

THEORIES AND PRACTICE OF RADIATION SAFETY IN NUCLEAR MEDICINE

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INTRODUCTION

Safety issues in nuclear medicine are numerous and may involve hazardous material issues, infection control, patient care, and radiation safety. Although all these safety issues are relevant in the daily duties of nuclear medicine technologists, radiation safety issues are perhaps the most pervasive and hence, most influential in the duties of technologists. This article will serve as a refresher course for experienced technologists, a study aid for technologists in training, and an educational tool to the layperson. The topics covered will include the nature of radioactivity, the biological effects of radiation, and finally, radiation safety precautions the nuclear medicine technologist can take to minimize radiation exposure.

NATURE OF RADIOACTIVITY

The atom is the basic structural unit of matter and is composed primarily of neutrons, protons, and electrons. Neutrons carry no electrical charge, but protons carry a positive charge. Neutrons and protons combine to form the nucleus of the atom, which carries an overall positive charge. Electrons are negatively charged and, when equal in charge to the protons, result in an electrically neutral atom.

Certain criteria must exist within the nucleus of the atom to keep the opposing forces of the positively charged protons from disrupting the structural integrity of the nucleus. When these criteria are not met, the nucleus becomes unstable, possesses additional energy, and is said to be radioactive. For each individual radioactive element, the process by which an element seeks a stable state is unique with respect to its type, energy of emission, and rate of decay.

For atoms that contain 20 or fewer protons, nuclear stability exists when the number of protons equals the number of neutrons. Figure 1 represents this stable relationship between protons and neutrons by demonstrating a theoretical *line of stability*.

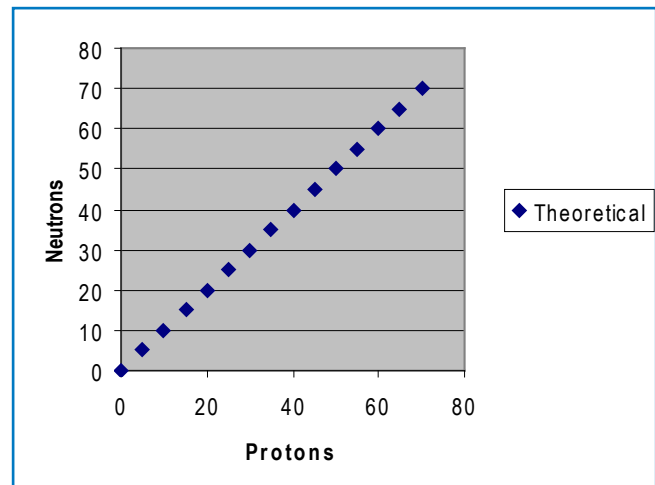


FIGURE 1. *Theoretical Line of Stability*

As the number of protons increases above 20, it takes an increasingly greater number of neutrons to overcome the opposing forces of the protons within the nucleus. This ratio of neutrons to protons (n:p ratio) continues to increase until the element $^{209}_{83}\text{Bi}_{126}$ (126 neutrons and 83 protons) is reached. No stable *nuclides* beyond $^{209}_{83}\text{Bi}_{126}$ exist (Figure 2).

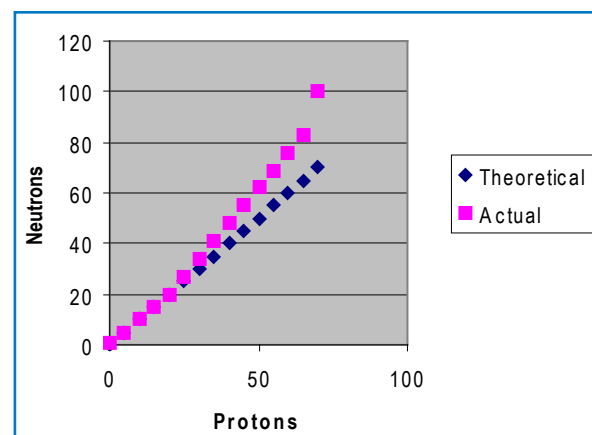


FIGURE 2. *Actual Line of Stability*

If you were to graph the number of protons compared to the number of neutrons in a radioactive element, you would find that they lie either above or below the actual line of stability. Those elements lying above the actual line of stability need more protons or fewer neutrons to become stable. They are said to be either *proton poor* or *neutron rich*. Those radioactive elements that lie below the actual line of stability need more neutrons or fewer protons to become stable. They are said to be either *neutron poor* or *proton rich*. The process of radioactive decay will adjust the n:p ratio until nuclear stability is achieved.

RADIOACTIVE EMISSIONS

Several types of radioactive emissions are relevant in nuclear medicine technology. From the radiation safety perspective, it is helpful if we categorize these radioactive emissions as either *particulate radiation* or *electromagnetic radiation*. However, it should be noted that it is uncommon for a radioactive material to decay by a single mode. Most radioactive materials decay simultaneously by a number of means, both particulate and electromagnetic.

Particulate Radiation. This type of radioactive emission involves a tangible particle being emitted from the nucleus of the atom. Such radioactive emissions tend to deposit their energy along very short pathways. If taken into the body, this type of radioactive decay can do considerable tissue damage. Therapies routinely performed in nuclear medicine rely on the ability to deliver particulate emitters to diseased sites so that destruction of pathological tissue can occur.

Outside the body, this type of radioactive emission poses little threat. Often the skin or even air can sufficiently provide enough protection from externally emitted particulate radiation. The primary safety issue with particulate radiation is to prevent its unintentional entry into the body.

Beta particles are the most commonly encountered particulate radiation in nuclear medicine. These particles have the same mass and charge as an electron and are often thought of as “electrons in transit.” However, unlike regular electrons that reside outside of the nucleus, beta particles originate from within the nucleus. Beta particles may be expected when the n:p ratio is high. The intranuclear effect of a beta emission would be the conversion of a neutron (neutral electrical charge) into a proton (positive electrical charge) and a beta particle (negative electrical charge). The beta particle is then ejected from the nucleus of the atom. This process decreases the n:p ratio by decreasing the number of neutrons while simultaneously increasing the number of protons.

The energy released in beta decay is shared between the beta particle and an electrically neutral subatomic particle known as an *antineutrino*. The energy sharing between the beta particle and antineutrino is more or less random from one radioactive decay to the next.

Consequently, although there is a maximum energy that may be imparted to the beta particle, the beta particle is actually capable of possessing a range of energies. The actual energy of the beta particle will be equal to the maximum energy minus the energy of the antineutrino. A graph, known as the *beta spectrum*, can be drawn to demonstrate the energy imparted to a beta particle versus its frequency of occurrence (Figure 3). You can see that the graph contains a maximum value noted as E_{\max} . The most frequently occurring energy for a beta particle is approximately one third of E_{\max} .

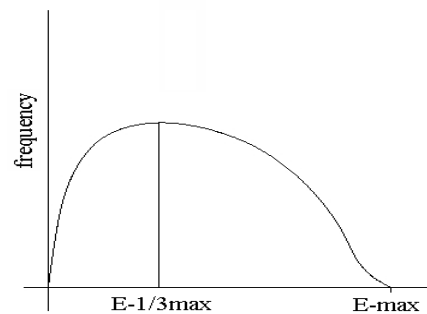


FIGURE 3. Beta Spectrum Graph

A phenomenon that may occur with the emission of a beta particle is known as *bremstrahlung* (or “braking”) radiation. Bremsstrahlung radiation occurs when a beta particle interacts with the nuclei of nearby atoms. As the beta particle passes close to nearby atoms, the positive charge of the nuclei slows down the beta particle. By decelerating, the beta particle loses energy that it gives off in the form of bremsstrahlung radiation. The greater the density of the material (ie, larger number of protons in nucleus), the greater will be the bremsstrahlung radiation production. Hence, it is recommended that materials containing few protons within the nucleus, such as plastic or lucite, be used for shielding when administering beta-emitting radiopharmaceuticals.

Positron emissions are another type of particulate radiation frequently used in nuclear medicine imaging. Nuclei with a low n:p ratio are candidates for emitting positrons. It is convenient to think of the positron as a high-velocity particle of identical size to the beta particle but with an opposite charge. Within the nucleus, the positron is released when a proton (positive electrical charge) is converted into a neutron (neutral electrical charge) and a positron (a physically smaller positively charged entity). The positron is ejected from the nucleus in the form of a positron. This process increases the n:p ratio by increasing the number of neutrons while simultaneously decreasing the number of protons.

Perhaps the most important outcome associated with positron emission is the *annihilation reaction*. This only occurs once the positron leaves the atom. As the positron loses its momentum and comes to rest, it is attracted to a nearby electron. In the resulting collision between the positron and electron, both the mass of the positron

and electron are completely annihilated and converted to energy. This energy is dissipated in the form of two, 511 keV photons emitted in completely opposite directions. The detection of these annihilation photons is the basis of positron emission tomography.

Electromagnetic Radiation. This type of radiation has a number of unique characteristics. Electromagnetic radiation is composed of photons. Photons are discrete packets of energy with negligible mass that possess both particulate and wavelike characteristics. One type of electromagnetic radiation is differentiated from another by its wavelength and frequency. Common examples of electromagnetic radiation include visible light, radio-waves, microwaves, and—in the medical world—gamma rays and x-rays.

Gamma rays and *x-rays* tend to pass through human tissue in a manner inverse to the density of the tissue. In other words, as the density of the tissue increases, the ability of the gamma ray or x-ray to pass through the tissue decreases. Although some of the energy is deposited in tissue and thus can be responsible for tissue damage, much will pass through the body so that it can be detected by scanners or film. These last two characteristics are what make gamma rays and x-rays useful for medical imaging. They incur minimal tissue damage (relative to particulate radiation) and, unlike particulate radiation, are easy to detect outside the body.

MODES OF RADIOACTIVE DECAY

Isomeric transition. This mode is the most important decay scheme in nuclear medicine technology because this is the means by which technetium 99m decays to technetium 99. *The American Heritage Dictionary*¹ defines an isomer as:

“Any of two or more nuclei with the same mass number and atomic number that have different radioactive properties and can exist in any of several energy states for a measurable period of time.”

^{99m}Tc is slightly more energetic than ^{99}Tc . Since this more energetic state is only a temporary arrangement, the more energetic energy level is said to be *metastable* and is designated by the letter “m.” The metastable atom will eventually reach the lower energy level by giving off energy, usually in the form of a *gamma ray*. Because *gamma rays* of this energy type deposit little energy within the body and are easily detectable outside the body, isomeric transition is one of the preferred means of radioactive decay in nuclear medicine.

Electron Capture. This mode is another means of radioactive decay preferred in nuclear medicine imaging. As with isomeric transition, *electron capture* deposits little energy within the body and is easily detectable outside the body. *Electron capture*, like positron emission, results from an excess of positive charge within the nucleus and,

in fact, competes with positron emission. Electron capture results when the nucleus captures one of the electrons of the atom. Once an electron is captured, a vacancy is created that is filled by other electrons. In order to assume the vacancy, these electrons will need to give up energy in the form of *characteristic x-rays*. The energy of the *characteristic x-ray* is determined by how tightly the involved electrons were bound to the atom. Any difference in this binding energy will be imparted to the characteristic x-ray.

X-rays, like gamma rays, are part of the electromagnetic spectrum and are desirable for medical imaging purposes. Although x-rays and gamma rays differ in frequency and wavelength, the biggest difference between them is their point of origin. X-rays originate from outside the nucleus, whereas gamma rays originate from within.

BIOLOGICAL EFFECTS OF RADIATION

Individuals trained in the radiation sciences are well aware that radiation is literally all around us. It is in soil, food, water, and building materials. Also, radiation from cosmic sources permeates the atmosphere around us. In fact, our own bodies contain radioactivity. The actual effects of radiation from these sources are unknown, but some researchers have implicated low levels of radiation exposure—along with other environmental hazards—as being responsible for the aging process, birth defects, genetic disorders, and tumor growth.

STOCHASTIC EFFECTS

The term *stochastic effects* is applied to those radiation effects that may occur regardless of how small the radiation exposure. The severity of stochastic effects is the same whether they are produced by large or small levels of radiation exposure. Common examples of stochastic effects are tumors and genetic alterations.² The current guidelines for radiation protection are based on the assumption that any radiation dose, no matter how small, can result in detrimental health defects.³

RADIATION HORMESIS

At first glance, the notion of *radiation hormesis* appears to contradict the assumptions behind *stochastic effects*. The theory behind *radiation hormesis* proposes that small doses of radiation are actually helpful to the living being. A number of studies have been released that support this thesis. However, many of these studies have been performed outside the United States and are thus difficult to obtain for review.⁴⁻⁶ The most supportive study of *radiation hormesis* is an unpublished document from the United States Department of Energy. This study involved thousands of naval shipyard workers who were exposed to external sources of low-level radiation.⁷ This study showed that the death rate for cancer among radiation-exposed workers was slightly—but not

significantly—less than that of the general US population. A notable finding in this study was that the corresponding death rate among naval shipyard workers *not* exposed to radiation was 12-24% higher.^{8,9} These findings imply that low levels of radiation exposure do not lead to higher cancer rates and may actually serve a protective function by reducing cancer rates among the occupationally exposed.

However, this does not mean that there are no deleterious effects from low levels of radiation exposure. Many scientists, even those who support the tenets of *radiation hormesis*, do not make this assumption. Instead, the argument is made that the positive effects associated with low levels of radiation exposure outweigh the deleterious effects. What is clear is that humans—as well as all living organisms—have developed and evolved in a radiation-filled environment and have thrived as a species regardless of the actual effects of low-level radiation.

Unlike the debate regarding the potential deleterious effects of low-level radiation exposures, there is no doubt that radiation exposure in larger amounts does have undesirable effects in both single-celled and multi-celled organisms. However, a radiation exposure must be large in order to induce deleterious outcomes that manifest within a few weeks or less of the exposure. Outcomes that manifest within this period are referred to as *early effects*. The actual outcome of early effects depends on the size of the radiation exposure; some early effects may occur within as little as a few minutes after the exposure. Because the outcome of early effects is known and linked with specific levels of radiation exposure, they are often referred to as *deterministic* or *non-stochastic effects*.

A predictable sequence of events follows exposure to high levels of radiation. This sequence of events is known as *acute radiation syndrome*. The time it takes to complete the sequence, the observable symptoms, the severity of the symptoms, and the outcome depends on the amount of radiation received. Fortunately, it is highly unlikely that a diagnostic medical imaging technologist would receive enough radiation from occupational exposure to precipitate *acute radiation syndrome*.

According to the Centers for Disease Control and Prevention,¹⁰ individuals exposed to radiation will get *acute radiation syndrome* only if all of the following conditions exist:

1. The radiation dose is high (diagnostic medical exposures are not considered high).
2. The radiation is penetrating (ie, able to reach internal organs).
3. The person's entire body, or most of it, receives the dose.
4. The radiation is received in a short time, usually within minutes.

The stages experienced in *acute radiation syndrome* are as follows:

1. Prodromal
2. Latent
3. Manifest illness
 - a. Bone marrow syndrome (hematologic)
 - b. Gastrointestinal (GI) syndrome
 - c. CNS syndrome (cardiovascular)
4. Death or recovery

The *prodromal* stage is sometimes referred to as the NVD syndrome because the symptoms associated with this stage are nausea, vomiting, and diarrhea. The symptoms and their severity depend on the amount of radiation absorbed; they may last from minutes to days.

The *latent stage* follows the *prodromal stage*. During the latent period the severity of symptoms subsides and thus the sickness may appear to subside. The duration of the latent stage, like that of the *prodromal*, depends upon the amount of radiation absorbed and may last anywhere from a few hours to a few weeks.

During the third stage, the distinguishing symptoms of the syndrome will manifest. The actual syndrome experienced again depends on the dose absorbed (this subject will be addressed shortly).

The final stage is *recovery or death*. Recovery is only possible with lower levels of radiation exposure.

The first of three illnesses that may be seen during the manifest illness stage is the *bone marrow syndrome*, which is sometimes called the hematologic syndrome. A radiation exposure between 0.7 to 10 Gy (70-1000 rad) will result in this specific syndrome. Radiation exposures of this magnitude prey upon the radiosensitive nature of the blood-forming elements of the bone marrow. This syndrome generally involves a mild prodromal syndrome, followed by a latent period lasting up to four weeks. During the latent period, there will be a reduction in the number of red blood cells, white blood cells, and platelets. If the dose proves lethal, the primary cause of death is the destruction of the bone marrow, resulting in infection and hemorrhage.

The *gastrointestinal syndrome* (GI syndrome) will manifest following radiation exposures between 10 to 100 Gy (1000-10,000 rad). Blood-forming elements are also affected at this level of exposure, but there is not sufficient time for those symptoms to be manifested. After a latent period of 3 to 5 days, the individual will experience additional nausea and vomiting, prolonged and often bloody diarrhea, and dehydration. Survival is extremely unlikely with this syndrome. Irreparable changes in the GI tract and bone marrow usually cause infection, dehydration, and electrolyte imbalance. Death usually occurs within 2 weeks.

Absorbed radiation doses greater than 50 Gy will result in the CNS syndrome. Blood-forming elements and the gastrointestinal mucosa are also affected at this level, but usually there is not sufficient time for manifestation of these symptoms. The onset of the prodromal syndrome occurs within a few minutes and is of a severe nature. Following a brief latent period of 6 to 12 hours, the individual will experience disorientation, loss of coordination, respiratory distress, convulsions, coma, and finally, death. Death occurs within 3 days and is due to widespread failure of the circulatory system as well as edema within the skull (Table 1).^{10,11}

Depending upon the source of information, there may be considerable overlap in the absorbed radiation dosage needed to induce various radiation syndromes. This overlap exists due to the variability of radiosensitivity between individuals, the magnitude and length of exposure, the type of radiation involved, the extent of bodily exposure, as well as other variables.

Table 1. Manifest Illness Syndromes Due to Radiation Exposure

Syndrome	Dose	Significant Occurrence	Outcome
Bone Marrow	0.7 to 10 Gy	Affects blood-forming elements	Possible recovery
GI	10 and 100 Gy	Destroys gastrointestinal mucosa	Death within 2 weeks
CNS	Greater than 50 Gy	Neurologic and circulatory breakdown	Death within 3 days

Unlike early effects that may occur within minutes, *late effects* may take years to manifest. Most late effects are stochastic effects and may be experienced as *somatic effects* in the form of leukemia or tumor formation. It is also possible that the stochastic effects will be expressed in future generations (ie, *hereditary effects*) in the form of genetic alterations. Cataract formation, although a late effect, is an example of a *deterministic* or *non-stochastic effect* because cataract formation is associated with specific levels of radiation exposure.¹²

RADIATION SAFETY FOR THE NUCLEAR MEDICINE TECHNOLOGIST

ALARA is an acronym for *as low as reasonably achievable*. This is the principle regarding radiation exposure that all nuclear medicine technologists are required to assume in their day-to-day activities. Nuclear medicine technologists are required to apply this principle to themselves as well as the patient, hospital personnel, visitors, and other incidentally encountered individuals.

ALARA is based upon the assumption that there is no safe level of exposure (ie, stochastic effects). It is assumed that all radiation exposure, no matter how small, has a

chance of generating some late effect. Hence, under the *ALARA* concept, it is not enough to keep exposure levels under those set by state and federal authorities. Nuclear medicine technologists must make every effort to minimize radiation exposure to themselves and all others at all times; otherwise, they are in violation of the *ALARA* concept and risk reprimand by state and federal authorities.

Federal regulatory authority is held by the Nuclear Regulatory Commission (NRC). Some states have adopted the criteria established by the NRC but have chosen to self-regulate the production and use of radioactive materials. States that have taken these actions are known as agreement states. The NRC and hence, the agreement states, have adopted limits for occupationally exposed workers. These limits may be found in Title 10, Part 20, of the Code of Federal Regulations (10CFR20). See Table 2.

Table 2. Nuclear Regulatory Commission Limits for Occupational Radiation Exposure

Exposure Type	Description	Exposure Limit
TEDE -Total effective dose equivalent	DDE + CEDE	5 rem
DDE - Deep dose equivalent	External whole-body dose from an external source of radioactive material.	5 rem
CEDE - Committed effective dose equivalent	Internal dose equivalent for the whole body from an intake of radioactive material. Usually zero in nuclear medicine technologists.	5 rem
SDE - Shallow dose equivalent	External exposure of the skin of the whole body or the skin of an extremity at a tissue depth of 0.007 cm	50 rem
LDE - Lens dose	External exposure of the equivalent lens of the eye, taken as the dose equivalent at a tissue depth of 0.3 cm	15 rem
Fetus/embryo	Estimated by body badge worn on abdomen	0.5 rem

RADIATION BADGES

Radiation exposure to the individual is checked regularly-usually monthly-by the use of two types of badges. The first badge, the *film or body badge*, should be worn between the shoulder and waist. Because this badge is used to determine the radiation dose received by the body, it should be worn under any leaded apron or other radiation protection device. The badge uses a film that will become darker with increasing radiation exposure. Typically, the badge will have some type of material of various depths positioned over the film to estimate radiation exposure at different tissue depths. An individual's radiation exposure is determined by examining the darkness of the film.

The second type of badge is used to measure radiation exposure to the hands. This badge has a different technology than the body badge. The badge is actually a ring(s) that can be worn on one or both hands. Each ring contains a single *thermoluminescent dosimeter* (TLD). If the institution only issues a single ring to technologists, it should be worn on the dominant hand. However, because both hands will be used to handle radioactive materials, it is ideal if the technologist has a ring for each hand. The ring(s) should be worn so that the TLD faces the same direction as the palm of the hand. The TLD stores energy from radiation events. When technologists turn in their ring badges, the TLDs are removed and heated. The heat causes release of the stored energy in the form of a light flash. The intensity of the light flash can be measured; this measure of intensity indicates the radiation exposure to the hands.

When not in use, all badges should be stored in a non-radiation area. Radiation badges stored in a radiation area could potentially receive additional radiation exposure. This would imply that the technologist received a larger (sometimes significantly so) radiation exposure than actually received.

PRIMARY FACTORS THAT REDUCE RADIATION EXPOSURE

The three most important methods for reducing radiation exposure are *time, distance, and shielding*. Regarding time, the technologist should minimize time spent near radioactive sources. However, because patients are themselves a source of radiation, special care needs to be taken to minimize exposure without alienating the patient. This means that technologists need to learn to work quickly, efficiently, and accurately. Repeating one's work may be annoying to the technologist, patient, and physician, but it also increases the amount of exposure time. Strive to perform procedures correctly the first time. If practical, rehearse new or infrequently performed tasks before working with the radioactivity.

Although the job description of the nuclear medicine technologist requires proximity to radioactive sources, the technologist should maximize the distance from these sources whenever possible. When required to handle radioactive materials, technologists should use forceps, tongs, vial racks, or any other suitable instrument that will increase the distance between the technologist and the source of radioactivity. Radioactive materials should be stored in more remote areas of the laboratory away from high-traffic areas or areas where duties typically not associated with radioactive materials (ie, filing, scheduling) are performed. Most nuclear medicine procedures require the technologist to be in close proximity to the radioactive patient. The technologist should seek to maximize that distance without alienating the patient. An additional half to full step

away from the patient will dramatically reduce one's exposure from the patient.

Putting distance between the source of radioactivity and the technologist is extremely effective because, according to the *inverse square law*, exposure decreases with distance. This means that radiation exposure varies inversely with the square of the distance from the source. Thus, doubling the distance from a source decreases the exposure by a factor of four. Tripling the distance from a source decreases the exposure by a factor of nine.

Shielding is one of the most effective steps one can take in minimizing radiation exposure. Regulations require that all syringes be shielded during kit preparation and patient administration. Likewise, all vials containing radioactive material must also be appropriately shielded. All molybdenum 99-technetium 99m generators are required to be shielded beyond their own internal shielding devices. That is, internal shielding of generators may satisfy Department of Transportation safety requirements but is not adequate for laboratory use. Almost all radiopharmaceuticals are required to be stored behind lead shielding during kit preparation or while working with patient doses.

It is important that the appropriate shielding material be selected for the radioactive material being used. Most shielding devices are made of lead, leaded glass, tungsten, or some combination of these materials. However, this type of shielding is not appropriate for all circumstances. When using beta emitters such as phosphorus 32 and strontium 89 it is necessary to use lucite as a shield to prevent the production of bremsstrahlung radiation. If dense shielding materials are used with beta emitters, the technologist will actually receive significant radiation exposure due to the bremsstrahlung radiation.

When using shielding made of lead, leaded glass, tungsten, or some other material designed to attenuate photons, one must consider the energy of the radioactive emissions. For example, the amount of lead shielding needed to attenuate the 140-keV photon of ^{99m}Tc may not be enough to attenuate the 364-keV photon of iodine 131. Although it is not in the day-to-day duties of the nuclear medicine technologist to calculate appropriate shielding, it is important to understand where these calculations come from. Each commonly used radioisotope in nuclear medicine has had a *half-value layer* (HVL) calculated for different materials. The half-value layer is the thickness of some material that would be required to attenuate half the photons directed at it by a source of radiation. If one were divide the number 0.693 by the HVL, an *attenuation coefficient* can be derived that is unique for the material and the radiation source. Once the attenuation coefficient is derived, the thickness of shielding needed to attenuate the desired proportion of photons can be determined.

OTHER FACTORS THAT REDUCE RADIATION EXPOSURE

The worst-case scenario for a nuclear medicine technologist regarding radiation exposure is that one would become internally contaminated. To minimize this risk, activities that would enhance the likelihood of internal radiation exposure are forbidden in areas where radioactivity is used. This means that eating, drinking, chewing gum, or applying cosmetics or lip balms in restricted areas are forbidden activities. Regulators have been rumored to look in waste containers during inspections for cups, chewed gum, food remnants, or other items that may indicate forbidden activities.

Other potential sources of internal contamination exist with the use and storage of radioactive gases and volatile radioactive materials because they can be inhaled, absorbed through mucous membranes, or absorbed through the skin. Xenon gas is used in closed breathing systems in negative pressure rooms. However, many experienced technologists will affirm that these precautions may not serve their protective function unless the patient is cooperative. Hence, perhaps the most effective way to minimize one's exposure to xenon gas is to make sure the patient is familiarized with the procedure and clearly understands the technologist's expectations.

Radioiodine poses a special problem because it is a volatile material that tends to become airborne quite easily. Complicating matters is that radioiodine is easily absorbed through the skin or mucous membranes and stored in the thyroid gland. To minimize risk from accidental breakage or spillage, packages or containers of radioiodine should be opened under a fume (exhaust) hood. Similarly, radioiodine should be stored behind shielding within a fume hood. When handling radioiodine, technologists should consider wearing disposable protective sleeves. Gloves are required. Any technologist administering radioiodine therapy or handling open vials of liquid radioiodine should undergo thyroid survey with a thyroid uptake probe within 72 hours of the therapy to check for internal radioiodine contamination.

Radioiodine therapy constitutes a multitude of potential risks to many individuals. According to the ALARA concept, the technologist needs to minimize the exposure of the patient and other persons incidentally exposed to the radioactive material. Because radioiodine-treated patients will return home either right after the therapy or after a short hospitalization, technologists must educate patients and their families regarding ways to minimize incidental radiation exposure.

Radioiodine therapy with ^{131}I poses a dual threat because it is a beta emitter that emits a 364-keV gamma ray. The beta particle can do considerable internal damage if ingested and the energetic 364-keV gamma emission is capable of delivering a radiation exposure at a distance. The patient and family need to be aware that radioiodine can be passed through sweat, saliva, urine, and stool. The

patient's eating utensils should be disposable or washed and kept separately from that of others. The patient should sleep alone; kissing, holding, and intimacy should be discouraged until approved by the nuclear medicine physician. Breast-feeding should be discontinued, and contact with children should be minimized. Patients must diligently wash their hands, and care must be taken to flush the toilet after each use.

The pregnant technologist needs to take special precautions. Young or developing cells are more radiosensitive than mature, developed cells. In order to protect the developing fetus/embryo, lower exposure limits have been adopted. Currently, the exposure limit for the embryo/fetus for the entire pregnancy is 0.5 rem. This is *not* an annual limit as are most other exposure limits. This limit is for the duration of the pregnancy. However, it should be noted that in order for these lower limits to be in force, the worker must file a declaration of pregnancy form with the institution's radiation safety office.

Individual institutions may take different precautions for the pregnant worker. However, when it is possible, the pregnant worker should be excused from those procedures that yield the most exposure. Some of these procedures would include patient administration and radiopharmacy. All pregnant technologists should make use of leaded aprons and take extra precautions against airborne radiopharmaceuticals. Pregnant technologists should wear two film badges. The first should be worn in its usual location to estimate exposure to the technologist. The second badge should be worn near the developing fetus. That way a more accurate estimate can be made regarding fetal exposure. If the technologist is wearing a leaded apron, the second badge should be worn under the apron. The dose records for the embryo/fetus will be permanently kept in the declared pregnant worker's dosimetry files.

Nuclear medicine technologists and other occupationally exposed workers find themselves constantly exposed to low levels of radioactivity. The overall effects of this exposure are still uncertain. However, unless future research proves otherwise, the technologist should assume that radiation exposure—no matter how small—has potential deleterious effects. With this in mind, technologists should diligently apply what they know regarding time, distance, shielding, and the ALARA concept to minimize radiation exposure to themselves, fellow workers, patients and their families, and incidentally encountered individuals.

GLOSSARY

Abbreviation	Description	Definition
eV	electron volt - unit of energy	The energy given to an electron by accelerating it through 1 volt of electrical potential
keV	1,000 eV - unit of energy	Unit most frequently used to describe energy of radioactive emissions used in diagnostic imaging
rem	roentgen equivalent man	Equal to the absorbed dose in rads multiplied by the quality factor of the type of radiation
rad	radiation absorbed dose	One rad = the absorption of 100 ergs per gram of absorbing tissue
Gy	gray	1Gy = 100 rad

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THEORIES AND PRACTICE OF RADIATION SAFETY IN NUC MED POST TEST

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1. An atom is radioactive when

- an imbalance exists between the neutron and protons within the nucleus.
- an imbalance exists between the magnitude of the electrons and the protons.
- neutrons and protons combine to form the nucleus.
- an atom has 20 or fewer protons.

2. For each individual radioactive element, the process by which an element seeks a stable state is

- unique with respect to its type and energy of emission.
- unique in its rate of decay.
- unique in its number of protons.
 - 1 only
 - 3 only
 - 1 and 2
 - 1, 2, and 3

3. The theoretical line of stability

- is identical to the actual line of stability.
- demonstrates that a proton excess is needed for nuclear stability.
- is created when the number of neutrons equals the number of electrons.
- is created when the number of protons equals the number of neutrons.

4. Radioisotopes that lay above the actual line of stability

- have too few protons.
- are stable.
- have too many protons.
- have too few neutrons.

5. Beta particles

- originate from electrons.
- originate from a stable nucleus.
- are emitted when the n:p ratio is too high.
- are emitted when there are too many protons.

6. E_{\max} is the

- energy imparted to the antineutrino.
- maximum energy of a positron.
- average energy of a beta particle.
- maximum energy that can be imparted to a beta particle.

7. Bremsstrahlung radiation

- is a type of particulate radiation.
- is caused by lucite shielding.
- is given off as a beta particle slows down.
- is given off in an annihilation reaction.

8. Positron emissions

- result from a nucleus with a low n:p ratio.
- are high-velocity particles of identical size, but opposite in charge, to a beta particle.

- compete with electron capture.

- 1 only
- 2 only
- 3 only
- 1, 2, and 3

9. Isomeric transition

- results in an abundance of particulate radiation.
- requires radiopharmaceuticals to be stored under a fume hood.
- is one of the preferred means of radioactive decay in nuclear medicine.
- can be shielded with lucite.

10. Gamma rays

- originate from the actual line of stability.
- only originate from nuclei with a high n:p ratio.
- usually deposit little energy within the body and are easily detectable outside the body.
- are a type of particulate radiation.

11. Stochastic effects assume that

- any radiation dose, no matter how small, can result in detrimental health effects.
- low levels of radiation exposure serve a protective function.
- the outcome of a radiation exposure is predictable given a certain level of exposure.
- shipyard workers are more healthy than the rest of the population.

12. Radiation hormesis is

- a controversial topic regarding the potentially beneficial results of low levels of radiation exposure.
- another term for somatic effects.
- a proven science.
 - 1 only
 - 2 only
 - 3 only
 - 2 and 3

13. Cataract formation is a type of non-stochastic effect because

- it is associated with specific levels of radiation exposure.
- it is considered an early effect of radiation exposure.
- it is manifested by the individual receiving the exposure.
- it is the result of genetic alterations.

14. Acute radiation syndrome

- is always fatal.
- is associated with exposures to large amounts of radiation.
- results in radiation hormesis.
- almost always manifests as genetic defects in future generations.

15. The prodromal stage of acute radiation syndrome is

- the same regardless of the size of the radiation exposure.
- also known as the NVD syndrome.

- c. the stage when distinguishing symptoms of the syndrome will manifest.
 - d. associated with a drastic decrease in red blood cells.
- 16. The latent stage of acute radiation syndrome is**
- a. also known as the NVD syndrome.
 - b. characterized by a temporary lapse of symptoms.
 - c. very brief and involves the bone marrow.
 - d. a stochastic effect.
- 17. Which of the following statements is most accurate with respect to the ALARA concept?**
- a. ALARA is best met by being careful with one's time, distance, and badges.
 - b. if a technologist's exposure level is low it is not possible to follow the ALARA concept.
 - c. ALARA has no bearing on beta emitters because they only require lucite shielding.
 - d. ALARA does not require application to visitors or other incidentally encountered individuals.
- 18. Film or body badges**
- a. should be stored in radiation areas when not in use because the technologist wishes to err on the high side of radiation exposure estimates.
 - b. contain thermoluminescent dosimeters.
 - c. should be kept in the technologist's locker to avoid losing them.
 - d. should be worn between the shoulder and waist.
- 19. Radioiodine, in the form of ^{131}I ,**
- a. is readily absorbed through the skin or mucous membranes.
 - b. should be stored on the shelf with other radiopharmaceuticals.
 - c. decays by positron emission.
 - d. is metastable.
- 20. Internal radiation exposure is kept to a minimum by**
- 1. refraining from eating or drinking within radiation areas.
 - 2. storing volatile radiopharmaceuticals under a fume hood.
 - 3. fully informing patients of the details of the procedure as well as the technologist's expectations during a xenon study.
- a. 1 only
 - b. 2 only
 - c. 3 only
 - d. 1, 2, and 3

