

RADIATION PROTECTION IN EDUCATIONAL INSTITUTIONS



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Radiation Protection in Educational Institutions

**Recommendations of the
NATIONAL COUNCIL ON RADIATION
PROTECTION AND MEASUREMENTS**

June 25, 2007

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[For detailed information on the availability of NCRP publications see page 135.]

Preface

This Report was developed under the auspices of Program Area Committee 2 of the National Council on Radiation Protection and Measurements (NCRP). The primary focus of this Committee is operational radiation safety. This Report provides radiation protection guidance for educational institutions that use radioactive material or radiation-producing equipment for educational purposes (training and research) or for other support of an institution (such as in a student health clinic). It supersedes NCRP Report No. 32, *Radiation Protection in Educational Institutions*, which was issued in 1966.

This Report is primarily addressed to the individuals who have responsibility for the safe use of sources of radiation at an educational institution. These individuals could include an administrator, a safety officer or other staff member, or a faculty member.

This Report provides specific information on the hazards associated with sources of ionizing radiation in science demonstrations, experiments, and student projects. It also provides recommendations on how to use these sources of ionizing radiation in a safe manner and how to comply with applicable regulations. Since the potential hazards associated with the use of such sources in the educational institutions covered in this Report are relatively low, the potential risk to faculty, staff and students is correspondingly low when simple basic precautions are followed.

For ionizing radiation, NCRP has adopted the International System (SI) of Quantities and Units for its reports (NCRP Report No. 82, *SI Units in Radiation Protection and Measurements*). However, many existing regulatory requirements currently are presented in the system of quantities and units previously used. Therefore, in this Report, the corresponding information for the previous system is displayed in parentheses after that for the SI system [e.g., 10 mSv (1 rem)].

The U.S. Nuclear Regulatory Commission issued new regulations (effective November 30, 2007) to implement an expanded definition of byproduct material required by the Energy Policy Act of 2005. These regulations will impact radioactive-material licensees

for many years as the new regulatory requirements are established for these types of radioactive material.

This Report also contains guidance on the safe use of nonionizing-radiation sources that are covered in many radiation safety programs, for example, lasers, and microwave and radiofrequency radiation-producing equipment.

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Thomas S. Tenforde
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1. Executive Summary

The purpose of this Report is to provide guidance for the safe use of ionizing- and nonionizing-radiation sources in educational institutions, including both teaching and research activities. Brief explanations of the terms radiation, ionizing radiation, and nonionizing radiation are given in the Glossary.

To take advantage of the benefits of using radiation sources in these activities, it is necessary to provide radiation safety controls commensurate with the potential hazard. Since the sources of radiation used in many educational institutions usually produce only low radiation levels, the potential hazard to faculty, staff and students is usually correspondingly low when simple basic precautions are followed.

This Report is intended primarily for those institutions that do not need a full-time radiation safety professional because the uses and radiation levels of the sources are limited. In these instances, an individual with limited expertise in radiation safety (*e.g.*, a professor, teacher, researcher, or general safety staff member) could assume the responsibility for implementing the radiation safety program. Usually, this individual is called the radiation safety officer (RSO). This individual may have other safety responsibilities in addition to radiation safety. Full-time RSOs may also find this Report helpful.

To assist administrators in determining whether a radiation safety program is necessary, and to assist the RSO in assuming the responsibility for the radiation safety program, this Report provides information on the following topics:

- types of ionizing radiation including alpha and beta particles, neutrons, and gamma and x rays;
- potential health effects of exposure to ionizing radiation, and the applicable radiation dose limits;
- potential hazards and the safety controls for nonionizing radiation [*e.g.*, radiofrequency, microwave, ultraviolet (UV), infrared and visible];
- an administrative structure appropriate for effectively controlling radiation sources at an educational institution;

- academic disciplines (*e.g.*, biology, physics, geology, general science, or chemistry) where radiation sources could potentially be used or found and what types of radiation sources might be used or found in each discipline;
- regulatory requirements that apply to various types and radiation levels of sources;
- sources that are exempt from licensing requirements;
- sources that are authorized by a general license issued by a regulatory agency;
- sources that require a specific license from the U.S. Nuclear Regulatory Commission (NRC) or a state;
- components of a radiation safety program, including radiation-source inventory control, safety procedures, routine monitoring of the workplace, radiation-safety training, audits, contamination control, waste management, record keeping, emergency-response procedures, and security; and
- technicalities and legal commitments of licensing and of establishing and managing a radiation safety program.

2. Introduction

High school and college science classes are ideal places to provide a basic understanding of radiation sources (radioactive material and radiation-producing machines) while explaining the beneficial uses in radiation-related technologies, radiation detection, and radiation control. Such classes might use low-level, safe sources of radioactive material in demonstrations, for laboratory exercises or science fair projects; or the classes might use a machine that can electronically produce x rays. Additional types, uses and locations of radiation sources are covered in Section 4 and Appendix A.

The procedures and other controls employed to ensure the safe use of radiation sources are generally referred to as the radiation safety program. The radiation safety program establishes safe conditions for users of radiation sources, as well as for bystanders, the facility and the environment. Radiation safety requirements might be as simple as making sure that radiation sources are handled and used as recommended and not subjected to any procedures that could alter the inherent safety of the source. An example might be that assurance is provided that a source is not damaged, opened or cut into smaller pieces. Or, there may be a requirement that all sources must be used under the direct supervision and control of a teacher who is responsible for radiation safety of the sources. Most radioactive material employed for educational demonstrations is exempt from licensing and regulations governing its use. However, such exemptions assume that nothing will be done to defeat the built-in safety of the source.

Another example of simple radiation safety requirements is the handling of self-illuminated exit signs. The light for these signs is produced by tritium, a radioactive isotope of hydrogen, irradiating phosphors contained in glass ampoules (Linsley, 2005). These signs are safe so long as their integrity is not violated (*i.e.*, the glass ampoules are not broken or removed from the signs). Breakage could cause contamination of individuals, the facility, and the environment, particularly contamination of the individual who caused the removal or breakage. The radiation safety requirements concerning these exit signs include periodic inventory of the signs, monitoring for expiration dates to return signs to manufacturers, and preventing discard of any of these signs into normal solid waste.

High schools and small colleges and universities might limit their use of radiation sources to demonstrations by teachers and lecturers. More extensive educational programs may use radioactive material or radiation-producing machines in closely supervised experiments conducted by students, or in research conducted by teachers, staff and students. Possession and use of radioactive material or radiation-producing machines may be subject to regulation by government agencies, which may require a formal institutional radiation safety program. It is not uncommon for an individual who performed research with a radiation source as a part of his or her post-graduate education to continue with a career at a college or university with a small radiation safety program. Such an individual might be named as the RSO with the responsibility to oversee all use of radiation sources at a college or small university. This individual may have no or limited formal training in radiation safety. Administrators with limited knowledge of radiation sources might also find such sources within their areas of responsibility. All such individuals can benefit from the guidance provided by this Report in reviewing the qualifications for their RSO and providing assurance that they have an effective radiation safety program matching their radiation sources, that they provide assurance those involved are aware of any associated risks, and that they understand the legal commitments and costs of compliance with applicable regulations and licenses. This Report provides guidance for administrators, safety staff or officers, or teachers responsible for the safe use of radiation sources. It also provides information on whom to contact for specific guidance in evaluating a particular situation or interpreting of the rules and regulations under which they must operate.

Large universities that have specific licenses of limited or broad scope for possession and use of radioactive material will have, as required by their licenses, well-defined and documented radiation safety programs. Examples could be universities with programs in medical or health sciences, including those with specialties in public health, nursing, pharmacy and chiropractic, and those with programs in veterinary medicine and biomedical or biochemical research. There might be little additional information in this Report that would be of benefit to them. However, the RSO from such an institution that is asked to help evaluate a high school program or a limited use program at a college or small university could benefit from this Report, especially for use in training the administrators.

Anyone involved in the decision to obtain and use radiation sources should be aware of the responsibilities and potential legal

liabilities incurred by such use and ownership. For certain uses, there may be radioactive-material license fees or fees for registration of radiation-producing machines. Sources that could be potentially threatening to public health and safety are subject to security requirements (Section 7.1.3). Additional security requirements may apply to radioactive material containing quantities of radionuclides deemed to be high risk from a national security standpoint. For educational and research activities that generate low-level radioactive waste, there may be substantial costs for disposal of that waste. Disposal options for radiation sources that reach the ends of their lives or are otherwise no longer needed may be limited and likewise costly. Furthermore, experience has shown that improper use of radiation sources can result in legal liabilities. It is the responsibility of each educational institution to ensure that radiation sources are used in a manner that protects users, other employees, students, members of the public, and the environment.

The obligations and responsibilities associated with the use of radiation sources should not limit their application in an educational institution. The key is to make decisions to use radiation sources in an informed manner. In the United States, thousands of educational institutions routinely employ devices containing radiation sources to provide for student and teacher safety, for example, smoke detectors and self-luminous exit signs, and many also use radiation sources in educational and research activities. The radiation safety programs for these educational institutions will vary in size and complexity and each educational institution should adjust its radiation safety program to its particular activities. This Report is intended to inform and assist institution administrators, teachers, students, those assigned radiation safety responsibilities, and regulators in assessing their programs and determining what will be needed to ensure the safe use of radiation sources in educational institutions.

Therefore, this Report will be of benefit to the following:

- *High schools:* The principal of the high school, science teachers using radiation sources, students doing science fair projects involving radiation sources, and school board members concerned about safe use of radiation sources in the school.
- *Small colleges and specialty academies:* The chancellor, college president, dean, provost, faculty who use radiation sources, RSO or other safety officer, and students working with radiation sources in research or educational projects.

- *Large colleges and universities:* May be of use to the RSO for training of others.
- *Safety officers and safety committees:* Responsible individuals who want guidance in evaluating radiation safety programs.
- *Regulators:* Individuals who want a basic document to recommend in response to inquiries about radiation safety for programs using radiation sources.

To assist the reader in accessing the numerous NRC regulations [Title 10 of the Code of Federal Regulations (10 CFR)] that are cited in this Report, Appendix B provides a listing of the citations, and brief instructions for quickly accessing the current version of the regulations on the NRC website (the regulations are updated by NRC periodically). The citations will appear in the text of this Report as in the following examples (rather than in the usual reference format):

- NRC [10 CFR 30.18] or [NRC, 10 CFR 30.18]
- NRC [10 CFR 71] or [NRC, 10 CFR 71]
- NRC [10 CFR 170.11(a)(4)] or [NRC, 10 CFR 170.11(a)(4)]

The information after 10 CFR refers to the regulation part. Appendix B also provides the title for each citation, and the listing is in the ascending order of the 10 CFR part number (number before the period) and the specific paragraph (number following the period), and in some cases the specific portion of the paragraph (letters and numbers in parentheses). Two sample citations are listed below:

- 10 CFR 30.50(c)(2). Rules of general applicability to domestic licensing of byproduct material. Records, inspections, tests, and reports. Reporting requirements.
- 10 CFR 31. General domestic licenses for byproduct material.

To further assist those persons the educational institutions designate as responsible administrator and responsible individual (as defined and discussed in Sections 6.1 and 6.2), check lists that will help them carry out their administrative or technical duties with regard to radiation protection and the institutions' radiation safety programs are provided in Section 8. These check lists include citations to the applicable parts of this Report.

Terms and symbols used in this Report are defined in the text and in the Glossary. National Council on Radiation Protection and Measurements (NCRP) recommendations throughout this Report are expressed in terms of *shall* and *should* (in *italics*) where:

- *shall* indicates a recommendation that is necessary to meet the currently accepted standards of radiation protection; and
- *should* indicates an advisory recommendation that is to be applied when practicable or practical (*e.g.*, cost effective).

Requirements from regulatory agencies and other cognizant authorities are also noted throughout this Report. In those cases, the terms “shall” and “should” may also be used in expressing the legal commitments of the regulations or other requirements, but the terms are not in italics. Also, when the term “should” appears in the context of its general usage, it is not in italics.

3. Radiation Basics and Protection

Radiation can be categorized into two classes: ionizing and non-ionizing. Ionizing radiation has enough energy per particle or photon to ionize atoms (*i.e.*, remove electrons from atoms) whereas nonionizing radiation does not have sufficient energy to ionize atoms.

3.1 Ionizing Radiation

Ionizing radiation originates from the decay of individual radioactive atoms or from radiation-producing equipment such as x-ray machines or particle accelerators that produce the radiation by electronic means.

3.1.1 *Decay of Radioactive Atoms*

The nuclei of radioactive atoms have either unstable nuclear configurations or nuclei that are in excited energy states. The particular unstable nuclear configuration or excited energy state determines the route or routes by which a nucleus undergoes the nuclear transformation process (commonly called radioactive decay). Radioactive decay alters the nucleus and allows it to achieve a more stable state. The nuclear transformation process produces radiation (*i.e.*, energy in the form of waves or particles). Radiation may also be produced by the deexcitation of excited orbital electrons. Radioactive atoms either occur naturally or are produced by nuclear interactions created by human activities that use nuclear reactors or particle accelerators.

The primary types of ionizing radiation emitted by radioactive atoms are: alpha particles (which have the mass and charge of a helium nucleus, two protons, and two neutrons); beta particles (either electrons or positively-charged electrons called positrons); gamma rays (electromagnetic radiation emitted from the nucleus of radioactive atoms); and x rays [electromagnetic radiation resulting from deexcitation of orbital electrons following excitation (*i.e.*, the addition of energy to the atom), or from deceleration of electrons passing through matter]. Many nuclear transformation processes

can result in more than one of these types of radiation being emitted from the atom.

In some sealed sources, radioactive material that emits alpha particles (*e.g.*, americium or plutonium) is combined with beryllium to take advantage of the nuclear interaction whereby the beryllium nucleus absorbs an alpha particle and emits an energetic neutron (*i.e.*, neutron radiation).

The quantity *activity* is the average number of spontaneous nuclear transformations occurring in a radioactive material per unit time. The special name for the unit of activity is becquerel (Bq), which is defined as one nuclear transformation per second. The special unit previously used for activity was curie (Ci), which is 3.7×10^{10} Bq. In this Report, activity is expressed in becquerel, followed by the value in curie in parentheses.

All the radioactive nuclei in a sample do not transform at once; each nucleus has the same probability of nuclear transformation in a specific time period. The number of atoms transformed per unit time decreases as the number of radioactive nuclei decreases. This results in an exponential decrease in activity with time. The time for half the atoms of a given radionuclide present to undergo nuclear transformation is called the *half-life*. After one half-life, half the radioactive nuclei remain; after two half-lives, one-fourth remains, and so forth. The half-life is unique to each radionuclide and is an important factor in radiation protection; the longer the half-life the longer the radioactive material will emit radiation. Conversely, the shorter the half-life, the faster the activity will decrease. Therefore, the half-life can play a significant role in radioactive waste disposal; radionuclides with long half-lives require proper disposal, whereas radionuclides with short half-lives may be kept to allow the activity to decrease to very low levels (*e.g.*, 10 half-lives would result in ~0.1 % of the original activity) within a reasonably short storage period.

3.1.2 Machines

The two most common types of machines that produce ionizing radiation are x-ray machines and particle accelerators (*e.g.*, linear accelerators, Van de Graaf accelerators, and cyclotrons). X-ray machines produce x rays by accelerating electrons to high speeds. When the high-speed electrons interact with the metal atoms of the target material (usually tungsten), most of their kinetic energy is converted to heat within the target. However, in a small percentage of the interactions the kinetic energy of the electrons is released as characteristic x rays and as bremsstrahlung (Glossary). Particle

accelerators use radiofrequency, microwave, or static electrical fields to accelerate charged particles, such as electrons, protons and alpha particles, to high energies, and use magnetic fields to steer and focus the particles. When these particles strike target atoms, they give up their energy to heat, ionizations, or nuclear interactions. These interactions can produce ionizing radiation in the form of protons, electrons, neutrons, alpha particles, gamma rays, and x rays. Depending on the energies of the accelerated particles, these interactions can also produce radioactive atoms in the target material.

3.2 Nonionizing Radiation

Nonionizing radiation refers to the portion of the electromagnetic spectrum that includes UV, visible, infrared, microwave, radiofrequency, and extremely-low-frequency radiation. The ability of electromagnetic radiation to penetrate the body is determined by its wavelength. Unlike ionizing radiation, which interacts with atoms and produces both ionizations and excitations, nonionizing radiation typically causes excitations only. Some forms of nonionizing radiation have the ability to penetrate into the body (*e.g.*, radiofrequency, microwave) while others do not penetrate an appreciable distance (*e.g.*, UV, infrared and visible). The primary result of exposure to nonionizing electromagnetic radiation is deposition of heat in the irradiated material. Information about biological effects, sources, locations of use, and nonionizing radiation-safety programs is given in Section 7.3.

3.3 Penetration of Ionizing Radiation

A major difference among the different types of ionizing radiations is the ability of the radiations to penetrate material. Some ionizing radiations penetrate to great depths within the body or even pass through the body, while others cannot penetrate the skin.

3.3.1 *Alpha Particles*

Alpha particles are the least penetrating type of radiation. A single sheet of paper is thick enough to stop alpha particles that result from radioactive decay. The dead layer of skin stops such alpha particles; and such alpha particles travel only a few centimeters in air. However, if an alpha-emitting radionuclide is inhaled or ingested, it can be assimilated in internal organs or other tissues, resulting in radiation dose at the site of deposition.

3.3.2 *Beta Particles*

Beta particles (electrons or positrons) may travel several meters in air; the range depends on the energy of the beta particle. The range of beta particles in tissue is typically <1 cm. Beta particles that originate outside the body can penetrate live layers of the skin, the top layer of underlying tissue, and the lens of the eyes, but cannot penetrate to the internal organs. However, if beta-emitting radionuclides are inhaled or ingested, the beta particles can deliver a radiation dose to the internal organs and tissues in which the radionuclides are deposited.

3.3.3 *X and Gamma Rays*

X and gamma rays are highly-penetrating ionizing radiations and can readily penetrate the body. Therefore, x and gamma rays generated either inside or outside the body can deliver a radiation dose to the internal organs and tissues; the extent of penetration depends on the energy of the x or gamma ray.

3.3.4 *Neutrons*

Neutrons are also penetrating radiation and interact with materials in such a way as to ultimately produce ionizations. With regard to radiation dose, the chief interactions are elastic scattering with the material nuclei and capture by a nucleus followed by the emission of a photon or another particle (*i.e.*, ionizing radiation). Neutrons are produced by nuclear reactions, such as fission of a uranium nucleus, when an alpha particle interacts with a beryllium nucleus, or when a nucleus undergoes spontaneous fission. Therefore, neutron sources are external to the body, but the neutrons can penetrate to internal organs.

3.3.5 *Other Charged Particles*

Other kinds of charged particles can be generated in radiation-producing machines. Electrons can be accelerated to such energies as to be able to cause ionizations. These accelerated electrons interact like beta particles. Protons and other heavy charged particles can also be accelerated to become ionizing radiation. Only very high-energy charged particles are capable of penetrating deeper than the skin.

3.3.6 Radiation Quantities

General comments on the terms and quantities used in radiation protection, namely, exposure, dose, absorbed dose, equivalent dose, and effective dose (also effective dose equivalent), are given here. The generic term *radiation dose* (or *dose*) is used in this Report when the context is not specific to a particular radiation dose quantity. When the context is specific, the name for the quantity is used (e.g., absorbed dose). The generic term *exposure* is used for both ionizing and nonionizing radiation. The rest of the quantities are specific to ionizing radiation. The Glossary contains more formal definitions.

3.3.6.1 Exposure. In this Report, the term *exposure* means being subjected to a type of ionizing or nonionizing radiation. For example, individuals receive exposure from the sun when they go outdoors and allow themselves to be subjected to the visible and UV rays (nonionizing radiation) coming from the sun. If individuals receive too much exposure from the sun, it can cause them harm (e.g., severe sunburn). For another example, individuals receive exposure to ionizing radiation from natural, or background, sources such as cosmic rays and radioactive material in the earth. Exposure is also a defined ionizing radiation quantity (Glossary), but it is not used in this Report in that context.

3.3.6.2 Absorbed Dose. The quantity *absorbed dose* refers to the total energy per unit mass of matter that is absorbed from ionizing radiation and is applicable without modification to all types of ionizing radiation. The special name for the unit of absorbed dose is gray (Gy); the previous special unit was rad (Glossary).¹

3.3.6.3 Equivalent Dose. The term *equivalent dose* refers to a calculated quantity obtained by multiplying the mean absorbed dose in an organ or tissue by a factor assigned to the type of ionizing radiation incident on the body (the radiation weighting factor). If the type of radiation is x rays, gamma rays, or beta particles, the radiation weighting factor is assigned a value of one. However, if

¹For ionizing radiation, NCRP has adopted the International System (SI) of Quantities and Units for its reports (NCRP, 1985). However, many existing regulatory requirements are presented in the system of quantities and units previously used. Therefore, in this Report, the corresponding information for the previous system is displayed in parentheses after that for the SI system [e.g., 10 mGy (1 rad) or 10 mSv (1 rem)].

the absorbed dose is from one of the types of radiation that are more effective in producing harm to biological tissue (*e.g.*, alpha particles or neutrons), the radiation weighting factor is greater than one, up to a value of 20, depending on the type and energy of the radiation. The special name for the unit of equivalent dose is sievert (Sv); the previous special unit was rem (Glossary).

3.3.6.4 Effective Dose. The term *effective dose* also refers to a calculated quantity. In the past and in some existing regulations in the United States the term *effective dose equivalent* is also found. Both quantities consider the doses to organs and tissues of the body and represent the whole-body dose that would pose the same overall radiation detriment as that from the doses to organs and tissues that are actually exposed. The quantities are used primarily in determining compliance with radiation protection regulations, particularly radiation dose limits. They also have been used to compare radiation exposure from different types of sources. The special name for the unit of effective dose and effective dose equivalent is also the sievert; the previous special unit was also the rem.

3.4 Sources of Ionizing-Radiation Exposure

All living things are exposed to radiation as part of their environment. Natural background radiation comes from three sources: cosmic radiation, terrestrial radionuclides, and radionuclides in the body. Cosmic radiation consists of both solar and galactic radiation; it is greater at Earth's poles than at the equator, and is also greater at higher altitudes. The radiation dose rates (*i.e.*, dose per hour) from cosmic radiation at a typical transcontinental or transatlantic airplane flight altitude [*e.g.*, 12 km (~39,400 feet)] are on the order of 150 times greater than that at sea level (NCRP, 1987a; 1987b). Terrestrial exposure is caused by radionuclides in the rocks and soil and from building materials, including a radioactive isotope of potassium, the uranium decay series, and the thorium decay series. Uranium and thorium each decay into a series of radioactive nuclei, some of which emit gamma radiation. Radiation dose rates for terrestrial radiation vary up to a factor of about five over different areas of the United States (NCRP, 1987b). Radionuclides in the body are from the ingestion and inhalation of naturally-occurring radionuclides, including a radioactive isotope of potassium and cosmic-ray-produced radioactive carbon and hydrogen. In addition, the inhalation of radon decay products (radon progeny), which are a part of the uranium decay series, results in a significant fraction of the total radiation dose from natural sources. Another

environmental source of radiation exposure is fallout from past nuclear-weapons testing, but the residual fallout is no longer a significant source of exposure to members of the public.

Figure 3.1 presents average or typical effective doses from a few types of radiation exposures for individuals in the U.S. population. For example, natural background radiation (*i.e.*, the total for cosmic, terrestrial and radionuclides in the body), not including radon in homes, results in an average effective dose of $\sim 1 \text{ mSv y}^{-1}$ ($\sim 100 \text{ mrem y}^{-1}$). The contributions from the three sources of natural background radiation are: cosmic, $\sim 0.3 \text{ mSv y}^{-1}$ ($\sim 30 \text{ mrem y}^{-1}$); terrestrial, $\sim 0.3 \text{ mSv y}^{-1}$ ($\sim 30 \text{ mrem y}^{-1}$); and radionuclides in the body, $\sim 0.4 \text{ mSv y}^{-1}$ ($\sim 40 \text{ mrem y}^{-1}$). As another example (Figure 3.1), the effective dose from a typical full-mouth dental x-ray series is $\sim 0.07 \text{ mSv}$ ($\sim 7 \text{ mrem}$).

3.5 Health Effects of Ionizing-Radiation Exposure

When ionizing radiation interacts with matter, energy is absorbed by the processes of ionization and excitation. Energy absorbed in living tissues initiates physical and chemical reactions that can result in biological damage to deoxyribonucleic acid (DNA) and cells, but that may or may not result in observable biological effects in humans. The biological effects that may occur can be divided into two categories with regard to the individuals affected: (1) somatic effects that occur in the individuals exposed, and (2) hereditary effects that occur in the offspring of the individuals exposed. In addition, the effects can be divided into two groups regarding the relationship between the effect and the level of dose: (1) deterministic effects, and (2) stochastic effects. Deterministic effects occur in all individuals who receive greater than a threshold dose (which may vary for a given individual and the individual's physical condition), and the severity of the effect increases with the magnitude of the dose above the threshold. For example, a radiation-induced skin burn is regarded as being deterministic. Stochastic effects are those where the probability of occurrence (rather than severity in an affected individual) is a function of dose. Stochastic effects are commonly regarded for radiation protection purposes as having no threshold. For example, hereditary effects and cancer are regarded as being stochastic.

3.5.1 Deterministic

Most organs and tissues of the body are unaffected by the loss of even substantial numbers of cells, but if the number lost is large

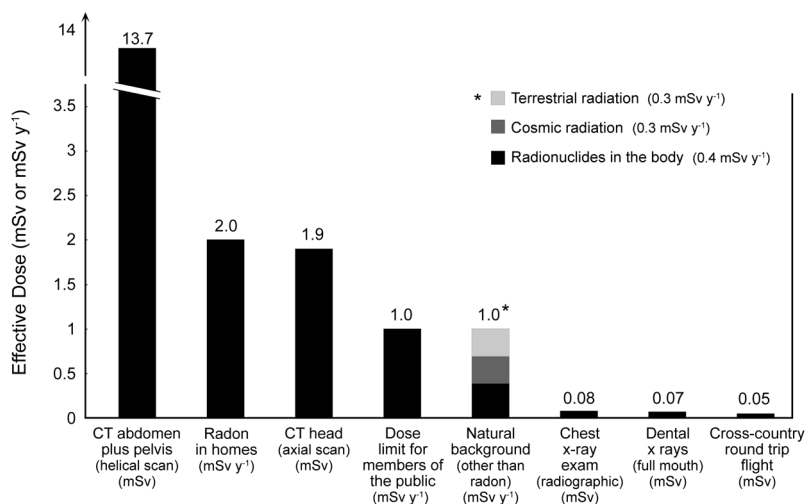


Fig. 3.1. Examples of average or typical effective doses from various sources to individuals in the population of the United States. Effective doses in millirem can be obtained by multiplying the values given in millisieverts by 100. The references for the effective dose values given are: chest x-ray exam, natural background, and radon in homes (NCRP, 1987a);² dose limit for members of the public (NCRP, 1993a); airline flight (NCRP, 1987b); computed tomography (CT) scans (CRCPD, 2007); and dental x rays (NCRP, 2003a). The dose limit for members of the public excludes exposures from natural background (and radon in homes) and from exposures received by patients as part of their health care.

enough, there will be observable harm, reflecting a loss of tissue function. The probability of causing such harm will be zero at low doses, but above some level of dose (*i.e.*, the threshold), the probability will increase to unity (100 %). Above the threshold, the severity of harm will also increase with dose. One example of a deterministic effect is acute radiation syndrome. An accident that delivers a whole-body dose on the order of 1 Gy (100 rad) over a short time (hours to days) can result in early symptoms of the acute radiation syndrome (such as nausea and vomiting) within a few hours (Mettler and Upton, 1995). A second example is erythema or more severe skin burns. Erythema can result from a fluoroscopically-guided interventional procedure that delivers more than 2 Gy (200 rad) to a localized area of skin and a skin burn can result from

²NCRP is in the process of updating its previous report, *Ionizing Radiation Exposure of the Population of the United States* (NCRP, 1987a).

such a procedure that delivers more than 10 Gy (1,000 rad) to a localized area of skin; the injury may not become apparent until weeks after the exposure (ICRP, 2000a). In properly managed radiation safety programs in educational institutions, deterministic effects should not occur because the absorbed doses are orders of magnitude below the thresholds for such effects.

3.5.2 Cancer, Hereditary and Other

There may be no threshold of absorbed dose for the initiation of some deleterious biological changes (*i.e.*, stochastic effects). Consequently, low levels of absorbed dose in organs or tissues may increase the risk (*i.e.*, the probability) of cancer in an exposed population, and low levels of absorbed dose in the gonads may induce mutations or chromosomal changes potentially capable of inducing hereditary disorders in the progeny of exposed parents. Hereditary effects have not been observed in exposed human populations; the projected risks are derived mostly from studies in fruit flies and mice. An increased risk of cancer has been observed in populations receiving relatively high doses in a short period of time (*i.e.*, at high dose rates), primarily the Japanese atomic-bomb survivors and populations receiving relatively high doses at high dose rates from medical procedures performed in the early days of application of ionizing radiation in medicine. Also, given the increased cure rates of radiation therapy patients who are living longer lives, researchers are evaluating the risk for these patients of developing a different cancer or other long-term health effect (*e.g.*, cardiovascular disease or reduced intellectual development) (EBCTCG, 2005; Hall *et al.*, 2004).

The nominal risks (*i.e.*, the probability of occurrence) for radiation-induced fatal cancers and serious hereditary effects that underlie the current radiation dose limits are:

- *Fatal cancers*: The projected lifetime risk for the development of fatal cancer (leukemia and solid cancers) for a population consisting of equal numbers of males and females of all ages is ~5 % per 1 Gy (100 rad) [*i.e.*, about five chances in 100 if every member of the population received a whole-body absorbed dose of 1 Gy (100 rad)] (ICRP, 1991; NCRP, 1993a).³ For a population consisting of only adult workers, the risk is ~4 % per 1 Gy (100 rad) (approximately four chances in 100) (ICRP, 1991; NCRP, 1993a; NRC, 1996a). In comparison, the *baseline incidence of cancer* (number of cases in the absence of this radiation exposure) in the U.S.

population is ~42 % (~42 chances in 100) (NAS/NRC, 2006); the *baseline mortality for cancer* (number of deaths in the absence of this radiation exposure) in the U.S. population is ~20 % (~20 chances in 100) (NAS/NRC, 2006).

- *Hereditary effects*: The current predicted risk of hereditary effects (which is based on nonhuman studies) for the first generation is 0.3 to 0.47 % (3 to 4.7 cases per 1,000 progeny) per 1 Gy (100 rad) of parental radiation [*i.e.*, per 1 Gy (100 rad) of gonadal absorbed dose]. These values are ~0.4 to ~0.6 % of the spontaneous frequency, which is 738 per 1,000 progeny (NAS/NRC, 2006; UNSCEAR, 2001).

Radiation safety programs and radiation dose limits are designed to limit the risk of these health effects. Radiation safety programs also provide guidance to reduce dose to the user, other staff and members of the public by utilizing the as low as reasonably achievable (ALARA) principle (Glossary). Doses received from working with radioactive material and radiation-producing machines at educational institutions are usually well below the annual effective dose limit of 1 mSv (100 mrem) for individuals under the age of 18 and for members of the public (Section 3.6). The annual effective dose limit of 1 mSv (100 mrem) is 1,000 times less than the 1 Gy (100 rad) absorbed doses for the whole body and the gonads at which the nominal values of the risks noted above have been derived.

3.5.3 Following Exposure In Utero

The potential effects due to ionizing radiation exposure *in utero* depend on the fetal stage of development at the time of exposure and the magnitude of dose received by the embryo or fetus (ICRP, 2000b). A recent assessment of biological effects after exposure *in utero* is provided in Publication 90 of the International Commission of Radiological Protection (ICRP, 2003). A brief summary of these effects is presented here.

- For exposure to the embryo in the first three weeks following conception and at absorbed doses under 0.1 Gy (10 rad)

³The most recent assessment in the United States of health risks from exposure to low levels of ionizing radiation is the BEIR VII report of the National Academy of Sciences/National Research Council (NAS/NRC, 2006). The comparable value one can derive from NAS/NRC (2006) for fatal cancers is 5.7 % per 1 Gy (100 rad).

in the embryo, there is either no effect on the embryo, or very infrequently the embryo may be aborted. If the embryo is exposed during this period, no deterministic effects are expected in the child at the time of birth.

- For exposure to the fetus in the period of major organogenesis (starting with the fourth week after conception), there is potential for malformations of the organs under development at the time of exposure (a deterministic effect) with a threshold estimated at >0.1 Gy (>10 rad).
- For exposure to the fetus in the 8th through 25th weeks following conception, there is potential for increased probability of severe mental retardation, perhaps associated with an observed downward shift in intelligence quotient. Fetal doses in excess of ~ 0.1 Gy (~ 10 rad) may result in a verifiable decrease of intelligence quotient. Fetal doses in the range of 1 Gy (100 rad) result in a high probability of severe mental retardation. The effect is greater for exposures in the post-conception period 8th through 15th weeks than for the 16th through 25th weeks.
- For exposure to the fetus in the third week following conception until the end of pregnancy, there is an increased risk of cancer occurring later in life that may be similar in magnitude to the increased risk for cancer from radiation exposure received at any time in the child's first decade of life.

Radiation safety programs and the relevant radiation dose limits are designed also to limit the risk of health effects associated with exposure *in utero*, and protect the embryo and fetus to a level comparable to protection of members of the public (Sections 3.6.1 and 3.6.3).

3.6 Radiation Dose Limits

NCRP Report No. 116 (NCRP, 1993a) gives recommended radiation dose limits for various population groups and situations.⁴ The information given below is applicable to the groups of concern in this Report. NCRP (1993a) provides additional discussion of radiation dose limits, and provides background on the quantities

⁴The comparable dose limits for ionizing radiation that apply in the United States for the radiation sources regulated by NRC are found in NRC [10 CFR 20]. Educational institutions are required to meet the dose limits established by the regulatory authority or authorities that issue the institution's licenses or registrations.

effective dose and equivalent dose. The radiation dose limits mentioned below are for human-produced exposures, but do not apply to radiation doses to an individual resulting from that individual's medical care or from exposure to natural background radiation. However, prudent practice dictates that all radiation exposures *should* be consistent with the ALARA principle.

3.6.1 *Members of the Public*

For continuous (or frequent) exposure, NCRP (1993a) recommends that the annual effective dose for members of the public *shall not* exceed 1 mSv (100 mrem). An infrequent higher annual effective dose is allowed if required, but *shall not* exceed 5 mSv (500 mrem), and the average effective dose over several years *should not* exceed 1 mSv y^{-1} (100 mrem y^{-1}). Such infrequent exposures *should* be limited to a small group of individuals and the same individuals *should not* receive such exposures often. NCRP Statement No. 10 (NCRP, 2004) provides additional discussion of the application of the effective dose limits for members of the public.

3.6.2 *Individuals Under 18 y of Age*

For necessary and occasional educational and training purposes involving persons under 18 y of age, NCRP (1993a) recommends that the annual effective dose for such individuals *shall not* exceed 1 mSv (100 mrem). This is considered to be a part of the annual dose limit of 5 mSv (500 mrem) for infrequent exposure for members of the public (NCRP, 1993a).

To avoid the occurrence of deterministic effects (*i.e.*, effects in the exposed individual that increase in severity with increasing radiation dose above a threshold dose), the following equivalent dose limits for specific organs or tissues are recommended:

- for the lens of the eyes, the equivalent dose *shall not* exceed 15 mSv (1.5 rem) annually; and
- for the hands, feet and skin, the equivalent dose *shall not* exceed 50 mSv (5 rem) annually.

These equivalent dose limits are one-tenth of the corresponding values for occupational exposure.

3.6.3 Occupational Exposure

For radiation exposure received as a result of an individual's occupation (*i.e.*, occupational exposure) (Glossary), NCRP (1993a) recommends that the annual effective dose for such individuals *shall not* exceed 50 mSv (5 rem), and *shall not* exceed a cumulative effective dose of 10 mSv (1 rem) times the individual's age in years.

To avoid the occurrence of deterministic effects, the following equivalent dose limits for specific organs or tissues are recommended for the:

- lens of the eyes, the equivalent dose *shall not* exceed 150 mSv (15 rem) annually; and
- hands, feet and skin, the equivalent dose *shall not* exceed 500 mSv (50 rem) annually.

For individuals who are pregnant and in occupational situations, NCRP (1993a) recommends that the monthly equivalent dose *shall not* exceed 0.5 mSv (50 mrem) to the embryo or fetus of the individual, once the pregnancy is known.

3.7 Basic Principles of Radiation Protection

The overall objectives of a radiation safety program for use of radiation at an educational institution are to:

1. justify any activity that involves radiation exposure based on the benefit exceeding the cost or risk;
2. ensure that the radiation exposure from a justifiable activity is maintained as low as reasonably achievable (the ALARA principle); and
3. ensure that individuals or groups of individuals do not exceed the radiation dose limits.

The basic radiation protection principles used to meet these objectives, in particular the radiation dose management required for Objectives 2 and 3, are discussed below. Many references are available to provide more in-depth descriptions and data useful in the establishment of a radiation safety program (Belanger and Papin, 2003; Bevelacqua, 1999; Cember, 1996; Cember and Johnson, 1999; Shapiro, 2002; Shleien *et al.*, 1998; Turner, 1995).

3.7.1 Dose Rate and Exposure Time

In the case of radiation dose management, the dose rate from a radiation source is the measure of radiation dose per unit time [e.g., 10 mSv h^{-1} (1 rem h^{-1})] at some specific distance. In all uses of radiation sources, one *should* choose the source of minimum dose rate. For a source of given dose rate, the absorbed dose is proportional to the duration of the exposure. Use of a radiation source, therefore, *should* be carefully planned to minimize the exposure time. Practicing the procedure using simulated sources (dry runs) may be useful.

3.7.2 Distance from the Source to the Individual

Increasing the distance from a source to an individual can be very effective in reducing the dose rate because the dose rate varies inversely with the square of the distance from a point source of radiation to the individual. Thus, the dose rate may be reduced to 1 % by a 10-fold increase in distance (i.e., $1/10 \times 1/10$). While this inverse square law theoretically is applicable only for a point source, it may be used for most radiation protection purposes where the source-to-subject distance is more than three times the maximum dimension of the source.

3.7.3 Shielding

Any substance may serve to attenuate, or shield, radiation to acceptable levels provided sufficient thickness is used. Certain materials, however, are more effective in shielding certain types of radiation.

3.7.3.1 Alpha Particles. As noted in Section 3.3.1, alpha particles are stopped by an ordinary sheet of paper or a few centimeters of air. Alpha-particle sources that remain external to the body are not a radiation hazard.

3.7.3.2 Beta Particles. Although more penetrating than alpha particles, beta particles can be readily and completely absorbed. For example, beta particles with an energy of one million electron volts (1 MeV) are completely absorbed by 0.15 cm of aluminum. As beta particles slow down in a material, x rays can be produced, especially in materials with high atomic numbers (Z). Beta-particle shields, therefore, usually have a low- Z material (e.g., water, plastic or aluminum) to minimize producing these x rays, which are called bremsstrahlung. In addition, for the case of a positron (a beta

particle with one positive charge), the final interaction will be annihilation with a free electron, causing the release of two 0.511 MeV photons.

3.7.3.3 *X and Gamma Rays.* X and gamma rays of a single energy (monoenergetic) are attenuated exponentially. Therefore, theoretically it is not possible to attenuate the radiation completely, although the dose rate can be reduced by any desired factor. Thus, if a certain thickness of shielding, the half-value layer, reduces the dose rate to one-half the initial dose rate, then a thickness of three such layers will reduce the dose rate to one-eighth (*i.e.*, $1/2 \times 1/2 \times 1/2$) the initial dose rate. Shielding thickness can also be described in tenth-value layers, or the thickness required to reduce the dose rate to one-tenth the initial dose rate. Half- and tenth-value layers vary with x- or gamma-ray energy, generally increasing with increased energy and, in some materials, decreasing when energies exceed a few million electron volts. Shielding materials of high density and high-*Z*, such as lead, are generally the most effective shields for x and gamma rays. However, steel, concrete, brick, or other materials can provide the same degree of shielding, but greater thicknesses are required.

3.7.3.4 *Neutrons.* Neutrons tend to be scattered rather than absorbed by materials of high-*Z*. They are more easily attenuated in materials containing atoms of low-*Z*, such as paraffin or water, which are rich in hydrogen. Most educational institutions with small radiation safety programs do not possess neutron sources.

3.7.3.5 *Charged Particles.* Charged particles can be shielded in similar ways as alpha and beta particles. As with neutron sources, radiation-producing machines designed to emit charged particles are not typically owned by an educational institution with a small radiation safety program.

3.7.3.6 *Shielding Considerations.* In providing shielding for any of the above types of radiation, the shield material *should* be placed as near as possible to the radiation source. The required thickness of the shield is not reduced by this procedure, but its area is decreased, thus reducing its total volume and weight. Insofar as the application of the radiation source permits, the source *should* be completely surrounded by shielding, either added or inherent to the location of the source (such as an existing earth barrier). This is the reason modern x-ray tubes are enclosed in a protective housing which limits the radiation to the useful beam.

It may not be sufficient merely to provide shielding between the source and the person to be protected. Radiation may be scattered by any object it strikes, and this scattered radiation, coming from various places, may add to possible exposure. Additional shielding may be required against such scattered radiation (Figure 3.2).

3.7.4 Containment of Radioactive Material

Each of the factors discussed previously pertains to protection against radiation emitted by a source at a distance external to the body (an external source). On the other hand, containment of radioactive material minimizes the potential or resultant spread of radioactive material to undesired locations, called contamination (Glossary), thereby providing protection principally against radioactive material getting on or inside the body (an internal hazard).

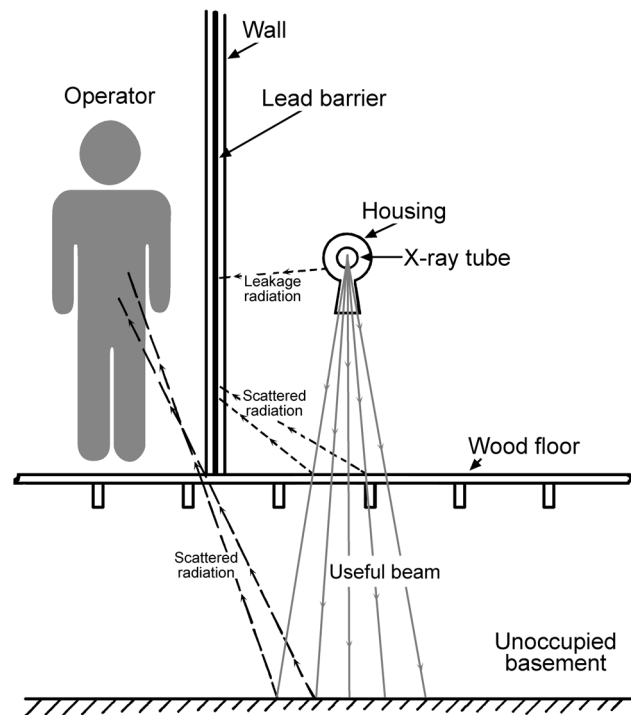


Fig. 3.2. An example of an unsatisfactory shielding arrangement. The lead barrier between the operator and source does not necessarily provide adequate shielding against scattered radiation from the unoccupied basement. Satisfactory protection would be achieved in the situation shown here if lead shielding were provided also on the floor to keep scattered radiation from the basement from reaching the operator.

When possible, use of radioactive material *should* be planned in such a way that the radionuclide is confined in a sealed container (*i.e.*, sealed source) to minimize any possibility of contamination. Radioactive material in liquid, gaseous, or finely divided form may be easily dispersed and result in contamination of the area, nearby individuals, and the environment. Special care *should* be taken to avoid contamination from such unsealed sources, which could lead to intake of the radioactive material, and thus internal radiation dose received by an individual. The routes of intake include a person breathing contaminated air, a person consuming contaminated food or drink, a person absorbing radioactive material through the skin, or a person taking in radioactive material through a wound. The hazards of the different types of radiation can change dramatically when the radioactive material is inside the body (Section 3.3).

General rules to follow for use of unsealed radioactive material are:

- Maintain good housekeeping at all times. Keep the use area neat, wash glassware regularly, and do not let radioactive waste or contaminated material accumulate.
- Control use of unsealed radioactive material by maintaining inventory of the materials, and properly labeling radioactive-material containers and potentially contaminated areas.
- Periodically survey for radioactive contamination on hands, clothing, and the work area during and after completion of a procedure.
- Wear proper personal protective equipment, such as a laboratory coat, safety glasses, and impermeable plastic gloves, when handling unsealed radioactive material.
- Keep containers of radioactive solutions closed except when in actual use.
- If gaseous or volatile sources or aerosols are employed or can be generated, use the radioactive material in a fume hood or other properly ventilated area.
- Do not pipette radioactive solutions by mouth.
- Do not eat, drink or smoke, or store food, beverages and personal items, in any area used for work with radioactive material.
- Follow emergency procedures in case of a spill or other release of unsealed radioactive material, in order to evaluate and prevent further spread of contamination.

A more detailed listing for safe use of radionuclides and model emergency procedures for educational institutions can be found in NUREG 1556, Vol. 7, Appendix P (NRC, 1999a).

4. Types, Locations and Uses of Sources

4.1 Types of Sources

4.1.1 *Naturally-Occurring Radioactive Material*

Naturally-occurring radioactive material (NORM) is found throughout the environment and possession of NORM usually is not regulated (see also Section 5.2.1). However, if such radioactive material contains a sufficiently high concentration of uranium or thorium, it is defined and regulated as source material [NRC, 10 CFR 40]. Under some circumstances, the concentration of the radionuclides in NORM may be increased by human activities. As examples, such technologically-enhanced naturally-occurring radioactive material (TENORM) may result from mining operations, the production and processing of oil and gas, and the extraction of phosphate in the fertilizer industry. There are varying regulatory controls for generating, possessing and transferring TENORM.

4.1.2 *Human-Produced Radioactive Material*

Human-produced radioactive material results from nuclear fission or through the application of nuclear reactions that convert a nonradioactive (stable) element into one that is radioactive, usually employing a nuclear reactor or particle accelerator (e.g., stable ^{59}Co can be irradiated with neutrons in a nuclear reactor to produce ^{60}Co). Although particle accelerators could be used for research and teaching, particle accelerators used to produce radioactive material, and nuclear reactors, are not found at the educational institutions for which this Report is written. Therefore, any human-produced radioactive material used at these institutions will be obtained from other suppliers.

4.1.3 *Radiation-Producing Equipment*

4.1.3.1 Nonionizing. There is a wide variety of devices and processes that use or produce nonionizing radiation and they are

found in industry, medicine, dentistry, telecommunications and the entertainment industry, electrical power transmission, research laboratories, educational institutions, food preparation, and in the home. Specific information about biological effects, sources, location of use, and safety management of nonionizing radiation is given in Section 7.3.

4.1.3.2 Ionizing. Ionizing radiation-producing equipment found in educational institutions typically falls into two categories: x-ray machines used for medical purposes, and x-ray and other radiation-producing equipment used for teaching or research purposes.

Modern medical x-ray machines have many safety features built into the equipment that are prescribed by federal performance standards (FDA, 2006a) and state regulations [for example, CRCPD (2001)] (Section 7.2). However, proper facility design, installation, personnel training and safety procedures are required to minimize the doses received by patients and maximize the medical information obtained. Older medical x-ray machines may not comply with the latest equipment design requirements. In either case, the cognizant state regulatory agency *should* be contacted to ensure that such equipment is operating safely and within regulatory requirements.

Radiation-producing equipment used for research or teaching at educational institutions with smaller radiation safety programs includes diagnostic x-ray systems, analytical x-ray systems (diffractometers, x-ray fluorescence systems), some electron-beam microscopes, and some particle accelerators. For these sources, appropriate controls should be implemented to operate the equipment safely.

- *Diffractometers* are analytical x-ray machines that irradiate a sample of material with x rays to study the scattered x-ray pattern produced by the crystalline structure of the irradiated material.
- *X-ray fluorescence systems* are analytical x-ray machines that use x rays to excite orbital electrons in a sample and then measure the spectrum of characteristic x rays emitted by the sample's elemental constituents.
- *Electron-beam microscopes* are devices that use the wave characteristics of an electron beam to visualize the microscopic surface structure of material. X rays are produced when the primary beam or backscattered electrons strike metal parts of the microscope.

- *Particle accelerators* are machines that accelerate atomic and sub-atomic charged particles to high kinetic energies. These machines, depending upon their design and method of accelerating the particles, include Van de Graff machines, linear accelerators, and cyclotrons. Other types of accelerators are also possible. Particle accelerators operating at higher voltages (>10 MV) can also yield neutrons and high-energy x rays that in turn can interact with machine components and other materials in the vicinity to produce radioactive material.

4.1.4 *Legacy Sources*

In this Report, the term *legacy source* describes radiation sources that no longer have a use, or that are unexpectedly rediscovered. They may remain from past institutional activities and have one or more common characteristics: (1) they are or may be sources of radiation, (2) they were not previously known to the current administration as being on campus or being potentially hazardous, or (3) they are known to be a potential radiation hazard but, despite no longer being used, remain on campus. They may be radioactive material or machines capable of producing radiation. Their presence may be the result of acquisitions in the past by the institution or individuals associated with the institution, or the result of past educational programs.

Important aspects of legacy sources are listed below.

- They may be in the form of sealed sources, unsealed forms such as chemicals and mineral samples, contamination (radioactive material that is present in undesired locations), radioactive waste material, and even ordinary consumer products. Legacy radiation-producing machines may consist of fully-assembled units that are still operational.
- They often (but not always) predate current radiation safety programs and regulatory programs, and equipment standards.
- They may include orphan sources that come into the possession of the institution. Orphan sources are radioactive sources that are subject to regulatory and institutional controls for radiation safety that, because of loss, theft or abandonment, escape such controls.
- They may not be labeled, marked, or otherwise readily recognized as a source of radiation or having the potential to be a source of radiation, and the purpose of the source and its origins may not be apparent.

Resources exist that can aid an institution in identifying legacy sources, in evaluating their potential hazard, and in determining options for ultimate disposition. The cognizant NRC regional office or the cognizant state radiation control program *should* be contacted by the educational institution for assistance in identifying and assessing legacy sources (CRCPD, 2006; NRC, 2007a). See also the Conference of Radiation Control Program Directors (CRCPD) Nationwide Orphan Source Program (CRCPD, 2005a), and the Oak Ridge Associated Universities web library (ORAU, 2006) provides pictures of radioactive sources. Los Alamos National Laboratory manages the off-site Source Recovery Project tasked with recovering abandoned, orphaned and unwanted radioactive sealed sources (LANL, 2006).

4.2 Locations and Uses of Sources

Several different departments or programs in an educational institution may possess or use radioactive material or radiation-producing machines. For educational institutions that have radioactive-material licenses or radiation-producing machine registrations (Section 5), the types of radioactive material, radiation-producing machines and their locations of use are well known. However, educational institutions may also possess or use radioactive material that does not require a license or radiation-producing machines that are not registered. In addition, radioactive material not possessed by an educational institution but located in or near the institution may impact the institution (*e.g.*, used by onsite or nearby contractor or contained in transport through or nearby the institution).

This Section identifies examples of these radiation sources and the educational departments where they might be found.⁵ Table A.1 in Appendix A summarizes the locations and types of sources noted in this Section, as well as the levels of regulatory control (Section 5). Tables A.2 and A.3 in Appendix A provide general precautions and disposal requirements for radioactive material not requiring a specific license and x-ray generating equipment, respectively (Section 7).

⁵This Section is not intended to list all possible radiation sources in all possible situations. It provides some guidance to those individuals responsible for small radiation safety programs and educational administrators about where sources of ionizing radiation may be found, particularly those sources not managed under a specific radioactive material license or radiation-producing machine registration.

Examples of nonionizing-radiation sources and the potential locations of their use in educational facilities are discussed in Section 7.3 on the management of nonionizing-radiation safety programs.

4.2.1 General Teaching Programs

The nature of radioactive decay and radiation interactions makes study of these phenomena an excellent tool for demonstrating mathematical and statistical concepts. The study of radioactivity and the use of radiation and its detection are basic physics topics covered in many educational courses.

License-exempt radioactive sources may be used in mathematics or statistics programs, or in physics, chemistry or engineering classes (e.g., the use of a radioactive source to check or demonstrate the operation of a radiation-detection instrument). The most common license-exempt sources include sealed disc sources of ^{133}Ba , ^{109}Cd , ^{57}Co , ^{60}Co , ^{137}Cs , ^{152}Eu , ^{54}Mn , ^{22}Na , ^{210}Po , ^{90}Sr , ^{204}Tl , and ^{65}Zn . The maximum license-exempt activities of these sources range from 3.7 kBq (0.1 μCi) (alpha-particle and high-energy beta-particle sources) to 370 kBq (10 μCi) (most beta-particle and gamma-ray sources). See the Glossary for definitions of becquerel (Bq) and curie (Ci). Ionizing-radiation sources that require licensing or registration are used under the specific requirements of the institution's license. Many of the same types of radioactive material and radiation-producing machines may be found in several different departments.

4.2.2 Biological Sciences

Radioactive material and x rays are essential tools in biological sciences. Many types of radioactive material are used in tracer studies of biological systems. The typical radionuclides used are ^3H (tritium), ^{14}C , ^{32}P , ^{33}P , ^{35}S , and ^{125}I . Examples of procedures using these kinds of radioactive material are:

- southern blots (detection of specific DNA fragments by gel-transfer hybridization which typically uses ^{32}P);
- northern blots [detection of specific sequences in ribonucleic acid (RNA) by gel-transfer hybridization which typically uses ^{32}P];
- western blots (detection of specific proteins by gel-transfer hybridization which typically uses ^{32}P or ^{35}S);
- ^3H in DNA and RNA synthesis, protein tracer, metabolic, enzyme reaction, and toxin studies;

- ^{14}C in DNA and RNA synthesis, metabolic, enzyme reaction, pharmacokinetic, and cellular processes studies;
- ^{35}S in DNA sequencing, protein and metabolic studies, and enzyme assays;
- ^{32}P and ^{33}P in DNA and RNA synthesis and protein labeling studies, and protein and lipid kinase assays; and
- ^{125}I in radioimmunoassay, protein metabolism, and hormone studies.

Prepackaged units containing small quantities of radioactive material used in these studies are often referred to as “kits.” Radioactive material may also be used in the biological sciences as tracers in plants or in animals.

The study of effects of radiation exposure on biological systems is an important part of biological sciences. Radiation can be used as a tool to study other biological mechanisms. Self-shielded irradiators, typically using ^{137}Cs or ^{60}Co sealed sources, or x-ray producing irradiators may be used for the irradiation of biological samples and small animals. Self-shielded irradiators (including sterilizers) containing high-activity sealed sources may require additional security specifically defined by regulations, license conditions, or orders from regulatory agencies (Section 7.1.3).

Equipment used to measure radioactive material or radiation fields may include a radioactive source used to check, test or adjust the equipment. For instance, radiation survey meters often have a low-level “check” source attached to test that the meters are functioning properly. Another example is liquid scintillation counters, often used to measure beta-emitting radioactive material, that have radioactive sources as part of their internal calibration system. Other types of equipment used in biological laboratories may contain radioactive sources, such as gas chromatographs, which may utilize the radiation from radioactive sources to perform chemical analyses. Removal of these types of equipment from service requires proper disposal of these radioactive sources (Section 7.1.2.4).

X-ray machines can be used in biological sciences to make diagnostic images of animals or can be used as irradiation sources, and electron-beam microscopes are used to image minute biological systems.⁶

⁶Electron-beam microscope sample preparation may use radioactive uranium compounds, such as uranyl nitrate and uranyl acetate, to stain biological specimens and give contrast between different structures, such as between the cell wall and the interior of the cell.

4.2.3 *Chemistry*

Radioactive material and x rays have been essential tools in chemistry. The type and extent of use of radioactive material in chemistry depends on the extent of the educational institution's radiochemistry program. The application of licensed radioactive material in chemistry includes tracer studies of chemical systems, studies of chemical reactions involving particular radiochemicals, and development of particular chemicals containing radioactive substances.

Chemistry programs will often have inventories of chemicals which include uranium or thorium compounds, and some projects may involve the extraction and concentration of NORM. Anti-static devices, typically containing ^{210}Po , may be used in conjunction with precision balances. Gas chromatographs may contain electron-capture detectors that contain plated sources of ^{63}Ni .

Several types of radiation-producing machines are used in chemical analysis. Examples are x-ray fluorescence detectors and x-ray diffraction units.

4.2.4 *Geological and Earth Sciences*

Geological samples may contain concentrations of uranium, thorium and other NORM. Geologists may employ equipment using radioactive sources, such as soil density gauges or well-logging sources (e.g., $^{241}\text{Am}/\text{Be}$, ^{137}Cs). Radioactive material and radiation-producing machines listed for chemistry may also be used in the geological and earth sciences.

4.2.5 *Physics*

The radioactive material and radiation-producing machines listed for chemistry may also be used in physics. In addition, physics departments may use a linear accelerator or cyclotron to produce specific types of radiation (e.g., protons, deuterons, x rays) or radioactive material (e.g., ^{18}F , ^{64}Cu , ^{124}I , $^{94\text{m}}\text{Tc}$), or may use a source of neutrons (such as a plutonium-beryllium source) to demonstrate neutron physics.

4.2.6 *Engineering*

Radioactive material and radiation-producing machines listed for chemistry may also be used in engineering programs. In addition, radioactive sources may be used in particle research studies (e.g., ^{46}Sc , ^{60}Co) or anti-static devices (such as ^{85}Kr gas tubes). Some

engineering departments may use specialized equipment that contains radioactive material (*e.g.*, ^{60}Co , ^{137}Cs) or an x-ray source used to measure material properties (*e.g.*, an x-ray diffractometer).

4.2.7 *History, Arts and Media Programs*

Typically, history museums and arts and other media programs do not use radioactive material that requires a license, but items containing license-exempt quantities of radioactive material can be found. Some finished optical lenses, such as camera or microscope lenses, contain thorium. Glassware and glazed ceramic tableware, such as orange or orange-red Fiesta® dinnerware (Homer Laughlin China Company, Newell, West Virginia) made before the 1970s and Vaseline glass, contain concentrated quantities of uranium or thorium. Some anti-static devices used by photographers contain plated ^{210}Po sources. Some early photographic film, negatives and prints used thorium and uranium emulsions.

Art departments may have kilns lined with firebrick and may use clays that can contain concentrated quantities of uranium, thorium and other NORM.

4.2.8 *Agricultural and Animal Sciences*

Radioactive material and radiation-producing machines listed for the biological sciences, chemistry and engineering may also be used in the agricultural or animal sciences. Cabinet x-ray systems or other x-ray imaging equipment may be used in animal research.

4.2.9 *Student Health*

Student health facilities (*e.g.*, health clinic, dental clinic, athletic facility) may be large enough to employ a conventional diagnostic x-ray machine or a computed tomography system. The educational institution *should* ensure that these x-ray imaging systems are under the control of a licensed physician and are registered with the cognizant state authority. Medical images *should* be interpreted by a radiologist, and the systems *should* undergo initial and periodic quality assurance checks performed by a qualified expert (Glossary).

4.2.10 *Facilities Management*

An educational institution's facilities management department may possess and use many types of radioactive-material sources

that do not require a license. Self-luminous products like time-pieces and other instrument dials may be used. Many types of smoke detectors contain small radioactive sources (typically ^{241}Am). Some incandescent gas mantles, vacuum tubes, welding rods, and fluorescent light bulbs contain small quantities of thorium. Fertilizers can contain concentrated quantities of uranium, thorium and other NORM.

An educational institution may possess and use devices containing radioactive material that are subject to specific regulatory requirements. These requirements are usually described in documents provided by the manufacturer. One example is a self-luminous exit sign that contains ^3H (tritium). Another example is a tank level-gauge that uses a ^{137}Cs sealed source. Educational institutions should be cautious of using and retaining such sources, because disposal of these devices may be difficult and expensive if the manufacturer goes out of business.

In certain areas of the United States, building design or indoor air-quality assessment may have to include management of exposure from radon to students, faculty, staff and visitors. The U.S. Environmental Protection Agency (EPA) and some state radiation safety programs provide educational institutions guidance to minimize indoor radon levels (CDPH, 2007; EPA, 2006; NHHS, 2007; NJDEP, 2007a).

4.2.11 *Other Potential Sources*

Educational institutions may encounter the situation in which a student, staff member, or faculty member undergoing a nuclear medicine diagnostic or therapy procedure is released from a medical facility with residual radioactive material from the procedure still in the individual. The release of patients containing radioactive material is regulated by NRC and Agreement States (Section 5.2.2) to ensure that such patients do not present a significant radiation risk to other individuals. However, this radioactive material may eventually be excreted by the individual, inadvertently end up in trash or other waste, and later be detected at a waste treatment or recycling facility or landfill. Subsequent to the discovery of the radioactive material, the waste handling company may be able to trace its point of origin. The educational institution may become involved in any investigation that ensues, and should cooperate in the investigation with the involved individual, the medical institution involved in the medical administration of the radiopharmaceutical or radiation therapy source, and the cognizant radiation regulatory agency.

An educational institution may have contractors onsite that use radioactive sources in their work, such as an industrial radiography source used to test welds, or soil moisture and density gauges. The contractor is licensed to possess and use these radioactive sources. The contractor may be required to alert the educational institution to the use of these sources.

The use of radioactive material is widespread and transportation of radioactive material is common. An educational institution may be affected if there is a transportation accident involving a delivery company [*e.g.*, FedEx[®] (Memphis, Tennessee), DHL[®] (Deutsche Post World Net, Bonn, Germany)] transporting packages containing radioactive material. The regulatory requirements established by the U.S. Department of Transportation (DOT, 2006) and the International Air Transport Association (IATA, 2006) provide for the safe transport of radioactive material.

5. Legal and Regulatory Responsibilities

5.1 Introduction

The characteristics of a radiation source (*e.g.*, radionuclide, activity, encapsulation) determine the legal and regulatory responsibilities for that source. The extent, complexity and formality of these legal and regulatory responsibilities vary greatly for the different types of radiation sources. This variation is based on differences in the evolution of federal, state and local laws or standards governing the use of radiation sources, and does not necessarily reflect the magnitude of health risk from each source.

5.2 Radioactive-Material Licenses

A radioactive-material license provides regulatory approval to possess and use radioactive material that is not exempt from regulation. The radioactive-material licensing agency is either NRC or the cognizant state for the educational institution.

5.2.1 *U.S. Nuclear Regulatory Commission*

NRC is a federal commission established by Congress through the Energy Reorganization Act of 1974 (ERA, 1974) [NRC, 10 CFR 30.1]. NRC is responsible for the regulation of source material, special nuclear material, and byproduct material [NRC, 10 CFR 1].

- Source material refers to uranium or thorium. It is the raw material for producing special nuclear material [NRC, 10 CFR 40].
- Special nuclear material is the fissionable material extracted or made from source material and includes ^{239}Pu , and uranium enriched in ^{233}U or ^{235}U [NRC, 10 CFR 70].
- The original definition of byproduct material (AEA, 1954) was any radioactive material created through the use of special nuclear material (*i.e.*, radioactive atoms resulting from the fission process or made radioactive through bombardment by neutrons resulting when the atoms of special nuclear material undergo fission) [NRC, 10 CFR 30]. It also

includes the tailings or waste from ore processed primarily to recover source material. NRC issued new regulations (effective November 30, 2007) to implement an expanded definition of byproduct material (NRC, 2007b) as required by the Energy Policy Act of 2005 (EPACT, 2005). EPACT expanded the Atomic Energy Act of 1954 (AEA, 1954) definition of byproduct material to include: (1) any discrete source of ^{226}Ra , (2) any material made radioactive by use of a particle accelerator, and (3) any discrete source of NORM, other than source material, that would pose a similar threat as a discrete source of ^{226}Ra .

This regulatory authority change is required by EPACT (2005) to be fully implemented by August 2009. This change will impact radioactive-material licensees for many years as the new regulatory requirements are established for the types of radioactive material added to the expanded byproduct material definition.

Before seeking a license to possess these types of material, the educational institution *should* contact NRC or the cognizant state agency to discuss the institution's needs and the licensing process. The educational institution may also benefit by contacting an affiliated educational institution which has a radioactive-material license to discuss technical and regulatory issues, gain practical knowledge from the affiliated institution's radiation safety program, and perhaps share equipment, expertise and, in some cases, share license coverage.

5.2.2 Agreement States

Under Section 274 of the Atomic Energy Act of 1954 (AEA, 1954), NRC may relinquish to the states portions of its regulatory authority to license and regulate byproduct material (radionuclides), source material (uranium and thorium), and certain quantities of special nuclear material. The states that have successfully undergone the process to attain such authority are called Agreement States. The majority of states are Agreement States, and more information on Agreement States is available at NRC (2006a). Those states that have become Agreement States must adopt regulations that are the same as or more stringent than NRC regulations for the possession and use of radioactive material. An Agreement State issues each licensee a single license for any byproduct, naturally-occurring and accelerator-produced radioactive material. Some Agreement States have established specific regulatory authority with local governments for certain large cities (*e.g.*, New York City and Los Angeles).

5.2.3 *States*

In states that are not Agreement States, an NRC license is required if the licensee desires to possess radioactive material regulated by NRC. A separate state license or registration may be required to possess naturally-occurring or accelerator-produced radioactive material. Information concerning states that are not Agreement States can be found at NRC (2006b). Also, CRCPD maintains a website that provides information on all state radiation programs (CRCPD, 2006), as well as many resources for radiation protection in general.

5.2.4 *Occupational Safety and Health Administration*

The Occupational Safety and Health Administration (OSHA) is part of the U.S. Department of Labor. OSHA's mission is to prevent work-related injuries, illnesses and deaths (OSHA, 1970). Therefore, OSHA's regulations on ionizing radiation (OSHA, 1996a) apply only to occupational exposures. With respect to radioactive material, an educational institution in compliance with the use of radioactive material approved under NRC regulations or under an NRC or Agreement State license is considered to be in compliance with OSHA's regulations on ionizing radiation (OSHA, 1996b). For other radioactive material, an educational institution may or may not be subject to OSHA regulations. States can develop and operate their own job safety and health programs (OSHA, 1970), and most adopt the federal standards. These are called State Plan States and they may establish plans that cover both the private sector and state and local government employees, or that cover public employees only. If a state is not recognized by OSHA as a State Plan State, then a private educational institution is subject to OSHA regulations, but a public educational institution is not subject to OSHA regulations because OSHA regulations do not otherwise apply to non-federal public institutions. OSHA maintains the list of State Plan States on its website (OSHA, 2007a).

5.2.5 *Exempt Radioactive Material*

Certain quantities of radioactive material and certain concentrations of radioactive material are exempt from the licensing requirements of both NRC and the states. In general, these are very low activities or concentrations [*i.e.*, kilobecquerel (activity) or becquerel per milliliter (concentration)]. Tables listing exempt concentrations and quantities can be found in NRC [10 CFR 30.70;

10 CFR 30.71] or the cognizant state's regulations pertaining to license requirements. In addition, certain consumer products contain radioactive material that is exempt from licensing on the part of the user (e.g., watches containing radioactive material in luminous dials and smoke detectors). A listing of radioactive material found in educational institutions that is typically exempt from licensing is provided in Table A.1 in Appendix A.

5.2.6 *General Licenses*

General licenses [NRC, 10 CFR 31] are issued by regulatory agencies for certain applications involving radioactive material (e.g., some gauging devices containing radioactive sources, and radioactive material for specific uses, such as radioactive exit signs, liquid-scintillation-counter internal sources, and some gas-chromatograph units). See Table A.1 in Appendix A for a listing of radiation sources found in educational institutions that can be used under a general license.

General licenses may be used by any person meeting the conditions contained in the regulation. In some cases, prior registration with the licensing agency may be required. The sources or devices used under a general license must be obtained from a manufacturer or distributor licensed to transfer them to persons under a general license. Persons possessing generally-licensed material may be required to register their use through the NRC [NRC, 10 CFR 31.11], and may be required to fulfill certain regulatory obligations, such as having the sealed source leak tested, following the label instructions, not abandoning the source, and reporting to NRC theft, loss, and any change in ownership of a radioactive source [NRC, 10 CFR 31.5].

5.2.7 *Specific Licenses*

Specific licenses are issued (after application to and approval by the licensing agency) for the possession and use of radioactive material not exempt or covered under a general license. Specific licenses are issued for radioactive-material programs that satisfy the following:

- applicants specify appropriate uses for the radioactive material;
- applicants have equipment and facilities adequate to protect health and minimize danger to life or property;

- applicants are qualified by training and experience to use the material requested in a manner that protects health and minimizes danger to life or property;
- applicants satisfy all regulatory requirements; and
- applicants have adequate procedures so that the licensed activities will not adversely affect the environment.

There are two types of specific licenses: limited scope and broad scope. Specific licenses of limited scope (NRC, 1999a) are usually issued for programs that are small (involving one or a few users of radioactive material) or for applications that are limited (involving a small number of different radionuclides or limited uses of radioactive material). The license application is prescriptive and describes in detail each aspect of the radiation safety program associated with use of the material. For such programs, one of the users is often named as RSO (*i.e.*, the individual who is responsible for ensuring or overseeing all aspects of the safe use of the material). Limited scope licenses usually do not require the establishment of a radiation safety committee to oversee and ensure the safe use and disposal of the radioactive material.

Specific licenses of broad scope (NRC, 1999b) are issued for programs that use a large number of different radionuclides by a large number of authorized users in a multitude of different places or laboratories. The requirements for such licenses and programs are more demanding and often include the designation of an RSO who has specified training and experience to permit effective oversight of the radioactive material used in the program. Often, such programs also require the establishment of a radiation safety committee to formulate institutional radiation safety policies, approve uses and users, and monitor the program. Broad-scope licenses require a review and audit of the effectiveness of the radiation safety program and guidance to the RSO on the operational uses of radiation and radioactive material (NRC, 1999b). If a radiation safety committee is required, its collective membership *should* be knowledgeable about the safe use of radioactive material and radiation-producing equipment, and about management of the institution, including the institution's legal, financial, procurement, and other business functions with regard to its radiation safety program. A specific license of broad scope allows for more flexibility on the part of the licensee. For example, a Type A specific license of broad scope usually has activity limits on the order of curies ($1 \text{ Ci} = 37 \times 10^9 \text{ Bq} = 37 \text{ GBq}$) and the licensee is allowed to establish, review and grant its own authorizations for applications of radioactive material or radiation use under its license [NRC,