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INTERNATIONAL STANDARD

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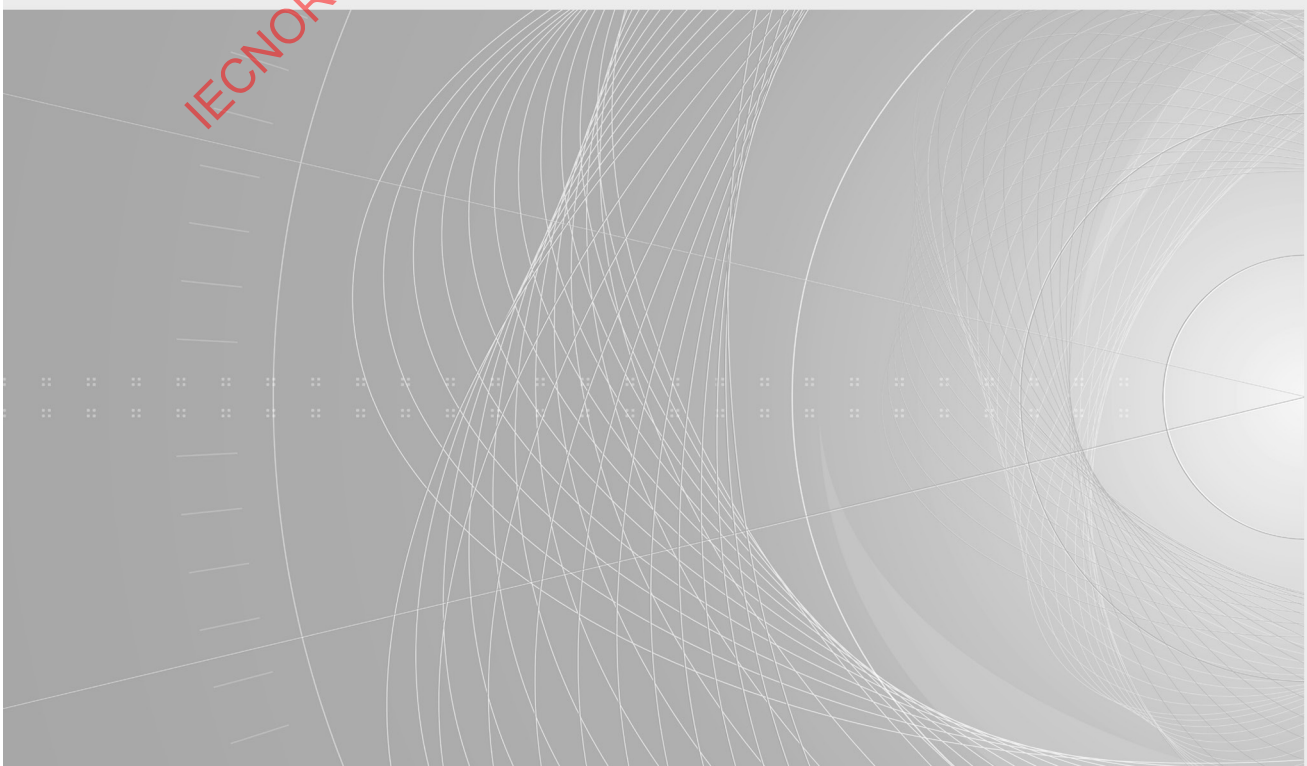
Radiation protection instrumentation – X-ray systems for the security screening of persons



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Radiation protection instrumentation – X-ray systems for the security screening of persons

INTERNATIONAL
ELECTROTECHNICAL
COMMISSION

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RADIATION PROTECTION INSTRUMENTATION – X-RAY SYSTEMS FOR THE SECURITY SCREENING OF PERSONS

FOREWORD

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IEC 62463 has been prepared by subcommittee 45B: Radiation protection instrumentation, of IEC technical committee 45: Nuclear instrumentation. It is an International Standard.

This second edition cancels and replaces the first edition published in 2010. This edition constitutes a technical revision.

This edition includes the following significant technical changes with respect to the previous edition:

a) title modified;
b) the main dose quantity was updated from ambient dose equivalent (H*(10)) to the operational quantities recommended in ICRU Report 95:2020;
c) the scope has been updated from X-ray systems for screening persons to X-ray systems that deliberately expose persons to X-rays for security purposes, which clarifies the ambiguity of whether occupied vehicle scanners are within scope;

d) the scheme for classifying systems was changed from one based on whether the system is backscatter, transmission or a combination to a classification system based on the dose level and administrative controls;

e) numerous electrical, environmental, electromagnetic, and mechanical safety requirements were updated.

The text of this International Standard is based on the following documents:

Draft	Report on voting
45B/1058/FDIS	45B/1068/RVD

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

The language used for the development of this International Standard is English.

This document was drafted in accordance with ISO/IEC Directives, Part 2, and developed in accordance with ISO/IEC Directives, Part 1 and ISO/IEC Directives, IEC Supplement, available at www.iec.ch/members_experts/refdocs. The main document types developed by IEC are described in greater detail at www.iec.ch/publications.

The committee has decided that the contents of this document will remain unchanged until the stability date indicated on the IEC website under webstore.iec.ch in the data related to the specific document. At this date, the document will be

- reconfirmed,
- withdrawn, or
- revised.

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INTRODUCTION

This document concerns the radiation safety of security screening systems where persons are intentionally exposed to X-rays. The document is applicable to a wide range of system designs, X-ray spectra, and irradiation geometries, and while current screening systems can be divided into X-ray backscatter, X-ray transmission, and combination systems, the methods in the document are general enough to be applicable to other systems too. The document sets dose limits in terms of effective dose and uses the operational quantities described in ICRU Report 95 to estimate the effective dose per screening. The document also specifies other requirements related to the electrical, environmental, electromagnetic, and mechanical safety of the systems.

RADIATION PROTECTION INSTRUMENTATION – X-RAY SYSTEMS FOR THE SECURITY SCREENING OF PERSONS

1 Scope

This document is applicable to security screening systems designed to expose persons to X-rays. In particular, the document applies to systems where the body is exposed to the primary beam of X-rays. It is common to divide currently used systems into three types: backscatter systems, transmission systems and combination backscatter/transmission systems. Some examples of systems that fall within the scope of this document are backscatter X-ray scanners; transmission X-ray scanners; occupied vehicle scanners.

The purpose of this document is to provide standardized requirements and test methods to ensure the safe operation of X-ray personnel screening systems, from a radiation protection point of view. In particular, the document specifies requirements related to the radiation protection of the persons being screened, persons who are in the vicinity of the equipment and the operators. Standard methods are provided to estimate the effective dose to the persons being screened. There are several simplifying assumptions inherent in such procedures that limit their accuracy. Nevertheless, there is value in having simple standard methods for dose estimation, e.g. for regulatory use. When highly accurate dose estimates are needed, different methods should be used that account for the particular characteristics of the X-ray system and persons being screened.

The document does not address image quality or detection performance.

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 60721-3-3:2019, *Classification of environmental conditions – Part 3-3: Classification of groups of environmental parameters and their severities – Stationary use at weatherprotected locations*

IEC 61187:1993, *Electrical and electronic equipment – Documentation*

IEC 61326-1:2020, *Electrical equipment for measurement, control and laboratory use – EMC requirements – Part 1: General requirements*

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

IEC 62061:2021, *Safety of machinery – Functional safety of safety-related control systems*

ISO 4037-1:2019, *Radiological protection – 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 methods*

ISO 13849-1:2023, *Safety of machinery – Safety-related parts of control systems – Part 1: General principles for design*

ICRU Report 95:2020, *Operational Quantities for External Radiation Exposure*

3 Terms and definitions

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

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

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

NOTE The general terminology concerning X-ray screening systems is given in IEC 60050-395:2014.

3.1
ambient dose
H*
ambient dose at a point in a radiation field is defined as:

$$H^{*} = K \times h^{*}_{E_{\max}}$$

where

K is the air kerma at the point, and

$h^{*}_{E_{\max}}$ is a conversion coefficient relating air kerma to the maximum value of effective dose, $E_{\max}$, for various irradiation conditions

Note 1 to entry: See ICRU Report 95 for more details. H^{*} corresponds to the maximum effective dose that could be received by a person if they were uniformly irradiated by an equivalent field of radiation. More specifically, it is the maximum effective dose as calculated by exposure of the whole-body ICRP/ICRU adult reference phantoms (ICRP, 2009) for broad uniform parallel beams of the radiation field incident in irradiation geometries antero-posterior (AP), posterior-anterior (PA), left lateral (LLAT), right lateral (RLAT), rotational (ROT), isotropic (ISO), superior hemisphere semi-isotropic (SS-ISO), and inferior hemisphere semi-isotropic (IS-ISO).

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

3.3
effective dose
dose quantity intended to reflect the whole body stochastic health risk due to radiation exposure (see ICRP Report 103)

Note 1 to entry: It is calculated based on the sum of the equivalent doses in various organs multiplied by the appropriate tissue weighting factors.

3.4
general-use system
X-ray screening system that is configured to deliver an effective dose of less than 0,25 µSv per screening (using the dose estimation methods defined in this document) and operating using the administrative controls specified in this document. Given proper justification and certain restrictions, general-use systems may be operated without specific controls that would limit the number of individuals scanned or the number of scans per individual in a year

Note 1 to entry: This definition was reproduced, with the permission of the Health Physics Society (HPS), from ANSI/HPS N43.17-2009 (R2018)

3.5
half value layer
HVL
HVLx
thickness of the specified material which attenuates the X-ray beam so that the air kerma rate is reduced to one half of its original value

Note 1 to entry: The measurement should be made in narrow-beam geometry, meaning the contribution of all scattered radiation, other than any which might initially be present in the beam, is excluded.

3.6
filtration
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

Note 1 to entry: 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.

3.7
limited-use system
personnel screening system that is configured to deliver an effective dose of less than 10 μSv per screening (using the dose estimation methods defined in this standard) and which does not meet the definition of a general-use system. Limited-use systems require additional controls and documentation to ensure that annual individual dose limits are not exceeded

Note 1 to entry: This definition was reproduced, with the permission of the Health Physics Society (HPS), from ANSI/HPS N43.17.

3.8
occupied zone
volume in which a person could be exposed to the primary X-ray beam while the SOP is being followed. This volume uses the same frame of reference as a person being scanned

3.9
operator
person that controls one or more aspects of the screening procedure. An operator is authorized to perform their duties, appropriately trained, and performs their duties according to the SOP

3.10
personal dose
H_p
personal dose at a point in a radiation field is defined as:

$$H_p = K \times h_p$$

where

K is the air kerma at the point, and

h_p is a conversion coefficient relating air kerma to the personal dose, H_p, that is appropriate for the spectrum and irradiation geometry

Note 1 to entry: See ICRU Report 95 for more details.

3.11
primary beam
consists of X-rays that have exited the beam-defining aperture but have not been absorbed or scattered

3.12
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

3.13
reference position
location within the occupied zone that receives the greatest dose per screening. The reference position uses the same frame of reference as the person, which may be moving relative to the X-ray source in some cases

3.14
restricted zone
volume surrounding the X-ray system where access for the general public is restricted during operation of the scanner

3.15
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

3.16
scanning system
system
whole equipment used to produce a scan, including the X-ray generator and collimator

3.17
screening procedure
procedure, described in the SOP, that is followed to completely inspect something using the X-ray system

Note 1 to entry: Depending on the concept of operation of the system, this could involve taking multiple scans.

3.18
standard operating procedure
SOP
document developed by the facility that describes the processes for performing screenings using the X-ray system

3.19
ripple
ratio, expressed as a percentage, defined for a given current by the Formula:

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

where

U_{max} is the maximum value, and

U_{min} is the minimum value of the voltage.

3.20
X-ray unit
assembly comprising a high voltage supply, an X-ray tube with its protective housing, and high voltage electrical connections

3.21
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 document, 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 60050-395.

5 General test procedures

5.1 Nature of tests

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

5.2 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 document shall be performed under the standard test conditions given in the third column of Table 1.

Table 1 – Reference conditions and standard test conditions

Influence quantities	Reference conditions (unless otherwise indicated by the manufacturer)	Standard test conditions (unless otherwise indicated by the manufacturer)
Warm-up time	15 min	> 15 min
Ambient temperature	20 °C	18 °C to 22 °C
Relative humidity	65 %	50 % to 75 %
Atmospheric pressure	101,3 kPa	70 kPa to 106 kPa
Power supply voltage	Nominal power supply voltage	Nominal power supply voltage ±1 %
Power supply frequency	Nominal frequency	Nominal frequency ±1 %
Power supply waveform	Sinusoidal	Sinusoidal with total harmonic distortion lower than 5 %
Gamma radiation background	Air kerma rate 0,1 μGy·h^{-1}	Less than air kerma rate of 0,25 μGy·h^{-1}
Electromagnetic field of external origin	Negligible	Less than the lowest value that causes interference
Magnetic induction of external origin	Negligible	Less than twice the value of the induction due to earth's magnetic field
Equipment controls	Set up for normal operation	Set up for normal operation

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

5.3 Tests performed under standard test conditions

Table 2 lists the tests to be performed under standard test conditions and gives references to the sections describing applicable requirements and test methods.

Table 2 – Tests performed under standard test conditions

Characteristics under test	Requirements (subclause)	Method of test (subclause)
Effective dose to person being scanned	8.2	8.3

5.4 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 3, unless otherwise specified in the test procedure concerned.

Table 3 – Tests performed with variations of influence quantities

Characteristic under test or influence quantity	Range of values of influence quantities	Limits of variation of indications or of the reference air kerma	Method of tests (subclause)
Mains operation	From –10 % to +10 % of nominal power supply Voltage From 47 Hz to 51 Hz or 57 Hz to 61 Hz	10 %	9.2
Temperature	From 5 °C to +40 °C	Operation to remain satisfactory. Air kerma change less than 10 %	10.1.2
Relative humidity	From 40 % to 93 % at 35 °C	Operation to remain satisfactory. Air kerma change less than 10 %	10.2.2
Susceptibility to electromagnetic fields	IEC 61326-1	No change in operational status. No alarms or other outputs should be activated when the assembly is exposed to the field. Air kerma change less than 10 %	11.2
Conducted RF	IEC 61326-1	No change in operational status. No alarms or other outputs should be activated when the assembly is exposed to the field. Air kerma change less than 10 %	11.2
Surges and ring waves	IEC 61326-1	No change in operational status. No alarms or other outputs should be activated. Air kerma change less than 10 %.	11.2
Electrostatic discharge	IEC 61326-1	No alarms or other outputs should be activated when the monitor is exposed to the discharge. Air kerma change less than 10 %	11.2
Vibration	class 3M11, IEC 60721-3-3:2019	Operation to remain satisfactory	12.2

6 Safety considerations

6.1 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. 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 6.4.1.

6.2 Shielding

6.2.1 Requirements

The ambient dose or ambient dose equivalent shall only exceed 1 µSv in any one hour in the occupied zone and the restricted zone. National regulations may stipulate lower dose limits and additional rules may apply (see Annex C, for example). A spatial map shall be produced that indicates regions where the ambient dose or ambient dose equivalent will not exceed 1 µSv in any one hour. This map could take the form of a detailed isodose curve or a simpler map that indicates a rectangular region where the ambient dose or ambient dose equivalent may exceed 1 µSv in any one hour.

6.2.2 Method of test

Determine the region surrounding the scanner where the average ambient dose or ambient dose equivalent may exceed 1 µSv in any one hour. 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, repeat the radiation survey with the doors open and panels removed. Operate the X-ray scanner in the mode and using any settings (e.g., tube voltage, current and filtration) that produce the highest dose.

Perform the test with a scatter phantom placed in the occupied zone at a location where a scanned individual is typically located. Ensure that the scatter phantom weighs 70 kg ± 15 kg and is composed of some combination of water, polyethylene or alternative material that is tissue equivalent for the radiation field of interest. Ensure the center of mass of the phantom is above 50 cm from the floor of the scanner. An example implementation could be constructed using a polyethylene pipe filled with water (25 cm diameter and 150 cm high).

Estimate the average dose in any one hour by operating the scanner for at least five screening procedures that repeatedly follow each other as fast as the device is able to perform. Integrate the dose values over this time and divide by the time necessary to perform the screenings. Based on such measurements, produce the spatial map described in 6.2.1.

6.3 System controls and normal operation indications

6.3.1 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 shall be prevented until the fault is cleared. Interlocks, indications and alarms shall be independent of the system's normal controls and operation indicators.

6.3.2 Method of test

Verify that the operator's control panel displays the information as required in 6.3.1.

Simulate a fault condition and verify that no operation is possible. Examples of simulated fault conditions include stopping movement of the X-ray beam, stopping movement of a belt, disabling necessary indicator lights, or opening a chassis door that is required to be locked.

6.4 Safety indicators and interlocks

6.4.1 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 manufacturer shall evaluate the system by a risk reduction method. As a result of this they shall meet IEC 61508 or other international recognized standards providing equivalent functional safety (e.g., ISO 13849-1 or IEC 62061).

6.4.2 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. For each safety function the risk-reduction method shall specify a "safety integrity level" (SIL) or "performance level" (PL_r), as defined in IEC 62061 and ISO 13849-1, respectively.

6.4.3 Method of test

Switch on the equipment and allow it to run its start-up and possible self-test routines. Simulate a fault condition in each one of the monitored parameters, verify the operation of the interlocks and record the warning or fault description.

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

7.1 General

In practice, the X-ray spectrum primarily depends on:

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

7.2 Tube potential characteristics of the X-ray unit

7.2.1 Requirements

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

7.2.2 Method of test

Estimate the maximum energy present in the X-ray beam. The best methods employ a calibrated resistor chain or involve the measurement of the maximum photon energy by spectrometry. Calibrate the measurement equipment at several points close to the stated operating tube potential. If the estimate 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.

8 Effective dose at the position of the person being screened

8.1 Classification of systems

For the purpose of this document, personnel screening systems are divided into two classes based on their dose and administrative controls: general-use systems and limited use systems. General-use systems deliver low doses, so individuals can be scanned regularly and still stay well below applicable annual limits. Such systems therefore require fewer engineering and administrative controls compared with other X-ray systems. Limited use systems deliver a higher dose than general-use systems, and require additional administrative controls to ensure that individuals are not exposed to annual doses that are above applicable limits. Requirements for the two classes of systems are given in 8.2.

8.2 Requirements

8.2.1 General

The dose and administrative control requirements are different for the different classes of systems. Lower dose requirements may be specified by national regulations or other applicable rules.

8.2.2 General-use systems

General use systems shall deliver an effective dose of less than 0,25 µSv per screening. Additionally, the effective dose received by individuals from one facility shall not exceed 250 µSv over a 12-month period[2]. Compliance with this requirement shall be demonstrated by documenting the routine screening procedures of the facility and typical behavior of the persons being screened. If individuals are routinely screened more than twice each day by the same facility, then documentation shall be kept that shows that the effective dose to any one individual shall not exceed 250 µSv in one year. This can be done, for example, by estimating the maximum number of times an individual might be scanned and multiplying it by the effective dose per screening, as estimated using the methods in this document. If such documentation does not exist for a system, then it shall not be considered a general-use system.

8.2.3 Limited-use systems

Limited-use systems shall deliver an effective dose of less than 10 µSv per screening. Additionally, such systems shall have administrative controls, in the form of documented procedures, that ensure that the effective dose to any individual shall be limited to less than 250 µSv in any 12-month period. This shall be accomplished by keeping records to demonstrate that the effective dose multiplied by the number of screenings to any individual in a 12-month period does not exceed 250 µSv.

8.3 Method of test

The procedure for estimating the effective dose per screening is given in Annex A. Guidance on detector choice is given in Annex B. Operate the X-ray system using the procedures in the SOP. If multiple settings or modes of operation are described in the SOP, then operate the system using the mode with the highest effective dose per screening. Measure the effective dose per screening using the methods described in Annex A, based on measurements made at the reference position using a reference instrument.

9 Electrical characteristics

9.1 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 %.

NOTE General electrical safety considerations are covered by other international standards, e.g. IEC 61010-1.

9.2 Method of test

Measure the air kerma per screening at the reference position under reference conditions. Then measure the air kerma per screening over the voltage and frequency ranges given in 9.1.

[2] The NCRP and ICRP recommend that the effective dose to members of the general public from all non-medical radiation sources not exceed 1 mSv in any one year. To ensure this value is not exceeded, and since members of the general public may receive doses from multiple facilities, a limit of 250 μSv in one year was chosen.

10 Environmental conditions

10.1 Ambient temperature

10.1.1 Requirements

The equipment shall be capable of operating over the temperature range specified by the manufacturer, at least 5 °C to 40 °C, with changes in the air kerma per screening at the reference position not exceeding 10 % with all the safety systems operational.

10.1.2 Method of test

Measure the air kerma per screening at the reference position at 20 °C under reference conditions.

Operate the equipment at a temperature of 5 °C or lower, depending on the temperature range specified in 10.1.1 and measure the air kerma per screening. Keep the equipment at this temperature for at least 2 h before the test. Operate the equipment at a temperature of 40 °C or higher and repeat the test at this temperature for at least 2 h.

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

10.2 Relative humidity

10.2.1 Requirements

The equipment shall be capable of operating over the relative humidity range specified by the manufacturer, at least 40 % to 93 % at +35 °C without changes in the air kerma per screening at the reference position exceeding 10 % with all the safety systems operational.

10.2.2 Method of test

Measure the air kerma per screening at the reference position at 65 % relative humidity and 35 °C under reference conditions. Then measure the air kerma per screening for the humidity range given in 10.2.1.

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

11 Electromagnetic compatibility

11.1 Requirements

The equipment shall be in compliance with IEC 61326-1.

Concerning immunity tests the equipment shall fulfil at least the requirements for basic electromagnetic environments. If the manufacturer allows the use in an industrial environment the test requirements for industrial electromagnetic environment shall be used.

Concerning the immunity tests

– susceptibility to electromagnetic fields,
– conducted disturbances induced by bursts and radio frequencies,
– surges and ring waves, and
– electrostatic discharge,

the following performance criterions shall be fulfilled in addition to the performance criterions given in IEC 61326-1.

There shall be no change in the operational status while the system is exposed to the fields. No alarms or other outputs shall be activated, and all the safety systems shall remain operational during and after these tests.

11.2 Method of test

Perform test according to IEC 61326-1 with parameters given in IEC 61326-1 and verify that there is no change in the operational status and no alarms or other outputs are activated for each test. Verify that all the safety systems are operational after these tests according to 6.4.3.

12 Mechanical characteristics

12.1 Requirements

The equipment shall be able to withstand vibrations according to IEC 60721-3-3:2019 class 3M11 without effecting its performance. No alarms or other changes in operation shall occur during the exposure to vibration.

12.2 Method of test

Expose equipment to vibrations with acceleration spectral density and frequency range according to IEC 60721-3-3:2019 class 3M11 (see Table 5 in IEC 60721-3-3:2019). Inspect for physical damage and check the operation including the safety system after each vibration interval.

13 Documentation

13.1 Standard operating procedure

An SOP should be kept with the X-ray system and include all details necessary for the operator to perform their duties. It should include details of all administrative controls and should describe the expected behaviour of any persons that are expected to be exposed to the primary beam.

13.2 Other documentation

The following details should be documented and kept with the X-ray screening system, in accordance with IEC 61187:

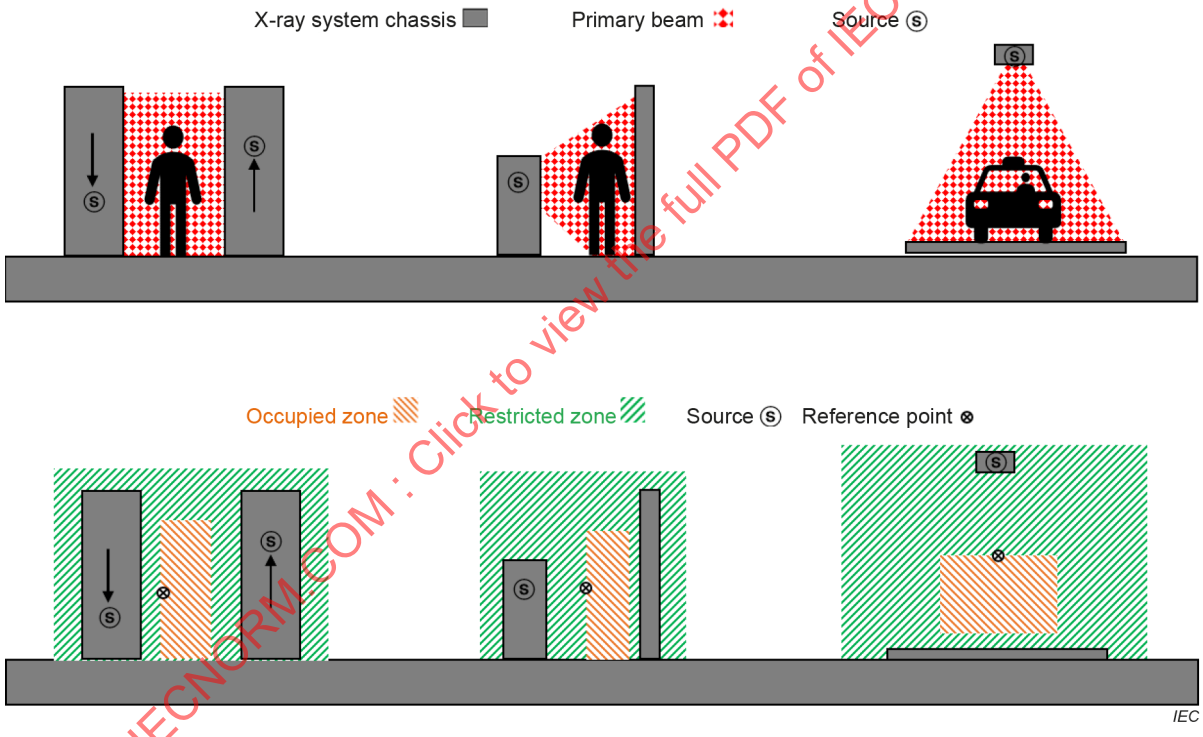
– operational mode, namely backscatter, (B), or transmission, (T), or combined backscatter and transmission (BT);
– field of application: intended uses, types of objects detected;
– X-ray operating conditions, high potential, tube current, filtration, HVL;
– scanning technique used for example pencil beam or slit collimator;
– radiation detector type;
– dose per screening at the reference position;
– location of the reference position;
– the number of screenings per year that would be required to reach 250 μSv;
– shielding thickness and leakage dose rate at 30 cm from external surfaces of the enclosure;
– drawing with iso-dose curves around the equipment including recommendations for areas in which operators or bystanders are permitted;
– list of safety interlocks and their purposes;
– scan speed, speed of the movable platform and/or of the X-ray unit;
– distance between focal spot of the X-ray tube and the beam outlet;
– maximum time for a scan.

Annex A
(normative)

Estimation of the effective dose per screening at the reference position

A.1 General

This Annex describes the procedure that shall be followed when estimating the dose per screening using this standard. There are several simplifying assumptions inherent in this procedure that limit its accuracy. For example, the use of the kerma-to-dose coefficients from ICRP/ICRU Report 95 mean that a parallel beam geometry has been assumed. The dose values are also based on the ICRP/ICRU adult reference computational phantoms, so they reflect the average of a male and a female with BMI in the 21 to 23 range. Similarly, it is a simplifying assumption to characterize an X-ray beam by its HVL alone. Nevertheless, there is value in having a simple standard method for dose estimation, e.g., for regulatory use. When highly accurate dose estimates are needed, different methods should be used that account for the particular characteristics of the X-ray system and persons being screened.



The top row shows the geometry of the primary beam of an example X-ray backscatter scanner (left), a transmission X-ray scanner (middle), and an occupied vehicle scanner (right). These are illustrative examples and may or may not match the geometry of real systems. The bottom row shows the occupied zone and the restricted zone for these systems, as viewed from one particular angle. The position of the source is indicated as an Ⓢ.

Figure A.1 – Illustrative examples

A.2 Determination of the reference position

The reference position is the location in the occupied zone that receives the highest dose per screening. See the glossary for definitions of the reference position and occupied zone and see Figure A.1 for some examples. The determination of this point can be partially based on knowledge of the system geometry, but this knowledge should be validated with a sampling of real measurements. Particular care should be taken to identify any anomalous areas of high exposure. For example, some previous backscatter systems utilized a translating X-ray beam, which showed the highest exposure at the end points where the beam movement slowed down.

These definitions are applicable whether the person being scanned is stationary or moving relative to the X-ray source. Consider a system like that in the middle row of Figure A.1, where the person stands on a platform that is translated into the page past a fan-beam of X-rays. The occupied zone uses the frame of reference of the person and platform and encompasses the volume where a person could be exposed to the primary X-ray beam while following the SOP. In this example, the reference position is the point in the occupied zone that gets closest to the X-ray source. This point translates through the fan beam during the screening process.

A.3 Measurement of the air kerma at the reference position

The air kerma per screening at the reference position, K_{REF}, shall be measured. The measurement should be made using an appropriate detector that has been calibrated using a standard X-ray beam that is traceable to a national lab (e.g. BIPM, NIST, PTB, NPL and others), potentially via a secondary lab. The standard X-ray beam should be comparable, in terms of kilovoltage and filtration, to the beam that irradiates the reference position. The detector should be operated in integrating mode and should be exposed to radiation in the same manner as a person would be. K_{REF} should be determined based on the average of at least 10 scans. See Annex B for more detailed informative guidance.

If the air kerma at the reference position can be broken down into distinct contributions due to primary beam irradiation from the anterior-posterior, posterior-anterior, and lateral directions, then it is recommended that that be done. In other words, if all these quantities have been measured and if they satisfy $K_{\mathrm{REF}} = K_{\mathrm{AP}} + K_{\mathrm{PA}} + K_{\mathrm{LAT}}$ to within estimated measurement uncertainties, where K_{AP} is the air kerma at the reference position due to the anterior-posterior primary beam, K_{PA} is the air kerma at the reference position due to the posterior- anterior primary beam, and K_{LAT} is the air kerma at the reference position due to lateral primary beam(s).

A.4 Estimation of the half-value layer of aluminum of the beam

The half-value layer of aluminum, HVL_{Al}, of all the X-ray beams that contribute to K_{REF} should be measured. The measurements should be made by measuring the air kerma at the reference position as a function of aluminum filtration using narrow-beam geometry. It may be impractical to make these measurements using the normal scanning procedure, so it is acceptable to make measurements in other configurations, as long as they do not alter the spectra. For example, one might make changes to stop the motion of a flying spot of X-rays or configure a multi-source system to only run one source at a time. Measurements should be made using aluminum attenuators of at least 99 % purity, adding thickness until the air kerma is reduced to at least 30 % of the unattenuated beam.

If an HVL_{Al} measurement is not made, then an alternate method for estimating the dose is also provided as part of the next section. In general, this alternative method will give results that greatly overestimate the effective dose. Nevertheless, this approach may be useful to show compliance with the standard, for example, when evaluating a system for which it is difficult or impossible to make a reasonable estimate of the HVL_{Al}.

A.5 Estimation of the effective dose

The effective dose is estimated using the operational quantities described in ICRU/ICRP Report 95. The true effective dose is a weighted sum of organ doses and is not amenable to direct measurement and can generally only be estimated by simulation. Operational quantities are point quantities that provide estimates of the true effective dose that would occur if a person were exposed to a large-area, uniform beam with the same properties. See ICRU/ICRP Report 95 for a detailed discussion of the definition of these quantities, how they were determined, their limitations and practical considerations for their use.

The effective dose, E, shall be estimated based on one of the two equations below which combine the measured air kerma value(s) with conversion coefficients to the appropriate operational quantities. The first formula should be used if the total air kerma per screening can be expressed as the sum of measured anterior-posterior, posterior-anterior, and lateral contributions. Otherwise, the second formula should be used.

$$E = K_{\mathrm{AP}} C_{\mathrm{AP}} + K_{\mathrm{PA}} C_{\mathrm{PA}} + K_{\mathrm{LAT}} C_{\mathrm{LAT}}$$

$$E = K_{\mathrm{REF}} C_{\mathrm{AMB}}$$

Here, C_{AP}, C_{PA} and C_{LAT} are coefficients for converting from air kerma to personal dose for photons irradiating a person from the anterior-posterior, posterior-anterior, and lateral directions, and C_{AMB} is a coefficient for converting from air kerma to ambient dose. Values for these coefficients should be chosen from Table A.1 from the row with the HVL value that is closest to the measured value. If an HVL measurement was not made, then the maximum value from each column can be used.

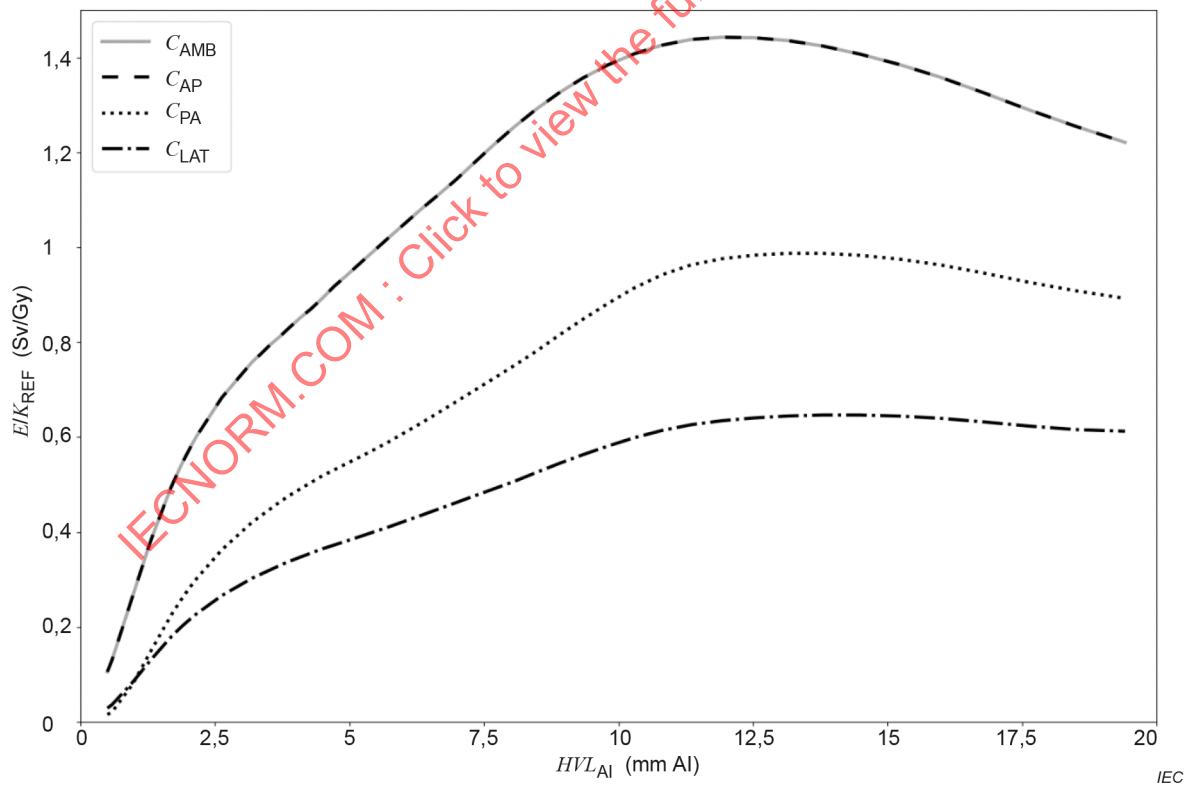
Table A.1 – Conversion coefficients from air kerma to operational quantities for estimating effective dose

HVL_{Al}	C_{AP}	C_{PA}	C_{LAT}	C_{AMB}	HVL_{AL}	C_{AP}	C_{PA}	C_{LAT}	C_{AMB}
mm	Sv/Gy	Sv/Gy	Sv/Gy	Sv/Gy	mm	Sv/Gy	Sv/Gy	Sv/Gy	Sv/Gy
0,500	0,106	0,016	0,029	0,106	3,193	0,759	0,421	0,303	0,759
0,525	0,113	0,017	0,031	0,113	3,352	0,775	0,434	0,311	0,775
0,551	0,120	0,019	0,033	0,120	3,520	0,794	0,448	0,320	0,794
0,579	0,128	0,020	0,036	0,128	3,696	0,811	0,463	0,329	0,811
0,608	0,138	0,024	0,039	0,138	3,881	0,830	0,477	0,338	0,830
0,638	0,148	0,029	0,043	0,148	4,075	0,850	0,490	0,347	0,850
0,670	0,160	0,034	0,047	0,160	4,279	0,870	0,504	0,355	0,870
0,704	0,171	0,039	0,051	0,171	4,493	0,892	0,518	0,365	0,892
0,739	0,184	0,044	0,055	0,184	4,717	0,918	0,531	0,373	0,918
0,776	0,197	0,050	0,060	0,197	4,953	0,941	0,545	0,381	0,941
0,814	0,210	0,056	0,064	0,210	5,201	0,967	0,558	0,391	0,967
0,855	0,225	0,062	0,069	0,225	5,461	0,993	0,574	0,401	0,993
0,898	0,240	0,068	0,075	0,240	5,734	1,021	0,590	0,411	1,021
0,943	0,255	0,075	0,080	0,255	6,020	1,049	0,609	0,423	1,049
0,990	0,272	0,083	0,086	0,272	6,321	1,079	0,629	0,435	1,079
1,039	0,289	0,094	0,093	0,289	6,637	1,109	0,650	0,448	1,109
1,091	0,307	0,104	0,101	0,307	6,969	1,141	0,674	0,461	1,141
1,146	0,326	0,116	0,108	0,326	7,318	1,178	0,698	0,476	1,178
1,203	0,346	0,128	0,116	0,346	7,684	1,216	0,724	0,491	1,216
1,263	0,367	0,140	0,125	0,367	8,068	1,254	0,751	0,507	1,254
1,327	0,388	0,153	0,133	0,388	8,471	1,291	0,781	0,525	1,291
1,393	0,408	0,166	0,142	0,408	8,895	1,325	0,815	0,544	1,325
1,463	0,428	0,180	0,151	0,428	9,340	1,357	0,848	0,563	1,357
1,536	0,450	0,195	0,160	0,450	9,807	1,384	0,882	0,581	1,384
1,613	0,473	0,210	0,170	0,473	10,297	1,408	0,914	0,599	1,408
1,693	0,497	0,226	0,180	0,497	10,812	1,426	0,942	0,614	1,426
1,778	0,518	0,241	0,190	0,518	11,352	1,438	0,963	0,626	1,438

HVL_{Al} mm	C_{AP} Sv/Gy	C_{PA} Sv/Gy	C_{LAT} Sv/Gy	C_{AMB} Sv/Gy
1,867	0,539	0,257	0,199	0,539
1,960	0,560	0,272	0,209	0,560
2,058	0,581	0,287	0,219	0,581
2,161	0,602	0,302	0,228	0,602
2,269	0,621	0,316	0,237	0,621
2,382	0,641	0,331	0,246	0,641
2,502	0,661	0,346	0,256	0,661
2,627	0,683	0,362	0,266	0,683
2,758	0,701	0,376	0,275	0,701
2,896	0,719	0,390	0,284	0,719
3,041	0,738	0,405	0,293	0,738

HVL_{AL} mm	C_{AP} Sv/Gy	C_{PA} Sv/Gy	C_{LAT} Sv/Gy	C_{AMB} Sv/Gy
11,920	1,442	0,976	0,635	1,442
12,516	1,441	0,983	0,640	1,441
13,142	1,435	0,987	0,645	1,435
13,799	1,424	0,987	0,647	1,424
14,489	1,407	0,983	0,647	1,407
15,213	1,385	0,975	0,644	1,385
15,974	1,359	0,963	0,640	1,359
16,773	1,326	0,946	0,632	1,326
17,611	1,290	0,927	0,623	1,290
18,492	1,255	0,908	0,616	1,255
19,416	1,221	0,892	0,612	1,221

The values in Table A.1 are derived from the values in ICRU/ICRP Report 95, which are tabulated for monoenergetic photons. To determine the conversion coefficients, a variety of x-ray beams were considered, including monochromatic x-ray beams and x-ray tube beams with various filtration configurations (minimum 1 mm aluminum). The conversion coefficient for each HVL value was calculated based on the beam that gave the highest dose for that HVL value. See also Figure A.2.



Note that the lines for C_{AP} and C_{AMB} overlap.

Figure A.2 – Conversion coefficients from air kerma to effective dose from Table A.1 plotted as a function of HVL_{Al}