

SCREENING OF HUMANS FOR SECURITY PURPOSES USING IONIZING RADIATION SCANNING SYSTEMS



National Council on Radiation Protection and Measurements

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[For detailed information on the availability
of this and other NCRP commentaries see page 37.]

Preface

This Commentary has been prepared at the request of the Food and Drug Administration (FDA). FDA asked the National Council on Radiation Protection and Measurements (NCRP) for advice on radiation protection issues concerning exposure to ionizing radiation from radiation-producing devices used for nonmedical security purposes. These devices, particularly x-ray scanning systems, are being evaluated by various agencies (*e.g.*, U.S. Customs and Border Protection and the Transportation Security Administration) for use in security screening of humans.

The use of such scanning devices involves a broad societal decision that needs to be made through appropriate procedures by the authorities utilizing the x-ray producing electronic products (and other types of ionizing radiation producing systems) as a security device for screening humans. This Commentary provides an evaluation of radiation levels, radiation risk, and radiation protection measures that should be taken into consideration by implementing authorities. However, NCRP cannot render an opinion on the net benefit of using these devices based on their ionizing radiation aspects alone.

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1. Summary

This Commentary from the National Council on Radiation Protection and Measurements (NCRP) presents radiation protection advice concerning ionizing radiation-producing devices that are being evaluated for various uses in screening of humans for the purpose of security. Chief among the devices being evaluated at the present time are scanning systems that utilize x rays. This Commentary primarily addresses systems utilizing ionizing radiation, but also describes briefly some systems under consideration that utilize nonionizing radiation (Section 3.4).

The Commentary stresses that this advice is limited to radiation matters such as the levels of radiation exposure encountered, the radiation risk associated with ionizing radiation in general (as well as the risk associated with the actual levels encountered), and the application of NCRP radiation protection principles to this radiation source. The overall justification for use of such devices for specific security applications and what constitutes a net benefit to society are broader questions that are outside of NCRP's role as defined by its Congressional charter.

Government agencies and other institutions are considering the use of ionizing radiation scanning systems for national security, protection of life, detection of contraband, or the prevention of significant economic loss. These applications might involve scanning a large number of members of the general public or they might involve the investigation of a small number of suspected individuals. The benefit of such procedures would be to a segment of society or society as a whole, as would be the case for national security or detection of contraband.

Two types of x-ray scanning systems currently exist for security screening of individuals: backscatter systems and transmission systems. With backscatter systems, the x rays do not penetrate to depths much beyond the surface of the individual, so they are useful for imaging objects hidden under clothing but are not useful for detecting objects hidden in body cavities. Backscatter systems are currently being used in the United States by Customs and Border Protection (CBP) and by several prisons for interdiction of drugs, weapons and contraband. A typical scan lasts about 8 s and results in an effective dose (Section 2.3) of approximately $0.03 \mu\text{Sv}$ (microsievert)¹ to the individual. With transmission systems, the x rays traverse through the body, similar to a medical x ray, so that objects that have been swallowed or hidden in body cavities may be visible. At least one model of a transmission scanning system is currently used outside the United States to screen workers exiting mines (*e.g.*, diamond mines) and at customs checkpoints in lieu of invasive body-cavity inspection. Subjects being scanned move through the beam in approximately 10 s and the effective dose per scan is on the order of 3 to 6 μSv .

Possible future developments for systems to scan humans using ionizing radiation are: combination systems using backscatter and transmission, systems using gamma rays, scanning of passenger vehicles at customs checkpoints or vulnerable bridges or tunnels, software algorithms that alleviate privacy concerns by recognizing and avoiding depiction of human anatomy, and improved imaging technology or radiation detection that permits the use of lower levels of radiation exposure (Section 3.3).

¹1 μSv is equal to 0.1 mrem (millirem) in the previous system of units for radiation doses.

Presently, there are also security scanners for the inspection of trucks, sea containers, train cars, or other cargo containers that use either gamma rays emitted by a radionuclide (*e.g.*, ^{137}Cs or ^{60}Co) or machine-generated radiation (*e.g.*, x rays or neutrons). Although these systems are not intended to expose humans intentionally, individuals hiding inside the container or vehicle being inspected can be inadvertently exposed. Radiation doses from these systems that would be received by humans hiding in the cargo compartment are in the range of <1 to ~ 100 μSv per scan for the radionuclide or x-ray sources. In addition, a pulsed fast neutron analysis (PFNA) system is being evaluated for use in scanning cargo with neutrons. This system can identify a number of illicit materials by the pattern of the resulting gamma radiation. The radiation protection advice for PFNA systems is the subject of NCRP Commentary No. 17 (NCRP, 2003).

Screening systems that do not utilize ionizing radiation are also available and the following types are rapidly evolving: trace-chemical detection devices, millimeter-wave holographic imagers, dielectric portals, ultrasound imagers, and quadrupole resonance analyzers (Section 3.4). Such devices should be evaluated as alternatives to systems that utilize ionizing radiation.

The goal of radiation protection is to prevent the occurrence of serious radiation-induced acute and chronic deterministic effects (*e.g.*, cataracts) and to reduce the potential for stochastic effects (*e.g.*, cancers) in exposed persons to a degree that is acceptable in relation to the benefits to the individual and to society from the activities that generate such exposures (NCRP, 1993). Section 5 and Appendix A of this Commentary discuss health effects related to exposure to low doses of ionizing radiation. The radiation protection principles underlying NCRP recommendations are: justification of the practice; keeping radiation exposures as low as reasonably achievable, economic and social factors being taken into account (the ALARA principle); and dose limits for individuals (Section 6).

NCRP (1993) recommends that the annual dose limit for a member of the general public for continuous or frequent exposure should not exceed an effective dose of 1 mSv (millisievert), excluding exposures from natural background and from medical care. This recommendation is designed to limit exposure of members of the public to reasonable levels of risk comparable to other common risks (NCRP, 1993). However, because a member of the public might be exposed to more than one source of man-made radiation in a year, NCRP (1993) recommended that:

“...whenever the potential exists for exposure of an individual member of the public to exceed 25 percent of the annual effective dose limit as a result of irradiation attributable to a single site, the site operator should ensure that the annual exposure of the maximally exposed individual, from all man-made exposures (excepting that individual’s medical exposure), does not exceed 1 mSv on a continuous basis. Alternatively, if such an assessment is not conducted, no single source or set of sources under one control should result in an individual being exposed to more than 0.25 mSv annually.”

It is this administrative control of 0.25 mSv effective dose (or less) per year for a member of the public (for a single source or set of sources under one control) that this Commentary recommends be used for individuals undergoing security screening procedures with x-ray scanning devices. In this Commentary, the term “under one control” typically refers to the use of ionizing radiation scanning systems at one or more security checkpoints at a given venue (such as multiple checkpoints at a given airport). The word “venue” is used in this context throughout this Commentary.

NCRP (1993) also includes the concept of a negligible individual dose (NID). NID is an effective dose corresponding to the level of average annual excess risk of fatal health effects attributable to radiation exposure below which effort to further reduce the exposure to an individual is not warranted. NID was set at an annual effective dose of 10 μSv (0.01 mSv) per source or practice. This concept is useful in developing radiation protection advice for exposures from the x-ray scanning systems, and in helping to put levels of effective dose per scan encountered with an x-ray scanning system into perspective.

This Commentary recommends classifying scanning systems that utilize ionizing radiation for security screening of humans into two categories: *general-use* and *limited-use systems*.

1.1 General-Use Systems

General-use systems should adhere to an effective dose of 0.1 μSv or less per scan, and can be used mostly without regard to the number of individuals scanned or the number of scans per individual in a year.

An effective dose of 0.1 μSv per scan would allow 2,500 scans of an individual annually (*i.e.*, if each scan required 0.1 μSv) without exceeding the administrative control of 0.25 mSv to a member of the general public for a single source or set of sources under one control. Assuming 250 workdays per year, this would correspond to an average of 10 scans each day, a frequency that is unlikely to be encountered. An effective dose of 0.1 μSv (or less) per scan is consistent with the American National Standards Institute (ANSI) standard which recommends that value (or less) per scan for security scanners (ANSI, 2002).

1.2 Limited-Use Systems

Limited-use systems include all other ionizing radiation scanning systems that require effective doses per scan greater than 0.1 μSv and less than or equal to 10 μSv . These systems should be used with discretion in terms of the number of individuals scanned and the number of scans per individual in a year. At 10 μSv per scan, an effective dose of 0.25 mSv would be reached after 25 scans.

The users of these systems will need to determine how to implement the use of a limited-use system to provide reasonable assurance that the annual effective dose to an individual is 0.25 mSv or less for a single source or set of sources at a given venue. NCRP recognizes that providing reasonable assurance that individuals will not exceed 0.25 mSv y^{-1} may be difficult to implement. However, users of these systems must accept such responsibility.

Manufacturers of limited-use systems should always design the systems to utilize the lowest amount of radiation (below 10 μSv per scan) commensurate with the required imaging performance of the device, in keeping with the ALARA principle (Section 6).

Manufacturers of all ionizing radiation scanning systems should provide the user with information on the effective dose to an individual per scan (for each possible operational mode), using appropriate calculations such as the ANSI (2002) method, and taking account of the x-ray energy spectrum for each operational mode of the system. In addition, the manufacturer will need to provide the corresponding values of a readily measured field quantity (such as air kerma) for each mode of operation. Such information will be necessary in routine practice to verify the system performance for a given mode of operation, and to assist the user in achieving the administrative control of 0.25 mSv effective dose (or less) per year. This verification procedure assumes that the relationship between the field quantity and the resulting effective dose is relatively constant for a given mode of operation.

A number of other considerations, important to the implementation of the radiation protection advice set out above for general-use and limited-use systems, are listed in Section 10.

This Commentary recommends that the annual effective dose limit for public bystanders (*i.e.*, individuals not undergoing scanning) should be the same as that for individual members of the public (*i.e.*, 1 mSv for continuous or frequent exposure from all relevant sources), and should be implemented in the same manner as for individuals undergoing scanning by adhering to the administrative control of 0.25 mSv effective dose (or less) per year for a single source or set of sources at a given venue. This Commentary also recommends that scanning systems be designed and installed in such a way as to allow the same level of control on effective dose for operators as for members of the general public.

2. Introduction

The Food and Drug Administration (FDA) asked NCRP for advice on radiation protection issues concerning exposure to ionizing radiation from radiation-producing devices used for nonmedical security purposes. These devices, particularly x-ray scanning systems, are being considered for use by various agencies (*e.g.*, CBP and Transportation Security Administration) for use in security screening of humans.

This NCRP Commentary addresses: (1) the types of ionizing radiation scanning systems that are being proposed for use in screening humans, (2) the circumstances under which individuals might be scanned by the devices, (3) the possible types of sites of use of the security devices, (4) the levels of ionizing radiation received from these devices by individuals being scanned for security purposes, (5) the potential for adverse health outcomes from these devices, (6) the limitation of radiation exposure to individuals who undergo scanning for security purposes, and (7) the limitation of general public exposure from use of ionizing radiation from these scanning devices.

2.1 Scope of the FDA Request

In particular, FDA asked NCRP to address the following topics:

- risk assessment (including genetic risks and cancer);
- appropriate use conditions and locations of equipment;
- targeted and susceptible populations (frequent flyers, prison visitors, women of child-bearing age, children, etc.);
- single examination dose limits, repeat exposures, operator exposure, and annual exposure/dose limits;
- need for and appropriate use of “informed consent”;
- operator experience and training in the context of “image” quality;
- what constitutes a “net benefit” [protecting life (weapons), catching contraband, reducing losses (theft), etc.];
- record keeping of an individual’s exposure; and
- general screening versus evaluations of a targeted individual.

2.2 Scope of NCRP Advice

The radiation protection advice in this Commentary addresses the topics above and other related topics in the following ways:

- It is compatible with the existing NCRP system of radiation protection recommended in NCRP Report No. 116, *Limitation of Exposure to Ionizing Radiation* (NCRP, 1993), but also takes into account the enhanced concern for security in the United States.

- It includes a brief review of the known risks from ionizing radiation (*e.g.*, genetic effects, cancer mortality and morbidity) and particularly the significance of those risks at the radiation levels resulting from the use of these scanning devices.
- It points out that justification of the use of such devices (*e.g.*, at airports, bus stations, gangways to ships, or other locations) and what constitutes a “net benefit” (*e.g.*, protection of life from weapons, or detection of contraband) are broader societal questions and outside of NCRP’s role as defined by its Congressional charter.
- It considers the groups of individuals that would be screened or otherwise investigated with scanners for security purposes (*e.g.*, individuals being inspected for contraband or other reasons). It also considers special subgroups such as pregnant women (for protection of the embryo or fetus) and individuals who might undergo multiple exposures (*e.g.*, frequent flyers, prison visitors).
- It provides recommendations for keeping radiation doses commensurate with the need to obtain useful images for security purposes. It also addresses the ALARA principle (Section 6.1) and its application to the use of security devices. Consideration is given to the doses resulting from single and multiple inspections of scanned individuals, and to the doses to system operators and public bystanders (*i.e.*, persons other than the individuals scanned).
- It includes the need for appropriate communication with the affected parties (*i.e.*, individuals who are scanned and operators of devices) concerning radiation exposure and its possible consequences, and the need for responsible parties to provide such information that is easy to understand and presented in the individual’s primary language.
- It addresses the requirements for training and experience of operators of the scanning devices concerning radiation exposure aspects. The requirements will vary depending on the detection capabilities of the scanning device and the associated radiation risk to operators and to individuals exposed to the radiation produced by the imaging system. The training requirements depend on the manufacturer’s specifications, plus decisions by the authorized agency on the types of material to be detected (*e.g.*, plastic explosives, firearms, other contraband) and the necessary image quality needed to detect the items.
- It addresses the possible need for record keeping for radiation exposure of the various scanned individuals or groups, including when record keeping might be necessary, who should keep the records and the quantities to be recorded.
- It addresses initial and periodic testing of the scanning systems to ensure conformance with the appropriate effective dose per scan criterion.

2.3 Effective Dose

Radiation doses from exposures that may result in delayed stochastic effects are expressed in the quantity effective dose (E):

$$E = \sum_T w_T H_T \quad (2.1)$$

where H_T is the equivalent dose in an organ or tissue T, and w_T is the tissue weighting factor that accounts for the radiation sensitivity of an organ or tissue T. In this Commentary, effective doses are given in milli- or microsieverts.

The equivalent dose (H_T) (also given in milli- or microsieverts) is obtained as:

$$H_T = \sum_R w_R D_{T,R} \quad (2.2)$$

where $D_{T,R}$ is the mean absorbed dose [in milligray (mGy) or microgray (μ Gy)] in an organ or tissue T due to a given type of radiation R, and w_R is the radiation weighting factor that accounts for the biological effectiveness of radiation type R. For external exposure, w_R applies to the type of radiation incident on the body.

The purpose of effective dose is to place on a common scale the radiation doses: (1) from different types of ionizing radiation that have different biological effectiveness, and (2) in different organs or tissues that have different radiation sensitivities. When the type of radiation interacting with the human body is x or gamma rays, w_R is assigned the value of one (ICRP, 1991; NCRP, 1993). The values of w_T for the various organs or tissues are the same for all radiations and can be found in the International Commission on Radiological Protection (ICRP) Publication 60 (ICRP, 1991) or NCRP Report No. 116 (NCRP, 1993).