HUMAN HEALTH

ENVIRONMENTAL HEALTH

GUIDE TO THE SAFE HANDLING OF RADIOACTIVE MATERIALS IN RESEARCH

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For the Better

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This guide is based on well-established radiological safety practices and our experience handling radioactive materials since 1956. We hope the guide will help keep you, your colleagues and the environment safe as you work with radioactive materials in your research.

CHARACTERISTICS OF RADIOACTIVE MATERIALS

To establish appropriate controls on the use of radioactive materials, it is important to know the basic characteristics of these materials.

Radioactive materials have certain characteristics, such as the types of radiations emitted and the rate of emission. Knowledge of these characteristics is helpful in establishing protective controls for the use of the material.

Radioactivity

A nuclide is an atom with a particular number of protons and neutrons in its nucleus. A radionuclide is a nuclide that has the property of spontaneously converting part of its mass into energy and emitting this energy in the form of energetic particles and electromagnetic radiation. The radionuclide emits radiation. This property is called radioactivity and the actual event is referred to as radioactive decay, disintegration or transformation.

For example, hydrogen-1 (^{1}H) is composed of one proton and one electron. This is normal stable hydrogen. ^{2}H (also called deuterium or "heavy" hydrogen) consists of one proton, one electron and one neutron. ^{2}H is also stable. ^{3}H, tritium, is composed of one proton, one electron, and two neutrons. ^{3}H is not stable; it is a radionuclide and a radioisotope of hydrogen.

When ^{3}H spontaneously converts part of its mass into energy and emits this energy in the form of energetic nuclear particles, it yields helium-3, which is stable, plus energetic particles.

Radioactive Decay

All radionuclides eventually decay to stable nuclides, but some undergo a series of decays before they reach the stable nuclide. Strontium-90, for example, is a radionuclide that decays into the radionuclide yttrium-90, which subsequently decays into the stable nuclide zirconium-90. This is a series decay with ^{90}Sr being the "parent" and ^{90}Y the "progeny."

The process of radioactive decay is spontaneous and the time when a particle atom will decay is not known. However, when large number of radioactive atoms are present, the fraction of atoms that will decay in a given time span (the decay rate) can be specified. A quantity that uniquely identifies the rate of decay is the half-life of the radionuclide. This is the time required for one half of the atoms present to decay. The half-life is a useful measure because no two radionuclides have exactly the same half-life. Also, the half-life is unaffected by the chemical or physical environment of the atom.

The quantity of radioactive material present at a particular time is usually expressed in terms of the rate of decay at that time. For example, a vial may contain enough tritium to support 1×10^{10} disintegrations per second (d/s). The activity of the tritium at that time is therefore 1×10^{10} d/s. Two units of activity are the curie (Ci) and the becquerel (Bq):

$$1 \text{ curie (Ci)} = 3.7 \times 10^{10} \text{ d/s}$$

and

$$1 \text{ becquerel (Bq)} = 1 \text{ d/s}$$

Thus the vial contains 1×10^{10} Bq or 0.27 Ci of tritium.

Radiation

The manner in which a radionuclide will emit radiation is well defined and very characteristic. The term "manner" refers to the type, energy and intensity of the radiation.

The major types or radiation are:

- **Alpha particles** – massive charged particles, identical in mass and charge with ^{4}He nuclei, that are emitted from the nucleus with discrete energies (for example, ^{238}U alpha particles).
- **Beta particles** – light charged particles that come in positive (positron) and negative (negatron) forms, have the same mass as an electron and are emitted from the nucleus with a continuous range of energies up to some maximum energy (for example, ^{22}Na emits positrons, ^{32}P, ^{3}H, ^{14}C, ^{35}S and ^{131}I all emit negatrons).
- **Gamma rays** – electromagnetic radiation emitted from the nucleus with discrete energies (for example, ^{131}I, ^{125}I, ^{57}Co, ^{51}Cr, ^{137}Cs).
- **X-rays** – electromagnetic radiation emitted from the electron shells of an atom with discrete energies (for example, ^{131}I, ^{125}I).

Two other types of radiation are generated in the material surrounding the radioactive atoms rather than by the radioactive atoms themselves. These are external bremsstrahlung and annihilation radiation.

- **External bremsstrahlung** consists of photons created by the acceleration of changed particles in the electromagnetic field of the nucleus. The photons are emitted with a continuous range of energies up to the maximum energy of the charged particle. For example, when phosphorous-32 (^{32}P) beta particles interact with certain materials, for example, lead, significant external bremsstrahlung radiation fields can be generated.
- **Annihilation radiation** consists of two 0.511 MeV photons formed by the mutual annihilation of a positive beta particle and an electron. For example, when sodium-22 (^{22}Na) positive beta particles interact with matter, annihilation radiation is emitted.

Energy of Radiation

The energy of radiation is typically given in units of electron volts (eV), kiloelectron volts (keV) or megaelectron volts (MeV). The energy of a discrete radiation, such as a gamma ray, may be expressed as "it emits a 1MeV gamma ray." A similar statement for a continuous radiation, "it emits a 1MeV beta particle," is ambiguous because it could be referring to a mean energy of the beta particle spectrum, etc. To avoid this problem, the energy must be specified in this way: "It emits a beta particle with a maximum energy of 1MeV."

The intensity of a radiation is the fraction of all decays that emit a particular radiation. For example, every time an ^{3}H atom decays, it emits a beta particle with a range of energies up to a maximum energy of 18keV. The intensity of this beta is, therefore, 100%.

Physical, Chemical and Biological Properties of Radionuclides

The fact that a material is radioactive seldom changes its other physical, chemical or biological properties. For example, a volatile iodine solution remains volatile if it is iodine-131; carbon-14-labeled methane burns like methane; and ^{3}H labeled glucose is metabolized like glucose. This property is what makes radionuclides so useful for biological tracer studies. Knowledge of this property can be used to the advantage of a radiation protection program.

Some sources are stored in containers that are meant to be opened to permit the material to be removed. These are called "unsealed" sources. Other sources, not designed to be opened, are appropriately called "sealed" sources. Working with unsealed sources presents a much higher risk of contamination than working with sealed sources. Therefore, special precautions must be observed.

Sources of Radioactive Material

Radioactive material can be

- **reactor-produced (by-product) material**
- **accelerator-produced material**
- **naturally-occurring material**

Radioactive material produced in nuclear reactors (i.e., by the fission process itself or by the neutrons emitted) is called reactor-produced or by-product material. By-product material is regulated by the United States Nuclear Regulatory Commission or an agreement state. Many of the radionuclides commonly used in biological research, ^{3}H, ^{14}C, ^{35}S, ^{32}P, ^{125}I, ^{33}P and ^{131}I, are by-product materials.

Radioactive materials produced by charged particle accelerators are called accelerator-produced materials (e.g., ^{22}Na, ^{57}Co and ^{111}In).

A naturally-occurring radioactive material is any radioactive material that occurs naturally on earth. All naturally-occurring radioactive material is regulated by each state, with the exception of the following, which are regulated by the United States Nuclear Regulatory Commission: "source" material (uranium, thorium and ores that contain greater than 0.05% uranium or thorium by weight) and "special nuclear material" (uranium enriched in ^{233}U or ^{235}U). A good example of state-regulated naturally-occurring radioactive material is radium-226.

WHY IONIZING RADIATION IS POTENTIALLY HAZARDOUS

To work safely with radioactive materials, it is necessary to have an understanding of the potential hazards they pose and how to avoid these hazards.

Ionizing radiation imparts energy to living cells. In large enough doses, this energy can damage cellular structures, such as chromosomes and membranes. If not repaired, this damage can kill the cell or impair its ability to function normally. Whether this damage is harmful depends on many factors, including the type of cell, the absorbed dose and the rate of absorption.

Effects of High Doses of Radiation

Individuals and populations exposed to high doses of radiation display various types of detrimental effects. In some cases, the severity of these effects in an individual is proportional to the dose delivered – the higher the dose the greater the severity. Examples of such proportional effects are erythema (reddening of the skin), epilation (loss of hair), cataracts and "acute radiation syndrome." These are known as deterministic effects and they all display a threshold: below a certain dose, no effects are observed.

Serious birth defects caused by irradiation of the fetus or embryo appear to exhibit a threshold at approximately 5 rem, the incidence of birth defects is not significantly different from the normal incidence. To prevent the occurrence of radiation-induced birth defects, the United States Nuclear Regulatory Commission requires radiation exposures for pregnant workers to be kept under 0.5 rem for the pregnancy period.

Another important type of effect is radiation carcinogenesis. The incidence of radiation-induced carcinogenesis in a population is assumed to be proportional to dose. It is assumed that these effects occur without threshold and that there are no effects only when the dose is zero. This has been observed in heavily irradiated populations such as the survivors of the Hiroshima and Nagasaki bombings, where an increase in cancer has occurred.

Radiation mutagenesis is the induction of changes in hereditary traits caused by radiation damage to the chromosomes. All such hereditary changes are assumed to be detrimental to the survival of a person's descendants. Radiation mutagenesis has never been observed in any irradiated human population. This does not mean that no genetic damage has occurred. In fact, data from animal studies suggest otherwise. Rather, the absence of observable effects in humans suggests that the genetic effects of radiation are too subtle to detect amidst the normal background of mutations in the human population.

Occupational Exposure to Radiation

Occupational dose limits are tens to hundreds of times lower than the threshold doses for deterministic effects. Therefore, such effects occur only as a result of accidents, radiation therapy and acts of war.

Radiation mutagenesis and carcinogenesis are assumed to occur without threshold. In other words, these effects are assumed to occur to some degree in any irradiated population, not just highly irradiated populations. The primary hazards of occupational exposure to radiation are assumed to be an increase in the incidence of radiation mutagenesis and carcinogenesis in the worker population.

It is important to note that no statistically significant increase in these effects has ever been observed in a regulated worker population. Statistics show that the risk, if any, is small compared to the other health or safety hazards of the workplace.

References

Brent, Robert L., "Radiation Teratogenesis," Teratology (21) 281-298, 1980.

National Academy of Sciences – National Research Council, Committee on the Biological Effects of Ionizing Radiation (BEIR, V), Health Effects of Exposure to Low Levels of Ionizing Radiation, National Academy Press, Washington, D.C., 1990.

RELATIVE RISKS OF LOW-LEVEL RADIATION

As with any chemical, the small quantities of radioactive materials used in medicine and research demand care in handling, but the risk to human health is surprisingly small when compared to experiences in everyday life.

As simple an act as crossing the street carries some risk. Certainly, all work situations carry some risk of personal injury. Working with radioactive materials is not hazard-free, but when placed in the proper perspective of other living and working environments, the occupational dangers are seen to be slight.

The Mathematical Concept of Risk

A risk is the mathematical probability that an injury, damage or other detrimental event will occur. Risks are usually calculated by observing a group of people and counting the number of times a detrimental effect occurs. The risk of the detrimental effect occurring is the number of events divided by the number of people in the group.

For example, assume that there are 150 million drivers in the United States and that 50,000 are killed in automobile accidents each year. The average risk of death from automobile accidents for each driver is 150,000,000 ÷ 50,000, or one in three thousand per driver per year.

However, calculating the risk of contracting cancer as a result of working with radioactive materials cannot be done in such a simple way. At the low levels associated with medical and research applications, no link between cancer and occupational exposure has been observed. In other words, people who work with radiopharmaceuticals and comparable materials show about the same rate of cancer as the population in general. That is not to say no risk is present. It means that the risk from occupational radiation exposure is so small that it cannot be measured directly. Instead the risk is estimated from observations of people who have been exposed to high doses of radiation. These estimates are intended to be conservative; the actual risk may be much lower.

Comparison of Risks

Another way to express the risk of an action is to compute the extent to which one's life may be shortened as a result of that action. This is done by a formula that compares average life expectancy with life expectancy given the occurrence of certain events. In general, the assumption is that the less an event shortens one's life, the less the risk.

REGULATION OF RADIOACTIVE MATERIALS

In the United States, a variety of regulations at the local, state and federal levels work together to ensure effective control of low-level radioactive materials used in medicine and research.

The procurement, possession, transportation and use of radioactive materials are regulated by government agencies at the local, state and federal levels. Which agencies regulate a particular activity depends on the activity, type and quantity of radioactive material, and the geographic location.

This guide is designed to provide information on these regulations to people who work with radioactive materials.

Federal Regulations

Federal regulations are issued in the Code of Federal Regulations (CFR). Current updates are given in the Federal Register.

The United States Nuclear Regulatory Commission (USNRC) regulates the procurement, possession and use of radioactive materials produced in nuclear reactors. Relevant regulations from Title 10 of the Code of Federal Regulations are summarized below.

10 CFR 19: Notices, Instructions, and Reports to Workers; Inspections

- Lists documents that must be posted for inspection by employees.
- Sets requirements for training employees.
- Sets requirements for informing employees of dose equivalents received from internal and external sources.
- Establishes the right of an employee representative to be present at USNRC inspections; for employees to consult privately with the USNRC; and for employees to request an inspection.
- Establishes legal rights of USNRC to impose civil and criminal penalties, revoke licenses and obtain injunctions for violations of the regulations.
- Establishes the right of a licensee to request an exemption from specific requirements of the regulations.

10 CFR 20: Standards for Protection Against Radiation

- Establishes the right of the USNRC to regulate total dose equivalents received from licensed and unlicensed radioactive materials.
- States that all exposures to radiation must be maintained as low as reasonably achievable (ALARA).
- Lists dose equivalent limits for occupational and nonoccupational exposure to radiation.
- Lists occupational radioactive material intake limits.
- Lists effluent concentration limits for release of radionuclides to the environment.
- Excludes medical procedures from Part 20 regulations.
- Establishes need for surveys and personnel monitoring.
- Lists monitoring requirements.
- Lists procedures for receipt of packages containing radioactive material.
- States procedures for waste disposal and for control of radioactive material.
- Lists requirements for records and reports.

10 CFR 30: Rules of General Applicability to Domestic Licensing of By-Product Material

- Establishes to whom general and specific licenses for radionuclides are issued and for what purposes.
- Regulates the transfer of licensed materials.
- Lists reporting requirements.
- Establishes recordkeeping requirements for inspections, tests, procedures and reports.
- Establishes control and reporting procedures for licensees handling large quantities of tritium (more than 10 Ci (370GBq) at a time).
- Discusses enforcement of license conditions and penalties for violations (similar to that in 10CFR20).
- Specifies possession limits which if exceeded require licensees to maintain a formal emergency plan for responding to an off-site release of radioactive material.
- Specifies possession limits which if exceeded require licensees to submit a decommissioning funding plan.
- Specifies financial assurance requirements to ensure capability to implement a decommissioning plan.

Regulation of Radioactive Materials (contd.)

10 CFR 31: General Domestic License for By-Product Materials

- Details those radionuclides and devices containing radioactive materials that are generally licensed.

10 CFR 33: Specific Domestic License of Broad Scope for By-Product Materials

- Lists types of broad-scope specific licenses available and the requirements and scope of each.

10 CFR 71: Packaging of Radioactive Materials for Transport and Transportation of Radioactive Materials Under Certain Conditions

- Establishes requirements for the transportation and packaging of licensed by-product materials.

Transportation and Mailing Regulations

The United States Department of Transportation (USDOT) regulates the transportation of radioactive materials once they have left a licensed establishment. These regulations, which are in addition to those given in 10 CFR 71, are listed in 49 CFR.

40 CFR 173 SUBPART I – RADIOACTIVE MATERIALS COVERS THE FOLLOWING:

- Required package design.
- Radiation levels and contamination limits for packages and vehicles.
- Thermal limits for packages.
- Package labeling requirements.
- Requirements for shipment of fissionable materials.

The United States Postal Service regulates the shipment of radioactive materials in the mail. 39 CFR 124 covers the following:

- What types and quantities of radioactive material my be shipped in the mail.
- Packaging requirements.

OSHA Regulations

The Occupational Safety and Health Administration (OSHA) of the United States Department of Labor has regulations in 29 CFR concerning occupational exposure to ionizing radiation for those not regulated by other federal or state agencies.

29 CFR 1910.96, Ionizing Radiation covers the following:

- Standards for exposure to ionizing radiation and radioactive materials.
- Requirements for informing and training workers (similar to regulations given in 10CFR19 and 10CFR20).

State Regulations

States typically regulate radioactive material and sources of radiation not regulated by the USNRC. These include X-ray machines, accelerators, radium, etc. A state can assume the responsibility for regulating by-product material by agreement with the USNRC, thereby becoming an "Agreement State." State regulations are usually equally or more restrictive than equivalent USNRC regulations.

Local Regulations

In addition to the regulations cited above, there may be applicable city or municipal restrictions on the transportation of radioactive materials.

Procedures and Devices for Measuring Personal Dose

In working with radioactive materials, careful monitoring of the amount of ionizing radiation delivered to your body allows you to verify that safe practices are being followed.

The risks of working with radioactive materials are reduced to acceptable levels by engineered and procedural controls. The monitoring of personal dose equivalents is an important method to verify that these controls are effective.

Radiation protection dosimetry can be divided into two categories:

- External dosimetry, where the radiation source is outside the body and the biological properties of the source do not influence the dose equivalent received.
- Internal dosimetry, where the radiation source is inside the body and the dose equivalent received depends on the biological properties of the source.

External Dosimetry

External dosimetry is commonly performed by one or both of the following methods:

- You wear an integrating dosimeter (a "personal" dosimeter) that indicates the dose equivalent at a point on the body.
- The dose equivalent is estimated by considering the dose equivalent rate in the area and how long you worked there. The dose equivalent rate might be measured or calculated.

Personal Dosimeters

The most common personal dosimeters are a film dosimeter, thermoluminescent dosimeter (TLD), optically stimulated luminescent dosimeters (OSLD) and pocket ionization chamber (PIC or "pencil dosimeter").

Film dosimeters consist of a small piece of photographic film in a light-proof package. Filters are placed over the film to obtain information about the type and energy of the incident radiation. This information is needed to adjust the dose equivalent indicated by the film because the film does not respond to radiation in exactly the same way as tissue. Film dosimeters fade and are sensitive to heat. They have the advantages of being relatively inexpensive and providing a permanent record of the dose equivalent received.

TLDs are small inorganic crystals that, when heated, emit a quantity of light. Under certain conditions, the light emitted is proportional to the energy deposited in the crystal. TLDs are small, rugged, reusable and respond to most types of radiation in the same way as tissue. However, TLDs are more expensive than film dosimeters and do not provide a permanent record of the dose equivalent.

OSLDs are similar to TLDs except that the absorbed radiation energy is released by laser light instead of heat. These dosimeters are also small and rugged, can be reanalyzed and are more sensitive than TLDs.

PICs are small ionization chambers that are relatively expensive and not very rugged. Direct reading PICs may be read in the field without erasing the accumulated dose. This provides an immediate reading of the dose equivalent being received during an operation, which is very helpful in reducing doses.

Personal dosimeters should be worn on the part of your body that receives the greatest dose in relation to its dose limit. Preferably, several dosimeters should be worn at key locations. Dosimeters should be stored in an area where there is a low, constant background. They should be kept free of contamination.

Estimating Dose Equivalents

The dose equivalent you receive can be estimated by measuring the dose rate with a survey meter and multiplying by the length of time you stay in the radiation field. This method is useful for estimating the magnitude of the dose likely to be received. However, problems can arise when the dose equivalent rate is incorrectly measured, the dose equivalent rate measured is not representative of the radiation fields where you work or the time you will spend in the field is underestimated.

Internal Dosimetry

The distribution and retention of a radioactive material will influence the dose equivalent received once it is inside the body. Therefore, in internal dosimetry, you don't try to directly measure dose; instead, you characterize the distribution and retention of the radioactive material. Once this is known, the dose equivalent can be readily calculated using standard internal dosimetry methods.

Procedures and Devices for Measuring Personal Dose (contd.)

The distribution and retention of radioactive material in the body is commonly estimated in three ways:

- The quantity of radioactive material that enters your body is monitored, and Reference Man biokinetic models are used to estimate the distribution and retention of the radioactive material.
- The rate at which radioactive material is excreted from your body is monitored over a period of time, and Reference Man models are used to estimate the distribution and retention of the radioactive materials.
- The quantity of radioactive material in a particular region or organ of your body is directly monitored over a period of time and the dose equivalent to that organ is estimated.

Monitoring Methods

Air sampling near the breathing zone is an acceptable method of monitoring the intake of radioactive material. To produce reasonable results, it is important to obtain a representative sample of the air you breathe. For example, if the room air concentration is not uniform, the air should be sampled as close to the "nose" as possible.

A practical method of monitoring the excretion of a radioactive material is urine bioassay. This method is not very useful for those radioactive materials that are not readily excreted. Steps should be taken to keep bioassay samples free from extraneous contamination. For example, bioassay samples should be submitted away from the workplace in a contamination-free area.

Thyroid monitoring for radioiodine is one of the best examples of directly determining the quantity of a radioactive material in an organ. Direct monitoring for radioactivity in a specific organ or the whole body can be effective, provided that the radioactive material emits radiation that can be easily detected from outside of the body and when there is no external contamination of the body.

Monitoring Requirements

The Nuclear Regulatory Commission regulations require that occupationally exposed individuals must be monitored for external or internal dose if it is likely that they will receive an external or internal dose exceeding ten percent of the applicable regulatory limits.

If the licensee is required to monitor any individual for both internal and external dose, then these doses must be summed to determine compliance with the applicable dose limit.

Dose Limits

Nuclear Regulatory Commission occupational dose limits are specified for a calendar year as follows:

Whole body – 5 rem

Any individual organ, skin or extremity – 50 rem

Lens of the eye – 15 rem

Occupation dose limits for minors are set at 10% of the above limits.

The dose limits for an embryo/fetus of an occupational exposed woman who declares in writing that she is pregnant is 500 millirem for the entire duration of the pregnancy.

Members of the public are limited to 100 millirem per year. Members of the public may be exposed to an additional 500 millirem per year, occasionally, from radiation from a patient who has been administered radioactive material.

All the above limits do not include exposure to radiation to patients from medical procedures or exposure to radiation in the environment due to consumer products, fallout or naturally-occurring radionuclides.

CONTROLLING EXPOSURE TO EXTERNAL RADIATION

Time, distance and shielding are the critical elements that must be controlled to ensure the protection of people who work with radioactive material that emit penetrating radiation.

External exposure is the irradiation of live tissue from sources outside the body. The following examples list some ionizing radiations that are capable of penetrating the dead outer layer of skin to reach live tissue:

- gamma rays (e.g. from ^{22}Na, ^{51}Cr, ^{125}I, ^{131}I)
- photons from positron annihilation (e.g. from ^{22}Na)
- beta particles with energies greater than about 100 keV (e.g. from ^{32}P, ^{90}Y)
- bremsstrahlung (e.g. from ^{32}P, ^{90}Y)
- x-rays (e.g. from ^{125}I)

The primary objective in controlling external exposure is to minimize the accumulated radiation dose. The committed dose may be reduced by reducing either the dose rate or the time of exposure. The dose rate can be reduced by placing shielding material between the source and you or by placing the source at a greater distance from you.

Time

The time of exposure to penetrating radiation can be reduced by planning operations or by using special procedures during operations.

Planning Operations

- Review the safety aspects of the operation in detail.
- Carry out trial runs with no or low levels of radioactivity.
- Design operations to be a sequence of simple steps that can be accomplished quickly and safely.
- Adjust equipment to ensure that you are comfortable when handling radioactivity.

During the Operation

- Equipment should be assembled before introducing the radiation source.
- The dose rates at various steps in the operation should be monitored or known to ensure that effort is concentrated to reduce time of working in high radiation fields.
- Operations that do not require proximity to radioactive materials – for example, paperwork or resting – should be carried out away from the radiation areas.
- Work with a sequence of sources, one at a time rather than in the presence of large sources of penetrating radiation.
- Regularly monitor and promptly remove contaminated gloves.

Distance

Ionizing radiation spreads through space like light or heat. Generally, the farther you are from a source of radiation the lower your dose rate.

Distance is very useful for protection when handling physically small sources. The dose rate from a small source is inversely proportional to the square of the distance from the source.

This "inverse square law" means, for example, that if the distance from the source is doubled, the dose rate will be one fourth.

If you get too close to a source, the dose rate can increase substantially. The dose rate at 0.1 inch from a small source will be 10,000 times higher than 10 inches from the source.

Since detectors used to measure dose rates tend to average the dose rate over the sensitive volume of the detector, large detectors will tend to underestimate dose rates close to a small source. A small detector such as a thermoluminescent dosimeter chip can be used to give a more accurate estimate of dose rates near a small source.

Methods for Reducing Exposure

The following methods can reduce exposure by increasing the distance between the operator and the source:

- Avoid direct handling of sources of penetrating radiation. Never directly handle unshielded multi-millicurie sources.
- Use forceps, tongs, custom-designed holders and spacers to maintain distance between your hand and the source.
- Design simple tools for securely handling sources (e.g. a Lucite block with cylindrical holes to hold a vial).
- Routinely store sources at the back of benches and ventilated enclosures remote from normal access.

Controlling Exposure to External Radiation (contd.)

Shielding

There is a variety of shielding materials that can be placed between you and the source to absorb most of the radiation that would otherwise reach you.

The choice of shielding material depends on the type of radiation and other functions served by the shields (such as containment, transparency or structural support).

Dense materials with high atomic numbers, such as lead, form the most effective and compact shields for small sources of penetrating radiation. Because beta rays are less penetrating than other rays, pure beta ray emitters can be effectively shielded by lighter materials such as glass, water or Lucite.

When high energy beta rays are emitted and absorbed, secondary x-rays and bremsstrahlung radiation are generated. The intensity of this secondary radiation increases if the beta rays are absorbed in high-atomic-number shielding material. This secondary radiation is more penetrating than the beta rays. When large quantities (i.e. greater than 100 mCi, or 3.7 GBq) of a pure beta emitter like ^{32}P are used, the quantity of secondary radiation may be excessive unless shielded. The best shielding configuration in this case is to use a 1/2-inch-thick Lucite acrylic sheet, or similar material, adjacent to the ^{32}P to absorb the beta rays, while minimizing the creation of secondary radiation. Use sheets of lead foil outside the shields of Lucite to absorb the more penetrating bremsstrahlung and x-rays.

Methods for Reducing Exposure

Methods to reduce exposure by using shielding materials include the following:

- When planning an operation, calculate the shielding needs using half-value layers and gamma-ray constants or dose-rate measurements.
- Check the adequacy of shields in all directions accessible to personnel by monitoring around (and especially beneath and behind) the operation.
- Store radioactive materials emitting penetrating radiation in lead containers with lead lids.
- Where space permits, concrete blocks may be used to enclose a radioactive storage area.
- Use mirrors, periscopes or transparent shields – for example, lead glass windows – to view operations. Avoid direct viewing by peering around shadow shields.
- Use a rigid frame to secure potentially-unstable shielding materials.
- Use custom-designed shields for syringe barrels when millicurie quantities are being handled.
- Avoid direct exposure to high-energy, beta-emitting sources. The dose rate to the skin from beta rays is 10 to 100 times as high as for gamma rays of the same energy and intensity.
- Whenever practical, use dilute solutions of high energy beta-emitting radionuclides since the larger volume of liquid will effectively absorb more of the beta rays.

PREVENTION OF INTERNAL RADIOACTIVE CONTAMINATION

The better the procedures for preventing contamination, the lower the risk to everyone working with low-level radioactive materials.

The main objective of controlling radioactive contamination is to prevent internal doses to workers. The primary means of contamination control is to prevent it by containing the radioactive materials during all handling phases. Other procedures should be followed when containment is impractical or as additional safety measures.

Radioactive contamination can enter the body by ingestion, inhalation or absorption through intact or damaged skin. To prevent internal exposure, it is necessary to intercept each of these contamination routes.

Preventing Ingestion

Intake through ingestion can be minimized by ensuring that potentially-contaminated objects are not placed in the mouth. In areas where unsealed radioactive materials are handled, do not eat, drink, smoke, apply cosmetics, pipette by mouth or place fingers, pens and pencils in your mouth.

Physical barriers can prevent accidental ingestion due to explosion or splashing.

Preventing Inhalation

Inhalation intakes can be prevented by ensuring that radioactive materials are secured in sealed containers. Suitable containers include NENSure™ vials, crimp-sealed vials, flame-sealed ampules or vacuum systems and vessels vented through traps or filters.

When sealed systems are impractical or additional precautions are necessary, radioactive materials that could become airborne should be handled in ventilated enclosures, such as fume hoods. Fume hoods provide protection by drawing air past the worker into an enclosure and safely exhausting it. In this process, small releases are diluted to negligible concentrations by the air flow.

Fume Hood Precautions

Be sure you know how to correctly operate a fume hood. Precautions include:

- Minimize the area of the window opening to maintain an air flow velocity of about 100 linear feet per minute. Avoid excessive velocities at the face of the fume hood in order to prevent turbulence.
- Check the fume hood for proper function before use. Adequate air flow can be indicated by a paper vane suspended from the upper edge of a window opening.
- Keep your head out of the fume hood and keep the sash in the closed position when processing radioactive materials.
- Keep equipment and operations toward the rear of the fume hood to avoid impeding the flow of air through the window.
- Avoid sudden movements at the fume hood face, which could draw contaminated air into the laboratory.
- Protection can be enhanced by providing a small window for each arm separated by a panel that acts as a barrier between your breathing zone and the fume hood interior.
- Use a glove box when the risk of airborne contamination is too high for the use of a fume hood. Protection is provided by maintaining the glove box at negative pressure and ensuring that the gloves are in good condition. Additional protection could be provided by wearing a respirator. This method is not recommended except as an aid in emergency recovery operations where large quantities of radioactive material are involved.*

Preventing Skin Absorption

Skin contamination is best prevented by using tools to avoid direct contact with potentially-contaminated objects and to prevent submersion in airborne radioactivity. Additional protection can be provided by using splash guards and by wearing gloves, a lab coat and other protective clothing.

Avoid sharp objects and handle syringes carefully to prevent inadvertent self-injection.

Special considerations should be given to protecting damaged skin. Open wounds or rashes should be covered or you should consider postponing operations until your skin has healed.

Regular checks should be made to ensure that skin contamination is quickly recognized. In the event of contamination of the skin, exposure of the skin and absorption can be minimized by promptly decontaminating the affected area.

Prevention of Internal Radioactive Contamination (contd.)

Other Internal Exposure Considerations

Other internal exposure considerations include:

- Minimize the quantity of radioactivity in process by designing operations appropriately.
- Remain aware of your internal exposure by performing appropriate bioassays. For operations where small quantities of radioactivity are handled, this may only be necessary as an initial check to show that exposure is negligible.
- Make sure safety procedures address accident potential and specify appropriate action, since the risk of internal exposure may increase under accident conditions. When large sources are spilled or released, personnel should leave the immediate vicinity. Proper recovery operations should be planned with the radiation safety staff to maintain exposure controls.
- Contamination controls are necessary for all unsealed sources, including low-energy beta emitters such as ^{3}H, ^{14}C, ^{35}S and ^{63}Ni. Unlike external exposure where skin and clothing can shield the body from non-penetrating radiation, all radioactive materials can contribute to an internal dose when taken into the body.

* *For an understanding of the complex training and respirator selection and maintenance requirements, consult Nuclear Regulatory Commission Regulatory Guide 8.15, Revision 1, "Acceptable Programs for Respiratory Protection," Washington, D.C. October 1999.*

PROTECTIVE CLOTHING WHEN HANDLING RADIOACTIVE MATERIALS

The best way to control potentially hazardous materials is at the source. However, protective clothing provides a good level of secondary protection.

If protective clothing is to be effective, it must be worn at all times. It must be worn properly, it must be the right fit and it must be in good condition.

Protecting Your Body and Clothing

Any time you are in an area where unsealed sources of radioactive material are being used, wear a lab coat. A lab coat, properly fastened, will protect against casual contamination. However, it is not effective against spills or splashing and it does not protect your head, neck, hands or feet.

Disposable lab coats are best for working around long-lived radionuclides. Reusable lab coats are acceptable when handling short-lived radionuclides, provided they are stored for a sufficient time to permit decay of any contamination prior to being washed.

Both cloth and disposable lab coats may be reused if they are free from contamination and in good condition. They should be stored in a controlled area and you should monitor lab coats both during operations and after removing them. Particular attention should be paid to the sleeves, pockets and lower front surfaces of the coat.

All lab coats should be fire-resistant.

Waterproof aprons, full-body jump suits and hoods provide additional protection in environments where the potential for more severe contamination is present.

Gloves

Whenever your hands are near unsealed radioactive material, you should wear gloves.

Gloves are secondary protection only. They should not be used to handle radioactive materials directly. When you no longer need gloves, they should be carefully removed, monitored and disposed or stored appropriately.

Rips or holes make gloves ineffective. Be careful working around hot surfaces, sharp objects or chemicals that can attack the glove material.(1)

Periodic changes of gloves are recommended. The greater the potential hazard, the more frequent a change of gloves is needed. Wearing two pair of gloves and frequently changing the outer pair is also a good safety practice.

Gloves should be monitored frequently. Don't use contaminated gloves or gloves that may be contaminated. If you are wearing gloves and they are exposed to radionuclides that emit penetrating radiation, remove the gloves as quickly as possible to minimize skin exposure. This is particularly important when handling high-energy beta emitters.

Footwear

Don't wear sandals or open-toe shoes. Comfortable, sturdy footwear should be selected that will protect against contamination or injury due to broken glass or corrosive materials. In some cases, steel-toed shoes may be desirable to protect against physical hazards.

In controlled areas where low-level floor contamination is a potential hazard, a separate pair of work shoes for use only in that area is a good idea. Disposable shoe covers of plastic or paper are available to prevent contamination of ordinary shoes. However, these can wear through rapidly and can be slippery.

Eye and Face Protection

Safety glasses provide protection for your eyes and face; however, remember that this is secondary protection only. Safety glasses are of some use in protecting against low-penetration radiation, such as low-energy x-rays and medium-energy beta particles but provide little protection from penetrating gamma radiation.

Respiratory Protection

Contain operations that create radioactive dust, vapor or gases. Vented enclosures with protective filters are available for such operations. Use of respiratory protection devices in lieu of such primary controls is not advisable.

In cases where entering a contaminated zone is unavoidable or in emergency situations, respiratory protection may be necessary. It may also be useful for certain decontamination operations.

If you wish to use respiratory protection, you first must have a medical examination. Also, you must be trained in the proper selection, fitting, operation and maintenance of the devices. Safety and medical departments within your organization are responsible for issuing authorizations to use respiratory protection and for maintaining records.(2)

References and Related Readings

1. Guidelines for the Selection of Chemical Protective Clothing, 3rd Edition, Feb. 1987, American Conference of Governmental Industrial Hygienists, Cincinnati, OH.
2. 29 CFR 1910.134 Respiratory Protection.

CONTAMINATION CONTROL

The best and most economical way to ensure the safety of people working with unsealed radioactive materials is to provide adequate controls and procedures for the containment of radioactivity.

Radioactive chemicals behave similarly to non-radioactive chemicals and are available in a variety of physical forms, including powders, liquids and gases. Because of their radiological properties, good control must be maintained over quantities of material that are sometimes invisible to the unaided eye.

It is safer, more economical and more effective to control contamination at the source than to attempt to decontaminate areas, equipment and personnel on a larger scale. Proper handling precautions serve as the primary barrier to prevent the spread and subsequent adverse effects of contamination. The primary objective of securing radioactive materials is to prevent internal doses to personnel from contamination that enters the body. Additional objectives include:

- Preventing external exposure to penetrating radiation from contaminated surfaces, clothing, skin or air.
- Minimizing releases of radioactive material to the environment.
- Preventing loss or cross-contamination of radiochemicals.
- Maintaining radioanalytical equipment free from contamination.
- Maintaining working areas free from contamination build-up, which would make it difficult to determine sources of contamination.

Sources of Contamination

The potential always exists for releasing radioactive materials. Vessels explode, implode, break, get dropped or get knocked over. You should also be aware of less visible sources of contamination, such as: released volatiles and aerosols; leakage and spattering during disconnection or opening of vessels; and material being transferred between open vessels.

Empty containers, waste materials and objects in the vicinity of unsealed radioactive materials should be viewed as potential sources of contamination.

Unless precautions are taken, contamination will rapidly spread by transferring contaminated objects or by touching them or by walking through contamination on the floor. Air currents can move airborne contamination to places distant from the original source.

Containment of Radioactive Material

The primary means of preventing contamination is to confine radioactive materials in sealed containers and closed systems. Sealed containers should always be used to store radioactive materials or to transfer them between work areas.

Containers should be designed to remain intact in an accident. The use of double containment is good practice. Inspect all equipment used to handle radioactive materials prior to use to ensure that it is free from defects that might cause leaks or spills.

Avoid breakage and spillage by securing vessels with clamps and massive stands. Keep containers closed when not in use.

Assume that radiochemicals (especially high-specific-activity beta emitters) will generate volatile components in storage unless tests have shown this to be of negligible concern. Prior to opening a container, remove volatile components by purging or venting through an appropriate filter, adsorber or cold trap. It may be useful to apply cryogenic techniques to condense any volatile components and prevent them from escaping.

Control of Surface Contamination

Surface contamination should be confined by using spill trays and absorbent coverings.

Keep areas designated for handling radioactive materials free of non-essential equipment. Surfaces in the vicinity should be easy to clean or protected by cleanable or disposable coverings.

Frequently monitor clothing, equipment and surfaces to ensure early detection of contamination during or upon completion of an operation. When practical, any surfaces found to be contaminated should be decontaminated promptly, especially if this effectively removes a significant source of exposure to you.

Potentially contaminated gloves should be disposed of properly or left in the work area, unless monitoring indicates that they are not contaminated.

Non-volatile radioactive materials can be safely handled in open containers. Care should be taken to prevent spillage when opening or handling the container.

Carefully transfer materials between containers. Avoid pouring. Instead, use pipettes and syringes, and slowly discharge the contents deep within the container to minimize the release of aerosols.

Inadvertent discharge of radioactive materials to the sewer should be prevented by procedural controls requiring segregation, assay and labeling of all materials and vessels placed near a laboratory sink.

Control of Airborne Contamination

Airborne contamination can result from released volatiles, from aerosols resulting from welding, grinding, or drilling of sealed sources and from disturbing coverings or surfaces where spilled liquids have been allowed to dry.

Handle potentially-volatile radiochemicals in ventilated enclosures rather than on an open bench. Fume hoods should be closed, except when it is necessary to gain access to set up equipment.

Traps and filters should be changed regularly and sealed before disposal as radioactive waste. Consider "bag-out" procedures for removing potentially-contaminated objects from a ventilated enclosure.

Conservative estimates of exhaust air concentration can be calculated by dividing the annual radioactivity processed by the volume of air discharged. Regulatory compliance can be demonstrated by keeping records indicating that environmental airborne concentrations do not exceed small fractions of the regulatory limits.(1)

When sufficiently large quantities are processed that could cause airborne concentrations that approach regulatory limits, consider installing continuous air sampling equipment to measure these concentrations.

It may be necessary to reduce emissions by suitable filters, adsorber beds or scrubbers. However, these steps should be avoided or considered to be only secondary means of protection. Improve controls at the source wherever possible.

When handling potentially volatile radiochemicals, use appropriate fixed and personal air monitors to maintain awareness of environmental and laboratory air conditions. This may be necessary only as an initial check in operations when air concentrations are expected to be negligible.

Contamination Control Zones

Handle radioactive materials only in designated areas. These areas should be conspicuously posted to warn people entering the areas.

When you leave the area where radioactive materials are handled, monitor and remove protective clothing, monitor your street clothes and exposed skin, wash your hands thoroughly and monitor again. All items, including personal belongings removed from the control zone, should be monitored and decontaminated before release.

Contamination control action levels should be established for each radionuclide and personnel should be trained to recognize when these are exceeded. Action might include immediate decontamination, investigation to determine the cause, call for assistance or the submission of samples for bioassay.

Other Contamination Control Considerations

Some other contamination control considerations include:

- **Operations should be designed to minimize the quantity of radioactivity in process**. In planning operations, devote special care to avoid generating volatile compounds and other conditions that may cause contamination.
- **At the end of the day, or on completion of an operation, all sources should be properly contained and stored**, equipment secured, and waste properly disposed of. The work area should be monitored and cleaned.
- **Safety procedures should address contamination potential under accident conditions and maintenance operations and specify appropriate actions** because the risk of contamination may increase under these conditions. Where large sources could be spilled or released, provide for prompt security of the affected area and plan recovery operations with radiation safety staff members to ensure that contamination controls are maintained.
- **Be aware of fixed surface contamination and consider appropriate controls**. Generally, fixed surface contamination represents an external exposure only. However even fixed contamination can become removable due to surface wear.
- **Before starting an operation, review in detail written procedures that include safety considerations**. Consider performing trial runs with no or low-levels of radioactivity before progressing to a new, full-scale run.
- **Good contamination controls can be maintained** by carefully following tested procedures and observing extreme cleanliness in the area.

References

1. Code of Federal Regulations Title 10, Part 20 Appendix B, Table 2, Column 1, U.S. Government Printing Office, Washington.

DETECTION OF CONTAMINATION

Contamination by radioactive materials can be prevented with proper safety precautions. However, if an accident should occur, appropriate steps must be taken to minimize the effects.

In facilities where radioactive materials are handled, you should regularly monitor yourself and your work area for fixed and removable contamination in order to:

- Ensure that contamination control is maintained.
- Ensure that contamination is not transferred to non-radioactive areas.
- Provide information about the effectiveness of contamination control measures.
- Prevent unnecessary personnel exposure resulting from intake of contamination.

Contamination can be removable, fixed or a combination of the two. Removable contamination may often represent a greater hazard than fixed contamination. Methods of detection should be used which can detect and differentiate between fixed or removable contamination.

The appropriate frequency and thoroughness of monitoring will depend on a variety of factors, including levels of activity handled, degree of containment and control exercised, training of radiation workers and whether the surveys are an official part of the license-required, radiation protection program.

Areas and items that should be monitored include hands, wrists, protective clothing, personal belongings, work surfaces, radioactivity processing and storage areas, heavy traffic areas, untidy areas and equipment and materials leaving radioactivity handling areas.

Selection of Appropriate Instruments

Identify those radionuclides which are handled, then select the appropriate instrument(s) based on the need for portability and the sensitivity of the instrument for the characteristic radiations emitted by the radionuclides in question. Use the table as a guide.

Instrument Selection Guide

Characteristic Radiation	Portable Instruments	Non-Portable Instruments
Low energy beta: ^{3}H, ^{63}Ni Medium energy beta; ^{14}C, ^{33}P, ^{35}S, ^{45}Ca	 $\underline{A}$, J	$\underline{H}$, $\underline{E}$, F $\underline{G}$, $\underline{H}$, E, F
Bremsstrahlung: ^{14}C, ^{33}P ^{35}S, ^{45}Ca High energy beta: ^{32}P, ^{90}Y	(C, D) $\underline{A}$, B, J	
Bremsstrahlung: ^{32}P Low energy gamma (or X-ray): ^{125}I	(C, D) $\underline{C}$, D	G, H, E, F $\underline{I}$, $\underline{H}$, (E, F, G)
Medium-high energy gamma: ^{131}I, ^{22}Na	$\underline{D}$, $\underline{A}$, $\underline{B}$, $\underline{C}$	I, $\underline{G}$, E, F, H

A = Ratemeter with end-window or pancake GM probe.
B = Ratemeter with thin wall GM probe.
C = Ratemeter with thin NaI (T1) scintillation probe.
D = Ratemeter with thick NaI (T1) scintillation probe.
E = Ratemeter with open-window gas-flow GM probe.
F = Open-window, gas-flow proportional counter.
G = Closed-window, gas-flow proportional counter.
H = Liquid scintillation counter (LSC) (or Liquid scintillation analyzer (LSA)).
I = Gamma spectrometer with semiconductor or scintillation detectors.
J = Ratemeter with plastic scintillation probe.
_ = Superior, ( ) = Limited usefulness

Additional instrument selection parameters include background radiation levels, degree of ruggedness and minimum detectability.

Portable instruments are often dedicated to a monitoring station where wipes and other items are brought for contamination monitoring.

Instrument Operation

Familiarize yourself with instrument operating instructions. Check for proper instrument function, including recent calibration, battery strength or operating voltage and response to check sources.

Monitoring for Contamination

To directly monitor a surface for contamination, bring the probe to within about one centimeter of the surface, being careful not to damage or contaminate the probe. If available, use the audio output to quickly locate contamination. Move the probe slowly over the surface. Adjust the meter range selector and observe the reading from a point directly above the meter face to ensure proper alignment of the needle and scale. Since the readout will fluctuate, look for the average value. High background levels may be overcome by partially shielding the probe or by selecting a probe less sensitive to the background radiation.

To test for removable contamination, for example on surfaces previously found contaminated with a portable survey meter, firmly smear the surface in question with a paper filter circle or any clean paper towel. A 4.25 cm-diameter filter is a convenient and commonly-used size. Avoid touching potentially-contaminated surfaces and wear gloves. Wipes can then be immersed in an appropriate scintillation cocktail – dirty side out – agitated and counted by LSC.

Alternatively, bring the wipe to the window of a GM or NaI probe and ratemeter and note any increase in the count rate. Do not move the probe if doing so causes a change in the background count rate. Wiping a standard surface area, such as 100 cm^2, yields results which can be compared from survey to survey. For instance, if wipes are held so that a 2 cm-wide path is firmly wiped, the length of the wipe should be 50 cm, thereby making the total area wiped equal to 100cm^2. A wipe survey is a qualitative, not a quantitative, indication of surface contamination. Maintaining a uniformity in the procedure will permit comparisons between wipes and between surveys, allowing trend analysis.

If cross-contamination of wipes is likely, wipes may be placed in individual envelopes prior to counting. Normally this can be avoided by careful handling. Collection of wipes can be performed quickly by attaching them lightly to a strip of two-sided tape mounted on a cardboard strip. If wipes are to be counted by LSC, do not mark directly on the wipe with any type of ink or organic-soluble marker.

Estimating Contamination Levels

The amount of radioactivity that has been detected by direct monitoring or by wipe survey can be readily estimated by subtracting the background count (bkg cpm) from the observed count rate (gross cpm) and then dividing the net count rate by the counting efficiency (c/d) for the radionuclide in question.

$$\frac{\text{(gross cpm)-(bkg cpm)}}{\text{efficiency}} = \text{net dpm}$$

Always express contamination levels in standard units such as dpm/100 cm^2 or microcuries/100 cm^2. If the identity of the radionuclide detected is not known, the most conservative (lowest) efficiency of the possible radionuclides should be used.

DECONTAMINATION PROCEDURES

Prevention of contamination is the best route to safety. However, you also need to be aware of personnel, equipment and area decontamination procedures.

Personnel Decontamination

Decontamination of personnel is necessary to prevent intakes by ingestion, inhalation or skin absorption, and to reduce the external exposure from radioactive material which remains on the skin or clothing.

To guide response and assess exposure, it is important to measure and document decontamination. Monitoring should be repeated after each phase or decontamination in order to assess the effectiveness of procedures.

Initial decontamination should be prompt and thorough, but it should employ only soap and water, or water flushing. Carefully perform decontamination to avoid the spread of contamination to floors and other surfaces. Properly dispose of contaminated waste generated during decontamination.

Decontaminating Skin

Decontaminate skin as follows:

1. Wet skin and apply soap.
2. Work up a good lather; keep lather wet.
3. Work lather into contaminated area by rubbing gently for two or three minutes. Apply water frequently.
4. Rinse area with tepid water.
5. Repeat procedure several times if necessary, using a soft brush to gently scrub the affected area. Discontinue before skin becomes abraded or sensitive. Apply hand cream if skin becomes chapped.
6. If your hands are contaminated, pay particular attention to monitoring between fingers and under nails. Clip nails if necessary to remove fixed contamination.

Only after several attempts with soap and water should harsher decontamination methods and cleaning agents be considered. These methods should be under the supervision of radiation safety and/or medical personnel. The benefits of decontamination should be weighed against the potential injury caused by harsher methods of decontamination.

Intensive Decontamination

Where large quantities of radioactivity are involved, decontamination of a grossly contaminated individual should be initiated immediately as follows:

1. Remove the individual from the contaminated area.
2. Use an emergency shower to rapidly wash off or dilute the contaminant. Watch out for slippery floors.
3. Remove contaminated clothing and isolate for later evaluation.
4. If necessary, flush eyes, ears, nose and mouth. Cotton swabs can be used to clean ear and nasal passages.
5. Provide a blanket or dry clothing to the individual and have them sit down when possible to avoid fainting due to the shock of the cold water and the stress of the situation.

If intake of contamination is suspected, consider the need to perform timely bioassays.

Equipment Decontamination

Effective decontamination of equipment permits it to be safely reused or disposed.

Decontamination agents and methods that minimize the volume of radioactive waste generated should be given preference. Avoid damage to the surface of equipment that will be reused because damaged surfaces will become more difficult to decontaminate in the future.

Perform decontamination as soon as possible after contamination to minimize fixation of the contaminant to the surface of the object.

Primary concerns in any decontamination situation are protecting personnel from exposure to radiation, contamination and harsh cleaning materials and preventing any spread of contamination.

Isolate the contaminated object in such a way as to prevent spread of contamination. Use a fume hood if the potential for airborne contamination exists. Post the area with a "Caution Radioactive Contamination" sign.

Monitor the object to determine contamination levels and locations, noting potential exposure hazards. Plan the decontamination procedure based on the nature, level and distribution of contamination.

Assemble all cleaning agents, tools, protective clothing and monitoring devices before initiating the decontamination.

Decontamination should proceed from the areas of lowest contamination to the area of highest contamination, unless prompt initial cleaning of the most contaminated area is necessary to reduce exposure. Monitor surfaces and personnel frequently during decontamination to ensure proper contamination control.

Properly package and label all waste generated, including potentially contaminated liquids, which should be assayed.

A final check of the equipment should be made to confirm that the contaminated levels have been reduced to acceptable levels. Monitor the work area and personnel once more. Consult with radiation personnel to determine whether submission of bioassay samples is appropriate.

Area Decontamination

Upon discovery of area contamination, promptly secure and post the area. Monitor to determine the full extent and nature of the contamination and determine if persons entered the contaminated zone.

For widespread, low levels of contamination, consider the appropriateness of using normal cleaning procedures using water and detergents. Considerations should include the quantity of waste water anticipated, ease of disposal, potential for generating airborne activity due to chemical action or disturbance of contaminate dust.

On completion of decontamination activities, secure all equipment used, monitor it and decontaminate or dispose as appropriate. Consider the need to maintain dedicated equipment and supplies to controlled areas where radioactive materials are handled. Clearly label such equipment to avoid its inadvertent use in other areas.

Alternative decontamination procedures should be considered when contamination is due to spilling large quantities of radioactive material or when conventional cleaning methods are impractical or will generate an unacceptable quantity of waste. Techniques employed for localized contamination are similar to those described for decontaminating equipment. Consider the need to provide for local ventilation or personnel protective equipment when significant airborne activity is measured or expected. Consider the need for protective clothing and the establishment of a temporary control zone and area for changing clothing when entering or leaving the control zone and personal monitoring when leaving.

A useful technique to avoid creating airborne activity is to wet down the area immediately before decontamination. This is accomplished by using a fine spray of water or suitable chemical. Do not direct the spray at the contaminated surface; rather, release it above the surface and allow the spray to settle on the contamination.

When low levels of volatile radiochemicals or short-lived radionuclides are involved, consider isolating the area to allow the activity to disperse or decay. It may be necessary to report this action to regulatory authorities depending on the quantities involved and the duration of the period of isolation. The area should be monitored to confirm that it is suitable for reoccupation.

As with personnel and equipment decontamination, the area should be monitored frequently to confirm progress and assure personnel protection. The need for bioassay and dosimetry should also be considered.

Selected Decontamination Agents and Methods

Skin Decontamination

Soap and water

Wet skin and apply soap. Work up a good lather and keep lather wet. Work lather into contamination area by rubbing gently for two to three minutes. Apply water frequently. Rinse area with tepid water. Repeat procedure several times if necessary, using a soft brush to gently scrub the area. Discontinue before skin becomes abraded or sensitive.

Abrasive or powdered hand soap

See above procedure, but use light pressure to avoid scratching or eroding skin.

Detergent (powdered) and corn meal, 50-50

Make into a paste. Use with additional water and a mild scrubbing action.

Sweating

Place hand in plastic glove and tape shut. Place in warm area until sweating is profuse. Remove glove promptly and wash immediately using standard techniques.

Non-porous Surface Decontamination

Water or water with detergent

Soak or apply as appropriate.

PerkinElmer NEN® Count-Off™

All purpose laboratory cleaner and radioactivity decontaminant. Dilute to a 2% solution. Use as a soak or scrub.

Commonly-available references containing additional information include the Radiological Health Handbook, and "NCRP Report Number 65."

RADIOACTIVE WASTE MINIMIZATION

The Benefits of Radioactive Waste Minimization

In this guide waste minimization is defined as the elimination of unnecessary waste and the minimization of unavoidable waste and/or rendering it less hazardous. An increasing number of federal, state and local regulations require radioactive waste minimization. Waste minimization plans are sometimes specified as a license condition and regulators may consider minimization to be necessary to maintain radiation exposure as low as reasonably achievable (ALARA).

Benefits of radioactive waste minimization include optimization of radiation safety, regulatory compliance, protection of the environment, public assurance and reduced costs.

Radioactive Waste Minimization Plan

Management should consider establishing a radioactive waste minimization plan. The plan should state management's commitment to waste minimization. Goals should be set which are clear, measurable, adaptable to changing conditions and achievable. The plan should include the establishment of an organization with individual accountability for implementing the plan. New and existing processes that generate waste should be systematically reviewed to identify opportunities to minimize waste. The costs and benefits of minimization options should be determined and the options prioritized.

Individuals should be empowered to seek out opportunities for continuous improvement and trained in waste minimization and trained to access sources of information and resources. Training should include a thorough understanding of applicable regulations and license conditions. Regular meetings should be held where ideas can be exchanged. Waste generators should receive timely feedback on the actual costs of the waste from their operations. Administrative controls should be considered which require investigation of waste practices that deviate from established goals and determine suitable preventive actions. The waste minimization program should be periodically audited and incentives awarded to individuals and teams who improve waste minimization performance.

Methods to Reduce the Generation of Radioactive Waste

The primary method to minimize waste is known as source reduction. The following are commonly used methods to prevent the generation of various waste forms:

When planning an operation consider alternate methods. If choosing non-radioactive chemicals ensure that the waste is not more hazardous then when choosing radiochemicals. Select short-lived radionuclides.

Avoid labeling procedures that generate a lot of waste by purchasing radiochemicals from manufacturers.

Order only the quantity of stabilized pure radiochemicals needed and when it is needed.

Select radiochemicals that generate waste that can be classified as diminimis and disposed as non-radioactive waste.

Substitute hazardous chemical reagents to avoid generating mixed waste (waste containing both radioactive materials and hazardous chemicals).

Separate packaging from shielded primary container of radioactive material outside area designated for handling radioactive material.

During radiochemical processes segregate radioactive from other materials, long-lived from short-lived radionuclides and radionuclides from hazardous chemicals, and avoid the use of equipment containing mercury.

Reduce the volume of radioactive waste by using designated areas equipped to maintain contamination control. Use non-porous cleanable surfaces, provide catch trays, liners, absorbents and coverings to confine contamination. Promptly clean-up spilled radioactive materials and use appropriate sensitive monitors to identify contaminated areas and sort materials for disposal. Minimize waste volume by cutting out and disposing only the contaminated portion of coverings.

Establish written operating procedures to efficiently manage materials in process. Ensure that the forms and quantities of radiochemicals in process are tracked. Maintain control by clearly labeling or color coding containers and tools to ensure their segregation in an operation, during interruptions in operations and in storage.

Consider process modifications to reduce waste generation. Use microscale quantities of radiochemicals and reagents. Maintain precision and reliability in handling radiochemicals by using process measurements and computer control automated equipment specifically designed for the operation. In new processes conduct prior trial runs with non-radioactive materials to ensure that subsequent runs with radiochemicals will work.

Minimize concentration and storage time to maximize the purity of radiochemicals and check the purity prior to use.

Reuse of Radiochemicals to Minimize Waste

- Repurify radiochemicals prior to use or reuse.
- Consider the recovery and reuse of radiochemicals from unsuccessful processes where possible.
- Consider the reuse of solvents used in high pressure liquid chromatography.
- Consider the recycle of radiochemicals not consumed in a process.

- Consider the reuse of storage containers, particularly containers used to handle waste.
- Plan operations to enable radiochemical by-products to be used sequentially.
- Network with other users to share and reuse radiochemicals.
- Evaluate the potential wastes and labor costs of cleaning versus disposal of contaminated equipment. Where practical decontaminate equipment to allow reuse. Consider consuming waste contaminated solvents to initiate the decontamination of equipment.
- Reuse lab coats to avoid disposing as waste. Hold coats contaminated with short-lived radionuclides for decay prior to reuse. Launder washable lab coats slightly contaminated with long-lived radionuclides.

Radioactive Waste Minimization by Treatment

A commonly preferred practice is to segregate radionuclides with short half-lives and allow them to decay prior to their disposal as non-radioactive waste. Licenses commonly allow radionuclides, such as ^{32}P, ^{33}P, ^{125}I, ^{131}I and ^{111}In, with half-lives less than 65 days to be handled this way. Regulators will often permit licensees to store other radionuclides such as ^{35}S with half lives less than 120 days provided that storage conditions are considered adequate.

Consider using filtration to separate waste forms to enable disposal or further treatment.

Consider carefully combining alkaline materials with acidic materials to produce a neutral waste form that can be subsequently disposed.

Thermal treatments can be used to reduce the volume of waste by removing the non-radioactive liquids by evaporation or by chemically converting an organic radiochemical into a disposable form.

Waste volume reduction ratios of 5 to 10 are commonly achieved through compaction. Volume reduction can often be optimized by segregating types of materials, shredding or freezing (in liquid nitrogen) plastics prior to compaction and placing plates in a compaction drum to prevent the waste from re-expanding between compaction cycles. Vial crushers can be used to reduce the volume of liquid scintillation vials. Investments in compaction and associated equipment commonly have payback periods of a few months.

The volume of used liquid scintillation cocktails, animal carcasses and slightly contaminated materials such as disposable protective clothing and coverings can be greatly reduced by incineration. Generally there are two methods involved. Incinerators maybe licensed to allow ^{3}H or ^{14}C or other volatile radionuclides to be released into the atmosphere below strictly conservative concentration limits. Generally the radionuclide content must be low or diminimis. Alternatively non-volatile radionuclides are retained in the ash and the lower volume disposed as radioactive waste.

When considering treatment it is important to ensure that regulations and licenses allow the process and the quantities involved.

Waste Minimization and Disposal

In the above sections the primary aim of waste minimization is to avoid generating waste or to treat wastes to remove their hazardous characteristics or enable them to be easily disposed. Generally regulators do not permit radioactive wastes to be stored indefinitely at the licensees site of origin. It is therefore important when planning the handling of radioactive materials that the final form for transportation and disposal and the associated costs are anticipated.

Certain radioactive wastes may be safely disposed at less cost as though they were not radioactive. These include wastes that contain short-lived radionuclides that have been held for decay for at least ten half-lives and that have been monitored and contain negligible radioactivity. To minimize the area used for storage it is prudent to segregate radionuclides in storage to allow the short-lived radionuclides to decay and be disposed sooner. Certain waste forms and certain radionuclides below specified diminimis concentration limits, such as ^{3}H and ^{14}C in liquid scintillation cocktails and animal carcasses, can be disposed as non-radioactive waste.

In preparing radioactive waste for disposal it is important that the waste is safe to handle in transportation and at the disposal site and is packaged in a form that will have minimal long term environmental impact. Preparation will typically include accurate assessment of the quantity, radionuclides and physical and chemical form. Liquid wastes will need to be solidified. Wastes are then encapsulated in specific containers with shielding as appropriate. Waste volume can sometimes be minimized by using radioactive wastes emitting non-penetrating radiation solidified in concrete to shield a core of wastes emitting penetrating radiation.

Generally packaging will increase the volume of waste and add cost, but will achieve a waste form which is safe to transport and dispose.

The requirements and costs for disposing the many categories of low-level radioactive waste are complex and vary according to disposal site. Consequently it is important to have a full understanding of the options prior to planning operations that will generate disposable low-level radioactive wastes.

SAFE STORAGE OF RADIOACTIVE WASTE

Reasons for Storing Radioactive Waste

Radioactive waste containing radionuclides with half-life less than 120 days are commonly placed into storage and allowed to decay prior to disposal as non-radioactive waste.

Waste storage areas are often needed to accumulate waste prior to treatment and/or packaging prior to disposal.

Certain radioactive wastes are stored due to lack of access for viable treatment or disposal. This commonly applies to certain mixed waste forms where viable treatment procedures are either unavailable or currently prohibitively expensive. Also low-level radioactive waste forms may have to be stored when access to a low-level radioactive waste disposal site has been denied.

Occasionally generators want to store low-level radioactive waste to avoid the high cost of disposal.

Planning Radioactive Waste Storage Facilities

When planning a radioactive waste storage facility the licensee should anticipate the radionuclides, quantity, waste forms and volumes, regulatory categories and potential radiation profiles of the waste containers.

The waste generation rate should be determined and the need to store waste due to temporary changes in access to disposal sites or the need to store orphan waste indefinitely should also be considered. The final estimate of storage space requirements should accommodate the need to access waste containers periodically for inspection and handling.

The licensee should keep informed of developments in access to disposal and treatment sites and use this information to periodically re-evaluate storage needs.

Another important planning consideration is the need to be aware of the regulatory requirements and license conditions concerning the storage of radioactive waste. Regulators will commonly prescribe storage conditions and procedures and may require a license amendment to change a practice. For example, regulators will commonly allow radionuclides with half-lives less than 65 days to be stored for decay, but may require enhanced storage conditions for storing for decay radionuclides, such as ^{35}S, with half lives between 65 and 120 days. Also regulators may require a specific license amendment to allow low-level radioactive waste to be temporarily stored when access for disposal is denied. Regulators may not permit low-level radioactive waste to be stored indefinitely if the only purpose is to avoid the cost of disposal.

Requirements for a Radioactive Waste Storage Area

Ideally a radioactive waste storage area should be a dedicated facility with centralized access, but off the normal traffic paths.

When the waste to be stored is heavy, or heavy machinery is needed to move waste containers, the floor must be designed to accommodate the anticipated loading. Often a basement floor will be the best location and this may also be a better place to store waste that emits a significant radiation field.

The floor and interior surfaces should be covered with non-porous materials to facilitate decontamination if a leakage or spillage occurs and to enable the storage area to be kept clean. If liquids are to be stored, the need to provide recessed floors, dyking or drainage to holding tanks should be considered.

The need to provide forced ventilation to prevent the build-up of solvent fumes or airborne radionuclides should be considered. The air should be exhausted to a safe area outside the building through a single duct designed to enable the air concentration to be accurately monitored. The need to provide diagnostic air sampling systems to locate the origin of released airborne activity in the storage area should also be considered.

The storage area should be provided with protection from fire and flood.

Lighting should be adequate to enable waste containers to be identified, inspected and safely handled.

The need for climate control should be considered. For long-term storage, a dry even cool temperature is preferred to minimize the degradation of the waste.

The storage area should be organized to enable different waste categories to be segregated and accessible for placement, periodic inspection, monitoring and routine and emergency retrieval.

The area might need to accommodate freezers for storing biological waste and shielding for containers emitting penetrating radiation. Shielding may be effected by surrounding containers by other containers or by using shielded storage bins or temporary concrete block walls. These should be constructed with consideration of the need to periodically inspect the waste containers.

The storage space should be organized to enable handling equipment to be safely used.

Preparation of Waste for Storage

Periodically areas where radioactive waste are generated should be audited to identify obsolete contaminated equipment and inadvertent accumulation of radioactive waste. Where possible these should be removed and promptly treated and disposed so as to optimize the waste placed in storage.

Each container used to store waste should be inspected prior to use to ensure that it complies with required specifications and is free from defects that might compromise its subsequent use.

Each container of waste accepted for storage should be fully and accurately characterized including waste form, radionuclide, quantity, date, radiation profile and origin.

Ideally each container of waste should be stabilized, compacted, packaged and labelled as appropriate for final disposal prior to placement in storage. For example waste containing radioiodine should be packaged in basic form with sodium hydroxide and sodium metabisulfite and charcoal to minimize volatilization. Charcoal can also be used with organic waste containing ^{3}H, ^{14}C and ^{35}S.

Biological wastes should be kept frozen or preserved with lime or disinfectants.

Biohazardous wastes should be deactivated prior to storage.

Wastes containing radionuclides emitting penetrating radiation should be placed in lead shielding prior to placement in the storage container. In some cases it might be necessary to place the more intense sources at the center of the container and pour a surrounding of concrete to provide extra shielding.

Each container should comply with prescribed concentration, quantity and radiation limits, as appropriate, and conspicuously labelled.

When received for storage, each container should be independently checked to ensure that it complies with all the storage requirements.

A record should be generated at the source of the characteristics of all waste placed in storage.

Management of Radioactive Waste in Storage

Waste containers should be placed in designated areas segregated according to hazardous characteristics such as flammability, toxicity and reactivity and according to category of waste such as low-level radioactive, incinerable, compactible, mixed waste, byproduct material, naturally occurring and accelerator produced waste.

The containers should be placed to minimize rehandling in anticipation of the final disposition and the need to periodically inspect and monitor them. Containers emitting significant radiation fields should be provided with additional shielding and/or placed in an area remote from the normal traffic path with due consideration of radiation exposure to unrestricted areas below, above or next to the storage area.

When containers are brought into the storage area they should be inspected and if necessary cleaned before placement. Of particular concern are metal containers destined for long term storage that may be spattered with salt used on roadways during winter snow storms. When a container is cleaned care should be taken to ensure that any detergent used is completely rinsed off.

Metal waste containers should be placed on wooden or plastic pallets to prevent corrosion from contact with the floor.

Waste containers should be periodically monitored and inspected for leakage or corrosion or other defects. Defective containers should be promptly addressed. This may require the replacement of lost or faded labelling or the removal and repair or repackaging of a container. In the discovery of a defect that may compromise the subsequent use of the container the cause of the defect should be fully investigated and preventive actions established. This might include a special inspection and recall of all similar containers in use.

In addition to monitoring individual containers the need to monitor for airborne radioactivity and identify containers causing the release should be considered.

The radiation levels in the storage area should be maintained low enough to enable the direct monitoring of containers for surface contamination. Where this is not possible contamination wipes should be assayed in a low background area to ensure adequate sensitivity.

In addition to surveying waste containers, traffic areas, handling equipment and adjacent areas should be monitored periodically to confirm contamination control and perimeters should be monitored to confirm radiation control.

Administrative action levels should be established for all radiological measurements including bioassay and personal dosimeters and any causes that threaten these action levels should be investigated and corrective and preventive actions determined.

All waste placed in storage should be documented and a current detailed inventory maintained.

The facility should be secured against inadvertent access.

Safe Storage of Radioactive Waste (contd.)

The waste should be neatly organized in clean brightly colored containers in keeping with the meticulous care that is taken to ensure safe storage. This can promote public acceptance that the waste is safely handled, when neighbors are invited to visit the facility.

The licensee should ensure that adequate equipment and staffing is provided to maintain the facility and that all staff involved in managing the waste are fully accountable and fully trained in their responsibilities.

Management of a Decay in Storage Facility

Radioactive waste generators may be licensed to store short-lived radionuclides for decay and subsequently dispose the waste as non-radioactive material.

The waste must be dated when placed in storage and held for decay for ten half-lives. The waste should also be dated to show when this storage period expires.

To minimize storage time the waste should be segregated according to half-life. In the event that segregation is not practical the waste must be stored for ten times the longest half-life in the container.

When ten-half lives have elapsed the waste must be removed to a low background area and carefully surveyed with a conventionally suitable contamination monitor.

All waste measuring less than twice background may be disposed as non-radioactive material. In the case of waste containing hazardous chemicals this is when the waste must be handled according to RCRA (Resource Conservation and Recovery Act) requirements.

If significant contamination is detected the radionuclide should be confirmed and if short-lived should be placed into storage for a second ten half-life decay cycle. If it is that the waste inadvertently contains a long-lived component this should be identified and quantitated and treated as low-level radioactive waste. It may be necessary to investigate procedures to determine the cause of low-level waste appearing in this short-lived waste category and provide appropriate preventive actions.

Usually the storage container can be recycled.

The measurements, date and disposal of the decayed waste must be recorded.

Management of Radioactive Waste Placed in Storage for an Indefinite Time Period

Certain types of waste cannot be disposed of promptly and must be placed into storage for an indefinite period of time. These include mixed waste forms that cannot be currently treated either because commercial treatment is not available or is prohibitively costly. Also temporary loss of access to treatment and/or disposal of low-level radioactive waste may cause waste to be stored. Other waste forms that can not be currently disposed include transuranics and greater than class "C" waste.

Certain mixed wastes in the form of ^{3}H and ^{14}C labeled hazardous organic compounds are stored in their original liquid form until viable treatment methods are available. The containers of mixed waste are placed inside secondary containers filled with absorbent material to prevent leakage. Dilute forms of mixed waste may not warrant this level of containment. The use of single thick-walled plastic containers may be considered when there is no need to protect against heat or fire.

Low-level radioactive waste or orphan waste that may have to be stored for an indefinite time should be packaged in containers that can withstand the effects of pressure build-up or corrosion. Pressure build-up from the radiolitic decomposition of organic chemicals in the waste can be minimized by absorbing the organics on clay which absorbs most of the radiation energy. Also the primary container is then put into a welded aluminum container sized to withstand the ultimate pressure.

The effects of corrosion are minimized by selecting corrosion resistant materials and/or providing containers that are too thick for corrosion to penetrate before the radioactive material has decayed to insignificant concentrations.

In situations where access to a disposal site has been temporarily interrupted the containers used for storage should be acceptable to the disposal site to avoid the need for repackaging.

THE ABC'S OF RADIATION SAFETY

Safety is more than just being careful. It's having a solid understanding of what's going on in your job – knowing the procedures, the environment and the technical terms involved.

The following glossary covers many of the common terms encountered in working situations where radioactive materials are present.

Absorption: The process by which radiation imparts some or all of its energy to any material through which it passes.

Annihilation (electron): An interaction between a positive and a negative electron in which they both disappear; their energy, including rest energy, is converted into electromagnetic radiation (called annihilation radiation).

Atom: Smallest particle of an element which is capable of entering into a chemical reaction.

Atomic Mass: The mass of a neutral atom of a nuclide, usually expressed in terms of "atomic mass units." The "atomic mass unit" is one twelfth the mass of one neutral atom of carbon-12, equivalent to 1.6604 X 10-24gm. (Symbol:u)

Atomic Number: The number of protons in the nucleus of an atom. (Symbol: Z)

Background Radiation: Ionizing radiation arising from radioactive material other than that directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material, etc.

Becquerel: The special name for the unit of activity. One becquerel equals one nuclear transformation per second (abbreviated Bq). (See Curie.)

Note that 1Ci = 3.7 x 10^{10}Bq, and 1Bq ~ = 2.7 x 10^{-11}Ci.

Beta Particle: Charged particle emitted from the nucleus of an atom, having a mass and charge equal in magnitude to that of the electron.

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

Calibration: Determination of variation from standard, or accuracy, of measuring instrument to ascertain necessary correction factors.

Carrier-free: An adjective applied to one or more radioactive isotopes of an element that are essentially undiluted with stable isotope carrier.

Carrier: A quantity of non-radioactive or non-labeled material of the same chemical composition as its corresponding radioactive or non-labeled counterpart. When mixed with the corresponding radioactive labeled mixture, the carrier permits chemical (and some physical) manipulation of the mixture with less label or radioactivity loss than would be true for the undiluted label or radioactivity.

Chamber, Ionization: An instrument designed to measure a quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

Chemical Atomic Weight: The weighted mean of the masses of the neutral atoms of an element expressed in atomic mass units.

Contamination, Radioactive: Presence of radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful. The harm may be in invalidating an experiment or a procedure, or in being a source of unnecessary exposure to personnel.

Controlled Area: A defined area in which the occupational exposure of personnel (to radiation) is under supervision.

Count (radiation measurement): The external indication of a device designed to enumerate ionizing events. It may refer to a single directed event or be a total number registered in a given period of time. The term is often erroneously used to designate a disintegration, ionizing event or voltage pulse.

Spurious Count: In a radiation counting device, a count caused by any agent other than radiation.

Counter, Gas Flow: A device in which an appropriate atmosphere is maintained in the counter tube by allowing a suitable gas to flow through the sensitive volume.

Counter, Geiger-Mueller: Highly-sensitive, gas-filled, radiation-measuring devices. It operates at voltages sufficiently high to produce avalanche ionization and the pulse produced is independent of the number of ions formed in the gas by the primary ionizing particle.

Counter, Proportional: Gas-filled radiation detection device. It operates at voltages sufficiently high to produce avalanche ionization and the pulse produced is proportional to the number of ions formed on the gas by the primary ionizing particle.

The ABC's of Radiation Safety (contd.)

Counter, Scintillation: The combination of fluor (scintillator), photomultiplier tube, and associated circuits for counting light emissions produced in the fluor.

Cosmic Rays: High-energy particulate and electromagnetic radiations which originate outside the earth's atmosphere.

Curie: The special unit of activity. One curie equals exactly 3.700 x 1010 nuclear transformations per second. (Abbreviated Ci) Several fractions of the curie are in common use:

Millicurie: One thousandth of a curie
(3.7×10^7 disintegrations per second). (Abbreviated mCi)

Microcurie: One millionth of a curie
(3.7×10^4 disintegrations per second). (Abbreviated µCi)

Picocurie: One millionth of a microcurie (3.7×10^{-2} disintegrations per second or 2.22 disintegrations per minute) (Abbreviated pCi). Replaces the term µµCi.

Decay, Radioactive: Disintegration of the nucleus of an unstable nuclide by spontaneous emission of charged particles and/or photons.

Decay Product: A nuclide resulting from the radioactive transformation of a radionuclide, formed either directly or as the result of successive transformations in a radioactive series. Some decay products are radioactive, others are stable.

Decontamination Factor: The ratio of the amount of undesired radioactive material initially present to the amount remaining after a suitable processing step has been completed. Decontamination factors may refer to the reduction of some particular type of radiation or to the gross measurable radioactivity.

Detector, Radiation: Any device for converting radiant energy to a form more suitable for observation. An instrument used to determine the presence, and sometimes the amount, of radiation or radioactivity.

Disintegration, Nuclear: A spontaneous nuclear transformation (radioactivity) characterized by the emission of energy and/or mass from the nucleus. When large numbers of nuclei are involved, the process is characterized by a definite half-life.

Dose, Absorbed: The mean energy imparted to matter by ionizing radiation per unit mass of irradiated material at a point of interest. The irradiated material is usually specified (e.g., absorbed dose in water, absorbed dose in lead, etc.). The unit of absorbed dose is $J.kg^{-1}$. The special name for the unit of absorbed dose is the gray (Gy):

$1Gy = 1J.kg^{-1}$

The special unit for absorbed dose is the rad:
$1 \text{ rad} = 100 \text{ erg.g}^{-1} = 0.01Gy$

Dose Equivalent: The product of the absorbed dose in tissue and various modifying factors. The dose equivalent is used in radiation protection as an indication of the biological effect that will be produced in an irradiated tissue. The unit of dose equivalent is $J.kg^{-1}$. The special name for the unit of dose equivalent is the sievert (Sv).

$1Sv = 1J.kg^{-1}$

The special unit of dose equivalent is the rem:
1 rem = 0.01Sv

Dose Rate, Absorbed: Absorbed dose delivered per unit time.

Dose Ratemeter: Any instrument which measures radiation dose rate.

Dosimeter: Instrument to detect and measure accumulated radiation exposure. In common use, a pencil-size ionization chamber with a self-reading electrometer used for personnel monitoring.

Efficiency (Counters): A measure of the probability that a count will be recorded when radiation is incident on a detector. Use varies considerably; ascertain which factors (window transmissions, sensitive volume, energy dependence, etc.) are included in a given case.

Electron: A stable elementary particle having an electric charge equal to $\pm 1.602^{10} \times 10\text{-}^{19}$ Coulomb, and a rest mass equal to 9.1091×10^{-31} kg.

Secondary Electron: An electron ejected from an atom, molecule or surface as a result of an interaction with a charged particle or photon.

Valence Electron: An electron which is gained, lost or shared in a chemical reaction.

Electron Volt: A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. (Abbreviated: eV, $1eV = 1.6 \times 10^{-12}$ erg.) Larger multiple units of the electron volt are frequently used: keV for thousand or kilo electron volts, MeV for million or mega electron volts.

Electroscope: Instrument for detecting the presence of electric charges by the deflection of charged bodies.

Element: A category of atoms all of the same atomic number.

Exposure: (1) Being in the same place at the same time as something, as in "exposure to neutrons" for example. (2) A measure of the ionization produced in air by photons. More specifically, it is the sum of the electrical charges in all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in the volume element. The unit of exposure is the C.kg^{-1}. The special unit of exposure is the roentgen (R):

1R = 2.58 x 10^{-4} C.kg^{-1} (exactly)

Film Badge: A packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or more films of differing sensitivity, and it may contain filters which shield parts of the film from certain types of radiation.

Gamma Ray: Very penetrating electromagnetic radiation of nuclear origin. Similar properties to x-ray (***see X-ray***).

Genetic Effect of Radiation: Hereditary changes produced by the absorption of ionizing radiations in the gonads.

Generator (Cow): A device in which radioactive progeny is eluted from an ion exchange column containing a parent radionuclide that is long-lived compared to the progeny.

Half-Life, Biological: The time required for the body to eliminate one half of an administered dosage of any substance by regular processes of elimination – approximately the same for both stable and radioactive isotopes of a particular element.

Half-Life, Effective: Time required for a radioactive element in the body to be diminished 50% as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half life} = \frac{\text{biological half-life x radioactive half-life}}{\text{biological half-life + radioactive half-life}}$$

Half-Life, Radioactive: Time required for a radioactive substance to lose 50% of its activity by radioactive decay. Each radionuclide has a unique half-life (also known as physical half-life).

Half-Value Layer: (Half Thickness): The thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one half its original value.

Health Physics: A term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation.

Health, Radiological: The art and science of protecting human beings from injury by radiation, and promoting better health through beneficial applications of radiation.

Inverse Square Law: The law that states that the intensity of radiation at any distance from a point source varies inversely as the square of that distance. For example: If the radiation exposure is 100R/hr at 1 inch from a source, the exposure will be 0.01 R/hr at 100 inches.

Ion: Atomic particle, atom or chemical radical bearing an electrical charge, either negative or positive.

Ionization: The process by which a neutral atom or molecule acquires either a positive or a negative charge.

Ionization Chamber: An instrument designed to measure the quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

Ionizing Radiation: (*See Radiation*.)

Isotopes: Nuclides having the same number of protons in their nuclei, and therefore the same atomic number, but differing in the number of neutrons and, therefore, in the mass number. Almost identical chemical properties exist between isotopes of a particular element.

Stable Isotope: A non-radioactive isotope of an element.

Kilo Electron Volt (keV): One thousand electron volts: 10^3 eV.

Labeled Compound: A compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopic composition, this compound or its fragments may be followed through physical, chemical or biological processes.

Mass Number: The number of protons and neutrons in the nucleus of an atom.

Millirem (m rem): One thousandth (1/1000) of a rem. (*See Rem*).

Milliroentgen (mR): A multiple of the roentgen equal to one one-thousandth (1/1000) of a roentgen. (*See Roentgen*).

Monitoring, Radiological: Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination present in an occupied region as a safety measure for purposes of health protection.

Area Monitoring: Routine monitoring of the level of radiation or radioactive contamination of any particular area, building, room or equipment.

Personnel Monitoring: Monitoring any part of an individual, the breath, excretions or any part of the clothing, for radioactive contamination (See Radiological Survey).

Nuclide: A species of atom characterized by the constitution of its nucleus. The nuclear constitution is specified by the number of protons (Z), number of neutrons (N) and energy content: or alternatively, by the atomic number (Z) and atomic mass. To be regarded as a distinct nuclide, the atom must be capable of existing for a measurable time. Therefore, nuclear isomers are separate nuclides, whereas promptly-decaying, excited nuclear states and unstable intermediates in nuclear reactions are not so considered.

Parent: Synonym for radionuclide that produces decay products.

The ABC's of Radiation Safety (contd.)

Progeny: Synonym for decay product.

Optically Stimulated Luminescent Dosimeter (OSLD): A dosimeter made of certain crystalline material which is capable of both storing a fraction of absorbed ionizing radiation and releasing this energy in the form of visible photons when illuminated. The amount of light released can be used as a measure of radiation exposure to these crystals.

Quality Factor (Q): The linear-energy-transfer-dependent factor by which absorbed doses are multiplied to obtain (for radiation protection purposes) a quantity that expresses, on a common scale for all ionizing radiations, the effectiveness of the absorbed dose.

Rad: the unit if absorbed dose equal to 0.01 J/kg in any medium. (*See Absorbed Dose*). (Written rad).

Radiation: (1) The emission and propagation of energy through space or through a material medium in the form of waves; for instance, the emission and propagation of electromagnetic waves, or sound and elastic waves. (2) The energy propagated through space or through a material medium as waves; for example, energy in the form of electromagnetic waves or elastic waves. The term radiation or radiant energy, when unqualified, usually refers to electromagnetic radiation. Such radiation commonly is classified, according to frequency, as Hertzian, infrared, visible (light), ultra-violet, x-ray and gamma ray. (*See Photon*) (3) By extension, corpuscular emissions, such as alpha and beta radiation, or rays of mixed or unknown type as cosmic radiation.

Annihilation Radiation: Photons produced when an electron and a positron unite and cease to exist. The annihilation of a positron-electron pair results in the production of two photons, each of 0.51MeV energy.

Background Radiation: Radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

Characteristic (Discrete) Radiation: Radiation originating from an atom after removal of an electron or excitation of the nucleus. The wavelength of the emitted radiation is specific, depending only on the nuclide and particular energy levels involved.

External Radiation: Radiation from a source outside the body. The radiation must penetrate the skin.

Internal Radiation: Radiation from a source within the body (as a result of deposition of radionuclides in body tissues).

Ionizing Radiation: Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.

Radiological Survey: Evaluation of the radiation hazards incident to the production, use or existence of radioactive materials or other sources of radiation under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved and a sufficient knowledge of processes using or affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

Radioactivity: The property of certain nuclides spontaneously emitting particles or gamma radiation or of emitting x-radiation following orbital electron capture or of undergoing spontaneous fission.

Natural Radioactivity: The property of radioactivity exhibited by more than 50 naturally occurring radionuclides.

Radiotoxicity: The potential of a radionuclide to cause damage to living tissue by absorption of energy from the disintegration of the radioactive material introduced into the body.

Rem: The special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, distribution factor and any other necessary factors. (*See Dose Equivalent*)

Relative Biological Effectiveness (RBE): A factor used in radiobiology to compare the biological effectiveness of absorbed radiation doses (i.e., rad) due to different types of ionizing radiation; more specifically, it is the experimentally-determined ratio of an absorbed dose of a reference radiation required to produce an identical biological effect in a particular experimental organism or tissue. NOTE: This term should not be used in radiation protection. (*See Quality Factor*)

Resolving Time, Counter: The minimum time interval between two distinct events which will permit both to be counted. It may refer to an electronic circuit, to a mechanical indicating device or to a counter tube.

Roentgen (R): The special unit of exposure. One roentgen equals 2.58 x 10-4 coulomb per kilogram of air. (*See Exposure*)

Scintillation Center: A counter in which light flashes produced by a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

Self-absorption: Absorption of radiation (emitted by radioactive atoms) by the material in which the atoms are located; in particular, the absorption of radiation within a sample being assayed.

Shielding Material: Any material which is used to absorb radiation and effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, water and plastic are examples of commonly-used shielding materials.

Smear (Smear or Swipe Test): A procedure in which a swab (e.g., a circle of filter paper) is rubbed on a surface and its radioactivity is measured to determine if the surface is contaminated with loose radioactive material.

Specific Activity: Total radioactivity of a given radionuclide per gram of a compound, element or radionuclide.

Standard, Radioactive: A sample of radioactive material, usually with a long half life, in which the number and type of radioactive atoms at a definite time is known. It may be used as a radiation source for calibrating radiation measurement equipment.

Thermoluminescent Dosimeter: A dosimeter made of certain crystalline material which is capable of both storing a fraction of absorbed ionizing radiation and releasing this energy in the form of visible photons when heated. The amount of light released can be used as a measure of radiation exposure to these crystals.

Tracer, Isotopic: The isotopic or non-natural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological or physical process. The observations may be made by measurement of radioactivity or isotopic abundance.

X-rays: Penetrating electromagnetic radiation having wavelengths shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extranuclear part of the atom as x-rays. X-rays are sometimes called roentgen rays after their discoverer, W. C. Roentgen.

This guide contains general information designed to provide a basic understanding of radiation safety. While we believe the information is accurate, regulatory requirements may change and information contained herein is not tailored to individual needs. A radiation protection specialist should be consulted for specific applications.

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