This article discusses radiation safety programs, including the members of the radiation safety team, their roles, and the challenges they face, with a focus on the radiation safety officer’s duties. Agencies that regulate radiation safety also are described. The importance of minimizing patient dose, ensuring that dosimetry badges are worn correctly, and using therapeutic radioactive materials safely are addressed. Finally, radiologic technologists’ role in using radiation safely is discussed, and the principles of time, distance, and shielding are reviewed.

In the United States, approximately 400 million radiologic procedures are performed every year. This number continues to rise, especially with increased use of advanced imaging modalities such as computed tomography (CT) and positron emission tomography. During the past 15 years, the number of advanced diagnostic medical imaging procedures has risen to an all-time high. The increase is largely attributed to advancements in diagnostic imaging that allow physicians to obtain more pathological information in a shorter time. As a result, overall radiation dose has increased by nearly 6 times since the early 1980s. In fact, more than 90% of radiation exposure from unnatural sources is from medical imaging.

A proper radiation safety program is essential to ensure the safety of patients and radiologic science professionals. A comprehensive radiation safety program is required when facilities apply for a radioactive materials license. The privilege to use radiation can be revoked and fines imposed if the rules of safe radiation handling are not followed.

History

The history of radiation safety dates back to the early 1900s. Although the concepts of time, distance, and shielding evolved about a year after the discovery of x-rays in 1895, it took some time before safety practices became mandatory. The effects of beam collimation and filtration on skin dose were recognized about 4 years following Roentgen’s discovery. Strategies to reduce exposure time and dose, including higher energy x-rays and intensifying screens, also were implemented at that time. Twenty years later, strategies for protecting personnel were recommended including
maximizing distance, limiting occupational time, and mandatory time off. Days off were considered “radiation holidays” as a method to reduce overall dose.4

However, before the late 1950s, only a few radiation protection programs had been established at the state and local levels. The Atomic Energy Act of 1954 gave states authorization to regulate the use of radioactive materials. The International Commission on Radiological Protection (ICRP) was renamed the National Council on Radiation Protection and Measurements in 1964, and the as low as reasonably achievable (ALARA) principle evolved shortly after that.4 Congress created the Nuclear Regulatory Commission (NRC) in 1974 to increase radiation protection standards, reactor safety, and environmental protection. The NRC develops policies and regulations for nuclear reactor and radioactive material safety, oversees the operations of licensees, and resolves legal issues. States that agree in writing to assume the same level of regulatory authority and control of the NRC guidelines are called Agreement States. These states govern their own radiation control programs in agreement with the NRC (see Figure 1).5

In recent years, the NRC has adopted a more holistic, risk-informed, performance-based approach to regulations. Although in the past many licensees adopted specific guidelines, now additional “best fit” practices are encouraged that still work in the regulatory framework but allow for small variances in individual work settings.6,7 Radiation safety teams should model their plans based on the clinical needs of the departments involved, and they are responsible for ensuring that those who use radiation-producing machines and radioactive materials comply with applicable state and federal regulations.

Radioactive Material Licensing
A medical practice or facility that intends to use medical radioactive materials must must have a specific limited scope or broad scope license from the NRC. The type of license issued depends on several factors including:

ALAR A principle is a well-known concept defined by the NRC as “making every reasonable effort” to keep radiation exposure as far below dose limits as is practical considering the purpose of its use, the state of technology, improvements in technology, and public health and safety. Radiation safety programs are required to implement an ALARA program to keep employees mindful of occupational exposure.

In a busy hospital environment, the radiation safety team likely will be tasked with many responsibilities in addition to the ALARA program including:

- Registering equipment.
- Establishing safety requirements for using medical radiation.
- Meeting licensing requirements for radioactive waste disposal.
- Providing training and documenting experience requirements for personnel.
- Verifying licensure of radiologic technologists.
- Providing training for employees who do not work directly with radiation.

An institution might have an in-house radiation safety team headed by an RSO who manages and maintains the radiation safety program for radioactive materials including materials used therapeutically and for research. In smaller institutions, the RSO could be an individual physician or a qualified radiologic technologist who handles all the responsibilities. A larger radiation safety team might comprise the RSO, authorized physician users, radiologic technologists, radiation therapists, and other qualified experts, all of whom are responsible for radiation safety and protection for all radiation areas in the hospital or clinic. Medical physicists often serve as team members or consultants for unique shielding cases or construction and remodeling of facilities where medical radiation is used. They likely are to be involved in equipment calibration and evaluation. Medical physicists often are involved in radiation therapy, brachytherapy, and stereotactic radiosurgeries as well.

The goal of the radiation safety program is to develop a set of clear policies and procedures to protect everyone likely to be exposed to radiation including patients, family members, building maintenance and cleaning staff, receptionists, nursing staff, physicians, and radiologic technologists. Policies should be simple
so that those involved can meet the program’s expectations.7

The Radiation Safety Officer

The authority and responsibilities for an RSO are outlined in 10 CFR 35.24.9 Employees working with radiation and radioactive materials have a role in the radiation safety program that varies from institution to institution; however, the NRC requires licensed facilities to identify a responsible, qualified individual on each radioactive materials license to serve as the RSO. This individual must meet specific qualifications. He or she must have the educational background, proper training, and professional experience to meet federal and state regulations. Educational requirements include certification by a specialty board recognized by the NRC. For example, training is required before handling radioactive sources and operating the afterloader units used for brachytherapy treatments in radiation oncology.10 Other requirements include a minimum of a bachelor’s degree in science or engineering and successful completion of an examination administered by the specialty board that covers radiation physics, protection, and math related to radioactivity, radiobiology, and dosimetry. Those with a bachelor’s degree also must have a minimum of 5 years’ health physics experience including at least 3 years in applied health physics. An applicant with a graduate degree in physics, medical physics, physical science, engineering, or mathematics is required to have 2 years’ experience working in medical physics and 1 year of experience working in radiation safety under the direction of a currently appointed RSO. He or she must be trained sufficiently in radiation safety, regulations, and emergency situations.11

Alternatively, an RSO in a clinical nuclear medicine facility providing diagnostic and therapeutic services can meet the qualifications by means of a different pathway. The RSO must be under the direction of an authorized physician on the institution’s radioactive materials license and pass an examination in radiation physics or radiation safety, or he or she can qualify by completing a structured education program that includes 1 year of full-time radiation safety experience under the supervision of a qualified RSO on a Commission or Agreement State license plus 200 hours of classroom and laboratory training in14:

- Radiation physics and instrumentation.
- Radiation protection.
- Mathematics pertaining to the use and measurement of radioactivity.
- Radiation biology.
- Radiation dosimetry.

Preparation must include work environment training in regard to shipping; surveying; performing equipment checks; operating equipment for measuring radiation doses; securing and controlling byproduct material; radiation safety, decontamination, and emergency procedures; and disposal of radioactive materials.15,14 Many radiologic technologists—mostly nuclear medicine technologists—serve as RSOs after completing this type of training.

The RSO must offer opportunities for technologists to provide input when developing procedures related to dose minimization. The RSO evaluates the feedback, and if changes are implemented, notifies workers.15

The RSO also is responsible for setting ALARA investigational limits for radiation workers at the institution. The RSO establishes trigger levels well below the 10 CFR Part 20 allowable occupational limits. These trigger levels, called investigational levels, are set by institutional policy to identify potential causes of excess radiation exposure. Investigational level 1 typically is set at about 10% of the allowable dose limit, or 5 mSv. Level 2 exposures represent a higher fractional exposure such as approximately 30% of the occupational limit. Should this limit be exceeded, the RSO notifies the worker that his or her dose limits are beyond the trigger value and provides ways for the employee to minimize exposure.15 Level 2 also requires the technologist’s signature of understanding and an explanation of his or her work practices and ways to reduce exposure. The RSO might conduct an investigation, especially if there is more than one occurrence.15

In addition, the RSO establishes procedures for pregnant technologists to declare their pregnancy and work safely around radiation. Pregnant technologists or therapists who are likely to receive an annual deep-dose equivalent (DDE) in excess of 1 mSv may voluntarily inform their employers, in writing, of the
pregnancy. When a pregnancy is declared, employees are provided a fetal badge in addition to the regular badge, to be worn at the waist, under shielding, to measure the DDE. A declared pregnant worker is limited to 5 mSv for the entire gestation period. If the dose to the fetus is found to be 4.5 mSv or more when the pregnancy is declared, the employee is allowed only 0.5 mSv for the remainder of the gestational period. Fetal badge readings should be monitored, and exposures should not exceed levels of 0.4 mSv to 0.45 mSv per month during the pregnancy. The RSO is required to maintain records of the dose to the pregnant worker and her fetus. If the monthly limit is reached, the RSO must notify the employee.7

The RSO must perform periodic testing on sealed radioactive sources to ensure there are no leaks. These types of sources often are used in clinical departments for calibration of equipment, reference dose standards, or in imaging procedures for anatomical markers and localization. Sealed sources are defined by the NRC as “any byproduct material that is encased in a capsule designed to prevent leakage or escape of the byproduct material.”9 The term sealed source can be misleading; it can give the impression that there will be no contamination on the outside of the container. However, it can leak, and wipe tests are required to maintain the integrity of a sealed source. In general, sources should be tested for leaks at least twice per year, if not quarterly. The frequency depends on the source itself, how often it is used, whether it has been used appropriately, and the age of the material. For example, testing is not required for sources with an activity of less than 3.7 GBq (100 mCi). Dated sources can exhibit deterioration, making them more likely to leak. In turn, their radioactivity could potentially contaminate health care workers and the general public.10

The RSO must ensure that all sources are stored properly and inaccessible to employees who do not have authority to handle them. All areas in which radionuclides are handled must be identified with a radioactive symbol and designated off limits to the general public.11

The radiation safety team conducts annual reviews of the radiation safety program to ensure all workers are following ALARA guidelines. The RSO evaluates radiation doses received by technologists monthly or quarterly to verify they are meeting the ALARA dose limits.

In addition, the RSO or authorized user provides regular education to staff about ALARA as part of the radiation safety program.12 Radiation safety programs are regularly inspected or audited to verify that state and federal regulations are met. Typically, an outside agency is hired to review personnel qualifications, dose monitoring devices and notifications, policies, and quality control. The agency provides a summary that describes safety violations that occurred during a previous calendar year. Violations include unusual occurrences or medical events. For example, if a radiation therapy patient received a higher total dose than prescribed, it would be a medical event and must be reported. Particular attention is paid to patient dose, number of studies or treatments performed, and calibration dates.13 The RSO may conduct performance-based audits at the same time as the general audit to ensure personnel are following safe practices and ALARA principles. Authorized users and technologists might be asked to describe specific tasks, or they could be observed while handling byproduct material. If they do not demonstrate competency during the audit, the RSO then provides training.

Authorized Users

In radiology and oncology, an authorized user usually is a diagnostic radiologist or nuclear medicine physician, radiation oncologist, or cardiologist who has met specific requirements. To receive, use, maintain, and transfer radioactive materials, this professional must be listed on the license. The authorized user may perform certain procedures based on expertise. Other physicians, technologists, and radiation therapists may work with byproduct material under the supervision of the authorized user. For most diagnostic procedures, radiopharmaceuticals can be administered by technologists with standing orders, and direct supervision is not necessary.14 Some therapeutic procedures that pose a higher risk to the patient require a written directive by the authorized user. The NRC requires written directives to be specific written orders that contain the patient’s name, dose, radiopharmaceutical drug name, and route of administration. Another type of authorized user is the nuclear pharmacist, who must meet the qualifications found in 10 CFR Part 35.55 to be employed in commercial or in-house radiopharmacies.15
Compliance Agencies

Facilities using ionizing radiation must adhere to relevant laws and regulations concerning its use. Regulations ensure that radiation is used safely, and lack of compliance leaves a facility open to risk. Violations of the regulations can result in major penalties including fines, revocation of the facility’s license to use, a poor reputation, and potential lawsuits initiated by employees, patients, or members of the general public.

The NRC and the Department of Transportation (DOT) regulate the transportation of radioactive materials. Preparation and packaging of materials must comply with NRC safety standards. The DOT establishes guidelines for shipping and transportation within the United States to ensure that materials are delivered safely. The International Air Transport Association (IATA) regulates international shipments of radioactive materials. Its requirements are more restrictive than those of the DOT and NRC. For example, IATA requires training for shippers every 2 years, whereas the DOT specifies training every 3 years.

Losing control of radioactive material can be grounds for revocation of a facility’s license; therefore, daily inventory control procedures should be part of regular recordkeeping. Only authorized users or their designees should order radioactive materials, and only from authorized vendors. The RSO should train employees in the proper shipping of materials including emergency response information, methods for avoiding accidents, and proper procedures for handling packages. Packages must be checked in and monitored for measurable radiation within 3 hours of receipt or, if delivered after hours, within the first 3 hours of the following shift.

Package labels must meet federal guidelines. They are color coded to represent the overall radiation exposure risk. Most packages received in clinical nuclear medicine and radiation therapy departments are labeled with radioactive White-I or Yellow-II labels. They are surveyed by a nuclear medicine technologist or an RSO, depending on whether the radioactive materials arrive at the radiology department or at the radiation safety hot lab. They are surveyed for removable contamination by means of a wipe test using a cotton swab, and the package is monitored with a Geiger-Mueller survey meter. Packages labeled with a White-I tag cannot exceed 0.005 mSv/hr at surface level. Yellow-II packages must be less than 0.5 mSv/hr at surface level. Once materials have been checked in properly and inventoried, recordkeeping is crucial to track them. Inventory records are kept in electronic data systems to assist in recordkeeping. The RSO can use specialized software to manage the radioisotope inventory, track orders and shipments, and receive notification when departments have disposed of decayed isotopes. For example, On Site Systems provides the Environmental Health and Safety Assistant software. It has additional features for ALARA and NRC reporting. Although inventory is monitored closely, theft or misplaced materials can occur. Lost or stolen materials must be reported to the NRC.

Some RSOs have oversight over nonimaging areas such as laboratories that use radioactive materials. Radioactive tissue and blood specimens must be measured using protocols established to meet the College of American Pathologists guidelines. For example, a sentinel lymph node biopsy specimen is tested in a frozen section laboratory after being injected with a radioactive substance and surgically removed. Specific protocols govern the handling, storing, and disposal of radioactive tissues. The College of American Pathologists can inspect a facility at any time to ensure proper radiation safety procedures are in place and the facility is compliant with regulations.

The Joint Commission stresses the importance of the right examination and right dose to avoid unnecessary patient radiation dose. Proper use criteria should be evaluated and, if possible, examinations that do not use ionizing radiation, such as magnetic resonance (MR) imaging or ultrasonography, should be considered. If the examination is medically necessary, clinical indications for the examination must be documented. The Commission also developed standards in equipment quality assurance testing, staff education and training, imaging protocols, prevention of duplicate studies, and proper follow-up for patient safety incidents. In addition, medical physicists are required to perform equipment performance evaluations for CT and MR scanners, positron emission tomography and other nuclear medicine scanners, and radiation therapy linear accelerators.
Minimizing Patient Dose

Diagnostic quality must be balanced with patient dose. For example, to reduce the dose from a chest radiograph, some image quality might be sacrificed. However, if a repeat image is required, the dose for that examination is greater. In CT imaging, using established protocols developed by a medical physicist or manufacturer is ideal for scanning only the organ of interest, rather than an entire abdomen, chest, or pelvis, thus keeping dose as low as possible. Scanning parameters are modified to obtain optimal images for specific cases such as renal stone visualization, orbit screening for metal, and lung nodule screening for smokers. The American Association of Physicists in Medicine formed a network to establish recommended guidelines for standardizing CT protocols. Its top priority was to develop protocols for the most common procedures: perfusion; adult head, chest, and abdomen; and pelvis. Manufacturers have made protocols available with the purchase of new CT equipment.

Avoiding unnecessary radiation exposure to children is most important. Considerably more pediatric CT scans are performed now than they were 20 years ago, with a 50% increase in chest scans specifically. Approximately 4 million scans are performed on children annually, and these are projected to cause 4870 future cancers. Although the scan time is short and images are detailed, the radiation exposure from CT scans is much higher than in radiography, resulting in 100 to 500 times greater amounts of radiation than plain radiographs. Consequently, children who have undergone CT imaging have a greater chance of developing cancer later in life because their rapidly dividing cells are sensitive to radiation exposure. It takes an average of 10 to 20 years for a malignancy to develop, and although it has not been proven, it has been suggested that radiation dose from CT scans could be a contributing factor to approximately 2% of all malignancies.

Effective dose is a numerical value of radiation dose calculated in millisieverts and is used to predict whole-body radiation risk from a specific procedure. Although effective dose originally was developed based on occupational exposure, it is useful for predicting cancer risk from cumulative radiation dose in patients. The effective dose for a CT examination is based on patient...
mass, the type of study, and the degree of sensitivity of the exposed organs. These doses are higher for children than for adults.  

A large, retrospective study of pediatric patients aged 15 years and younger was conducted to estimate lifetime cancer risk. Effective doses from CT scans were calculated for the most common pediatric studies: head, chest, abdomen and pelvis, and spine. Cancer risk models accounting for age and sex were used to associate the organ dose from specific scans with likelihood of developing cancer as an adult. Of nearly 750 cases, the authors found the highest doses were received during abdomen and pelvis scans, followed by chest and spine. Consequently, the risk of developing cancer of a solid organ was higher for abdomen and pelvis scans, with a greater risk for girls than boys. In addition, a greater risk of solid-organ cancer from chest and spine scans was noted in the girls. Although the risk for brain cancer was the lowest, head scans of children younger than 10 years were associated with a higher lifetime risk of developing leukemia. The researchers suggested that more than 40% of future cancers could be prevented by using CT protocols developed specifically for pediatric patients. This is the purpose of the Image Gently Alliance, a coalition whose mission is to increase awareness of the need to reduce radiation exposure to children. Resources are available for parents, technologists, radiologists, medical physicists, and referring physicians.

**Badge Compliance**

The RSO is responsible to ensure all users of radiation and radioactive material wear dosimetry badges at all times, especially during high radiation exposure procedures. Badge compliance is an issue among cardiologists, particularly cardiology fellows, and several reports document this including a study from the University of Illinois. A brief Web-based survey was sent to 2545 fellows, and 248 responded. Respondents were asked 10 questions about their radiation safety training, policy awareness, radiation exposure, use of radiation protection equipment, and awareness of personal exposure. Respondents in their fourth year reported the lowest use of radiation protective eyewear and dose monitoring badges. Their badge compliance rate was 48%, and only 24% reported wearing goggles during fluoroscopic procedures. Awareness of personal exposure was low, with 17% of fourth-year fellows knowing their dose within the previous year. The level of concern about radiation exposure health effects was relatively low as well. The majority of fourth-year fellows reported being concerned “sometimes,” compared with “always” or “never.” The results demonstrate a gap in their knowledge of radiation exposure, indicating that training might be lacking. Cardiology fellows are exposed to greater amounts of radiation during cardiac catheterizations than the attending physicians.

Badge compliance is even more important for interventional cardiologists than other physicians because they receive twice the annual dose of radiologists, or approximately 1.5 mSv to 8.4 mSv. This amount of radiation dose is equivalent to about 200 chest radiographs. The increased use of interventional cardiovascular procedures means these physicians’ exposure continues to increase.

One study compared a group of 10 healthy interventional cardiologists with typical exposure to a control group of health care workers who had not been exposed to radiation. Blood specimens were tested for antioxidant response markers in both groups. Although no statistically significant differences were found in reactive oxygen species or in serum antioxidant levels, the interventional cardiologists had higher levels of hydrogen peroxide. Higher amounts of lymphocytes also were found among the cardiologists. These findings indicate a measurable response to chronic low-dose radiation exposure.

According to an editorial comment in the journal *Cardiovascular Interventions*, cardiologists performing interventional procedures must take the lead in starting a radiation safety program, working closely with a physicist for equipment training, purchase, and maintenance. Selecting equipment that features options for decreasing dose is essential. Some options include in-pulse control, pulsed fluoroscopy, and beam filtration, which reduces patient dose by removing soft radiation beams. In-pulse control always keeps the beam at the correct power to obtain a diagnostic quality image, thereby reducing fluoroscopy time. Interventional
Radiation safety awareness is low among other health care professionals as well. Jentzsch et al surveyed trauma surgeons and surgical technologists about radiation safety practices in the operating room. A questionnaire was sent to 83 participants, the majority from a level 1 trauma center. Other participants worked at a children's hospital. All were asked about their frequency of wearing dosimetry badges, thyroid shields, and lead aprons. Compliance was low. The majority (54%) reported wearing badges and thyroid shields about half of the time. However, those from the trauma center were more likely to wear badges and thyroid shields than was the orthopedic staff from the children's facility. Compliance rates for wearing aprons were greater overall. The authors concluded that consistent radiation safety education is needed for anyone using or working near x-rays.

When enforcing badge compliance, it is important to distinguish between high and very high radiation areas. A high radiation area is one in which an individual could receive more than 1 mSv in 1 hour at approximately 1 foot (30 cm) from the source or from a surface that radiation has entered. In contrast, a room in which occupational absorbed dose could be more than 5 Gy in 1 hour at approximately 3 feet (1 m) from the source or irradiated surface is considered a very high radiation area. Staff must be monitored with a radiation badge if they work in high radiation areas, such as fluoroscopy or positron emission tomography, or very high radiation areas such as radiation therapy. Radiation monitoring also is required if personnel are likely to receive 10% of any yearly regulatory limit or if they have declared a pregnancy. Annual occupational dose limits are as follows:

- Total effective dose equivalent – 50 mSv.
- Lens of the eye – 150 mSv.
- Skin and extremities – 500 mSv.

**Advances in Technology**

Technological and therapeutic advancements create additional RSO responsibilities. RSOs must remain up to date on new treatments to provide education for authorized and supervised users, who can then provide information to the patient and his or her family. For example, a new injectable form of radium-223 was approved by the FDA for the treatment of metastatic prostate cancer. Specifically, radium-223 dichloride is a targeted therapy for bone metastases for patients in whom other forms of treatment have been unsuccessful. The radionuclide primarily releases alpha particles and has a half-life of 11.4 days. Clinical trials began in 2001, and pharmacologic properties, biodistribution, and dosimetry of prostate patients were evaluated. Results showed dose rates of 0.02 µSv h⁻¹ at 1 m from the patient immediately after administration. Therefore, the dose to the public falls within the acceptable range of 1 mSv or less. Personnel dose is considered safe at 5 mSv. The majority of the isotope is eliminated through the gastrointestinal tract; however, residual amounts might be present in the urinary or hematologic systems. Its low penetrating ability makes it safe for others to be around the patient because the majority of the isotope is absorbed into the bone and the strength is not as high as in most nuclear medicine procedures.

In radiation oncology, technological advances include higher photon energy use for treatments. In addition, hypofractionated therapy is becoming more widely used; with this treatment regimen, a patient receives a higher radiation dose per treatment to shorten the treatment course. The RSO and the radiation safety team must oversee the new treatment techniques because the potential for biological harm is greater.

**Therapeutic Radioactive Materials**

The use of therapeutic radioactive materials, such as iodine I 131 for the treatment of thyroid cancer, comes with its own challenges. Patients undergoing thyroid ablation using this drug must be isolated from others for several days. If their living conditions do not allow this or they cannot care for themselves independently at home, they must stay in a confined hospital room. All waste generated in the room must be isolated and monitored for radioactive contamination. According to 10 CFR 35.75, the patient can be released when he or she is unlikely to expose others to a total effective dose equivalent greater than 5 mSv.
This situation is fairly common and standard for the RSO and medical staff; however, some occasions can be difficult. RSOs and technologists must use problem-solving skills to deal with complex medical conditions and consult the literature describing these situations and how they were handled. One of the main challenges is measuring the radiiodine effective dose because the radioactive material is absorbed by other tissues in addition to the thyroid. There also might be residual dose to muscle and bone marrow. In addition, the biological half-life of iodine I 131 is longer in patients on dialysis compared with patients who have normal renal function. This prolonged internal exposure can damage other structures. Patients with renal failure require dialysis, which means a longer hospital stay with regular dose monitoring. Therefore, staff exposure is another concern, and dialysis nurses must be educated and properly protected while providing patient care. Ideally, they should wear a lead apron and a real-time dosimetry monitor. As long as dialysis is performed 24 hours after receiving the radiiodine, staff exposure can be kept to a minimum, which is less than the dose received from a chest radiograph.

The Radiologic Technologist’s Role

Radiologic technologists must comply with the regulations of the radiation protection program including knowing safety requirements and applying them correctly in daily practice. In addition to being mindful of patient exposure, technologists are responsible for practicing safe use of ionizing radiation and following the ALARA principle to minimize their occupational exposure. It is important for technologists to recognize the difference between effective dose and equivalent dose. Dose to organs and tissues affects the overall risk for radiation injury, which is the effective dose. This measure is based on the specific organs involved and radiation energy. Because the degree of organ radiosensitivity varies, effective dose uses a tissue weighting factor developed by the ICRP. It is expressed as a percentage defining the relative risk for stochastic effects, based on the total organ exposure. Stochastic effects are unpredictable biological changes that might result in the development of cancer or genetic mutation. Although the risk of severity cannot be anticipated, the possibility for biological damage increases with radiation dose. Gonads have the highest weighting factor of 0.20, followed by red bone marrow. The majority of organs have a factor of 0.05. Equivalent dose does not take organ and tissue dose into account. This quantity represents the harmful effects from overall absorbed dose based on radiation energy. Although the risk for biological damage is small, it exists whenever radiation doses reach a maximum limit. The effective dose strategy is currently the optimal method for evaluating exposure to radiation and estimating risk for bodily injury.

The fundamental principles of time, distance, and shielding can be applied when performing procedures associated with the highest occupational risks such as:

- Fluoroscopy.
- Interventional radiology.
- Mobile radiography.
- General radiography.
- Mobile C-arm fluoroscopy.

Time

Fluoroscopy time during lengthy cases increases occupational exposure. The longer the beam is on, the greater the exposure to the patient and staff. A cumulative timer should be used and reset before each procedure so an accurate beam time is displayed. Using the image hold function helps reduce exposure to both personnel and patients, allowing an image to be viewed without emitting constant radiation as with real-time imaging. Although the radiologist controls the beam time during interventional procedures, it is the radiologic technologist’s responsibility to ensure the equipment’s radiation dose reduction measures are working before the procedure begins. Options to decrease exposure include low-dose imaging, beam collimation, and the last-image hold feature.

Distance

To minimize dose when working in high-exposure areas, the technologist must maintain awareness of his or her body position during procedures. Mobile radiography can pose a risk to the technologist if distance between the operator and the source is insufficient. Avoiding scatter radiation is best achieved by standing a
minimum of 6 feet away from the patient, preferably at a 90° degree angle to the beam. Similarly, C-arm fluoroscopy results in a considerable amount of scatter from the patient. Because surgeons often are operating the equipment, the direction of the beam might not always be consistent. However, with awareness of the x-ray tube location, the technologist can adjust his or her position accordingly. More scatter radiation is present where the beam enters the patient or at the tube position. The rate of exposure is less where the beam exits the patient, which is the image intensifier side. Knowing this, the technologist should advise surgical personnel to avoid standing near the tube when the surgeon is capturing images. In the event that optimal distance cannot be achieved, personnel should wear protective aprons.

**Shielding**

Wearing protective attire, such as lead aprons, prevents scatter radiation from reaching personnel. A thickness of 0.25 mm is required for those working near x-ray beams with peak energy of at least 100 kVp, as in mammography, for example. Technologists working in fluoroscopy or interventional radiology are required to wear a wraparound apron with 0.5-mm lead equivalent. Those who spend a considerable amount of time using C-arm units are advised to wear thyroid shields of the same thickness.

In addition, scattered radiation to the technologist can be minimized with the use of a sliding protective lead barrier. This curtain is attached to the fluoroscopy unit above the table top and must be at least 0.25-mm lead equivalent. Another attachment that limits gonadal dose during fluoroscopy procedures is a Bucky slot shielding device. Typically, the Bucky tray is moved to the foot of the table; therefore the slot is open, allowing scatter radiation to reach personnel. The shielding device must be a minimum of 0.25-mm lead equivalent.

Patients often need assistance to hold still for a radiographic procedure. Although holding patients for the examination might be necessary, technologists should not practice this routinely. Lead aprons must be worn, and if the technologist’s extremities are near the primary beam, he or she also should wear lead gloves. Other options are available for patient immobilization such as a device for restraining an infant for an upright chest radiograph. If an immobilization device is not feasible, then a family member can wear an apron and assist with holding the patient.

Technologists should alert a department manager or lead technologist if an apron has obvious defects, especially one that is worn routinely during fluoroscopic or interventional procedures. Protective apparel should be inspected annually by a medical physicist, lead technologist, or department manager as required by the Joint Commission.

**Collimation**

Because scatter radiation from the patient is of primary concern in radiography, the technologist can employ methods to minimize occupational dose. Reducing Compton scatter is achieved by limiting the size of the beam through collimation. Several types of collimating features are available on radiographic equipment to protect the patient and personnel. For example, positive beam limitation helps to ensure that the image receptor size corresponds to the collimator. As long as the feature is enabled, the radiographer cannot open the collimators beyond the image receptor dimensions. This prevents exposing the patient unnecessarily (see Figure 2).

**Personal Dosimeters**

Although the RSO manages radiation monitoring, it is the technologist’s responsibility to wear dosimeters appropriately. These devices should be worn outside of clothing, under the apron in the same location while performing radiographic or CT procedures. In contrast, when working in fluoroscopy, the badge should be attached over the lead apron at the level of the thyroid. In addition to monitoring thyroid dose, other structures of the head and neck are exposed and must be monitored. Because a monitoring device is worn outside the apron, the dose reading closer to the body should be negligible. Abnormally high readings might indicate that the badge was misplaced. For example, forgetting the badge in a parked car or leaving it in a radiographic procedure room will result in additional heat to the dosimeter.
Minimizing Patient Dose

Patient dose is reduced through proper positioning, standardized techniques, and optimal patient exposure. Minimizing dose to pediatric patients is critical. Many departments use digital radiography (DR), which allows the radiologist to view an image on a remote station such as the picture archiving and communication system. Images can be viewed in different windows to show anatomical detail. However, the technologist faces obstacles with the use of DR in pediatric patients. Variations in equipment from different vendors require additional knowledge to perform examinations. Therefore, training technologists is necessary, especially because the FDA does not regulate the use of DR equipment. In addition, training documents and pediatric techniques typically are not provided with a DR unit. Manual techniques must be developed because automatic exposure control is not ideal for pediatric imaging. Often, the standard detectors are too large and are positioned for an adult, which affects image quality. Some suggest that units with smaller detectors be manufactured to optimize pediatric DR images.

Another issue with DR is the inability to use positioning devices to help children remain still for an examination. The typical items, such as sponges or towels, appear on the image, obscuring important anatomy. To avoid motion and repeat examinations, technologists should use DR-compatible positioning devices. Finally, patient exposure is not apparent from the image capture information because the contrast can be adjusted after the image is acquired. This could result in some technologists not focusing on minimizing dose and a lack of awareness of the effective dose to pediatric patients.

Implementing a repeat image analysis program also can help minimize patient dose. This analysis involves tracking the number of repeated studies and the reason the radiologist deemed them unreviewable. Reviewing images with positioning errors or incorrect exposure settings can be helpful for technologists and students and encourage them to make greater attempts to position correctly the first time, thereby reducing the number of repeat exposures.

Conclusion

The safe and proper use of ionizing radiation entails many elements. Technologists should be aware of ways to prevent unnecessary dose exposures to patients and to minimize their occupational dose. In addition, everyone in the health care setting should be educated about radiation safety. The RSO and the radiation safety team are responsible for compliance with regulations governing the use of ionizing radiation and ensuring the safety of patients and health care professionals working with it.
References


Radiation Safety Compliance

1. Which of the following are responsibilities of the Nuclear Regulatory Commission (NRC)?
   1. develop policies and regulations for radioactive material safety
   2. oversee operations of licensees
   3. resolve legal issues
   a. 1 and 2
   b. 1 and 3
   c. 2 and 3
   d. 1, 2, and 3

2. If a medical practice or facility intends to use radioactive materials it must have a:
   a. specific license for limited or broad scope.
   b. general license for exempt distribution studies.
   c. specific license for special and commercial nuclear material.
   d. general license for source material.

3. Under a broad scope license, a radiation safety committee must include all of the following personnel except a:
   a. radiation safety officer (RSO).
   b. nursing professional.
   c. radiologic technologist.
   d. department manager.

4. Qualifications to become a medical RSO in a clinical nuclear medicine facility include all of the following except:
   a. 200 hours of classroom and laboratory training in radiation protection, physics, math, biology, and dosimetry.
   b. 1 year of full-time supervised radiation safety experience under an RSO.
   c. training that includes shipping, surveying, equipment checks, measuring doses, emergency procedures, and disposal of radioactive materials.
   d. a master’s degree in radiation physics.
5. Some therapeutic procedures that pose a higher risk to the patient require a written directive by the authorized user. Which of the following pieces of information must be included in the written directive, according to the NRC?
   a. the medical record number
   b. radiopharmaceutical drug name
   c. reason for the procedure
   d. patient’s date of birth

6. Transportation of radioactive materials is regulated by all of the following organizations except the:
   a. NRC.
   b. Department of Transportation.
   c. International Air Transport Association.

7. The Joint Commission developed standards that include which of the following?
   a. performance evaluations of imaging equipment by the RSO
   b. mandatory quarterly radiation safety presentations
   c. lowering the annual allowable total effective dose equivalent
   d. proper follow-up of patient safety incidents

8. The Center for Devices and Radiological Health initiated programs for:
   a. safe use of radiation-emitting equipment.
   b. monitoring of occupationally exposed workers.
   c. transportation of radioisotopes across state lines.
   d. safe production of byproduct material.

9. According to the article, which of the following could be a contributing factor to approximately 2% of all malignancies?
   a. failure to wear radiation badges correctly and consistently
   b. improper packaging and disposal of radioactive materials
   c. radiation dose from CT scans
   d. radiation dose from interventional procedures

10. The annual occupational total effective dose equivalent limit is ______ mSv.
    a. 10
    b. 50
    c. 100
    d. 500

11. What is the primary difference between equivalent and effective dose?
    a. Equivalent dose applies to technologists and effective dose applies to patients.
    b. Equivalent dose takes organ and tissue dose into account.
    c. Effective dose applies to technologists and equivalent dose applies to patients.
    d. Effective dose takes organ and tissue dose into account.

12. Before an interventional procedure begins, who is responsible for ensuring the equipment’s dose reduction measures are working?
    a. the radiologist who will perform the procedure
    b. any authorized user
    c. the radiologic technologist
    d. the radiation safety officer

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