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INTERNATIONAL STANDARD

NORME INTERNATIONALE

Radiation protection instrumentation – X-ray systems for the screening of persons for security and the carrying of illicit items

Instrumentation pour la radioprotection – Systèmes radiographiques aux rayons X pour le contrôle des individus dans le cadre de la sécurité et du transport d'objets illicites

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

FDIS	Report on voting
45B/642/FDIS	45B/658/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

The existence of this standard does not indicate approval of the use of the relevant equipments. However these equipments exist and are used in some countries and are likely to be used to scan persons of all nationalities including nationals of those countries which ban their use. If other international organisations ban their use, this standard could be withdrawn. Meanwhile it is considered valuable to have this standard to reduce the radiation doses to members of the public and others likely to have to use the equipments. Personnel X-ray screening assemblies are used to examine persons in order to detect objects such as: weapons, explosives, smuggled or stolen items such as drugs or diamonds. The screening devices can be divided into three types: one type using the Compton backscattered X-rays (Backscatter system) for the image creation, one using the transmitted X-rays (Transmission system) for the image creation, and a third type as a combination of the two types (Backscatter + Transmission).

All three types consist of an X-ray unit and a detector unit, and take about 10 s to perform a scan.

The systems are operated by and the image is viewed on an external computer. Sophisticated software is used to evaluate the complex images and to enable the detection of hidden objects.

The main difference between the system types is the position of the detectors. Usually, they also differ in the tube voltage range used.

Backscatter X-ray systems, (B), use a narrow pencil shaped beam that scans the subject at high speed in a horizontal and vertical direction. Large detectors are installed on the same side of the subject as the X-ray source. The person stands in front of the enclosure and is scanned by the X-ray beam having a typical cross-sectional area of approximately 25 mm^2; this of course is the quantity limiting the spatial resolution of the system. Usually the person is scanned twice, once from the front and then from the back. Sometimes lateral scans are also performed. Typical systems use fixed peak voltage (kV) and current (mA) settings for the X-ray source. These are typically 50 kV and 5 mA. The total aluminium equivalent filtration is in the range of 1 mm to 7 mm.

Transmission X-ray systems, (T), often use a vertical fan–shaped beam of X-rays and a linear array of detectors. The person stands between the X-ray tube and the detector array and is scanned by the X-ray beam having a typical width of approximately 2 mm. The limiting quantity for the spatial resolution is the size of the detector elements. Typical systems use a fixed peak voltage (kV) and current (mA). Settings are in the range of about 140 kV to 220 kV and 0,1 mA to about 4 mA. The total aluminium equivalent thickness is in the range of about 1 mm to about 16 mm. The systems are capable of detecting objects within the body.

Backscatter plus transmission X-ray systems, (BT), are systems that use both backscattered and transmitted X-rays, during the same scan procedure.

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RADIATION PROTECTION INSTRUMENTATION – X-RAY SYSTEMS FOR THE SCREENING OF PERSONS FOR SECURITY AND THE CARRYING OF ILLICIT ITEMS

1 Scope and object

This International Standard is applicable to X-ray systems designed for screening people to detect if they are carrying objects that could be used for criminal purposes, e.g., terrorist use, drug smuggling and theft. These objects include weapons, explosives, chemical and biological agents and other concealed items.

Three types of X-ray screening systems are currently in use. These are backscatter systems, transmission systems and combination backscatter/transmission systems. With backscatter systems the X-rays are used to detect objects hidden under or within the person's clothing. With transmission systems objects swallowed or hidden in body cavities may be detected. Combined devices can be used to get both pieces of information simultaneously.

The object of this standard is to lay down standard requirements and also to specify general characteristics, general test procedures, radiation characteristics, electrical characteristics, environmental influences, mechanical characteristics, safety requirements and to provide examples of acceptable methods in terms of dose to the whole or part of the body for each screening procedure and the time taken for each screening procedure.

In particular the standard addresses the design requirements as they relate to the radiation protection of the people being screened, people who are in the vicinity of the equipment and the operators. The standard does not address the performance requirements for the quality of the object detection.

2 Normative references

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

IEC 60038:2009, *IEC standard voltages*

IEC 60050-393:2003, *International Electrotechnical Vocabulary (IEV) – Part 393: Nuclear instrumentation – Physical phenomena and basic concepts*

IEC 60050-394:2007, *International Electrotechnical Vocabulary (IEV) – Part 394: Nuclear instrumentation – Instruments, systems, equipments and detectors*

IEC 60068-2-27, *Environmental testing – Part 2-27: Tests – Test Ea and guidance: Shock*

IEC 60068-2-75:1997, *Environmental testing – Part 2-75: Tests – Test Eh: Hammer tests*

IEC 61000-4-2, *Electromagnetic compatibility (EMC) – Part 4-2: Testing and measurement techniques – Electrostatic discharge immunity test*

IEC 61000-4-3, *Electromagnetic compatibility (EMC) – Part 4-3: Testing and measurement techniques – Radiated, radio-frequency, electromagnetic field immunity test*

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IEC 61000-4-4, *Electromagnetic compatibility (EMC) – Part 4-4: Testing and measurement techniques – Electric fast transient/burst immunity test*

IEC 61000-4-5, *Electromagnetic compatibility (EMC) – Part 4-5: Testing and measurement techniques – Surge immunity test*

IEC 61000-4-6, *Electromagnetic compatibility (EMC) – Part 4-6: Testing and measurement techniques – Immunity to conducted disturbances, induced by radio-frequency fields*

IEC 61000-4-12, *Electromagnetic compatibility (EMC) – Part 4-12: Testing and measurement techniques – Ring wave immunity test*

IEC 61187, *Electrical and electronic equipment – Documentation*

IEC 61508 (all parts), *Functional safety of electrical/electronic/programmable electronic safety related systems*

ISO 4037 (all parts), *X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy*

ISO 4037-1:1996, *X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy – Part 1: Radiation characteristics and production method*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply. The general terminology concerning X-ray screening systems is given in IEC 60050-393:2003 and IEC 60050-394:2007.

3.1
ambient dose equivalent, Hx(d)
the ambient dose equivalent at a point in a radiation field, is the dose equivalent that would be produced by the corresponding expanded and aligned field, in the ICRU sphere at a depth, d, on the radius opposing the direction of the aligned field

[ICRU 51]

NOTE 1 The recommended depth, d, for strongly penetrating radiation is 10 mm, and ambient dose equivalent at this depth may be written as Hx*(10).

NOTE 2 Soft tissue means ICRU 4-element, see ICRU 39.

3.2
constant potential X-ray unit
unit in which the ripple of the high voltage does not exceed ±10 %

3.3
exposure beam location
that part of the external surface of the system enclosure through which the collimated X-ray beam passes

3.4
half value layer (air kerma), HVL or HVLx
the thickness of the specified material which attenuates the beam of radiation to an extent such that the air kerma rate is reduced to one half of its original value. In this definition, the contribution of all scattered radiation, other than any which might be present initially in the beam concerned, is deemed to be excluded.

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[ICRU 17]

3.5
filtration
the total filtration is made up of the fixed filtration and any additional filtration used by the manufacturer.

The fixed filtration comprises the inherent filtration of the tube, plus that due to the monitor ionisation chamber.

The inherent filtration of the tube is due to the various constituent elements (glass of the bulb, oil, window, etc.) and is expressed, for a given high voltage, as the thickness of an aluminium filter which, in the absence of the constituent elements of the tube, would supply a radiation having the same first HVL.

3.6
monitor instrument
instrument with an alarm used to monitor the stability of the ambient dose equivalent rate during an irradiation or to compare the ambient dose equivalent rate during a screening with the reference dose equivalent rate determined during the type testing

3.7
mode of operation
backscatter, transmission or backscatter and transmission system and scanning technique

3.8
operator
person authorised and fully trained to operate the system

3.9
reference instrument
instrument whose calibration is traceable either directly or indirectly to primary standards held by a national primary laboratory or to an acknowledged reference laboratory which holds appropriate standards

3.10
reference point
the point within the space that may be occupied by the person being screened receiving the maximum dose and at which for the purpose of the testing requirements of this standard the X-ray spectra (or HVL) and reference ambient dose equivalent per screening procedure is measured

3.11
safety interlocks
devices which are intended to prevent or interrupt the generation of X-radiation whenever safety is compromised by access to the interior of the system, operational irregularity or equipment failure

3.12
scan
the scanning cycle consisting of the operation necessary to produce one view (e.g., front view)

3.13
scanning system
the whole equipment used to produce a scan, including the X-ray generator and collimator

3.14
screening procedure
the sum of all scans necessary to examine one person

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3.15
enclosure
the containment within which the X-ray unit and its scanning system are enclosed

3.16
ripple
ratio, expressed as a percentage, defined for a given current by the formula:

$$(U_{max} - U_{min}) \times 100/U_{max}$$

where U_{max} is the maximum value and U_{min} the minimum value of the voltage.

3.17
user
the person being screened by the equipment

3.18
X-ray unit
assembly comprising a high voltage supply, an X-ray tube with its protective housing, and high voltage electrical connections

3.19
X-ray tube
vacuum tube designed to produce X-rays by bombardment of the anode by a beam of electrons accelerated through a potential difference

4 Units

In this standard, the units are the multiples and sub-multiples of units of the International System of Units (SI)[1]. The following non-SI units are also used:

Time: years, days, hours (h), minutes (min).

For energy: electron-volt (eV), (1 eV = 1,602 × 10^{-19} J).

NOTE Definitions of the radiation quantities and dosimetric terms are given in IEC 60050-393 and IEC 60050-394.

5 Classification of systems

Systems are classified according to whether they are backscatter X-ray systems, (B) or transmission X-ray systems, (T), or combined backscatter and transmission systems, (BT).

6 General test procedures

6.1 Nature of tests

Unless otherwise specified in the individual subclauses, all tests enumerated in this standard are to be considered as “type tests”.

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

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6.2 Reference conditions and standard test conditions

Reference and standard test conditions are given in Table 1. Reference conditions are those conditions to which the performance of the instrument is referred and standard test conditions indicate the necessary tolerances in practical testing. Except where otherwise specified, the tests in this standard shall be performed under the standard test conditions given in the third column of Table 1.

6.3 Tests performed under standard test conditions

Tests performed under standard test conditions are listed in Table 2, which indicates, for each characteristic under test, requirements according to the subclause where the corresponding test method is described.

6.4 Tests performed with variation of influence quantities

For those tests intended to determine the effects of variations in the influence quantities given in Table 3, all other influence quantities shall be maintained within the limits for the standard test conditions given in Table 1 unless otherwise specified in the test procedure concerned.

7 Safety considerations

7.1 General

The manufacturer shall provide a description of the radiation safety systems that are designed to prevent, during normal operation of the X-ray screening system, accidental exposure to the operator and public and for ensuring that the person being screened is not exposed above manufacturers stated maximum dose per screening procedure (see Clause 9). The accompanying manual provided by the manufacturer shall include details of the fail-safe features of the radiation safety exposure circuit. These details shall also include functional test instructions.

The manufacturer shall reference the radiological and electrical safety considerations used for the system by quoting applicable IEC and ISO publications, see 7.4.1.

7.2 Shielding

7.2.1 Requirements

When a person is being screened and the X-ray beam is emanating, shutter or beam stop open, the ambient dose equivalent rate to any area where other members of the public or the operator have access should not exceed 2,5 $\mu Sv \cdot h^{-1}$ taken over several scans. Where the doserate could exceed this value at a distance in excess of 30 cm from any external surface the manufacturer shall provide an isodose contour at this value. National regulations may stipulate lower limits.

7.2.2 Method of test

The direction in which the highest dose per screening procedure is emitted shall be identified by measurement. (Technical drawings and further physical aspects may assist in determining this but should not be relied upon.) Careful consideration should be given to control stations, fissures around doors, ventilation openings, shielding joints and any other vulnerable areas based on technical drawings. If there are outer doors or removable panels that are not locked or interlocked, the radiation survey shall be repeated with the doors open and panels removed. At the distance specified in 7.2.1, from the surface of the device the ambient dose equivalent per screening procedure (that means the sum of all scans necessary to examine a person) shall be measured. The X-ray scanner shall be operated in the mode with the greatest high voltage, greatest tube current and the smallest total filtration allowed to be used in operation. This shall be done for at least five subsequent screening procedures following each other as fast as the device is able to perform. The total dose over all these screening

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procedures shall be divided by the time all these screening procedures took. This value plus the overall uncertainty (k = 2) shall not exceed the ambient dose equivalent rate requirement listed in 7.2.1.

This dose equivalent rate shall be determined by a reference instrument having a response that is within 20 % of the true value over the energy range from 25 keV to the maximum energy in keV corresponding to the maximum operating voltage of the X-ray tube.

7.3 System controls and normal operation indications

7.3.1 Requirements

The operating conditions, namely the tube voltage and tube current, for each mode of operation shall be pre-set by the manufacturer and shall not be alterable by the system operator. If there is more than one mode, prior to each scan a mode indicator shall be clearly visible to the operator.

The operators control panel shall show the following:

- Electrical power to the system is on. Only the operator is permitted to switch on the power and this should require the use of a key.
- When the X-rays are being produced an “X-rays on” illuminated sign shall operate.
- The voltage and current for the operating mode shall be displayed when required by an engineer or maintenance staff.
- Indication shall be made for both when the shutter or beam stop is open and/or for when the scan is taking place, “scan on”.
- The production of x-rays shall only start if the illuminated sign “X-rays” is ready to operate.

Sufficient diagnostics shall be designed into the system to facilitate fault finding and to provide local and remote information on the status of the system. A self-test device shall be provided to perform self-testing continuously. Operation of the equipment after fault detection must be prevented until the fault is cleared. The manufacturer shall produce a test plan which shall demonstrate the normal operation of the system. This test plan shall contain all normal operational features, diagnostics, self-test facilities and safety features of the system.

If the moveable parts, e.g., the platform, X-ray unit or chopper, do not work properly the system shall shut down automatically.

7.3.2 Method of test

Using the manufacturer’s test plan verify that the operator’s control panel displays the information as required in 7.3.1.

Testing is done automatically by the software and related electronics. Interlocks, indications and alarms shall be independent of the system’s normal controls and operation indicators.

7.4 Safety indicators and interlocks

7.4.1 Safety standards

Appropriate requirements shall apply concerning specification, design, manufacturing, installation and operation of the equipment, with respect to the necessary hardware and software. The requirements shall be agreed between manufacturer and purchaser. In particular the purchaser (operator) shall decide the appropriate safety standard applicable to the site in which the system will be placed. The basic safety standard IEC 61508 Functional Safety of Electrical/ Electronic/Programmable electronic systems shall apply, as appropriate according to the required Safety Integrity Level (SIL) specified for the system.

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7.4.2 Requirements

Operational interlocks shall terminate the production of X-rays in the event of any operational problem that could result in abnormal or unintended radiation emission. Either through redundancy or special design, a malfunction of any operational interlock or any system monitoring an operational interlock shall also terminate X-ray production regardless of the actual radiation emission. This shall include, but is not limited to: unintended stopping or slowing of the scanning motion, abnormal or unintended X-ray source output, computer safety system malfunction, termination malfunction, and when applicable, X-ray shutter or beam stop mechanism malfunction.

7.4.3 Method of test

The manufacturer shall produce a test plan in accordance with IEC 61508 which shall demonstrate the operation of the safety alarms and interlocks for the SIL level specified.

The system shall be switched on and allowed to run its start up and self-test routines. A fault condition in each one of the monitored parameters shall be simulated and the warning or fault description recorded.

8 Conditions and methods for producing the X-ray screening spectra

8.1 General

In practice the spectra of the radiation produced depends primarily on:

– the high-voltage across the X-ray tube;
– the thickness and nature of the total filtration;
– the type and nature of the target.

8.2 Tube potential characteristics of the X-ray unit

8.2.1 Requirements

The conventionally true value of the potential shall be known to within ±5 %.

8.2.2 Method of test

Calibrate, at several points close to their stated operating tube potential, and under normal operating conditions, the equipment used to indicate the tube potential. The best methods employ a calibrated resistor chain or involve the measurement of the maximum photon energy by spectrometry. If the calibration is determined by spectrometry, the tube potential shall be found from the intersection of the extrapolated linear high energy part of the spectrum with the energy axis. Advice on methods of accomplishing this are described in ISO 4037-1.

9 Ambient dose equivalent at the position of the person being screened

9.1 Requirements

The ambient dose equivalent, Hx(10), at the reference point shall not exceed 0,4 µSv per screening procedure (that means the sum of all scans necessary to examine a person) for backscatter systems, (B) and 5 µSv per screening procedure (that means the sum of all scans necessary to examine a person) for transmission systems (T) and backscatter and transmission systems, (BT). Other values may be specified as required by national regulations.

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9.2 Method of test

The method used to determine the reference point of maximum dose and the dose at that point for each screening procedure shall be as described in Annex A. Measurements shall be made with a reference instrument. Calculation is not sufficient.

With the X-ray scanner operating in the mode with greatest high voltage, the greatest tube current, and the smallest total filtration, the ambient dose equivalent per scan procedure (that means the sum of all scans necessary to examine a person) shall be measured at the reference point applying the methods described in Annex A. This value plus the overall uncertainty (k = 2) shall not exceed the ambient dose equivalent requirements listed in 9.1.

10 Electrical characteristics

10.1 Supply voltage

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

– Series I: 230 V.

– Series II: 120 V and/or 240 V.

NOTE Nominal single phase power supplies of 100 V, 50 Hz or 60 Hz and of 117 V and/or 234 V, 60 Hz are used in some countries and a nominal single-phase power of 110 V, 50 Hz is also used as an alternative supply in other countries.

10.2 Requirements

The system shall be capable of operating from mains supply voltage tolerance from –10 % to +10 % and supply frequencies of 47 Hz to 51 Hz (57 Hz to 61 Hz in countries where the nominal frequency is 60 Hz) without the variation in the reference dose exceeding ±10 %.

10.3 Method of test

The ambient dose equivalent per scan at the reference point should first be measured under reference conditions. Then the ambient dose equivalent per scan should be measured over the voltage and frequency ranges given in 10.1 and none of these values should differ from the reference ambient dose equivalent per scan by more than ± 10 %.

11 Environmental conditions

11.1 Ambient temperature

11.1.1 Requirements

The equipment should be capable of operating over the temperature range –10 °C to +50 °C with changes in the reference ambient dose equivalent per scan not exceeding ±10 % with all the safety systems operational.

11.1.2 Method of test

The reference ambient dose equivalent per scan at the reference position should first be measured at 20 °C under reference conditions.

The equipment shall be operated at a temperature of at or below –10 °C and the ambient dose equivalent per scan measured The equipment shall have been kept at –10 °C for at least 2 h before the test. The equipment shall also be operated at a temperature of 50 °C or higher and the test repeated after being at 50 °C for at least 2 h.

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The high voltage applied to the X-ray tube and the current taken shall also be monitored under reference conditions and again after the equipment has been in the environment at –10 °C and at +50 °C for at least of 2 h .The applied voltage in both cases shall not exceed 1,02 times that under standard test conditions and the current drawn shall not exceed 1,05 times that under standard test conditions.

Verify that all the safety systems are operational over the above temperature range.

11.2 Relative humidity

11.2.1 Requirements

The equipment should be capable of operating over the relative humidity range 40 % to 93 % at +35 °C without changes in the reference ambient dose equivalent per scan exceeding ±10 % with all the safety systems operational.

11.2.2 Method of test

The reference ambient dose equivalent per scan at the reference position should first be measured at 65 % relative humidity and 35 °C under reference conditions. Then the ambient dose equivalent per scan should be measured over the humidity ranges given in 11.2.1 and none of these values should differ from the reference ambient dose equivalent per scan by more than ±10 %.

The high voltage applied to the X-ray tube and the current taken shall be monitored under standard test conditions and again after the equipment has been in an environment greater than +35 °C and with the relative humidity greater than 93 % in excess of 2 h and again at a temperature of +35 °C and with a relative humidity of 40 %. The applied voltage in both cases shall not exceed 1,02 of that under standard test conditions and the current drawn shall not exceed 1,05 of that of that under standard test conditions.

Verify that all the safety systems are operational over the above humidity range.

12 Electromagnetic compatibility

12.1 Susceptibility to electromagnetic fields

12.1.1 Requirements

There shall be no change in the operational status. No alarms or other outputs should be activated when the equipment is exposed to the field. The reference ambient dose equivalent per scan shall not change by more than ±10 % when the system is exposed to the radiated electromagnetic fields. All the safety systems shall remain operational during and after these tests.

12.1.2 Method of test

The field strength shall be 20 V/m over the frequency range from 80 MHz to 1 GHz and 1,4 GHz to 2,4 GHz and shall be varied in steps of 1 % (severity level 3 as described in IEC 61000-4-3). There shall also be no change in the operational status and no alarms or other outputs should be activated at any frequency.

Verify that all the safety systems are operational during and after these tests.

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12.2 Conducted disturbances induced by bursts and radio frequencies

12.2.1 Requirements

There shall be no change in the operational status. No alarms or other outputs should be activated when the equipment is exposed to the field. The reference ambient dose equivalent per scan shall not change by more than ±10 % when the system is exposed to bursts and radio frequencies. The safety systems shall remain operational during and after these tests.

The test applies to devices used in the presence of radio-frequency transmitters in the frequency range from 150 kHz to 80 MHz.

12.2.2 Method of test

Perform the following operations both with and without the presence of conducted disturbances induced by bursts (IEC 61000-4-4) and conducted disturbances induced by radio-frequency fields (IEC 61000-4-6) (the severity level shall in both cases be level 3).

a) Set the equipment to perform a screening procedure.

b) Set the frequency range from 150 kHz to 80 MHz at afield strength of 10 V, 80 % amplitude modulated with a 1 kHz sine wave.

The reference ambient dose equivalent per scan shall not change by more than ±10 % when the system is exposed to the above bursts and radiofrequencies. There shall also be no change in the operational status and no alarms or other outputs should be activated. Verify that all the safety systems remain operational during and after these tests.

12.3 Surges and ring waves

12.3.1 Requirements

The reference ambient dose equivalent per scan shall not change by more than ±10 % when the system is exposed to surges and oscillatory waves. There shall be no change in the operational status. No alarms or other outputs should be activated. All the safety systems shall remain operational during and after these tests.

12.3.2 Method of test

Connect the mains supply terminal via a coupling/decoupling network to the pulse generator in accordance with IEC 61000-4-5 and IEC 61000-4-12 (the severity level shall be level 3) and conduct the following operations.

a) Ten pulses should be applied to the device with a minimum time between surges of 1 min.

b) Each pulse should consist of a combination wave (1,2/50 µs – 8/20 µs) at a voltage of 2 kV.

Ring wave pulses should be not more than 2 kV. The reference ambient dose equivalent per scan shall not change by more than ±10 % when the system is exposed to the ring waves. There shall be no change in the operational status. No alarms or other outputs should be activated when the assembly is exposed to the ring waves. Verify that all the safety systems remain operational during and after these tests.

12.4 Electrostatic discharge

12.4.1 Requirements

The reference ambient dose equivalent per scan shall not change by more than ±10 % when the system is exposed to electrostatic discharges. No alarms or other outputs should be activated when the device is exposed to the discharges. All the safety systems shall remain operational during and after these tests.

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