identification results should not include any unexpected radionuclides and should indicate the presence of an 'unidentified' radionuclide. To be acceptable this should occur in 45 of 50 consecutive trials.

6.4.21. False identification requirement

The instrument should not identify a radionuclide that is not present when operated in a stable and low ambient radiation background. A shielded box or enclosure may be required to perform the test. Radioactive or nuclear material should not be indicated in any measurement when they are not present.

Test method:

Perform radionuclide identification with the instrument in a stable background of not more than 0.1 $\mu Sv \cdot h^{-1}$ with no radiation sources present. No unexpected radionuclides should be identified within 10 min. The test should consist of 50 trials and the performance is acceptable when the instrument does not identify a radionuclide in 45 of 50 consecutive trials. If naturally occurring radionuclides such as ^{40}K are identified, action should be taken to reduce or eliminate the source prior to the test. If the radionuclide is expected and cannot be removed, the test result should be acceptable when the expected naturally occurring radionuclide is identified. The nuclear material should not be indicated if not present. To test this, isotopes that have gamma energies of around 185 keV — ^{67}Ga, ^{166}Ho and the backscattering peak of ^{137}Cs in a strongly scattering environment (see Section 6.4.34) — should be measured for 1 min. The test should consist of 50 trials and the performance is acceptable when the instrument does not identify uranium in 45 of 50 consecutive trials.

6.4.22. Interference from surrounding material requirements

The instrument must be able to identify radionuclides in the presence of backscattered radiation.

Test method:

Expose the instrument to a ^{137}Cs source placed between two steel plates that are approximately 1 cm thick that produces an 0.5 $\mu Sv \cdot h^{-1}$ radiation field at the reference point of the detector. This test is acceptable if a ^{137}Cs source is correctly identified in 45 of 50 consecutive trials.

6.4.23. Identification of radioactive material typically causing innocent/nuisance alarms due to NORM

The following materials containing NORM are often encountered at borders:

(a) Coloured glass containing U;
(b) Optical lenses with Th;
(c) Video screens with Th;
(d) Gas lantern mantles with Th;
(e) Watches containing ^{226}Ra;
(f) Fertilizer and cat litter, etc. containing ^{40}K;
(g) Ceramics containing Th, U;
(h) Welding rods containing Th;
(i) Tails from the oil industry or desalination plants containing ^{228}Ra, Th.

Test method:

All NORM items producing a count rate three times the background rate should be properly identified without shielding. Due to the low dose rates at the detector the measurement time can be extended up to 10 min.

6.4.24. Physical dimensions

The multipurpose hand held identification device should be self-contained (no external detectors or cabling), having a comfortable, ergonomically designed carrying handle that allows for extended single handed operation, even with protective gloves. The outside dimensions should be less than 300 mm × 200 mm × 150 mm. The total weight should be less than 3 kg.

6.4.25. Vibration

The instrument must withstand exposure to vibrations without damage, as shown in Table 4.

Test method:

Conduct an external examination (visual inspection) and ensure that the instrument is functioning properly. Switch on the instrument and mount it on a shock machine. Expose the instrument to the vibration and shock transients shown in Table 4, in three directions. After the tests, check the instrument for mechanical damage and loose components. Verify that the instrument functions according to the manufacturer's specifications and that there are no additional alarms.

6.4.26. Mechanical shock

In its shipping case the instrument must withstand exposure to shocks, as shown in Table 4. In addition the device, as well as its shipping case, should survive without damage a drop test from a height of 1 m onto a concrete floor.

Test method:

Conduct an external examination (visual inspection) and ensure that the instrument is functioning properly. Switch on the instrument and mount it on a shock machine. Expose it to the shock transients shown in Table 4. After the tests check the instrument for mechanical damage or loose components. Verify that the instrument is functioning properly and that there are no additional alarms. Drop test the device on all sides of its shipping case at least 10 times.

6.4.27. Moisture resistance

The count rate or indicated dose rate from a ^{137}Cs source producing a dose rate of approximately 1 $\mu Sv \cdot h^{-1}$ at the detector should remain unchanged after the instrument has been sprayed with water for 30 min.

TABLE 4. VIBRATION AND SHOCK TRANSIENTS

Test	Criteria	Acceptability
Vibration	Frequency (Hz)	10–500
	Maximum acceleration (m/s^{-2})	10
	Number of axes	3
	Test duration	15 min/axis
Shock	Maximum acceleration(m/s^{-2})	300
	Pulse duration (ms)	6
	Total number of shocks/direction	3
	Direction of shocks	6

7. NEUTRON SEARCH DETECTORS

7.1. APPLICATION

The NSD can be used as the primary search (detection) device to search pedestrians, packages, cargo and vehicles, or as a complementary device to be used for searching and localization of neutron sources detected by RPM. It may also be used as an improvised automated neutron monitor, using its capability to alarm and retain these records for later review and retrieval in the memory.

The probability of detection is increased if the user moves the instrument closer to any radioactive material that is present. In addition the instrument is more likely to detect radiation if it is moved reasonably slowly over the area to be scanned. However, moving too slowly means that a survey takes longer and so there is a compromise between speed and sensitivity. Searching a motor vehicle is much more difficult and time consuming than searching people or packages. This device addresses the need to have a sufficiently effective hand held NSD to reduce the time to localize a neutron source detected with a portal monitor.

7.2. CHARACTERISTICS

The most important feature needed by an NSD is high neutron detection efficiency. This should be accomplished with an acceptable size, weight and ruggedness. It should be able to be operated single handedly for an extended period and be useable in outdoor conditions. Another important feature is a selectable dwell time with clear audible alarms and, if possible, visible indication of the neutron signal as a function of time (e.g. in a strip chart and red alarm light), thus making the neutron source localization process easier. The NSD should have a high contrast backlit display showing all necessary information including date and time, a local memory, a computer link and acoustic alarm/alert indicators. For some applications a silent alarm option (vibration) may be required. Background subtraction and alarm generation principles should be similar to those used in the search modes of PRDs and RIDs.

In the search mode the instruments should be able to take multichannel scaler (MCS)[9] measurements with a sufficiently short dwell time so that they

[9] MCS mode: a multi-channel analyser operated in timescale, i.e. the radiation intensity (neutron count rate in this case) is measured as a function of time. MCS dwell time is a time interval per one time channel.

can be used to quickly scan the surfaces of packages, pedestrians, vehicles and cargo. To determine the location of the radiation source the alarm indication should reset automatically when the neutron signal is no longer present. The repetition rate (frequency) of the audio alarm signal should increase with an increasing count rate. To ensure radiological safety during the search operation simultaneous display of count rate and automatic high dose rate alarming are essential. A timer/counter mode (neutron counts/s, per cent error and time, count rate preferably compared with previously measured background) should be available.

7.3. ESSENTIAL FUNCTIONAL REQUIREMENTS

The following features are considered essential to the usability of NSDs.

7.3.1. Generic requirements

(a) Single handed operation, even with protective gloves;
(b) Selectable (restricted access) radiological safety alarm threshold shown on the display;
(c) Rugged design for outdoor use in a wide range of temperature and humidity;
(d) Battery life of at least 8 h;
(e) Set-up parameters (some of them with restricted access) resettable to factory defaults;
(f) Minimum number of labelled operating buttons;
(g) Easy decontamination (smooth surfaces not absorbing or retaining radioactive material);
(h) Indication of the reference points on the detector casing (point with the highest counting efficiency if directed towards the test source and reference point for dose rate indications);
(i) Suitable documentation for the users such as an operating manual, technical service and maintenance manual, list of spare parts, troubleshooting and short checklist procedure;
(j) Power on startup test to indicate proper functioning of the instrument, date and time, and hardware and software versions.

7.3.2. Detector hardware and software

(a) High efficiency, moderated neutron detector option, e.g. a moderated ^{3}He tube;

(b) Reasonable insensitivity to gamma radiation;
(c) Detectors integrated in one instrument case in a stand-alone device;
(d) Gamma detector for safety gamma alarm detector integrated into the same case (e.g. small solid state or GM counter);
(e) Adequate display size, reliable under field conditions and temperature extremes illuminated with user settable light, 'display-on' time adjustable with 'always-on' option, automated contrast adjustment depending on temperature, limited manual adjustment if required;
(f) Multilanguage support for the graphic user interface;
(g) Indications in timer counter mode: elapsed time, counts/s, total counts, counts/s error in per cent if manually stopped;
(h) Set-up for search mode: user selectable dwell time and alarm multiplier related to FAR and sensitivity; background measuring time;
(i) Indications in search mode: numeric/graphic display indication of neutron counts/s, optional neutron dose rate (user selectable);
(j) Permanent screen indications in SEARCH mode, e.g. battery status, function keys, safety alarm thresholds, alarm multiplier, dwell time;
(k) Mode indications (e.g. COUNTER, SEARCH, SET-UP);
(l) Graphic signal intensity at least indication (MCS mode — strip chart);
(m) Neutron dose rate indication (counts/s or dose rate indication, user settable);
(n) Indication of remaining battery life or capacity, also during charging, when using recommended batteries;
(o) Defined/documented upper count rate/dose rate limits, overload indications, no breakdown of the overload indication in high radiation fields.

7.3.3. Acoustic and visual signals

(a) Alarm sounds if alarm threshold is exceeded (frequency of beeps proportional to number of neutrons above threshold), LED and vibration alarms;
(b) Increasing rate (not pitch) proportional to neutron rate;
(c) Visual and acoustic dose rate/counts/s alarm if a specified safety level is exceeded;
(d) Visual and acoustic low battery alarm;
(e) Visual, audible and silent alarm capability (vibration); display of selected alarm indication.

7.3.4. Internal memory and PC link

(a) Storage for at least 1000 measured alarm values (date and time, maximum signal size with at least some adjacent channels, optional full MCS data segment for alarm and history buffer);
(b) PC link using standard communication interface and cables (e.g. RS232, USB, splash water protected port);
(c) ASCII string data format;
(d) Standardized file information including all relevant set-up and diagnostics data and measurement results;
(e) Support PC software operating under Windows NT 2000 or XP with a set-up of the most restricted parameters, retrieval of the alarm list.

7.3.5. Power supply

(a) Rechargeable and non-rechargeable standard size battery option (to be used if the internal battery is dead or a charger is not available), warning sign if non-rechargeable batteries are being used;
(b) Set-up parameters, data and date/time setting that will not be lost if the main battery is completely discharged or is being replaced (long lasting buffer battery);
(c) Auto voltage sensing, optional universal AC adapter/charger, car battery adapter;
(d) Automatic change to a trickle charge, not overloading the battery if left on mains power;
(e) Charging and fully charged indications;
(f) Charging possible during operation;
(g) Battery life at least 8 h at room temperature, 6 h at –20°C;
(h) Charging time when instrument is turned off (to reach 90%) less than battery life.

7.4. TECHNICAL AND FUNCTIONAL PERFORMANCE SPECIFICATIONS AND TESTING

7.4.1. Neutron sensitivity

Static and dynamic detection efficiency

Absolute detection efficiency to fission spectrum neutrons should not be less than 20 counts/s per n·cm^{-2}·s^{-1} (20 cm^2). This is equivalent to 2 counts/s (background subtracted) when the ^{252}Cf standard neutron test source of 12 000 $n{\cdot}s^{-1}$ intensity is located at a 1 m distance from the reference point of the sensitive detector surface with the reference point of the instrument pointing towards the source. The NSD should trigger an alarm when exposed to a ^{252}Cf source with an emission rate of 12 000 $n{\cdot}s^{-1}$, moving with a speed of $0.5{\cdot}ms^{-1}$ at the distance of closest approach of 1 m.

Test method:

A ^{252}Cf standard neutron source configuration with an intensity of not more than 12 000 $n{\cdot}s^{-1}$ should be placed at a distance of 1 m from the detector sensitive area marked reference point, and measured within a time interval adequate to get a statistical uncertainty less than 10%. The count rate, determined in the timer/counter mode of the device, should be no less than 2 counts/s.

Nuclear material detection limit

One-hundred grams of WGPu (with specified chemical composition and physical shape) at a distance of 1 m should be detected within 5 s with an 80% detection probability at a 95% confidence level in standard (0.015 $n{\cdot}cm^{-2}{\cdot}s^{-1}$) background conditions.

Test method:

One-hundred grams of WGPu sample or equivalent (^{252}Cf source of about 6500 $n{\cdot}s^{-1}$ intensity) at a distance of 1 m and a 5 s measurement time should produce at least 45 alarms for 50 neutron test ‘pulses’.

False alarm rate

The FAR should be less than 1 per 10 min at a 2 s sampling time at a 95% confidence level at standard neutron background.

Test method:

There may be no more than one false alarm during 10 min at a 2 s sampling time. This requirement is met with a 95% confidence level if after 2 h there are no more than six false alarms.

7.4.2. Safety alarm

A safety alarm should be triggered if the dose rate of a standard ^{252}Cf source at the detector reference point reaches 100 μSv·h^{-1} (10 mrem·h^{-1}). The safety alarm level should be user settable (restricted access).

Test method:

The instrument must produce a safety alarm (acoustic and visual) when exposed to a standard neutron source configuration while being exposed in a low scattering environment to a neutron dose rate of 100 μSv·h^{-1} (10 mrem·h^{-1}) ±50%. The detector distance should be at least 50 cm and the measurement geometry should minimize neutron scatter.

7.4.3. Gamma insensitivity

The instrument should not count neutrons when exposed to a ^{60}Co gamma ray source producing an ambient dose equivalent rate at the neutron detector reference point of not less than 100 μSv·h^{-1} from the main direction.

Test method:

The neutron background rate should be measured in the timer counter mode with and without a gamma field. There should be no difference within a statistical error limit of ±30% (one sigma limit). The source should be placed at a distance of at least 0.5 m from the detector reference point, irradiating the whole detector volume.

7.4.4. Alarm setting

The instrument should allow neutron and gamma safety alarm thresholds to be set (defined as a constant counts/s or dose rate value), adjustable within the full range of operation (restricted access). Alarms should be both visual and acoustic. The alarm thresholds should be displayed on the screen.

7.4.5. Search mode

The instrument should give an acoustic and visual indication of the neutron source localization process with a changing audio signal repetition rate (frequency) and MCS graph or equivalent on the display, depending on the source to detector distance. It should produce a maximum acoustic signal rate (highest counts/s value on the display) at the closest distance to the given source. Scaling (either manual or preferably automatic) should be possible.

On startup of the search mode or at user request the background should be measured over a time period specified by the user (e.g. 300 s). It should be easy to manually remeasure the background. The alarm algorithm may also offer the option of adapting to a continuously changing background.

Test method:

The detector should be located 2 m from a 20 000 $n \cdot s^{-1}$ (±30%) intensity ^{252}Cf source. At a 2 s dwell time slowly (about 0.1 $m \cdot s^{-1}$) move the detector on the line with the closest detector to a source distance of about 10 cm. The audio alarm signal should trigger at about 1.2 m from the closest detector to source distance and increase in frequency until the maximum value is reached, when the distance is minimal. The count rate on the detector display (and, if available, the MCS or graph) should increase.

Other requirements are discussed in Sections 6.4.10–6.4.22.

Test method (see 6.4.26):

7.4.6. Physical dimensions

The NSD must be self-contained (no external parts except battery charger), having a comfortable ergonomically designed carrying handle. The outside dimensions should be no more than about 300 mm × 200 mm × 150 mm. The total weight should not exceed about 4 kg.

7.4.7. Ruggedness

The NSD must be resistant to vibration, shock and moisture. The detailed requirements and test descriptions are given in Sections 6.4.25–6.4.27.

8. DOCUMENTATION REQUIREMENTS

The manufacturer must provide an operating manual, a technical service and maintenance manual, a list of spare parts, troubleshooting and short checklist procedure, as outlined below. An MS PowerPoint presentation for instrument training should be included.

8.1. TECHNICAL SPECIFICATIONS

The manufacturer must provide a specification document containing the following information:

(a) Contact information for the manufacturer, i.e. name, address, telephone, fax, email address, etc.;
(b) Type of the instrument, purpose, types of radiation to be measured;
(c) Complete description of the instrument with general technical data, including optimal configuration, range of exposure rates, detection efficiency, sensitivity, accuracy, FAR, background influence, calibration data, reference points, modes of operation, alarm initiation algorithms, kinds of alarm, markings, power supply, mechanical, environmental and electrical characteristics, electromagnetic compatibility, reliability, factory test and QA sheet, guarantees and any other relevant information.

8.2. OPERATION AND MAINTENANCE MANUALS

The manufacturer must provide operating manuals, a short checklist operating procedure, schematic electrical diagrams, parts list with specifications, a troubleshooting guide, and a list of recommended spare parts.

8.3. INITIAL AND PERIODIC TEST PROCEDURE

The manufacturer must provide a test procedure for the verification of all relevant parameters (exposure and energy ranges, accuracy and stability).

8.4. ACCEPTANCE TEST REPORT

The manufacturer must provide a report on the test results performed to the technical specification requirements.

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Annex I

QUANTITIES AND UNITS

The measurement quantities and units used in this publication are count rate (counts per s [counts/s^{-1}]) and dose rate (ambient dose equivalent H*(10) rate, expressed in $Sv \cdot h^{-1}$ [I–1]). While count rates are used for detection and localization of radioactive material by portal monitors, personal radiation devices and search instruments, dose rates are preferable for radiation safety measurements, e.g. with multipurpose RID, neutron search devices or PRDs.

For specification of radiation levels in test procedures dose rates at a reference point can be expressed universally, independently of radiation specific, detector specific or geometrical parameters, in contrast to count rates which are relevant for a particular system only. On the other hand absolute detection efficiency expressed in count rate per unit of activity of specified radionuclide in the static mode is an intrinsic detection system parameter which does not depend on the actual background level and the car/truck/pedestrian speed. To specify detection sensitivity for nuclear material it is preferable to use mass of material since the effective radiation intensity at the detector greatly depends on the chemical form, shape and mass of material due to self-absorption of the low energy gamma radiation in the source.

REFERENCE TO ANNEX I

[I–1] INTERNATIONAL ELECTROTECHNICAL COMMISSION, Basic Environmental Testing Procedures, Part 2: Tests, Edn 5.0, IEC 60068-2, IEC, Geneva (1990).

Annex II

CRITERIA BASED ON STATISTICAL PROBABILITIES

II–1. DETECTION CRITERIA

Table II–1, derived from Ref. [II–1] and used in Ref. [II–2], specifies the minimum number of detections required to verify a given detection probability.

TABLE II–1. DETECTION CRITERIA FOR VERIFYING DETECTION PROBABILITY AT A >95% CONFIDENCE LEVEL

Total number of passages	Minimum number of detections required to verify a detection probability[a] of					
	0.50	0.75	0.80	0.85	0.90	0.95
20	15	19	20	20	—[b]	—
30	20	27	28	29	30	—
50	32	43	45	47	49	—
100	59	83	87	92	96	99
250	139	200	211	223	234	244
1000	527	774	822	869	916	962

[a] For total passages from a single evaluation, the detection probability is estimated to be greater than the column heading value with at least 95% confidence. For accumulated passages from more than one evaluation, the column heading is a point estimate of the detection probability.

[b] An inadequate total number of passages to estimate the indicated detection probability with at least 95% confidence in a single evaluation.

II–2. CRITERIA FOR FAR TESTING

The values in Table II–2 are derived from using binomial distribution for N tests with given average probability, assuming a 95% confidence level. For example, if within 30 000 tests the number of false alarms is not more than 4 the false alarm probability less than 1/3600 is verified with a 95% confidence level.

TABLE II–2. CRITERIA FOR VERIFYING FAR AT A 95% CONFIDENCE LEVEL

Total number of tests	Maximum number of false alarms required to verify the FAR at a 95% confidence level		
	1/1000	1/3600	1/10 000
3600	0	—	—
10 000	5	0	—
30 000	21	4	0
100 000	—	19	5

REFERENCES TO ANNEX II

[II–1] DIXON, W.J., MASSEY, F.J., Introduction to Statistical Analysis, McGraw-Hill, New York (1969).

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Annex III

CONVERSION TABLES FOR ACTIVITY AND DOSE RATE OF SPECIFIED SOURCES

TABLE III–1. CONVERSION OF GAMMA DOSE RATE TO SOURCE CHARACTERISTICS [III–1, III–2]

Radionuclide	Ambient dose equivalent/activity ratio at 1 m distance			nSv·h^{-1} per 1 MBq at various distances			
	μSv·h^{-1} per GBq	MBq per 0.1 μSv·h^{-1}	μCi per 10 μR·h^{-1}	0.5 m	1.0 m	1.5 m	3.0 m
^{137}Cs	95	1.05	28	380	95	42	10.6
^{60}Co	360	0.28	7.5	1440	360	160	40
^{241}Am	5.2	19	520	21	5.2	2.3	0.6
^{57}Co	21	4.8	128	84	21	9.3	2.3
^{133}Ba	52	1.9	52	208	52	23	5.8

TABLE III–2. CONVERSION TABLE OF NEUTRON EMISSION RATE, DOSE RATE AND NEUTRON FLUX FOR SPECIFIED NEUTRON SOURCES [III–3]

Source	Neutrons·s^{-1}	Dose rate at 1 m, μSv·h^{-1}		Neutron flux at 1 m, n·cm^{-2}·s^{-1}
		Neutron	Gamma	
^{252}Cf (1 μg)	2.3×10^6	23	1.4	18
^{240}Pu (1 g)	1020	0.01	~0.1	0.008
WGPu oxide (1 kg)	~1×10^5	~1	~10	~0.8
WGPu metal (1 kg)	~ 7×10^4	~0.7		~0.6

Note. A fast neutron source with an intensity of 10^6 n·s^{-1} produces about 10 μSv·h^{-1} at a distance of 1 m. A thermal neutron source of 10^6 n·s^{-1} produces about 1 μSv·h^{-1} at a distance of 1 m.

REFERENCES TO ANNEX III

[III–1] INTERNATIONAL ATOMIC ENERGY AGENCY, Calibration of Radiation Protection Monitoring Instruments, Safety Reports Series No. 16, IAEA, Vienna (2000).

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Annex IV

MINIMUM SET OF REFERENCE TEST SOURCES SUITABLE FOR ALL TEST PROCEDURES

TABLE IV–1. SOURCES FOR STATIC AND DYNAMIC DETECTION EFFICIENCY TESTING

Radionuclide	^{241}Am	^{57}Co	^{137}Cs	^{60}Co	^{133}Ba	^{252}Cf
Activity (MBq)	20	1	1	0.25	0.25	12 000 n·s–^{1}*

* Except PRD where it should be 20 000 n·s^{-1}.

TABLE IV–2. SOURCES FOR SAFETY ALARM AND NEUTRON CHANNEL INSENSITIVITY TO GAMMA RADIATION TESTING

Radionuclide	Required activity (MBq)	Comments
^{137}Cs	300	100 μSv·h^{-1} at 0.3 m
^{60}Co	300	100 μSv·h^{-1} at 1 m
^{252}Cf	2.3 × 10^{6}	100 μSv·h^{-1} at 0.5 m

GLOSSARY

alarm threshold value. Prescribed number of sigma multipliers above the background value.

safety alarm. Acoustic, visual or vibration signal produced when the radiation level exceeds the safety alarm threshold value.

safety alarm threshold value. Absolute ambient dose equivalent rate (or absolute count rate) equivalent to the maximum permissible value (100 μSv·h^{-1}). Exceeding of the safety alarm threshold requires immediate radiation safety measures.

standard gamma ray background. Ambient dose equivalent rate (dH*(10)/dt) of 0.1 μSv·h^{-1} ±50% as measured by a legal dose rate metre with a wide energy range of 30 keV^{-3} MeV.

standard neutron background. Value of the neutron flux outside and at sea level. This is approximately 0.015 n·cm^{-2}·s^{-1} (±30%).

standard neutron source configuration. A ^{252}Cf source emitting a specified number of neutrons per second surrounded by 1 cm of lead.

Illicit trafficking of nuclear and other radioactive material has been an issue of concern since the early 1990s. By the end of 2004, IAEA Member States had confirmed 540 cases, while another 500 remain unconfirmed. The attacks of September 2001 in the USA dramatically emphasized the requirement for enhanced control and security of these materials. The IAEA has adopted an integrated approach to protection against nuclear terrorism. This publication provides a set of technical specifications that can be used in design testing, qualifying and purchasing border radiation monitoring equipment.

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