

INTERNATIONAL STANDARD



**Radiation protection instrumentation –
Vehicle-mounted mobile systems for the detection of illicit trafficking of
radioactive materials**

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**Radiation protection instrumentation –
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INTERNATIONAL ELECTROTECHNICAL COMMISSION

**RADIATION PROTECTION INSTRUMENTATION –
VEHICLE-MOUNTED MOBILE SYSTEMS FOR THE DETECTION
OF ILLICIT TRAFFICKING OF RADIOACTIVE MATERIALS**

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The text of this standard is based on the following documents:

FDIS	Report on voting
45B/946/FDIS	45B/955/RVD

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

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INTRODUCTION

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

In response to the technical policy of the International Atomic Energy Agency (IAEA), the World Customs Organization (WCO), and the International Criminal Police Organization (Interpol) related to the detection and identification of special nuclear materials and security trends, radiation instrumentation companies have developed and manufactured instruments to assist in the detection of illicit movement of radioactive and special nuclear materials. This type of instrumentation is widely used for security purposes at nuclear facilities, border control checkpoints, and international seaports and airports.

To ensure that measurement results made at different locations are consistent, it is imperative that radiation instrumentation be designed to rigorous specifications based upon agreed performance requirements stated in this document. IEC standards have also been developed to address personal radiation detectors, radiation portal monitors, highly sensitive gamma and neutron detection systems, spectrometric personal radiation detectors, and backpack-based radiation detection and identification systems. Those standards are listed below.

Type of instrumentation	IEC number	Title of the standard
Body-worn	62401	Radiation protection instrumentation – Alarming Personal Radiation Devices (PRDs) for the detection of illicit trafficking of radioactive material
	62618	Radiation protection instrumentation – Spectroscopy-Based Alarming Personal Radiation Devices (SPRD) for the detection of illicit trafficking of radioactive material
	62694	Radiation protection instrumentation – Backpack-type radiation detector (BRD) for the detection of illicit trafficking of radioactive material
Portable or hand-held	62327	Radiation protection instrumentation – Hand-held instruments for the detection and identification of radionuclides and for the estimation of ambient dose equivalent rate from photon radiation
	62533	Radiation protection instrumentation – Highly sensitive hand-held instruments for photon detection of radioactive material
	62534	Radiation protection instrumentation – Highly sensitive hand-held instruments for neutron detection of radioactive material
Portal	62244	Radiation protection instrumentation – Installed radiation portal monitors (RPMs) for the detection of illicit trafficking of radioactive and nuclear materials
	62484	Radiation protection instrumentation – Spectroscopy-based portal monitors used for the detection and identification of illicit trafficking of radioactive material
Mobile system	63121	Radiation protection instrumentation – Vehicle-mounted mobile systems for the detection of illicit trafficking of radioactive materials
Data format	62755	Radiation protection instrumentation – Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials

RADIATION PROTECTION INSTRUMENTATION – VEHICLE-MOUNTED MOBILE SYSTEMS FOR THE DETECTION OF ILLICIT TRAFFICKING OF RADIOACTIVE MATERIALS

1 Scope

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

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

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 60050-395:2014, *International Electrotechnical Vocabulary (IEV): Part 395: Nuclear instrumentation: physical phenomena, basic concepts, instruments, systems, equipment and detectors*

IEC 61187, *Electrical and electronic measuring equipment – Documentation*

IEC 62706, *Radiation protection instrumentation – Environmental, electromagnetic and mechanical performance requirements*

IEC 62755, *Radiation protection instrumentation – Data format for radiation instruments used in the detection of illicit trafficking of radioactive materials*

3 Terms and definitions, abbreviated terms and symbols, quantities and units

3.1 Terms and definitions

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

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

- IEC Electropedia: available at <http://www.electropedia.org/>
- ISO Online browsing platform: available at <http://www.iso.org/obp>

3.1.1

acceptance test

contractual test to prove to the customer that a device meets certain conditions of its specification

3.1.2

alarm response

audible signal or visual signal, initiated when the reading of an instrument exceeds a pre-set value or falls outside a pre-set range

3.1.3

ambient dose equivalent

dose equivalent at a point in a radiation field, produced by the corresponding aligned and expanded field, in the ICRU sphere at a depth d , on the radius opposing the direction of the aligned field

Note 1 to entry: This definition does not include the notes that are part of the definition IEC 60050-395:2014,395-05-43.

3.1.4

background

radiation field in which there are no external sources present other than those in the natural radiation field at the location of the measurements

3.1.5

categorisation

ability of an instrument to determine the type of radioactive material based on its emitted radiation, e.g., naturally occurring radioactive material, nuclear material, medical radionuclides, and industrial sources

3.1.6

coefficient of variation

ratio of the standard deviation to the mean of a value

3.1.7

coverage factor

k

numerical factor, k , used as a multiplier of the combined standard uncertainty in order to obtain an expanded uncertainty

3.1.8

detection zone

location from which radiation emitted by an object being monitored may be detected by the detection assembly

3.1.9

error of indication

difference between the indicated value v of a quantity and the conventionally true value v_c of that quantity at the point of measurement

3.1.10 nuclear material

plutonium except that with isotopic concentration exceeding 80 % in plutonium-238 (^{238}Pu); uranium-233 (^{233}U); uranium enriched in the isotope 235 or 233 (^{235}U or ^{233}U); uranium containing the mixture of isotopes as occurring in nature other than in the form of ore or ore-residue; any material containing one or more of the foregoing

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

3.1.11 reference point

location marked on the instrument or described in the manual used to establish radiation source to instrument distances and orientation for test or calibration purposes

3.1.12 relative intrinsic error

relative error of indication of a piece of equipment or an assembly with respect to a quantity when subjected to a specified reference quantity under specified reference conditions, expressed as:

$$e_i = (v - v_c)/v_c,$$

where

v is the indicated value of a quantity, and

v_c is the conventionally true value of this quantity at the point of measurement.

Note 1 to entry: Simple definition: error of a measuring instrument when used under reference conditions.

3.1.13 type test

conformity test made on one or more items representative of the production

3.1.14 uncertainty <of measurement>

parameter, associated with the result of a measurement, that characterises the dispersion of the values that could reasonably be attributed to the measurand

3.2 Abbreviated terms and symbols

AAI	additional acceptable identification
CISPR	Comité International Spécial des Perturbations Radioélectriques (Special International Committee on Radio Interference)
COV	coefficient of variation
DU	depleted uranium
ESD	electrostatic discharge
HDPE	high-density polyethylene
HEU	highly-enriched uranium
ICRU	International commission on radiation units and measurements
NORM	naturally occurring radioactive material
PMMA	polymethyl methacrylate
RF	radio frequency
RGPu	reactor grade plutonium
RI	required identification

SNM special nuclear material
 WGPu weapons-grade plutonium

3.3 Quantities and units

In the present document, units of the International System (SI) are used¹. The definitions of radiation quantities are given in IEC 60050-395.

The following units may also be used:

- for energy: electron-volt (symbol: eV), $1 \text{ eV} = 1,602 \times 10^{-19} \text{ J}$;
- for time: years (symbol: y), days (symbol: d), hours (symbol: h), minutes (symbol: min);
- for temperature: degrees Celsius (symbol: °C), $0 \text{ °C} = 273,15 \text{ K}$.

Multiples and submultiples of SI units are used, when practicable, according to the SI system.

4 General test procedure

4.1 General

Unless otherwise specified in an individual step, tests enumerated in this document may be used as part of a type test or an acceptance test.

4.2 Standard test conditions

Except where otherwise specified, the tests described in this document should be performed under the standard test conditions given in Table 1, understanding that vehicle-mounted mobile systems may be large, and that testing may need to be performed in an uncontrolled environment. The ambient temperature, relative humidity, and atmospheric pressure shall be recorded during testing.

Table 1 – Standard test conditions

Influence quantity	Standard test conditions
Ambient temperature	18 °C to 25 °C
Relative humidity	≤ 75 %
Atmospheric pressure	70 kPa to 106,6 kPa
Gamma radiation background	Ambient dose equivalent rate less than or equal to $0,15 \mu\text{Sv}\cdot\text{h}^{-1}$
Neutron background	Neutron fluence rate less than $200 \text{ s}^{-1}\cdot\text{m}^{-2}$

NOTE Vehicle-mounted mobile systems are typically used in non-radiological areas, e.g., shipping ports and border locations. Man-made radiological materials such as radiation sources are not expected to be present in these areas. Non-radiological areas are expected to be used when testing vehicle-mounted mobile systems.

¹ International Bureau of Weights and Measures: The International System of Units, 8th edition, 2006.

4.3 Uncertainties

The radiation field or ambient dose equivalent rate uncertainty should not exceed $\pm 20\%$, except for the radiation background measurements, for which the uncertainty may be larger than the value stated here. Unless otherwise stated, the uncertainties are specified with a coverage factor $k = 1$.

4.4 Statistical fluctuations

For tests involving the use of radioactive sources to verify susceptibility to a climatic, electromagnetic, or mechanical condition (Clauses 7, 8, and 9), the radiation field produced by the sources to verify the vehicle-mounted mobile system response shall be adjusted to reduce the magnitude of the statistical fluctuations.

If the magnitude of the statistical fluctuations of the vehicle-mounted mobile system indication arising from the random nature of radiation alone is a significant fraction of the variation of the indication permitted in the test (i.e., fluctuations greater than 12%), then the radiation field should be increased to reduce the fluctuation of the readings (to ensure that the mean value of such readings may be estimated with sufficient accuracy to demonstrate compliance with the test in question). If the radiation field cannot be increased to meet the required coefficient of variation (COV) then the number of readings should be increased as necessary. The COV for the nominal mean reading shall be less than or equal to 12%.

For measurements without sources (i.e., at the level of background radiation), the vehicle-mounted mobile system is observed in order to verify that alarms and spurious indications are not produced by an influence quantity (e.g., temperature, humidity, RF, impact, vibration), as readings are expected to display large fluctuations. Therefore, testing without sources can be performed even when the COV is larger than 12%.

4.5 Background radiation during testing

Testing shall be performed in an area having a radiation background as defined in Table 1. The background shall be measured prior to testing and monitored during testing. A background spectrum shall also be acquired using a spectroscopic (e.g., high-purity germanium [HPGe]) detector to ensure that only naturally-occurring radionuclides (e.g., ^{40}K , ^{232}Th series, ^{238}U series) are present in the testing area. The neutron background should be measured unless it can be confirmed that no neutron sources are in the test area. The elevation at the test location shall be recorded.

4.6 Operating parameters and set up

Vehicle-mounted mobile systems shall be set up based on the manufacturer's specifications. Operating parameters such as alarm settings should remain unchanged throughout the test.

For testing purposes, the reference point is the centre point of the detection assembly face or the adjacent side of the vehicle to which the detection assembly is mounted; see Figure 1. The testing distance is measured from the front face of the detection assembly; it is not measured from the outside of the vehicle.

The vehicle-mounted mobile system shall be oriented as defined by the manufacturer. If the vehicle-mounted mobile system requires a background measurement, it shall be allowed to acquire the data in a manner specified by the manufacturer prior to the start of a test.

4.7 Setup and test parameters

Setup and test parameters are given in Table 2.

For testing purposes, the height of the detection zone is defined as ranging from 1 m to 3 m above the ground or road surface. The detection assembly shall be placed at the height specified by the manufacturer. Additional setup and test parameters are listed in Table 2 and illustrated in Figure 1.

Table 2 – Setup and test parameters

Source to reference point distance	Dynamic speed	Measurement time for static testing
cm	m•s ⁻¹	s
300 ± 1	2,2 ± 0,2	60

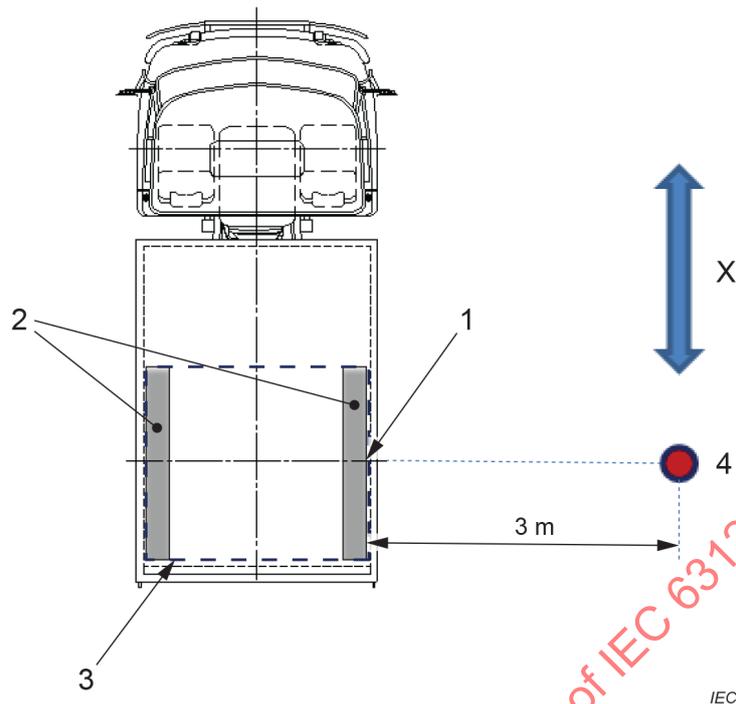
If the vehicle-mounted mobile system is two-sided, i.e., it utilises radiation detectors mounted on each side of the vehicle, then each side of the system should be tested independently. If the detector assemblies on both sides of the system are the same, it is not necessary to test both detector assemblies.

4.8 Dynamic testing

Unless otherwise stated, each source shall be passed horizontally through the middle of the bottom half and the middle of the top half of the detection zone (i.e., 1,5 m and 2,5 m from the ground) at the speed and distance provided in Table 2. The source shall be configured such that there is no shielding around the source other than that required for a specific test. The vehicle-mounted mobile system's alarm shall be reset between successive trials, if appropriate and as needed. There shall be a 10 s minimum delay between each trial with the source either shielded or positioned at a distance where it does not affect the background surrounding the vehicle-mounted mobile system.

4.9 Static testing

With the vehicle-mounted mobile system set up for a static measurement, place each source at the vertical centre of the detection zone (i.e., at 2 m from the ground), in the horizontal centre of the detection assembly, with the source at a distance of 3 m from the reference point, and initiate a measurement cycle for the static measurement time shown in Table 2. The vehicle-mounted mobile system's alarm shall be reset between each trial, if appropriate and as needed.



Key

- X Source direction for dynamic test
- 1 Reference point position
- 2 Detector(s)
- 3 Detection assembly
- 4 Source

Figure 1 – Reference point diagram for a two-sided vehicle-mounted mobile system (top down view)

4.10 Radiation sources

All radiation sources used for radiological testing (Clause 6) are listed in Table 3. The activity, emission rate, and fluence rate values at the time of testing shall be within (-0 %, +20 %) of the value shown in this table. Sources used for testing shall be traceable to the SI system of units through a national metrology institute. Source activities listed in Table 3 are based on photons emitted by stainless steel (0,25 mm thick) encapsulated sources; this does not apply to special nuclear material (SNM) sources. The specified activities are determined by the desired source emission rate. If the source is of a different construction, it is required to have the same emission rate for the selected photon energy listed in Table 3.

²⁵²Cf or ²⁴⁴Cm is the reference source for neutron alarm testing. The source shall have a neutron emission rate of 20 000 s⁻¹ (-0 %, +20 %) and, unless otherwise stated, be surrounded by a spherical high-density polyethylene (HDPE) moderator with a wall thickness of 4 cm. The inner cavity diameter of the moderator should be no larger than 3 cm.

NOTE Due to radioactive decay, the emission rate of the ²⁵²Cf source will be within the stated range of 20 000 – 24 000 s⁻¹ for ~8 months; for ²⁴⁴Cm, the emission rate will be in the stated range for ~4,7 y.

Medical radionuclides shall be surrounded by (8 ± 0,4) cm of polymethyl methacrylate (PMMA) to represent in-vivo configurations.

The test activities used for detection and identification purposes are not indicative of the alarm set point(s) or overall detection capability of a vehicle-mounted mobile system.

Table 3 – Test radionuclides and materials^a used for Clause 6 of this document

Radionuclide	Activity or neutron emission rate	Selected gamma-ray line keV
²⁴¹ Am	1,74 MBq	60
¹³³ Ba	370 kBq	276
⁶⁰ Co	370 kBq	1173
¹³⁷ Cs	590 kBq	662
²⁵² Cf or ²⁴⁴ Cm	$2 \times 10^4 \text{ s}^{-1}$	N/A
⁶⁷ Ga	3,5 MBq	185
¹³¹ I	850 kBq	365
^{99m} Tc	4,7 MBq	141
²⁰¹ Tl	8,3 MBq	167
²²⁶ Ra	590 kBq	295
²³² Th ^b	700 kBq	239
Source	Gamma fluence rate ($\text{s}^{-1} \cdot \text{cm}^{-2}$) at 1 m	
DU	1,04 (See 4.11)	1001
HEU	1,44 (See 4.11)	186
WGPu	0,40 (See 4.11)	375
<p>^a The activity, emission rate, and fluence rate values at the time of testing shall be within (-0 %, +20 %) of the values shown in this table. The uncertainty in the actual activity value shall be less than or equal to $\pm 5 \%$ (1σ, $k = 1$) for the gamma-ray sources. The uncertainty in the fluence rate shall be $\pm 10 \%$ (1σ, $k = 1$) for the HEU, WGPu, and DU sources. The uncertainty in the neutron emission rate shall be $\pm 10 \%$ (1σ, $k = 1$) for the ²⁵²Cf or ²⁴⁴Cm source.</p> <p>^b The ²³²Th source activity is based on thorium metal rods 3,5 mm thick.</p>		

4.11 Special nuclear material (SNM) and depleted uranium (DU) sources

For this document, highly-enriched uranium (HEU) has an enrichment that is $\geq 90 \%$ ²³⁵U, depleted uranium (DU) has a ²³⁵U abundance of 0,2 % to 0,4 %, and weapons-grade plutonium (WGPu) has composition of $\leq 6,5 \%$ ²⁴⁰Pu and $> 93 \%$ ²³⁹Pu.

NOTE The fluence rate stated in Table 4 for HEU is based on the emission rate from an HEU sphere with a mass of approximately 237 g. The fluence rate for WGPu is based on the emission rate from a WGPu sphere having a mass of approximately 15 g and surrounded by 1 cm thick Fe. The DU fluence rate is based on the emission rate from the side wall (along the equator) of a 10 kg right circular cylinder of DU with a diameter approximately equal to half its length. Each fluence rate for the gamma lines specified in Table 4 was determined at a source-to-detector distance of 1 m. The test distance is shown in Table 2.

Table 4 – SNM fluence rates

Material	Gamma line used for determination of fluence rate keV	Gamma emission rate s ⁻¹	Gamma fluence rate at 1 m s ⁻¹ •cm ⁻²
DU	1 001	1,07 × 10 ⁵	1,04
HEU	186	1,81 × 10 ⁵	1,44
WGPu	375	5,01 × 10 ⁴	0,40

For the materials listed in Table 4, different masses, shapes, and forms may be used for testing as long as the required fluence rate is obtained. The DU source may be assembled from available reference materials (e.g., 100 cm² plates). A complete description of the source including mass, form, shape, isotopic composition, and gamma energy spectrum shall be saved as part of the test record.

In order to gain consistency in testing, the WGPu source may need to be shielded (e.g., with copper alloy ASTM B152) to reduce the measured emissions at 60 keV from ²⁴¹Am. The shielding shall reduce the 60 keV ²⁴¹Am emission rate so that it is not more than a factor of 10 greater than the 375 keV ²³⁹Pu emission rate. For example, if the emission rate for the 375 keV line is 100 s⁻¹ then the emission rate for the 60 keV ²⁴¹Am line should not exceed 1 000 s⁻¹.

NOTE The factor 10 was determined from source material measurements.

Measurements shall be made using a characterised HPGe detector (i.e., with known full-energy-peak efficiency at the measurement distance, known energy calibration, and known measurement geometry). If the measurement geometry and distance are the same as those used for HPGe characterisation, use the equation below to determine the emission rates, *R*, for the 60 keV and 375 keV gamma-ray lines; if the geometry and/or distance is not the same, additional corrections should be made to account for the difference in the measurement efficiency.

$$R = \frac{A_n}{T_L \varepsilon(E)} \tag{1}$$

where

A_n is the net photo-peak area (in counts) for the gamma line of energy, *E*;

ε(E) is the detector full-energy-peak efficiency of the HPGe detector for gamma rays of energy, *E*;

T_L is the live time of the measurement (expressed in seconds).

4.12 Functionality test and test acceptance range requirements

4.12.1 General requirements

For most tests in Clauses 7, 8, and 9, the vehicle-mounted mobile system functionality is evaluated prior to and after the test and in some cases during the test as well. The measured response of the vehicle-mounted mobile system after the test (post-test measurement) is compared with the response measured prior to the test (pre-test measurement).

When applicable, depending on the test method, the source shall be kept in the same location throughout the duration of the test (pre-test measurements through post-test measurements). Otherwise, if the source needs to be removed during the test, to account for any possible bias introduced by the source placement, the source shall be removed and repositioned at the

same location between every reading for pre-test as well as for intermediate- and post-test measurements.

NOTE Markings and well-designed rigid fixtures can be used to indicate the source position and to aid in repeatability of the source placement throughout the test.

Gamma-ray measurements are performed using ^{241}Am and ^{60}Co sources (or other sources that emit low- and high-energy gamma-rays) and the neutron measurements are performed using a neutron source, e.g., ^{252}Cf , ^{244}Cm , $^{241}\text{AmBe}$. The neutron source may have measurable gamma-ray emissions. The ^{241}Am and ^{60}Co sources should be as stated in Table 3 and should be positioned so that the COV of each nominal mean reading is less than or equal to 12 %. The following guidance regarding sources applies:

- a) The same sources shall be used in the pre- and post-tests.
- b) The source activities and reference dates shall be recorded.
- c) The sources should activate the appropriate alarms during the pre-test measurements.
- d) If the vehicle-mounted mobile system has radionuclide identification capabilities, the dead time should be small (e.g., less than 5 %) in order to avoid pile-up effects.

Statistical fluctuations should be considered during these tests (see 4.4).

The pre-test, intermediate-test, and post-test measurements shall be carried out on the instrument under test as follows.

4.12.2 Pre-test measurements

- a) With the vehicle-mounted mobile system in position for test, expose it to a gamma-radiation field using ^{241}Am and ^{60}Co simultaneously, and a neutron source (if applicable). Source positions shall be marked or otherwise noted to ensure repeatability for the intermediate and post-test measurements.
- b) Record 10 gamma radiation readings (e.g., ambient dose-equivalent rates, exposure rates, count rates) with the source(s) present, in order to obtain the mean and standard deviation. The time between readings should be at least 1 s. The time between readings shall be long enough to ensure that the readings are independent. The selected time between readings is dependent on the integration time of the vehicle-mounted mobile system and the update time of the response indication.
- c) Increase the radiation field above the gamma alarm threshold to verify that the gamma alarm is activated. Remove the gamma sources.
- d) If applicable, record 10 neutron count-rate readings in order to obtain the mean and standard deviation. The time between readings should be at least 1 s. The time between readings shall be long enough to ensure that the readings are independent. The selected time between readings is dependent on the integration time of the vehicle-mounted mobile system and the update time of the response indication.
- e) If applicable, increase the radiation field above the neutron alarm threshold to verify that the neutron alarm is activated. Remove the neutron source.
- f) If applicable, perform a series of 10 radionuclide identifications with ^{241}Am and ^{60}Co , and record the identification results including the confidence indicators, if provided. Collect at least one spectrum from the 10-trial series. Remove the sources.
- g) Calculate the mean, \bar{x}_{pre} , and standard deviation, s_{pre} , of the count-rate or ambient dose equivalent rate readings.
- h) Calculate the COV and verify that it is ≤ 12 %. If the value is larger than 12 %, adjust the radiation field or the number of readings as described in 4.4.
- i) If applicable, the system shall correctly identify ^{241}Am and ^{60}Co in 10 out of the 10 trials.

4.12.3 Intermediate-test measurements

- a) If the intermediate-test is performed without sources present, the vehicle-mounted mobile system is observed to verify that alarms and spurious indications are not produced by an influence quantity (e.g., temperature, humidity, RF, impact, vibration), as readings may display large fluctuations.
- b) If the intermediate-test is performed with sources present, reposition each test source (gamma-ray sources and neutron source, if applicable), as needed, in the same location as in the pre-test.
- c) Record the same number of readings as in the pre-test (e.g., ambient dose-equivalent rates, exposure rates, neutron count rates) with the source(s) present.
- d) Increase the radiation field above the gamma alarm threshold to verify that the gamma alarm is activated. Remove the gamma sources.
- e) If applicable, increase the radiation field above the neutron alarm threshold to verify that the neutron alarm is activated. Remove the neutron source.
- f) If applicable, perform a series of 10 radionuclide identifications with ²⁴¹Am and ⁶⁰Co, and record the identification results including the confidence indicators, if provided. Collect at least one spectrum from the 10-trial series. Remove the sources.
- g) Calculate the mean, \bar{x}_{int} , and standard deviation, s_{int} , of the count-rate or ambient dose equivalent rate readings.
- h) If applicable, the system shall correctly identify ²⁴¹Am and ⁶⁰Co in 10 out of the 10 trials.

4.12.4 Post-test measurements

- a) Reposition each test source, as needed, in the same location as for the pre-test.
- b) Record the same number of readings as in the pre-test (e.g., ambient dose-equivalent rates, exposure rates, neutron count rates) with the source(s) present.
- c) Increase the radiation field above the gamma alarm threshold to verify that the gamma alarm is activated. Remove the gamma sources.
- d) If applicable, increase the radiation field above the neutron alarm threshold to verify that the neutron alarm is activated. Remove the neutron source.
- e) If applicable, perform a series of 10 radionuclide identifications with ²⁴¹Am and ⁶⁰Co, and record the identification results including the confidence indicators, if provided. Collect at least one spectrum from the 10-trial series. Remove the sources.
- f) Calculate the mean, \bar{x}_{post} , and standard deviation, s_{post} , of the post-test readings. If the number of gamma and/or neutron readings in the pre-test were changed from the expected value of 10, the same number of readings shall be recorded for the post-test measurements.
- g) In addition, calculate the test statistics as follows:

$$t_1 = \frac{\bar{x}_{post} - 0,85\bar{x}_{pre}}{\sqrt{\frac{s_{post}^2}{N} + \frac{(0,85 s_{pre})^2}{N}}} \tag{2}$$

$$t_2 = \frac{\bar{x}_{post} - 1,15\bar{x}_{pre}}{\sqrt{\frac{s_{post}^2}{N} + \frac{(1,15 s_{pre})^2}{N}}} \tag{3}$$

where

N is the number of readings taken in each pre-test and post-test measurements, normally equal to 10 unless an increase in the number of readings was required.

If $s_{pre} = s_{post} = 0$, then t_1 and t_2 are undefined; see acceptance criteria (4.12.5).

- h) If applicable, the system shall correctly identify ²⁴¹Am and ⁶⁰Co in 10 out of the 10 trials.

4.12.5 Acceptance criteria

The results are acceptable if changes in gamma and (if available) neutron response of the pre-test with the intermediate-test, and/or the post-test are such that $t_1 \geq -0,86$ and $t_2 \leq 0,86$. These criteria indicate that the vehicle-mounted mobile system's pre-test, intermediate-test, and post-test responses do not differ by more than 15 %.

If $s_{pre} = s_{post} = 0$, then the results are acceptable if changes in gamma and (if available) neutron response between the pre-test and post-test are such that $\bar{x}_{post} \geq 0,85 \bar{x}_{pre}$ and $\bar{x}_{post} \leq 1,15 \bar{x}_{pre}$.

Depending on the climatic, mechanical, or electromagnetic test, the vehicle-mounted mobile system's response during the test can be verified in two ways, with or without radioactive sources present. When tested using radioactive sources, the vehicle-mounted mobile system's response during the test is observed in the same manner as during the post-test defined in 4.12.4. When a test is performed without radioactive sources, the vehicle-mounted mobile system should not produce alarms above the required false-alarm rate, or spurious indications (e.g., instrument shut-down, large fluctuation in count rate readings, change in operating state) as a result of the climatic, mechanical, or electromagnetic test.

The results of the measurements are analysed in accordance with Table 5.

Table 5 – Test results analysis

Verification test	Analysis technique
Functionality	When the gamma or neutron (if applicable) radiation field is increased above the alarm threshold, verify that the alarm is activated. The results are acceptable if there are no unexpected alarms or fault indications during the test without the radioactive sources present.
Identification results	The identification results are acceptable if the complete and correct result is provided by the system in 10 out of 10 trials at each test point (see Table 7).
Radiation response	The results are acceptable if changes in gamma and neutron response from the pre-test to the intermediate-test and/or the post-test are such that $t_1 \geq -0,86$ and $t_2 \leq 0,86$. If $s_{pre} = s_{post} = 0$, then the results are acceptable if changes in gamma and neutron response between the pre-test and post-test are such that $\bar{x}_{post} \geq 0,85 \bar{x}_{pre}$ and $\bar{x}_{post} \leq 1,15 \bar{x}_{pre}$.

5 General requirements

5.1 General characteristics

Vehicle-mounted mobile systems addressed by this document detect radiological emissions from objects, containers, vehicles, or pedestrians when they are in the area surrounding the vehicle-mounted mobile system. Vehicle-mounted mobile systems shall detect gamma-ray emitting radionuclides, may detect neutrons, and may identify radionuclide(s). Vehicle-mounted mobile systems may also have the ability to indicate the direction or location of the radiation source relative to the vehicle-mounted mobile system.

Vehicle-mounted mobile systems shall be capable of operating independently of any peripheral device or remote station and shall be unaffected by malfunction of a peripheral device. Vehicle-mounted mobile systems shall be powered through the use of power from the vehicle or platform, battery(s), and/or power generator, as required (see 5.7). Vehicle-mounted mobile systems should be able to maintain their energy calibration automatically and continuously.

5.2 Physical configuration

Detection assemblies mounted to vehicles may be subjected to vibration and mechanical shock environments. Special precautions should be taken to help ensure safe transit and to reduce the transmission of shock and vibration to the vehicle-mounted mobile system. Mounting techniques, not addressed by this document, should be designed to ensure that components do not become unattached in the event of a crash.

5.3 Data storage and data files

5.3.1 Requirements

- a) The vehicle-mounted mobile system shall have the ability to store at least 8 h of measurement data as defined in step b). If mapping is provided, the vehicle-mounted mobile system shall store geolocation history.
- b) The data output from the vehicle-mounted mobile system for subsequent processing or use shall meet the requirements of IEC 62755. Each measurement data set shall contain the following information:

- Manufacturer name
- Instrument model
- Serial number
- Software version
- Instrument class (e.g., mobile)
- Gamma detector type (e.g., sodium iodide [NaI], Geiger Mueller tube [GMT], polyvinyl toluene [PVT])
- Date and time of measurement
- Measured background radiation level (e.g., counts)
- Measured gamma-ray radiation level (e.g., counts)
- Gamma-ray alarm indication

and should contain the following information:

- Monitor location via geolocation system
- Latitude and longitude
- Speed

If the vehicle-mounted mobile system has radionuclide identification capabilities, the data file shall include the following information:

- Background spectrum
- Live time and real time for the background spectrum
- Measured spectrum
- Live time and real time for the measured spectrum
- Energy calibration for the measured spectrum
- Radionuclide identification results
- Confidence indicator, if provided

If the vehicle-mounted mobile system has neutron detection capabilities, the data file shall include the following information:

- Neutron detector type (e.g., ^3He , Li glass)
- Background neutron level
- Measured neutron radiation levels
- Neutron alarm indication

- c) The vehicle-mounted mobile system shall have the ability to transfer each data file to an external device, such as a computer.
- d) The vehicle-mounted mobile system shall store 8 h of photon and (if provided) neutron count-rate time-history data. If mapping is provided, the vehicle-mounted mobile system shall store geolocation history.

5.3.2 Method of test

For all requirements except for step 5.3.1.b), inspect the vehicle-mounted mobile system or review the manufacturer-provided documentation to verify the requirements. Results of the verification shall be recorded.

For step 5.3.1.b):

- a) Using the ^{137}Cs source listed in Table 3, perform a single dynamic measurement, as described in 4.8, through the middle of the detection zone.
- b) Open the output data file and verify that the required data are contained within the file. Verify compliance of the output data file against IEC 62755.
- c) If the vehicle-mounted mobile system has neutron detection capabilities, repeat steps a) and b) using the neutron source listed in Table 3 following guidance found in 4.8.

5.4 Communications protocol

5.4.1 Requirements

Vehicle-mounted mobile systems shall have the ability to transfer data to an external device, such as a computer. The transfer should be achieved using a communications protocol such as Ethernet, USB, WiFi, or Bluetooth, or by other electronic means such as a removable media device. Consideration should be given to data security when transferring data.

5.4.2 Method of test

Review the information provided by the manufacturer to verify the requirement.

5.5 Indication and alarm features

5.5.1 Requirements

Alarm indicators (visible and/or audible) shall be provided by the user interface software (see 5.8.3) and may be provided by external alarm indicators (e.g., lights, beacons, or horns). External visual and audible alarm indicators, when provided, shall be designed to be tested without the use of radiation sources (e.g., visual and sound test). The user shall have the ability to select whether an indicator is visible or audible.

Once an alarm is activated, the vehicle-mounted mobile system shall be able to alarm again without the alarm being acknowledged or reset. The user shall not be able to disable all alarm indications concurrently.

5.5.2 Method of test

Following the manufacturer's guidance, verify that the visual and audible indicators can be tested without a radiation source, and that each visual and audible indicator can be enabled and disabled.

To verify that the vehicle-mounted mobile system remains functional when in an alarm state, perform the following process:

- a) Using a radiation source, cause the vehicle-mounted mobile system to alarm.
- b) Remove the source, but do not reset or acknowledge the alarm.

- c) After a period of 10 s, reintroduce the source to cause the vehicle-mounted mobile system to alarm again and verify that the alarm is indicated on the display (two alarms could be displayed simultaneously).
- d) Remove the source and acknowledge or reset the alarm(s).
- e) Review the stored data files to verify that two separate alarms were recorded.

5.6 Markings

5.6.1 Requirements

Exterior markings on the vehicle-mounted mobile system should be limited to the manufacturer's unique serial number, and voltage and current requirements. If equipped with an outlet plug or receptacle, the connection shall meet minimum applicable municipal, state, federal, and international code requirements.

5.6.2 Method of test

- a) Inspect the exterior markings of the vehicle-mounted mobile system and verify that the serial number, voltage, and current requirements are shown.
- b) If equipped with an outlet plug or receptacle, verify that the minimum applicable national or international code requirements are met by checking for approval labels or stickers.

5.7 Power supply

5.7.1 Requirements

Vehicle-mounted mobile systems shall have the ability to operate from AC and DC power sources. The following list details the power supply requirements:

- a) For AC, the vehicle-mounted mobile system shall be able to operate from single-phase AC supply voltage of 100 V to 240 V and from 47 Hz to 63 Hz.
- b) For DC, the vehicle-mounted mobile system shall be able to operate from 11 V to 14,5 V (nominal 12 V) or a USB power supply.
- c) Battery chargers shall meet the appropriate electrical standards.

5.7.2 Method of test

Inspect the vehicle-mounted mobile system and review the manufacturer-provided documentation to verify the requirements. Results of the verification shall be recorded.

5.8 User interface

5.8.1 User accessible controls requirements

The vehicle-mounted mobile system shall provide controls that enable the user to:

- a) Switch between transient (or mobile) scanning and static object measurements.
- b) Perform an identification and save the results, if identification is provided.
- c) Access stored measurement data.
- d) Access real-time mapping and alarm locations.
- e) Transfer data files.

Controls and switches should be designed in a way to reduce accidental operation including when a user is wearing weather-protective gloves.

5.8.2 Supervisory-user accessible indications and functions requirements

The following information and control shall be provided through access controls or special commands that are described in the manufacturer-provided documentation:

- a) Access to and control of operating parameters (e.g., radionuclide library, integration time).
- b) Access to and control of the data-logging process.
- c) Access to energy and/or efficiency calibration information.

5.8.3 User display and visual indicators requirements

The user display shall be non-reflecting and readable under different lighting conditions from a low ambient light level (<150 lx) to a high ambient light level (>10 000 lx). Displays designed to operate in an uncontrolled temperature environment shall be readable over the required temperature range (verified during temperature testing; see 7.2). Visual indicators shall include the following:

- a) Gamma alarm.
- b) Neutron alarm, if applicable.
- c) Real-time response display (e.g., strip-chart, waterfall) of gamma and neutron counts.
- d) Stored measurement data.
- e) Radiological over-range conditions (e.g., “over-range” or “high counts”).
- f) Operating mode.
- g) Battery lifetime, when applicable.
- h) Operational status (e.g., normal, calibration needed, stabilization needed).
- i) Indication of source direction, if provided.

Visual indicators should include the following:

- j) Real-time mapping with geolocation data and alarm locations.

If radionuclide identification capability is available, the following additional indicators shall be provided:

- k) Radionuclide identification result.
- l) Radionuclide present but cannot be identified (e.g., “not identified”, “unknown”).
- m) Count rate is too high for radionuclide identification.
- n) Spectral display from gamma detectors.

5.8.4 Warning indicators requirements

The following warning indications shall be provided on the display as a minimum:

- a) Detector failure condition.
- b) Energy stabilization invalid or not acceptable.
- c) Battery status.
- d) System failure.

5.8.5 Method of test

For 5.8.1 and 5.8.2, a minimum of three operators familiar with the use of these systems shall review the operating instructions provided by the manufacturer and attempt to perform each of the functions stated in 5.8.1 and 5.8.2.

For 5.8.3 and 5.8.4, review the manufacturer’s documentation and/or vehicle-mounted mobile system to verify that the visual and warning indicators are provided.

To verify the lighting requirements, each of the three operators shall perform the following steps:

- a) In an area with a low ambient light level (<150 lx), turn on the vehicle-mounted mobile system and verify that it is working properly and that the alarms and indications are visible (e.g., the battery is charged, the detector is working, self-check is passed). Note any observations regarding the readability of the display.
- b) Repeat step a) in an area with a high ambient light level (>10 000 lx).

If the vehicle-mounted mobile system has identification capabilities, perform the following steps:

- c) At normal light levels (no lux measurement requirement), move a radiation source to a position adjacent to the detection assembly while observing the display and perform a static identification of a single radionuclide (e.g., ^{137}Cs). Save the results using the process described in the manufacturer's documentation.
- d) Verify that the radionuclide identification results and confidence indicator (if applicable) are provided.
- e) Verify that a spectral display is provided for gamma detectors.

The results, including the subjective results from the three operators, shall be recorded.

6 Radiological tests

6.1 False alarm test

6.1.1 Requirements

When tested in an area with a stable background (only natural fluctuations) at the levels stated in Table 1, the false alarm rate shall be less than 1 alarm in 2 h.

Once the alarm thresholds are set up for testing, no changes shall be made that could affect the overall response of the system.

NOTE False alarms can be caused by inadequate counting statistics, background intensity variations, and/or system malfunction. Alarm capabilities are generally adjusted using alarm thresholds that inter-relate overall sensitivity and false alarm rates.

6.1.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with 4.6.
- b) Observe the vehicle-mounted mobile system for 10 h in an area that has a stable and controlled background.
- c) The results are acceptable if there is no more than 1 gamma alarm and no more than 1 neutron alarm.
- d) If the vehicle-mounted mobile system has radionuclide identification capabilities, the results are acceptable if there is no more than 1 identification of a non-background radionuclide.

NOTE The test is based on a 95 % upper confidence bound (for a Poisson distribution).

6.2 Gamma radiation alarm

6.2.1 Requirements

A gamma alarm shall be triggered when a gamma-emitting radiation source (^{241}Am , ^{137}Cs , and ^{60}Co) at the activities given in Table 3 passes by the vehicle-mounted mobile system. Test conditions shall be as stated in Table 1 and Table 2.

NOTE This requirement is not intended to estimate detection probability and the confidence in those estimates.

6.2.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with 4.6.
- b) When the vehicle-mounted mobile system is operational, perform the dynamic test method from 4.8 by passing the ^{241}Am source from Table 3 horizontally through the middle of the bottom half of the detection zone (i.e., 1,5 m from the ground) at the dynamic speed listed in Table 2. Reset the alarm after the trial, if applicable.
- c) Repeat the process stated in step b) for a total of 60 trials. There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background or shielded during the delay.
- d) Repeat steps b) and c) at the middle of the top half of the detection zone (i.e., 2,5 m from the ground).
- e) Repeat steps b), c), and d) using the ^{137}Cs source from Table 3.
- f) Repeat steps b), c), and d) using the ^{60}Co source from Table 3.

NOTE Each pass is 1 trial and there are 60 trials per test height per source providing a total of 120 trials (60 trials for each of the 2 test heights) per radionuclide.

- g) The results per radionuclide are considered acceptable when the vehicle-mounted mobile system produces a gamma alarm in at least 117 out of 120 trials.

6.3 Neutron radiation alarm

6.3.1 Requirements

A neutron alarm shall be triggered when a neutron source with the emission rate given in Table 3 passes by the vehicle-mounted mobile system under the conditions given in Table 1 and Table 2. The neutron source shall be surrounded by a 4 cm thick spherical HDPE moderator (see 4.10).

6.3.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with step 4.6.
- b) When the vehicle-mounted mobile system is operational, perform the dynamic test method from 4.8 by passing the moderated neutron source horizontally through the middle of the bottom half of the detection zone (i.e., 1,5 m from the ground) at the speed given in Table 2. Reset the alarm after the trial, if applicable.
- c) Repeat the process stated in step b) for a total of 60 trials. There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background or shielded during the delay.
- d) Repeat steps b) and c) at the middle of the top half of the detection zone (i.e., 2,5 m from the ground).
- e) The results are considered acceptable when the vehicle-mounted mobile system produces a neutron alarm in at least 117 out of 120 trials.

6.4 Over-range indication

6.4.1 Requirements

An over-range indication (e.g., “over-range”, “high counts”) shall be activated when the vehicle-mounted mobile system is exposed to a radiation field that is greater than the manufacturer-stated maximum dose rate.

If the over-range indication is reset or acknowledged by the user without the radiation field being reduced, a visual indication shall be provided indicating the presence of the radiation field and that the vehicle-mounted mobile system is not fully operational.

The time required to return to non-alarm condition after the radiation field is returned to background levels without any user interaction (other than acknowledging an audible alarm) shall not be greater than 1 min.

6.4.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with step 4.6.
- b) Perform the pre-test measurements in 4.12.2 with the gamma sources only.
- c) When the vehicle-mounted mobile system is operational, move a ^{137}Cs source (or several sources, as required), into the detection zone at a distance needed to produce a radiation field that is at least 50 % greater than the manufacturer's stated maximum value at the surface of the adjacent detection assembly and hold the position for a period of 1 min. The vehicle-mounted mobile system shall provide an "over-range" or similar indication and remain in that state until the radiation field is reduced to the pre-test level.
- d) Before reducing the radiation field back to background, acknowledge or reset the audible alarm, if provided, to verify that the visual indication of the over-range condition remains activated.
- e) Remove the radiation source, acknowledge or reset the alarm if provided, and measure the time required for the vehicle-mounted mobile system to indicate that it is ready to function.
- f) Perform the post-test measurements in 4.12.4 with the gamma sources only, 1 min after the ^{137}Cs source was removed.
- g) Repeat steps b) through f) two additional times for a total of 3 trials.
- h) Perform a 10-trial dynamic gamma response test using the ^{137}Cs source from Table 3 through the middle of the detection zone (i.e., 2 m from the ground) and a 10-trial dynamic neutron response test through the middle of the detection zone, in accordance with steps 6.2 and 6.3, respectively, to verify that the vehicle-mounted mobile system is functional. The system shall alarm in 10 out of 10 trials. If the system has radionuclide identification capabilities, it shall identify the ^{137}Cs source in 10 out of 10 trials.
- i) The results are considered acceptable when the vehicle-mounted mobile system provides indications as required during exposure to the over-range ^{137}Cs source, recovers within 1 min after the source is removed in each of the 3 successive trials, using the radiation response acceptance criteria in 4.12.5, and functions properly after the over-range exposure (as verified in step h)).

6.5 Neutron indication in the presence of photons

6.5.1 Requirements

A ^{137}Cs source that produces an ambient dose equivalent of $100 \mu\text{Sv}\cdot\text{h}^{-1}$ at 50 cm from the source shall not trigger the neutron alarm. The vehicle-mounted mobile system shall respond to the neutron source as required in 6.3 while simultaneously exposed to the same ^{137}Cs source.

NOTE $100 \mu\text{Sv}\cdot\text{h}^{-1}$ was selected based on typical dose equivalent rates produced by medical sources that may be seen during use. ^{137}Cs was selected due to its photon energy being above the maximum photon emission energy from commonly used medical radionuclides such as ^{131}I , $^{99\text{m}}\text{Tc}$, ^{201}Tl , and ^{67}Ga .

6.5.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with 4.6.
- b) Gamma interference test:
 - 1) When the vehicle-mounted mobile system is operational, perform the dynamic test method from 4.8 by passing the ^{137}Cs source, which produces an ambient dose equivalent of $100 \mu\text{Sv}\cdot\text{h}^{-1}$ at 50 cm from the source, horizontally through the centre of the detection zone (i.e., at 2 m from the ground) at the distance and speed given in Table 2.
 - 2) Record the gamma and neutron detector response including alarm and maximum count rate or maximum dose rate.
 - 3) Reset the alarm after the trial, if applicable.

- 4) Repeat the process stated in steps b) 1) to 3) for a total of 3 trials. There shall be a 10 s minimum delay between each trial with the source positioned at a distance where it does not affect the vehicle-mounted mobile system background; the source may be shielded during the delay.
- c) Neutron indication verification:
 - 1) Configure the test setup to simultaneously move the moderated neutron source as required in 6.3 and the ^{137}Cs source used in step b) above.
 - 2) Repeat steps b) 1) to 4) above using the source configuration from step 1).
- d) The results are acceptable if no neutron alarms are triggered when exposed to the ^{137}Cs field alone and if the neutron alarm activates while being exposed to the neutron source and ^{137}Cs . Gamma alarms are expected.

6.6 Slowly approaching source—vehicle-mounted mobile system is stationary during use

6.6.1 Requirements

The vehicle-mounted mobile system shall indicate when the ambient radiation background has increased to a level that is too high for it to operate as required. This may occur, for example, as a result of a slowly approaching radiation source.

6.6.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with 4.6.
- b) Set the dynamic test speed to $0,22 \text{ m}\cdot\text{s}^{-1}$.

Position the ^{137}Cs source from Table 3 at the vertical centre height of the detection zone (i.e., 2 m from the ground) at a lateral distance of at least 8 m from the centre of the detection assembly and at the source to reference point distance (from Table 2) normal to the detection assembly. The lateral distance selected is to ensure that the source does not affect the ambient background at the vehicle-mounted mobile system.

- c) With the vehicle-mounted mobile system operational, start moving the source towards and through the middle of the detection zone at the required speed.
- d) Record the response of the vehicle-mounted mobile system as the source approaches and passes through the detection zone. If the vehicle-mounted mobile system alarms or indicates that the background has changed, the trial can be considered complete and the source can be returned to the starting point.
- e) Repeat steps 0 through d) for a total of 3 trials with a time interval of 1 min between each trial.
- f) If applicable, repeat steps 0 through e) using the moderated neutron source.
- g) The results are considered acceptable if the vehicle-mounted mobile system alarms or indicates that the background has changed for each trial.

6.7 Background effects—vehicle-mounted mobile system is mobile during use

6.7.1 Requirements and background information

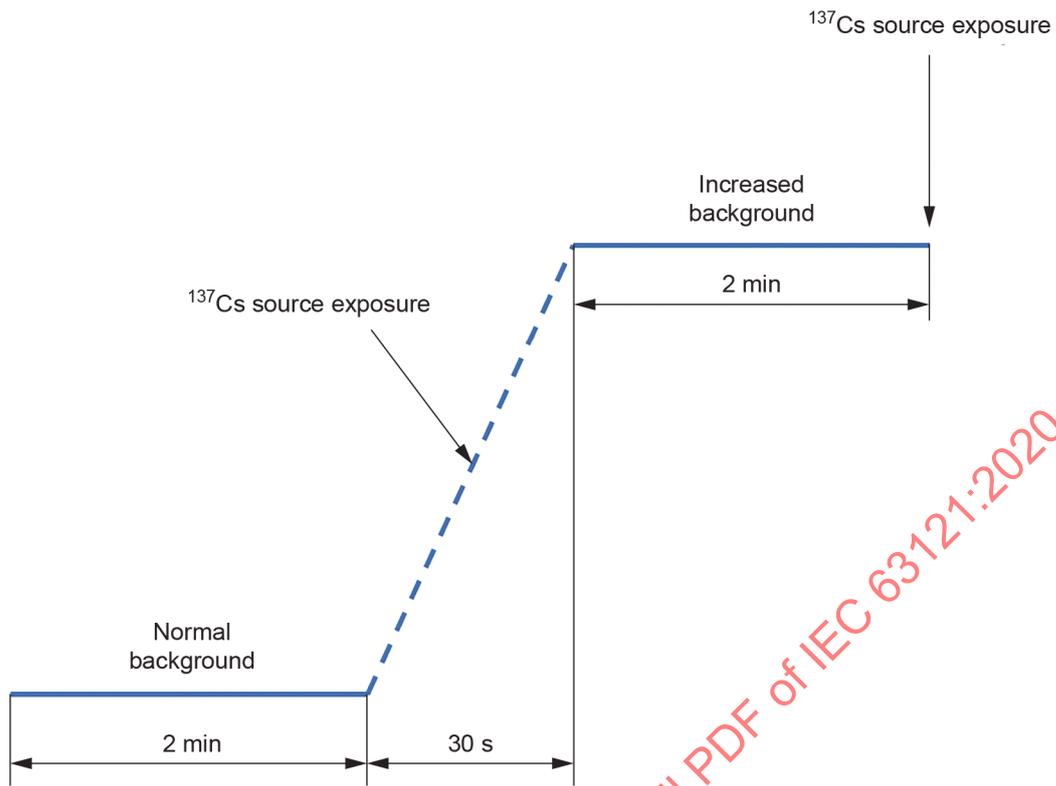
Vehicle-mounted mobile systems shall function normally when exposed to changing background situations that may be encountered during normal use. The vehicle-mounted mobile system shall provide a warning indication when a change in background is large enough to cause a substantial change in alarm probability, such as that which occurs when moving from different road surfaces or near different building materials.

NOTE To help ensure that the following test method was based on realistic field conditions, measurements were obtained using different detection technologies in urban, suburban, and rural areas. The measurements were obtained with each system mounted in a vehicle that was driven at posted speed limits and while operated at controlled speeds. The following test method was derived from those results. The test method includes a combination of increasing and decreasing background levels while introducing a source at different times.

6.7.2 Method of test

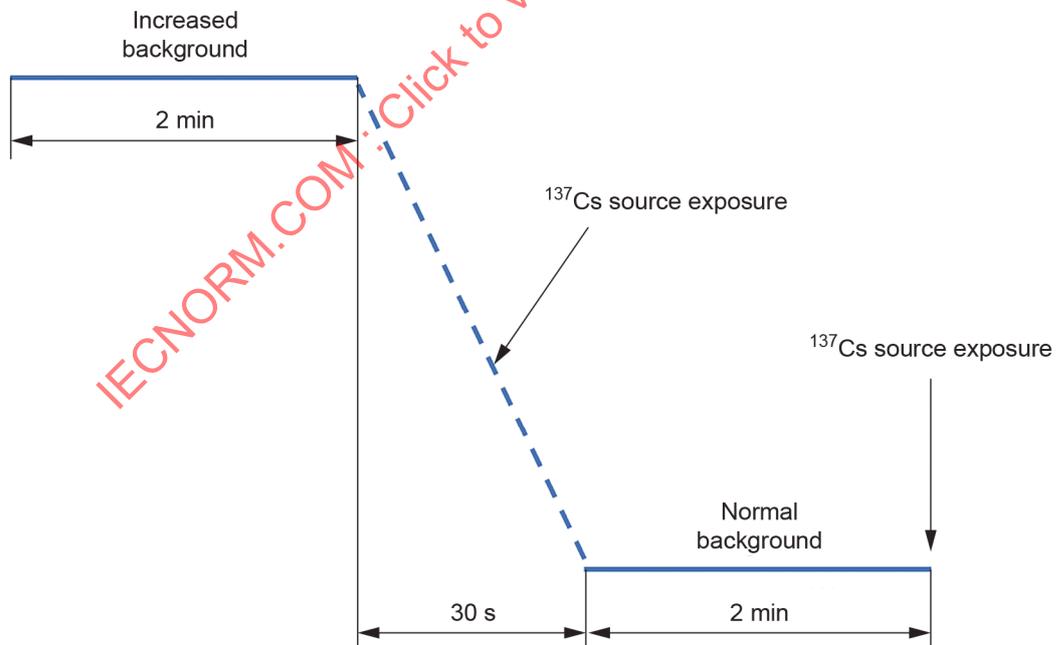
NOTE Figure 2 and Figure 3 provide a depiction of the process stated below.

- a) Determine the source to detector distance needed to increase the mean count rate at the vehicle-mounted mobile system in ambient background conditions by a factor of 3 ($\pm 20\%$). The source should be NORM such as granite blocks, zircon sand, or a combination of such materials. This will be the “artificially-increased-background” source. A single point source shall not be used.
- b) Set up the vehicle-mounted mobile system in accordance with 4.6 and allow it to start up in the normal background area.
- c) Background change only
 - 1) With the vehicle-mounted mobile system operating as it would during use (e.g., scanning), increase the count rate to the level determined in step a) using the artificially-increased-background source over a time period of 30 s by either moving the vehicle-mounted mobile system or the source. The vehicle-mounted mobile system should not activate any alarms during this time period. Identification of the radionuclide(s) in the artificially-increased-background source is permitted.
 - 2) Allow the vehicle-mounted mobile system to remain in the artificially-increased background for 2 min.
 - 3) Following the stabilization period, reduce the background over a time period of 30 s to the normal background area count rate.
 - 4) Repeat steps c) 1) through 3) for a total of 3 trials. During the process, no alarms should be activated and no identification of radionuclides, other than those used for the artificially-increased-background source, should occur. The vehicle-mounted mobile system may provide a warning indication if the change in background is large enough to cause a substantial change in the alarm probability.
- d) Background change with additional source
 - 1) With the vehicle-mounted mobile system operating as it would during use, increase the count rate to the level determined in step a) over a time period of 30 s by either moving the vehicle-mounted mobile system or the artificially-increased-background source.
 - 2) Midway through the 30 s background change, perform a dynamic test (1 trial) using ^{137}Cs through the middle of the detection zone (i.e., 2 m from the ground) in accordance with 4.8 and 6.2 and record the results.
 - 3) Allow the vehicle-mounted mobile system to remain in the artificial background for 2 min.
 - 4) At the end of the two minute period and without reducing the background, perform a dynamic test (1 trial) using ^{137}Cs through the middle of the detection zone (i.e., 2 m from the ground) in accordance with 4.8 and 6.2 and record the results.
 - 5) Following the test, reduce the background over a time period of 30 s to the normal background area count rate.
 - 6) Midway through the 30 s background change, perform a dynamic test (1 trial) using ^{137}Cs through the middle of the detection zone (i.e., 2 m from the ground) in accordance with 4.8 and 6.2 and record the results.
 - 7) Repeat steps d) 1) through 6) for a total of 3 trials. The vehicle-mounted mobile system shall alarm for each trial when exposed to the ^{137}Cs source.



IEC

Figure 2 – Increasing background with source



IEC

Figure 3 – Decreasing background with source

6.8 Radionuclide identification—when provided

6.8.1 Radionuclide categorisation

6.8.1.1 Requirements

The manufacturer shall state the radionuclides that the vehicle-mounted mobile system can identify and their categories. The identification library shall contain, as a minimum, the radionuclides listed in Table 6. The categories selected should be based on IAEA Safety Guide No. RS-G-1.9, which contains a list of radionuclides and their category. It should be possible to de-select individual radionuclides from the identification library.

Table 6 – Radionuclide library

^{241}Am	^{67}Ga	^{232}Th
^{133}Ba	^{131}I	^{192}Ir
^{57}Co	$^{99\text{m}}\text{Tc}$	^{238}U (DU)
^{60}Co	^{201}Tl	^{235}U (HEU)
^{137}Cs	^{226}Ra	^{239}Pu (WG Pu)

Table 7 provides a summary of the required identifications (RIs) as well as additional acceptable identifications (AAIs) for each test source. Table 7 shall be used for the radionuclide identification data analysis. Background radionuclides and radionuclides in the appropriate decay chain may be identified for all sources. A high resolution and high statistics spectrum should be acquired for all sources used for testing to determine potential impurities and radionuclide composition. The list of additional acceptable identifications (AAIs) listed in Table 7 should be updated based on the impurities and radionuclides measured in each source.

Table 7 – Radionuclide decay products and impurities

Source	Required identification (RI) (at least one)	Additional acceptable identification (AAI)
NORM	n/a	Thorium, Radium, ^{232}Th , ^{226}Ra , ^{40}K , NORM
^{241}Am	^{241}Am	n/a
^{133}Ba	^{133}Ba	n/a
^{60}Co	^{60}Co	n/a
^{137}Cs	^{137}Cs	n/a
^{67}Ga	^{67}Ga	n/a
^{131}I	^{131}I	n/a
$^{99\text{m}}\text{Tc}$	$^{99\text{m}}\text{Tc}$	^{99}Mo
^{201}Tl	^{201}Tl	^{202}Tl
^{226}Ra	^{226}Ra	Radium
^{232}Th	^{232}Th	Thorium
DU	^{238}U , Uranium, DU, U	^{235}U , $^{234\text{m}}\text{Pa}$, neutron
HEU	^{235}U , HEU, Uranium, U	^{238}U , $^{234\text{m}}\text{Pa}$, neutron
WG Pu	^{239}Pu , Plutonium, Pu, WG Pu	^{241}Pu , ^{240}Pu , ^{238}Pu , ^{241}Am , neutron, ^{237}U , ^{242}Pu , ^{233}U
$^{99\text{m}}\text{Tc}$ + HEU	$^{99\text{m}}\text{Tc}$ + any of ^{235}U , HEU, Uranium, U	^{238}U , $^{234\text{m}}\text{Pa}$, ^{99}Mo , neutron

Source	Required identification (RI) (at least one)	Additional acceptable identification (AAI)
^{131}I + WGPu	^{131}I + any of ^{239}Pu , Plutonium, Pu, WGPu	^{241}Pu , ^{240}Pu , ^{238}Pu , ^{241}Am , neutron, ^{237}U , ^{242}Pu , ^{233}U

6.8.1.2 Method of test

Verify that the requirement is met by review of manufacturer's provided information and/or the vehicle-mounted mobile system's identification library.

6.8.2 Single radionuclide identification

6.8.2.1 Requirements

The vehicle-mounted mobile system shall be able to identify the radionuclides and materials listed in Table 3 (except ^{252}Cf or ^{244}Cm) in the dynamic (4.8) and static (4.9) modes.

6.8.2.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with 4.6.
- b) Using the dynamic test from 4.8, perform the following:
 - 1) When the vehicle-mounted mobile system is operational, perform the dynamic test method from 4.8 by passing the ^{241}Am source from Table 3 horizontally through the middle of the bottom half of the detection zone (i.e., 1,5 m from the ground) at the speed listed in Table 2. Record the identification results and confidence indicator(s), if confidence indicators are provided. Reset the alarm after the trial, if applicable.
 - 2) Repeat the process stated in step 1) for a total of 10 trials. There shall be a 10 s minimum delay between each trial with the source either positioned at a distance where it does not affect the background or shielded during the delay.
 - 3) Repeat steps b) 1) and 2) at the middle of the top half of the detection zone (i.e., 2,5 m from the ground).
 - 4) Repeat steps b) 1), 2), and 3) using the remaining sources listed in Table 3. The medical radionuclides (^{67}Ga , $^{99\text{m}}\text{Tc}$, ^{131}I , and ^{201}Tl) shall be surrounded by 8 cm of PMMA to represent in-vivo configurations (see 4.10).
 - 5) The performance is considered acceptable when the identification results are complete and correct in at least 19 out of 20 consecutive dynamic trials for each radionuclide. The twenty trials combine the results from two test heights. See Annex A and Table 7 for information regarding the analysis process.
- c) Using the static test from 4.9, perform the following:
 - 1) Per the manufacturer's instructions, set up the vehicle-mounted mobile system to perform fixed-object measurements. This should require the user to perform some action to manually initiate a measurement.
 - 2) Position the ^{241}Am source from Table 3 at the middle of the detection zone (i.e., 2 m from the ground) and at the required evaluation distance (see Table 2).
 - 3) Initiate a measurement for the specified static-measurement time as shown in Table 2.
 - 4) Record the identification results and the confidence indicator(s), if confidence indicators are provided. Reset the alarm after the trial, if applicable.
 - 5) Repeat the process stated in steps c) 2) and 3) for a total of 20 trials without moving the source.
 - 6) Repeat steps c) 2) through 5) using the remaining sources listed in Table 3, except for ^{252}Cf or ^{244}Cm . The medical radionuclides (^{67}Ga , $^{99\text{m}}\text{Tc}$, ^{131}I , and ^{201}Tl) shall be surrounded by 8 cm PMMA to represent in-vivo configurations.

- 7) The performance is considered acceptable when the identification results are complete and correct in at least 19 out of 20 consecutive static trials for each radionuclide. See Annex A and Table 7 for information regarding the analysis process.

6.8.3 Simultaneous radionuclide identification

6.8.3.1 Requirements

Vehicle-mounted mobile systems shall have the ability to identify more than one radionuclide simultaneously.

6.8.3.2 Method of test

- a) Set up the vehicle-mounted mobile system in accordance with 4.6.
- b) Prepare to perform the test using the following source combinations:
 - 1) ^{99m}Tc + HEU
 - 2) ^{131}I + WGPu

Each source shall have the activity and configuration stated in Table 3 and 4.10. The sources shall be configured such that no source shields the other, with respect to the vehicle-mounted mobile system.

- c) Using the dynamic test from 4.8, perform the following:
 - 1) When the vehicle-mounted mobile system is operational, pass a source combination horizontally through the middle of the detection zone (i.e., 2 m from the ground) using the dynamic test method from 4.8 and at the speed given in Table 2.
 - 2) Record the identification results and the confidence indicator(s), if provided. Reset the alarm after the trial, if applicable.
 - 3) Repeat the process stated in steps c) 1) and 2) for a total of 10 trials. There shall be a 10 s minimum delay between each trial with the source combination either positioned at a distance where it does not affect the background or shielded during the delay.
 - 4) Repeat steps 1) through 3) for each source combination.
- d) Using the static test from 4.9, perform the following:
 - 1) Per the manufacturer's instructions, set up the vehicle-mounted mobile system to perform fixed-object measurements. This should require the user to perform some action to manually initiate a measurement.
 - 2) Position a source combination at the middle of the detection zone (i.e., 2 m from the ground) and at the required evaluation distance given in Table 2.
 - 3) Initiate a measurement for the specified static-measurement time as shown in Table 2.
 - 4) Record the identification results and the confidence indicator(s), if provided. Reset the alarm after the trial, if applicable.
 - 5) Repeat the process stated in steps d) 3) and 4) for a total of 10 trials without moving the source combination.
 - 6) Repeat steps 2) through 5) for each source combination.
- e) Record the number of complete and correct identifications (see Annex A and Table 7 for information regarding the analysis process) from each trial set. Identification of NORM radionuclides is not required. The results are considered acceptable if the identifications are complete and correct in at least 9 out of 10 consecutive dynamic or static trials.

6.8.4 Radionuclide not in library

6.8.4.1 Requirements

A vehicle-mounted mobile system shall alarm and indicate the presence of a radiation source (e.g., "not in library", "unknown") when exposed to radioactive material that it is not able to identify.

6.8.4.2 Method of test

- a) Select a radionuclide from Table 3. A single energy or simple spectrum source is recommended (e.g., ^{137}Cs).
- b) Access the source identification library and, following guidance provided by the manufacturer, de-select a radionuclide from the identification list. If a radionuclide cannot be de-selected from the identification library, perform the test using a radioactive source that is not listed in the library or a combination of sources that produce the required response.
- c) Set up the vehicle-mounted mobile system in accordance with 4.6.
- d) Using the dynamic test from 4.8, perform the following:
 - 1) When the vehicle-mounted mobile system is operational, perform the dynamic test from 4.8 by passing the selected source horizontally through the middle of the detection zone (i.e., 2 m from the ground) at the speed listed in Table 2. Record the identification results and the confidence indicator(s), if provided. Reset the alarm after the trial, if applicable.
 - 2) Repeat the process stated in step d) 1) for a total of 10 trials. There shall be a 10 s minimum delay between each trial with the source either positioned at a distance, where it does not affect the background, or shielded during the delay.
- e) Using the static test from 4.9, perform the following:
 - 1) Per the manufacturer's instructions, set up the vehicle-mounted mobile system to perform fixed-object measurements. This should require the user to perform some action to manually initiate a measurement.
 - 2) Position the test source at the middle of the detection zone (i.e., 2 m from the ground) and at the required evaluation distance.
 - 3) Initiate a measurement for the specified static-measurement time as shown in Table 2.
 - 4) Record the identification results and the confidence indicator(s), if provided. Reset the alarm after the trial, if applicable.
 - 5) Repeat the process stated in steps e) 3) and 4) for a total of 10 trials without removing the source from the detection zone.
- f) The results are considered acceptable if the response from each trial meets the stated indication requirements.

7 Climatic requirements

7.1 General

Vehicle-mounted mobile systems shall comply with IEC 62706 concerning the ambient temperature, relative humidity, and moisture and dust protection requirements for mobile instrumentation. To ensure that each requirement is met, ^{241}Am and ^{60}Co sources (or other sources that emit low- and high-energy gamma-rays) are used for gamma detectors and a neutron source (e.g., ^{252}Cf , ^{244}Cm , $^{241}\text{AmBe}$) is used for neutron detectors.

It is acceptable, but not recommended, to test the vehicle-mounted mobile system by testing components only, such as detector(s) and controller. Portions of the vehicle-mounted mobile system that are not intended for uncontrolled environments or that do not affect the radiological response of the vehicle-mounted mobile system, such as the trailer or vehicle, may be excluded from these tests. Cooling or heating systems that are part of the vehicle-mounted mobile system shall be tested together with the detection assembly.