



American National Standard
ANSI/HPS N43.14-2011

**Radiation Safety for Active Interrogation
Systems for Security Screening of Cargo,
Energies up to 100 MeV**

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American National Standards Institute, Inc.



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Radiation Safety for Active Interrogation Systems for Security Screening of Cargo, Energies up to 100 MeV

Abstract

(This abstract is not part of the American National Standard ANSI/HPS N43.14.)

This standard establishes radiation safety policies and procedures for the safe use of active interrogation systems in applications involving the detection of weapons of mass destruction (WMD) and other contraband in trucks and cargo containers. The intent and purpose of this standard is to ensure that the workers and members of the general public (including stowaways) are protected from excessive exposure to ionizing radiation (such as high-energy photons, neutrons, and charged particles) and that the radiation exposures to these individuals are maintained well within the regulatory limits as established by Nuclear Regulatory Commission (NRC), Occupational Safety and Health Administration (OSHA), and other federal and state regulatory agencies. This document also contains a number of annexes that provide useful information and guidance in implementing this standard.

Key words: active interrogation, bremsstrahlung, fast neutrons, gamma rays, health physics, high-energy photons, induced radioactivity, linear accelerator (LINAC), national standard, neutron activation, radiation generating device (RGD), radiation safety, sealed radioactive sources, sealed tube neutron generator (STNG), weapons of mass destruction (WMD), x-rays.

Preface

(This preface is not part of the American National Standard ANSI/HPS N43.14.)

Increased vigilance in the area of homeland security requires that cargo containers entering the USA be screened for the detection of weapons of mass destruction (WMD) and other contraband such as chemical warfare agents, drugs, and explosives. Although security imaging systems using x-rays and gamma rays have been deployed at U.S. ports of entry, there is a need to develop and deploy active interrogation systems to augment and enhance the process of interdiction of dangerous cargo.

Active interrogation systems depend on the interaction of the incident radiation, either neutrons or high-energy photons, with the nuclei of the object under interrogation. Nuclear reactions such as inelastic scattering ($n, n'\gamma$), thermal neutron capture (n, γ), photonuclear reactions (photo-fission [γ, xn], or fast neutron induced fission) are good examples of such reactions and yield information that can be used to “identify” the material. Another example is nuclear resonance fluorescence (NRF), in which the nuclear levels of the target nuclei are excited by incident photons with the resultant emission of characteristic fluorescence gamma rays, which are detected by appropriate detectors. In all these systems the object under interrogation is “actively” participating in the physical processes taking place in the system.

On the other hand, in a security imaging system using x-rays and gamma rays, the parts of the object being inspected are blocking different amounts of the incident radiation, thereby forming an image at the detector. This is the basis for “anomaly” detectors, which can give information about the size, shape, density, and location of the object of interest inside the container. Commercial examples of such techniques currently in use employ radiation sources such as radioisotopes, x-ray tubes, or bremsstrahlung from electron accelerators.

An ANSI standard, N42.41, entitled “Minimum Performance Criteria for Active Interrogation Systems Used for Homeland Security,” 2007, has been published by the IEEE Secretariat. The ANSI N42.41 standard deals primarily with the performance standards of active interrogation systems. This standard, ANSI N43.14, focuses on the establishment of radiation safety policies and procedures for the safe operation of the active interrogation systems.

There are gaps in federal and state regulations regarding the safe operation of accelerator systems and x-ray sources. NRC regulations apply only to radioactive byproduct use, whereas FDA regulations for devices producing radiation apply only to manufacturing and maintenance, but not to the operation of the devices. Active interrogation systems may employ byproduct materials, accelerators, x-ray generators, and combinations of these radiation sources for the production of the interrogating radiation. This standard specifies radiation safety policies and procedures for the operation of all of these diverse radiation sources by drawing on the most applicable existing NRC, FDA, and OSHA regulations and NCRP recommendations, without regard to regulatory boundary limits and extending the applicable standards to bridge the existing gaps.

Part A of this standard contains the following sections: Scope (Sec. 1.0), Applicable Documents (Normative References) (Sec. 2.0), Definitions of Terms (Sec. 3.0), Modalities of Systems and Types of Installations (Sec. 4.0), Administrative Controls (Sec. 5.0), Engineered Controls (Sec. 6.0), and Radiation Safety in System Operation (Sec. 7.0).

Part B of this standard contains informative material: Administrative Controls (Annex A), Radiation Safety for a “Closed” Installation (Annex B), Radiation Safety for an “Open” Installation (Annex C), Special Dose Rate Measurement Instrumentation (Annex D), Radiation Transport Code Simulations for Radiation Safety (Annex E), Induced Radioactivity (Annex F), and Bibliography (Informative References) (Annex G). The information in the annexes does not constitute the essential part of this standard and is for assistance in implementing the provisions of the standard only.

In the context of this standard, the meaning of the words “shall” and “should” is as follows. Those recommendations containing the word “shall” identify requirements that are necessary to meet the

standards of protection in this document, if one fully intends to adhere to this standard. Those using the word “should” signify advisory recommendations that are to be applied when practical.

Since the active interrogation systems will be deployed in close proximity to the public at locations such as land border crossings, seaports, and airports for the security screening of cargo, this standard establishes policies and procedures to ensure the radiation safety of the operators of these systems, members of the general public, and possible stowaways from excessive exposure to ionizing radiation. Furthermore, since active interrogation systems are frequently located and operated in close proximity to the public, the installations housing these systems have intentionally been provided additional radiation shielding such that all personnel (operators, dock workers, shipper's agents, etc.) in the vicinity of such installations do not receive a dose greater than 1 mSv (100 mrem) in a year. The ALARA (As Low As Reasonably Achievable) principle is used to keep the exposure as far below this level as practical.

This standard is also intended to provide guidance in the area of radiation safety to the manufacturers of active interrogation systems, test and evaluation teams of the developers of these systems, and other stakeholders.

Radiation Safety for Active Interrogation Systems for Security Screening of Cargo, Energies up to 100 MeV

1.0 Scope

This standard applies to non-intrusive inspection (NII) systems using active interrogation methods for the detection of contraband (drugs, explosives, and weapons of mass destruction [WMD]). High-energy neutrons have been used for such purposes but other methods are being developed that use high-energy photons as well. In particular, this standard covers the safety aspects of active interrogation systems, henceforth called "systems," using, but not limited to, high-energy x-rays (bremsstrahlung) produced by high-energy electron linear accelerators, high-energy neutrons produced by the (d,d) and (d,T) reactions, fission neutrons from ^{252}Cf , high-energy neutrons produced by (γ ,n) reaction in linear accelerators using Be/W targets, or other accelerator methods for producing high-energy photons and neutrons. (In this standard, the term *high-energy photons* is used to mean high-energy x-rays and gamma rays in the MeV range of energies.)

The maximum energy of the ionizing radiation used for interrogation by these systems is limited to 100 MeV because the use of general-purpose active interrogation systems employing energies greater than this level is not expected in the foreseeable future.

This standard does not apply to conventional security imaging systems using x-rays and gamma rays. However, it includes hybrid systems combining active interrogation systems with conventional security imaging systems. In that case, a hybrid system capable of doing both functions shall meet the standards of both types of systems.

This standard does not apply to general safety involving mechanical failure, electrical shock, chemical explosion, gases under pressure, and noxious gases. It also does

not apply to possible damaging effects of ionizing radiation to foods, medical devices, pharmaceuticals, photographic films and papers, and microelectronic devices containing computer chips.

2.0 Applicable Documents (Normative References)

2.1 Federal and State Regulations

- 10 CFR 20 (Standards for Protection Against Radiation), 2009 (NRC).
- 10 CFR 835 (Occupational Radiation Protection), 2009 (DOE).
- 29 CFR 1910.1096 (Ionizing Radiation), 2009 (OSHA). (Applicable to all workers not covered by NRC, DOE and state regulations.)
- Applicable state regulations.

2.2 Related ANSI Standards

- ANSI/IEEE N42.41, Minimum Performance Criteria for Active Interrogation Systems for Homeland Security, 2007.
- ANSI/HPS N43.3, For General Radiation Safety – Installations Using Non-medical X-Ray and Sealed Gamma-Ray Sources, Energies Up to 10 MeV, 2008.
- ANSI/HPS N43.6, Sealed Radioactive Sources – Classification, 2007.
- ANSI/HPS N13.6, Practice for Occupational Radiation Exposure Records Systems, Health Physics Society, May 6, 1999.
- ANSI/ANS-6.1.1, Neutron and Gamma-Ray Fluence-to-Dose Factors, 1991. (Withdrawn 2001 but still accurate [Nuclear News, 2004].)

3.0 Definitions of Terms

Note: The definitions of terms contained in this standard are not intended to convey all legitimate meanings of the terms. They are applicable only to the subject matter treated in this standard and are provided in this section for clarity and to facilitate common understanding of the provisions in this standard. These definitions are not intended to supersede similar terms that are defined in applicable federal and state regulations.

Absorbed Dose (D): The energy imparted to matter by ionizing radiation per unit mass of irradiated material. The SI (Système International) unit of absorbed dose is 1 joule per kilogram (J kg^{-1}) and its special name is gray (Gy). $1 \text{ Gy} = 100 \text{ rad}$.

Active Interrogation: Use of highly penetrating ionizing radiation (neutrons or photons) to detect and identify concealed chemical, explosive, and nuclear materials through the detection of stimulated secondary radiations (or, by nuclear resonance contrast), giving elemental composition of the substance of interest. This includes security imaging systems that have the ability to identify detected anomalies by elemental composition.

Agreement State: A state that has signed an agreement with the NRC authorizing the state to regulate certain uses of radioactive materials within the state.

ALARA [As Low As Reasonably Achievable]: The principle that requires making every reasonable effort to maintain exposures to radiation as far below the regulatory dose limits as practical, taking into consideration the state of technology, the economics of improvements in relation to benefits to health and safety, and other societal and socioeconomic considerations.

Attenuation: The reduction in intensity, flux, or fluence of radiation due to interactions of the radiation with the material through which it is passing.

Barrier: A structure (e.g., shielding wall or fence) that prevents or controls access to a building or an area where radiation levels and other hazards are unacceptable.

Beam: The flow of electromagnetic or particulate radiation that is either collimated into a fan or restricted to a cone.

Beam Stop: A physical or mechanical device capable of stopping the beam and keeping the downstream areas safe when inserted into the beam line.

Cargo: The goods or merchandise conveyed in a cargo container or truck.

Collimator: A device to limit the size, shape, and direction of the primary beam.

Committed Effective Dose (E_{50}): The sum of the committed equivalent doses to various tissues or organs in the body ($H_{T,50}$), each multiplied by the appropriate tissue weighting factor (w_T)—that is, $E_{50} = \sum w_T H_{T,50} + r_{\text{Remainder}} H_{\text{Remainder},50}$, where $r_{\text{Remainder}}$ is tissue weighting factor assigned to the remainder organs and tissues and $H_{\text{Remainder},50}$ is the committed equivalent dose to the remainder organs and tissues. Committed effective dose is expressed in units of Sv (rem).

Committed Equivalent Dose ($H_{T,50}$): The equivalent dose calculated to be received by a tissue or organ over a 50-y period after the intake of a radionuclide into the body. It does not include contributions from radiation sources external to the body. Committed equivalent dose is expressed in units of Sv (rem).

Contraband: For the purpose of this standard any material illegally imported into the United States. Examples are chemical warfare agents, drugs, explosives, and special nuclear material (SNM).

Controlled Area: A specified area in which access of personnel to radiation or radioactive material is controlled. A controlled area should be under the supervision of a person (such as the radiation safety officer) who has knowledge of the appropriate radiation protection practices and regulations and who has the authority to implement them. Radiation workers may be allowed access within this area if they meet access requirements (e.g., have required training and wear dosimeters). A controlled area may include within itself an exclusion zone, where no one is allowed to remain once the active interrogation system is operating.

Deep Equivalent Dose (H_d): The equivalent dose estimated for a tissue depth of 1 cm. The deep equivalent dose applies to external whole-body exposure and is intended to represent the upper limit to the dose received by the major organs and tissues of the body other than the skin, the lens of the eye, and the extremities.

Duty Factor: The fraction of actual beam ON time over the length of an accelerator beam cycle (e.g., a 5- μ s-long pulse with repetition rate of 200 Hz will have a duty factor of $0.001 = 10^{-3}$).

Effective Dose (E): The tissue weighted sum of the equivalent doses in all specified tissues and organs, given by the expression: $E = \sum w_T \times H_T$, where w_T is the tissue weighting factor and H_T is the equivalent dose in tissue or organ T. The unit of effective dose is joule per kilogram ($J\ kg^{-1}$) and its special name is sievert (Sv). $1\ Sv = 100\ rem$.

Equivalent Dose (H_T): The dose in a tissue or organ given by $H_T = \sum w_R \times D_{T,R}$, where w_R is the radiation weighting factor and $D_{T,R}$ is the mean absorbed dose from radiation R in a tissue or organ T. The unit of equivalent dose is joule per kilogram ($J\ kg^{-1}$) and its special name is sievert (Sv). $1\ Sv = 100\ rem$.

Exclusion Zone (or Area): A cordoned-off zone or area surrounding the active interrogation system inside which no one, not even a radiation worker, is allowed when the system is operating. This definition applies to "open" systems where there is no shielding in the path of the primary beam and it is possible to use distance for radiation safety. *A radiation safety exclusion zone can be a subset of the controlled area.*

Exposure: A measure of ionization produced in air by x or gamma radiation of energies less than or equal to 3 MeV. It is the sum of the electrical charges of all of the ions of one sign produced in air when all electrons liberated by photons in a volume of air are completely stopped in the air, divided by the mass of the air in that volume. The SI unit of exposure is coulomb per kilogram ($C\ kg^{-1}$). A roentgen, R, is the conventional unit for exposure, where $1\ R = 2.58 \times 10^{-4}\ C\ kg^{-1}$. ("Exposure" is also colloquially used to express contact with a radiation field. Its use either in the technical sense above or in the more conventional sense should be obvious by context.)

Facility: See Installation.

Gray (Gy): The special SI name given to the unit of absorbed dose. $1\ Gy = 1\ J\ kg^{-1} = 100\ rad$.

High-energy Photon: X- or gamma ray photon of energy greater than 1 MeV.

High Radiation Area: An area, accessible to individuals, in which radiation levels from radiation sources could result in an individual's receiving an equivalent deep-dose (H_d) in excess of 1 mSv (100 mrem) in 1 h at 30 cm (1 foot) from the radiation source or 30 cm (1 foot) from any surface that the radiation penetrates.

Ionizing Radiation: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, by interaction with matter, including x- and gamma rays, alpha or beta particles, or neutrons.

Induced Radioactivity: Radioactivity that is produced and remains after the source of radiation (neutrons, gamma rays, or x-rays) is turned off as a consequence of the primary radiation beam or secondary particles interacting with matter. This is also called *radioactivation* or *residual radioactivity*.

Installation: The structure, consisting of a building or barriers, inside which a system is set up for use.

Interlock: An engineered control system arranged to sense a limit or off-limit condition or improper sequence of events to enable equipment shutdown or prevent entry to an area of radiation hazard, or to terminate system operation to ensure radiation safety.

Leakage Radiation: All radiation, except the useful (primary) beam coming from the source of radiation (accelerator head or deuterium cell or tritium target).

Neutron Activation: See Induced Radioactivity.

Non-intrusive Inspection (NII) System: An imaging or active interrogation system that makes it possible to detect or identify contraband (e.g., WMD, drugs, explosives, or other illicit materials) or people without

opening containers (e.g., handbags, suitcases, cargo containers, etc.).

Non-radiation Worker: A worker who is not permitted to receive a whole-body dose greater than 1 mSv (100 mrem) in 1 y and 0.02 mSv (2 mrem) in any 1 h. This dose limit also applies to members of the general public.

Non-stochastic Effects: Health effects, the severity of which increase with dose and/or for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a non-stochastic (also called *deterministic*) effect.

Nuclear Resonance Contrast: Radiographic contrast that permits isotopic or elemental identification through energy-dependent resonances in either neutron- or gamma-induced reactions.

Occupancy Factor (T): The factor (fraction of time) by which the source term should be multiplied to correct for the degree or type of occupancy of the area specified. For example, it is 0 for unoccupied areas (wide-open space), 0.25 for parking lots and 1 for occupied areas such as office buildings. (See Table B1 in Annex B.)

Primary Radiation: Radiation coming directly from the source of radiation, not leakage or scattered radiation.

Primary Beam: A beam coming directly from the source of radiation, not leakage or scattered radiation.

Qualified Expert: In the context of radiation safety, a person having knowledge and training necessary to measure ionizing radiation, analyze the significance and evaluate the potential health hazards, and advise the workers and management regarding radiation protection. Examples of persons considered to be qualified experts are those possessing experience in industrial use of radiation and who are certified by the American Board of Health Physics, the American Board of Radiology, or the American Board of Medical Physics, or those individuals having equivalent qualifications.

Rad: The conventional unit of absorbed dose. One rad equals 100 erg g^{-1} (0.01 J kg^{-1}). $1 \text{ rad} = 0.01 \text{ Gy}$, or $100 \text{ rad} = 1 \text{ Gy}$.

Radiation Area: Any area accessible to individuals in which radiation levels could result in an individual's receiving deep-dose equivalent in excess of 0.05 mSv (5 mrem) in 1 h at 30 cm (1 foot) from the source or 30 cm (1 foot) from any surface that the radiation penetrates.

Radiation Generating Device (RGD): In the context of this standard it includes, but is not limited to, accelerators (e.g., betatrons, linear accelerators, and neutron generators) or radioisotopes (e.g., ^{252}Cf) capable of producing high-energy neutrons or photons in a pulsed or continuous mode for the purpose of active interrogation of contraband. These devices are typically housed within a fixed interlocked and/or shielded enclosure.

Radiation Safety Officer (RSO): A qualified expert who is responsible for establishing and maintaining a radiation safety program at a facility using an RGD.

Radiation Weighting Factor (w_R): An energy-dependent, dimensionless factor by which the absorbed dose is to be multiplied to obtain, for radiation safety purposes, a quantity that expresses the magnitude of radiation effects likely to be incurred by exposed persons on a common scale for all types of ionizing radiations. The radiation weighting factor (quality factor) for x-rays and gamma rays is 1 and that for neutrons of unspecified energy is 10, for example.

Radiation Worker: Any individual whose occupation involves exposure to radiation and who is likely to receive more than 1 mSv (100 mrem) but less than 50 mSv (5 rem) in a year from the occupation.

Rem: The conventional unit of effective or equivalent dose. One rem = 0.01 Sv, or $1 \text{ Sv} = 100 \text{ rem}$. It is only applicable to dose rates resulting in stochastic effects.

Roentgen (R): The conventional unit of exposure. One roentgen equals $2.58 \times 10^{-4} \text{ C kg}^{-1}$ of air at STP. One roentgen of x- or gamma rays gives an absorbed dose in air

of 8.78×10^{-3} Gy (0.878 rad) and an absorbed dose in tissue of $\sim 9.5 \times 10^{-3}$ Gy (~ 0.95 rad), depending on photon energy.

Scattered Radiation: Radiation whose path or direction of propagation has deviated as a result of interaction with matter and that has been reduced in energy and intensity.

Scram Switch: A switch or button used to terminate the emission of radiation from an RGD in any emergency situation.

Security Imaging System: A system that uses radiography with visual detection or a system with automated detection/material discrimination capability.

Sievert (Sv): The special name for the SI unit of equivalent dose (H). $1 \text{ Sv} = 1 \text{ J kg}^{-1} = 100 \text{ rem}$.

Shielding: Attenuating material used to reduce the intensity of radiation.

Skyshine: Radiation reflected back to earth by the atmosphere above an installation utilizing high-energy photons and neutrons.

Source Term: The output from a RGD at 1 m from the exit slit, expressed in gray (rad) per minute in the manufacturer's technical specification sheet.

Stochastic Effects: Health effects that occur randomly and for which the probability of the effect's occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Incidence of cancer is an example of a stochastic effect.

System: In the context of this standard, the (active interrogation) system includes the RGD (radiation source and its shielding, power supplies, and cooling systems); the detectors and associated electronics; safety interlocks; command center booth (operator console/data storage, and alarm/annunciator system); radiation monitoring systems; and the software that runs it.

Tenth-Value Layer (TVL): The thickness of material required to reduce the intensity of the beam to one-tenth its incident value.

Total Effective Dose (TED): The sum of the *deep equivalent dose* (for external exposures) and the *committed effective dose* (for internal exposures).

Use Factor (U): This is the ratio of the scan time and inspection time (including scan time) on a per-inspection basis and is usually calculated using an hourly, daily, or weekly time frame. For example, if the scan time is 10 s and the inspection time (time between the start of scans) is 60 s, then the use factor is $U = 10/60 = 0.167$.

Very High Radiation Area: Any area accessible to individuals in which radiation levels from radiation sources external to the body could result in an individual's receiving a deep-dose equivalent in excess of 5 Gy (500 rad) in 1 h at 1 m (3.3 feet) from the source or 1 m (3.3 feet) from any surface that the radiation penetrates.

4.0 Modalities of Systems and Types of Installations

The active interrogation systems may be distinguished by the details of their operation or modality. These systems can be configured in various modalities depending on the type of operation for which they are designed (e.g., scanning trucks or cargo containers, scanning packages on a conveyer belt, inspecting the interior of an abandoned vehicle, etc.).

From a radiation safety consideration, the types of installation will depend on whether radiation protection is afforded only through shielding (closed installation), or only through distance (open installation), or through a combination of material shielding and distance (hybrid installation).

4.1 Modalities of Active Interrogation Systems

Fixed Systems: Because of the size of the object to be interrogated, such as a cargo container, and the intensity and energy of the incident radiation, these systems are by necessity heavily shielded to protect the workers and members of the general public. Once installed at a given location they

cannot be moved and are fixed. For example, these systems can be located either inside a “closed” or inside a “hybrid” installation (see descriptions below).

Relocatable Systems: These systems are capable of being assembled and disassembled in a relatively short time, in case they are required to be moved to another location. For example, these systems can be located inside an “open” installation (see description below).

Transportable (or Mobile) Systems: These systems are mounted on a moving platform, such as a truck chassis, and can be transported to various locations. For example, these systems can be located inside an “open” installation (see description below).

Portable Systems: The components of these systems are small enough to be carried by a person and assembled on-site to perform the interrogation of the container. For example, these systems can be located inside an “open” installation (see description below).

Portal Systems: These systems are either fixed or can be relocated, and as the name implies the conveyance being examined is either pulled through them or is driven through them. For example, these systems can be located inside an “open” installation (see description below).

4.2 Types of Installations Containing Active Interrogation Systems

From radiation safety considerations, there are three types of installations defined as follows:

“Closed” installation: In this installation, the system is completely shielded, including the entrance and exit of the interrogation tunnel. Shielding of the primary and secondary (scattered as well as leakage) radiation is provided with the choice of appropriate materials of thicknesses sufficient to meet the design goal.

“Open” installation: In this installation, the source is shielded but the primary and the secondary radiations are not shielded. Protection from primary and secondary

(scattered as well as leakage) radiation is achieved through the use of distance (establishment of a radiation safety exclusion zone) around the system.

“Hybrid” installation: In this installation a combination of shielding and distance is used to ensure radiation safety of workers and members of the general public. An example is an installation where the doors of the fixed, shielded enclosure are left open to facilitate rapid inspection of trucks.

5.0 Administrative Controls

5.1 Radiation Safety Program Plan

A well written and carefully implemented radiation safety program plan constitutes the foundation of successful administrative controls. Each organization (manufacturer or user) shall have a radiation safety program plan in place to ensure the radiation safety of workers and members of the general public. It may be advisable for a small company or licensee to seek the assistance of a radiation safety consultant (e.g., a qualified expert). A discussion of the components of a radiation safety program plan is given in Appendix A for completeness. However, all radiation safety program plans shall be specific to the facility.

5.2 Radiation Safety Committee

The Radiation Safety Committee (RSC) should be a crucial part of the radiation safety program plan. The responsibilities of the RSC should include the following activities:

- Approve the installation, testing and evaluation, and operation of newly acquired active interrogation systems;
- Review installation radiation safety practices and standard operating procedure (SOP);
- Develop written rules and procedures for radiation safety;
- Appoint the radiation safety officer (RSO);
- Review dosimetry records;
- Approve an emergency response plan; and

- Ensure that the radiation exposure to workers and members of the general public, including stowaways, are kept ALARA (As Low As Reasonably Achievable).

Details of the RSC responsibilities are given in Annex A.

5.3 Radiation Safety Training

Radiation safety training at all levels (RSO, technicians, operators, and helpers) shall be conducted as part of the radiation safety program plan to ensure safe operation of the system. For details, see Annex A.

5.4 Monitoring of Radiation Exposure

Radiation exposure to system operators and workers shall be monitored with a dosimeter such as film, thermoluminescent dosimeter (TLD), optically stimulated luminescence (OSL) dosimeter, direct ion storage (DIS) dosimeter, radiophoto luminescent (RPL) dosimeter or electronic dosimeters, etc., provided under the scope of an accredited, licensed, or approved dosimetry service, while they are working in the vicinity of the active interrogation systems. The dosimeters shall be selected by a qualified expert to be appropriate for the types and energies of radiations being encountered. Dosimetry records shall be maintained for the duration of time specified by federal and state regulations.

5.5 Warning Signs for Access Control

Closed, open, and hybrid installations shall have appropriate access controls while the system is in operation, as given below.

5.5.1 “Closed” Installations All installations containing a fixed system shall display the most restrictive of the following signs at the entrances:

“GRAVE DANGER,” “VERY HIGH RADIATION AREA” and the radiation symbol (See 10 CFR 20), if the dose rate from the radiation source exceeds 5 Gy (500 rad) in any 1 h at 1 m from the source (see definition of Very High Radiation Area in Sec. 3).

“DANGER,” “HIGH RADIATION AREA” and the radiation symbol, if the dose rate from the radiation source exceeds 1 mSv (100 mrem) in any 1 h at 30 cm (1 foot) from the source (See definition of High Radiation Area in Sec. 3).

“CAUTION,” “RADIATION AREA” and the radiation symbol, if the dose rate from the radiation source exceeds 0.05 mSv (5 mrem) in any 1 h at 30 cm (1 foot) from the source (See definition of Radiation Area in Sec. 3).

The signs shall be placed so that they are readily visible to anyone approaching the access doors.

No person (with the exception of a stowaway), either within the controlled area or in the uncontrolled areas of the installation, shall be exposed to more than the maximum permissible dose (MPD). See Table 1.

The dose at any accessible uncontrolled area shall not exceed 0.02 mSv (2 mrem) in any 1 h on the outside surface of the enclosure. (See note below Table 1.)

5.5.2 “Open” Installations All installations containing systems that are not fixed shall display the most restrictive of the following signs at the boundaries of the radiation safety exclusion zone:

“DANGER,” “HIGH RADIATION AREA” and the radiation symbol, if the dose rate from the radiation source exceeds 1 mSv (100 mrem) in any 1 h at 30 cm (1 foot) from the source (see definition of High Radiation Area in Sec. 3).

“CAUTION,” “RADIATION AREA” and the radiation symbol, if the dose rate from the radiation source exceeds 0.05 mSv (5 mrem) in any 1 h at 30 cm (1 foot) from the source (see definition of Radiation Area in Sec. 3).

The signs shall be placed so that they are readily visible to anyone approaching the boundary of the radiation safety exclusion zone or controlled area.

No person (with the exception of a stowaway), either within the controlled area or in the uncontrolled areas of the installation, shall be exposed to more than the maximum permissible dose (MPD). See Table 1.

The dose at any accessible uncontrolled area shall not exceed 0.02 mSv (2 mrem) in

any 1 h at 30 cm (1 foot) from the boundary of the radiation safety exclusion zone or controlled area. See note below Table 1.

5.5.3 “Hybrid” Installations These installations shall have appropriate signage depending on the radiation levels to be expected, as shown above for “closed” and “open” installations.

Table 1. Maximum permissible dose (MPD) values.^a

Type of area/person	Part of body	MPD
Controlled area		
Radiation worker (wearing dosimeter)	Deep equivalent dose to head, trunk, arms Above the elbow or legs Above the knee	50 mSv (5 rem) in a year
Radiation worker (wearing dosimeter)	Lens of the eye	150 mSv (15 rem) in a year
Radiation worker (wearing dosimeter)	Hand, elbow, arms below elbow Foot, knee, and leg below knee	500 mSv (50 rem) in a year
Radiation worker (wearing dosimeter)	Skin or other organs not specifically listed	500 mSv (50 rem) in a year
Uncontrolled area		
Non-radiation worker and member of the general public (no dosimeters)	Whole body	1 mSv (100 mrem) in a year and 0.02 mSv (2 mrem) in an hour

^aSource: NRC and DOE regulations.

Note: It is important to realize that the 0.02 mSv (2 mrem) in any 1 h dose limit applies to **infrequent and short-term** exposures in an **uncontrolled** area. If a person were to be continuously exposed to this level of radiation during the 2000 work hours in a year, the cumulative ambient dose equivalent, $H^*(10)$ to that person during the year will be 40 mSv (4000 mrem), which far exceeds the 1 mSv (100 mrem) in a year.

5.6 Barriers for Access Control

All installations shall have appropriate barriers (shield walls, jersey barriers, yellow tape/orange cones, or a combination of all three barriers) for access control. These access controls may be supplemented with live TV monitoring or a guard in the vicinity of the radiation safety exclusion zone.

6.0 Engineered Controls

Each active interrogation system shall include a radiation safety system to prevent

system operators/workers and members of the general public from unnecessary radiation exposure. These engineered controls shall include a radiation generating device (RGD) control system, radiation area interlocks, emergency shutdown devices, and audible and visual warning devices for all types of installations. Additionally, radiation monitoring equipment shall be installed to ensure acceptable radiation levels are maintained for all three types of installations. This section presents a description of engineered controls to ensure the radiation safety for all types of installations.

6.1 Controls and Interlocks

All the controls and interlocks shall be fail-safe and tamper-resistant.

6.1.1 System Control Control systems for an RGD shall include easily identifiable instruments, readouts, and switches. The system should include an operator interlock (e.g., final keyed interlock) that is set only after all other procedures/requirements are met. The operator interlock should also include an emergency shutdown button that, when activated, immediately ceases system operation and prevents further operation until reset. During all operations, only a trained system operator should have access to the operator's keyed interlock. The trained operator should have complete operational authority to discontinue operation at any time he/she has a safety reason to terminate the operations.

6.1.2 Facility (Installation) Interlocks All entrances into inspection areas, including areas designated as high-radiation areas, shall have access restricted by an appropriate interlock system to prevent radiation exposure from exceeding acceptable limits. Such a system should provide immediate shutdown of system operation when any interlock component has been tripped. The complete interlock system should be designed such that each component is independent of the others and failure of any one component ceases system operation. When any component of the interlock system has been tripped, the complete system should include a design feature that only allows operations to resume after a manual resetting of the system at the location of the interlock trip, followed by a system reset at the operator console. Additionally, area search buttons can be incorporated into the interlock systems, thus ensuring confirmation the area is clear of personnel prior to operations.

In closed installations (see Sec. 6.3.1), interlock switches shall be included in the entrance/door design to ensure the door remains securely closed and undesired entrance into a high- or very-high-radiation area produces an immediate shutdown of RGD operation. Similar results can be

accomplished at open and hybrid installations by commercial crowd control barriers (jersey barriers, yellow tape/orange cones, or similar products) supplemented with interlocked fences/gates and other intrusion detection devices.

6.1.3 System Interlocks System interlocks shall be included that ensure that the operational parameters of the RGD system (i.e., dose rate at 1 m from the target, gas pressures, temperatures, etc.) are not exceeded.

6.1.4 Emergency Shutdown Switches (Scrams) Emergency shutdown switches (scram switches or buttons) shall be located in all high- or very-high-radiation areas and in close proximity to the RGD. Additional switches should be included at the operator console, which is typically located outside the radiation controlled area. When activated, these switches or buttons should provide immediate shutdown of system operation and should be manually reset after verifying at the operator console (located outside the controlled area) that a scram switch or button had been pushed prior to resuming system operation. Emergency shutdown switches should be clearly identifiable and accessible.

6.2 Warning Devices

Audible and visual warning devices shall be included in all high- or very-high-radiation areas, including entrances to these areas. The audible warning devices shall be designed to activate for an acceptable period of time, such as 20–30 s, prior to system operation. Visual warning devices (rotating red or magenta light beacon and/or flashing red or magenta light) should operate at all times when the system is producing radiation; visual warning devices (rotating amber or yellow light beacon and/or flashing amber or yellow light) should operate at all times when the system is capable of producing radiation. The warning system shall also include verbal warning through a public address system or intercom and video surveillance system. The warning devices should have signs in English and/or one other appropriate language, such as Spanish, explaining the significance of the devices.

6.3 Shielding

Sufficient shielding shall be designed and constructed, taking into account ALARA requirements, environmental radiation, and induced radioactivity of facility/operational components. High-energy x and gamma radiation is commonly shielded by lead, although other medium-Z materials (iron/steel) can also be used. Economic and volume considerations make concrete shielding a particularly attractive option for both neutron and photon shielding, particularly for fixed systems and closed facilities. Efficient neutron shielding can be readily accomplished through a combination of a low-Z moderating material (polyethylene, water, etc.) and a material with a large capture cross section (cadmium, boron, etc.).

6.3.1 “Closed” Installations A “closed” installation provides for complete shielding of a high-radiation area or very-high-radiation area (see definitions in Sec. 3), including the entrance and exit portals. Concrete or soil is a low-cost and large-volume shield material that typically provides this shielding. (See Annex B for an example of shielding calculations for a closed system.)

6.3.2 “Open” Installations In an “open” installation, it may be possible that only the source is shielded, while the primary and secondary radiation is not. As an example, source shielding can be quickly constructed with multiple layers of borated polyethylene bricks (or alternative low-Z material) for neutron sources and lead (or alternative high-Z materials) for bremsstrahlung sources.

In this case, distance can be used to provide protection from radiation. This is accomplished by the determination of the radiation safety exclusion zone around the active interrogation system. (See Annex C on how to determine the exclusion zone for an open installation.)

6.3.3 “Hybrid” Installations If distance cannot be used due to space (footprint) restrictions, sufficient shielding of the primary radiation shall be provided to ensure exposure levels are maintained below the

regulatory limits for workers and members of the general public. In this case, the protection from scattered and leakage radiation shall be provided by distance.

6.3.4 Additional Shielding Devices In addition to installation and system shielding, components such as beam stops and collimators should be used to minimize radiation levels. When applicable, components that prevent the steering or movement of inspecting radiation beams into occupied or undesired areas should be used.

6.4 Signage and Barriers

All entrances and pathways to all types of radiation areas shall have clearly displayed and appropriate signage and shall have access restricted by clearly identified barriers. These barriers may include facility interlocks, as described above, that initiate immediate RGD system shutdown when breached. Signage should include wording that explains the purpose of warning lights and alarms.

6.5 Radiation Monitoring Equipment

A complete radiation safety system shall include necessary radiation monitoring equipment. These monitors should be located at areas with direct access to inspection areas and provide personnel with accurate readings of radiation levels at the entrances and remotely at the operator control console. The monitors should operate independently of system controls and interlock systems. When possible, remote area monitors should have a high radiation set point that, when exceeded, ceases and prevents system operation. Further details regarding radiation monitoring equipment are provided in Annex D.

6.6 Additional Controls

Inspection systems should be engineered with a specific component intended to efficiently turn the system ON and OFF. While interlocks and other safety components may be used to prevent system operation (e.g., leaving an interlocked door in an open position), a key/switch designed

for the specific task of turning the system ON and OFF shall be used during standard startup and shutdown procedures. Finally, to ensure termination of any RGD operation, methods/procedures should be clearly defined to implement termination of all external power source(s) to the RGD and/or its housing.

7.0 Radiation Safety in System Operation

7.1 Exposure to Stowaways

The inadvertent exposure of stowaways by the active interrogation system shall not exceed the dose limit of 0.2 Sv (20 rem) per scan. See ANSI N42.41 (Sec. 6.11.4, p. 16) and Sec. B.6 of Annex B of this standard.

7.1.1 Pre-screening of Trucks and Cargo Containers The dose limit stated in Sec. 7.1 shall be allowed only if all of the following conditions are satisfied:

- A container or vehicle has been pre-screened by an x- or gamma-ray security imaging system that would expose any possible stowaway to no more than 5 mSv (500 mrem) per scan under any load conditions (see NCRP Statement No. 10);
- This prescreening is capable of detecting human occupancy with a probability greater than or equal to 95% while maintaining a probability of false alarm of less than or equal to 5% (with a confidence of 68.3% for both); and
- The pre-screening shows no human occupancy.

7.1.2 Verification of Probability of Detection for Human Occupancy The following tests shall suffice to establish a requirement of 95% probability of detection (PD) with no more than 5% probability of false alarms (PFA) (with a confidence of 68.3% for both):

In containers or vehicles from the normal stream of commerce, a realistic human head and torso phantom such as the RANDO phantom (see Ref. 1, Annex G) or the Lawrence Livermore Fission Product Phantom RS-550 (see Ref. 2, Annex G)

shall be positioned in any orientation that is consistent with stowaway concealment within the cargo, without knowledge of the operators of the pre-screening security imaging system. In a series of 46 tests, with 23 test vehicles or containers carrying the phantom secreted in normal cargo and with 23 carrying only normal cargo, the pre-screening security imaging system operator must not give any false reports (positive or negative), OR in a series of 94 tests, with 47 of the vehicles or containers carrying the phantom secreted in normal cargo and with 47 of the vehicles or containers carrying only normal cargo, the pre-screening security imaging system operator may give no more than one false positive report and no more than one false negative report (see Ref. 3, Annex G).

7.2 "Closed" Installations

7.2.1 Shielding A closed installation shall be properly shielded with materials of appropriate thickness to bring the dose rate down to acceptable levels for members of the general public (see Table 1, Sec. 5.5) at 30 cm (1 foot) from the outside of the shield walls. Primary and secondary (leakage and scattered) radiation shall be shielded as shown in the example calculation in Annex B.

7.2.2 Radiation Safety Surveys Radiation safety surveys shall be conducted after the system has been placed in operation to ensure that sufficient shielding has been provided. If not, modifications to the shielding shall be required. The radiation safety surveys shall be repeated every year after that and every time major changes are made to the RGD or changes are made to the operating parameters of the RGD and major repairs are made to the RGD or any of its existing shielding.

7.3 "Open" Installations

7.3.1 Radiation Safety Surveys Radiation safety surveys shall be conducted at the time of deployment (installation) and every year after that. They shall also be conducted each time operating parameters (such as beam current and voltage) of the RGD (linear accelerator [LINAC] or sealed tube neutron generator [STNG]) have been

changed and after major repairs affecting the performance of the RGD and the shielding around it.

7.3.2 Determination of Radiation Safety Exclusion Zone The results of the radiation safety surveys shall be used to determine the boundaries of the radiation safety exclusion zone around the system. See an example of the determination of the radiation safety exclusion zone in Annex C.

7.3.3 Radiation Source Safety If a system uses any radionuclide sealed sources for active interrogation, these radiation sources shall be listed in the official system manual, and their location within the system shall be visibly marked with standard radiation signs.

7.3.4 Leakage Test for Sealed Sources Sealed sources shall be leak-tested periodically, as required by NRC or Agreement State (see definition in Sec. 3) regulations.

7.3.5 Accidental or Deliberate Explosion If the interrogating system contains a capsule of radioactive source in gaseous form in any of its components, that capsule shall be tested and certified by the manufacturer not to lose its integrity in case of an accidental or deliberate detonation. This is to ensure that no airborne radioactivity is released to the environment in excess of that allowed by state and federal regulations.

If a solid radioactive source in the interrogating system is encapsulated (e.g., ^{60}Co or ^{252}Cf), the source encapsulation shall be such that source rupture will not occur in case of an accidental or deliberate explosion. It is the responsibility of the manufacturer to certify that the capsule will not lose its integrity.

7.3.6 Major Fire Individuals who may be called upon to fight a fire where the system is deployed or stored shall be made aware that radioactive material is present and should have received appropriate training.

For each radioactive source, the melting point of the encapsulating and braze (solder) materials shall be listed in the system manual. If the radioactive source is

breached because of high temperature, an estimate (by calculation) shall also be included in the system operational manual of the amount of airborne radioactivity at various distances from the breached source.

7.3.7 Secure Storage of Sealed Sources If the interrogation system is in the field and is not being used, appropriate precautions shall be taken to ensure that the shielded container(s) holding the radioactive sealed source(s) is (are) securely stored.

7.3.8 Radiation Safety Controls The system shall have redundant radiation safety controls, utilizing both hardware and software. These are controls for (a) the safe operation of the system and (b) the safety of the general public.

An example of a redundant system operation control is the turning OFF of a neutron generator via software by “clicking” an OFF icon on a computer screen, and a physical (manual) switch that directly turns off the high voltage on the neutron generator.

Another example of a redundant general public safety control is the marking of an exclusion zone with ropes and having visual contact of the exclusion area at all times during an interrogation, or in the absence of visual contact, observation of the exclusion area via closed-circuit TV (CCTV) cameras.

7.3.9 Control of Exclusion Zone (Controlled Area) For an open system, radiation protection of the operators and of the general public is afforded primarily through distance. The required exclusion zone for it shall be determined by actual measurement of dose rates around the system (see Annex D) and recorded in its operational manual and shall be established at each location where the system is to be operated. Control of the exclusion zone shall be maintained using redundant safety controls as written in Sec. 7.3.8 above.

7.3.10 Klystrons and Magnetrons Any device utilizing high-power microwaves can produce additional intense x-rays. The generation of these x-rays is erratic and unpredictable and increases rapidly with RF

power and age of klystron/magnetron. Hence, all such devices, if located outside a shielded enclosure, shall be shielded and controlled by the manufacturer of the RGD in the same manner as the other radiation sources.

7.4 Skyshine

Every effort shall be made to mitigate the effects of neutron and/or photon skyshine in the vicinity of the installation. Please refer to extensive and useful discussion of issues concerning skyshine from neutrons and photons in NCRP reports (Refs. 4 and 5, Annex G).

7.5 Induced Radioactivity

With any system based on high-energy x-rays and fast neutrons as interrogating radiation, it is unavoidable that some of the nuclei in the material exposed to these radiations will be converted to radioactive nuclides. The radionuclide production (which is based on the thermal neutron flux, the thermal neutron cross section, and the quantity of target nuclides) and the lifetime of these radionuclides (if longer than a few minutes) may pose a radiation hazard to workers and members of the general public. Three sets of materials that may be affected are (1) materials normally found in the accelerator components, (2) materials used for shielding, and (3) materials found in the ground. A discussion of this subject is provided in Annex F for general information.

7.5.1 Radiation Survey to Monitor Activation Products

The interrogation system shall have a yearly certified radiation survey for each of its major components, indicating the amount of induced radioactivity (in Bq). The radiation survey shall be conducted before and after it has been used for a specified period of time (daily, weekly). Along with the survey, a table of known half-lives for radioactive sources and potential activation products associated with operation of the system should be available in the operational manual of the system. See Annex F for more information.

7.5.2 Storage and Disposal of Activation Products

Activation products generated as a result of the operation of an active interrogation system shall be stored and disposed in the proper manner according to federal and state radioactive waste disposal regulations.

7.6 Environmental Assessment (EA) or Environmental Impact Statement (EIS)

An EA shall be performed, or an EIS shall be prepared, in accordance with the provisions of the National Environmental Policy Act (NEPA) of 1969, prior to the deployment of an active interrogation system. (An integral part of this effort involves effects of radiation on workers and members of the general public and measures taken to ensure the radiation safety of these individuals.)

Annex A Administrative Controls

Note: This Annex is not part of the standard but contains explanatory information.

A.1 Radiation Safety Program Plan

A.1.1 Radiation Safety Program Organization

It is necessary for an organization (manufacturer of active interrogation systems or user agency) to have an organizational structure in place to provide the necessary administrative controls for the safe operation of the system. This organizational structure includes a radiation safety committee (RSC), radiation safety staff, radiation safety training program, and radiation exposure monitoring program. These components of the program plan are described below.

A.1.2 Radiation Safety Committee

State and federal regulations sometimes require the establishment of a radiation safety committee (RSC) composed of representatives of senior management, program office and the safety office, and other offices involved in the operation of the facilities/installations. A charter is written and approved by the senior management to guide the activities of the RSC.

The RSC has one designated representative from each office utilizing (deploying) the system. The designated individuals have training and qualifications to meet the requirements for understanding the safe and efficient operation of the RGD. The RSC is chaired by a facility employee typically designated by the president/director of the organization. The chairperson is responsible for scheduling meetings, preparing agendas, managing committee proceedings, and ensuring that the meeting minutes are recorded and distributed to committee members. The chairperson reports the deliberations of the committee and the status of the radiation safety program to the president/director and the safety office.

The RSC reviews the use of the system and has the right to revoke or suspend the privilege of using RGDs. The RSC provides oversight of the facility radiation safety program. In general, the RSC meets at least quarterly to:

- Approve policies and procedures for the radiation protection of operators and members of the general public;
- Discuss any radiation safety problems requiring a general solution;
- Determine whether current procedures are maintaining radiation exposures As Low As Reasonably Achievable (ALARA);
- Consider any proposals for the use of new active interrogation systems;
- Evaluate the safety of those proposals and the qualifications of operators;
- Audit the radiation safety program to ensure that the organization meets the regulatory requirements; and
- Approve an emergency response plan.

A.1.3 Radiation Safety Officer

The radiation safety officer (RSO) is qualified by training and experience in radiation protection and is, by virtue of education, training, and experience, able to provide advice and assistance in radiation safety matters. The RSO is the lead management representative responsible for implementing the radiation safety program at the facilities and installations under the control of the organization. He/she is responsible for maintaining the radiation safety and radiological health standards throughout the organization. He/she is required to communicate with the appropriate levels of management to halt any unsafe operation of the system.

The RSO is responsible for the development, documentation, and implementation of