NCRP REPORT No. 157

RADIATION PROTECTION IN EDUCATIONAL INSTITUTIONS

National Council on Radiation Protection & Measurements

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Radiation Protection in Educational Institutions

Recommendations of the
NATIONAL COUNCIL ON RADIATION PROTECTION AND MEASUREMENTS

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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.

This Report was prepared by Scientific Committee 46-17 on Operational Health Physics. Serving on Scientific Committee 46-17 were:

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Thomas S. Tenforde
President

Contents

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 nonionizing. 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

[1]For 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 ~1 mSv y^{-1} (~100 mrem y^{-1}). The contributions from the three sources of natural background radiation are: cosmic, ~0.3 mSv y^{-1} (~30 mrem y^{-1}); terrestrial, ~0.3 mSv y^{-1} (~30 mrem y^{-1}); and radionuclides in the body, ~0.4 mSv y^{-1} (~40 mrem y^{-1}). As another example (Figure 3.1), the effective dose from a typical full-mouth dental x-ray series is ~0.07 mSv (~7 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

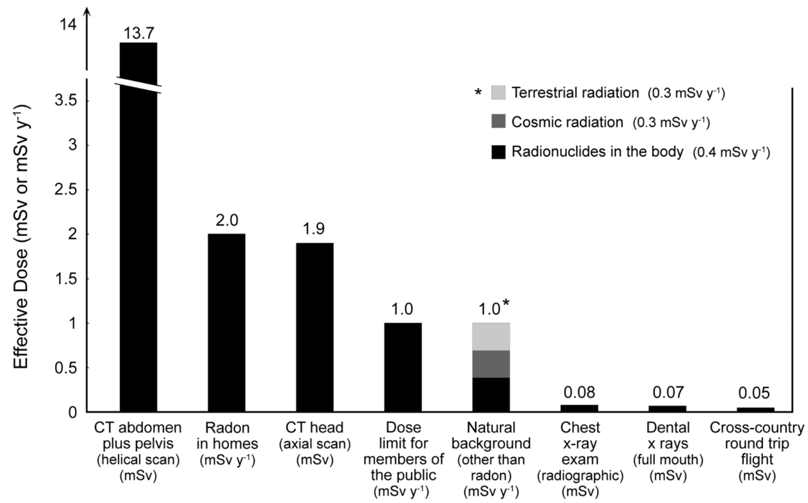

Fig. 3.1. Examples of average or typical effective doses from various sources to individuals in the population of the United States. Effective doses in millirem can be obtained by multiplying the values given in millisieverts by 100. The references for the effective dose values given are: chest x-ray 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

[2]NCRP 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)

[3]The 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

[4]The 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).

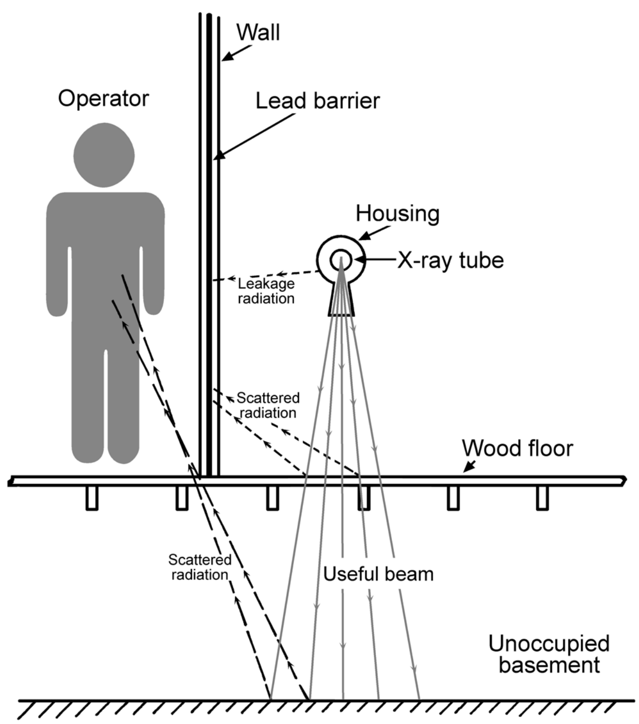

Fig. 3.2. An example of an unsatisfactory shielding arrangement. The lead barrier between the operator and source does not necessarily provide adequate shielding against scattered radiation from the unoccupied basement. Satisfactory protection would be achieved in the situation shown here if lead shielding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

[5]This 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 ^{3}H (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);
- ^{3}H 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]

[6]Electron-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.*, $^{241}Am/Be$, ^{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, ^{94m}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 Lauglin 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 timepieces 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 ^{3}H (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, 10 CFR 33.13]. This Report is not written for this most complex of radioactive-material licenses, but for licensees with lower quantities (*i.e.*, lesser activity limits) and limited uses. Guidance for licenses of broad scope is provided in specific regulations and guides (NRC, 1999b) [NRC, 10 CFR 33].

5.2.8 *Responsibilities Accompanying a License*

Obtaining a license to use radioactive material or to use radiation-producing equipment under a registration or permit obligates the licensee, registrant, or permit holder to most of the following:

- limit uses to those that are approved by the regulating authority;
- provide equipment and facilities to adequately protect health and minimize danger to life or property;
- limit uses to individuals who are qualified by training and experience to use the radioactive material or equipment in a manner that protects health and minimizes danger to life or property;
- ensure compliance with regulations and all conditions of the license;
- provide adequate training for individuals approved to handle radioactive material or use radiation-producing equipment;
- provide personal monitoring for users of radioactive material and other radiation sources to ensure that the users' exposures are within regulatory limits and are consistent with the ALARA principle;
- provide adequate security for radioactive material and radiation-producing equipment to ensure they are not handled or operated except by individuals specifically approved to do so;
- provide documented inventories of radioactive material or radiation-producing equipment to ensure appropriate tracking and adequate security;
- provide for safe, effective and approved disposal of radioactive material and radiation-producing equipment no longer needed;
- maintain appropriate records to substantiate the effectiveness of the radiation safety program and compliance with rules, regulations, and license or permit conditions;
- ensure uses of radioactive material or radiation will not adversely affect the environment;

- provide for immediate and effective response to emergencies involving radioactive material or radiation-producing equipment;
- provide financial assurance to support effective decontamination, decommissioning and disposal upon termination of a license or permit; and
- conduct and document annual reviews of the radiation safety program.

5.2.9 *Determining Need and Type of License*

To evaluate the need for and type of radioactive-material license, registration or permit for radiation sources, the applicant is required to determine:

- what quantities of radioactive material and types of radiation-producing equipment are needed;
- the types of uses and what operations are planned for the radioactive material and radiation-producing equipment;
- whether a radioactive-material license, registration or permit already exists and if it adequately covers the existing inventory and possible future needs;
- where the material and equipment will be stored and used, including storage for unwanted and surplus radioactive sources and radioactive waste;
- how many individuals will be specified as authorized users of the radioactive material and radiation-producing equipment;
- the potential for personal and environmental exposures;
- what radiation detection and monitoring equipment exists or might be needed;
- the level of training needed for the users and the radiation safety staff; and
- whether special equipment or supplies are needed to ensure effectiveness of the program for the existing sources or for future needs.

Once the evaluation has been accomplished, the applicant can decide the appropriate type of license, registration or permit that might be required and the specific regulatory group to contact for advice.

5.3 Ionizing Radiation-Producing Machines

The U.S. Food and Drug Administration (FDA) has jurisdiction over the manufacturers of electronic products that emit ionizing radiation. FDA has various reporting requirements for the manufacturers and has set federal performance standards relating to radiation emission for several types of electronic products that emit ionizing radiation (FDA, 2006b). Manufacturers of such products must adhere to these performance standards at the time of installation or purchase. Some examples of electronic products that can emit ionizing radiation are medical x-ray equipment, particle accelerators, cabinet x-ray systems, and cathode-ray-tube televisions.

As discussed in Section 5.2.4, OSHA has federal jurisdiction over occupational exposure to ionizing radiation. In the case of ionizing radiation-producing machines, an educational institution may or may not be subject to OSHA regulations, as discussed in Section 5.2.4. Educational institutions located in some large local jurisdictions (*e.g.*, the cities of Los Angeles and New York City) may also be subject to local radiation safety regulations.

States have regulatory jurisdiction over an educational institution's use of ionizing radiation and the equipment producing ionizing radiation. However, the degree of control varies among the different states.

The potential radiation hazard from ionizing radiation-producing equipment ranges from minor to severe. Factors that affect the potential hazard are the type of radiation produced, energy of the radiation, the current of the electron or particle beam producing the x rays and neutrons (in the case of particle accelerators), the shielding inherent in the equipment, interlock systems designed to shut off the radiation if the shielding is breached, and built-in warning and alarm systems. The specific radiation safety program for each piece of ionizing radiation-producing equipment should provide an adequate level of safety.

Usually, possession and use of radiation-producing equipment (*e.g.*, electron-beam microscopes, x-ray machines, or accelerators) are authorized by registration rather than licensing. In some states certain types of radiation-producing machines, such as particle accelerators, require a state permit to operate. The responsibilities of a registrant or permit holder are the same as those listed in Section 5.2.7.

5.4 Nonionizing Radiation-Producing Machines

FDA has jurisdiction over the manufacturers of electronic products that emit nonionizing radiation. FDA has various reporting requirements for manufacturers and has set federal performance standards relating to radiation emission for several types of electronic products that emit nonionizing radiation (FDA, 2006c).

Manufacturers of such products must adhere to these performance standards at the time of installation or purchase. Some examples of electronic products that can emit nonionizing radiation are home microwave ovens, lasers, cell phones, radiofrequency sealers, and microwave heaters, sealers and industrial ovens.

OSHA has federal jurisdiction over occupational exposure to nonionizing radiation (OSHA, 1996c). In the case of nonionizing-radiation-producing machines, an educational institution may or may not be subject to OSHA regulations, as discussed in Section 5.2.4. In addition, some states, such as New Jersey (NJDEP, 2007b) require registration of certain types of nonionizing radiation-producing machines. Each educational institution that utilizes nonionizing radiation-producing machines should review what specific regulatory requirements apply.

See Section 7.3 for additional information on the safe use of nonionizing-radiation sources.

6. Administrative Responsibilities

An educational institution should be aware of any plans to acquire radioactive material, x-ray producing equipment, or laser equipment. The acquisition and use of such materials and equipment require appropriate management oversight and safety controls. Therefore, a responsible administrator (RA) *should* be designated who has overall responsibility for the radiation safety program.

6.1 Responsible Administrator

As discussed in Section 2, individuals who typically are appointed to serve as the responsible administrator (RA) for an educational institution's radiation safety program are as follows:

- *High schools*: The principal of the high school, with delegation from the school board.
- *Small colleges and specialty academies*: The chancellor, college president, or other senior manager delegated by the institution.
- *Larger colleges and universities*: Same as for a small college. However, this individual or a designee will also serve as the executive management representative to the radiation safety committee.

NRC expects an RA to have authority to provide necessary resources to achieve regulatory compliance (NRC, 1999a). The responsibilities of the RA typically include:

- overall administration of the radiation safety program;
- providing adequate personnel and other necessary resources so that the radiation safety program can be implemented and maintained;
- informing staff members that sources of radiation can only be brought on campus with administrative approval;
- obtaining an accounting of any radiation sources already on campus (if it is unclear whether the sources are radioactive,

obtain help from a regulatory agency or from a qualified expert) (Section 5);
- determining whether each source in the inventory is needed, and if not, determining the proper means of disposal;
- maintaining overall responsibility for the program, even though delegating authority (in writing) to implement the day-to-day operation of the radiation safety program to a responsible individual (RI) (Section 6.2);
- informing staff members that the RI reports to the RA for purposes of radiation safety to avoid chain-of-command issues;
- meeting with the RI periodically to discuss the radiation safety program;
- receiving periodic written reports from the RI on the status of the radiation safety program, including any noncompliance items;
- serving on the radiation safety committee if such a committee is required;
- maintaining an overall understanding of the radiation safety program, including any regulatory requirements;
- evaluating the impact on institutional insurance because of the presence of radioactive material or radiation-producing equipment;
- assuring adequate funding for decommissioning sources, equipment and facilities; and
- halting an activity where there have been malicious, willful or serious violations of radiation safety program requirements.

For further guidance on administrative requirements, consult the NUREG 1556 series of documents (NRC, 1998; 1999a; 1999b; 2005a) provided by NRC.

6.2 Responsible Individual

The RA may delegate authority to a responsible individual (RI) to implement the day-to-day radiation safety program. At many institutions, the RI is referred to as the RSO and is usually the person named as the educational institution's contact for licensing or registration of radiation sources. As discussed in Section 2, individuals who typically are appointed to serve as the RI for a radiation safety program at an educational institution are as follows:

- a teacher or professor;
- an existing safety staff member or the safety officer; or
- a researcher.

Typically, where there is only a single user of radioactive material or radiation-producing machines, this user is named the RI. As the number of users and complexity of uses of radioactive material and radiation-producing equipment increase, the responsibilities of the RI become correspondingly more complex. At these multi-user institutions, the radiation safety responsibilities can become the primary part of the RI's job. In these situations, the RI is typically referred to as the RSO. As the size of the radiation safety program increases, additional staff may be required to support the RI.

The individual appointed as the RSO *should* have an appropriate level of training and experience, and an understanding of radiation quantities and units, instrumentation, regulations, and good radiation practices, commensurate with the responsibilities to be assumed. Specific guidance on such RSO training, experience and qualifications can be found in AAHP (2003) and NCRP (1998; 2000).

The responsibilities of the RI typically include:

- assisting the RA in addressing the questions listed in Section 6.1, so the scope of the radiation safety program can be developed;
- developing, implementing and overseeing the radiation safety program on a day-to-day basis;
- providing the RA with a list of resources (personnel and equipment) required to operate an effective radiation safety program;
- receiving training commensurate with his or her responsibilities;
- providing or arranging for training for the users of the radioactive material or radiation-producing equipment.
- ensuring that all of the components necessary for the radiation safety program (*i.e.*, compliance with regulations, license/registration/permit conditions, institutional policies, and good practice) are implemented. Based on the uses of radioactive material and radiation-producing equipment, these could include providing, developing and conducting periodic inspections of personal monitoring, safety procedures, radiation surveys, material and equipment labeling, posting of necessary warning signs, radioactive-source security, waste disposal, and emergency-response procedures;

- developing and maintaining the necessary documentation for the radiation safety program (*e.g.*, safety procedures, source and equipment inventory, licensing records, training records, survey records);
- obtaining and maintaining any required licenses or equipment registrations;
- arranging for proper disposal of radioactive waste;
- identifying and evaluating nonradiological hazards associated with activities;
- keeping the RA informed about the status of the radiation safety program through periodic meetings and reports; and
- stopping any unsafe activities involving radiation sources.
- conducting and documenting annual reviews of the radiation safety program.

6.3 Scope of the Radiation Safety Program

In educational institutions where the activity of radioactive material and the intensity of machine-produced radiations are low, there may not be a need for a radiation safety professional (*i.e.*, a qualified expert) to serve as the RI. If the potential hazards associated with the use of such sources of ionizing radiation are properly managed, the potential risk to faculty, staff and students following simple basic precautions is correspondingly low. Otherwise, a more extensive radiation safety program *should* be instituted with the assistance of a qualified expert. That assistance may range from performing the initial review to establishing a new radiation safety program, to performing periodic audits of an existing program. Programs requiring that a qualified expert be named as the RSO are beyond the scope of this Report, as noted in Section 2.

The scope of the radiation safety program at an educational institution *should* be commensurate with the potential radiological hazards. Some of the questions that should be asked by the RA and the RI to assess the potential hazards of the use of radiation sources are:

- What is the specific nature (*e.g.*, radionuclide, quantity, chemical and physical form, packaging, type of equipment) of the radioactive material or radiation-producing equipment and what is the origin of each source of radiation?
- Is a specific license from a regulatory agency required for the radioactive material? If so, what type and which regulatory agency issues that license?

- What are the registration requirements for the radiation-producing equipment?
- Are there fees associated with the licensing or registration process?
- How will the institution dispose of the material or equipment when it is no longer needed?
- Are there hazards in addition to radiation associated with the equipment operation or the materials use and storage?
- Are there limitations on how the radioactive material or radiation-producing equipment can be used? Can any of the sources of radiation be taken apart for teaching purposes?
- Are there any external radiation exposure hazards?
- What are the external levels of radiation produced by the radioactive material or radiation-producing equipment?
- Are there potential inhalation or ingestion hazards associated with the types and forms of the radioactive material? Will the radioactive material be in a dispersible form?
- Does the institutional insurance on the property or legal requirements (*e.g.*, lease agreements, covenants, and local codes) restrict the presence of radioactive material or radiation-producing machines?
- Are there specific legal concerns for minors working with or in the vicinity of the radioactive material?
- What procedures are necessary to minimize hazards in the event of fire, explosion, or natural disasters such as a tornado or flood?
- Are there any chemical hazards associated with the radioactive material or equipment that could result in additional disposal costs?
- Will the materials or equipment be used only for demonstrations or will students handle them?
- Are there any special security requirements associated with the radioactive material or other radiation sources?

7. Radiation Safety Program Management

All educational institutions encounter a myriad of safety issues. Applying fundamental radiation safety principles is similar to applying safety principles in other fields and, when done correctly, typifies the best attributes of a safety culture. Many educational institutions rely on their safety departments (Green, 1998) to help with radiation safety issues, such as managing a previously unknown radiation source, assisting an instructor using a radiation source to maintain the safety of students, instructors and others, or maintaining a technical staff responsible for daily operation of the radiation safety program. The structure of a radiation safety program depends on the types and complexity of the radiation sources being used. While people may believe that use of radiation is highly regulated because it is so dangerous, risks associated with its use are manageable and are often less than other hazards (*e.g.*, those associated with chemical, physical or biological agents) managed at an educational institution.

Radiation safety is the responsibility of individuals at all levels of the institution, from those individuals using the radiation sources to those working around or otherwise supporting these individuals. The basic features of a radiation safety program (LaMastra, 1998; NCRP, 1998) include:

- commitment by management, lead by the RA, that radiation sources will be used in a safe manner and in compliance with regulations;
- an RI with clearly defined duties and authority that are understood by management, the RI, supervisors and workers;
- individuals (*e.g.*, faculty, research staff, students) with a good familiarity of applicable consensus standards, regulations and program requirements, who accept and fulfill their radiation safety responsibilities;
- good working relationships among the RI, RA, management and users of radiation sources;
- policies for the ALARA principle, pregnant workers, and the safety of minors.

- a training program for those working with radiation sources;
- a program for performing radiation surveys, monitoring, inspections and audits;
- a set of administrative controls;
- written safe operating and emergency procedures;
- a program for safe disposal of radioactive waste; and
- a policy for reporting malfunctions of equipment, exposure hazards, exposure incidents, loss of radioactive material, violations, and other safety concerns to the RSO and the cognizant regulatory agency.

For the purpose of this Report, radiation safety programs are divided into three categories according to the type of radiation source: radioactive material, ionizing radiation-producing machines, and nonionizing radiation.

7.1 Radioactive-Material Safety Program

Establishment of a formal radioactive-material safety program is required when an educational institution has a radioactive-material license or registration. The size and complexity of that program is determined by the uses of radioactive material under the license or registration.

However, if an educational institution does not have a radioactive-material license or registration, the institution may still encounter circumstances involving radioactive material. Some of these circumstances may arise from incidents that are not under the institution's control, such as: radon levels in institution buildings; community response to radiological terrorism; and students, teachers or staff undergoing medical procedures where their bodies still contain radioactive material. Also, certain quantities and concentrations of radioactive material have been designated as exempt by regulatory agencies (Section 5.2.4 and Table A.1), and the institution's possession of these exempt sources does not require adherence to specific radiation safety regulations. Other radioactive material or devices are possessed under general licenses (Section 5.2.5 and Table A.1), and the institution's possession of these generally licensed sources may require the institution to adhere to specific regulatory requirements. It is therefore prudent for all educational institutions to maintain some basic knowledge of these types of radiation sources and their risks, and be able to recognize and respond to associated radiation safety issues. Table A.2 provides general precautions and disposal requirements for examples of radioactive material not requiring a specific license.

An educational institution is required to apply for and receive a specific license[7] from either NRC or an Agreement State (Section 5.2.2) to receive, possess and use radioactive material that is not otherwise exempt or generally licensed. NRC publishes several guidance documents describing the information and commitments required for a license application (NRC, 1998; 1999a; 1999b; 2005a). It is essential that management and the individuals responsible for the radiation safety program understand how to interpret the educational institution's radioactive-material license documents and what legal commitments the institution has made to establish, manage and oversee its radioactive-material safety program. The descriptions given in this Section are meant to address an educational institution with limited types and quantities of radioactive material applying for an NRC license.[8]

7.1.1 *Specific License*

Effective management of a radiation safety program is essential to achieving safe operations that comply with applicable regulations. NRC states "management refers to the processes for conducting and controlling the radiation safety program and to the individuals who are responsible for those processes and have authority to provide necessary resources to ensure safety and to achieve regulatory compliance" (NRC, 1999a).

To ensure adequate involvement from the administrators of the educational institution, NRC requires that a representative of the administration sign the license application acknowledging the institution's commitment and responsibility for the following:

[7]If an educational institution has a specific license to receive, possess and use licensed radioactive material, the institution may choose to continue to possess exempt radioactive sources as exempt and generally-licensed radioactive material under the general license. The institution also has the option of adding any of these radioactive sources to its specific license, thus making them subject to the terms and conditions of the specific license. In any case, licensees are required to ensure that dose limits are not exceeded, whether or not the dose results from licensed sources or unlicensed sources.

[8]These descriptions are not intended for medical use licenses (NRC, 2005a), Type A broad-scope licenses (NRC, 1999b), or distribution or manufacturing licenses. Educational institutions applying for a license or registration from an Agreement State may use these descriptions for understanding the processes, but should contact their Agreement State agency for specific guidance and requirements.

- radiation safety, security and control of radioactive material, and compliance with regulations;
- completeness and accuracy of the radiation safety records and all information provided to NRC [NRC, 10 CFR 30.9];
- knowledge about the contents of the license and application;
- compliance with current NRC and DOT regulations [NRC, 10 CFR 71] (DOT, 2006) and the licensee's operating and emergency procedures;
- provision of adequate resources (including space, equipment, personnel, time, and, if needed, contractors) to the radiation safety program to ensure that the public and workers are protected from radiation hazards, and that compliance with regulations is maintained;
- selection and assignment of a qualified individual to serve as RSO with responsibility for the overall radiation safety program;
- prohibition against discrimination of employees engaged in protected activities [NRC, 10 CFR 30.7] (*e.g.*, providing NRC or the educational institution information about alleged or possible violations, refusing to engage in any unlawful practice, or requesting NRC to institute action against the educational institution);
- provision of information to employees regarding the employee protection [NRC, 10 CFR 30.7] and deliberate misconduct [NRC, 10 CFR 30.10] provisions;
- obtaining NRC's prior written consent before transferring control of the license;
- notifying the cognizant NRC regional administrator in writing, immediately following filing of a petition for voluntary or involuntary bankruptcy; and
- notifying the cognizant authorities of reportable events such as loss of control of radioactive material, radiation doses that exceed a regulatory limit, and certain contamination events.

NRC also requires that the following fiscal responsibilities be met by an institution requesting a radioactive-material license:

- license application and amendment fees. Note: NRC makes some exemptions to this requirement for nonprofit educational institutions [NRC, 10 CFR 170.11(a)(4)]. Each Agreement State has its own regulations concerning these fees;
- annual license fees. Note: NRC also makes some exemptions to this requirement for nonprofit educational institutions

[NRC, 10 CFR 170.11(a)(4)]. Each Agreement State has its own regulations concerning these fees; and

- determination of eventual costs to decommission (*i.e.*, remove all licensed radioactive material and cleanup residual radioactive contamination from all use areas). A decommissioning funding plan may not be required if the license possession limits meet the requirements listed in NRC [10 CFR 30.35] and the licensee provides an NRC approved method of assuring the educational institution will be financially able to fund decommissioning costs.

An example of a license issued by NRC is shown in Figure 7.1. The educational institution is considered a licensee once it is issued an NRC or Agreement State license. The format of the license is as follows:

- *NRC Form 374*: The paragraph in the heading documents the authority and legal obligations of the licensee.
- *Items 1 and 2*: The legal name and address of the educational institution.
- *Items 3 and 5*: Unique license number and the docket number, both of which NRC uses for tracking the license. Each change to the license is noted by the amendment number, which is found at the top of the first page and just below the docket number on subsequent pages. In this example, the latest amendment (No. 12) was issued based on the educational institution's amendment request letter dated March 27, 2006. NRC typically reissues an amended license in its entirety and places in bold type the changes made in the current amendment.
- *Item 4*: Expiration date, typically 10 y after the license is issued. For continuation of the license, a renewal application must be submitted at least 30 d prior to this expiration date.
- *Items 6 to 8*: Under these item headings, each radionuclide, also called licensed material, requested in the application and subsequent amendments is listed along with its corresponding chemical or physical form, and the maximum amount the licensee may have at any one time. Each is identified by its letter. For example, License Item E describes ^{63}Ni sources used in gas chromatographs. In this example, the possession limit for ^{32}P was changed from the previous amendment (8.C).

NRC FORM 374 (SIMULATED SAMPLE) — U.S. NUCLEAR REGULATORY COMMISSION — PAGE 1 OF 6 PAGES, Amendment No. 12

MATERIALS LICENSE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and Title 10, Code of Federal Regulations, Chapter I, Parts 30, 31, 32, 33, 34, 35, 36, 39, 40, and 70, and in reliance on statements and representations heretofore made by the licensee, a license is hereby issued authorizing the licensee to receive, acquire, possess, and transfer byproduct, source, and special nuclear material designated below; to use such material for the purpose(s) and at the place(s) designated below; to deliver or transfer such material to persons authorized to receive it in accordance with the regulations of the applicable Part(s). This license shall be deemed to contain the conditions specified In Section 183 of the Atomic Energy Act of 1954, as amended, and is subject to all applicable rules, regulations, and orders of the U.S. Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

Licensee	In accordance with letter dated **March 27, 2006**
1. Educational Institution	
2. 999 Research Boulevard Universityville, State 98765	3. License number 99-12345-01 is amended in its entirety to read as follows:
	4. Expiration date May 31, 2009
	5. Docket No. 030-56789 Reference No.

6. Byproduct, source, and/or special nuclear material	7. Chemical and/or physical form	8. Maximum amount that licensee may possess at any one time under this license
A. Hydrogen-3	A. Any	A. 7.4 MBq (200 mCi)
B. Carbon-14	B. Any	B. 1.85 MBq (50 mCi)
C. Phosphorus-32	C. Any	C. **3.7 MBq (100 mCi)**
D. Calcium-45	D. Any	D. 0.074 MBq (2 mCi)

Fig. 7.1. Example of an amendment to an NRC License. The items in bold type (at 3, 8.C, 11.B and 24.B) are changes from the previous license. The example here is based on the example licenses listed in NRC's NUREG 1556 series (NRC, 2006c). The citations to 10 CFR refer to various parts of Title 10 of the Code of Federal Regulations (Appendix B).

Note that this educational institution chose to include items 6.E and 6.F in its specific license, rather than managing these sources under general license (NRC 1999a). Also, some NRC licenses continue to list activity units only in curie.

<table>
<tr><td colspan="2">NRC FORM 374A U.S. NUCLEAR REGULATORY COMMISSION
(SIMULATED SAMPLE)</td><td>PAGE 2 OF 6 PAGES</td></tr>
<tr><td colspan="2" rowspan="3">MATERIALS LICENSE
SUPPLEMENTARY SHEET</td><td>License Number
99-12345-01</td></tr>
<tr><td>Docket or Reference Number
030-56789</td></tr>
<tr><td>Amendment No. 12</td></tr>
<tr><td>E. Nickel-63</td><td>E. Foils or plated sources registered either with NRC under 10 CFR 32.210 or with an Agreement State and incorporated in a compatible gas chromatograph as specified in Item 9 of this license</td><td>E. No single source to exceed the maximum activity specified in the certificate of registration issued by the U.S. Nuclear Regulatory Commission or an Agreement State</td></tr>
<tr><td>F. Hydrogen-3</td><td>F. Foils registered either with NRC under 10 CFR 32.210 or with an Agreement State and incorporated in a compatible gas chromatograph as specified in Item 9 of this license</td><td>F. No single source to exceed the maximum activity specified in the certificate of registration issued by the U.S. Nuclear Regulatory Commission or an Agreement State</td></tr>
<tr><td colspan="3">9. Authorized Use

A through D. Research and development as defined in 10 CFR 30.4; animal studies; student instruction.

E and F. To be used for sample analysis in compatible gas chromatography devices that have been registered either with NRC under 10 CFR 32.210 or with an Agreement State and have been distributed in accordance with an NRC or Agreement State specific license authorizing distribution to persons specifically authorized by an NRC or Agreement State license to receive, possess, and use the devices.</td></tr>
</table>

Fig. 7.1. (*continued*).

NRC FORM 374A U.S. NUCLEAR REGULATORY COMMISSION (SIMULATED SAMPLE)	PAGE 3 OF 6 PAGES
MATERIALS LICENSE SUPPLEMENTARY SHEET	License Number 99-12345-01
	Docket or Reference Number 030-56789
	Amendment No. 12

CONDITIONS

10. Licensed material shall be used only at the licensee's facilities located at 999 Research Boulevard, Universityville, Any State.

11. A. Licensed material shall be used by, or under the supervision of J. Jones, Ph.D., S. Park, Ph.D., P. Smith, Ph.D., or W. Singh, M.S.

    B. The Radiation Safety Officer for this license is **P. Smith, Ph.D.**

12. Licensed material shall not be used on human beings.

13. The licensee shall not use licensed material in field applications where activity is released except as provided otherwise by specific conditions of this license.

14. Experimental animals or the products from experimental animals that have been administered licensed material shall not be used for human consumption.

15. Detector cells containing licensed material shall not be opened or the foil sources removed from the detector cell by the licensee.

16. A. Sealed sources shall be tested for leakage and/or contamination at intervals not to exceed the intervals specified in the certificate of registration issued by the U.S. Nuclear Regulatory Commission under 10 CFR 32.210 or under equivalent regulations of an Agreement State.

    B. In the absence of a certificate from a transferor indicating that a leak test has been made, within the intervals specified in the certificate of registration issued by the U.S. Nuclear Regulatory Commission under 10 CFR 32.210 or under equivalent regulations of an Agreement State, prior to the transfer, a sealed source received from another person shall not be put into use until tested and the test results received.

Fig. 7.1. (*continued*).

NRC FORM 374A U.S. NUCLEAR REGULATORY COMMISSION (SIMULATED SAMPLE)	PAGE 4 OF 6 PAGES
MATERIALS LICENSE SUPPLEMENTARY SHEET	License Number 99-12345-01
	Docket or Reference Number 030-56789
	Amendment No. 12

C. Sealed sources need not be leak tested if they contain only hydrogen-3; or they contain only a radioactive gas; or the half-life of the radionuclide is 30 days or less; or they contain no more than 3.7 MBq (100 μCi) of beta and/or gamma-emitting material or not more than 0.37 MBq (10 μCi) of alpha-emitting material.

D. Sealed sources need not be tested if they are in storage, and are not being used. However, when they are removed from storage for use or transferred to another person, and have not been tested within the required leak test interval, they shall be tested before use or transfer. No sealed source shall be stored for a period of more than 10 years without being tested for leakage and/or contamination.

E. The leak test shall be capable of detecting the presence of 185 Bq (0.005 Ci) of radioactive material on the test sample. If the test reveals the presence of 185 Bq (0.005 Ci) or more of removable contamination, a report shall be filed with the U.S. Nuclear Regulatory Commission in accordance with 10 CFR 30.50(c)(2), and the source shall be removed immediately from service and decontaminated, repaired, or disposed of in accordance with Commission regulations.

F. Tests for leakage and/or contamination, limited to leak test sample collection, shall be performed by the licensee or by other person specifically licensed by the U.S. Nuclear Regulatory Commission or an Agreement State to perform such services.

17. Maintenance, repair, cleaning, replacement, and disposal of foils contained in detector cells shall be performed only by the device manufacturer or by other persons specifically authorized by the U.S. Nuclear Regulatory Commission or an Agreement State to perform such services.

Fig. 7.1. (*continued*).

NRC FORM 374A U.S. NUCLEAR REGULATORY COMMISSION (SIMULATED SAMPLE)	PAGE 5 OF 6 PAGES
MATERIALS LICENSE SUPPLEMENTARY SHEET	License Number 99-12345-01
	Docket or Reference Number 030-56789
	Amendment No. 12

18. A. Detector cells containing a titanium tritide foil or a scandium tritide foil shall only be used in conjunction with a properly operating temperature control mechanism which prevents the foil temperature from exceeding that specified in the certificate of registration issued by the U.S. Nuclear Regulatory Commission pursuant to 10 CFR 32.210 or equivalent regulations from an Agreement State.

    B. When in use, detector cells containing a titanium tritide foil or a scandium tritide foil shall be vented to the outside.

19. The licensee shall conduct a physical inventory every six months, or at intervals approved by the U.S. Nuclear Regulatory Commission, to account for all source and/or devices received and possessed under the license. Records of inventories shall be maintained for five years from the date of each inventory, and shall include the radionuclides, quantities, manufacturer's name and model numbers, and the date of the inventory.

20. The licensee is authorized to hold radioactive material with a physical half-life of less than or equal to 120 days for decay-in-storage before disposal in ordinary trash, provided:

    A. Before disposal as ordinary trash, the waste shall be surveyed at the container surface with the appropriate survey instrument set on its most sensitive scale and with no interposed shielding to determine that its activity cannot be distinguished from the background radiation level. All radiation labels shall be removed or obliterated.

    B. A record of each such disposal permitted under this License Condition shall be retained for three years. The record must include the date of disposal, the date on which the byproduct material was placed in storage, the radionuclides disposed, the survey instrument used, the background radiation dose rate, the dose rate measured at the surface of each waste container, and the name of the individual who performed the disposal.

Fig. 7.1. (*continued*).

NRC FORM 374A U.S. NUCLEAR REGULATORY COMMISSION (SIMULATED SAMPLE)	PAGE 6 OF 6 PAGES
MATERIALS LICENSE SUPPLEMENTARY SHEET	License Number 99-12345-01
	Docket or Reference Number 030-56789
	Amendment No. 12

21. Radioactive waste generated shall be stored in accordance with the statements, representations, and procedures included with the waste storage plan described in the licensee's application dated January 22, 1999.

22. The licensee is authorized to transport licensed material in accordance with the provisions of 10 CFR 71, "Packaging and Transportation of Radioactive Material."

23. In addition to the possession limits in Item 8, the licensee shall further restrict the possession of licensed material to quantities below the minimum limit specified in 10 CFR 30.35(d) for establishing decommissioning financial assurance.

24. Except as specifically provided otherwise in this license, the licensee shall conduct its program in accordance with the statements, representations, and procedures contained in the documents, including any enclosures, listed below. The U.S. Nuclear Regulatory Commission's regulations shall govern unless the statements, representations, and procedures in the licensee's application and correspondence are more restrictive than the regulation.

    A. Application dated January 22, 1999

    B. Letters dated August 25, 2001, September 14, 2005 and **March 27, 2006**.

For the U.S. Nuclear Regulatory Commission

Date:_______________ By:_____________________________

Division of Nuclear Materials Safety
Region 1
King of Prussia, Pennsylvania 19406

Fig. 7.1. (*continued*).

- *Item 9*: Listed here are the only uses allowed for each of the license items as requested in the application and subsequent amendments.
- *Items 10 to 24*: These items are also called license conditions.
- *Item 10*: Listed here are the only locations, as identified by address in the application, where the licensee is allowed to use licensed material.
- *Item 11*: Listed here are the names of the authorized users and the RSO. In this example, the RSO was changed.
- *Items 12 to 23*: These license conditions list various requirements the licensee must meet. Many of these conditions are the same for every licensee with these types of radioactive material and uses.

The last license condition, which is Item 24 for the example license here, requires the educational institution (*i.e.*, the licensee) to comply with all of the commitments made in the license application and in any subsequent amendment letters. Therefore, it is important that the educational institution understands that it is responsible for meeting all applicable regulatory requirements, all requirements listed in its license document, and all commitments made in its license application and in subsequent license amendment request letters and attachments.

7.1.2 *Radiation Safety Oversight Program*

Each educational institution should assess its use of radioactive material and develop an appropriate oversight program. Some educational institutions that occasionally use licensed material with low activity will need only a limited type of radiation safety oversight program that includes establishment of the proper safety training and procedures, and periodic review to make certain that training and procedures are carried out. The educational institution will generally give authority to perform the oversight for a limited program to the instructor using the radiation sources. If more than one instructor uses licensed material, then the radiation safety program oversight may reside with one instructor with authority as the RSO, or oversight may reside with an individual in a centralized administrative group (such as a safety group) who is given authority as and trained to be the RSO. Depending on the size and complexity of licensed-material use, additional radiation safety staff may be required to assist the RSO.

7.1.2.1 *Training.* Before beginning work with licensed material, individuals *shall* receive radiation safety training commensurate with their assigned duties and specific to the educational institution's radiation safety program. Each individual *should* also receive periodic refresher training. NRC and Agreement States require that individuals whose assigned duties involve occupational exposure to radiation or radioactive material receive instruction commensurate with their duties and responsibilities [NRC, 10 CFR 19.12]. Each individual *should* be instructed on his or her responsibility to report promptly to the educational institution any condition that may lead to or cause an unsafe condition or a regulatory noncompliance, without fear of retaliation (NRC, 1996b; 2005b).

The educational institution is required to establish a radiation safety training program and in its license application describe the topics covered, groups of workers to be trained, how assessment of training will be made, the qualifications of instructors, and the method and frequency of training. Educational institutions may establish a formal class or classes, including hands-on or laboratory exercises, to provide radiation safety education and training to radiation safety staff, licensed-material users, and other students that want to learn about the topics.

7.1.2.2 *Facilities and Equipment*. Educational institutions should provide facilities and equipment with sufficient engineering controls and barriers to protect the health and safety of the public and its employees, to keep exposures to radiation and radioactive material consistent with the ALARA principle, and to minimize the danger to life and property from the uses of the types and quantities of radioactive material they possess. The educational institution is required to describe the facilities and equipment available at the locations where radioactive material will be used, and the facilities and equipment provided for the radiation safety oversight program.

7.1.2.3 *Radiation Safety.* Key elements of the radiation safety program are noted below under the following topics: audit, radiation monitoring instruments, radioactive material receipt and accountability, radiation dose controls, personal radiation monitoring, safe use of radioactive material, emergency procedures, radiation surveys, transportation of radioactive material, and minimization of radioactive contamination.

7.1.2.3.1 *Audit*. The educational institution is required to review the content and implementation of its radiation safety oversight program at least annually to ensure compliance with applicable regulations and the terms and conditions of its license, and to assess that radiation exposures are consistent with the ALARA principle. If problems or potential violations of NRC or state requirements are identified, the educational institution is required to first evaluate the safety significance of each identified problem and potential violation to set priorities and identify resources to correct them (NRC, 1996c). A key aspect to an effective radiation protection program is performance-based audits, or inspections, in which the RSO or designee observes the actual uses of radioactive material, or interviews the involved students, faculty or staff asking them to describe or demonstrate procedures, for example:

- how to use a survey meter;
- how to safely receive, handle or dispose of radioactive material;
- how to report a safety concern or violation; or
- what to do in case of a spill, an accident or some other emergency.

Violations, or potential for a violation, may be identified during an audit, following an accident, or from a student, faculty or staff member reporting a safety concern. The RSO and the RA *should* ensure that the causes of the violation, or potential violation, are identified, corrective actions are developed and implemented, and the effectiveness of the corrective actions periodically evaluated. Certain identified problems or potential violations may require notification or a report to NRC or the state regulatory agency [Appendix N in NRC (1999b)]. When an educational institution self-identifies violations and makes prompt and effective corrective actions, regulatory agencies may not take enforcement actions if the violations do not recur.

7.1.2.3.2 *Radiation monitoring instruments*. The educational institution is required to possess or have access to calibrated radiation detection and measurement instruments or hire qualified services to perform, as necessary, the following:

- radiation surveys on receipt of radioactive-material packages;
- radioactive-contamination surveys;
- sealed source leak tests;
- air sampling to measure airborne radioactive material;
- bioassay measurements to assess intakes of radioactive material by individuals;

- effluent release measurements for radioactive material released from water effluents or air exhausts; and
- radiation dose or dose-rate measurements outside of radiation use areas.

The instruments should be appropriate for the type of radiation being measured and the type of measurement being made (*e.g.*, count rate, dose rate).

7.1.2.3.3 *Radioactive-material receipt and accountability.* The educational institution is required to develop, implement and maintain written procedures for surveying and safely opening packages in accordance with the regulations [NRC, 10 CFR 20.1906]. The educational institution is required to have in place an accountability and control system for detecting losses of licensed material. Transfer of licensed radioactive material to another institution or entity cannot be made by the licensed institution without first obtaining written verification that the other institution or entity is licensed or otherwise approved to receive and possess the radioactive material. Certain quantities of radioactive material may require that enhanced security measures be put in place (Section 7.1.3).

7.1.2.3.4 *Radiation dose controls*. The educational institution is required to keep radiation doses to individuals below the regulatory limits. In addition, the institution is required to perform an evaluation of the radiation dose that an individual working with radiation sources or radioactive material is likely to receive. This prospective evaluation is done to determine whether the institution is required to provide personal radiation monitoring to a specific individual or category of worker [NRC, 10 CFR 20.1502]. The educational institution is also required to ensure, either by calculation or direct measurement, that licensed material will be used, transported, stored and disposed in such a way that members of the public will not receive effective doses exceeding 1 mSv y^{-1} (100 mrem y^{-1}) [NRC, 10 CFR 20.1301], and the dose received in any unrestricted area will not exceed 0.02 mSv (2 mrem) in-any-one-hour from licensed operations [NRC, 10 CFR 20.1302]. And, to the extent practical, the institution must use procedures and engineering controls based upon sound radiation protection practices to make sure all radiation exposures are consistent with the ALARA principle.

7.1.2.3.5 *Personal radiation monitoring.* Regulatory authorities typically require personal radiation monitoring if an individual is likely to exceed 10 % of the annual occupational dose limit [NRC, 10 CFR 20.1502(a)(1) and (2)]. Personal radiation monitors for external radiation dose are often called personal dosimeters or radiation badges. These radiation badges are worn by radiation workers to measure doses to the whole body, skin, and lens of the eye (*e.g.*, using chest badges or collar badges). Special ring badges or wrist badges are worn to measure dose to a radiation worker's extremities. NRC requires that personal dosimeters (other than those used for measuring dose to extremities) that require processing to determine the radiation dose be processed and evaluated by an accredited dosimetry processor [NRC, 10 CFR 20.1501(c)]. A radiation worker's internal radiation dose may be monitored by using a personal air monitoring system to measure the concentration of radioactive material in the air the radiation worker is breathing. If a radiation worker is believed to have taken in radioactive material, either by inhalation, ingestion, absorption, or wound entry, the worker's internal radiation dose is calculated from knowing how much radioactive material is in the worker's body, where it is, how it got there, and how long it has remained in the body. The quantity of internal radioactive material that emits gamma radiation may be measured by direct counting of the radiation worker's whole body or external counting of the worker's thyroid. Another method of measuring internal radioactive material, called bioassay, measures the quantity of radioactive material in a biological sample (*e.g.*, urine). Educational institutions that are licensed for small quantities of radioactive material very likely will not be required to have a personal radiation monitoring program. Any personal radiation monitoring that requires internal dose measurements and calculations *should* be done by a qualified expert.

7.1.2.3.6 *Safe use of radioactive material*. The educational institution is required to develop and maintain written procedures for the safe use of licensed radioactive material. The institution is responsible for the security and safe use of all licensed radioactive material from the time it arrives at the institution until it is transferred or properly disposed. The written procedures *should* provide reasonable assurance that only appropriately trained personnel will handle and use licensed material and should also include operational and administrative procedures. The following elements *should* be included in the written procedures:

- definition of responsibilities;
- measures for control of radioactive contamination;

- proper handling and disposal of radioactive waste;
- personal and area radiation monitoring;
- requirements for and use of protective clothing, shielding, and other safety equipment;
- requirements for room posting and container or equipment labeling;
- radionuclide-specific procedures based on the hazards associated with the radionuclides and their physical and chemical forms;
- requirements for radioactive-material security;
- record-keeping requirements; and
- requirements to report information to NRC or the state authority.

7.1.2.3.7 *Emergency procedures*. The educational institution is required to develop and maintain written procedures for response to emergencies involving licensed radioactive material. These written procedures *should* describe how to handle events ranging from a minor spill of radioactive material to a major accident that may require intervention by outside emergency response personnel. These procedures *should* describe provisions for immediate response, after-hours notification, handling of each type of emergency, equipment, and the appropriate roles of users and the radiation safety staff. The institution's staff *should* have a clear understanding of its role in an emergency with step-by-step instructions and clear directions on whom to notify. NCRP Report No. 111 (NCRP, 1991) provides generic guidance for developing emergency procedures.

7.1.2.3.8 *Radiation surveys*. The educational institution is required to conduct radiation surveys to evaluate radiological conditions and potential hazards in its workplace. These surveys may be measurements (*e.g.*, radiation levels measured with survey instruments or results of tests for removable contamination), calculations, or a combination of measurements and calculations. Sealed radioactive sources possessed by the institution are required to be tested on a required frequency to determine whether there is any radioactive material leaking from the sealed sources. The regulatory agency (NRC or the state) will evaluate whether the institution selects and properly uses the appropriate survey instruments to accurately assess the radiological conditions. The regulatory agency will also determine the acceptable frequency for leak testing of sealed sources.

7.1.2.3.9 *Transportation of radioactive material*. Educational institutions that will transport or ship licensed material, including radioactive waste, are required to develop, implement and maintain safety programs for transport of radioactive material to ensure compliance with NRC [10 CFR 71] or state authority, and DOT (2006) regulations. An educational institution using vehicles on public roads to transfer radioactive material between its own buildings is required to meet these transportation regulations.

7.1.2.3.10 *Minimization of radioactive contamination*. When designing or evaluating an area for unsealed radioactive-material use, the educational institution *should* consider the following items to minimize radioactive contamination:

- implementation of and adherence to good radiation safety practices in operations;
- minimization of areas, to the extent practical, where radioactive material is used and stored;
- maximization of the frequency of radiation surveys, within reason, to minimize the spread of contamination in the event of a spill;
- choice of radioactive material to be used, whenever practical, with consideration of the type of radiation emitted and its half-life, and the chemical composition of the material;
- appropriate filtration of effluent streams;
- use of nonporous materials for laboratory bench tops, flooring, and other surfaces;
- use of disposable absorbent and impermeable laboratory bench coverings or cleanable trays to reduce the spread of contamination and to simplify its cleanup;
- ventilation stacks and ductwork with minimal lengths and minimal abrupt changes in direction to minimize probability of depositing the radioactive effluents on the inside of ductwork;
- use of appropriate plumbing materials with minimal pipe lengths and traps; and
- minimization of the number of disposal sites (sinks) for liquid radioactive waste.

7.1.2.4 *Radioactive Waste Management*. Radioactive waste is commonly generated when conducting licensed activities. Such waste may include unneeded sealed sources, used or unused unsealed radioactive material and unusable items contaminated with radioactive material (*e.g.*, absorbent paper, gloves). The educational institution is required to establish a program for proper management and disposal of radioactive waste. The program is required to include procedures for handling, safe and secure storage, characterization, minimization, and disposal of radioactive waste. All radioactive waste is required to be stored in appropriate containers until its disposal and the integrity of the waste containers is required to be ensured. Radioactive waste containers are required to be appropriately labeled. All radioactive waste is required to be secured against unauthorized access or removal. Licensees may not receive radioactive waste from other licensees for processing, storage or disposal, unless specifically authorized to do so by NRC or the Agreement State.

Typically, educational institutions manage radioactive waste generated at their facilities by the following four methods: decay-in-storage, release into the sanitary sewer, transfer to an authorized recipient, and disposal allowed for specific radioactive waste.

7.1.2.4.1 *Decay-in-storage.* This radioactive-waste disposal method consists of storing the waste in a secure location for enough time to allow all of the radioactive material to decay below detectable levels. Most radioactive-material licenses include a license condition with specifications (such as surveying the waste before disposal as ordinary trash) that the licensee is required to meet for disposal of radioactive waste by decay-in-storage (License Item 20 in Figure 7.1). In 2005, NRC changed its decay-in-storage requirements to allow this disposal method for radioactive material with half-lives ≤120 d and to no longer require that the waste be held at least 10 half-lives (NRC, 2005c).

7.1.2.4.2 *Release into sanitary sewer.* Liquid radioactive waste may be released into the sanitary sewer system if certain concentration, total quantity, and solubility requirements are met. NRC [10 CFR 20.2003] lists the NRC requirements. The educational institution using this disposal method must also meet any state or local requirements for sanitary-sewage disposal of radioactive material and hazardous materials.

7.1.2.4.3 *Transfer to an authorized recipient*. Radioactive material may be transferred only if the recipient is authorized to receive and possess the type and quantity of radioactive material [NRC, 10 CFR 30.41]. For disposal of sealed sources, including those possessed under a general license, the manufacturer of the sealed source or the equipment containing the sealed source may take the sealed source back for a fee, and may provide service to remove the source and ship it back to its manufacturing facility. The educational institution is still required to confirm by reviewing written certification, which can be provided by the manufacturer, that the manufacturer is authorized to receive the source. Radioactive waste may only be transferred to a radioactive-waste disposal facility licensed to accept that type of radioactive waste. Many licensees utilize the services of a company, known as a radioactive-waste broker, which provides packaging, transportation, waste processing, and ultimate disposal. All licensees should carefully evaluate a radioactive waste broker's capability and compliance record in providing its advertised services.

7.1.2.4.4 *Disposal allowed for specific radioactive waste*. Specific types of radioactive waste containing small concentrations of ^{3}H or ^{14}C may be disposed by NRC licensees as if they were not radioactive [NRC, 10 CFR 20.2005]. State licensees should verify that their state regulations allow this method of disposal before utilizing it.

Some of the radioactive waste may also contain additional hazardous materials (*e.g.*, biohazard or chemical hazard). Such waste is called mixed waste, and its storage and disposal is required to comply also with EPA (1989) and all other applicable federal, state and local regulatory requirements. For instance, mixed waste containing certain types of chemical waste is required to be shipped for disposal within 90 d, which may not allow the full time needed for decay-in-storage. Educational institutions will find that disposal of radioactive waste that cannot be held for decay-in-storage, and in particular mixed waste and some sealed sources, can be expensive. NCRP Report No. 143 (NCRP, 2003b) provides guidance on minimizing the volume and activity of low-level radioactive and mixed waste that are generated and that require disposal.

7.1.2.5 *Record Keeping*. The educational institution is required to maintain records of various aspects of its radiation safety oversight program. These records must contain specific information that depends on the nature of the radioactive material, be maintained for specific periods of time and be made available for inspections by NRC or the state. NCRP Report No. 114 (NCRP, 1992) provides guidance in establishing appropriate maintenance of radiation safety program records. An example of NRC record-keeping requirements can be found in Appendix X of NRC (2005a).

7.1.3 *Security of Radioactive Material*

Security of radioactive material is an important aspect of radiation safety. The intent of security measures is to avoid the inadvertent loss of control of radioactive material and to prevent exposures or contamination. Incidents involving the deliberate use of radioactive sources to cause harm have been remarkably few to date.

The events of September 11, 2001 and the subsequent discovery that terrorist organizations have considered use of a radiological dispersal device, commonly called a dirty bomb (*i.e.*, a device that uses conventional explosives to disperse radioactive material), have caused a rethinking of security of radioactive material. In particular, security requirements now address the possibility of deliberate theft or diversion of radioactive material to cause harm or widespread panic and the willingness of persons to risk injury and death to themselves in doing so.

Security measures for use of radionuclides should address two aspects. First, prior to obtaining a radionuclide, the user should incorporate security considerations into planning for its use and storage. Second, the level of security should be consistent with potential risk associated with the radionuclide and its use. Levels of security can range from access controls typical for research laboratories containing other hazardous materials to specific security systems designed to limit access and continuously monitor the control of higher-risk radioactive-material sources.

Security systems designed for higher-risk radioactive-material sources, by their very nature, cannot provide complete protection against theft, diversion or attack. The basic design of these security systems is to deter access, detect unauthorized access, delay removal of the source, and defend against source removal. The most effective security is provided by a layered, integrated system that provides multiple barriers to lessen the possibility of theft, diversion or attack. An integrated system provides barriers at each stage of such a source's life cycle (*i.e.*, from "cradle to grave").

7.1.3.1 *Security Groups*. The International Atomic Energy Agency (IAEA) categorizes radioactive sources for the purpose of assigning them to Security Groups (IAEA, 2003a).[9] NRC has adopted the IAEA categorization scheme (NRC, 2006d). The Security Groups, source categories, and examples that might be encountered in small educational institutions are listed in Table 7.1. The threshold

[9]IAEA has also published guidance for implementing security measures (IAEA, 2003b).

activities for a number of common radionuclides that would place a radioactive source in Security Group D are listed in Table 7.2.

A source with an activity less than the threshold activity for Security Group D does not need security measures beyond regular good radiation safety practices. However, prudent radiation safety procedures should include more than just minimum security. A risk-based approach *should* be taken to establish reasonable security requirements for low-activity radionuclides typically licensed for use at educational institutions. Farley *et al*. (2003) developed such a scheme that takes into account the radionuclides in use, their quantities, and their physical form to determine the appropriate level of security.

TABLE 7.1—*IAEA categories for radioactive sources for the purpose of assigning them to Security Groups.*

Security Group[a]	Source Category[b]	Examples
A	1	Self-shielded irradiators
B	2 and 3	Neutron sources
C	4	Portable gauges; Static eliminators
D	5	X-ray fluorescence devices; Electron-capture devices; Self-luminous exit signs

[a]Recommended security for each group [IAEA (2003b)]:

Security Group A: Measures should be established to deter unauthorized access, and to detect unauthorized access and acquisition of the source in a timely manner. These measures should be such as to delay acquisition until response is possible.

Security Group B: Measures should be established to deter unauthorized access, and to detect unauthorized access and acquisition of the source in a timely manner.

Security Group C; Measures should be established to deter unauthorized access and verify the presence of the source at set intervals.

Security Group D: Measures should be established to ensure safe use of the source and adequately protect it as an asset, verifying its presence at set intervals.

[b]General description of each source category [IAEA (2003a)]:

Source Category 1: Personally extremely dangerous if not safely managed or securely protected.

Source Category 2: Personally very dangerous if not safely managed or securely protected.

Source Category 3: Personally dangerous if not safely managed or securely protected.

Source Category 4: Unlikely to be dangerous.

Source Category 5: Not dangerous.

TABLE 7.2—*Threshold activities for a number of common radionuclides that would place a radioactive source in Security Group D.*

Radionuclide	Security Group D Threshold Activity [GBq (Ci)][a]	
^{241}Am (including AmBe)	0.6	(0.016)
^{109}Cd	200	(5.4)
^{57}Co	7	(0.19)
^{60}Co	0.3	(0.0081)
^{137}Cs	1	(0.027)
^{55}Fe	8,000	(220)
^{3}H	20,000	(540)
^{125}I	2	(0.054)
^{131}I	2	(0.054)
^{192}Ir	0.8	(0.022)
^{85}Kr	300	(8.1)
^{99}Mo	3	(0.081)
^{63}Ni	600	(16)
^{32}P	100	(2.7)
^{103}Pd	900	(24)
^{147}Pm	400	(11)
^{210}Po	0.6	(0.016)
PuBe	0.6	(0.016)
^{226}Ra	0.4	(0.011)
^{75}Se	2	(0.054)
^{90}Sr (^{90}Y)	10	(0.27)
^{99m}Tc	7	(0.19)

[a]The values given in gigabecquerel (GBq) (G = 10^9) are from IAEA (2003a). Conversion of gigabecquerel to curie (Ci) was made using the following relationships: 1 Ci = 37×10^9 Bq = 37 GBq; and 1 GBq = 0.027 Ci. For example: 200 GBq = 5.4 Ci; 0.3 GBq = 0.0081 Ci.

Most high schools, small colleges, and universities will have only Security Group D and lower-risk radioactive sources. However, some colleges and universities and a few high schools may still have self-shielded irradiators (Security Group A) and neutron sources (Security Group B) received during the 1950s and 1960s through programs sponsored by the U.S. Atomic Energy Commission. Sources in Security Groups A and B require security measures beyond those discussed in this Report. Institutions possessing such sources should consult with their licensing agency for specific information on current security requirements.

7.1.3.2 *Security Measures*. Security measures may be taken by a combination of administrative and technical actions that integrate safety and security through normal institutional safety arrangements, radiation protection procedures, and appropriate equipment and facility design to meet the security objective. *Administrative actions* are policies, procedures, and established practices that personnel are expected to follow to safely and securely manage radioactive sources. *Technical actions* typically provide barriers to the access of sources by separating the source from unauthorized persons and deterring unauthorized access. Administrative actions support and supplement technical actions.

Examples of security measures that are most applicable to educational institutions are:

- posting signs and limiting access consistent with actions taken by laboratories containing chemical or biological material;
- requiring access controls such as locks on doors, cabinets, refrigerators and containers holding radioactive sources;
- training users and other individuals with access to the secured area in their security responsibilities;
- limiting and controlling access and keys;
- providing surveillance during use;
- ensuring radioactive material is returned to secured storage after use; and
- requiring periodic inventory and record keeping.

The RSO *should* coordinate with the educational institution's security program in establishing appropriate security measures.

Institutional security measures for radioactive sources, especially higher-risk sources (Security Groups A, B and C), may require modification to take into account local and temporal factors such as:

- changes in national security threat levels;
- security advisories and orders issued by the licensing or other agency having jurisdiction;[10]
- license requirements; and
- factors unique to the facility or circumstances of use, transport or storage of the source (*e.g.*, aggregation of sources at one location).

7.1.3.3 *End-of-Life Security for Higher-Risk Sources*. Unique security concerns arise when a higher-risk source reaches the end of its working life or is otherwise no longer wanted. Options for disposal of such sources are limited and the disposal costs can be high. As a result, many used sources are being put on sale in the second-hand market. While recycling of higher-risk sources is desirable and encouraged (by among others, IAEA), such sources become more vulnerable to diversion. The educational institution's responsibility to ensure appropriate control and security for higher-risk sources continues when the sources are no longer used, and disposal of these sources *should* occur soon after the sources are no longer of use to the educational institution.

NRC and the Agreement States request information on disposal plans when reviewing license applications. Acceptable options include returning a higher-risk source to the manufacturer, disposal to a radioactive-waste broker or licensed radioactive-waste disposal site, or transfer to another authorized licensee. Educational institutions must understand that they continue to have security responsibility and will eventually pay for disposal costs when a higher-risk source is no longer needed.

Return to the manufacturer is not a guaranteed disposal option. Manufacturers can go out of business or change their policies for accepting used higher-risk sources. Most manufacturers will not accept used sources made by other manufacturers. Even if this option is available, there may be a substantial cost, especially if the user is not trading in the higher-risk source for a replacement source.

Radioactive-waste brokers may accept a higher-risk source only if they are authorized and if they are able to transfer it to another licensee or properly dispose the source. There will be charges for

[10]NRC issued License Orders to licensees, including academic institutions, possessing radioactive-material quantities of concern requiring implementation of additional security measures, called increased controls (NRC, 2006e).

this disposal service, as well as for preparation and shipping. The costs for these services are often substantial and may exceed the original cost of the source or device containing the source.

Disposal to a commercial low-level radioactive waste site is an option constrained state-by-state according to restrictions imposed by low-level radioactive waste disposal compacts (LLRWPAA, 1985) and by disposal facility license conditions. Furthermore, radioactive sources classified as greater than Class C low-level radioactive waste cannot be disposed in commercial waste disposal sites [NRC, 10 CFR 61.55(a)(2)]. Instead, limited options for greater than Class C sources are available in the form of recovery and storage by the U.S. Department of Energy and recycling of these sources (LANL, 2006).

In many cases when confronted with these limitations, licensees choose to place their higher-risk sources into extended storage. Extended storage of radioactive sources at facilities not originally intended for this purpose increases the chance that source security will be forgotten and increases the risk of theft or other loss of control.

Because of these issues associated with higher-risk sources that are no longer needed, high school, college and university administrators should know if they currently possess this type of source, and should be aware that long-term storage of these unwanted sources is not recommended and that reselling of the sources can be problematic. The administrators should carefully review and accept responsibility for all these issues before deciding to procure a higher-risk source. Accordingly, they should plan and provide in advance for the costs of disposing higher-risk sources when no longer needed.

7.1.3.4 *Consideration of Alternative Technologies*. Administrators, teachers and staff of educational institutions should examine the availability of alternatives to the currently used radioactive-material sources. Alternative technologies can minimize, and in some cases avoid, the radiation safety and security issues associated with a radioactive-material source, especially those for higher-risk sources. Examples of alternative technologies are:

- a different type of ionizing-radiation source (*e.g.*, machine-produced radiation versus radiation from a radioactive source);
- a different type of radiation (*e.g.*, imaging systems based upon nonionizing radiation instead of those based on ionizing radiation);

- a radioactive source having different ionizing-radiation characteristics that makes disposal easier (*e.g.*, one having a shorter half-life or falling into a lower low-level waste disposal classification);
- a radioactive source having different physical attributes that reduce potential consequences if control of the source is lost (*e.g.*, in a nondispersible form such as a solid metal versus a soluble salt or dispersible powder);
- a nonradioactive tracer in selected applications such as biomedical research in lieu of radioactive tracers (*e.g.*, using digoxigenin-labeled probe versus ^{32}P-labeled probe);
- a radioactive source having different physical attributes that facilitate safe handling (*e.g.*, less energetic beta particles such as using ^{33}P instead of ^{32}P); or
- an alternative technology (*e.g.*, use of a battery backup or a capacitor discharge system on an electrically-powered exit sign instead of using a tritium exit sign).

7.2 Ionizing Radiation-Producing-Machine Program

The acquisition (whether through purchase or as a gift) of an ionizing radiation-producing machine should be a well-coordinated and planned activity. The first step in the program is to determine what safety and regulatory requirements will be associated with possessing and using the device or machine. This is equally true whether the machine is a particle accelerator, a diagnostic or therapeutic x-ray machine, a cabinet x-ray unit, an electron-beam microscope, an x-ray diffraction unit, an industrial-type x-ray unit, or any other device or machine that can produce x rays or ionizing particles when it is energized.

Some things that should be considered when planning to obtain such equipment are:

- the expense of putting the system into operation, especially if it is used equipment that has been removed from another facility. When systems are moved, components can be damaged, wires can be cut, and safety features such as shielding can be removed or damaged;
- the expense and planning of facilities for housing and using the equipment. Electrical and shielding requirements can be expensive, and, depending on the location, shielding needs can be extensive;
- specialty staff required to operate the equipment;
- additional specialty equipment (such as x-ray film processors) that may be needed to support use of the system; or

- equipment that produces radioactive material as a byproduct of its operation, or contains other hazardous materials (*e.g.*, asbestos or mercury). Such materials can have additional requirements for staffing, handling and housing and could be expensive to deal with and dispose properly.

If there is not a qualified expert on staff who can advise the institution regarding the safety and regulatory requirements associated with the possession and use of the device or machine the institution is acquiring, an outside qualified expert *should* be consulted regarding these requirements. If the educational institution does not have a qualified expert on staff and does not know how to find an outside qualified expert, it can contact the state radiation control program for assistance in identifying such an individual. The CRCPD website (CRCPD, 2006) maintains a current list of radiation control program contacts for each of the states, the District of Columbia, and some of the territories of the United States. The CRCPD website also provides information regarding radiation protection for x-ray systems in the healing arts (CRCPD, 2001), analytical x-ray equipment (CRCPD, 1991a), and particle accelerators (CRCPD, 1991b) in its *Suggested State Regulations for Control of Radiation*.

Since the possession and use of ionizing radiation-producing machines are usually regulated by an agency of the state in which the institution is located, the management *shall* contact the state radiation control program or a qualified expert to determine the requirements for registration or licensing of the machines or devices that will be acquired. Although most states do not require registration of the machine or device until the unit is in operation, some states may require registration prior to operation for some ionizing radiation-producing machines or devices. Also, some states require that the facility shielding design be submitted for approval prior to the start of construction and installation of the equipment. The state radiation control program or the qualified expert can provide the institution with that information.

An ionizing radiation-producing machine program *should* be in place prior to beginning the operation of the machine or device. As a minimum, this program *should* be described in writing and *should* include:

- radiation exposure monitoring of faculty, staff and students, as required;
- initial and periodic radiation safety training for individuals using the machine or device;

- initial and periodic radiation surveys;
- maintenance of the machine or device;
- radiation safety records maintenance;
- posting of radiation areas and other required postings and labeling;
- in some circumstances, the use and testing of interlock systems and warning signals;
- procedures and training for the safe use of machines, devices and materials;
- final safety review and radiation survey of the equipment and facility prior to initial operation; and
- a list of actions that *shall not* be done (*e.g.*, bypass of interlocks) with the system or facility.

Once an ionizing radiation-producing machine program is implemented, the management of the institution *shall* require strict adherence to the program and provide continuing oversight of the program by the designated RSO to ensure that each machine or device is operated safely and in accordance with all applicable regulations.

Caution has to be exercised when considering the acceptance of donated ionizing radiation-producing machines or devices. The management of the educational institution *should* determine before accepting the piece of equipment that it can be legally operated and that its subsequent disposal will not be subject to excessive costs due to the presence of polychlorinated biphenyls or other hazardous materials. The qualified expert can advise the institution regarding these issues.

7.3 Nonionizing-Radiation Safety Program

Nonionizing radiation refers to the portion of the electromagnetic spectrum that includes UV, visible, infrared, microwave, radiofrequency, and extremely-low-frequency radiation. Static electric and magnetic fields are also often included in radiation safety programs, but are not covered in this Report. Exposures to some nonionizing-radiation sources can result in immediate and obvious biological effects, such as accidental burns from exposure to a powerful research laser or "sunburn" from unshielded and excessive exposure to an UV light source. While research continues on other nonionizing radiations, the current weight of evidence does not indicate there are adverse health effects from radiofrequency or microwave exposure levels that are within regulatory guidelines (ICNIRP, 1998; IEEE, 2005a; NCRP, 2003c; NRPB, 2004). Some nonionizing-radiation sources can affect electronic systems, such as computer screens or computer data storage systems or medical devices, which can result in effects ranging from a nuisance to a medical emergency. Nonionizing-radiation exposure standards are reviewed periodically and protection strategies are adopted or refined to ensure the safe uses of nonionizing-radiation sources.

As with ionizing radiation, educational institutions using nonionizing radiation-producing equipment *should* obtain the advice of qualified experts when determining if nonionizing-radiation safety programs are effective and in compliance with all applicable regulations. Regulatory authority over various nonionizing radiations resides with OSHA (1996c) or states with OSHA-approved State Plans for occupational exposures, and with the Federal Communications Commission (FCC, 2000) for environmental exposure control. Institutions *should* follow the safety instructions provided by the manufacturer for each nonionizing source and the safety protocols established by standard-setting organizations, such as the American National Standards Institute (ANSI) and the Institute of Electrical and Electronics Engineers (IEEE). Additional organizations such as NCRP and the International Commission on Non-Ionizing Radiation Protection (ICNIRP) publish nonionizing-radiation safety recommendations.

This Section on nonionizing-radiation safety programs is included to provide an educational institution general information on examples of nonionizing-radiation sources the institution may possess and safety programs for these sources. The information is not intended to be inclusive. Additional resources for information on various types of nonionizing-radiation safety programs include: CRCPD website with links to example programs (CRCPD, 2003); IEEE recommendations for a radiofrequency safety program (IEEE, 2005b); New Jersey Department of Environmental Protection Nonionizing Radiation Section website (NJDEP, 2007b); NCRP Report No. 119 (NCRP, 1993b); and OSHA website on nonionizing radiation (OSHA, 2007b).

7.3.1 *Common Sources*

Various types of nonionizing-radiation sources are listed below.

- *Lasers* are nonionizing-radiation devices that emit UV, visible or infrared radiation. Lasers are used throughout medicine, research, and in consumer products. Compact disc players, laser pointers, and laser light shows are examples of products or activities that employ lasers. Examples of medical lasers are laser devices used in surgery and in the treatment of certain skin disorders. Lasers are also used in the biological sciences, physics and chemistry; some of these lasers can be extremely powerful. All departments may use laser pointers, and art and theater departments may use lasers in light shows.

- *UV sources* may be found in sterilization facilities, industrial coating applications, devices such as tanning booths, and lighting sources. Biological sciences, engineering and art departments may use UV radiation sources. Mercury vapor lamps used in lighting gymnasiums and sports fields emit UV radiation and are manufactured or enclosed in a lighting fixture with UV shielding.
- *Microwave sources* are used in ovens for cooking, sterilization applications, chemical digestion processes, and devices used in physics and electronics research and development. Microwave antennas emit and receive microwave radiation in wireless communications systems.
- *Radiofrequency sources* are used in many areas of communication, such as cellular towers and phones, and radio and television transmitters. High-intensity radiofrequency radiation is emitted in some heaters, sealers, and dryer devices used in manufacturing plastic, wood, paper and textile materials. There are also other devices that generate very low levels of radiofrequency energy during the course of their operation although these devices are not intentionally designed to generate or emit radiofrequency energy (*e.g.*, direct-current motors, mechanical light switches, fluorescent lights, television or computer cathode-ray-tube displays, equipment with a switching power supply).

7.3.2 *Elements of a Safety Program*

Educational institutions that use nonionizing-radiation sources *should* have a nonionizing-radiation safety program designed to ensure that:

- all uses of nonionizing-radiation sources are conducted in a manner that protects the health and safety of the user, other employees and members of the public;
- the program evaluates all nonionizing-radiation sources to ensure protection of personnel;

- a safe working environment is provided that is in compliance with applicable regulations and institutional policies or guidelines; and
- proper registration is made for all equipment as required by the cognizant state regulatory authority.

Nonionizing-radiation safety programs (Glaser, 1992; IEEE, 2005b) have the same general requirements as those of an ionizing-radiation safety program, namely:

- ensure well-defined written policies and procedures for the safe use of nonionizing-radiation sources of concern;
- limit uses to those that are approved by the regulating authority;
- provide equipment and facilities to adequately protect health and minimize danger to life and property;
- limit users to individuals who are qualified by training and experience to use the nonionizing-radiation equipment safely;
- ensure that regulatory requirements are met;
- provide adequate training for individuals approved to operate nonionizing radiation-producing equipment;
- provide qualified technical evaluations of the nonionizing-radiation safety program periodically and advice to administration on the adequacy of the program and any corrective actions needed;
- provide documentation of the effectiveness of the nonionizing-radiation safety program and compliance with rules, regulations, and good safety practices; and
- provide prompt reviews of all instances of alleged infractions of good safety practice or injury from the use of nonionizing-radiation equipment, and implement appropriate corrective actions.

Some of the considerations that would go into an evaluation of a nonionizing-radiation safety program are similar to the considerations for a laser safety program (Section 7.3.3).

7.3.3 *Laser Safety Program*

Lasers can be found at all types of educational institutions. Most of these lasers will be totally contained within equipment and therefore not capable of causing harm (*e.g.*, a compact disc or digital video-disc player) or will not cause harm by employing simple controls (*e.g.*, a laser pointer). The hazard from and level of control needed for a laser depends on its capability of causing harm, the environment in which it is used, and the personnel who use the laser or may be exposed to the laser radiation (ANSI, 2000a). Educational institutions may use lasers in classrooms, teaching laboratories, science fairs or projects, auditorium demonstrations, outdoors, or for entertainment activities (ANSI, 2000a). The hazards presented by use of certain lasers may require an educational institution to establish a formal laser safety program and appoint a laser safety officer. This Report includes general discussion of a laser safety program to provide an example of a nonionizing-radiation safety program. More details for the safe use of lasers in an educational institution can be found in ANSI Standard Z136.5 (ANSI, 2000a). Regulatory control of lasers can vary from state to state, and the educational institution is required to meet the regulations that apply to its use of lasers. Some states have adopted the CRCPD suggested state regulations that apply to lasers (CRCPD, 2005b).

In the management of a safety program for lasers, the following factors should be considered (Edwards, 2002; Edwards *et al.*, 2002; 2003; Lewandowski and Hinz, 2005; Lewandowski *et al.*, 2004):

- What type of laser is being used?
- What class of laser is being used?
- What wavelength is the laser emitting?
- What is the power at the given wavelength?
- Is the laser operated in a continuous wave or pulsed mode?
- If it is pulsed, what is its repetition rate and pulse duration?
- Are warning signs and interlocks indicated; if so, are they provided and used?
- Are the laser and its beam enclosed to ensure no human contact with the beam?
- Are enclosures and safety curtains adequate (for protection from both the direct beam and any reflections)?
- Is appropriate eye protection provided and used as indicated?
- Have all users been properly trained?
- Are there other hazards in addition to the laser beam (*e.g.*, high voltages, potential for fire, potentially dangerous fumes, and confined spaces)?
- Does operation of the laser create other hazards (*e.g.*, UV radiation or x rays)?
- Are appropriate actions taken to protect from these other hazards?

- Are there emergency-off switches for electrical power supplies?

7.3.3.1 *Classifications*. Lasers are classified according to their hazard potential. The classification is based on energy output accessible to an individual during normal operation or maintenance (ANSI, 2000b; Classic, 1992; FDA, 2006d; LIA, 1989), as given below:

- *Class 1* lasers are incapable of producing biological effects under normal operating conditions, and no safety requirements are necessary (this does not apply to embedded Class 3b or 4 lasers that are Class 1 during normal operation but 3b or 4 during maintenance or beam alignment). The Class 1 accessible emission limit (AEL) for continuous-wave (CW) lasers ranges from 4×10^{-4} to 100 mW depending on wavelength emitted. For example, the maximum AEL for CW lasers in the visible wavelength range is 0.4 mW.
- *Class 2* lasers include only those emitting in the visible (400 to 700 nm) wavelength range. Those systems intended for a specific use where the output is NOT intended for viewing belong in Class 2a. Lasers in Class 2a are similar to Class 1 in hazard potential, provided the accessible radiation does not exceed the Class 1 AEL for an exposure duration of 10^3 s. Class 2 lasers have an AEL for CW at 1 mW, or if the laser is continuously pulsed, it can emit accessible radiation exceeding the Class 1 AEL for no more than 0.25 s duration.
- *Class 3* lasers, in general, have emissions greater than Class 1 but <500 mW. However, the classification is dependent on wavelength and exposure duration. Two subclasses of Class 3 lasers exist:
  - *Class 3a* lasers are those that have accessible output power up to five times the Class 1 AELs for wavelengths in the invisible wavelength range (<400 or >700 nm), or up to five times the Class 2 AELs for wavelengths in the visible wavelength range (400 to 700 nm).
  - *Class 3b* represents all other lasers with accessible output power greater than Class 1 but <500 mW.
- *Class 4* lasers have the highest hazard level and include CW lasers with accessible output power levels >500 mW.

7.3.3.2 *Safety Considerations*. Manufacturers are required to classify lasers based on maximum accessible output emissions prior to sale. However, modifications of the unit can affect the output and might require reclassification. Some of the particular safety considerations with laser usage are given below.

- *Eye damage*: Biological effects in the eye depend on the wavelength of the laser beam and the amount of energy absorbed by the structure of the eye. The retina absorbs visible and near-infrared wavelengths (400 to 1,400 nm). Radiation that passes through the lens is focused, like sunlight passing through a magnifying glass. When it impinges on the retina, its energy concentration has increased by roughly 100,000 times. The blue light region includes wavelengths in the 400 to 500 nm range. Long-term exposure to these wavelengths poses a significant retinal hazard. The cornea absorbs middle-UV (200 to 315 nm) and far-infrared (3,000 to 10^6 nm) wavelengths, causing risk of photokeratitis. Near-UV (315 to 400 nm) and middle-infrared (1,400 to 3,000 nm) wavelengths penetrate further, to the lens of the eye. These wavelengths may contribute to the production of cataracts (OSHA, 1999). Laser users and all personnel in the laser environment *shall* wear the appropriate protective eyewear. ANSI (2000a) recommends that faculty, staff and students who work directly with a Class 3b or 4 laser or laser system on a continuing basis undergo medical surveillance.
- *Skin burns*: Some lasers are capable of causing skin burns. Depending on the laser's capability of harming the skin, controls *should* be in place to limit or prevent skin exposure time.
- *Airborne contaminants*: Products used for laser operations and airborne contaminants (smoke plumes) created by laser interactions are potentially hazardous to the user and other individuals in the immediate area. OSHA has set permissible exposure limits for the allowable concentration of these contaminants (NIOSH, 1978). Smoke evacuation equipment capable of filtering particles down to 0.1 μ diameter is necessary during any procedure where smoke plumes might ensue from the laser procedure.
- *Electrical*: The electrical systems associated with Class 4 lasers are potentially hazardous and can be lethal. Only qualified, specifically trained, authorized individuals *shall* repair and troubleshoot these electrical systems.
- *Fire*: A Class 4 laser can cause a fire if the beam interacts with flammable materials. Careful positioning of the laser is required prior to activation of the laser beam. Flammable

materials in the target area *should* be dampened prior to activating the beam.

7.3.3.3 *Precautions*. A listing of precautions in the use of lasers is given below. Additional guidance can be found in ANSI (2000b):

- *Signs*: Place appropriate warning signs (*i.e.*, Laser in Use) on the doors leading into the laser use area prior to laser usage.
- *Windows*: Cover windows in the laser use area with appropriate protective material prior to laser usage.
- *Fire extinguisher*: Provide an appropriate fire extinguisher in the laser use area before beginning laser usage.
- *Protective glasses*: Wear appropriate protective glasses (each person in the room). Note that lasers may operate at different wavelengths that can require different protective glasses.
- *Smoke evacuator*: Have an appropriate smoke evacuator operating before beginning laser usage.
- *Surfaces*: Use only nonreflective surfaces in the laser beam area.
- *Flammables*: Appropriately dampen all flammables in the target area before beginning laser usage.
- *Laser positioning*: Carefully position the distal end of the light guide in alignment with the target before placing the laser in the "ready" mode.
- *Operation*: Place the laser in "stand-by" mode at all times when it is not being used. Periodically, during the laser usage, make a visual inspection of the dials and mode indicators.
- *Post-use procedures:* When the laser is no longer in use, ensure that the laser is turned off, the target is removed from the beam line, electrical supplies are secured, supplies of gas and water are turned off as applicable, protective equipment is visually inspected for signs of accidental exposure, and the laser system is secured from unauthorized or accidental operation.

8. Check Lists for Responsible Administrator and Responsible Individual

The following check lists have been developed to assist the educational institution, and in particular the institution's responsible administrator (RA) and responsible individual (RI), review the needs and scope of their radiation safety program, and direct them to specific sections of this Report that may aid them in their review. An educational institution may choose to assign different radiation safety programs to different RAs and RIs, or may choose to assign all radiation safety programs to one RA and one RI, or any combination. Therefore, not all aspects of the following check lists may apply to one individual.

TABLE 8.1—*Responsible administrator check list.*

Item	Radioactive Material			Ionizing-Radiation Machines			Nonionizing-Radiation Machines		
	No	Yes	Section	No	Yes	Section	No	Yes	Section
1. Do you have any radiation sources?			4.1.1, 4.1.2, 4.1.4, 5.1.4, 4.2.1			4.1.2, 4.1.3, 4.1.4, 4.2.1			4.1.3.1, 7.3.1
2. Do you as the RA have the authority to provide disbursement of the necessary resources to the radiation safety program to ensure the safe use of radiation sources and regulatory compliance?			6.1			6.1			6.1
3. Do you know which regulatory authorities govern your use of radiation sources?			5.2, Table A.1			5.3, Table A.1			5.4
4. Do you know which regulations you must meet for each radiation source?			5.2			5.3			5.4
5. Do you have a license(s) and/or registration(s) for your use of radiation sources?			1, 5.2.9, Table A.1			1, 5.3, Table A.1			5.4

6.	Do you know the contents of the license(s) and/or registration(s) and of the corresponding application(s)?	7.1	7.2	7.3.2
7.	Do you know your responsibilities as the RA for a radiation safety program?	1, 2, 6.1	1, 2, 6.1	1, 2, 6.1
8.	Do you know who the RIs are?	6.2	6.2[a]	6.2[a]
9.	Does each RI have the proper qualifications and training?	6.2	6.2[a]	6.2[a]
10.	Does each radiation safety program:			
	a. Meet the requirements of the license and/or registration and provide assurance of compliance with the regulations?	5.2.8, 6.3, 7, 7.1	5.2.8, 6.3[a], 7	5.2.8[a], 6.3[a], 7, 7.3.3
	b. Provide adequate protection from radiation hazards?	3.1, 3.3, 7.1.2, Table A.2	3.1, 3.3, 7.1.2[a], Table A.2	3.2, 7.3.3.1, 7.3.3.2
	c. Ensure there is the required security for each radiation source?	7.1.3	7.2	7.3

TABLE 8.1—*(continued)*.

Item	Radioactive Material			Ionizing-Radiation Machines			Nonionizing-Radiation Machines		
	No	Yes	Section	No	Yes	Section	No	Yes	Section
d. Maintain control over radiation sources?			7.1.2.2, 7.1.2.4, Table A.2			7.1.2.2[a], 7.2, Table A.3			7.3.3.3
e. Establish and perform the operating and emergency procedures required by all regulatory authorities?			7.1.2			7.1.2[a]			7.3
f. Retain complete and accurate radiation safety records, and provide complete and accurate information to the regulatory authority required by the regulations?			7.1.2.5			7.1.2.5[a]			7.1.2.5[a]
11. Does the educational institution prohibit discrimination of employees engaged in protected activities, and provide information to employees regarding employee protection and deliberate misconduct?			7.1.2.1			7.1.2.1[a]			7.1.2.1[a]

12.	Does the educational institution provide adequate resources (including space, equipment, personnel, time, and, if needed, contractors) to the radiation safety program to ensure that the public and workers are protected from radiation hazards and compliance with regulations is maintained?	6.1	6.1	6.1
13.	Does the institution provide adequate assurance that decommissioning of radioactive-material use sites will be carried out with minimum impact on the public, occupational health and safety, and the environment by maintaining the required record keeping and, in the case of some licensees, submitting financial assurance information to the regulatory authority?	6.1, 7.1.2.4, 7.1.2.5, 7.1.3.3		
14.	Do you periodically review status of the radiation safety program(s) and items in the RI Check List with the assigned RI?	6.1, 7.1.1	6.1	6.1

TABLE 8.1—*(continued)*.

Item	Radioactive Material			Ionizing-Radiation Machines			Nonionizing-Radiation Machines		
	No	Yes	Section	No	Yes	Section	No	Yes	Section
15. Do you as the RA remain involved with your assigned radiation safety program and provide the educational institution assurance that radiation safety activities are being performed safely and all regulatory requirements are being met?			6.1			6.1			6.1

[a]Information may be applied, as applicable, to other radiation sources.

TABLE 8.2—*Responsible individual check list.*

Item	Radioactive Material			Ionizing-Radiation Machines	Nonionizing-Radiation Machines
	No	Yes	Section	Section	Section
1. Do you know you have been assigned as the RI for a radiation safety program and have you accepted that responsibility?			6.2	6.2	6.2
2. Do you have the basic technical knowledge and general understanding of the radiation sources, associated hazards, and safety procedures?			3, 6.2	3, 6.2	3, 6.2, 7.3
3. Do you know your radiation safety program responsibilities as the RI?			4, 5.2, 6.2, 7.1	4, 5.3, 6.2, 7.3	5.4, 6.2, 7.3
4. Do you have full access to activities involving radiation sources and do you have the authority to stop operations that you consider to be unsafe?			7	7	7[a]

TABLE 8.2—*(continued)*.

Item	Radioactive Material			Ionizing-Radiation Machines	Nonionizing-Radiation Machines
	No	Yes	Section	Section	Section
5. Do you know the details for answering all the questions in the RA's check list for your radiation safety program responsibilities?			6.2	6.2	6.2
6. Do you have sufficient time, resources and commitment from your educational institution to fulfill your radiation safety duties and responsibilities?			6.2, 7.1.1	6.2	6.2
7. Do you periodically review with your RA all the items in the RA's check list?			6.2	6.2	6.2
8. Do you as the RI conduct or oversee adequate reviews to ensure that radiation safety activities are being performed safely according to the educational institution's approved policy and procedures, and that all regulatory requirements are being met?			6.3, 7.1.2, 7.1.3	6.3, 7.2	6.3, 7.3

[a]Information may be applied, as applicable, to other radiation sources.

Appendix A

Additional Information on Radioactive Material and Radiation-Producing Equipment

TABLE A.1—*Summary of locations and types of radiation sources found in educational institutions and the associated levels of regulatory control.*

Locations	No License or Exempt	General License[a]	Specific License	Radiation Machine
Academic departments				
General	Faculty, staff or students as released nuclear medicine patients			
	Check sources			
	Gas lantern mantles (thorium)			
	Isogenerator (for half-life experiments) ($^{137}Cs/^{137m}Ba$)			
Agricultural and animal sciences	Fertilizers with concentrated natural radioactive material (TENORM – check local regulation)	Liquid scintillation counter with internal source (^{133}Ba)	Soil moisture (americium-beryllium) and density (^{137}Cs) gauges	X-ray diffraction unit or diffractometer

			Tracers in biological systems (*e.g.*, ^{3}H, ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{125}I)	Cabinet x-ray unit or other x-ray imaging equipment
History, art and media programs	Finished optical lenses (thorium)			
	Fiesta® dinnerware, Vaseline glass, depression glass (uranium or thorium)			
		Antistatic devices (^{210}Po)		
	Clays and firebrick with concentrated natural radioactive material			
	Welding rods (thorium or uranium)			
	Some photographic film, negatives and prints (thorium or uranium)			

TABLE A.1—*(continued)*.

Locations	No License or Exempt	General License[a]	Specific License	Radiation Machine
Biological sciences	Check sources (*e.g.*, ^{14}C, ^{22}Na, ^{90}Sr, ^{137}Cs, ^{60}Co)	Anti-static device for precision balances (*e.g.*, ^{210}Po, ^{241}Am)	Tracers in biological systems (*e.g.*, ^{3}H, ^{14}C, ^{32}P, ^{33}P, ^{35}S, ^{125}I)	Electron-beam microscope
		Liquid scintillation counter with internal source (^{133}Ba)	Irradiator using a radionuclide (sealed source) (*e.g.*, ^{60}Co or ^{137}Cs)	Cabinet x-ray unit or other x-ray imaging equipment
		Thorium or uranium used as stains with electron-beam microscope		Irradiator using x rays
Chemistry	Chemicals with concentrations of natural radioactive material	Electron capture detector (^{63}Ni) in gas chromatograph		X-ray diffraction unit or diffractometer
	Check sources	Anti-static device for precision balances (*e.g.*, ^{210}Po, ^{241}Am)		X-ray fluorescence unit
		Chemical mixtures containing ≤0.05 % uranium or thorium		Electron-beam microscope

		Liquid scintillation counter with internal source (^{133}Ba)		
		Thorium or uranium used as stains with electron-beam microscope		
Engineering	Some aircraft and missile counterweights (uranium)	Thorium or uranium used as stains with electron-beam microscope	Large anti-static source (^{85}Kr)	X-ray diffraction unit or diffractometer
	Some aircraft engine parts (thorium)		Particle-research tracers (^{46}Sc, ^{60}Co)	Electron-beam microscope
			Gamma transmission or diffraction units (^{60}Co, ^{137}Cs)	
Geological and earth sciences	Ores containing concentrations of natural radioactive material	Materials with <6.8 kg of uranium or thorium at one time	Soil moisture gauge (americium-beryllium)	Electron-beam microscope

TABLE A.1—*(continued)*.

Locations	No License or Exempt	General License[a]	Specific License	Radiation Machine
		Anti-static device for precision balances (*e.g.*, ^{210}Po, ^{241}Am)	Soil density gauge (^{137}Cs)	X-ray diffraction unit or diffractometer
		Thorium or uranium used as stains with electron-beam microscope	Well logging gauge (*e.g.*, (americium-beryllium, ^{137}Cs)	
Mathematics	Check sources			
	Isogenerator (for half-life experiments) ($^{137}Cs/^{137m}Ba$)			
Physics	Check sources	Thorium or uranium used as stains with electron-beam microscope	Neutron generating sources (*e.g.*, plutonium-beryllium source, americium-beryllium source)	X-ray diffraction unit or diffractometer
		Military hardware, such as gunsights (^{3}H), dials (*e.g.*, ^{3}H, ^{226}Ra), satellite parts (^{177}La), and lenses (thorium)		Linear accelerator Van de Graff machine Cyclotron Other types of accelerators

				Electron-beam microscope
Academic facilities				
General facilities and physical plant	Fluorescent bulbs with radioactive initiators (*e.g.*, ^{3}H, ^{147}Pm, ^{85}Kr)	Exit signs (^{3}H)	Soil moisture (americium-beryllium) and density (^{137}Cs) gauges	
	Smoke detectors (^{241}Am or ^{226}Ra)		Gauge to measure tank level or coal chute flow rate (^{137}Cs); some may be generally licensed	
	Self-luminous products like timepieces or instrument dials (*e.g.*, ^{3}H, ^{226}Ra)			
	Firebrick or incinerators [TENORM (*e.g.*, thorium, uranium and zirconium)]			
	Welding rods (thorium or uranium)			

TABLE A.1—*(continued)*.

Locations	No License or Exempt	General License[a]	Specific License	Radiation Machine
	Vacuum tubes (thorium or uranium)			
Student health clinic				Diagnostic x-ray machine
Student housing	Students as released nuclear medicine patients	Exit signs (^{3}H)		
Outside sources				
Contractors	Building materials containing naturally-occurring radionuclides		Industrial radiography sources (^{192}Ir)	
			Lead paint testers (^{109}Cd)	
Transportation	Some shielding in shipping containers (natural or depleted uranium)		Radioactive packages, such as delivered by FedEx® and DHL®	

[a]Some licensees may choose to include general-license material in their specific license. In this case, the material is bound by the specific license commitments and not by the general-license regulations.

TABLE A.2—*General precautions and disposal requirements for radioactive material not requiring a specific license.*

Item	General Precautions[a]	Disposal[b]	Exemption Reference
No License Required			
Glazed ceramic tableware	2	1	NRC [10 CFR 40.13(c)(2)]
Uranium ore samples	2, 4	1	NRC [10 CFR 40.13(b)]
Lantern mantles containing thorium	2, 4	1	NRC [10 CFR 40.13(c)(1)]
Quack medical devices[c] containing ^{226}Ra	1, 2, 4	1	Change in regulations (NRC, 2007b) may require license
Potassium chloride	None	1	Ordinary consumer product
Luminous-dial time pieces	2, 3, 4	1	NRC [10 CFR 30.15(a)(1)]
Smoke detectors[d]	1, 2, 4	1	NRC [10 CFR 30.20]
Exempt quantities of radioactive material	2, 4, 7	1	NRC [10 CFR 30.18]
Rare-earth compounds containing ≤0.25 % uranium or thorium	2, 4	1	NRC [10 CFR 40.13(c)(1)]
Electron tubes containing radionuclides	1, 2, 4	1	NRC [10 CFR 30.15(a)(8)]

TABLE A.2—*(continued)*.

Item	General Precautions[a]	Disposal[b]	Exemption Reference
Chemical mixtures containing ≤0.05 % uranium or thorium	2, 4	1	NRC [10 CFR 40.13(a)]
Welding rods containing thorium	2, 4	1	NRC [10 CFR 40.13(c)(1)]
Optical lenses containing thorium	2, 4	1	NRC [10 CFR 40.13(c)(7)]
Uranium used in shipping containers	2, 4, 6	2	NRC [10 CFR 40.13(c)(6)]
General license required			
Tritium exit signs	1	2	NRC [10 CFR 31.5]
Static eliminators	1, 2, 4, 7	1	NRC [10 CFR 31.3]
Air-ionization devices	1, 2, 4, 7	1	NRC [10 CFR 31.3]
Calibration sources containing ^{241}Am	1, 2, 4, 7	2	NRC [10 CFR 31.8]
Devices for measuring or controlling operations	1, 2, 4, 5, 7, 8	2	NRC [10 CFR 31.5]

^{14}C, ^{125}I, ^{131}I for *in vitro* or lab tests	2, 4, 5, 7	2	NRC [10 CFR 31.11]
^{3}H for *in vitro* or lab tests	2, 4, 5, 7	2	NRC [10 CFR 31.11]

[a]General precautions:
1. Do not disassemble.
2. Do not disperse material.
3. Do not remove luminous material.
4. Avoid breathing or ingesting material.
5. Perform periodic survey to determine integrity of container.
6. Label "Caution – Radioactive Shielding – Uranium."
7. Labeled by the manufacturer.
8. Appoint an individual who is knowledgeable of the regulations required to be followed by the general license.

[b]Disposal:
1. Dispose in ordinary trash.
2. Return to manufacturer or licensed vendor for disposal.

[c]Some states do not exempt these items.

[d]Most smoke detectors contain ^{241}Am sources. Some older smoke detectors can contain ^{226}Ra, which may not be an exempt source in some states.

TABLE A.3—*General precautions and disposal requirements for x-ray generating equipment.*

X-Ray Generating Equipment	General Precautions[a]	Disposal[b]	Registration
Electron-beam microscopes	1, 2, 3	1	Refer to state regulations
X-ray tubes	2, 3, 4	1	Refer to state regulations
Sources of high voltage in a vacuum	2, 3, 4	1	Refer to state regulations
X-ray diffraction machine	2, 3, 4, 5	1	Refer to state regulations

[a]General precautions:
1. Do not disassemble.
2. Provide adequate shielding.
3. Perform periodic monitoring to insure integrity of shielding.
4. Provide personal dosimetry.
5. Labeled by the manufacturer.

[b]Disposal:
1. Disable the equipment to be inoperable.

Appendix B

Citations to NRC Title 10 Code of Federal Regulations

To access the location on the NRC website where the Part numbers of Title 10, Code of Federal Regulations (10 CFR) are listed:

- go to http://www.nrc.gov/reading-rm/doc-collections/cfr;
- move down the screen and click on the desired Part number; and
- move down the next screen and click as necessary to get to the subparts.

The NRC 10 CFR citations found in this Report are:

10 CFR 1. Statement of organization and general information.
10 CFR 19.12. Notices, instruction and reports to workers: Inspection and investigations. Instruction to workers.
10 CFR 20. Standards for protection against radiation.
10 CFR 20.1301. Standards for protection against radiation. Radiation dose limits for individual members of the public. Dose limits for individual members of the public.
10 CFR 20.1302. Standards for protection against radiation. Radiation dose limits for individual members of the public. Compliance with dose limits for individual members of the public.
10 CFR 20.1501(c). Standards for protection against radiation. Surveys and monitoring. General.
10 CFR 20.1502. Standards for protection against radiation. Surveys and monitoring. Conditions requiring individual monitoring of external and internal occupational dose.

10 CFR 20.1502(a)(1) and (2). Standards for protection against radiation. Surveys and monitoring. Conditions requiring individual monitoring of external and internal occupational dose.

10 CFR 20.1906. Standards for protection against radiation. Precautionary procedures. Procedures for receiving and opening packages.

10 CFR 20.2003. Standards for protection against radiation. Waste disposal. Disposal by release into sanitary sewerage.

10 CFR 20.2005. Standards for protection against radiation. Waste disposal. Disposal of specific wastes.

10 CFR 30. Rules of general applicability to domestic licensing of byproduct material.

10 CFR 30.1. Rules of general applicability to domestic licensing of byproduct material. General provisions. Scope.

10 CFR 30.4. Rules of general applicability to domestic licensing of byproduct material. General provisions. Definitions.

10 CFR 30.7. Rules of general applicability to domestic licensing of byproduct material. General provisions. Employee protection.

10 CFR 30.9. Rules of general applicability to domestic licensing of byproduct material. General provisions. Completeness and accuracy of information.

10 CFR 30.10. Rules of general applicability to domestic licensing of byproduct material. General provisions. Deliberate misconduct.

10 CFR 30.15(a)(1). Rules of general applicability to domestic licensing of byproduct material. Exemptions. Certain items containing byproduct material.

10 CFR 30.15(a)(8). Rules of general applicability to domestic licensing of byproduct material. Exemptions. Certain items containing byproduct material.

10 CFR 30.18. Rules of general applicability to domestic licensing of byproduct material. Exemptions. Exempt quantities.

10 CFR 30.20. Rules of general applicability to domestic licensing of byproduct material. Exemptions. Gas and aerosol detectors containing byproduct material.

10 CFR 30.35. Rules of general applicability to domestic licensing of byproduct material. Licenses. Financial assurance and record keeping for decommissioning.

10 CFR 30.35(d). Rules of general applicability to domestic licensing of byproduct material. Licenses. Financial assurance and record keeping for decommissioning.

10 CFR 30.41. Rules of general applicability to domestic licensing of byproduct material. Licenses. Transfer of byproduct material.

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 30.70. Rules of general applicability to domestic licensing of byproduct material. Schedules. Schedule A – Exempt concentrations.

10 CFR 30.71. Rules of general applicability to domestic licensing of byproduct material. Schedules. Schedule B.

10 CFR 31. General domestic licenses for byproduct material.

10 CFR 31.3. General domestic licenses for byproduct material. Certain devices and equipment.

10 CFR 31.5. General domestic licenses for byproduct material. Certain detecting, measuring, gauging, or controlling devices and certain devices for producing light or an ionized atmosphere.

10 CFR 31.8. General domestic licenses for byproduct material. Americium-241 in the form of calibration or reference sources.

10 CFR 31.11. General domestic licenses for byproduct material. General license for use of byproduct material for certain in vitro clinical or laboratory testing.

10 CFR 32.210. Specific domestic licenses to manufacture or transfer certain items containing byproduct material. Specifically licensed items. Registration of product information.

10 CFR 33. Specific domestic licenses of broad scope for byproduct material.

10 CFR 33.13. Specific domestic licenses of broad scope for byproduct material. Specific licenses of broad scope. Requirements for the issuance of a Type A specific license of broad scope.

10 CFR 40. Domestic licensing of source material.

10 CFR 40.13(a). Domestic licensing of source material. Exemptions. Unimportant quantities of source material.
10 CFR 40.13(b). Domestic licensing of source material. Exemptions. Unimportant quantities of source material.
10 CFR 40.13(c)(1). Domestic licensing of source material. Exemptions. Unimportant quantities of source material.
10 CFR 40.13(c)(2). Domestic licensing of source material. Exemptions. Unimportant quantities of source material.
10 CFR 40.13(c)(6). Domestic licensing of source material. Exemptions. Unimportant quantities of source material.
10 CFR 40.13(c)(7). Domestic licensing of source material. Exemptions. Unimportant quantities of source material.
10 CFR 61.55(a)(2). Licensing requirements for land disposal of radioactive waste. Technical requirements for land disposal facilities. Waste classification. Classification of waste for near surface disposal. Classes of waste.
10 CFR 70. Domestic licensing of special nuclear material.
10 CFR 71. Packaging and transportation of radioactive material.
10 CFR 170.11(a)(4). Fees for facilities, materials, import and export licenses, and other regulatory services under the Atomic Energy Act of 1954, as amended. General provisions. Exemptions.

Glossary

absorbed dose: The energy imparted to matter by ionizing radiation per unit mass of irradiated material at the point of interest. In the Systeme Internationale (SI), the unit is J kg^{-1} with the special name gray (Gy). The special unit previously used was rad. 1 Gy = 100 rad.

activity: The average number of spontaneous nuclear transformations occurring in a radioactive material per unit time. The unit for activity in the SI system is reciprocal second (s^{-1}) (*i.e.*, one nuclear transformation per second), with the special name becquerel (Bq). The special unit previously used was curie (Ci); 1 Ci = 3.7×10^{10} Bq.

alpha particle: A positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus with a mass number of 4 and an electric charge of +2. It has low penetrating power and a short range (a few centimeters in air). The most energetic alpha particle from nuclear transformation will generally fail to penetrate the dead layer of skin cells. Alpha particles may represent a hazard when radionuclides are deposited inside the body (*e.g.*, *via* inhalation or ingestion).

as low as reasonably achievable (ALARA): A principle of radiation protection philosophy that requires that exposures to ionizing radiation be kept as low as reasonably achievable, economic and social factors being taken into account. The protection from radiation exposure is ALARA when the expenditure of further resources would be unwarranted by the reduction in exposure that would be achieved.

atomic number: The number of positively charged protons in the nucleus of an atom.

background radiation: Radiation from cosmic sources, naturally-occurring radioactive material in the earth and in the body (including exposure from radon), and global fallout as it exists in the environment from past testing of nuclear explosive devices. The typically quoted average effective dose to an individual from all sources of background radiation is ~3 mSv y^{-1}(~300 mrem y^{-1}). This value includes a major contribution from radon, which is ~2 mSv y^{-1}(~200 mrem y^{-1}).

becquerel (Bq): The special name for the unit of activity in the SI system [*i.e.*, one nuclear transformation per second (s^{-1})]. The special unit previously used was curie (Ci); 3.7×10^{10} Bq = 1 Ci.

beta particle: A charged particle emitted from a nucleus during nuclear transformation. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

bioassay: The determination of kinds, quantities or concentrations, and in some cases the locations of radioactive material in the human body.

bremsstrahlung: Secondary photon radiation produced by deceleration of charged particles passing through matter.

byproduct material: Any radioactive material (except special nuclear material) produced in a nuclear reactor; tailings or wastes produced by the extraction or concentration of uranium or thorium from ore processed primarily for its source material content; any discrete source of ^{226}Ra (*e.g.*, sealed or plated source, self-luminous time piece or instrument dial); or any radioactive material produced in a particle accelerator operated to produce radioactive material (see **source material** and **special nuclear material**).

characteristic x ray: Secondary photon radiation produced when a vacancy in the inner electron shell of an atom is filled by an outer-shell electron of the atom.

contamination (radioactive): Radioactive material that is present in undesired locations such as on the surface of or inside structures, areas, objects or individuals.

cosmic radiation: Penetrating ionizing radiation, both particulate and electromagnetic, that originates in outer space.

curie (Ci): The special unit previously used for activity (see **activity** and **becquerel**).

decay (radioactive): (see **radioactivity**).

decommission: The process of closing down a facility followed by reducing the residual quantities of radioactive material to a level that permits the release of the property for either limited (restricted) or unrestricted use.

decontamination: The reduction or removal of contaminating radioactive material from a structure, area, object or person.

deterministic effects: Effects that occur in all individuals who receive greater than a threshold dose; the severity of the effect varies with the dose. Examples are radiation-induced cataracts (lens of the eye) and radiation-induced erythema (skin).

effective dose: The sum of the weighted equivalent doses for the radiosensitive tissues and organs of the body. Each equivalent dose is modified by a tissue weighting factor that takes into account the relative radiation detriment for the tissue or organ. The tissue weighting factor for a particular tissue or organ represents the fraction of the total radiation detriment to the whole body attributed to that tissue when the whole body is irradiated uniformly. The tissue weighting factors have been developed from a reference population of equal numbers of both sexes and a wide range of ages. A similar quantity is effective dose equivalent (an earlier formulation of effective dose) that is also the sum of weighted doses for the radiosensitive tissues and organs of the body. These weighted doses (called dose equivalents) were also modified by tissue weighting factors (but an earlier set of factors different than used for effective dose). The SI unit of effective dose (and effective dose equivalent) is J kg^{-1} with the special name sievert (Sv); 1 Sv = 1 J kg^{-1} (see also **equivalent dose** and **radiation detriment**).

effective dose equivalent: (see **effective dose**).

electromagnetic radiation: A traveling wave motion consisting of changing electric or magnetic fields. Familiar types of electromagnetic radiation are: x and gamma rays of short wavelength and high energy; ultraviolet, visible and infrared; microwave; and radiofrequency radiation of relatively long wavelength and low energy.

electron volt: Unit of energy equal to that acquired by an electron falling through a potential difference of 1 V.

equivalent dose. The mean absorbed dose (gray) in a tissue or organ modified by the radiation weighting factor for the type and energy of radiation incident on the body. The SI unit of equivalent dose is J kg^{-1} with the special name sievert (Sv); 1 Sv = 1 J kg^{-1}. For low linear-energy-transfer radiations (*e.g.*, gamma rays, electrons), the radiation weighting factor is assigned a value of unity and therefore 1 Gy is numerically equivalent to 1 Sv.

exposure: In this Report, a general term used to express the act of being exposed to ionizing or nonionizing radiation. Exposure is also a defined ionizing radiation quantity. It is a measure of the ionization produced in air by x or gamma rays. The unit of exposure is coulomb per kilogram (C kg^{-1}). The special name for exposure is roentgen (R), where 1 R = 2.58×10^{-4} C kg^{-1} (see **irradiation**).

fission (nuclear): A nuclear transformation characterized by the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy.

fluoroscopy: A medical x-ray procedure used for observation of the internal features of the body by means of the fluorescence produced on a screen by a continuous field of x rays transmitted through the body.

gamma rays: Electromagnetic radiation emitted by the atomic nucleus. Gamma rays have high penetrating ability compared to alpha and beta particles.

gonad: An ovary or testis.

gray (Gy): The special name for the SI unit of absorbed dose expressed in terms of energy imparted per unit mass of a material. 1 Gy = 1 J kg^{-1} (see **rad**).

half-life: The time in which one-half of the atoms (on average) of a particular radioactive substance disintegrate into another nuclear form (also called physical or radiological half-life).

hereditary effects: Effects expressed in offspring due to alteration of reproductive cells in the parent(s).

higher-risk source: A radioactive-material source in Security Groups A, B or C (Table 7.1).

ionizing radiation: Particulate or electromagnetic radiation that is capable of removing electrons from a neutral atom or molecule either directly or indirectly, resulting in an excess charge.

irradiation: The process of exposure to radiation.

isotope: One of several nuclides having the same number of protons in their nuclei, but different nuclear mass numbers due to different numbers of neutrons in the nucleus.

laser: A device that utilizes the natural oscillations of atoms or molecules between energy levels for generating coherent electromagnetic radiation in ultraviolet, visible or infrared regions of the spectrum. Laser is an acronym for light amplification by stimulated emission of radiation.

legacy source: In this Report, a radiation source from the past, often referring to radiation-producing machines, radioactive waste, or materials from prior operations at an educational institution.

low-level radioactive waste: A general term for a wide range of radioactive waste that contain low concentrations of radionuclides, where the low concentrations are defined by U.S. regulations.

monitoring: Periodic or continuous determination of exposure rate or dose rate in an area (area monitoring), or of the exposure received by a person (personal monitoring), or the measurement of contamination levels.

naturally-occurring radioactive material (NORM): Materials found in the natural environment containing inherent concentrations of radionuclides. Examples include materials containing long-lived radioactive isotopes of the elements uranium, thorium and potassium, and of their decay products (*e.g.*, the elements radium and radon) that have always been present in Earth's crust.

neutron: An uncharged elementary particle having a mass slightly greater than a proton that is usually stable when within the nucleus but is unstable otherwise.

nonionizing radiation: Electromagnetic radiation that includes the ultraviolet, visible, infrared, microwave, radiofrequency, and extremely-low-frequency portions of the electromagnetic spectrum. Unlike ionizing radiation, nonionizing radiation is unable to ionize atoms in its interactions with matter.

occupational exposure: Exposures to individuals that are incurred in the workplace as a result of situations that can reasonably be regarded as being the responsibility of management (radiation exposures received by patients associated with their medical diagnosis or treatment are excluded).

particle accelerator: A device for imparting energy of motion to charged particles.

personal monitoring: The use of portable survey meters to determine the presence or quantity of radioactive contamination on an individual, or the use of a dosimeter (*i.e.*, a small portable measurement and recording device) to determine an individual's radiation dose.

personal protective equipment: Specialized clothing or equipment worn by an employee to protect against a hazard.

positron: A particle equal in mass to an electron and having an equal but positive charge.

practicable: Likely to meet a need, but not yet tested in practice or proved in service or use (implies an expectation).

practical: Proven effective in use (implies an actual established usefulness).

proton: An elementary nuclear particle with a positive charge equal to the charge of an electron and a mass equal to the nucleus of the hydrogen atom.

qualified expert: As used in this Report, a person having the knowledge and training to measure radiation, to evaluate radiation safety techniques, and to advise regarding radiation protection needs. For ionizing radiation, the qualified expert is a person who is certified by the American Board of Health Physics, the American Board of Radiology, the American Board of Medical Physics, or the Canadian College of Physicists in Medicine.

rad: The special unit previously used for absorbed dose; 100 rad = 1 Gy (see **gray)**.

radiation: Energy propagated through space in the form of electromagnetic waves or particles (see **ionizing radiation** and **nonionizing radiation**).

radiation detriment: Radiation detriment is the risk of radiation-induced health outcomes, including fatal and nonfatal cancer, hereditary effects, and loss of life-span from cancer and hereditary disease, weighted for severity and time of expression of the harmful effect.

radiation dose (or dose): A general term used 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, equivalent dose, effective dose).

radiation dose rate (or dose rate): The radiation dose delivered per unit time.

radiation safety officer (RSO): The person directly responsible for radiation protection. It is the RSO's responsibility to ensure that all procedures are carried out in compliance with pertinent established rules, including recommendations in this Report.

radiation survey: Evaluation of radiation hazards that customarily includes a physical survey of the arrangement and use of equipment and measurements of the exposure rates under expected operating conditions.

radiation weighting factor: The factor by which the mean absorbed dose in a tissue or organ is modified to account for the relative biological effectiveness for stochastic effects of the type of radiation incident on the body (see **stochastic effects**).

radioactivity: The property or characteristic of an unstable atomic nucleus to spontaneously transform with emission of energy in the form of ionizing radiation (see **activity**).

radionuclide: An unstable (radioactive) nuclide. A nuclide is a species of atom characterized by the constitution of its nucleus (*i.e.*, the number of protons and neutrons, and the energy content).

radon (and radon progeny): Radon (Rn) is a colorless, odorless, naturally-occurring, and gaseous element resulting from radioactive decay of isotopes of radium. Radon progeny are short-lived decay products of ^{222}Rn or ^{220}Rn.

rem: The special unit previously used for the quantities equivalent dose and effective dose (or effective dose equivalent); 100 rem = 1 Sv (see **sievert**).

responsible administrator (RA): In this Report, an individual at an educational institution who has overall management responsibility for the radiation safety program. Examples of an RA are: the principal of a high school (delegated by the school board); the chancellor, president or other senior manager at a small college, specialty academy, or a larger college or university. In the case of a larger college or university, the RA or a designee will also serve as the executive representative to the radiation safety committee.

scintillation counter: A radiation detector composed of a combination of phosphor, photomultiplier device, and associated electronic circuits for counting light emissions produced in the phosphor by ionizing radiation.

sealed source: Radioactive material encased in a capsule designed to prevent leakage or escape of the material.

shall: The term *shall* (in *italics*) indicates a recommendation from NCRP that is necessary to meet the currently accepted standards of radiation protection. When the term "shall" is used to express requirements from regulatory agencies or other cognizant authorities, it is not in italics.

shielding: Any material or obstruction that attenuates radiation (*i.e.*, reduces the radiation level by absorption and scattering) and thus tends to protect personnel or materials from the effects of ionizing radiation.

***should*:** The term *should* (in *italics*) indicates an advisory recommendation from NCRP that is to be applied when practicable or practical (*e.g.*, cost effective). When the term "should" is used to express requirements from regulatory agencies or other cognizant authorities, it is not in italics. Also, when the term "should" appears in the context of its general usage, it is not in italics.

sievert (Sv): The special name (in the SI system) for the unit of equivalent dose and effective dose (or effective dose equivalent); 1 Sv = 1 J kg^{-1}. 1 Sv = 100 rem (see **rem**).

somatic effects: Effects of radiation limited to the exposed individual, as distinguished from hereditary effects that may be expressed in subsequent unexposed generations.

source (or radiation source): Radiation-producing equipment or an aggregate of radioactive nuclei.

source material: Uranium, thorium or any combination thereof in any physical or chemical form, or ores that contain by weight 1/20 of 1 % (0.05 %) or more of uranium, thorium or any combination thereof.

Source material does not include special nuclear material (see **special nuclear material**).

special nuclear material: Plutonium, ^{233}U, uranium enriched in the isotope 233 or in the isotope 235 and any other material NRC determines to be special nuclear material, or any material artificially enriched by any of these types of radioactive material.

spontaneous fission: (see **fission**).

standards: In this Report, refers to a variety of activities established by legislative or regulatory means for the safe use and application of ionizing and nonionizing radiation. Examples include: dose and dose-rate limits, permissible concentrations, rules for handling, regulations for transportation, regulations for industrial control of radiation, electronic product performance requirements, and control of radioactive material.

stochastic effects: Effects, the probability of which, rather than their severity, is assumed to be a function of dose without a threshold. For example, cancer and hereditary effects are regarded as being stochastic.

technologically-enhanced naturally-occurring radioactive material (TENORM): Naturally-occurring radioactive material whose concentrations of radionuclides are increased by or as a result of past or present human practices. TENORM does not include background radiation or the naturally-occurring radionuclides in rocks or soils. TENORM also does not include uranium or thorium in source material as defined in the Atomic Energy Act of 1954 and NRC regulations.

x rays: Penetrating electromagnetic radiation having a range of wavelengths (energies) that are similar to those of gamma photons. X rays are usually produced by interaction of the electron field around certain nuclei or by the slowing down of energetic electrons. Once formed, there is no physical difference between x- and gamma-ray photons; however, there is a difference in their origin (see also **bremsstrahlung** and **characteristic x ray**).

Symbols and Acronyms

AEL	accessible emission limit
ALARA	as low as reasonably achievable
CFR	Code of Federal Regulations
CW	continuous wave
DNA	deoxyribonucleic acid
NORM	naturally-occurring radioactive material
RA	responsible administrator
RI	responsible individual
RNA	ribonucleic acid
RSO	radiation safety officer
SI	Systeme Internationale (International System of Quantities and Units)
TENORM	technologically-enhanced naturally-occurring radioactive material
UV	ultraviolet
Z	atomic number

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The NCRP

The National Council on Radiation Protection and Measurements is a non-profit corporation chartered by Congress in 1964 to:

1. Collect, analyze, develop and disseminate in the public interest information and recommendations about (a) protection against radiation and (b) radiation measurements, quantities and units, particularly those concerned with radiation protection.
2. Provide a means by which organizations concerned with the scientific and related aspects of radiation protection and of radiation quantities, units and measurements may cooperate for effective utilization of their combined resources, and to stimulate the work of such organizations.
3. Develop basic concepts about radiation quantities, units and measurements, about the application of these concepts, and about radiation protection.
4. Cooperate with the International Commission on Radiological Protection, the International Commission on Radiation Units and Measurements, and other national and international organizations, governmental and private, concerned with radiation quantities, units and measurements and with radiation protection.

The Council is the successor to the unincorporated association of scientists known as the National Committee on Radiation Protection and Measurements and was formed to carry on the work begun by the Committee in 1929.

The participants in the Council's work are the Council members and members of scientific and administrative committees. Council members are selected solely on the basis of their scientific expertise and serve as individuals, not as representatives of any particular organization. The scientific committees, composed of experts having detailed knowledge and competence in the particular area of the committee's interest, draft proposed recommendations. These are then submitted to the full membership of the Council for careful review and approval before being published.

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Eugene L. Saenger (1982) *Ethics, Trade-Offs and Medical Radiation*
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Harold O. Wyckoff (1980) *From "Quantity of Radiation" and "Dose" to "Exposure" and "Absorbed Dose"—An Historical Review*
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Currently, the following committees are actively engaged in formulating recommendations:

Program Area Committee 1: Basic Criteria, Epidemiology, Radiobiology, and Risk

SC 1-8 Risk to Thyroid from Ionizing Radiation
SC 1-13 Impact of Individual Susceptibility and Previous Radiation Exposure on Radiation Risk for Astronauts
SC 1-15 Radiation Safety in NASA Lunar Missions'
SC 1-17 Second Cancers and Cardiopulmonary Effects After Radiotherapy
SC 85 Risk of Lung Cancer from Radon

Program Area Committee 2: Operational Radiation Safety

SC 2-3 Radiation Safety Issues for Image-Guided Interventional Medical Procedures
SC 2-4 Self Assessment of Radiation Safety Programs

Program Area Committee 3: Nuclear and Radiological Security and Safety

Program Area Committee 4: Radiation Protection in Medicine

SC 4-1 Management of Persons Contaminated with Radionuclides
SC 4-2 Population Monitoring and Decontamination Following a Nuclear/Radiological Incident

Program Area Committee 5: Environmental Radiation and Radioactive Waste Issues

SC 64-22 Design of Effective Effluent and Environmental Monitoring Programs

Program Area Committee 6: Radiation Measurements and Dosimetry

SC 6-1 Uncertainties in the Measurement and Dosimetry of External Radiation Sources
SC 6-2 Radiation Exposure of the U.S. Population
SC 6-3 Uncertainties in Internal Radiation Dosimetry
SC 6-4 Fundamental Principles of Dose Reconstruction
SC 6-5 Radiation Protection and Measurement Issues Related to Cargo Scanning with High-Energy X Rays Produced by Accelerators
SC 6-6 Skin Doses from Dermal Contamination
SC 6-7 Evaluation of Inhalation Doses in Scenarios Involving Resuspension by Nuclear Detonations at the Nevada Test Site

In recognition of its responsibility to facilitate and stimulate cooperation among organizations concerned with the scientific and related aspects of radiation protection and measurement, the Council has created a category of NCRP Collaborating Organizations. Organizations or groups of organizations that are national or international in scope and are concerned with scientific problems involving radiation quantities, units, measurements and effects, or radiation protection may be admitted to collaborating status by the Council. Collaborating Organizations provide a means by which NCRP can gain input into its activities from a wider segment of society. At the same time, the relationships with the Collaborating Organizations facilitate wider dissemination of information about the Council's activities, interests and concerns. Collaborating Organizations have the opportunity to comment on draft reports (at the time that these are submitted to the members of the Council). This is intended to capitalize on the fact that Collaborating Organizations are in an excellent position to both contribute to the identification of what needs to be treated in NCRP reports and to identify problems that might result from proposed recommendations. The present Collaborating Organizations with which NCRP maintains liaison are as follows:

American Academy of Dermatology
American Academy of Environmental Engineers
American Academy of Health Physics
American Academy of Orthopaedic Surgeons
American Association of Physicists in Medicine
American College of Cardiology
American College of Medical Physics
American College of Nuclear Physicians
American College of Occupational and Environmental Medicine
American College of Radiology
American Conference of Governmental Industrial Hygienists
American Dental Association
American Industrial Hygiene Association
American Institute of Ultrasound in Medicine
American Medical Association
American Nuclear Society
American Pharmaceutical Association
American Podiatric Medical Association
American Public Health Association
American Radium Society
American Roentgen Ray Society
American Society for Therapeutic Radiology and Oncology
American Society of Emergency Radiology
American Society of Health-System Pharmacists
American Society of Nuclear Cardiology
American Society of Radiologic Technologists
Association of Educators in Imaging and Radiological Sciences
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College of American Pathologists
Conference of Radiation Control Program Directors, Inc.
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Defense Threat Reduction Agency
Electric Power Research Institute
Federal Communications Commission
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Genetics Society of America
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National Electrical Manufacturers Association

National Institute for Occupational Safety and Health
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Nuclear Energy Institute
Office of Science and Technology Policy
Paper, Allied-Industrial, Chemical and Energy Workers International Union
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Radiation Research Society
Radiological Society of North America
Society for Cardiovascular Angiography and Interventions
Society for Pediatric Radiology
Society for Risk Analysis
Society of Chairmen of Academic Radiology Departments
Society of Interventional Radiology
Society of Nuclear Medicine
Society of Radiologists in Ultrasound
Society of Skeletal Radiology
U.S. Air Force
U.S. Army
U.S. Coast Guard
U.S. Department of Energy
U.S. Department of Housing and Urban Development
U.S. Department of Labor
U.S. Department of Transportation
U.S. Environmental Protection Agency
U.S. Navy
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NCRP has found its relationships with these organizations to be extremely valuable to continued progress in its program.

Another aspect of the cooperative efforts of NCRP relates to the Special Liaison relationships established with various governmental organizations that have an interest in radiation protection and measurements. This liaison relationship provides: (1) an opportunity for participating organizations to designate an individual to provide liaison between the organization and NCRP; (2) that the individual designated will receive copies of draft NCRP reports (at the time that these are submitted to the members of the Council) with an invitation to comment, but not vote; and (3) that new NCRP efforts might be discussed with liaison individuals as appropriate, so that they might have an opportunity to make suggestions on new studies and related matters. The following organizations participate in the Special Liaison Program:

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Bundesamt fur Strahlenschutz (Germany)
Canadian Nuclear Safety Commission
Central Laboratory for Radiological Protection (Poland)
China Institute for Radiation Protection
Commissariat a l'Energie Atomique (France)

Commonwealth Scientific Instrumentation Research Organization (Australia)
European Commission
Health Council of the Netherlands
Health Protection Agency
International Commission on Non-ionizing Radiation Protection
International Commission on Radiation Units and Measurements
Japan Radiation Council
Korea Institute of Nuclear Safety
Russian Scientific Commission on Radiation Protection
South African Forum for Radiation Protection
World Association of Nuclear Operators
World Health Organization, Radiation and Environmental Health

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American Nuclear Society
American Osteopathic College of Radiology
American Podiatric Medical Association
American Public Health Association
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NCRP seeks to promulgate information and recommendations based on leading scientific judgment on matters of radiation protection and measurement and to foster cooperation among organizations concerned with these matters. These efforts are intended to serve the public interest and the Council welcomes comments and suggestions on its reports or activities.

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NCRP Reports

No.	Title
8	*Control and Removal of Radioactive Contamination in Laboratories* (1951)
22	*Maximum Permissible Body Burdens and Maximum Permissible Concentrations of Radionuclides in Air and in Water for Occupational Exposure* (1959) [includes Addendum 1 issued in August 1963]
25	*Measurement of Absorbed Dose of Neutrons, and of Mixtures of Neutrons and Gamma Rays* (1961)
27	*Stopping Powers for Use with Cavity Chambers* (1961)
30	*Safe Handling of Radioactive Materials* (1964)
32	*Radiation Protection in Educational Institutions* (1966)
35	*Dental X-Ray Protection* (1970)
36	*Radiation Protection in Veterinary Medicine* (1970)
37	*Precautions in the Management of Patients Who Have Received Therapeutic Amounts of Radionuclides* (1970)
38	*Protection Against Neutron Radiation* (1971)
40	*Protection Against Radiation from Brachytherapy Sources* (1972)
41	*Specification of Gamma-Ray Brachytherapy Sources* (1974)
42	*Radiological Factors Affecting Decision-Making in a Nuclear Attack* (1974)
44	*Krypton-85 in the Atmosphere—Accumulation, Biological Significance, and Control Technology* (1975)
46	*Alpha-Emitting Particles in Lungs* (1975)

47 *Tritium Measurement Techniques* (1976)
49 *Structural Shielding Design and Evaluation for Medical Use of X Rays and Gamma Rays of Energies Up to 10 MeV* (1976)
50 *Environmental Radiation Measurements* (1976)
52 *Cesium-137 from the Environment to Man: Metabolism and Dose* (1977)
54 *Medical Radiation Exposure of Pregnant and Potentially Pregnant Women* (1977)
55 *Protection of the Thyroid Gland in the Event of Releases of Radioiodine* (1977)
57 *Instrumentation and Monitoring Methods for Radiation Protection* (1978)
58 *A Handbook of Radioactivity Measurements Procedures*, 2nd ed. (1985)
60 *Physical, Chemical, and Biological Properties of Radiocerium Relevant to Radiation Protection Guidelines* (1978)
61 *Radiation Safety Training Criteria for Industrial Radiography* (1978)
62 *Tritium in the Environment* (1979)
63 *Tritium and Other Radionuclide Labeled Organic Compounds Incorporated in Genetic Material* (1979)
64 *Influence of Dose and Its Distribution in Time on Dose-Response Relationships for Low-LET Radiations* (1980)
65 *Management of Persons Accidentally Contaminated with Radionuclides* (1980)
67 *Radiofrequency Electromagnetic Fields—Properties, Quantities and Units, Biophysical Interaction, and Measurements* (1981)
68 *Radiation Protection in Pediatric Radiology* (1981)
69 *Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV* (1981)
70 *Nuclear Medicine—Factors Influencing the Choice and Use of Radionuclides in Diagnosis and Therapy* (1982)
72 *Radiation Protection and Measurement for Low-Voltage Neutron Generators* (1983)
73 *Protection in Nuclear Medicine and Ultrasound Diagnostic Procedures in Children* (1983)
74 *Biological Effects of Ultrasound: Mechanisms and Clinical Implications* (1983)
75 *Iodine-129: Evaluation of Releases from Nuclear Power Generation* (1983)
76 *Radiological Assessment: Predicting the Transport, Bioaccumulation, and Uptake by Man of Radionuclides Released to the Environment* (1984)
77 *Exposures from the Uranium Series with Emphasis on Radon and Its Daughters* (1984)
78 *Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States* (1984)
79 *Neutron Contamination from Medical Electron Accelerators* (1984)
80 *Induction of Thyroid Cancer by Ionizing Radiation* (1985)
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82 *SI Units in Radiation Protection and Measurements* (1985)

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84 *General Concepts for the Dosimetry of Internally Deposited Radionuclides* (1985)
86 *Biological Effects and Exposure Criteria for Radiofrequency Electromagnetic Fields* (1986)
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88 *Radiation Alarms and Access Control Systems* (1986)
89 *Genetic Effects from Internally Deposited Radionuclides* (1987)
90 *Neptunium: Radiation Protection Guidelines* (1988)
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93 *Ionizing Radiation Exposure of the Population of the United States* (1987)
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102 *Medical X-Ray, Electron Beam and Gamma-Ray Protection for Energies Up to 50 MeV (Equipment Design, Performance and Use)* (1989)
103 *Control of Radon in Houses* (1989)
104 *The Relative Biological Effectiveness of Radiations of Different Quality* (1990)
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NCRP Commentaries

No.	Title
1	*Krypton-85 in the Atmosphere—With Specific Reference to the Public Health Significance of the Proposed Controlled Release at Three Mile Island* (1980)
4	*Guidelines for the Release of Waste Water from Nuclear Facilities with Special Reference to the Public Health Significance of the Proposed Release of Treated Waste Waters at Three Mile Island* (1987)
5	*Review of the Publication, Living Without Landfills* (1989)
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15	*Evaluating the Reliability of Biokinetic and Dosimetric Models and Parameters Used to Assess Individual Doses for Risk Assessment Purposes* (1998)

16 *Screening of Humans for Security Purposes Using Ionizing Radiation Scanning Systems* (2003)
17 *Pulsed Fast Neutron Analysis System Used in Security Surveillance* (2003)
18 *Biological Effects of Modulated Radiofrequency Fields* (2003)
19 *Key Elements of Preparing Emergency Responders for Nuclear and Radiological Terrorism* (2005)

Proceedings of the Annual Meeting

No.	Title
1	*Perceptions of Risk,* Proceedings of the Fifteenth Annual Meeting held on March 14-15, 1979 (including Taylor Lecture No. 3) (1980)
3	*Critical Issues in Setting Radiation Dose Limits*, Proceedings of the Seventeenth Annual Meeting held on April 8-9, 1981 (including Taylor Lecture No. 5) (1982)
4	*Radiation Protection and New Medical Diagnostic Approaches,* Proceedings of the Eighteenth Annual Meeting held on April 6-7, 1982 (including Taylor Lecture No. 6) (1983)
5	*Environmental Radioactivity,* Proceedings of the Nineteenth Annual Meeting held on April 6-7, 1983 (including Taylor Lecture No. 7) (1983)
6	*Some Issues Important in Developing Basic Radiation Protection Recommendations*, Proceedings of the Twentieth Annual Meeting held on April 4-5, 1984 (including Taylor Lecture No. 8) (1985)
7	*Radioactive Waste*, Proceedings of the Twenty-first Annual Meeting held on April 3-4, 1985 (including Taylor Lecture No. 9)(1986)
8	*Nonionizing Electromagnetic Radiations and Ultrasound,* Proceedings of the Twenty-second Annual Meeting held on April 2-3, 1986 (including Taylor Lecture No. 10) (1988)
9	*New Dosimetry at Hiroshima and Nagasaki and Its Implications for Risk Estimates*, Proceedings of the Twenty-third Annual Meeting held on April 8-9, 1987 (including Taylor Lecture No. 11) (1988)
10	*Radon*, Proceedings of the Twenty-fourth Annual Meeting held on March 30-31, 1988 (including Taylor Lecture No. 12) (1989)
11	*Radiation Protection Today—The NCRP at Sixty Years*, Proceedings of the Twenty-fifth Annual Meeting held on April 5-6, 1989 (including Taylor Lecture No. 13) (1990)
12	*Health and Ecological Implications of Radioactively Contaminated Environments*, Proceedings of the Twenty-sixth Annual Meeting held on April 4-5, 1990 (including Taylor Lecture No. 14) (1991)
13	*Genes, Cancer and Radiation Protection,* Proceedings of the Twenty-seventh Annual Meeting held on April 3-4, 1991 (including Taylor Lecture No. 15) (1992)
14	*Radiation Protection in Medicine,* Proceedings of the Twenty-eighth Annual Meeting held on April 1-2, 1992 (including Taylor Lecture No. 16) (1993)
15	*Radiation Science and Societal Decision Making,* Proceedings of the Twenty-ninth Annual Meeting held on April 7-8, 1993 (including Taylor Lecture No. 17) (1994)

16 *Extremely-Low-Frequency Electromagnetic Fields: Issues in Biological Effects and Public Health*, Proceedings of the Thirtieth Annual Meeting held on April 6-7, 1994 (not published).

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26 *Advances in Consequence Management for Radiological Terrorism Events*, Proceedings of the Fortieth Annual Meeting held on April 14–15, 2004, Health Phys. **89**, 415–588 (2005)

27 *Managing the Disposition of Low-Activity Radioactive Materials,* Proceedings of the Forty-first Annual Meeting held on March 30–31, 2005, Health Phys. **91**, 413–536 (2006)

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No.	Title
1	*The Squares of the Natural Numbers in Radiation Protection by* Herbert M. Parker (1977)
2	*Why be Quantitative about Radiation Risk Estimates?* by Sir Edward Pochin (1978)
3	*Radiation Protection—Concepts and Trade Offs* by Hymer L. Friedell (1979) [available also in *Perceptions of Risk*, see above]
4	*From "Quantity of Radiation" and "Dose" to "Exposure" and "Absorbed Dose"—An Historical Review* by Harold O. Wyckoff (1980)

5 *How Well Can We Assess Genetic Risk? Not Very* by James F. Crow (1981) [available also in *Critical Issues in Setting Radiation Dose Limits*, see above]

6 *Ethics, Trade-offs and Medical Radiation* by Eugene L. Saenger (1982) [available also in *Radiation Protection and New Medical Diagnostic Approaches*, see above]

7 *The Human Environment—Past, Present and Future* by Merril Eisenbud (1983) [available also in *Environmental Radioactivity*, see above]

8 *Limitation and Assessment in Radiation Protection* by Harald H. Rossi (1984) [available also in *Some Issues Important in Developing Basic Radiation Protection Recommendations*, see above]

9 *Truth (and Beauty) in Radiation Measurement* by John H. Harley (1985) [available also in *Radioactive Waste*, see above]

10 *Biological Effects of Non-ionizing Radiations: Cellular Properties and Interactions* by Herman P. Schwan (1987) [available also in *Nonionizing Electromagnetic Radiations and Ultrasound*, see above]

11 *How to be Quantitative about Radiation Risk Estimates* by Seymour Jablon (1988) [available also in *New Dosimetry at Hiroshima and Nagasaki and its Implications for Risk Estimates*, see above]

12 *How Safe is Safe Enough?* by Bo Lindell (1988) [available also in *Radon*, see above]

13 *Radiobiology and Radiation Protection: The Past Century and Prospects for the Future* by Arthur C. Upton (1989) [available also in *Radiation Protection Today*, see above]

14 *Radiation Protection and the Internal Emitter Saga* by J. Newell Stannard (1990) [available also in *Health and Ecological Implications of Radioactively Contaminated Environments*, see above]

15 *When is a Dose Not a Dose?* by Victor P. Bond (1992) [available also in *Genes, Cancer and Radiation Protection*, see above]

16 *Dose and Risk in Diagnostic Radiology: How Big? How Little?* by Edward W. Webster (1992) [available also in *Radiation Protection in Medicine*, see above]

17 *Science, Radiation Protection and the NCRP* by Warren K. Sinclair (1993) [available also in *Radiation Science and Societal Decision Making,* see above]

18 *Mice, Myths and Men* by R.J. Michael Fry (1995)

19 *Certainty and Uncertainty in Radiation Research* by Albrecht M. Kellerer. Health Phys. **69**, 446–453 (1995)

20 *70 Years of Radiation Genetics: Fruit Flies, Mice and Humans* by Seymour Abrahamson. Health Phys. **71**, 624–633 (1996)

21 *Radionuclides in the Body: Meeting the Challenge* by William J. Bair. Health Phys. **73**, 423–432 (1997)

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23 *Back to Background: Natural Radiation and Radioactivity Exposed* by Naomi H. Harley. Health Phys. **79**, 121–128 (2000)

24 *Administered Radioactivity: Unde Venimus Quoque Imus* by S. James Adelstein. Health Phys. **80**, 317–324 (2001)

25 *Assuring the Safety of Medical Diagnostic Ultrasound* by Wesley L. Nyborg. Health Phys. **82**, 578–587 (2002)
26 *Developing Mechanistic Data for Incorporation into Cancer and Genetic Risk Assessments: Old Problems and New Approaches* by R. Julian Preston. Health Phys. **85**, 4–12 (2003)
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28 *Radiation Protection in the Aftermath of a Terrorist Attack Involving Exposure to Ionizing Radiation* by Abel J. Gonzalez, Health Phys. **89**, 418–446 (2005)
29 *Nontargeted Effects of Radiation: Implications for Low Dose Exposures* by John B. Little, Health Phys. **91**, 416–426 (2006)

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No.	Title
1	*The Control of Exposure of the Public to Ionizing Radiation in the Event of Accident or Attack*, Proceedings of a Symposium held April 27-29, 1981 (1982)
2	*Radioactive and Mixed Waste—Risk as a Basis for Waste Classification,* Proceedings of a Symposium held November 9, 1994 (1995)
3	*Acceptability of Risk from Radiation—Application to Human Space Flight,* Proceedings of a Symposium held May 29, 1996 (1997)
4	*21st Century Biodosimetry: Quantifying the Past and Predicting the Future*, Proceedings of a Symposium held February 22, 2001, Radiat. Prot. Dosim. **97**(1), (2001)
5	*National Conference on Dose Reduction in CT, with an Emphasis on Pediatric Patients*, Summary of a Symposium held November 6-7, 2002, Am. J. Roentgenol. **181**(2), 321–339 (2003)

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No.	Title
1	"Blood Counts, Statement of the National Committee on Radiation Protection," Radiology **63**, 428 (1954)
2	"Statements on Maximum Permissible Dose from Television Receivers and Maximum Permissible Dose to the Skin of the Whole Body," Am. J. Roentgenol., Radium Ther. and Nucl. Med. **84**, 152 (1960) and Radiology **75**, 122 (1960)
3	*X-Ray Protection Standards for Home Television Receivers, Interim Statement of the National Council on Radiation Protection and Measurements* (1968)
4	*Specification of Units of Natural Uranium and Natural Thorium, Statement of the National Council on Radiation Protection and Measurements* (1973)
5	*NCRP Statement on Dose Limit for Neutrons* (1980)
6	*Control of Air Emissions of Radionuclides* (1984)

7	*The Probability That a Particular Malignancy May Have Been Caused by a Specified Irradiation* (1992)
8	*The Application of ALARA for Occupational Exposures* (1999)
9	*Extension of the Skin Dose Limit for Hot Particles to Other External Sources of Skin Irradiation* (2001)
10	*Recent Applications of the NCRP Public Dose Limit Recommendation for Ionizing Radiation* (2004)

Other Documents

The following documents were published outside of the NCRP report, commentary and statement series:

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Index