

Radiation Safety Certification—A Review

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Abstract

It has become common for nuclear medicine technologists to assume the responsibilities, or even the role, of the radiation safety officer (RSO) or associate radiation safety officer (ARSO). Their responsibilities are primarily related to the radioactive materials license, but increasingly can include additional safety responsibilities within the hospital. This includes Computed Tomography (CT), Magnetic Resonance Imaging (MRI) and Fluoroscopy safety. Many technologists reading this article may be interested in sitting for the Radiation Safety advanced certification exam by the Nuclear Medicine Technology Certification Board (NMTCB). A consultation of the content outline for that exam (found on the NMTCB website) is a good place to start . The content outline is quite extensive and cannot be covered within a single article.

The purpose of this article is to provide a brief summary of some of the knowledge technologists need to assume the role of an RSO or ARSO.

Keywords: radiation safety officer, nuclear medicine technologist

The Regulations:

A good place to start is to review the following Nuclear Regulatory Commission (NRC) regulations:

- NRC Title 10CFR19 Notices, Instructions and Reports to Workers
- NRC Title 10CFR20 Standards for Protection Against Radiation
- NRC Title 10CFR35 Medical Use of Byproduct Material
- NRC Title 10CFR71 Transportation of Radioactive Material

It is important to note that facilities are bound by what is in their application for the radioactive materials (RAM) license. When the license application is initially submitted either to the NRC or the state (if you are in an agreement state), it may contain items that are more strict than the regulations require. A technologist should always consult the facilities' RAM license application before beginning work at a new facility. Annual refresher training for occupationally exposed workers should include these license specific items in radiation safety (*1*).

Within the NRC regulations, licensing information can be found, as well as training and experience requirements for Radiation Safety Officers (RSOs). The pathway for technologists to become RSO's include 200 hours of didactic training (usually obtained in nuclear medicine school) and one year of full-time radiation safety experience under the supervision of an existing RSO. This training and experience must have been obtained within the 7 years preceding the date of application or the individual must have had related continuing education (*1*).

The transportation of radioactive material is regulated by the Department of Transportation (DOT), however, the NRC can (and will) enforce those regulations. This includes Hazardous Materials (Haz Mat) training for anyone involved in transporting radioactive materials. Haz Mat

training needs to be done every three years (2). Radioactive packages need to be labeled with one of the following labels: White I, Yellow II, or Yellow III (3). Incoming radioactive packages must be checked-in within 3 hours of receipt (4). Incoming and outgoing radioactive packages require dose rate and removable contamination surveys to be performed (1). See table 1. When a package is returned to a radiopharmacy, it is labeled as an “Excepted” Package and only limited quantities of radioactive material can be included (5). If the limited quantity is exceeded, the department should allow for decay prior to returning the package. One common confusion amongst RSO’s is the difference between exempt quantities and limited quantities. An exempt quantity is the amount of each radionuclide that you can obtain without a RAM license. A limited quantity is the quantity of material that can be shipped in an excepted package (5).

Physics Review

The atom is made of a nucleus (protons and neutrons) and an electron cloud. An element, like Technetium or Iodine is the identity of the atom. The number of protons in the nucleus determines this identity (or elemental name). This number of protons in the nucleus is the atomic number, denoted by the letter Z (6).

If an atom is unstable, it is said to be radioactive. It will emit radiation (energy) until it becomes stable again. The amount of time it is unstable can be measured in half-lives (the amount of time it takes for half of the energy to decay). There are three modes of radioactive decay originating from an unstable nucleus: alpha, isobaric (beta or electron capture) and isomeric (gamma emission or internal conversion). Alpha and beta decay are particulate decay. An alpha particle is simply a helium nucleus (2 protons and 2 neutrons). A beta particle is an electron and can be either positive or negative. Isobaric decay can either be beta decay or electron capture and occurs when the nucleus is either proton-rich or neutron-rich. Beta positive decay occurs when

the nucleus is proton rich and beta negative decay occurs when the nucleus is neutron rich.

Electron capture is an alternate decay pathway to beta positive decay. If a nucleus is proton rich, but does not have enough energy for beta positive to occur, an electron will be absorbed into the nucleus. The result is the emission of a characteristic x-ray. Gamma decay is the emission of a photon, which has no mass or charge. Gamma emission is usually the result of another decay process. Radioactive decay can be calculated using the half-life of the radionuclide (4).

There are two units of radioactivity: Becquerel and Curie. The Becquerel was named after Henri Becquerel who discovered spontaneous radioactivity. A Becquerel is equivalent to one disintegration per second (dps). The Curie was named after Marie Curie who discovered radium. One Curie is equivalent to 3.7×10^{10} Becquerels. This is the amount of radioactivity in one gram of radium. An easy conversion between Becquerels and Curies is $1 \text{ MBq} = 37 \text{ mCi}$ (4).

When radiation interacts with matter, excitation or ionization can occur. Excitation causes an electron in the matter to be elevated to a higher energy shell. Ionization causes the electron in the atom to be removed completely, leaving an ion pair (the electron and the new positively charged atom). Radiation used in nuclear medicine, Computed Tomography (CT), fluoroscopy and therapy is ionizing radiation (6).

Alpha particles have a high linear energy transfer (LET) and will cause a significant number of ionizations making them useful in therapeutic applications. Beta positive particles (positrons) will interact with a negatively charged electron causing an annihilation reaction resulting in two 511 keV photons emitting in opposite directions. Beta negative particles will interact with matter by producing bremsstrahlung radiation. Bremsstrahlung radiation is also known as braking radiation. As the beta negative particle passes close to the nucleus, the attracted forces

cause the beta negative particle to brake, releasing excess energy as bremsstrahlung radiation (an x-ray) (6).

Radionuclides can be produced in three basic ways: reactor, accelerator, or generator. A nuclear reactor utilizes neutrons to induce fission in uranium. Reactor produced radionuclides include ^{99}Mo , ^{133}Xe , ^{131}I , ^{137}Cs . Accelerators utilize charged particles by rapidly accelerating them and slamming them into a target material. A cyclotron is an accelerator that utilizes two magnets (called Dees, for their shape). Cyclotron produced radionuclides include ^{123}I , ^{201}Tl , ^{57}Co , and many PET radionuclides. A generator has a long-lived parent that decays into a useful radioactive daughter. Generator produced radionuclides include $^{99\text{m}}\text{Tc}$, ^{82}Rb , and ^{68}Ga (4).

Gamma rays and x-rays differ in their origin. Gamma rays originate in the nucleus and x-rays originate in the electron cloud. There is more energy in the nucleus than the electron cloud, so gamma rays have the potential to have higher energy than x-rays. However, some x-rays do have higher energy than some gamma rays.

There are two types of x-rays produced in an x-ray tube: bremsstrahlung x-rays and characteristic x-rays (4). The energy of the x-rays are measured in peak kilovoltage (kVp). X-rays are polyenergetic and are produced over a spectrum of energies, whereas gamma rays are monoenergetic. Gamma rays are measured in kiloelectron volts (keV). The amount of x-rays used are measured in milliamperere-seconds (mAs). Increasing the kVp is done for larger patients because the higher energy x-rays can penetrate the body. Increasing the mAs is to allow for more information (higher quality) CT, but also increases the dose to the patient (4).

A fluoroscopy unit uses a continuous x-ray beam to produce a live image on a monitor. There are several exams that are performed under fluoroscopy, including barium studies, cardiac

catheterization, arthrography, and placement of intravenous (IV) catheters. It is also used for lumbar punctures, biopsies and guided injections into joints. High dose fluoroscopic procedures are seen in interventional radiology, the cardiac catheterization lab and the operating room (7).

MRI utilizes the charge of the atomic nuclei. In fact, MRI was once referred to as Nuclear Magnetic Resonance (NMR). The unit of measurement for a magnetic field is the Tesla. One Tesla is equal to 10,000 gauss. MRI units are calibrated in the range of 0.5 to 4 Tesla (8). MRI machines do not produce ionizing radiation.

Instrumentation Review

There are two main types of instruments that can be used to detect radiation: gas filled detectors and scintillators. A dose calibrator is a gas-filled instrument known as an ionization chamber. It is located at the lower end of the gas ionization curve (lower voltage). It is useful in measuring high amounts of radiation and is less accurate with low amounts of radiation. A portable ionization chamber, sometimes called a Cutie-Pie, can be used to detect the amount of radiation emitting from a radionuclide therapy patient. A Geiger-meuller (GM) meter is a gas filled detector located at the upper end of the gas ionization curve (higher voltage). It is useful in detecting small amounts of radioactive contamination (9). Keep in mind that GM meters are usually calibrated using a high energy ^{137}Cs source. As such, when they are used to detect lower energy isotopes (i.e. $^{99\text{m}}\text{Tc}$), they will over compensate and your reading will be higher than what is actually there. This makes the instrument very sensitive when looking for contamination in the department (4).

Scintillators can be liquid or solid. A liquid scintillator is very efficient and is used for counting low energy beta particles. A solid scintillator is much less efficient and found in well counters,

gamma cameras and PET cameras. Well counters are useful in detecting removable contamination. The efficiency of well counters varies. Therefore, it is important to correct the counts by the instrument's efficiency and report all values in disintegrations, not counts (9).

Radiation detection instruments need to be calibrated and checked regularly. A GM meter should be calibrated annually using a high activity ^{137}Cs source. It should also be checked for a response each day before use. The daily check should include a battery check, annual calibration expiration date check and source check. Some meters have a dedicated source. The reading should be within $\pm 20\%$ of the expected reading (4).

There are four tests that are required for a dose calibrator. The accuracy test is performed annually and includes measuring a source with a known amount of radioactivity. A minimum of two sources should be used. The most common sources are ^{137}Cs , ^{133}Ba and ^{57}Co . The measured amount is compared to the known amount. Accuracy should be within $\pm 10\%$. A constancy test, a test of precision, is performed daily. The expected value comes from either previous readings or calculated readings. Precision should be within $\pm 10\%$ of the expected reading. A geometry test is performed to ensure that radioactivity in different geometric variations (i.e. different volumes or different size syringes or vials), is precise. This test is done when a new dose calibrator is brought into the department, after repairs or when a new size syringe or vial is introduced. Measurements should be within $\pm 10\%$ of the expected value. A linearity test is performed quarterly to ensure that the dose calibrators is accurate over a wide range of activities. This test can be done with the decay method or the attenuation sleeve method. Readings should be within $\pm 10\%$ of the expected value (4). See table 2.

Measuring Radiation

There are several units used to measure radiation exposure and dose. The unit of exposure is the Roentgen (R). This is the unit used on GM meters. One Roentgen is equivalent to 2.58×10^{-4} Coulombs per kilogram. The unit of exposure measures ionizations in air (i.e. gas filled detectors, like the GM meter) and is useful for photons only. The unit of absorbed dose is the RAD or Gray (100 RAD = 1 Gray). This unit measures the amount of energy imparted on a material. It is useful for photons and particulate radiation, but does not distinguish between the two. The REM or Sievert (100 REM = 1 Sievert) is a unit of equivalent dose. This unit also measures the amount of energy imparted on a material, but differentiates between different types of materials by multiplying by the quality factor for that type of radiation. When you multiply RAD or Gray by the quality factor, the unit changes to REM or Sievert (unit of equivalent dose). The quality factor for x-rays, gamma rays and beta particles all have a quality factor of one. The unit of effective dose is also in REM or Sievert, but takes into consideration what part of the body was exposed. If the whole body was exposed (as assumed with whole body badges), the tissue weighting factor is one. If only part of the body was exposed, the tissue-weighting factor is less than one (4). See table 3.

Occupational dose should be measured for any worker likely to receive 10% of the annual limit (5 Sievert or 500 mrem) (1). This can be monitored using radiation badges (whole body and rings). Commonly, a whole body dosimeter is worn on the body between the neck and waist. The badge is made of an optically stimulated luminescence (OSL) detection material. Ring badges containing a thermoluminescence dosimeter (TLD) chip is worn on the dominant hand, facing the palm to measure extremity exposure. Film dosimeters and pocket dosimeters can also be used to measure exposure to occupational workers (4).

Bioassays are used to detect an individual's exposure to internal radiation. The most common bioassay is a thyroid count done to detect an individual's exposure to ^{131}I . Other bioassays include a urine sample, nasal swab and whole body counting. The occupational workers total dose is the sum of the deep dose equivalent (external dose) and committed dose equivalent (internal dose) (*I*).

Individuals can be internally exposed by either ingestion, absorption or inhalation. The Annual Limit of Intake (ALI) results in an effective dose of 5 REM (0.05 Sievert). Each radiopharmaceutical has a level that leads to one ALI. If a dose is inhaled, the air concentration can be calculated for different radionuclides to produce a Derived Air Concentration or DAC. While ^{133}Xe is airborne, the preferred method of determining workers' exposure is to ^{133}Xe is to use the deep dose equivalent, which is a measure of external dose (*I*).

In addition to monitoring an individual's exposure, room monitoring is useful to reduce exposure as well. Ambient dose rate surveys are performed using a GM meter to detect contamination or sources of radioactivity in an area. Trigger levels for ambient dose rate should be set at five mrem/hr (50 uSv/hr) for restricted areas and 0.2 mrem/hr (2 uSv/hr) for unrestricted areas (*I*). Wipe tests are performed using a well counter to identify areas where there is removable contamination. A trigger level of 22,000 dpm/100 cm² should be established (*I*).

Sealed sources should also be monitored. A biannual inventory should be maintained and removable contamination (leak test) should be measured. All sealed sources should be inventoried and leak tested with the following exceptions: sources with a half-life less than 30 days, sources containing gaseous material, sources containing 100 uCi or less, and sources in storage and not being used (*I*). The leak test result should be less than 0.005 uCi (185 Bq) (*I*).

To use a well counter to perform a leak test, a Minimum Detectable Activity (MDA) needs to be established on that well counter. The MDA needs to be less than 0.005 μCi (185 Bq).

Radiation Protection and ALARA

A deterministic effect to radiation occurs when a threshold is reached. The severity of the effect increases with dose. Examples of deterministic effects are skin erythema and cataracts.

Stochastic effects are random effects and their prevalence is more likely with a higher dose (4).

The three basic methods of radiation safety are time, distance and shielding. Limiting time near a radiation source will lower exposure. Utilizing distance (using the inverse square law) can reduce exposure. The inverse square law states that if you double your distance from the source, you reduce the exposure rate to $\frac{1}{4}$ of the original value. Shielding can be utilized to reduce exposure. This reduction can be calculated using the linear attenuation coefficient. Each shielding material has a half-value layer (HVL) for each radionuclide. The linear attenuation coefficient is $0.693/\text{HVL}$ (4).

Radiation workers must not exceed annual limits. The annual limits for a radiation worker is 5 REM (0.05 Sievert) to the whole body, 15 REM (0.15 Sievert) to the lens of the eye and 50 REM (0.5 Sievert) to an extremity or skin of the whole body. Minors (those under the age of 18) have an annual limit of 10% of the adult limit. Radiation workers who have voluntarily declared pregnancy have a 50 mrem/month (0.05 Sievert/month) or 500 mrem (0.5 Sievert) over the gestational period for the fetus (4).

The public must also be protected from radiation exposure. The limits to the public are less than 2 mrem (0.02 mSv) in any hour. This is a total dose in a one hour period, not a dose rate. In

addition, it must be less than 100 mrem (1 mSv) in one year. This exposure does not include doses received from radioactive patients (6).

Radiation workers must be notified at least annually of their radiation exposure. Records must be kept by the employer for the entire length of the license. Employers should follow the As Low As Reasonable Achievable (ALARA) principle to keep exposure low. Notifications should be provided to workers who exceed 10% of the quarterly limit (125 mrem or 0.125 Sieverts). In addition, for workers who exceed 30% of the quarterly limit (375 mrem or 0.375 Sieverts), a plan of action should be implemented to reduce exposure (1).

Restricted areas are those where people may be exposed to radiation or radioactive materials. A restricted area should have controlled access. Doors to restricted areas should be locked when a direct line of sight is unavailable. In addition, signs indicating the level or type of radiation should be posted. The following signs are used: “Caution, Radiation Area”, “Caution, High Radiation Area”, “Grave Danger, Very High Radiation Area”, “Caution, Airborne Radioactivity Area”, and “Caution, Radioactive Materials” (4).

Currently, there are no regulations regarding the amount of radiation exposure to patients.

Radiation workers should strive to utilize the appropriate dose for the exam. The Image Gently and Image Wisely campaigns are useful resources for identifying appropriate doses. Many factors can affect patient dose, including the half-life and biodistribution of the radiopharmaceutical. Patients should be evaluated to determine pregnancy or lactation status. Patients who are lactating (even if they discontinue breast feeding) may have increased breast uptake. The risks and benefits must be explained to the patient prior to performing the procedure.

CT dose is measured in CT Dose Index (CTDI). This is the dose measured in a phantom and can be used to evaluate risk to populations, not to individual patients. The CTDI is a summed dose based on kVp, mAs, collimation, and rotation speed (4). Dose Length Product (DLP) is the CTDI multiplied by the length of the scan. Both CTDI and DLP are measured in mGy. There are two CTDI phantoms. The large (body phantom) measures 32 cm in diameter. The small (head phantom) measures 16 cm in diameter. Both CTDI and DLP is a measure of how much radiation is being used, not how much is absorbed by the individual patient (10).

kVp is usually set between 80 and 140. mAs is usually set between 50 and 400. Automatic Exposure Control (AEC) is used to adjust the tube current as the body is being scanned.

Different areas of the body have different densities. AEC adjusts accordingly (10).

The effective dose (in mSv) can be calculated for adults by multiplying the DLP by the k factor.

The k factor is found in the American Association of Physicists in Medicine (AAPM) report 96 (11). In addition, patient size will make a difference when identifying the dose to the patient.

Size Specific Dose Estimates (SSDE) are factors that take into account different patient size.

Smaller patients will have an underestimated CTDI and larger patients will have an overestimated CTDI. SSDE can be found in AAPM Report 204 (12).

There are four main metrics for fluoroscopy dose: Fluoroscopy time, Air kerma, Dose Area Product and Peak skin dose. Fluoroscopy time is the amount of time a patient is exposed. Air kerma is expressed in J/kg or Gray. It is a quantity of absorbed dose. Dose Area Product is the absorbed dose multiplied by the area radiated and is expressed in Gray-cm². Peak skin dose is the highest dose to any portion of the patient's skin during a procedure (13).

It is important to know that the biggest safety risk associated with MRI is that objects can become projectiles and slam into the magnet, burns that can be created due to energy deposition and hearing loss due to loud noises produced by the MRI scanner (14). To prevent unauthorized access into the MRI suite, the ACR recommends four safety zones. Zone one includes areas that are open to the general public. This area is less than 5 Gauss (0.5 mT). Zone two is also a public area, but it is the intermediate area that separates zone one from zones three and four. This is typically where the technologist will perform patient screening. Zone three is the area near the magnet room. Only screened individuals may enter zone three. Zone four is the magnet room itself (15).

Emergency Procedures and Adverse Events

There are several emergency procedures in place for individuals working with radioactive materials. Major and a minor radiation spills are handled differently. Many times the radiation safety officer will not be involved with a minor spill as it can be handled in the department (10). Other examples of emergency situations include radiotherapy patients requiring emergency care, as well as the unexpected death of a radiotherapy patient. RSO's may also be called upon to lead emergency responses for radiologic events.

The term "misadministration" has been replaced with "medical event". Technologists thought a misadministration occurred when the wrong radiopharmaceutical was administered even if the dose was less than the 5 REM threshold. However, by definition this would not have been a misadministration. It would be an error. It still required reporting, but not to the NRC. A medical event occurs when an error and an excess exposure occurs at the same time. An error occurs when the wrong patient, wrong amount or wrong route occurs. An excess exposure occurs when a dose amount is given that leads to greater than 5 REM (0.05 Sieverts) whole body

dose, 50 REM (0.5 Sievert) to an organ or tissue, or 50 REM (0.5 Sievert) to the skin. Therapies are examples of excess exposures. When an excess exposure and an error occur with the same administration, a medical event has occurred. The most common medical event in a nuclear medicine department occurs with the administration of ^{131}I . A medical event must be reported to the NRC within one calendar day after discovery of the event (1).

Conclusion:

Technologists seeking to assume the responsibilities of RSO or ARSO should seek multiple references when preparing for that role. In addition to reading and understanding the regulations, at least one year of experience should be sought under the supervision of an RSO.

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Label	Surface Limit	Transport Index (1 meter)
<i>White I</i>	0.5 mR/hr	N/A
<i>Yellow II</i>	50 mR/hr	1 mR/hr
<i>Yellow III</i>	200 mR/hr	10 mR/hr

Table 1. Package Labels for Radioactive Materials Packages

Test	Purpose	Source	Frequency	Passing Level
<i>Accuracy</i>	Accuracy	Cs-137, Co-57, Ba-133	Annually	+/- 10%
<i>Constancy</i>	Precision	Cs-137 or Co-57	Daily, before use	+/- 10%
<i>Linearity</i>	Precise over range of activities	Tc-99m or F-18	Quarterly	+/- 10%
<i>Geometry</i>	Precise over different configurations/volumes	Tc-99m	New or after repairs	+/- 10%

Table 2. Dose Calibrator Quality Control

Measurement	US Unit	SI Unit	Conversion
<i>Activity</i>	Curie	Becquerel	1 mCi = 37 MBq
<i>Ionizations in air</i>	Roentgen	C/kg	1 R = 2.59 X 10 ⁻⁴ C/kg
<i>Absorbed dose</i>	RAD	Gray	100 RAD = 1 Gray
<i>Equivalent dose (Absorbed Dose times radiation quality factor)</i>	REM	Sievert	100 REM = 1 Sievert
<i>Effective dose (Equivalent dose times tissue weighting factor)</i>	REM	Sievert	100 REM = 1 Sievert

Table 3. Radiation Measurement Units