

**ANSI/HPS N43.17-2002**

*American National Standard*

**Radiation Safety For Personnel Security Screening  
Systems Using X-rays**

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**Foreword** (This foreword is not part of American National Standard N43.17)

A new imaging technology is gaining importance in screening applications for security and contraband. Systems that use ionizing radiation, designed to be used directly on people, have been installed by several institutions in the United States since the 1990's. The technology allows much lower doses than more conventional x-ray methods. The doses are typically lower than allowable limits for incidental exposure to the general population from man-made sources. When the technology became commercially available, little guidance existed for this type of intentional, non-medical radiation exposure. In June of 2000 the HPS/ANSI Accredited Committee N43 appointed working group N43.17 to draft a consensus standard addressing the radiation safety of this technology.

This standard applies to security screening systems that use x-rays and are designed to be used on people. Specifically, this standard applies to systems used to detect objects carried on the individual being exposed. 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 of the realm of radiation safety. The standard is intended for manufacturers, distributors, installers, and users of the systems.

In setting dose limits the standard takes into consideration the minimization of the dose as balanced against the security benefit to society. This precludes the frivolous use of the security devices where no benefit is to be derived. The standard contains two informative annexes. Annex A provides information on risks associated with radiation doses and the rationale for the dose requirements in the standard. Annex B provides information required to make appropriate radiation measurements.

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## 1. Scope

This standard applies to security screening systems that use x-rays and are designed to be used on people. Specifically, this standard applies to systems used to detect objects carried on the individual being exposed. 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 of the realm of radiation safety.

## 2. Definitions

The following are terms that are either of key significance or have a specific meaning in this standard that may 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 B contains additional information on radiation quantities and units.

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

**Air kerma:** The total initial kinetic energy transferred to charged particles in a unit mass of air as a result of irradiation. The unit of air kerma is the joule per kilogram or gray (Gy). (For x-ray energies < 300 keV, 1 Gy  $\cong$  114 roentgen).

**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 under specified conditions, as the material in question.

**Beam exit surface:** The surface of the outer system assembly from which the direct

x-ray beam emanates. The subject being scanned is exposed through this surface.

**Dose:** When a specific dose quantity (e.g. "effective dose") is not indicated in this standard, dose means the skin entrance *equivalent dose*. The unit used is the sievert (Sv). (1 Sv = 100 rem. For the purpose of this standard the dose in rems may be taken to equal the exposure measured in roentgens).

**Effective dose:** A summation of the *equivalent doses* in tissues or organs each multiplied by the appropriate tissue weighting factor.

**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).

**External surface:** The outside surface of the security screening system containing all associated x-ray sources.

**Facility:** A location of use where one or more screening systems may be installed.

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

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

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

**Operator:** Any employee associated with the operation of the system.

**Personnel security screening system:** A system designed for the detection of contraband and weapons concealed on a person. (In the body of this standard also referred to as "screening system" or "system".)

**Safety interlock:** A device that is intended to prevent or interrupt the generation of x-radiation whenever safety is compromised either by access to the interior of the system or by an operational malfunction.

**Scan:** The scanning cycle consisting of the operation necessary to produce one view (e.g. front view).

**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.

**Technique factors:** (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.

### 3. 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 takes into consideration: (1) the minimization of the dose and (2) the security benefit to society. This precludes the frivolous use of these security devices where no benefit is to be derived.

### 4. Federal, state, and local regulations

Manufacturers and distributors of personnel security screening systems shall comply with applicable requirements in the U.S. Code of Federal Regulations (CFR), Title 21, Parts 1002 through 1005 (FDA). User facilities shall comply with applicable requirements in CFR Title 29, Standard 1910.1096 regarding occupational safety (OSHA). In addition, the installation and operation of these systems may be subject to state and local regulations, which may involve registration, licensing, and compliance with specific rules. The person or persons in charge of the installation and operation shall ensure compliance with all applicable regulations.

## 5. Dose limitation

### 5.1 Subject dose limitation

The radiation dose delivered to a human subject shall be as low as reasonably achievable (ALARA) while meeting the desired detection performance. Under maximum operating parameters, the effective dose shall not exceed 0.10  $\mu\text{Sv}$  (10  $\mu\text{rem}$ ) per scan of the subject's front. The measurement shall be made 30 cm from the beam exit surface at the location where maximum emission occurs. (An air kerma measurement of 87 nGy or less [exposure  $\leq$  10  $\mu\text{R}$ ] ensures that the limit is being met, provided that the system is operating below 150 kV. See Annex B for more information.) For the purpose of estimating effective dose using the charts in Annex B the kilovoltage should be known with an accuracy of  $\pm 5\%$  or better. The total aluminum-equivalent filtration of the beam exit surface and any other material in the beam path shall be determined by the manufacturer for each value of kilovoltage used by comparison with aluminum attenuators of at least 99% purity. The facility shall be operated to ensure that no individual scanned receives from the facility an effective dose in excess of 0.25 mSv (25 mrem) in any twelve-month period (see Sec. 7.8 d). The manufacturer shall ensure that operating kilovoltage and primary beam filtration are optimized for the best performance at the lowest dose. For a discussion on the rationale for the dose limits see Annex A.

### 5.2 Dose limitation for special groups

Various subgroups of the general population may be more susceptible to radiation-induced health effects than others. The dose limits of section 5.1 take into consideration the most sensitive members of the population. For a discussion on the dose to special groups see Annex A.

### 5.3 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) 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) per year. Both these levels are subject to the radiation safety principle of ALARA. That is, even though these exposures may be acceptable, they must 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 radiation background. The NCRP defines a category for extremely low radiation exposures called the Negligible Individual Dose (NID), and sets its value at 0.01 mSv (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 0.1  $\mu$ Sv (10  $\mu$ rem) maximum dose per scan produced by systems operating under this standard. By direct calculation, an individual screened less than 100 times per year would receive a radiation exposure within the NID. Likewise, an individual screened up to 10,000 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 any other source). However, the use of radiation exposure in personnel security screening is a unique application. Accordingly, it is the intent of this standard to further define the acceptable uses of the technology, and to interpret the principles of ALARA and NID in this specific context. Systems operating under this standard should only be used in the legitimate search for concealed weapons and contraband, plus 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  $\mu$ Sv (1000  $\mu$ rem) 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 100 times per year (at the maximum system emission defined above) 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  $\mu$ Sv (1000  $\mu$ rem) 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.

### 5.4 Dose to bystanders

An inspection zone shall be established around the personnel security screening system where bystanders are prohibited during the operation of the device. Radiation doses outside of this inspection zone shall not exceed 20  $\mu$ Sv (2 mrem) in any one hour. The system should be positioned and operated such that personnel at any work station do not exceed a dose of 1 mSv (100 mrem) per year.

### 5.5 Shielding

Under maximum operating parameters, the leakage dose rate at any point 30 cm from any external surface of the device, excluding the beam exit surface, shall not exceed 2.5  $\mu$ Sv (0.25 mrem) in any one hour. For units that employ a shutter or beamstop, this limit shall also apply to the beam exit surface

while the shutter is closed or the beam is aligned with the beamstop.

## **6 System and manufacturing requirements**

### **6.1 Indicators and controls**

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.

Power to the system shall be controlled by a key switch. The key shall be captured whenever it is in a position that allows x-ray exposures to be initiated. Turning on the key switch shall never result in the external emission of x radiation. A separate control shall be used to initiate a scan sequence.

There shall be at least one lighted indicator clearly visible on the "beam exit surface" side of the unit to indicate that a scan is in progress. There shall be at least one indicator clearly visible from any location from which a scan can be initiated which indicates when a scan is in progress. In addition, for any 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.

### **6.2 Safety interlocks**

#### **6.2.1 Access panel interlocks**

A tool or key shall be required to open or remove access panels. Access panels shall have at least one safety interlock.

#### **6.2.2 Operational interlocks**

Operational interlocks shall terminate the production of x-rays in the event of any operating problem that could result in

abnormal or unintended radiation emission. Either through redundancy or special design, a malfunction of any operational interlock or any system monitoring an operational interlock must also terminate x-ray production, regardless of the actual radiation emission. This shall include, but is not limited to: unintended stoppage of beam motion, abnormal or unintended x-ray source output, computer system malfunction, termination malfunction, and, when applicable, x-ray shutter or beam stop mechanism malfunction.

In the event of a malfunction, the system shall terminate x-ray production rapidly enough to limit the subject exposure to a "dose times exposed area" of  $250 \mu\text{Sv cm}^2$  ( $25 \text{ mrem cm}^2$ ). (For example:  $25 \mu\text{rem}$  over a 1000 square centimeter area or  $50 \mu\text{rem}$  over a 500 square centimeter area, etc.) Additionally, no location on the subject's body shall receive a dose exceeding 25 mrem, regardless of the exposed area.

Following interruption of x-ray generation by the functioning of any safety interlock, resetting the interlock shall not result in the production of x-rays. Use of the normal control sequence shall be necessary for resumption of x-ray generation.

#### **6.2.3 Automatic termination**

External emission of x-rays shall terminate at the completion of the scanning cycle.

### **6.3 Ground fault**

Any ground fault shall not result in the production of x-rays.

### **6.4 Labeling**

Every manufacturer of a system to which this standard is applicable 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; (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.

The radiation source and shielding assembly shall have a clear and visible radiation warning label. The positioning of the label shall be visible from any point where service access might be gained.

### 6.5 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 Sec. 6.4 *Labeling*. Additionally, notification of state and/or federal regulators may be required for modifications which are considered to be manufacturing.

### 6.6 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) Warnings of life threatening dangers (such as unauthorized modification of the system);
- b) State and/or local licensing/registration may be required;
- c) Operational procedures needed to use the system safely;
- d) Preventive maintenance requirements for safe operation;
- e) Other requirements and recommendations specified in this standard that are applicable to the end user;

- f) Technique factors for each operating mode and total aluminum-equivalent filtration.

### 6.7 Records to be maintained by manufacturers

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

- a) Description of the quality control procedures with respect to the system's radiation safety;
- b) Records of the 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 which 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) Copies of 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 which 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 Sec. 6.8 *Records to be obtained by dealers and distributors*.

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

## 6.8 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:

- 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 number and serial 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.

## 7 Operating requirements

### 7.1 Responsible individual

The institution operating the screening system shall designate a person responsible for ensuring compliance with the requirements of this section.

### 7.2 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.

### 7.3 Operating procedures

The operating institution shall document its procedures for operating the system. These

procedures shall include all the topics listed in Sec. 6.6 *Information to be provided to the end user*. These procedures shall be consistent with the manufacturer's operator's manual.

### 7.4 Information to be provided to the subject

At a minimum, the institution operating the system shall inform each person being scanned of the following:

- a) The system emits radiation;
- b) The dose from one scan shall not exceed 0.1  $\mu\text{Sv}$  (10  $\mu\text{rem}$ );
- c) An example shall be provided to compare the dose to a commonly known source of radiation, such as "The radiation from one scan is equivalent to approximately 20 minutes of exposure to naturally occurring background radiation";
- d) The system conforms with the ANSI/HPS consensus standard N43.17; if requested, information on how to acquire this standard shall be provided.

### 7.5 Personnel training

All personnel associated with the operation of the system 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) Supervised practical operations.

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

## 7.6 Preventive maintenance

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

## 7.7 Radiation surveys

Radiation surveys shall verify subject dose, radiation leakage, inspection zone, and any other parameter specified by the manufacturer.

Surveys shall be performed:

- a) upon installation;
- b) at least once every twelve months;
- c) after any maintenance which affects the radiation shielding or x-ray production components;
- d) after any incident which may have damaged the system in such a way that x-ray leakage may occur.

Refer to Annex B for information on measurements of effective dose and selection of instrumentation.

## 7.8 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 7.5;
- b) Upgrades, modifications, maintenance, and repair records shall be maintained for the life of the system;
- c) Records of radiation surveys as required in Sec. 7.7 *Radiation surveys*;

- d) Evidence to show that the dose limits specified in Sec. 5.1 through 5.4 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 Sec. 7.1 *Responsible individual*.
- b) A complete set of operating procedures as required in section 7.3 shall be readily available to the operator of each system.

## 8 References

Food and Drug Administration (FDA). *Radiological Health*. 21CFR1002-1005. Washington: GPO.

National Council on Radiation Protection and Measurements (NCRP). 1993. *Limitation of Exposure to Ionizing Radiation*. NCRP Report 116. Bethesda, MD: NCRP.

Occupational Safety and Health Administration (OSHA). *Ionizing Radiation*. 29CFR1910.1096. Washington: GPO.

## **ANNEX A**

(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.

#### **A1 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) has 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 (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 Sv be used for the general population (NCRP 1993). Application of this risk estimate means that each 0.01  $\mu\text{Sv}$  (1  $\mu\text{rem}$ ) of effective dose received is considered to contribute  $5 \times 10^{-10}$ , or 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.

The NCRP recommends 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). 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. As information relating to other sources of radiation exposure may be difficult to obtain, 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). Since systems operating in accordance with this standard produce a maximum dose of 0.1  $\mu\text{Sv}$  (10  $\mu\text{rem}$ ) per scan, only individuals who are scanned an average of seven or more times each day would exceed the annual 0.25 mSv limit. The associated incremental risk is 1 in 200,000,000 per scan. To put this in perspective, this same risk of death results from about one minute of riding in an automobile. Likewise, this same risk of death is experienced about each ten 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 U.S., 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).

#### **A2 Dose to operators**

Compliance with the Occupational Safety & Health Administration's standards for radiation safety is mandatory in the U.S. (OSHA). It is recommended that the manufacturers of systems covered by the present standard provide a system which, when installed and operated as designed, ensures that the operator dose not exceed an annual effective dose of 1mSv (100 mrem). Systems that comply with N43.17 are likely to meet this requirement, which is also the recommended dose limit for the general public. The user of the system should ensure that the system is operated in accordance with the manufacturer's instructions. Personnel dosimeters are not typically required at these dose levels.

### A3 Dose to special groups

Various subgroups of the general population may be more susceptible to radiation-induced health effect than others. This includes pregnant and potentially pregnant women, children, infants, persons receiving radiation treatment for medical conditions, and others. In some cases, the NCRP recommends lower limits on exposure to these special groups. For example, the NCRP recommends a maximum occupational dose of 0.5 mSv/month to the embryo or fetus. This means that a pregnant radiation worker should receive a lower dose than the occupational limit of 50 mSv/year that applies to other workers. However, the reduced limits for special groups are only made for radiation doses that are far in excess of what is covered by this standard. For example, the reduced limit on occupational exposure to a pregnant woman corresponds to approximately 5,000 security examinations per month. The NCRP makes no distinction between members of the population in its recommendations on exposure for the general public or for the Negligible Individual Dose. Rather, NCRP sets the limits at a level appropriate for the most sensitive members of the population. Correspondingly, there is no need to distinguish between members of the population being scanned by the systems operating under this standard.

### A4 References for Annex A

National Academy of Sciences/National Research Council (NAS/NRC), Committee on the Biological Effects of Ionizing Radiation. 1990. *Health Effects of Exposure to Low Levels of Ionizing Radiation*. BEIR V. Washington: National Academy Press.

National Council on Radiation Protection and Measurements (NCRP). 1993. *Risk Estimates for Radiation Protection*. NCRP Report 115. Bethesda, MD: NCRP.

Occupational Safety and Health Administration (OSHA). *Ionizing Radiation*. 29CFR1910.1096. Washington: GPO.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 1988. *Sources, Effects and Risks of Ionizing Radiation, Report to the General Assembly with Annexes*. United Nations Publication E.88.IX.7. New York: UN.

## ANNEX B

(Informative)

### Radiation Measurements

This annex contains information necessary for making appropriate and accurate measurements of the radiation output. The methods and conversion coefficients needed to convert the measurements to effective dose are presented. The discussion of this annex pertains only to measurements of x-radiation in the energy range typical of personnel security scanners and is not intended to be a comprehensive treatment of radiation dosimetry.

#### B1 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. It is not sufficient to understand how the radiation affects the various tissues, we must also quantify it. In order to measure the radiation we must first rely on its interactions with various detector materials, then we need to find a relationship between the measurement and the radiation quantity of concern. For the purpose of this discussion we will concentrate on the quantities *effective dose* and *air kerma*.

Many quantities have been defined for radiation dose, including absorbed dose, equivalent dose, effective dose, and others. In general, *dose* implies energy imparted (per unit mass) by the radiation on a material. Different materials absorb different amounts of energy, so when speaking of dose, the irradiated material, tissue, or organ needs to be specified. The quantity *kerma* refers to the sum of the initial kinetic energy of all ionizing particles liberated (per unit mass) in a material directly by the radiation. Kerma is related to dose and, for the photon energies of interest (up to approx. 300 keV), is numerically a very good approximation of dose. The SI unit for dose and kerma is the joule per kilogram or *gray*, abbreviated Gy. The old unit of dose was the *rad* (1 Gy = 100 rad). *Air kerma* (related to the energy deposited in a unit mass of air) is useful because air is an important detection material and calibrations are often in terms of this quantity. Therefore air kerma, in Gy, can be readily measured. In the old system of units the relevant unit was the *roentgen* (R), a unit of *exposure* (1 Gy<sub>air</sub>  $\cong$  114 R, for energies < 300 keV). *Effective dose* is a measure of the effect of a radiation exposure on the whole body. The SI unit of effective dose is the *sievert*, abbreviated Sv. The old unit of *effective dose equivalent* (similar to the new effective dose) was the *rem* (1 Sv = 100 rem). Effective dose can be extremely difficult to measure because the energy imparted on each organ must be known. This is difficult to estimate because, within the body, the radiation beam undergoes attenuation, scatter, and changes in the energy spectrum. However, when the spectrum of the entrance x-ray beam is known and the beam is incident uniformly on the body from a known direction, it is possible to use published conversion coefficients to calculate effective dose. **Note:** the units gray, rad, sievert, and rem have different values depending on the specified absorbing medium or the specified dose quantity, or both. When an instrument reads directly in these units, do not assume that the desired quantity is being measured.

## **B2 Types of radiation detectors**

### **B2.1 Ionization chamber**

The ionization chamber is a type of radiation probe consisting of an air volume 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 must be made.

### **B2.2 Geiger counter**

The Geiger counter consists of a Geiger Muller (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, which 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 in locating a source of radiation and giving a general idea of its strength.

### **B2.3 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.

## **B3 Measurement for the estimation of effective dose**

### **B3.1 Instrument selection**

Personnel security screening systems, in general, expose one side of the body uniformly to the same radiation beam. In this case the effective dose may be estimated by using the conversion coefficients of Fig. B.1 (for front scans) and Fig. B.2 (for rear scans). In order to do this, an accurate measurement of air kerma (or exposure) is needed. This can be accomplished by using an appropriate ionization chamber instrument. The instrument must have: (1) an integrating mode, (2) high sensitivity, and (3) low dependence on the energy of x-rays.

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 Gy/s or R/s) is not useful for this type of measurement that involves a small and rapidly moving x-ray beam. In order to obtain an accurate reading, the entire volume of the ionization chamber must receive the same amount of radiation exposure.

Instrument sensitivity and resolution are extremely important. The level of air kerma to be measured is 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 must 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 must be very sensitive. Automatic background subtraction is not recommended. If the instrument used performs automatic background subtraction, the process must be understood and care must 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 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. The effects may be minimized by choosing the best system for the energy range in question and by proper calibration. A large (at least 1500 cc), non pressurized ion chamber is recommended. A good quality electrometer with at least a 0.1 pC resolution, capable of measuring a pulse of charge of 5 pC magnitude and 10 msec duration, within  $\pm 10\%$  accuracy is also recommended (this is approximately the charge produced in 1500 cc of air by 10  $\mu$ R).

### **B3.2 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 NIST beams shown in Table B.1 are some of the most appropriate for this type of calibration.

**Table B.1 - NIST calibration beams**

Beam code	Tube kilovoltage (kV)	HVL (mm Al)	Filtration (mm Al)
M30	30	0.36	0.5
M40	40	0.73	0.89
M50	50	1.02	1.07
M60	60	1.68	1.56
M80	80	2.97	2.61
M100	100	5.02	5.0
M120	100	6.79	6.87
L80	80	1.83	1.45
L100	100	2.77	1.98

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, as 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), as this yields a higher measurement. (Note: the tube kilovoltage in kV determines the highest photon energy in the x-ray beam in keV.)

### B3.3 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

$n$  is the number of scans

The air kerma (in Gy) or exposure (in R) can then be converted to effective dose (in Sv or rem) from a frontal scan. This is done by obtaining the appropriate conversion coefficient from Fig. B.1.

## B4 Conversion of polyenergetic air kerma (or exposure) measurements to effective dose

### B4.1 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. B.1 and B.2. 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 B.4.2, including Figs. B.3-B.6, describes how the data in Figs. B.1 and B.2 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. B.1 and B.2 by 1.14 (i.e.  $1 \text{ rem/R} = 1.14 \text{ Sv/Gy}$ ).
- To convert exposure in C/kg to effective dose in sievert multiply the value taken from Figs. B.1 and B.2 by 38.8 [i.e.  $1 \text{ rem/R} = 38.8 \text{ Sv/(C/kg)}$ ].
- To convert exposure in R to effective dose in sievert divide the value taken from Figs. B.1 and B.2 by 100 (i.e.  $1 \text{ rem/R} = 0.01 \text{ Sv/R}$ ).

### B4.2 Sources of data and methods

The conversion data presented in Figs. B.1 and B.2 were prepared by 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. B.1 and B.2) were obtained from tabulated data in a standard reference (Birch 1979; pp. 15-43). As an example, Fig. B.3 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. B.4 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 1979; Table 2, p. 12). The vertical axis of this graph is a relative scale.

When the curve in Fig. B.4 is multiplied by a photon spectrum (such as the examples shown in Fig. B.3), 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. B.5 shows the normalized exposure spectra for the two examples.

The curves in Fig. B.5 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. B.6 shows the conversion coefficient between *exposure* (in roentgens) and *effective dose* (in Rem), for mono-chromatic 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. B.7. 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. B.1 and B.2.

The solid curves shown in Figs. B.1 and B.2 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 aluminum filtration

$\rho_a$  is the density of aluminum

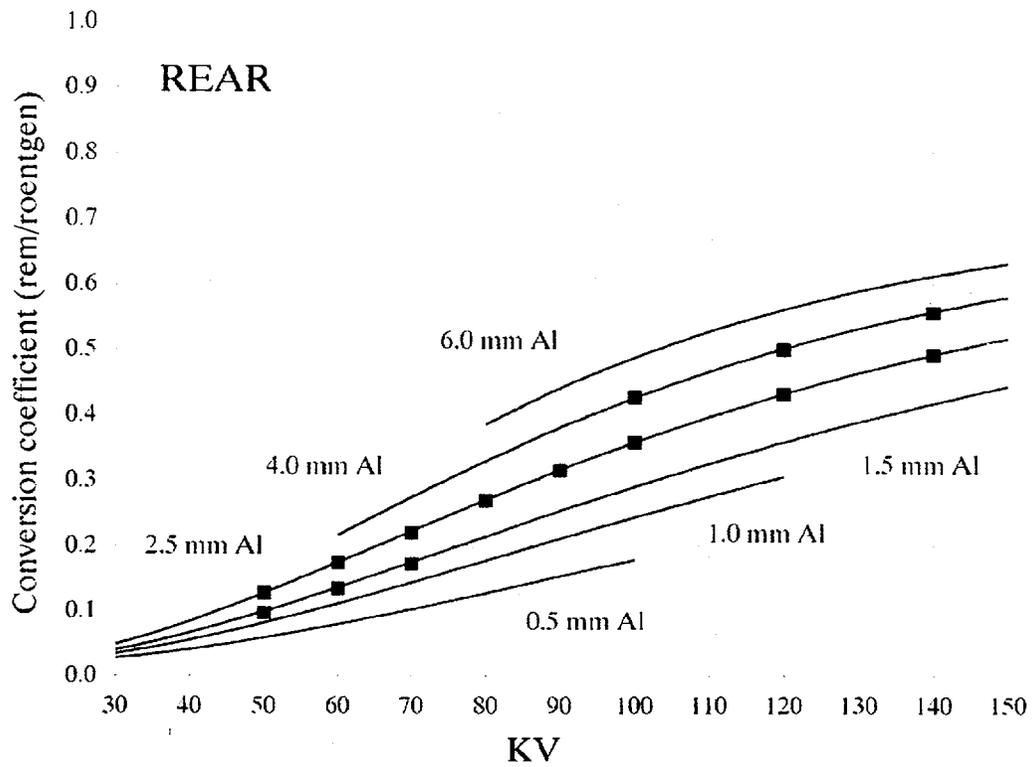
$\mu(E)$  is the energy dependent mass attenuation coefficient of aluminum.

## B5 References for Annex B

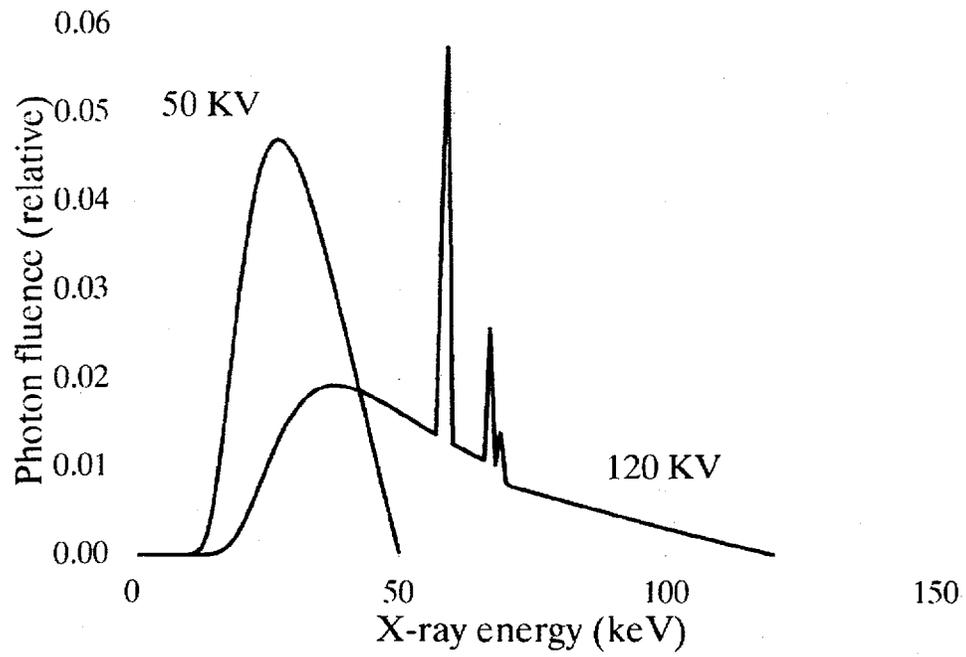
Attix, F.H. 1986. *Introduction to Radiological Physics and Radiation Dosimetry*. N.Y. John Wiley & Sons, Inc.

Birch, Marshall, and Ardran. 1979. *Catalogue of Spectral Data for Diagnostic X-rays*. Scientific Report Series 30. London: The Hospital Physicists' Association.

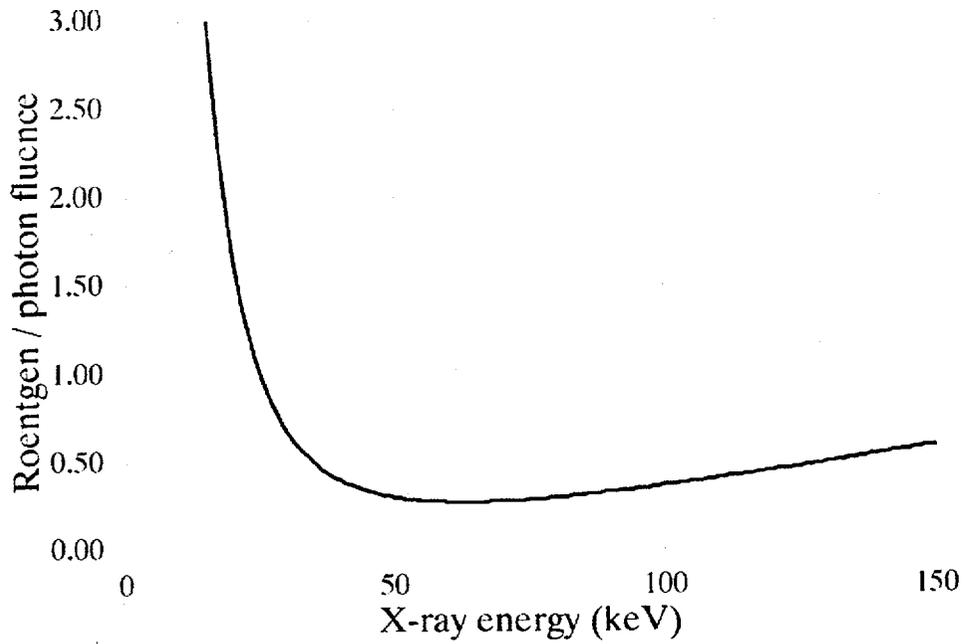
International Commission on Radiation Units and Measurements (ICRU). 1998. *Conversion Coefficients for Use in Radiological Protection Against External Radiation*. ICRU Report 57. Bethesda, MD: ICRU.



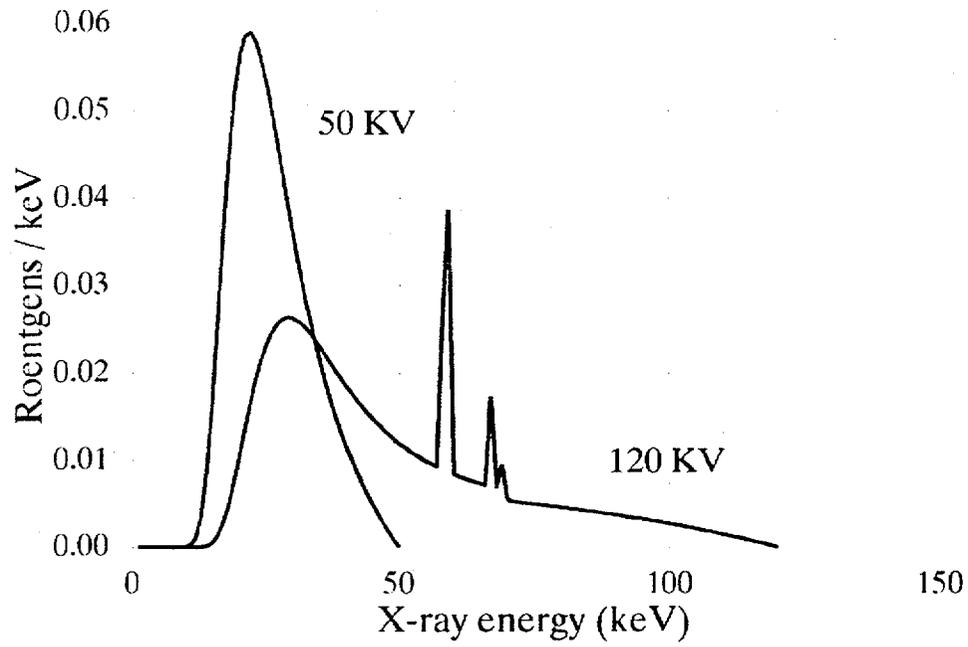
**Fig. B.2 - Conversion between exposure and effective dose for a rear scan.** These curves provide the conversion coefficient between measured exposure (in roentgens) and effective dose (in rem), as a function of the x-ray tube potential (KV) and beam filtration (mm of Aluminum) for a rear scan. When 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).



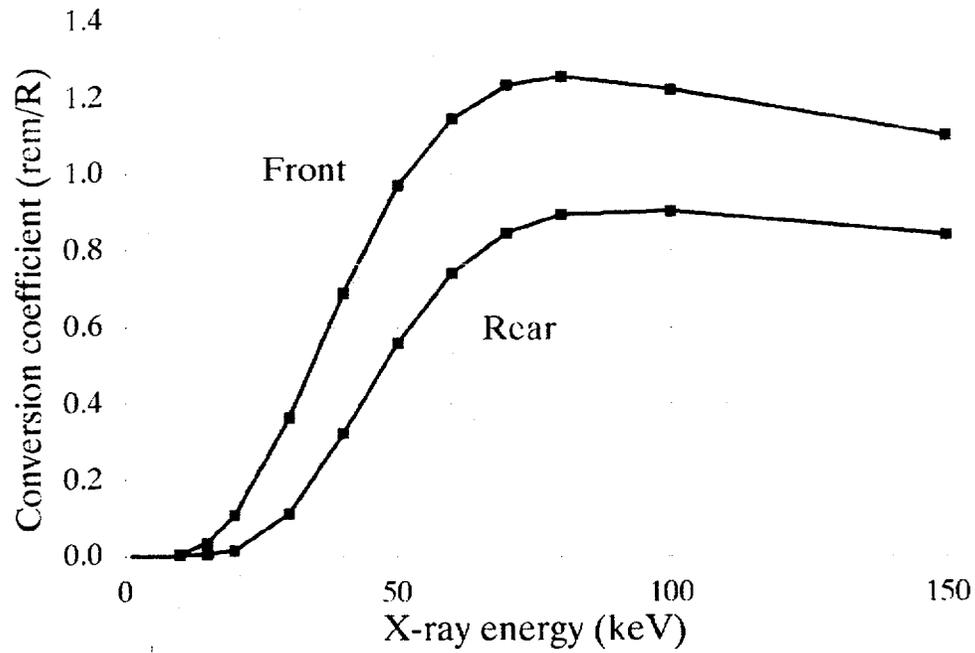
**Fig. B.3 - Photon Spectra.** Examples of two photon spectra: 50 kV with 1.5 mm aluminum filtration, and 120 kV with 2.5 mm aluminum filtration.



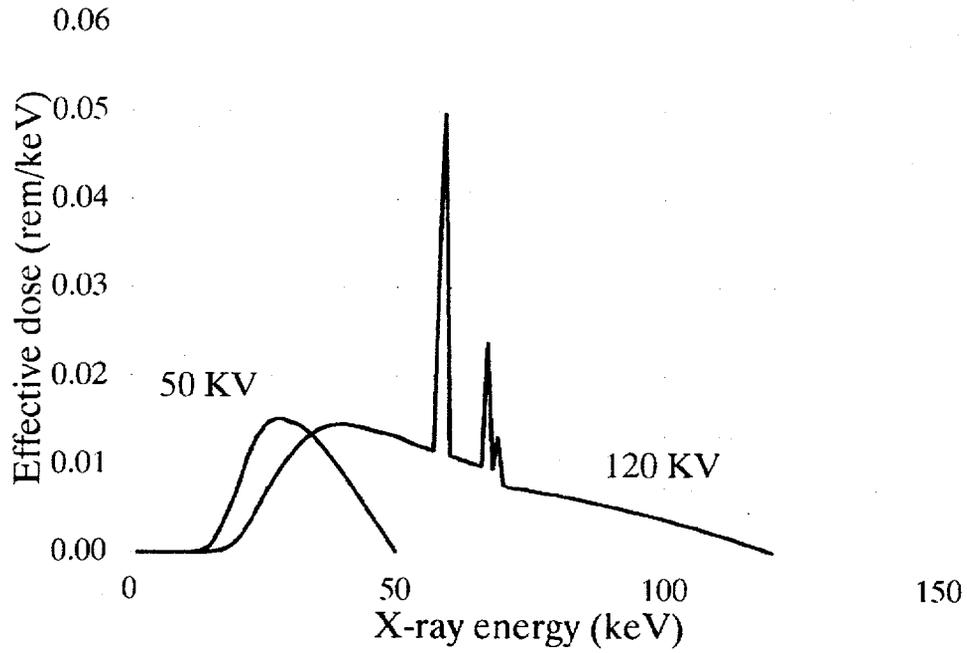
**Fig.B.4 - Photon fluence to exposure conversion.** The curve represents relative conversion coefficients between *photon fluence* (i.e., the number of photons per unit area) and *exposure* (in units of roentgens) for monochromatic x-rays (Birch 1979; Table 2, p. 12).



**Fig. B.5 - Exposure spectra.** The normalized exposure spectra for the two examples of Fig. B.3.



**Fig. B.6 - Monochromatic conversion.** The conversion coefficient between *exposure* (in roentgens) and *effective dose* (in rems), for mono-chromatic 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. B.7 - Effective dose spectra.** The effective dose spectra obtained by multiplying the exposure spectra of Fig. B.5 by the conversion curve for a frontal scan shown in Fig. B.6. 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. B.1 and B.2.