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Radiation Safety for Personnel Security Screening Systems Using X-Ray or Gamma Radiation

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The Health Physics Society N43.17 Standards Subcommittee responsible for the development of N43.17-2002 had the following members: Frank Cerra (chair), Martin Annis, Edgar Bailey, Terry Brayer, Larry Cothran, Daniel Kassiday, Andy Kotowski, Roy Lindquist, William Passetti, Richard Schueller, Timothy Scroggins, Gerald Smith, Steve Smith, Richard Whitman, Pamela Zaresk.

The N43.17 Subcommittee responsible for the current revision had the following members:

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Daniel Kassiday, Co-Chair, Food and Drug Administration
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Amit Verma, Rapiscan Systems, Inc.
Rick Whitman, DHS Customs and Border Protection
Doug Wicks, Secure Path, Inc.
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Michael Wilson, Braun International USA, LLC

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Foreword (This foreword is not part of American National Standard ANSI/HPS N43.17-2009.)

This standard is a revision of ANSI/HPS N43.17-2002 and applies to security screening systems in which people are intentionally exposed to ionizing radiation. The standard provides guidelines specific to the radiation safety aspects of the design and operation of these systems. It does not include electrical safety guidelines or any other safety, performance, or use considerations outside the realm of radiation safety. The standard is intended for manufacturers, distributors, installers, and users of the systems.

The original standard, N43.17-2002, included requirements that were intended for self-enclosed, full-body, x-ray scanners that operated by scanning a person who was standing still. New system designs and new use requirements have developed since publication of the original standard. The new designs include portal systems, multi-source systems, vehicle scanners meant for screening occupied vehicles, scanners for inspecting casts and prosthetic devices, and scanners using a radioisotope as the source of radiation. The new types of uses include the use of vehicle and cargo scanners to inspect people and the limited use of higher-dose systems as defined in NCRP Commentary 16[*]. The present standard includes requirements that cover these new developments.

The following major changes were made with respect to the original standard:

1. Systems were broken down into two categories, general-use and limited-use, in accordance with NCRP Commentary 16.
2. The limit on dose to a person screened was changed from a per-scan limit to a per-screening limit.
3. The method of calculating the reference effective dose based on the measured half-value layer was introduced.
4. The user requirements were expanded considerably to cover sufficient administrative and operational controls necessary for limited-use systems.
5. The concept of Ambient Dose Equivalent Area Product was introduced to deal with partial-body scanners.
6. Appropriate equivalent requirements were added for radioisotope-based systems.

Notwithstanding the changes, there is consistency of radiation protection between the original standard and the revised standard. All systems complying with the original standard also comply with the present requirements for the general-use category. The final goal of limiting the annual effective dose to members of the public to 0.25 mSv (25 mrem) was preserved and applies to all types of systems.

It is important to reiterate that this standard includes requirements for both the manufacturers and users of screening systems. Section 6 of this standard contains requirements for both manufacturers and users. Section 7 contains only manufacturer requirements. Section 8 contains mostly user requirements with some manufacturer requirements pertaining to installation. Full compliance with this standard only pertains to systems manufactured and operated according to the standard. Simply procuring equipment that meets all the manufacturing performance requirements does not guarantee compliance. This is true for general-use as well as limited-use systems, but the importance of proper implementation of administrative controls for limited-use systems cannot be understated. The authors of this standard recommend establishing a mechanism for independent oversight of the use of limited-use systems that are not subject to licensing or registration by the U.S. Nuclear Regulatory Commission or state governments.

Users and potential users of personnel security screening systems are encouraged to consult the document *Guidance for Security Screening of Humans Utilizing Ionizing Radiation*, available from the Interagency Steering Committee on Radiation Standards (ISCORS Technical Report 2008-1, http://www.iscors.org/library.htm).

[*] National Council on Radiation Protection and Measurements. Screening of humans for security purposes using ionizing radiation scanning systems. Bethesda, MD: NCRP; NCRP Commentary 16; 2003.

Radiation Safety for Personnel Security Screening Systems Using X-Ray or Gamma Radiation

1.0 Scope

This standard applies to the manufacture and operation of security screening systems that are intended to expose humans to primary beam x-rays, gamma radiation, or both. This standard does not address neutron-based systems. Examples of screening practices covered by this standard include the following:

- Direct screening of humans to detect objects hidden within an individual's body or clothing.
- Knowingly exposing human occupants to the primary beam when screening vehicles or structures.
- Screening of orthopedic casts and prosthetic devices while being worn.

The standard provides requirements specific to the ionizing radiation safety aspects of both the design and operation of these systems. It does not include electrical safety guidelines or any other safety, performance, or use considerations outside the realm of radiation safety. The limits in this standard are not intended to apply to stowaways not authorized to be in the area and not known to be present prior to scanning.

It is recognized that the need for security might sometimes call for exceeding the dose limits set in this standard. This should be based on an analysis demonstrating that the security benefit outweighs the risk from the radiation exposure incurred by the individuals screened. This standard does not address the evaluation of the societal benefit of security screening. Therefore, screening operations that exceed this standard's dose limits are beyond the scope of this standard and shall not claim compliance with this standard.

Medical diagnostic systems should be used under medical supervision and are not covered by this standard.

2.0 Definitions

The following are terms that are either of key significance or have a specific meaning in this standard that might differ from the term's usage elsewhere. This is not meant to be a comprehensive glossary of terms used in radiation protection. The discussion in Annex C contains additional information on radiation quantities and units.

Access panel: Any panel designed to be removed or opened for maintenance or service purposes that when removed or opened affects the radiation leakage pattern or allows intrusion into the radiation field.

ADAP: see Ambient Dose Equivalent Area Product

Administrative control: A documented, compulsory, routine procedure aimed at controlling the radiation exposure received by individuals and ensuring that the appropriate dose limits are not exceeded.

Air kerma: The total initial kinetic energy transferred to charged particles per mass of air as a result of irradiation. The unit of air kerma is the joule per kilogram or gray (Gy). (1 Gy air kerma corresponds to approximately a 114-roentgen exposure).

ALARA: As Low As Reasonably Achievable, economic and social factors being taken into account.

Aluminum-equivalent filtration: The thickness of aluminum affording the same attenuation of the x-ray beam as the material in question under specified conditions.

Ambient dose equivalent area product (ADAP): The product of the ambient dose equivalent, $H^*(10)$, and the *scan area* at a defined distance (used only for partial-body scanners).

Ambient dose equivalent, *H*(d)*: The dose equivalent at a point in a radiation field produced by the corresponding expanded and aligned field in the ICRU sphere (ICRU

1998) at a depth *d* on the radius opposing the direction of the aligned field. Dose equivalent is the product of the absorbed dose *D* at a point in tissue (i.e., the mean energy imparted per unit mass) and the quality factor *Q* at that point. The unit of dose equivalent, *H,* and of ambient dose equivalent, *H**(*d*), is the joule per kilogram (J kg^{-1}), with the special name sievert (Sv, 1 Sv = 100 rem).

Backscatter system: A security screening system that makes use of radiation scattered or deflected from an object or person to form an image of the scattering object or person.

Beam exit surface: The surface of the outer system assembly from which the direct x-ray or gamma ray beam emanates. This may be a flat surface or the outer surface of a port or collimator. The subject being scanned is exposed through this surface. Systems with more than one radiation source may have more than one beam exit surface.

Beam stop: A radiation shield meant to intercept the direct beam of radiation.

Bystander: Any person other than the individual being screened who is not directly associated with operation of the system.

Effective dose: A summation of the *equivalent doses* in tissues or organs each multiplied by the appropriate tissue weighting factor as defined by the International Commission on Radiation Units and Measurements (ICRU 1998)**.** The tissue weighting factors were modified by the International Commission on Radiological Protection in its Publication 103 (ICRP 2007). The unit of effective dose is joule per kilogram, and its special name is sievert (Sv, 1 Sv = 100 rem).

Engineering control: A safety component of the system design that prevents improper operation or unintended radiation exposure. Examples of engineering controls include one-way turnstiles, interlocked motion sensors, etc.

Equivalent dose: The absorbed dose in an organ or tissue multiplied by the appropriate radiation weighting factor. The unit of equivalent dose is joule per kilogram, and its special name is sievert (Sv, 1 Sv = 100 rem). See ICRU (1998).

External surface: The outside surface of the enclosure containing all associated ionizing radiation sources.

Facility: See Operating facility.

General-use system: A personnel screening system that delivers a reference effective dose equal to or less than 0.25 μSv (25 μrem) per screening as defined in this standard. 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.

Ground fault: An accidental electrical grounding of an electrical conductor.

Half-value layer (HVL): The thickness of specified material that attenuates the radiation beam such that the air-kerma (or exposure) rate is reduced to one-half of its original value. The HVL is determined in such a way that scattered radiation, other than that initially present in the beam, is excluded (i.e., in narrow-beam geometry).

High radiation area: An area, accessible to individuals, in which radiation levels could result in an individual's receiving a dose equivalent in excess of 1 mSv (100 mrem) in 1 hour at 30 cm from a beam exit surface. The ambient dose equivalent at 10 mm, H*(10), shall be used for determining the potential dose to individuals.

Inspection zone: The general area established by the operating institution for the purpose of limiting or controlling access to the area where the screening will be performed. This includes but is not limited to any ingress, egress, gate, portal, traffic path, and areas, access to which is restricted due to the presence of radiation. The ambient dose equivalent, H*(10), outside of the inspection zone shall not exceed 20 μSv (2 mrem) in any 1 hour.

Institution: See Operating institution.

Limited-use system: A personnel screening system that is capable of delivering a reference effective dose greater than 0.25 µSv (25 µrem) per screening but shall not exceed a reference effective dose of 10 µSv (1 mrem) per screening as defined in this standard. Limited-use systems require additional controls and documentation to ensure that annual individual dose limits are not exceeded.

Mode of operation: A selectable set of technique factors or machine settings that is pre-determined by the manufacturer for a specific purpose.

Multiple source system: A system utilizing more than one source of radiation.

NID: Negligible Individual Dose. An annual effective dose lower than or equal to 0.01 mSv (1 mrem).

Occupancy factor: The fraction of time relative to 2,000 hours per year (full occupancy) that a maximally exposed individual is expected to remain in a given area.

Operating facility (also facility): A location of use where one or more screening systems may be installed.

Operating institution (also institution, user, end user): A government or private organization that controls the deployment of screening systems at one or more facilities.

Operator: Any employee associated with the operation of the system whose responsibilities include at least one of the following: initiating or stopping the scan, verifying the system is operating correctly, providing information and instructions to the screened individuals, and controlling access to the inspection zone. This does not include other employees, such as individuals who may be remotely viewing the image results but are not directly responsible for the other functions.

Personnel security screening system: A system designed for the detection of contraband and weapons concealed on a person or in a vehicle while being occupied by one or more people (in the body of this standard also referred to as "screening system" or "system").

Primary beam: The beam of radiation emanating from the system intended to reach the target being scanned. This excludes scattered radiation and radiation transmitted through shielding.

Portal system: A system designed to image persons who move through the inspection zone under their own control, by a moving walkway, or within a vehicle. It does not include systems that move the individual through the inspection zone in a controlled manner, such as a moving platform on which the subject is normally required to remain still (see Stationary- subject system).

Qualified service provider: As it pertains to radiation surveys, a person having the knowledge—as demonstrated by documented training and experience—to properly measure ionizing radiation and analyze the results relative to the requirements of this standard. As it pertains to radioisotope maintenance, a person having the necessary training and experience to safely maintain and repair the system and who is registered or licensed according to regulatory requirements at the location where the service is being performed.

Radiation area: An area, accessible to individuals, in which radiation levels could result in an individual's receiving a dose equivalent in excess of 0.05 mSv (5 mrem) in 1 hour at 30 cm from a beam exit surface. The ambient dose equivalent at 10 mm, H*(10), shall be used for determining the potential dose to individuals.

Reference effective dose, E_{REF}: A quantity based on measurable parameters used by this standard for setting dose limits. It is derived from the effective dose to the average adult as defined in ICRU Report 57 (ICRU 1998) and as modified by ICRP Publication 103 (ICRP 2007). It is obtained from air kerma (or exposure) and HVL measurements as described in Section 6.1.3 of this standard, "Determination of the Reference Effective Dose."

Safety interlock: A device that is intended to automatically prevent or interrupt the radiation hazard whenever safety is compromised by access to the interior of the system, unauthorized access to a radiation area, or by an operational malfunction.

Scan: The operation necessary to produce one image (e.g., front view) from one radiation source. One radiation source simultaneously producing multiple images also constitutes one scan. Two sources simultaneously producing two images constitute two scans. In some cases several scans may be required for a single screening of the subject.

Scan area: The total area on the reference plane that is covered by the primary beam as it scans. The reference plane is the plane containing the reference measuring point and is perpendicular to the beam direction at the reference point (used only for partial-body scanners).

Screening: The sum of radiation exposures or scans necessary to image objects concealed on all sides of the body as intended by the system design under normal conditions. Examples: 1) for backscatter systems a screening typically consists of four scans, one from each side; 2) for transmission systems a screening typically consists of one scan; 3) for portal systems a screening consists of a complete pass through the inspection zone.

Shall: The word "shall" is used to indicate a requirement.

Should: The word "should" is used to indicate a provision that is not required but is recommended as good practice.

Shutter: A means of turning a radiation beam on and off by blocking the beam with a suitable thickness of shielding material. This may be accomplished by moving the shield in front of the radiation source or by moving the radiation source behind the shield.

Sievert (abbreviated Sv): The unit of equivalent dose, ambient dose equivalent, and effective dose. One sievert represents one joule of photon energy absorbed in each kilogram of irradiated tissue.

Stationary-subject system: A system designed to image a person who remains stationary while a scan is occurring. This includes systems that move the individual through the inspection zone in a controlled manner, such as a moving platform on which the subject is normally required to remain still.

Structure: Any physical enclosure containing humans that might be inspected. Includes but is not limited to vehicles, cargo containers, walls, wheelchairs, buildings, etc.

Technique factors: The x-ray settings, including 1) the peak kilovoltage applied to the x-ray tube, 2) the electric current passing through the x-ray tube, and 3) the scan time.

Transmission system: A security screening system using the conventional means of radiographic imaging in which x- rays or gamma rays pass through a target (e.g., person or container) and create shadow-grams of enclosed objects (e.g., contraband) based on their radiation attenuating properties.

3.0 General Considerations

The devices that are subject to this standard are unique in that they intentionally expose people to ionizing radiation for non-medical purposes. This standard recognizes the potential for a net security benefit to society and presupposes appropriate justification of each screening practice. These security devices shall not be used frivolously where no security benefit is to be derived.

4.0 Federal, State, and Local Regulations

Manufacturers, distributors, and users of security screening systems under this standard shall comply with all applicable requirements in the U.S. Code of Federal Regulations (CFR): Title 21, Parts 1000 through 1005 (FDA), regarding x-ray systems; Title 10, Parts 20 and 30 through 33 (NRC), regarding radioactive materials;

and Title 29, Part 1910.1096 (OSHA), regarding occupational safety. In addition, the installation, maintenance, and operation of these systems may be subject to state and local regulations, which may involve registration, licensing, and compliance with specific requirements.

5.0 System Categories and Classes

Personnel screening systems are divided into two categories based on the radiation output:

- Category 1 – general-use systems
- Category 2 – limited-use systems

The systems are also classified into two classes based on their configuration:

- Class A – full-body scanners
- Class B – partial-body scanners

Both categories may include systems of both classes. The requirements of this standard are specific to each category and each class. Manufacturers shall identify the category and class of each system in all statements of conformance with this standard.

5.1 Categories

5.1.1 Category 1: General-use Systems For the purpose of this standard, general-use systems are systems that guarantee a high degree of radiation safety due to the extremely low doses delivered and engineering controls incorporated in the system. The probability of any one individual's receiving a cumulative effective dose in excess of the annual limit from general-use systems is extremely low. Therefore, general-use systems require few administrative controls and may be operated without the need for tracking the number of individuals scanned or the number of scans per individual in a year.

Category 1 systems shall conform to the dose limitation requirements of Section 6.1.1, "Dose Limitation for General-Use Systems," of this standard.

5.1.2 Category 2: Limited-use Systems For the purpose of this standard, limited-use systems are systems that require additional administrative controls in order to ensure that members of the public are not subjected to a cumulative effective dose in excess of the allowed annual limit. Limited-use systems may be suitable when additional security measures are necessary and when a general-use system is not adequate. These systems shall either be used with discretion in terms of the number of individuals scanned and the number of scans per individual in a year or shall be used with rigorous administrative controls that guarantee the same dose limitation per screening as general-use systems.

Category 2 systems shall conform to the dose limitation requirements of Section 6.1.2, "Dose Limitation for Limited-use Systems," of this standard.

5.2 Classes

5.2.1 Class A: Full-body Scanners This class includes all systems that image the full body of a person. Systems in which the subject stands in place, portal systems, and multi-purpose scanners used to intentionally scan humans who may be pedestrians or vehicle occupants are examples of full-body scanners.

For the purpose of this standard, any system for which at least one dimension of the scan area is greater than 50 cm shall be considered a full-body scanner.

5.2.2 Class B: Partial-body Scanners This class includes systems designed to image a small part of the body. Partial-body scanners are used typically to inspect orthopedic casts, braces, and prosthetic devices. For the purpose of this standard, any system for which no dimension of the scan area is greater than 50 cm shall be considered a partial-body scanner.

6.0 Dose Limitation

This section contains dose limits and associated requirements. Some of the requirements of this section pertain to the system performance and are directed to the

system manufacturer. Other requirements in this section pertain to operating procedures and are directed to the user organization. Additional, specific requirements for achieving the dose limits are included in Section 7.0, "System and Manufacturing Requirements," and Section 8.0, "Operating Requirements."

6.1 Dose to Scanned Individuals

The radiation dose delivered to a scanned individual shall be as low as reasonably achievable (ALARA) while meeting the required detection performance. When using transmission systems, to minimize the effective dose received, persons undergoing screening should be positioned facing away from the source of radiation.

The system manufacturer shall ensure that operating parameters are optimized for the best performance at the lowest dose.

6.1.1 Dose Limitation for General-use Systems

6.1.1.1 Class A (Full-body Scanner) For Class A (full-body) scanners the reference effective dose as determined according to Section 6.1.3, "Determination of the Reference Effective Dose," shall not exceed 0.25 µSv (25 µrem) per screening.

For Class A general-use systems, the reference effective dose received by individuals from one facility shall not exceed 250 µSv (25 mrem) over a 12-month period. Compliance with this requirement shall be demonstrated as follows: if the nature of the screening operation is such that one or more adult individuals may be screened routinely more than twice each day of the year by the same facility (e.g., as in routine screening of employees), the facility shall keep records to show that either: 1) the number of screenings received by any individual does not exceed 1,000 per 12-month period or 2) the reference effective dose multiplied by the number of screenings does not exceed 250 µSv (25 mrem) over a 12-month period for any individual. Note: the reference effective dose is based on a computational adult model and is not always indicative of the actual effective dose, especially for small children. Therefore, practices that involve daily screening of the same population of children are not recommended without additional analysis.

Table 1 can be used to aid in meeting the annual dose requirement.

Table 1. The number of allowed screenings for one individual.

Reference effective dose per screening (µSv)	(µrem)	Standard is met if number of screenings per year does not exceed	Standard is met if number of screenings every month does not exceed	Standard is met if number of screenings every week does not exceed	Standard is met if the number of screenings every day does not exceed
0.05	5	5,000	416	96	13
0.10	10	2,500	208	48	6
0.15	15	1,667	138	32	4
0.20	20	1,250	104	24	3
0.25	25	1,000	83	19	2
0.5*	50	500	41	9	
1.0*	100	250	20	4	
2.0*	200	125	10	2	
3.0*	300	80	6	1	
4.0*	400	62	5	1	
5.0*	500	50	4		
10.0*	1,000	25	2		

*Applies to limited-use systems only.

6.1.1.2 Class B (Partial-body Scanner) For Class B (partial-body) scanners the ambient dose equivalent area product (ADAP) is calculated by multiplying the ambient dose equivalent, H*(10) and the scanned area. The ADAP shall not exceed 0.03 µSv m^2 (3 µrem m^2) per scan. The measurement shall be made at the point of maximum exposure on a plane at the optimum imaging distance. The measurement shall be made under operating conditions that produce the highest radiation exposure.

For Class B general-use systems no individual screened shall receive more than *N* scans by the same facility in a twelve month period, where *N* = 75 µSv m^2/ADAP (7,500 µrem m^2/ADAP). Note: *N* refers to a number of scans, not a number of screenings.

6.1.2 Dose Limitation for Limited-use Systems

6.1.2.1 Class A (Full-body Scanner) The reference effective dose as determined according to Section 6.1.3, "Determination of the Reference Effective Dose," shall not exceed 10 µSv (1 mrem) per screening.

6.1.2.2 Administrative Controls for Class A (Full-body Scanner) Administrative controls are required for the operation of all limited-use, full-body scanners. There are two options:

EITHER

a. Administrative controls shall be in the form of documented procedures that ensure that the effective dose to individuals as determined according to Section 6.1.3, "Determination of the Reference Effective Dose," shall not exceed 0.25 µSv (25 µrem) per screening.

   In addition, the reference effective dose received by individuals from one facility shall not exceed 250 µSv (25 mrem) over a 12-month period. Compliance with this requirement shall be demonstrated as follows: if the nature of the screening operation is such that one or more adult individuals may be screened routinely more than twice each day by the same facility (e.g., as in routine screening of employees), the facility shall keep records to show that either: 1) the number of screenings received by any individual does not exceed 1,000 per 12-month period or 2) the reference effective dose multiplied by the number of screenings does not exceed 250 µSv (25 mrem) over a 12-month period for any individual. Note: the reference effective dose is calculated for a reference adult and is not always indicative of the actual effective dose, especially for small children. Therefore, practices that involve daily screening of the same population of children are not recommended without additional analysis.

   Table 1 can be used to aid in meeting the annual dose requirement.

OR

b. Administrative controls shall be in the form of documented procedures that ensure that the effective dose to any individual screened shall be limited to 250 µSv (25 mrem) in any 12-month period. This shall be accomplished by keeping records to demonstrate that the reference effective dose multiplied by the number of screenings to any individual in a 12-month period does not exceed 250 µSv (25 mrem).

It is recognized that the need for security may sometimes call for either the 10 µSv (1 mrem) per-screening limit or the 250 µSv (25 mrem) annual limit to be exceeded. This decision should be based on an analysis demonstrating that the security benefit outweighs the risk from the radiation exposure incurred by the individuals screened. This standard does not address the societal benefit of security screening. Therefore, screening operations that exceed the above dose limits are beyond the scope

of this standard and shall not claim compliance with this standard.

6.1.2.3 Class B (Partial-body Scanner) The ambient dose equivalent area product (ADAP) shall not exceed 3 µSv m^2 (300 µrem m^2) per scan. The measurement shall be made at the point of maximum exposure on a plane at the optimum imaging distance. The measurement shall be made under operating conditions that produce the highest radiation exposure.

For Class B limited-use systems no individual screened shall receive more than *N* scans by the same facility in a 12-month period, where *N* = 75 µSv m^2/ADAP (7,500 µrem m^2/ADAP).

6.1.3 Determination of the Reference Effective Dose The reference effective dose for Class A full-body scanners shall be determined from measurements of the half-value layer (HVL) and air kerma (or exposure) according to Sections 6.1.3.1 and 6.1.3.2, respectively. One of the equations (1) or (1a) below shall be used.

$$E_{REF} = K_a \times C \qquad \text{(eq.1)}$$

where
E_{REF} is the reference effective dose in Sv,
K_a is the measured air kerma in Gy, and
C in Sv/Gy is given by
C = 0.125 × HVL in mm of Al or
C = 1.14, whichever is smaller.

Or, when using traditional units the equivalent equation is

$$E_{REF} = X \times C_R \text{ (eq. 1a)}$$

where
E_{REF} is the reference effective dose in rem,
X is the measured exposure in R, and
C_R in rem/R is given by
C_R = 0.110 × HVL in mm of Al or
C_R = 1.00, whichever is smaller.

Note: C and C_R achieve their maximum value at HVL = 9.1 mm Al. This corresponds to an effective photon energy slightly less than 60 keV. Therefore, a C of 1.14 Sv/Gy (C_R of 1.00 rem/R) shall be used for systems using ^{60}Co, ^{137}Cs, or any other isotope whose emissions equal or exceed 60 keV.
6.1.3.1 Determination of the Half-Value Layer For x-ray systems, the aluminum HVL shall be measured according to the procedure in Annex C.

Note: In some cases, compliance with this standard may be shown by assuming the maximum value of the conversion coefficient, C, 1.14 Sv/Gy (C_R of 1.00 rem/R), thus not relying on a measurement of HVL. However, knowledge of the HVL can aid operating facilities in properly calibrating radiation measuring instruments and setting appropriate annual scan limits.

6.1.3.2 ***Measurement of the Reference Air Kerma or Exposure*** Compliance with the reference effective dose limits shall be determined by making measurements using an instrument calibrated in terms of exposure or air kerma in the appropriate energy range (see Annex C). The measurement shall be made at the point of maximum exposure but no closer than 30 cm from a beam exit surface, a tunnel wall or virtual tunnel wall. The measurement shall be made under operating conditions that produce the highest radiation exposure to individuals.

The probe of the air kerma (exposure) measuring instrument shall be scanned in the same manner as a human subject. For portal systems, the probe shall be scanned at the minimum allowed speed of transit through the irradiated space. For stationary-subject systems, the probe shall be stationary. For radiation that is incident from more than one direction, a probe having uniform response in all the directions shall be used (for example, a cylindrical or spherical ion chamber is suitable for dual, front and back scanners).

The integrated air kerma (exposure) obtained over as many scans as required by a full screening shall be used in the determination of E_{REF}.

6.2 Dose to Bystanders, Operators, and Other Employees

An inspection zone shall be established around the personnel security screening system where bystanders are prohibited during the operation of the device. A means shall be provided for any operator responsible for initiating a scan to maintain full visual surveillance of the inspection zone. The ambient dose equivalent, H*(10), outside of this inspection zone shall not exceed **20 μSv (2 mrem) in any 1 hour**.

Any area accessible to individuals in which radiation levels could result in an individual's receiving a dose equivalent in excess of 0.05 mSv (5 mrem) in 1 hour at no less than 30 cm from a beam exit surface, a tunnel wall or virtual tunnel wall shall be posted with a sign displaying the radiation symbol as specified in Fig. 1 and the words "CAUTION, RADIATION AREA."

Any area accessible to individuals in which radiation levels could result in an individual receiving a dose equivalent in excess of 1 mSv (100 mrem) in any 1 hour at no less than 30 cm from the beam exit surface, a tunnel wall or virtual tunnel wall shall be posted with a sign displaying the radiation symbol as specified in Fig. 1 and the words "CAUTION, HIGH RADIATION AREA."

The ambient dose equivalent at 10 mm, H*(10), shall be used for determining the potential dose to individuals for the purpose of establishing the radiation area and high radiation area.

The system should be positioned and operated such that the ambient dose equivalent at any work station does not exceed 1 mSv (100 mrem) per year. See Annex B, Section B2, "Dose to Operators and Other Employees," for more information.

6.3 Shielding

Under maximum operating parameters, the leakage ambient dose equivalent at any point 30 cm from any external surface of the system, outside of the primary beam, shall not exceed 2.5 μSv (0.25 mrem) in any 1 hour. For units that employ a shutter this limit shall also apply to the region of the primary beam while the shutter is closed. For units that employ a beam stop this limit shall also apply to the region adjacent to the beam stop opposite the source of radiation.

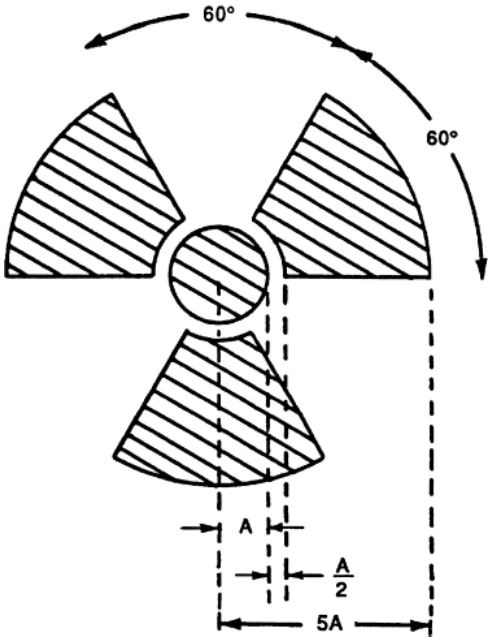

Fig. 1. Radiation symbol (note: cross-hatched area to be purple, magenta, or black; background to be yellow).

7.0 System and Manufacturing Requirements

The requirements of this section apply to the design and manufacture of systems. These requirements are in addition to design and manufacturing requirements necessary to meet the dose limitations of Section 6, "Dose Limitation."

7.1 Filtration

For all x-ray systems, the x-ray beam shall be attenuated by no less than 1 mm of aluminum-equivalent total filtration before exiting the beam exit surface.

7.2 Indicators, Controls, and Safety Interlocks

7.2.1 Requirements for All Systems The requirements of this subsection apply to all the systems regardless of category or type of radiation source. In addition to these requirements systems must comply with the requirements of one of the sections 7.2.2 through 7.2.5 as appropriate.

a. There shall be at least one indicator, clearly visible from any location from which a scan can be initiated, that indicates when a scan is in progress.
b. There shall be at least one lighted indicator clearly visible from the inspection zone. For portal systems the indicator shall be visible from any approach to the inspection zone to indicate that a scan is in progress.
c. Power to the system shall be controlled by a key switch. The key shall be captured (unable to be removed) whenever it is in a position that allows exposures to be initiated. Turning on the key switch shall never result in the external emission of radiation.
d. Each system shall have a means for the operator to initiate the emission of radiation other than the function of an interlock or the main power control.
e. Each system shall have a means for the operator to terminate the emission of radiation other than the function of an interlock.
f. Means shall be provided to ensure that operators have a clear view of the scanning area. This can be a direct, mirror view, or real-time video of the scanning area. Engineering controls should be provided to ensure that individuals do not reenter the scanning area from the exit while x-rays are being produced (e.g., one way turnstile, see also specific requirements in Sections **7.2.2** through 7.2.5).
g. A ground fault shall not result in the generation of x-rays or activate a scan beam from a sealed radioactive source.
h. Failure of any single component of the system shall not cause failure of more than one safety interlock.
i. A tool or key shall be required to open or remove access panels. Access panels shall have at least one safety interlock.
j. For stationary-subject systems, the scanning motion of the x-ray beam relative to the subject shall be interlocked and the exposure shall terminate when the rate of motion of the beam in any direction falls below a preset minimum speed. The minimum speed shall be chosen so that the dose during the exposure period is within the applicable limit.
k. For portal systems, the minimum walking or driving velocity through the inspection zone shall be determined by the manufacturer. The minimum speed shall ensure that the dose during the exposure period is within the applicable limit.
l. Operational interlocks shall terminate the primary beam in the event of any system problem that could result in abnormal or unintended radiation emission. This shall include, but is not limited to, unintended stoppage of beam motion, abnormal or unintended x-ray source output, computer safety system malfunction, termination malfunction, and shutter or beam stop mechanism malfunction.
m. In the event of a malfunction, the system shall terminate radiation exposure rapidly enough so that no location on the subject's body shall receive an ambient dose equivalent (H*10) exceeding 250 µSv (25 mrem), regardless of the size of the exposed area.
n. Following interruption of x-ray production or external gamma emission by the functioning of any safety interlock, resetting the interlock shall not result in the production of x-rays or emission of gamma radiation. Use of the normal control sequence shall be necessary for resumption of x-ray generation or gamma radiation emission.

7.2.2 Requirements for General-use Systems Using X-ray Sources In addition to the requirements of Section 7.2.1, "Requirements for All Systems," the following requirements apply to general-use systems using x-ray sources:

a. For any x-ray system that normally keeps high voltage applied to the x-ray tube at times other than during a scan, there shall be at least one lighted "x-ray on" indicator at the control console where x-rays are initiated indicating when x-rays are being produced.
b. Technique factors for each mode of operation shall be preset 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.
c. Each access panel to the x-ray source shall have at least one safety interlock to terminate the x-ray production when opened.
d. The following warning label shall be permanently affixed or inscribed on the x-ray system at the location of any controls used to initiate x-ray generation: "CAUTION: X-RAYS PRODUCED WHEN ENERGIZED."
e. X-ray emission shall automatically terminate after a preset time or exposure.
f. For portal systems, motion sensors shall monitor the speed of pedestrians or vehicles through the inspection zone (in the forward direction) and the radiation exposure shall terminate when the speed drops below the minimum (as determined according to Section 7.2.1 k).

7.2.3 Requirements for Limited-use Systems Using X-ray Sources In addition to the requirements of Section 7.2.1, "Requirements for All Systems," the following requirements apply to limited-use systems using x-ray sources:

a. For any x-ray system that normally keeps high voltage applied to the x-ray tube at times other than during a scan, there shall be at least one lighted "x-ray on" indicator at the control console where x-rays are initiated indicating when x-rays are being produced.
b. Technique factors for each mode of operation shall be preset 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.**
c. Each access panel to the x-ray source shall have at least one safety interlock to terminate the x-ray production when opened.
d. The following warning label shall be permanently affixed or inscribed on the x-ray system at the location of any controls used to initiate x-ray generation: "CAUTION: X-RAYS PRODUCED WHEN ENERGIZED."
e. X-ray emission should automatically terminate after a preset time or exposure.

7.2.4 Requirements for General-use Systems Using Gamma Sources In addition to the requirements of Section 7.2.1, "Requirements for All Systems," the following requirements apply to general-use systems using gamma sources:

a. The gamma system shall use only sealed sources that meet the classification requirements of ANSI/HPS N43.6-2007, "Sealed Radioactive Sources – Classification."
b. A means shall be provided to physically lock shutters in the closed position when not in use.
c. Radiation emission shall automatically terminate after a preset time or exposure.
d. There shall be two independent shutters. Upon shutdown or loss of power both shutters shall move to the closed position. At least one shutter shall be capable of being manually operated.
e. For portal systems, motion sensors shall monitor the speed of pedestrians or vehicles through the inspection zone (in the forward direction). Radiation emission shall terminate when the speed drops below the minimum (as determined according to 7.2.1 k).

7.2.5 Requirements for Limited-use Systems Using Gamma Sources In addition to the requirements of Section 7.2.1, "Requirements for All Systems," the following requirements apply to limited-use systems using gamma sources:

a. The gamma system shall use only sealed sources that meet the classification requirements of ANSI /HPS N43.6-2007, “Sealed Radioactive Sources – Classification.”
b. A means shall be provided to physically lock shutters in the closed position when not in use.
c. Radiation emission should automatically terminate after a preset time or exposure.
d. There shall be two independent shutters, each having its own control. Upon shutdown or loss of power both shutters shall move to the closed position. At least one shutter shall be capable of being manually operated.

7.3 Labeling

Every manufacturer of a system to which this standard applies shall provide the following information: 1) the full name and address of the manufacturer of the system; 2) **the place and month and year** of manufacture; and 3) the model, serial number and any other information needed to identify the specific design and configuration of the system. This information shall be provided in the form of a tag or label permanently affixed or inscribed on the system so as to be legible and readily accessible to view when the system is fully assembled for use.

For gamma systems, the source and shielding assembly shall have a clear and visible radiation warning label(s) in accordance with the sealed source device registry (SSDR). The positioning of the label shall be visible from any point where service access might be gained.

7.4 Modifications

Any modification of a system that affects any aspect of the system’s performance for which this standard has an applicable requirement shall be construed as manufacturing under this standard. The manufacturer who performs such modification shall re-identify the system in accordance with the provisions of Section 7.3, “Labeling.” Additionally, notification of state and/or federal regulators may be required for modifications that are considered to be manufacturing.

7.5 Information to Be Provided to the End User

The manufacturer shall provide information to the end user sufficient to achieve and maintain compliance with this standard, allow the safe use of the system, fulfill regulatory requirements, and prevent intentional or frivolous misuse. This includes but is not necessarily limited to the following:

a. Category and class of the system according to Section 5.0 of this standard, “System Categories and Classes.”
b. Warnings of potential safety hazards (such as unauthorized modification of the system).
c. A statement that state and/or local registration or licensing may be required.
d. Operational procedures and training needed to use the system safely.
e. Preventive maintenance requirements for safe operation.
f. Other requirements and recommendations specified in this standard that are applicable to the end user.
g. For x-ray systems, the technique factors for each operating mode and the beam quality, stated as the HVL of the system in mm of aluminum, of the primary beam.
h. The reference effective dose per screening measured by the manufacturer. This information shall include a definition of “screening” for the system (e.g., number of scans required).
i. Identification of the area around the system where the ambient dose equivalent, H*(10), is greater than 20 µSv (2 mrem) in 1 hour of operation at the maximum throughput. (This is the minimum boundary of the inspection zone; see Section 6.2).
j. Identification of the area around the system where the ambient dose equivalent, H*(10), is greater than 0.5 µSv (50 µrem) in 1 hour of operation at the maximum throughput. (This is the recommended area of exclusion for

work stations occupied full-time, see Annex B Section B.2).

7.6 Records To Be Maintained by Manufacturers

Manufacturers shall establish and maintain the following records with respect to systems covered by this standard:

a. Quality control procedures related to the system's radiation safety.
b. Results of tests for radiation safety, including the control of unnecessary, secondary, or leakage radiation; the methods, devices, and procedures used in such tests; and the basis for selecting such methods, devices, and procedures.
c. For those systems displaying aging effects that may increase radiation emission, records of the results of tests for durability and stability of the system, and the basis for selecting these tests.
d. All written communications between the manufacturer and dealers, distributors, and purchasers concerning radiation safety including complaints, investigations, instructions, or explanations affecting the use, repair, adjustment, maintenance, or testing of the listed system.
e. Data on production and sales volume levels if available.
f. A record of the manufacturer's distribution of systems in a form that shall enable the tracing of specific systems or production lots to distributors or to dealers in those instances in which the manufacturer distributes directly to dealers.
g. The records outlined in Section 7.7, "Records To Be Obtained by Dealers and Distributors."
h. Any incidents involving unplanned exposures as reported by the users.

All records shall be maintained for a period of at least 5 years.

7.7 Records To Be Obtained by Dealers and Distributors

Dealers and distributors of systems covered by this standard shall obtain enough information as is necessary to identify and locate first purchasers. If a manufacturer also acts as a dealer or distributor, the manufacturer shall obtain this information. The information shall include the following:

a. The name and mailing address of the distributor, dealer, or purchaser to whom the system was transferred.
b. Identification and brand name of the system.
c. Model and serial numbers or other identification number of the system.
d. Date of sale, award, or lease.

The information obtained shall be forwarded promptly to the appropriate manufacturer of the system.

8.0 Operating Requirements

The requirements of this section apply to the operation of systems. These requirements are in conjunction with any other operating requirements necessary to meet the dose limits of Section 6.0, "Dose Limitation." The requirements for running a security screening operation in accordance with general radiation safety principles differ depending on the category of screening systems being used.

8.1 Operation of General-use Systems

This section includes a minimum set of requirements for a screening operation that involves only general-use systems.

8.1.1 Responsible Individual The institution operating the screening system shall designate a person(s) responsible for ensuring compliance with the requirements of this section and all applicable regulatory requirements.

8.1.2 Installation The manufacturer shall be responsible for providing adequate installation procedures to ensure compliance with this standard and the system's specification. The installer shall comply with the manufacturer's installation requirements. This does not exempt the manufacturer or installer from compliance with other applicable standards, codes, or regulations. A radiation survey of the system shall be performed by a qualified service provider

following installation. The purpose of the survey is to verify that the dose to the target and the maximum hourly dose around the installation are in compliance with all requirements of this standard and any other applicable federal, state, or local regulations.

8.1.3 Operating Procedures The operating institution shall document its procedures for operating the system. These procedures shall include all the topics listed in Section 7.5, "Information To Be Provided to the End User." These procedures shall be consistent with the manufacturer's operator's manual.

8.1.4 Information To Be Provided to Screened Individuals The institution operating the system shall inform each person being screened that the system emits radiation and that more information is available. Posters, signs, and handouts are examples of appropriate means to provide this information.

At a minimum, the institution operating the system shall make the following information available to screening subjects prior to scanning:

a. The estimated effective dose from one screening (i.e., the reference effective dose) is less than 0.25 µSv (25 µrem).
b. An example shall be provided to compare the dose to a commonly known source of radiation, for example: "The radiation from one screening is roughly equivalent to one hour of exposure to the average naturally occurring background radiation."
c. The screening complies with the ANSI/HPS consensus standard N43.17; if requested, information on how to acquire this standard shall be provided.

8.1.5 Personnel Training All operators shall receive appropriate training sufficient to operate the system in conformance with this standard. This training shall include:

a. Familiarity with the information being provided to the subject.
b. Radiation safety training, including:
    1. Types of radiation
    2. Sources and magnitude of common exposures
    3. Units of measurement
    4. Time, distance, and shielding
    5. Concept of ALARA
    6. Biological effects of radiation and radiation risks
    7. Operating and emergency procedures.
c. Other safety hazards (e.g., unauthorized disassembly of the system).
d. Physical security procedures to prevent unauthorized use or access.
e. Operator awareness and control of inspection zones.
f. How to use survey equipment/dosimetry if applicable.
g. Rights of declared pregnant workers.
h. Regulatory requirements
i. Supervised practical operations.

Proficiency shall be demonstrated at the conclusion of training. Refresher training shall be provided at least once every 12 months.

8.1.6 Preventive Maintenance The operating institution shall follow the manufacturer's recommended maintenance schedule. Preventive maintenance shall be performed by qualified personnel.

For gamma systems, a maintenance verification of the source integrity shall be performed on the system by a qualified service provider at least once per year.

See also Section 7.4, "Modifications."

8.1.7 Radiation Surveys Radiation surveys shall verify the reference effective dose, radiation leakage, inspection zone, and any other parameters specified by the manufacturer.

Surveys shall be performed:

a. Upon installation.
b. At least once every 12 months.
c. After any maintenance that affects the radiation shielding, shutter mechanism, or x-ray production components.
d. After any incident that may have damaged the system in such a way that unintended radiation emission occurs.

Refer to Annex C for information on radiation measurements and selection of instruments.

8.1.8 System Disposal For radionuclide systems disposal shall be performed in accordance with the requirements of the appropriate government entity (e.g., NRC regulations and license conditions).
Note: Although not a radiation safety issue, be aware that most x-ray systems contain hazardous materials and their disposal should be in accordance with applicable regulations.

8.1.9 Records and Documentation The institution operating the system shall collect and maintain the following records:

a. Each operator's training records including sufficient information to show compliance with Section 8.1.5. "Personnel Training."
b. Upgrades, modifications, maintenance, and repair records shall be maintained for the life of the system.
c. Records of radiation surveys as required in Section 8.1.7, "Radiation Surveys."
d. Evidence to show that the dose limits specified in Sections 6.1 through 6.2 are being met.
e. The number of scans conducted.

These records shall be maintained on-site at the facility a minimum of 5 years or more as noted above or as required by federal, state, or local regulations.

Additionally the following information shall be kept current:

a. The name and contact information for the responsible individual designated as required in Section 8.1.1, "Responsible Individual."
b. A complete set of operating procedures as required in Section 8.1.3, "Operating Procedures," shall be readily available to the operator of each system.

8.2 Operation of Limited-use Systems

The requirements of this section apply when the screening operation involves one or more limited-use systems, either independently or in conjunction with general-use systems. Institutions carrying out such operations shall document and implement a radiation safety program appropriate to the practice and products to be used.

8.2.1 Responsibilities

a. Senior Management shall —
   1. Make the ultimate decision to use security screening systems and be ultimately responsible for radiation safety.
   2. Designate an individual responsible for radiation safety. This individual shall have direct access to senior management for radiation safety issues. This individual shall have training and experience commensurate with the scope of the radiation safety program.

b. The individual responsible for radiation safety shall—
   1. Immediately terminate any unsafe activity involving personnel security screening systems.
   2. Ensure compliance with the requirements of this section and all applicable regulatory requirements.
   3. Formulate, implement, and exercise staff supervision over the radiation safety program.
   4. Formulate, implement, and supervise an active, documented program to keep ionizing radiation doses to levels that are ALARA.
   5. Advise and assist management and personnel in all matters regarding radiation safety.
   6. Review current and proposed uses of the system for compliance with applicable standards, regulatory requirements, and guidance.
   7. Ensure radiation safety considerations are incorporated into system operating procedures.
   8. Review and approve the location/relocation of security screening systems to ensure compliance with radiation safety criteria and manufacturer's recommendations/specifications.
   9. Ensure that radiation safety surveys are performed in compliance with this standard.

10. Maintain radiation safety records in accordance with Section 8.2.9, "Recordkeeping," of this standard.

8.2.2 Installation The manufacturer shall be responsible for providing adequate installation procedures to ensure compliance with this standard and the system's specification. The installer shall comply with the manufacturer's installation requirements. This does not exempt the manufacturer or installer from compliance with other applicable standards, codes, or regulations. **A radiation survey of the system shall be performed by a qualified service provider following installation. The purpose of the survey is to verify that the dose to the target and the dose rate around the installation are in compliance with all requirements of this standard and any other applicable federal, state, or local regulations.**

a. Security screening systems shall be installed in accordance with the manufacturer's installation instructions. Only properly trained individuals shall install security screening systems.
b. Security screening systems shall be installed in locations that are as far as reasonably possible from routinely occupied areas, subject to the operational requirements. Consideration shall also be given to the direction of the primary beam relative to occupied areas, traffic flow, and the number of scans per day, the reference effective dose, and locations of existing walls or structures that can provide shielding.
c. **During installation the inspection zone and any radiation areas for the system shall be determined, documented, and clearly delineated**.

8.2.3 Operating Procedures The operating institution shall document its procedures for operating the system. **These procedures shall include all the topics listed in Section 7.5, "Information to Be Provided to the End User,"** and all the administrative controls necessary to comply with the applicable section 6.1.2.2 or 6.1.2.3 of this standard. The procedures shall be consistent with the manufacturer's operator's manual.

In addition the following procedures shall be established:

a. Authorization for use – The procedures to ensure that the system is used only in an approved manner by authorized personnel. Appropriate methods to achieve this include key controls and user names with passwords.
b. System damage or malfunction – In the event of damage to the system or a system malfunction, procedures for removing the system from service until appropriate maintenance or repair personnel have corrected the problem.

8.2.4 Information To Be Provided to Screened Individuals The institution operating the system shall inform each person being screened that the system emits radiation and that more information is available. Posters, signs, and handouts are examples of appropriate means to provide this information.

At a minimum, the institution operating the system shall make the following information available to screening subjects prior to scanning:

a. The estimated effective dose from one screening (i.e., the reference effective dose).
b. An example shall be provided to compare the dose to a commonly known source of radiation, for example: "The radiation dose from one screening is roughly equivalent to that received from natural sources during a typical three-hour flight at 30,000 feet."
c. The screening complies with the ANSI/HPS consensus standard N43.17; if requested, information on how to acquire this standard shall be provided.

8.2.5 Personnel Training

a. Each operator shall be provided with training on the operation and use of the security screening system(s). At a minimum, this training shall include pre-operational checks, operation of the system, subject positioning, interpretation of images, procedures to be followed if the system is damaged or malfunctions, and practical operational experience. Periodic updates shall be

provided as the security screening systems or relevant threats change.

b. **Each individual associated with the operation of the security screening system shall be provided radiation safety training prior to performing security screening operations.** At a minimum, this training shall include the following:
   1. The types of radiation
   2. Sources and magnitudes of typical exposures
   3. Radiation units
   4. Concept of time, distance, and shielding
   5. Concept of ALARA
   6. Biological effects
   7. Radiation risk
   8. Basic risk communication concepts
   9. Training on the administrative controls associated with ensuring that dose to subjects is limited and on the importance of these administrative controls (i.e., much more emphasis on administrative controls for limited-use systems)
c. Other safety hazards (e.g., unauthorized disassembly of the system)
d. Physical security procedures to prevent unauthorized use or access
e. Operator awareness and control of inspection zones
f. How to use relevant radiation meters and personnel dosimetry if applicable
g. Rights of declared pregnant workers
h. Regulatory requirements
i. Supervised practical operations

Proficiency shall be demonstrated at the conclusion of training. Refresher training **shall** be provided at least once every 12 months.

8.2.6 Preventive Maintenance The operating institution shall follow the manufacturer's recommended maintenance schedule. Preventive maintenance shall be performed by qualified personnel.

For gamma systems, a maintenance verification of the source integrity shall be performed on the system by a qualified service provider at least once per year.

Contingency plans for the possibility of repairs outside of the recommended preventive maintenance schedule should be made when purchasing a system.

See also Section 7.4, “Modifications.”

8.2.7 Radiation Surveys Radiation surveys **shall** verify subject dose, radiation leakage, inspection zone, radiation area, and any other parameters specified by the manufacturer.

Surveys shall be performed:

a. Upon installation.
b. At least once every 12 months.
c. After any maintenance that affects the radiation shielding, shutter mechanism, or x-ray production components.
d. After any incident that may have damaged the system in such a way that unintended radiation emission occurs.

Refer to Annex C for information on radiation measurements and selection of instruments.

8.2.8 System Disposal For radionuclide systems, disposal shall be performed in accordance with the requirements of the appropriate government entity (e.g., NRC regulations and license conditions).

Note: Although not a radiation safety issue, be aware that most x-ray systems contain hazardous materials and their disposal should be in accordance with applicable regulations.

8.2.9 Records and Documentation

a. Maintenance Logs. Records of upgrades, modifications, maintenance, and repair shall be maintained for the life of the system.
b. Survey Records, including the following:
   1. System make, model, serial number, and location
   2. Surveyor
   3. Survey date
   4. Instrumentation make, model, serial number, and calibration dates
   5. Results of visual inspection of system safety features

6. Background measurements
7. Survey measurements
8. Survey diagram
9. System parameters at which measurements were made

c. Training Records. Records of training shall be maintained that contain the date of training, an outline of the training, and the names of those in attendance.

d. Use logs. For individuals who could receive radiation doses approaching 0.25 mSv (25 mrem) in any 12-month period, such as screened employees or frequent visitors, records shall be maintained to demonstrate that the administrative control of 0.25 mSv (25 mrem) is not exceeded. These records shall include the following:

1. The names and identifying information of individuals routinely screened
2. The reference effective dose per screening
3. The number of times and dates when each individual was screened
4. The cumulative reference effective dose for the number of screenings undergone by each individual over the past 12 months

e. The name and contact information for the responsible individual designated as required in Section 8.2.1, "Responsibilities."

f. A complete set of operating procedures as required in Section 8.1.3, "Operating Procedures," shall be readily available to the operator of each system.

These records shall be maintained on -site at the facility a minimum of 5 years or more as noted above or as required by federal, state, or local regulations.

9.0 References

Food and Drug Administration (FDA). Radiological health. 21 CFR 1000–1005. Washington, DC: U.S. Government Printing Office.

International Commission on Radiation Units and Measurements (ICRU). Conversion coefficients for use in radiological protection against external radiation. Bethesda, MD: ICRU; ICRU Report 57; 1998.

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ANNEX A (Informative)

Reference Effective Dose and Ambient Dose Equivalent Area Product (ADAP)

A.1 Reference Effective Dose

The dose limits to screened individuals in ANSI/HPS N43.17 are based on the "reference effective dose" defined in the standard. This section describes the motivation for the reference effective dose, its derivation, and comparison with the adult effective dose using the tissue weighting factors of the 2007 ICRP recommendations.

A.1.1 Rationale

The quantity "effective dose" was defined by the International Commission on Radiation Units and Measurements in its Report 57 (ICRU 1998) and is meant to provide a realistic indicator of radiation risk. The effective dose is a summation of the doses in tissues or organs each multiplied by the appropriate tissue weighting factor. The tissue weighting factors, which are based on the vulnerability of individual body organs to radiation, were modified by the International Commission on Radiological Protection in its Publication 103 (ICRP 2007). The potential effective dose from a security scan is not amenable to a direct measurement, but it can be estimated (for the average adult) if the exposure conditions are known. The dose limitation scheme of ANSI N43.17-2002 was based on the effective dose for a uniform, full-body, x-ray exposure incident from one direction (i.e., anterior–posterior, AP, projection). For that case, a chart of conversion coefficients was provided based on the kilovoltage and filtration of the x-ray machine. The N43.17-2002 limit of 0.1 µSv (10 µrem) was based on one scan from a backscatter system, taking into account that multiple scans would be necessary for viewing all sides of the body.

When considering other exposure geometries and transmission systems that require only one scan per screening, the N43.17-2002 method of estimating effective dose is no longer feasible. An accurate estimation of effective dose for all circumstances is much more complicated and is not practical for the purpose of this standard. However, it was desired to preserve a system of dose limitation that would not penalize systems using lower-energy x-rays. These systems generally deliver a lower effective dose per scan whereas the measured air kerma or entrance skin dose may be higher than with systems operating at higher energy. This is illustrated by the examples shown in Table A1 based on the AP projection and a beam air kerma of 10 µGy (1 mrem).

Table A1. Comparison of effective dose and ambient dose equivalent for two x-ray spectra, each yielding 10 µGy air kerma.

X-ray tube potential (kV)	Filtration (mm of Al)	Air kerma (µGy)	Ambient dose equivalent, H*(10), (µSv)	Effective dose (µSv)
50	1	10	8.2	2.4
120	6	10	15.5	9.1

The “reference effective dose” of the present standard was conceived for the purpose of preserving an equitable system of dose limitation based on a measurable effective dose-like quantity.

A.1.2 Derivation

The conversion coefficients from air kerma (exposure) to effective dose were calculated for a number of x-ray beam spectra. The beams included many NIST and ISO standard beams and known beams from existing personnel scanners. Beams with little total filtration were also included to provide worst-case information. The PCXMC Monte Carlo computer code (Servomaa 1998) was used to calculate the adult effective dose based on the kilovoltage, filtration, and tungsten anode angle. The effective dose, based on the ICRU Report 57 (ICRU 1998) tissue weighting factors, was calculated for anterior–posterior (AP), posterior–anterior (PA), left lateral (LLAT), and right lateral (RLAT) projections. A large source-to-skin distance was used in order to approximate a uniform beam intensity incident from each of the four directions. For x-ray beams without measured HVL values the HVL was calculated using IPEM Report 78 (IPEM 1997). To verify the accuracy of the Monte Carlo program the effective dose for some of the spectra was also calculated by interpolating the conversion coefficients published in ICRU Report 57 and integrating over the energy spectrum, yielding similar results. The conversion coefficients were plotted as a function of the HVL and are shown in Figs. A1–A4. The ICRU conversion coefficients for monoenergetic photons were also included in the plots. For each projection, it was found that the effective dose for monoenergetic photons and for all the spectra having at least 1 mm AL total filtration follows a relatively close-grouped pattern as a function of HVL.

The ICRU Report 57 conversion coefficients for monoenergetic photons are shown in Fig. A5. For defining the reference effective dose, the average conversion coefficients of four projections (AP, PA, RLAT, and LLAT) and two projections (AP and PA) were considered. The averages are useful for considering multiple scans from backscatter systems. The four-scan average coincides approximately with the ICRU rotational conversion coefficients and is useful for considering uncertain geometries, such as portals with multiple sources. The AP–PA combination was deemed the most appropriate for approximating average effective doses from most personnel security screening applications at the time of publication of this standard. It averages the two most common projections for backscatter systems and also effectively averages transmission systems that may be used in either the AP or PA mode.

The conversion of air kerma or exposure to reference effective dose is taken to be a straight line until it reaches a maximum of 1.14 Sv/Gy or 1 rem/R. The line, shown in Fig. A4, closely approximates the AP-PA-average conversion coefficients as a function of HVL in the HVL region below 9 mm Al.

A.1.3 Revised Tissue Weighting Factors

ICRP, in its Report 103, recently published new tissue weighting factors (ICRP 2007). For many of the spectra considered, the PCXMC-calculated organ doses were weighted according to the ICRP 103 factors to calculate the new effective dose. Because some organs specified in ICRP 103 were not included in the PCXMC output, the absorbed doses to these organs were approximated as follows:

1. The dose to the salivary glands was approximated using the average of the esophagus and thyroid doses.

2. The prostate dose was approximated using the urinary bladder dose.
3. The dose to the oral mucosa was approximated using the average of the esophagus and thyroid doses.
4. The dose to the extrathoracic region was approximated using the average of the esophagus and thyroid doses.
5. The dose to the lymph nodes was approximated using the muscle dose.

These approximations are based on general anatomy and information from ICRP Publication 89 (ICRP 2003). The contribution of each of these newly weighted tissues is extremely small for external x-rays.

The results were again plotted as a function of HVL and are shown in Fig. A6 in relation to the reference effective dose as described above.

The differences in effective dose using the old and new tissue-weighting factors were found to be relatively small; the old weighting factors generally yielded higher effective doses. Fig. A5 shows that when AP and PA scans contribute equally to the exposure the reference effective dose is a reasonable approximation of the effective dose calculated according to ICRP 103.

A.1.4 Conclusion

The reference effective dose defined in this standard is a reasonable approximation of effective dose for the wide range of energy spectra used in security screening systems. In the United States the National Institute of Standards and Technology provides traceability of instruments to the primary air kerma standards. The reference effective dose can be readily calculated from measurements of air kerma (or exposure) and HVL, which is also based on air kerma. The reference effective dose is a more equitable dose indicator for personnel security screening than any of the operational quantities defined by the ICRU. The reference effective dose accurately approximates the adult effective dose for typical front and back x-ray exposures and reasonably approximates effective dose for all other exposure conditions.

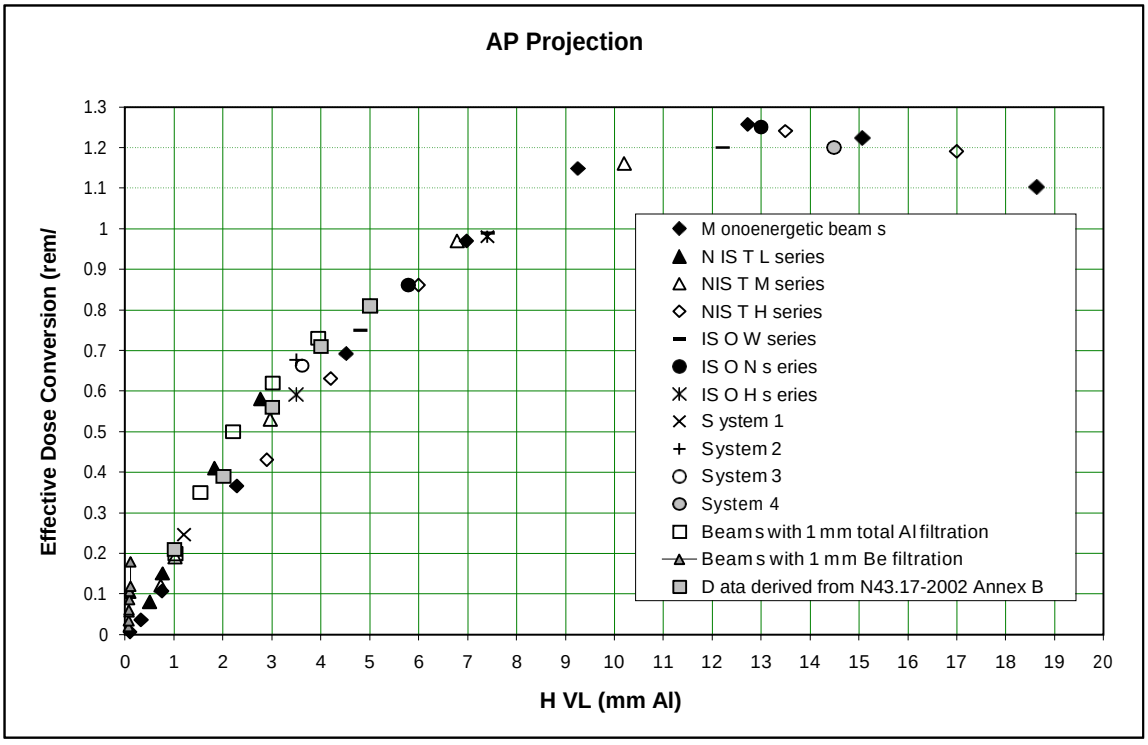

Fig. A1. Conversion coefficients from exposure to the ICRU 57 effective dose as a function of half-value layer for various x-ray spectra. This chart applies to the anterior-posterior (AP) projection.

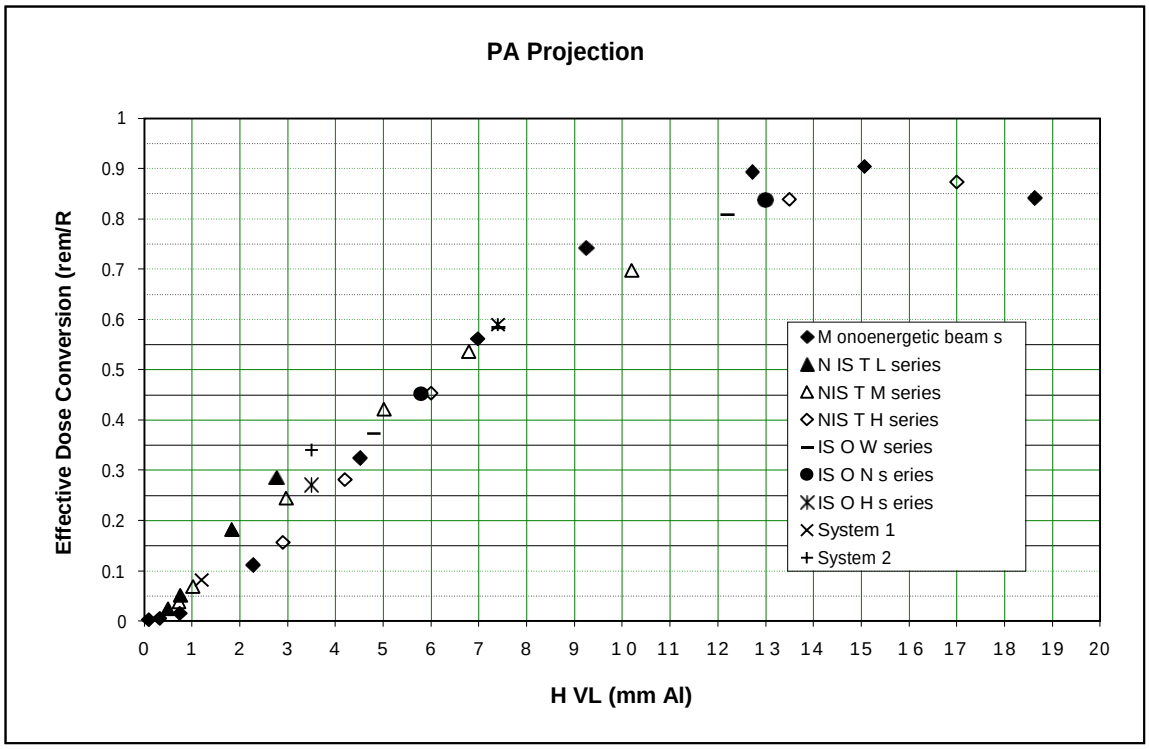

Fig. A2. Conversion coefficients from exposure to the ICRU 57 effective dose as a function of half-value layer for various x-ray spectra. This chart applies to the posterior-anterior (PA) projection.

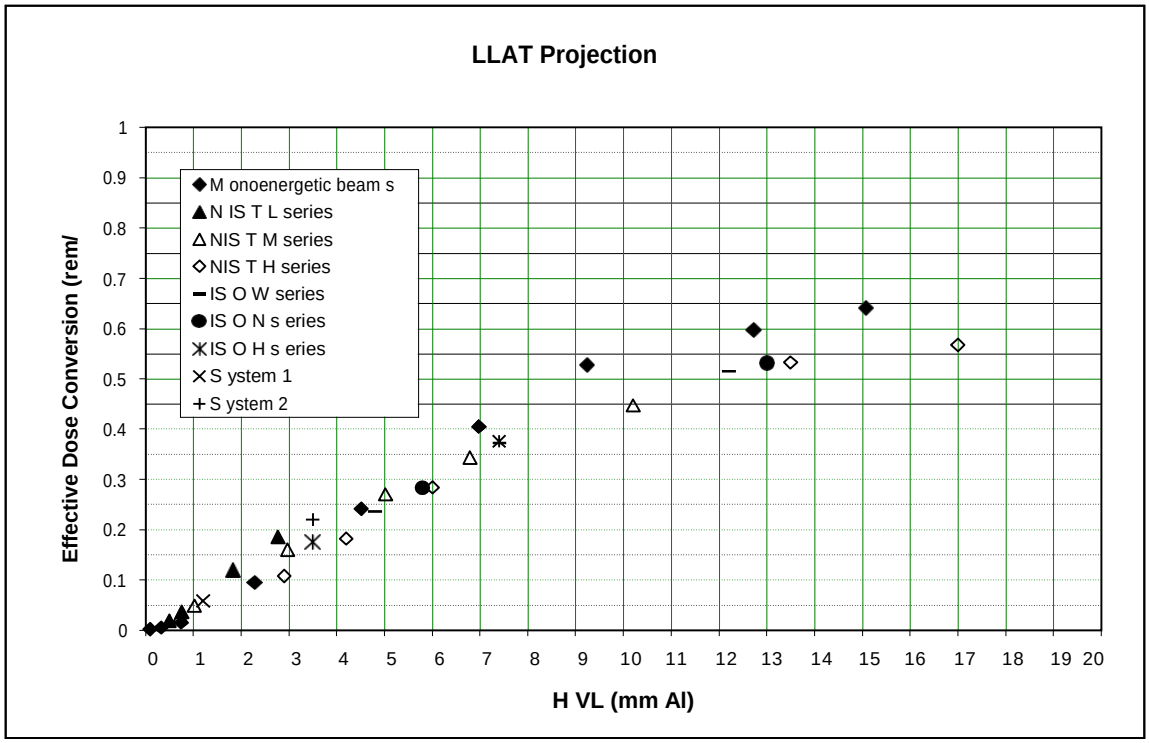

Fig. A3. Conversion coefficients from exposure to the ICRU 57 effective dose as a function of half-value layer for various x-ray spectra. This chart applies to the left lateral (LLAT) projection.

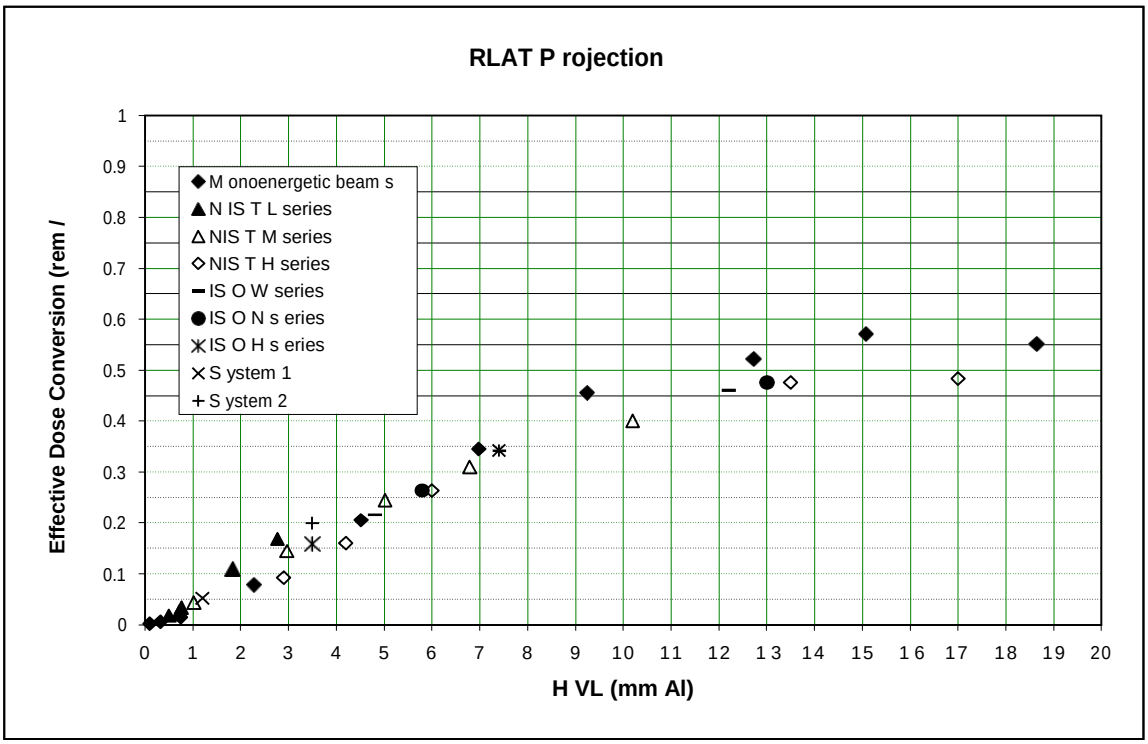

Fig. A4. Conversion coefficients from exposure to effective dose as a function of half-value layer for various x-ray spectra. This chart applies to the right lateral (RLAT) projection.

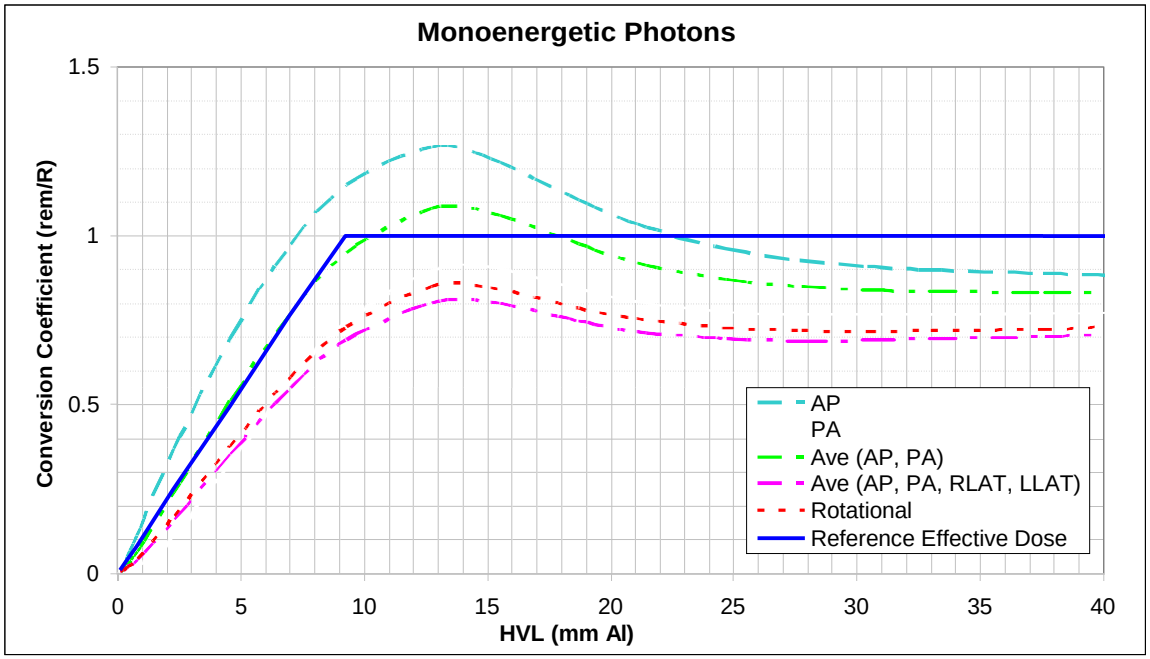

Fig. A5. Conversion coefficients from exposure to the ICRU 57 effective dose for monoenergetic photons incident from various directions. The reference effective dose, shown as the straight lines, was derived from the average of AP and PA projections.

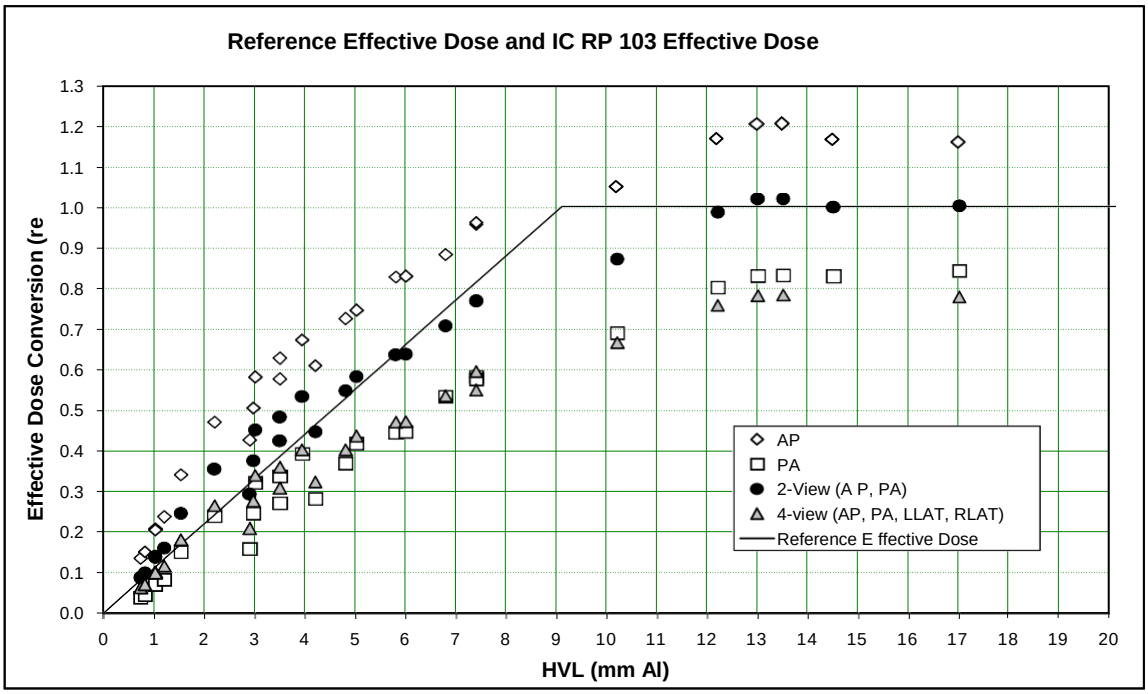

Fig. A6. Conversion coefficients from exposure to effective dose using the ICRP 103 tissue weighting factors. The reference effective dose is shown for comparison. For each combination of projections a wide range of very narrow to very wide x-ray spectra are represented.

A.2 Ambient Dose Equivalent Area Product (ADAP)

The dose limits in ANSI/HPS N43.17 that apply to partial-body scanners are based on the "ambient dose equivalent area product" (ADAP) defined in the standard. This section describes the derivation of the ADAP.

For partial-body scanners, such as screening systems for casts and prostheses, it was desired to prescribe dose limits that would result in effective doses not exceeding the limits of the full-body scanners. That is, for general-use systems the effective dose to a subject being screened should not exceed 0.25 µSv per screening or about 0.1 µSv per scan (25 µrem and 10 µrem, respectively). To determine potential effective doses the case of an existing cast scanner was studied extensively. Several hypothetical cases using higher-energy x-rays and different field sizes were also considered.

The scanner that was studied consisted of a 50 kV x-ray generator with about 1 mm total Al-equivalent filtration and a field of view of 15 × 25 cm (6 × 10 inches). Effective doses were calculated for several projections and body sizes using the PCXMC Monte Carlo program. Projections of the limbs produced very low effective doses. The effective doses for leg projections were well under 0.001 µSv (0.1 µrem) for the average adult. The PCXMC code did not allow for separation of the arms from the body and the effective dose from arm projections was up to about 0.02 µSv (2 µrem). Simulation of projections involving the chest, neck, and the lower abdomen produced much higher effective doses. Worst-case results for these projections are shown in Table A2.

Table A2. Worst-case effective doses obtained using Monte Carlo simulations for the studied cast scanner with a 15 × 25 cm field of view.

Age (height, weight)	AP projection	Effective dose per unit skin entrance exposure (μrem/μR)	Effective dose (μrem)
5 y.o. child h = 139 cm w = 19 kg	Chest & neck	0.130	9.96
	Abdomen	0.176	13.5
10 y.o. child h = 109 cm w = 32 kg	Chest & neck	0.090	6.92
	Abdomen	0.144	11.1
adult h = 174 cm w = 71 kg	Lower abdomen	0.077	5.94
	Uterus absorbed dose (lower abdomen projection)	0.092	7.05

A dose-area product quantity was judged to be the most appropriate for setting limits for this type of scanner. Based on ICRP recommendations, the ambient dose equivalent at 10 mm depth, H*(10), was chosen as the dose quantity. So, the ADAP was defined as the product of ambient dose equivalent and scan area. The ADAP for the studied cast scanner was measured at about 0.025 μSv m^2 (2.5 μrem m^2). Based on the original premise that the effective dose should not exceed 0.1 μSv (10 μrem) per scan and the results of Table A2, it was clear that the dose limit for general-use partial-body scanners should be near the dose delivered by the studied scanner. Thus, the ADAP general-use limit was set at 0.03 μSv m^2 (3 μrem m^2). The ADAP limit for limited-use systems was set at 3 μSv m^2 (300 μrem m^2) based on a maximum effective dose of 10 μSv (1 mrem) per scan.

For the case of the studied cast scanner, the worst-case effective dose to an adult from one scan is about 0.06 μSv (6 μrem). The annual goal of 250 μSv (25 mrem) effective dose can be met if the number of scans to any one individual does not exceed 4,167. Since the ADAP is about 0.025 μSv m^2 (2.5 μrem m^2), a formula of (100 μSv m^2)/ADAP [(10,000 μrem m^2)/ADAP] for the maximum number of scans would ensure compliance with the annual limit. For the studied scanner this is a conservative formula because the average effective dose is likely to be much less than 6 μrem per scan. However, the relationship between ADAP and effective dose is non-linear. Also, the effective dose per unit ambient dose equivalent is higher at x-ray spectra of higher effective energy. Therefore the annual limit on scans was set at (75 μSv m^2)/ADAP [(7,500 μrem m^2)/ADAP].

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ANNEX B (Informative)
Radiation Dose Discussion

This annex contains information on the risks associated with radiation doses and the rationale for the dose requirements of the standard.

B.1 Radiation Risk and Rationale for Subject Dose Limits

Various organizations have studied the biological effects of ionizing radiation exposure. The National Council on Radiation Protection and Measurements (NCRP) reviewed two independent studies, one by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 1988) and the other by the National Academy of Sciences/National Research Council, Committee on the Biological Effects of Ionizing Radiation, known as BEIR V (NAS/NRC 1990). Based on this review, the NCRP recommends that, for radiation protection purposes, an incremental lifetime risk of fatal cancer of 5% per sievert be used for the general population (NCRP 1993). The 5% per sievert risk is also consistent with the more recent BEIR VII report (NAS/NRC 2006). Application of this risk estimate means that each 0.01 µSv (1 µrem) of effective dose received is considered to contribute 5×10^{-10} (one chance in two billion) to an individual's risk of contracting a fatal cancer during his or her lifetime. These low-dose estimates assume a "linear no-threshold" relationship between radiation exposure and health effects.

Both the NCRP and the International Commission on Radiological Protection (ICRP) recommend that members of the general population who are frequently exposed to ionizing radiation not exceed an annual effective dose of 1 mSv (100 mrem) from all man-made, non-medical sources (NCRP 1993; ICRP 2007). Further, the NCRP recommends that institutions ensure that the individuals they expose do not repeatedly exceed the 1 mSv yearly limit from all non-medical sources. Information relating to other sources of radiation exposure may be difficult to obtain, so institutions have the option to ensure that the radiation sources under their own control do not contribute to an individual more than an annual effective dose of 0.25 mSv (25 mrem).

General-use systems operating in accordance with this standard produce a maximum reference effective dose of 0.25 µSv (25 µrem) per screening. Therefore, an individual may be screened up to 1,000 times each year without exceeding the annual 0.25 mSv (25 mrem) limit. The associated incremental risk of death is 1 in 80,000,000 per screening. To put this in perspective, this same risk of death results from about 2.5 minutes of riding in an automobile. Likewise, this same risk of death is experienced about each 25 minutes of working in a "safe" field such as a secretary or office administrator, due to occupational deaths from accidents, homicides, and other causes. (The automobile death rate is calculated from: 250 million people in the United States, each driving an average of 10,000 miles per year, at an average speed of 30 mph, resulting in 25,000 traffic deaths per year. The occupational death rate is based on 5 deaths per 100,000 employees per year, a typical value for "safe" occupations).

B.2 Dose to Operators and Other Employees

Compliance with the Occupational Safety & Health Administration's standards for radiation safety is mandatory in the United States (OSHA). It is recommended that the manufacturers of systems covered by the present standard provide a system that, when installed and operated as designed, ensures that the operator dose not exceed an annual ambient dose equivalent of 1 mSv (100 mrem). This ensures compliance with the NCRP recommended annual dose limit for the general public. Personnel dosimeters are not typically required at these dose levels. The 1 mSv annual limit is achieved by positioning all work stations outside of the primary beam up to a minimum distance or by shielding the primary beam. The minimum combination of distance and shielding is determined based on the maximum throughput of the system and the occupancy factor at the work station. That is, through a combination of distance and shielding, the ambient dose equivalent at any work station should not exceed

$$H^*(10)_{scan} = 1{,}000\ \mu Sv/(N_{max} \times 2{,}000 \times OF)$$

where
$H^*(10)_{scan}$ is the maximum ambient dose equivalent per scan,
N_{max} is the number of scans that the system can deliver in 1 hour, and
OF is the occupancy factor of the maximally exposed worker at the work station as a fraction of full time (full time is 2,000 hours/year).

For example, if the system can produce 180 scans per hour, the primary beam is not shielded, and an employee spends one half of the work day at the work station, then the maximum ambient dose equivalent for a single scan is 1,000/(180 × 2,000 × 0.5), or 0.0056 µSv (0.56 µrem). Therefore, in this example, the distance at which an ambient dose equivalent of 0.56 µrem is measured is the minimum distance from the scanner to that work station.

Manufacturers should specify the distance at which the maximum hourly dose, H*(10), is 0.5 µSv (50 µrem). This is the minimum distance for a full-time work station. The user of the system should ensure that the system is operated in accordance with the manufacturer's instructions.

B.3 Dose to Special Groups

Various subgroups of the general population may be more susceptible to radiation-induced health effects. This includes pregnant and potentially pregnant women, children, infants, persons receiving radiation treatment for medical conditions, and others. For occupationally exposed individuals the NCRP recommends lower dose limits to these special groups. For example, the NCRP recommends a maximum occupational dose of 0.5 mSv/month (50 mrem/month) to the embryo or fetus. This means that a pregnant worker should receive a lower dose than the occupational limit of 50 mSv/year (5 rem/year). For the general population NCRP does not recommend different limits for special groups.

B.4 Dose Minimization and Negligible Individual Dose

Under recommendations of the National Council on Radiation Protection and Measurements (NCRP 1993) occupationally exposed individuals can receive up to 0.05 Sv (5 rem) effective dose per year. Likewise, NCRP recommends that members of the general public (including special groups such as pregnant women and children) receive less than 1 mSv (0.1 rem) effective dose per year. Both these levels are subject to the radiation safety principle of ALARA. That is, even though these radiation exposures may be acceptable, they shall be kept As Low As Reasonably Achievable, while taking into account the benefit derived from the exposure. As an exposure is made smaller, the risk from the exposure is also reduced. When the exposure is reduced beyond a certain point it becomes indistinguishable from variations in the natural background radiation. The NCRP defines a category for extremely low radiation exposures called the Negligible Individual Dose (NID) and sets its value at 10 µSv (1 mrem) per year. At radiation exposures below the NID, efforts to reduce the dose further are not warranted.

These recommendations can be applied to the 0.25 µSv (25 µrem) maximum dose per screening allowed for general-use systems operating under this standard. By direct calculation, an individual screened less than 40 times per year would receive a radiation exposure within the NID. Likewise, an individual screened up to 4,000 times per year would still be within the recommended dose limit for members of the general public (assuming the individual did not receive radiation exposure from other non-medical, man-made sources). However, the use of radiation exposure in personnel security screening is a unique application. Accordingly, the following interpretation of the principles of ALARA and NID in this specific context is recommended.

Systems operating under this standard should only be used in the legitimate search for concealed weapons and contraband, along with related activities such as training and service. Use of these systems for unnecessary or frivolous activities is contrary to the recommendations of this standard and the intended use of the applicable systems. Consistent with the principles of ALARA and NID, the number of examinations an individual receives per year can be divided into two general categories. In applications where the subject is likely to receive less than 10 µSv (1,000 µrem) per year, procedures for conducting scans can generally be based on the necessity of the scan, without explicit consideration of the radiation dose involved. That is, when subjects are examined less than about 40 times per year at the maximum emission for general-use systems, the primary

concern is that the system not be used for any obviously unneeded or frivolous activity. In applications where significantly more frequent examinations are conducted, reasonable efforts should be made to reduce the number of scans, taking into account the nature of the application. This does not mean that 10 µSv (1,000 µrem) per year is a safety limit or a sharp division between two regulatory categories. Rather, it is meant to provide users of the system a general guideline regarding when efforts should be expended to reduce the number of examinations taking place.

B.5 References for Annex B

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ANNEX C (Informative)
Radiation Measurements

This annex contains information necessary for making accurate measurements of the radiation output of personnel security screening systems. The discussion of this annex pertains only to measurements of x and gamma radiation that are relevant to this standard and is not intended to be a comprehensive treatment of radiation dosimetry.

C.1 Quantities and Units

There are many quantities and corresponding units of measurement for ionizing radiation. These are defined in the International Commission on Radiation Units and Measurements' Report 57 (ICRU 1998). The number and complexity of these quantities stem from the complex way radiation interacts with matter. For radiation protection purposes we are interested in the damage that radiation can cause to the cells of the human body. The severity of the damage depends on the type, energy, and intensity of the radiation and on the sensitivity of the tissue irradiated. Machine-produced x-rays are usually composed of a wide energy spectrum and the body, in turn, is composed of a wide range of tissues. In order to measure the radiation dose it is necessary to consider the relationship between the interactions of the radiation with the various detector materials and the interactions of the radiation with human tissues.

For the purpose of this discussion we will concentrate on the quantities used in this standard: air kerma, ambient dose equivalent, and effective dose. Air kerma (and exposure) was chosen because it can be measured accurately and can be related to the other dose quantities. Ambient dose equivalent was chosen because it is the recommended quantity for describing the potential dose that can be received at a location. Effective dose is only used in the standard in that it is approximated by the reference effective dose. Effective dose is deemed to be proportional to the risk of harmful effects of radiation on a human body, taking into account the exact exposure conditions and human physiology.

In general, dose denotes energy imparted (per unit mass) by the radiation on a material. Different materials absorb different amounts of energy and the proportion of energy absorbed varies with depth in the material. The ambient dose equivalent is the dose calculated at a point in a water phantom (consisting of a sphere of water 30 cm in diameter) multiplied by a quality factor that depends on the radiation type (i.e., alpha, beta, gamma and x rays, or neutrons). Ambient dose equivalent assumes a uniform radiation field and is denoted by H*(d), where d is the depth in the sphere at which the dose is calculated (d = 0.7 mm is customary for estimating shallow skin dose; d = 10 mm is customary to estimate deep dose). Effective dose is a summation of the doses to all the body organs, each multiplied by a tissue weighting factor and the radiation quality factor. The tissue weighting factor depends on each organ's vulnerability to radiation. The SI unit of ambient dose equivalent and ef fective dose is the sievert, abbreviated Sv. The old unit was the rem (1 Sv = 100 rem). One sievert represents the equivalent of one joule of photon energy being deposited in a kilogram of tissue.

The term *kerma* refers to the sum of the initial kinetic energy of all ionizing particles liberated (per unit mass) in a material. Air kerma (related to the energy deposited in a unit mass of air) is useful because air is an important detection material and instrument calibrations are often in terms of this quantity. Therefore, air kerma can be readily measured. The measurement can serve as a basis for calculating the other dose quantities. The SI unit for air kerma is the joule per kilogram or gray, abbreviated Gy. The old unit was the rad (1 Gy = 100 rad). In the old system of units the relevant unit was the roentgen (R), a unit of exposure (an air kerma of 1 Gy corresponds to an exposure of 114 R). The conversion from air kerma to ambient dose equivalent is shown Fig. C1. Conversions from air kerma to effective dose are discussed in Annex B and in Section C5 below. The conversion from air kerma to the reference effective dose is given by equations (1) and (1a) in Section 6.1.3 of the standard.

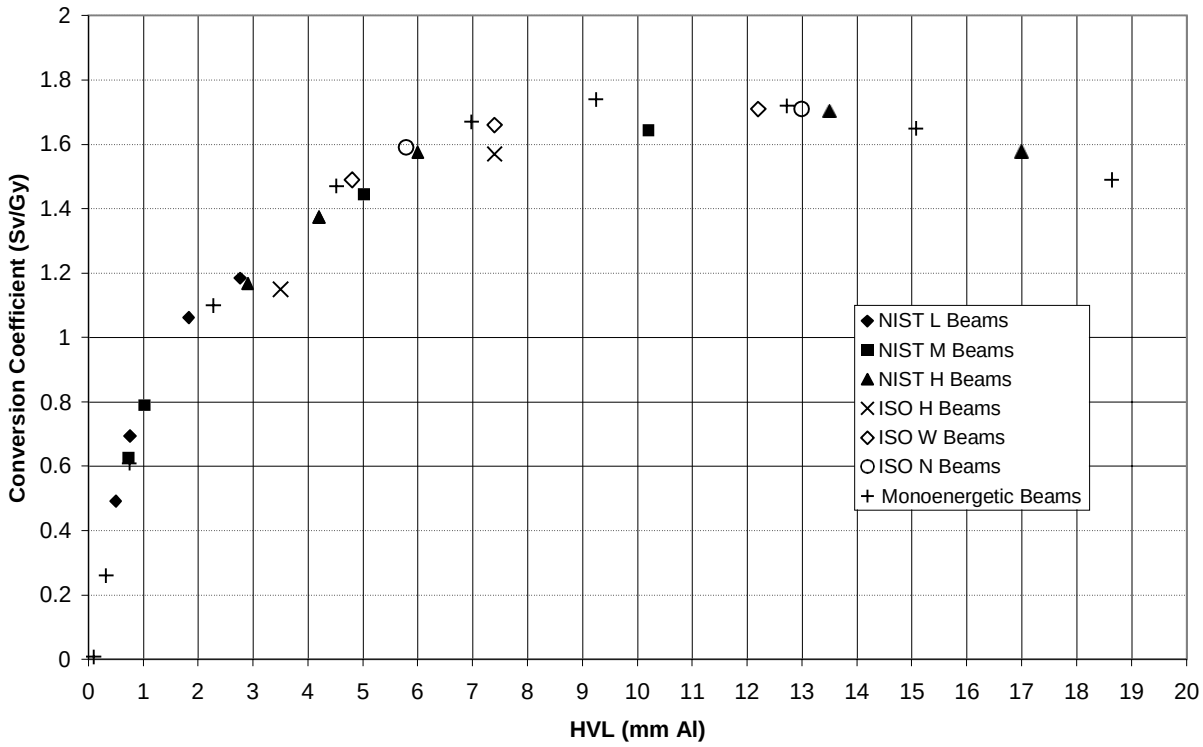

Fig. C1. The conversion coefficients from air kerma to H*(10) as a function of HVL. The data for NIST x-ray beams is from Soares (1995). The data for ISO x -ray beams is from ISO (1999). The data for monoenergetic photons is from ICRU (1998). To convert from exposure in roentgens (R) to ambient dose equivalent in rems, multiply the conversion coefficient from the chart by 0.88.

C.2 Types of Radiation Detectors

C.2.1 Ionization Chamber

The ionization chamber is a type of radiation probe consisting of a volume of air (or other gas) between two electrodes. A voltage is applied to the electrodes. When the chamber is irradiated, electrically charged ions are created in the air volume and collected on the oppositely charged electrode. The number of ions created is proportional to the energy deposited in the air volume. An electrometer is used to measure the charge or electrical current. The amount of charge produced per unit mass of air is a measure of exposure, which is proportional to air kerma. The exposure and air kerma rates are given by measurement of the electrical current (charge produced per unit time). If the air volume is not sealed, the mass of air in the volume changes with temperature and pressure. Therefore, appropriate gas law corrections should be made. The ionization chamber is the detector most often used when high quality measurements of air kerma or exposure are desired.

C.2.2 Geiger Counter

The Geiger counter consists of a Geiger-Mueller (GM) tube and a pulse counting circuit. The GM tube is similar to an ionization chamber except that it is filled with a special gas and operates at higher voltage. The electrodes are usually in the form of a cylinder and a concentric thin wire. Because of this geometry and the small thickness of the wire, the electric field near the inner electrode is extremely high. When radiation interacts with the gas it ionizes the gas, producing electron-ion pairs. The resulting free electrons are accelerated by the electric field and go on to produce other electron-ion pairs, which in turn produce more ionization. This avalanche effect results in a fairly large electrical pulse that can easily be detected and counted by the circuitry. This makes the Geiger counter

extremely sensitive to radiation. However, the pulses counted are a measure of "events" rather than actual energy deposited. Unless the instrument is calibrated in a radiation field having an energy spectrum identical to the field measured, it is difficult to estimate dose from a Geiger counter reading. Geiger counters are useful for locating a source of radiation and giving a general idea of its strength. It is rarely appropriate for quantifying pulsed radiation fields.

C.2.3 Scintillation Detector

Scintillation detectors consist of a scintillator material, a photomultiplier tube (or solid-state light detector), and associated electronics. When the scintillator is exposed to ionizing radiation, a portion of the energy absorbed is immediately released in the form of visible light. The light is directed to the photomultiplier tube, which converts it to an amplified electrical signal. Like the GM tube, the scintillation detector can be very sensitive. It has the advantage, however, that the signal is proportional to the energy absorbed in the crystal. If the electrical circuit measures the current or charge produced (rather than counting the number of electrical pulses produced), the resulting measurement is an indication of dose. Although this is a very good way to measure the dose delivered to the scintillator, it is not always indicative of the dose that would be delivered to human tissue. Some scintillator materials, called tissue-equivalent, mimic the radiation response of muscle tissue for a certain energy range.

C.2.4 Semiconductor Detector

Semiconductor or solid-state detectors consist of a semiconductor diode. A diode is a junction of p-type and n-type semiconductor material, such as silicon. Through the addition of impurities, the n-type material contains an excess of free electrons whereas the p-type material contains an excess of "holes" or electron vacancies. When a bias voltage is applied across the junction so that the p side is positive with respect to the n side the diode acts as a conductor, allowing an electric current to flow. When the bias is such that the p side is negative with respect to the n side the diode acts as an insulator, turning off the current flow. The latter condition is called reverse bias. When a reverse bias is applied to the diode, a depleted region forms at the p-n junction where all the holes and free electrons are swept away by the bias potential. In the presence of ionizing radiation this depleted region acts like an ion chamber, only it is much more sensitive. The electric pulse created by an ionizing event is proportional to the energy of the ionizing photon or particle. Germanium semiconductor detectors have a very high energy resolution and fast charge-collecting time, which makes them very useful for spectrometry applications. One drawback is that they need to be cooled to cryogenic temperatures in order to keep electronic noise down. Room-temperature semiconductor detectors made of silicon, cadmium telluride, mercuric iodide, or cadmium-zinc-telluride can be used for dose and dose rate measurements. The advantages are generally high sensitivity, small size, and fast response. The main disadvantage is a very high energy dependence.

C.3 Air Kerma Measurements for Compliance with ANSI/HPS N43.17

C.3.1 Instrument Selection

For checking compliance with the dose limits for full-body scanners an instrument is needed that is capable of making accurate measurements of air kerma (or exposure) for the types of irradiation conditions encountered in personnel screening. This instrument is used to make determinations of the reference effective dose by measuring the air kerma per scan and the HVL of the primary beam (see Section 6.1.3 of the standard).

Partial-body scanners require measurements of ambient dose equivalent for the ADAP determination. For this purpose, an air kerma measurement may be used along with a conversion based on Fig. C1 or the instrument and probe may be calibrated directly in terms of H*(10). For traceability to the National Institute of Standards and Technology, a calibration in terms of air kerma is preferred. Calculation of the ADAP also requires knowledge of the scan area size. The edge of the scan area may be determined using a small GM detector, semiconductor detector, x-ray film or by using techniques based on scanned images.

The verification of shielding also requires H*(10) measurements and the above discussion regarding the instrument calibration applies. For this purpose, a second instrument for localizing

the “hot spots” is also useful. A count rate meter employing a probe “wand” consisting of an array of GM tubes is a suitable localization instrument. The instrument should indicate the responses of the GM tubes separately so that localization of the highest exposure is possible. At least two such instruments are commercially available for surveying cabinet x-ray systems. After the “hot spots” are found, follow-up measurements using the calibrated meter should be made at those locations.

The rest of this discussion pertains to accurate measurements of air kerma. The most appropriate instrument for air kerma measurements should include an ionization chamber as the detector. The instrument should have 1) an integrating mode, 2) high sensitivity, and 3) low energy dependence. The integrating mode is necessary in order to measure the total accumulated electrical charge during the course of one or more complete scans. This yields a measurement of the air kerma (or exposure) “seen” by the side of the body facing the source of radiation. An instrument having only a rate mode (i.e., measuring in grays per second or roentgens per second) is not useful for measurements involving a scanning beam. In order to obtain an accurate reading, the entire volume of the ionization chamber should receive the same amount of radiation exposure during the course of the scan.

Instrument sensitivity and resolution are extremely important. The level of air kerma to be measured is typically only slightly higher than background radiation. The electrical signal produced is so small that it requires a very stable electrical circuit with a minimum of electronic noise in order to be measured accurately. The ionization chamber should be large enough so that enough electrical charge may be produced for the electrometer to make an accurate measurement. Even with a large-volume ion chamber, the electrometer itself should be very sensitive. Automatic background subtraction is not recommended. If the instrument used performs automatic background subtraction, the process should be understood and care should be taken that all of the “real” signal is measured, taking into account the time-dependent ionization rate and the sequence and duration of scanning of the ionization chamber volume.

The energy dependence is also very important. The x-ray fields in question are composed in large part of photons of relatively low energies. The air volume in the ionization chamber is enclosed by the chamber wall. The wall preferentially attenuates the lower-energy photons, so a thin wall is preferable. However, for a large chamber, because of structural integrity the wall cannot be made very thin. Some ionization chambers are pressurized in order to maximize the air mass and therefore the sensitivity. This requires a thicker wall to hold the pressure, and the pressurized air itself also attenuates the radiation. All these factors point to the fact that there will be energy dependence, particularly when measuring x-ray systems operating at low kilovoltage. The effects may be minimized by choosing the best ion chamber-electrometer system for the energy range in question and by proper calibration. A large (at least 1,500 cc), nonpressurized ion chamber is recommended. A good-quality electrometer with at least a 0.1 picocoulomb (pC) resolution, capable of measuring a pulse of charge of 5 pC magnitude and 10 ms duration within $\pm$ 10% accuracy, is also recommended (this is approximately the charge produced in 1,500 cc of air by 10 μR).

C.3.2 Calibration

The instrument and ion chamber should be calibrated in a beam that approximates the x-ray spectrum of the security scanner being tested. The calibration should be traceable to one of the National Institute of Standards and Technology’s (NIST) standard beams. The standard beams shown in Table C1 are some of the most appropriate for this type of calibration.

Table C1. NIST calibration beams.

Beam code	Tube kilovoltage (kV)	HVL (mm Al)	Filtration (mm/material)
M30	30	0.36	0.5/Al
M40	40	0.73	0.89/Al
M50	50	1.02	1.07/Al
M60	60	1.68	1.56/Al
M80	80	2.97	2.61/Al
M100	100	5.02	5.0/Al
M120	100	6.79	6.87/Al
M150	150	10.2	5/Al + 0.25/Cu
M200	200	14.9	4.1/Al + 1.12/Cu
M250	250	18.5	5.25/Al + 3.2/Cu
L80	80	1.83	1.45
L100	100	2.77	1.98
Radioisotopes		Effective energy (keV)	
^{137}Cs		662	
^{60}Co		1,250	

The beam having the closest kilovoltage (kV) and filtration to those of the security system should be chosen. If the half-value layer (HVL) is known, this should be used to pick the calibration beam, because it is a good indicator of effective energy. If the values of HVL, kV, and filtration desired are not available in calibration beams, then the two points bracketing those values should be used. For beams of about 100 kV and lower it is generally safer to use a calibration energy that is somewhat lower (i.e., calibration kV, filter thickness, or HVL lower than those of the scanner), because this yields a higher measurement. (Note: the tube kilovoltage in kV determines the highest photon energy in the x-ray beam in keV.)

C.3.3 Measurement

After positioning the ionization chamber for a measurement, a background reading of air kerma (Gy) or exposure (R) over a time interval should be obtained. After resetting the electrometer, the ion chamber should be scanned a number of times, for the same total time interval as the background measurement. The number of scans (and time interval of the measurement) should be chosen so as to produce sufficiently reproducible results. The air kerma or exposure of one scan is given by:

$$K = \frac{(R_s - R_b) \times CF}{n}$$

where
K is the air kerma or exposure per scan,
R_s is the integrated reading obtained from all the scans,
R_b is the background reading,
CF is the appropriate energy-dependent calibration factor of the ionization chamber, and
n is the number of scans.

C.4 Determination of the Half-Value Layer

The half-value layer (HVL) of the x-ray beam is needed in order to obtain the appropriate conversion coefficient C or C_R to use in equation (1) or (1a). A meter and probe suitable for air kerma or exposure measurements as described in Section C.3 should be used. The meter sensitivity and resolution should be no greater than 5% of the reading at the maximum attenuation (after background subtraction). The

following is a suggested procedure for measuring the HVL.

a. The measuring probe should be placed at the approximate location of a screened individual.
b. The scanning motion may be disabled for this test in order to achieve higher radiation intensities. Alternatively, a high-sensitivity probe may be scanned in the same manner as a screening subject. As attenuators are added (or removed) the geometry of each measurement should be kept identical.
c. A lead collimator should be placed at approximately 1/2 to 1/3 the distance from the probe to the x-ray source. The collimator should have a diameter no larger than 0.1d, where d is the distance between the collimator and the x-ray source (e.g., a 5-cm collimator at 50 cm from the source or a 7-cm collimator at 70 cm from the source, producing a 10-cm-diameter beam at 100 cm from the source). Note: because these are relative measurements, the beam need not cover the entire probe or ion chamber provided the geometry stays the same.
d. Aluminum attenuators of at least 99% purity should be used. Thicknesses should be added in suitable steps until the air kerma or exposure is reduced to at least 30% of the unattenuated beam. The attenuators should be placed over the collimator added for this measurement.
e. Air kerma (exposure) results, obtained according to the procedure in Section C.3.3 above, should be plotted as a function of Al thickness added. The HVL is found by interpolation to the Al thickness producing an attenuation of 0.5.

C.5 Determination of Effective Dose for Polyenergetic X-Ray Spectra

THE FOLLOWING SECTION IS TAKEN FROM ANNEX B OF THE 2002 EDITION OF ANSI/HPS N43.17. IT PRESENTS A METHOD FOR DETERMINING CONVERSION COEFFICIENTS FOR EFFECTIVE DOSE FROM THE X-RAY KILOVOLTAGE AND FILTRATION. THE METHOD IS BASED ON THE CONVERSION COEFFICIENTS OF ICRU 57 (ICRU 1998) AND DOES NOT INCORPORATE THE TISSUE WEIGHTING FACTORS RECOMMENDED IN THE 2007 ICRP RECOMMENDATIONS (ICRP 2007). THE SECTION IS INSERTED HERE FOR INFORMATION ONLY AND TO PROVIDE AN ALTERNATE METHOD OF ESTIMATING EFFECTIVE DOSE FOR COMPARISON. THIS IS NOT A METHOD FOR DETERMINING THE REFERENCE EFFECTIVE DOSE FOR THE PURPOSE OF COMPLYING WITH THE PRESENT STANDARD.

C.5.1 Conversion Coefficients

The conversion coefficient between air kerma in Gy (or exposure in R) and effective dose in Sv (or rem) is dependent on the energy spectrum of the x-ray beam, which can generally be specified by two parameters: the kilovoltage applied to the x-ray tube (i.e., the kV) and the filtration the beam has passed through. This filtration is usually expressed in millimeters of aluminum. Conversion coefficients have been tabulated for various values of kV and beam filtration and are shown in Figs. C2 and C3. Since effective dose is different for exposures to the front and rear of the body due to different impacts of the radiation on the various organs, separate charts are provided. Section C5.2, including Figs. C4–C7, describes how the data in Figs. C2 and C3 were prepared.

The conversion coefficients are shown in units of rem/R (used to convert exposure in R to effective dose in rem). For the sake of simplicity other units have not been included in the charts but the appropriate conversion coefficients may be obtained as follows:

- To convert air kerma in gray to effective dose in sievert multiply the value taken from Figs. C2 and C3 by 1.14 (i.e., 1 rem/R = 1.14 Sv/Gy).
- To convert exposure in C/kg to effective dose in sievert multiply the value taken from Figs. C2 and C3 by 38.8 [i.e., 1 rem/R = 38.8 Sv/(C/kg)].
- To convert exposure in R to effective dose in sievert divide the value taken from Figs. C2 and C3 by 100 (i.e., 1 rem/R = 0.01 Sv/R).

C.5.2 Sources of Data and Methods

The conversion data presented in Figs. C2 and C3 were prepared using the following sources and methods of calculation.

Photon spectra for the 14 combinations of kV and beam filtration (shown by the square

markers in Figs. C2 and C3) were obtained from tabulated data in a standard reference (Birch et al. 1979; pp. 15–43). As an example, Fig. C4 shows two of these photon spectra, for 50 kV with 1.5 mm aluminum filtration, and 120 kV with 2.5 mm aluminum. These spectral curves, as well as the other curves discussed below, are calculated and stored with one data point per keV. That is, 150 points are used to represent a spectrum running from 1 to 150 keV. Note that the term "kV" is used instead of "kVp" to describe these spectra, since they are based on constant potential operation.

Fig. C5 shows the conversion coefficient between *photon fluence* (i.e., the number of photons per unit area) and *exposure* (in units of roentgens) for monochromatic x-rays (Birch et al. 1979; Table 2, p. 12). The vertical axis of this graph is a relative scale.

When the curve in Fig. C5 is multiplied by a photon spectrum (such as the examples shown in Fig. C4), an *exposure spectrum* is produced. This exposure spectrum is analogous to the *kerma in air spectrum* in the SI system of units. After converting each of the 14 spectra in this manner, each exposure spectrum is normalized such that the sum of all the values in each spectrum is unity. Fig. C6 shows the normalized exposure spectra for the two examples.

The curves in Fig. C6 can be understood by considering an x-ray beam that produces an exposure of exactly one roentgen. The exposure spectrum breaks this one roentgen exposure into 150 different energy bands, each 1 keV wide. Each point in the spectrum represents the exposure resulting from x-rays within its energy band, and the sum of all the points is equal to one roentgen.

Fig. C7 shows the conversion coefficient between *exposure* (in roentgens) and *effective dose* (in rem), for monochromatic x-ray beams. The markers in this graph are from a standard reference (ICRU 1998). The values between these points (the solid lines) are obtained by linear interpolation. When this curve is multiplied by each of the 14 exposure spectra, 14 effective dose spectra are produced, such as the examples shown in Fig. C8. The total effective dose produced by each spectrum is found by summing the effective doses at each individual energy. These are the values reported by the square markers in Figs. C2 and C3.

The solid curves shown in Figs. C2 and C3 are obtained by the same procedure, except the photon spectra are generated from the equation for *Kramer's spectrum* (Attix 1986; p. 214):

$$\Phi(E) = (V - E)\, K \exp[-t_a \rho_a \mu(E)]$$

where
$\Phi(E)$ is the photon fluence at energy E,
V is the voltage applied to the x-ray tube in kV (equal to the peak photon energy in keV),
E is the photon energy in keV,
K is a normalization factor determined by comparison with the Birch spectra,
t_a is the thickness of alumin um filtration,
ρ_a is the density of aluminum, and
$\mu(E)$ is the energy dependent mass attenuation coefficient of aluminum.

C.6 References for Annex C

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Birch R, Marshall M, Ardran GM. Catalogue of spectral data for diagnostic x-rays. London: The Hospital Physicists' Association; Scientific Report Series 30; 1979.

International Commission on Radiation Units and Measurements (ICRU). Conversion coefficients for use in radiological protection against external radiation. Bethesda, MD: ICRU; ICRU Report 57; 1998.

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International Standards Organization (ISO). X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy – Part 3. ISO Standard 4037-3; 1999.

Soares CG, Martin PR. A consistent set of photon conversion coefficients for personnel and environmental dosimetry. In: Proceedings of the Panasonic Users Group Meeting, Somerset, PA, June 5–9; 1995.

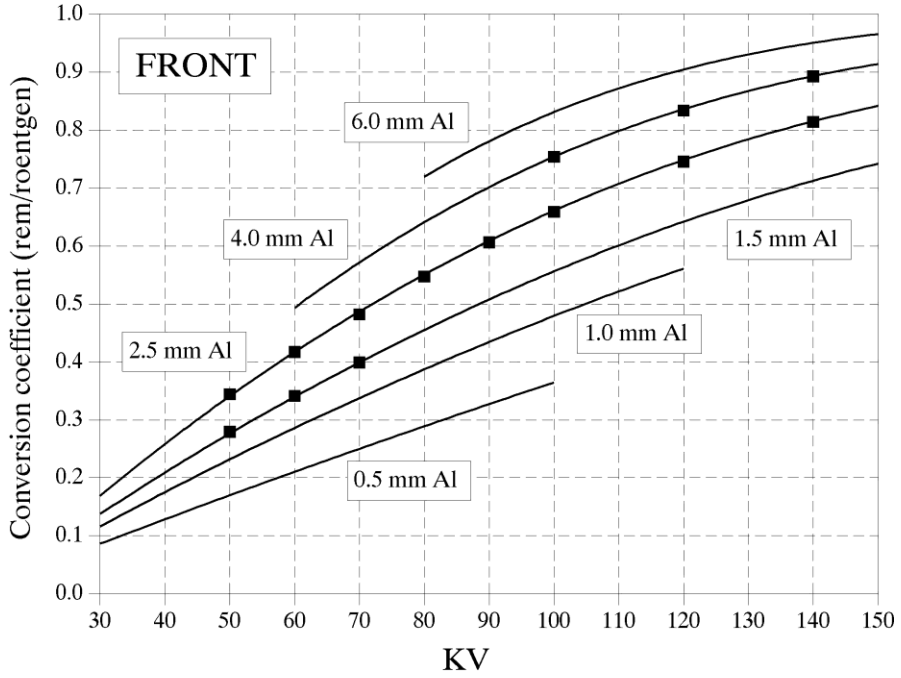

Fig. C2. Conversion between exposure and effective dose for a frontal scan. These curves provide the conversion coefficient between measured exposure (in roentgens) and effective dose (in rem), as a function of the x-ray tube potential (KV) and beam filtration (mm of Aluminum) for a front scan. When converting from air kerma (in Gy) to effective dose (in Sv) the conversion coefficients from the y-axis should be multiplied by 1.14 (see text).

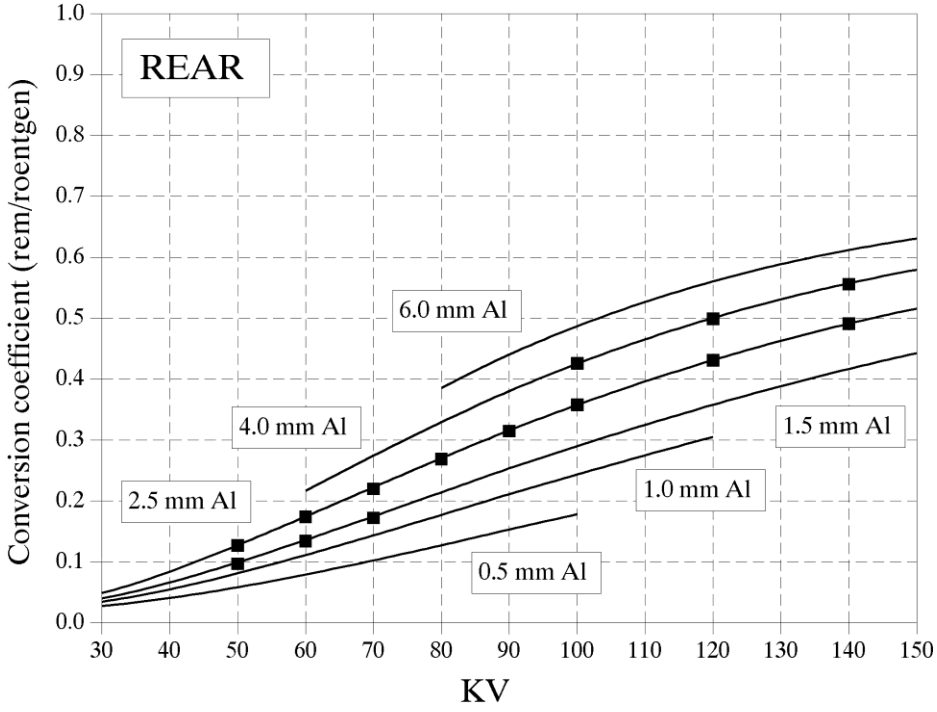

Fig. C3. Conversion between exposure and effective dose for a rear scan. These curves provide the conversion coefficient between measured exposure (in roentgens) and effective dose (in rem), as a function of the x-ray tube potential (KV) and beam filtration (mm of aluminum) for a rear scan. When converting from air kerma (in Gy) to effective dose (in Sv) the conversion coefficients from the y-axis should be multiplied by 1.14 (see text).

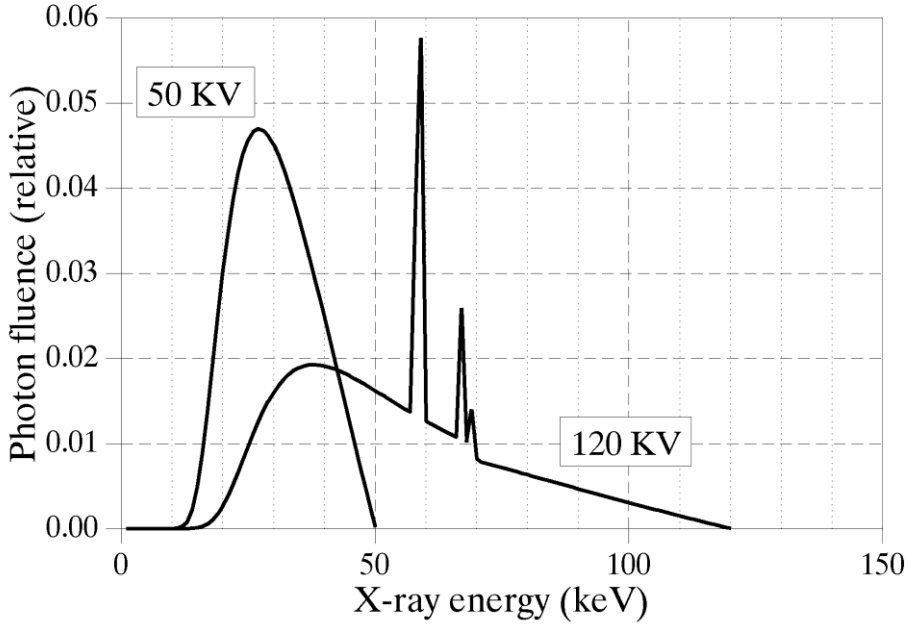

Fig. C4. Photon spectra. Examples of two photon spectra: 50 kV with 1.5 mm aluminum filtration, and 120 kV with 2.5 mm aluminum filtration.

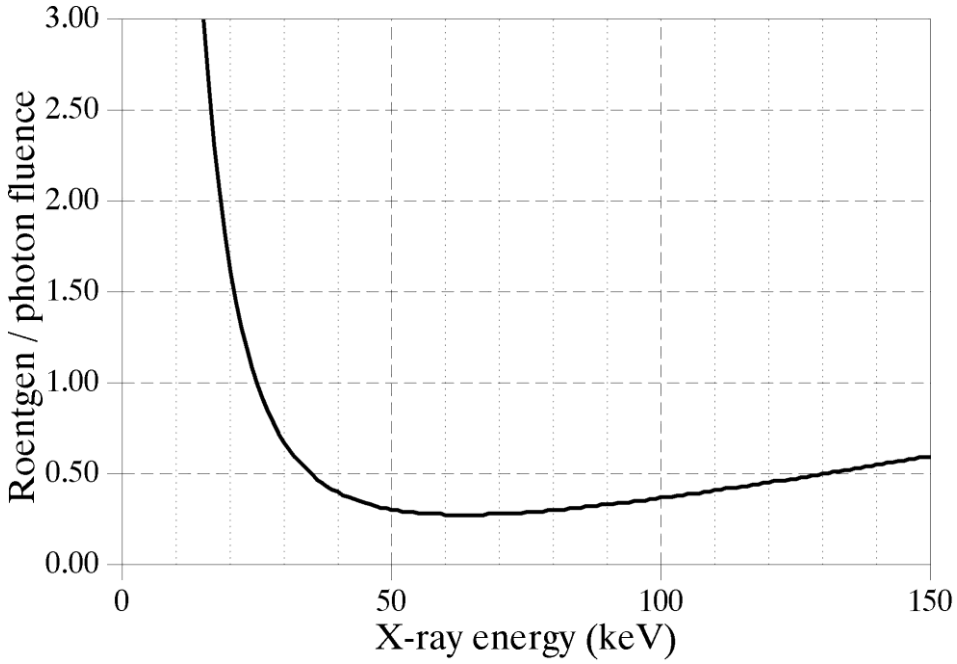

Fig. C5. Photon fluence to exposure conversion. The curve represents relative conversion coefficients between *photon fluence* (i.e., the number of photons per unit area) and *exposure* (in units of roentgens) for monochromatic x-rays (Birch et al. 1979; Table 2, p. 12).

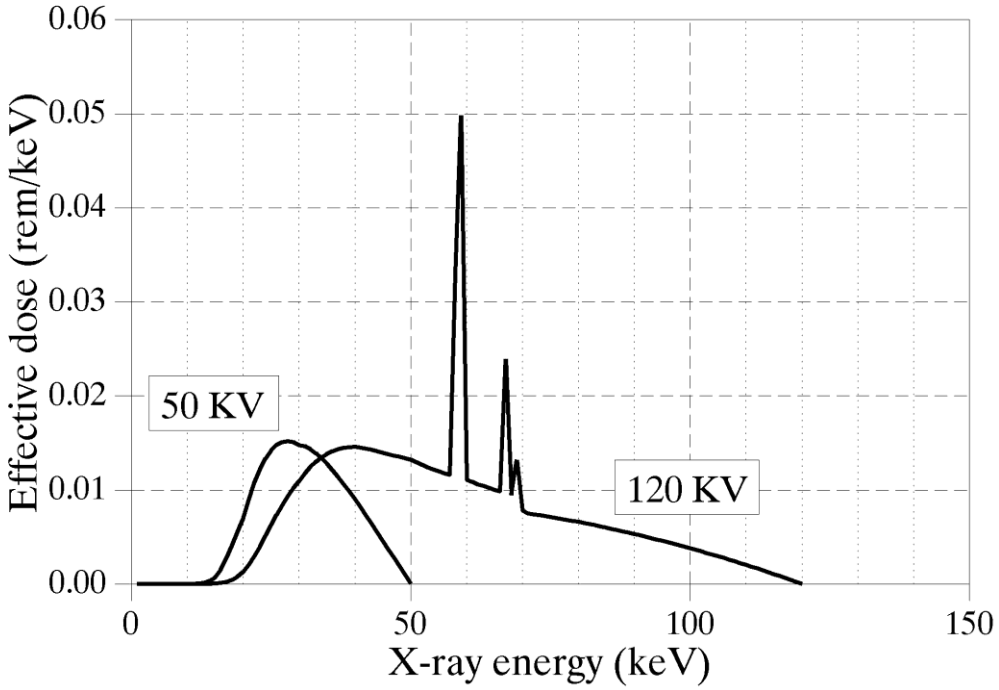

Fig. C6. Exposure spectra. The normalized exposure spectra for the two examples of Fig. C4.

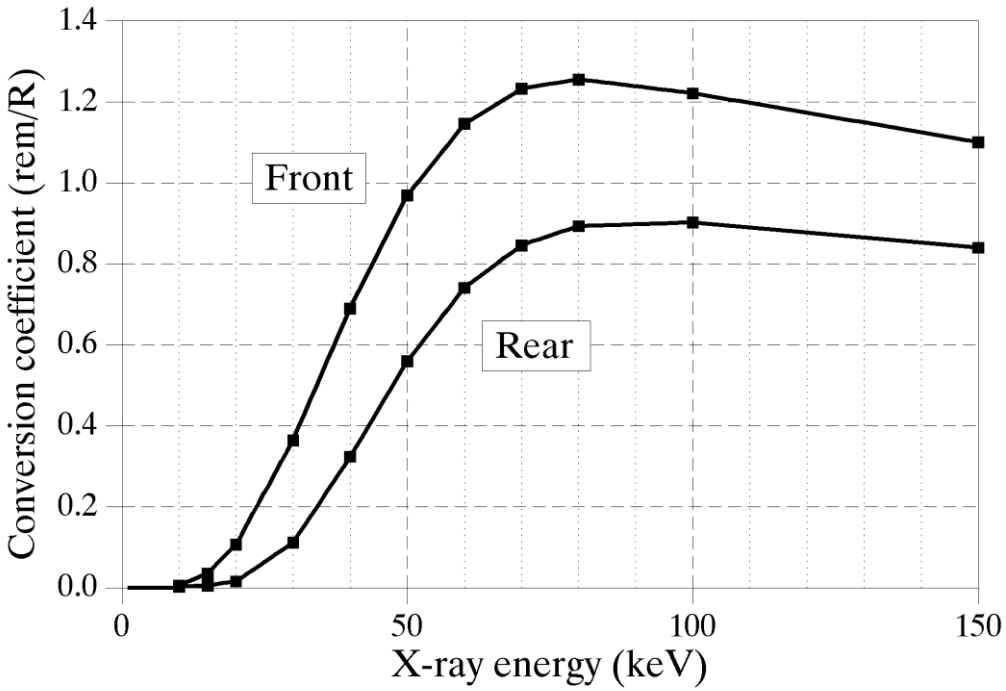

Fig. C7. Monochromatic conversion. The conversion coefficient between *exposure* (in roentgens) and *effective dose* (in rems) for monochromatic x-ray beams. The markers in this graph are from a standard reference (ICRU 1998). The values between these points (the solid lines) are obtained by linear interpolation.

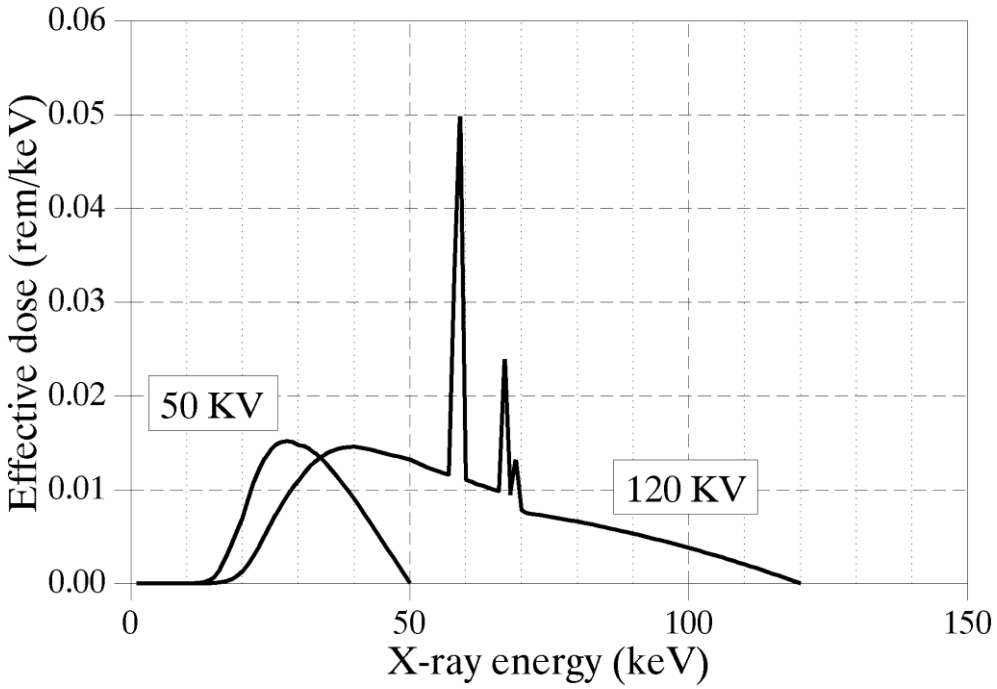

Fig. C8. Effective dose spectra. The effective dose spectra obtained by multiplying the exposure spectra of Fig. C5 by the conversion curve for a frontal scan shown in Fig. C7. The total effective dose produced by each spectrum is found by summing the effective doses at each individual energy. These are the values reported by the square markers in Figs. C2 and C3.