Alternately, internally deposited radioactive material may cause an ***internal radiation dose*** to the whole body or other organ or tissue. Smaller fractions of these measured quantities often have a prefix, e.g., milli (m) means 1/1,000. For example, 1 rad = 1,000 mrad.

The International System of Units (SI) for radiation measurement is now the official system of measurement and uses the "gray" (Gy) and "sievert" (Sv) for absorbed dose and equivalent dose respectively. Conversions are as follows:
1 Gy = 100 rad
1 mGy = 100 mrad
1 Sv = 100 rem
1 mSv = 100 mrem

With radiation counting systems, radioactive transformation events can be measured in units of "disintegrations per minute" (dpm) or, "counts per minute" (cpm). Background radiation levels are typically less than 0.02 mrem per hour, but due to differences in detector size and efficiency, the cpm reading on various survey meters will vary considerably.

Half-life

Probably the best known property of radioactivity is the half-life T. After one-half life has elapsed, the number of radioactive decay events in a sample per unit time will be observed to have reduced by one-half. The decay rate or activity at any time t can be described mathematically:[7]
At = A0 e-[0.693 t/(T)]
Where:
A0 = initial activity
At = final activity at time t
t = lapsed time
T = isotope half-life
Alternatively, if n is the number of elapsed half-lives, then:
At = A0 (1/2)n
Half-lives range from billionths of a second to billions of years. The half-life is characteristic of the radioisotope at hand, and cannot be inferred. The half-life is included with the description of the decay scheme.[5]

4. Measures of Activity[8]

The size or weight of a quantity of material does not indicate how much radioactivity is present. A large quantity of material can contain a very small amount of radioactivity, or a very small amount of material can have a lot of radioactivity. For example, uranium-238, with a 4.5-billion-year half-life, has only 0.00015 curies of activity per pound, while cobalt-60, with a 5.3-year half-life, has nearly 513,000 curies of activity per pound. This "specific activity" or curies per unit mass, of a radioisotope depends on the unique radioactive ***half-life*** and dictates the time it takes for half the radioactive atoms to decay.
In the United States, the amount of radioactivity present is traditionally determined by estimating the number of ***curies (Ci)*** present. The more curies present, the greater amount of radioactivity and emitted radiation.

Common fractions of the curie are the millicurie (1 mCi = 1/1,000 Ci) and the microcurie (1 µCi = 1/1,000,000 Ci). In terms of transformations per unit time, 1 µCi = 2,220,000 dpm. The SI system uses the unit of ***becquerel (Bq)*** as its unit of radioactivity. One curie is 37 billion Bq. Since the Bq represents such a small amount, one is likely to see a prefix noting a large multiplier used with the Bq as follows:
37 GBq = 37 billion Bq = 1 curie
1 MBq = 1 million Bq = ~ 27 microcuries
1 GBq = 1 billion Bq = ~ 27 millicuries
1TBq = 1 trillion Bq = ~ 27 curies

Radiation risks for older and younger patients[9]

As you get older you are more likely to need an X-ray examination. Fortunately radiation risks for older people are lower. This is because there is less time for a radiation-induced cancer to develop, so the chances of it happening are greatly reduced. Children, however, with most of their life still ahead of them, may be at twice the risk of middle-aged people from the same X-ray examination. This is why particular attention is paid to ensuring that there is a clear medical benefit for every child who is X-rayed. The radiation dose is also kept as low as possible without detracting from the information the examination can provide.

A baby in the womb may also be more sensitive to radiation than an adult, so we are particularly careful about X-rays during pregnancy. There is no problem with something like an X-ray of the hand or the chest because the radiation does not go anywhere near the baby. However, special precautions are required for examinations where the womb is in, or near, the beam of radiation, or for isotope scans where the radioactive material could reach the baby through the mother's circulating blood.[10]

If you are about to have such an examination and are a woman of childbearing age, the radiographer or radiologist will ask you if there is any chance of your being pregnant. If this is a possibility, your case will be discussed with the doctors looking after you to decide whether or not to recommend postponing the investigation. There will be occasions when diagnosing and treating your illness is essential for your health and your unborn child. When this health benefit clearly outweighs the small radiation risks, the X-ray or scan may go ahead after discussing all the options with you.[11]

Radiation risks for future generations[11]
If the reproductive organs (ovaries or testes) are exposed to radiation there is a possibility that hereditary diseases or abnormalities may be passed on to future generations. Although the effect has never been seen in humans, lead-rubber shields can be placed over the ovaries or testes during some X-ray examinations, as a precaution. They are only necessary for examinations of the lower abdomen and thighs on patients who are young enough to have children. Even then, there are some examinations where it is not practicable to use gonad shields since they will obscure important diagnostic information.

Occupational Exposure Limits to Radiation[12]

The limits were recommended by the ICRP and NCRP with the objective of ensuring that working in a radiation-related industry was as safe as working in other comparable industries. The dose limits and the principle of as low as reasonably achievable (ALARA) should ensure that risks to work, are maintained indistinguishable from risks from background radiation.

No level of radiation exposure is free of some associated risk. Thus the principle of radiation safety is to keep the level of exposure ALARA.

The **deep-dose equivalen**t is the whole-body dose from an external source of ionizing radiation.

This value is the dose equivalent at a tissue depth of 1 cm.

The **lens dose equivalent** is the dose equivalent to the lens of the eye from an external source of ionizing radiation. This value is the dose equivalent at a tissue depth of 0.3 cm.

The **shallow-dose equivalent** is the external dose to the skin of the whole-body or extremities from an external source of ionizing radiation. This value is the dose equivalent at a tissue depth of 0.007 cm averaged over and area of 10 cm2.

The dose limit to **non-occupational workers** and **members of the public** are two percent of the annual occupational dose limit. Therefore, a non-radiation worker can receive a whole body dose of no more that 0.1 rem/year from industrial ionizing radiation. This exposure would be in addition to the 0.3 rem/year from natural background radiation and the 0.33 rem/year from manmade sources such as medical x-rays.

Additional limits for pregnant workers[13]

Because of the increased health risks to the rapidly developing embryo and fetus, pregnant women can receive no more than 0.5 rem during the entire gestation period and no more than 0.05 rem each month. This is 10% of the dose limit that normally applies to radiation workers.

Posting Requirements[14]

The use of warning or caution signs is necessary to warn unauthorized or unsuspecting personnel of a hazard and to remind authorized personnel as well. Radioactive Materials, Radiation Areas, High Radiation Areas, Very High Radiation Areas, Airborne Radioactivity Areas, shipping containers and vehicles shall be marked or posted as required by various regulations. Health Physics will assist in providing the necessary information, signs, and/or labels. All signs, labels, and signals will be posted in a conspicuous place. The standard radiation symbol appears with the required trefoil symbol as shown below. The symbol is magenta, purple, or black on a yellow background.

Labeling requirements[15]

Containers with greater than 10 CFR 20 Appendix C quantities must be labeled with the radiation symbol, the words "Caution, Radioactive Material," and appropriate precautionary information such as radionuclide, activity, date, dose rate at a specified distance, and chemical form.

Radioactive Package Receipt Requirements

Most radioactive materials packages found at the SHC, LPCH or VAPAHCS contain radioactive drugs. The radioactive drugs are given to patients for the detection and treatment of disease. Packages of radioactive materials are safe to handle under normal conditions. Studies show that cargo handlers get very little radiation exposure from handling them. If a package is labeled as containing radioactive material, or appears damaged, it must be promptly monitored for dose rate and contamination. If certain thresholds are exceeded, Health Physics must notify the carrier, the Department of Health Services and the Nuclear Regulatory Commission. Contact Health Physics if any package labeled as containing radioactive material is left unattended in public areas.

General workplace safety guidance[14]

Safe use of hazardous materials in the workplace depends on the cooperation of individuals who have been educated in the science and technology of the materials, who have technical training specific to their application, and who follow administrative and technical procedures established to ensure a safe and orderly workplace.

Security[5]

No matter what source of radiation you work with, one way to enhance safety is to allow access only to those with business in the area. If you see unfamiliar individuals in the area, it is important to question them or call security. Regulatory agencies consider a high degree of security to be an important compliance matter.

The Basic Principles of Radiation Protection

External contamination occurs when radioactive material, in the form of dust, powder, or liquid, comes into contact with a person's skin, hair, or clothing. In other words, the contact is external to a person's body. People who are externally contaminated can become internally contaminated if radioactive material gets into their bodies.

Internal contamination occurs when people swallow or breathe in radioactive materials, or when radioactive materials enter the body through an open wound or are absorbed through the skin. Some types of radioactive materials stay in the body and are deposited in different body organs. Other types are eliminated from the body in blood, sweat, urine, and feces.

A person exposed to radiation is not necessarily contaminated with radioactive material. A person who has been exposed to radiation has had radioactive waves or particles penetrate the body, like having an x-ray. For a person to be contaminated, radioactive material must be on or inside of his or her body. A contaminated person is exposed to radiation released by the radioactive material on or inside the body. An uncontaminated person can be exposed by being too close to radioactive material or a contaminated person, place, or thing.

The use of universal precautions when handling human blood, human tissue and body fluids equally protects occupational workers from radioactive material contamination. In general the basic means of reducing your exposure to radiation and keeping your exposure ALARA regardless of the specific source of radiation are as follows:[16]

- Keep the time of exposure to a minimum
- Maintain distance from source
- Where appropriate, place shielding between yourself and the source
- Protect yourself against radioactive contamination

Protection against Radiation Exposure

The radiation worker can control and limit his/her exposure to penetrating radiation by taking advantage of *time, distance,* and *shielding*.

By reducing the *time* of exposure to a radiation source, the dose to the worker is reduced in direct proportion with that time. Time directly influences the dose received: if you minimize the time spent near the source, the dose received is minimized. The exposure rate from a radiation source drops off by the inverse of the distance squared. If a problem arises during a procedure, don't stand next to the source and discuss your options with others present. Move away from the source or return it to storage, if possible.

The third exposure control is based on radiation shields, automatic interlock devices, and in-place radiation monitoring instruments. Except temporary or portable shields, this type of control is usually built into the particular facility.

Lead shielding for fluoroscopic units[17]

Leaded eyewear and thyroid shields are recommended if monthly collar badges readings exceed 400 mrem. Transparent upper body shields are usually suspended from the ceiling and protect the upper torso, face and neck. The shield is contoured so that it can be positioned between the irradiated patient anatomy and the operator.

Flat panel mobile shields and when used must be placed between personnel and the sources of radiation (i.e., the irradiated area of the patient and the x-ray tube). Mobile shields are recommended for the operator and for ancillary personnel who must be in the room but who are not performing patient-side-work.

X-ray attenuating surgical gloves help to reduce the risk of radiation dermatitis in physician's hands from exposure to scattered radiation. These gloves do NOT adequately shield hands in the primary x-ray field.

Lead Apron Policy[17]

Lead aprons are used in medical facilities to protect workers and patients from unnecessary x-ray radiation exposure from diagnostic radiology procedures. A lead apron is a protective garment which is designed to shield the body from harmful radiation, usually in the context of medical imaging. Both patients and medical personnel utilize lead aprons, which are customized for a wide range of usages. As is the case with many protective garments, it is important to remember that a lead apron is only effective when it is worn properly, matched with the appropriate radiation energy and is used in a safe and regularly inspected environment. For example, per California Title 17 (*30307 Fluoroscopic Installations*) "Protective aprons of at least 0.25 mm lead equivalent shall be worn in the fluoroscopy room by each person, except the patient, whose body is likely to be exposed to 5 mR/hr or more." Personnel who are required to wear lead aprons or other similar radiation protection devices should visually inspect these devices prior to each use for obvious signs of damage such as tears or sagging of lead.

Examples of when a lead apron is effective and appropriate[17]

A lead apron is inadequate for shielding 111In or 131I but is appropriate for an 80 kVp xray beam (about 95 percent of the x-rays will be shielded). The lead apron can cause stress and pain in the back muscles; to protect back strain often a skirt style apron covering the lower abdomen is adequate. For fluoroscopic procedures a lead apron of at least 0.25 mm lead equivalence (0.5 mm is recommended) will reduce scattered x-rays by 95%. Additionally a thyroid collar is recommended. A lead apron is not necessary if only imaging patients (e.g., chest radiograph).

All occupation workers exposed to greater than 5 mrem/hr from fluoroscopic units must wear lead. Dose rates of greater than 5 mrem/hr can be measured within 6 feet of the table and includes where the fluoroscopist stands.

Examples of when a lead apron is NOT appropriate

A lead apron does not provide much shielding for 137Cs or 131I therapy patients. In the case of therapy patients, heavy portable shields are provided. Radiation Oncology provides shields for brachytherapy patients and Health Physics provides shields for the radioactive iodine therapy patients.

Lead Apron Inspection and Inventory Policy

Due to standards set forth by the Joint Commission, health care organizations must perform annual inspections on medical equipment, including lead aprons. SHC, LPCH and VAPAHCS are responsible for lead apron inspection and inventory.

The recommended apron inspection policy is as follows:

- Annually perform a visual and tactile inspection
- Look for visible damage (wear and tear) and feel for sagging and deformities.
- In cases of questionable condition, one can choose to use fluoroscopy or radiography to look for holes and cracks.

- During fluoroscopic examination, use manual settings and low technique factors (e.g. 80 KVp).
- Do not use the automatic brightness control, as this will drive the tube current and high voltage up, resulting in unnecessary radiation exposure to personnel and wear on the tube.
- Lead aprons can also be examined radiographically.
- Fluoroscopic lead apron are to be discarded if inspections determine there is:
- A defect greater than 15 square mm found on parts of the apron shielding a critical organ (e.g., chest, pelvic area).
- A defect greater than 670 square mm along the seam, in overlapped areas, or on the back of the lead apron.
- Thyroid shields with defects greater than 11 square mm.

5. Conclusion

Patients now have more information than ever and are empowered to understand the importance of safety and dose when undergoing medical imaging procedures. Radiologic technologists are poised to educate and protect patients. Collaboration of medical imaging stakeholders to support radiologic technologists' education and efforts to promote a culture of safety and lifelong learning can effect change in medical imaging. In the busy, budget-driven environment of health care, training time and attention often are sacrificed, yet training is critical to successfully implementing new and emerging technologies.

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