

Radiation Safety Training Study Guide

Technical Safety Office, Phone: 282-2310/2311
(Rev. 08/07)

GLOSSARY

Absorbed Dose: The mean energy per unit mass imparted to any matter by any type of ionizing radiation.

Annual Limit on Intake (ALI): The quantity of a radionuclide which, if taken into the body, produces a committed effective dose equivalent of 5 rem. Because of differences in physiological transport mechanisms, the ALIs vary depending on the route of intake. For purposes of contamination control and bioassay procedures, the most conservative ALI, either for ingestion or inhalation, is used.

Bioassay: A bioassay involves directly measuring the radioactive material that may be present in an individual's body. In some instance, bioassays mean the radioactive materials excreted from the body to infer what is present within human tissue.

Bioassay Interval: The bioassay interval is the maximum time that may elapse between bioassays that will assure detection of the verification level for a given nuclide and assay method. The bioassay interval for a particular radionuclide is determined by its physical and metabolic characteristics, and by the instrumentation used for the measurement. For most commonly used radionuclides and typical analytical systems, the bioassay interval is 13 weeks (one calendar quarter); for P-32, and a few other very short-lived radionuclides, however, the bioassay interval is only one month.

Committed Dose Equivalent (CDE): The dose equivalent to organs or a tissues of reference that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

Committed Effective Dose Equivalent (CEDE): The sum of the products of the weighing factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

Contamination Survey: A systematic investigation to determine the presence, or to verify the absence, of radioactive materials in unwanted locations, e. g. on the body or personal clothing, on surfaces of objects that may be touched or handled, on equipment or materials to be removed from a restricted area, etc.

Deep Dose Equivalent (DDE): The dose equivalent at a tissue depth of 1 cm, resulting from whole body external exposure.

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Dose Equivalent (DE): The product of the radiation absorbed dose and the radiation weighing factor, and all other necessary modifying factors at the location of interest.

Effective Dose Equivalent (EDE): The sum of the products of the dose equivalent to the organ or tissue, and the tissue weighing factors applicable to each of the body organs or tissues that are irradiated.

Exposure: Usually refers to any condition which creates the potential for any individual to receive a radiation dose, either from external irradiation or from internal contamination with radioactive materials.

Extremity: Means hand, elbow, arm below the elbow, foot, knee, and leg below the knee.

Eye Dose Equivalent: Applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 cm (300 mg/cm²).

Penetrating: The dose rate from photons at 1 meter from a point source of 1 millicurie, assumed to be proportional to the inverse of the square of the distance between the point source and the receptor.

Radioactive Contamination: Unwanted presence of radioactive substances on surfaces, air or inside the human body.

Radioactive Half-life: The amount of time that it takes for a radioactive isotope to be reduced by one half of its value through the process of radioactive decay.

Radioactive Material: Any material having a specific activity greater than 70 Bq/g (0.002 mCi/g), in accordance with 49 CFR 173.403. Also, any non-radioactive material (activity less than 70 Bq/g) with surface contamination (both fixed and non-fixed/removable) that, when averaged over each 300 cm² (46.5 in²) of all surfaces, is equal to or greater than 0.4 Bq/cm² (10⁻⁵ mCi/cm²) for beta and gamma emitters and low-toxicity alpha emitters; and equal to or greater than 0.04 Bq/cm² (10⁻⁶ mCi/cm²) for all other alpha emitters.

Reference Quantity (RQ): A quantity of a radionuclide (expressed in microcuries) related to its relative hazard potential and used to prescribe requirements for handling, monitoring, labeling and disposal. Reference quantities are obtained from 10CFR20, Appendix C.

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Shallow-dose Equivalent: Applies to the external exposure of the skin or an extremity and is taken as the dose equivalent at a tissue depth of 0.007 cm ($7\text{mg}/\text{cm}^2$) averaged over an area of 1 square centimeter.

Tissue Weighing Factors: The proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly.

Total Effective Dose Equivalent (TEDE): Sum of the deep dose equivalent and committed effective dose equivalent.

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COURSE OBJECTIVE

Upon completion of this training course, the participant will have an introductory knowledge of radiation, radioactive materials, and radiation producing machinery.

RADIATION INTRODUCTION COURSE OUTLINE

Radiation introduction training is designed to familiarize the student with Idaho State University's requirements for personnel who have the potential to come in contact with radioactive materials and radiation producing machines. At the completion of the course, the participant must successfully complete a written examination. Seventy percent (70%) on the written test is considered a passing score.

ISU'S ORGANIZATIONAL ENTITIES

Provost and Vice President for Academic Affairs (P-VPAA)

The Provost and Vice President for Academic Affairs is the official spokesperson for the University on matters pertaining to radiation protection. The P-VPAA appoints RSC members.

Radiation Safety Committee (RSC)

The Radiation Safety Committee is the governing body for all aspects of radiation protection within the University, including affiliated research, clinical, instructional and service units using radiation sources in facilities owned or controlled by the University. The RSC will ensure that all possession, use and disposition of radiation sources by University personnel complies with pertinent federal and state regulations and with the specific conditions of licenses issued to the University, and that all concomitant radiation exposures are maintained as low as reasonably achievable (ALARA). The RSC is empowered and directed to promulgate policies, rules and procedures for the safe use of ionizing radiation. The RSC reports to the P-VPAA. The RSC has many knowledgeable faculty with expertise in radiation protection.

Radiation Safety Officer (RSO)

The Radiation Safety Officer is the individual appointed by the P-VPAA and approved by the Nuclear Regulatory Commission (NRC) to administer the radiation protection program and to provide technical guidance to the RSC and to radiation users. The RSO is authorized and directed to promulgate and enforce such procedures as are necessary to assure compliance with applicable federal

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and state regulations and to ensure the accurate interpretation and effective implementation of the policies and rules established by the RSC. The RSO is responsible for receipts, uses, transfers and disposal of radioactive materials. Additionally, the RSO is responsible for investigating deviations from approved radiation safety policy such as spills, losses, thefts, variations from approved radiation safety practice, and implementing corrective actions as necessary. The RSO receives direction from the RSC with regard to policy. The RSO provides technical advice to the RSC, radiation users and the administration.

Technical Safety Office (TSO)

The Technical Safety Office is the organizational entity that provides administrative and technical services in support of the radiation protection program. The Director of the Technical Safety Office, who is normally the RSO, reports to the P-VPAA.

Responsible User

A "responsible user" is an individual authorized by the Radiation Safety committee to acquire (via the TSO) and use specific radiation sources and to supervise such use by others. Responsible users are typically the faculty in charge of the research project.

Radiation Users

A "radiation user" is any individual whose official duties or authorized activities include handling, operating, or working in the presence of, any type of radiation source, (sealed, unsealed, machine), whether or not such use is confined to a restricted area.

"Badged personnel" are individuals who may receive more than one tenth (10%) of the occupational radiation dose limit in any calendar quarter. This category includes those personnel who rarely receive more than 100 mrem in any calendar quarter, but who work with radiation sources or radiation producing devices that could produce such a dose under certain conditions. The radiation exposures received by these individuals are individually monitored.

"Potentially exposed" personnel are individuals who have a need to enter *restricted areas* as part of their job description or have a potential of exposure to a radiation source or radiation producing device but do not normally work in the presence of a radiation field. This category includes custodial, receiving and security personnel.

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CONCEPTS IN RADIATION PHYSICS

Atomic structure

The basic particles of the atom:

- Protons
- Neutrons
- Electrons

Only certain combinations of neutrons and protons in the nucleus result in stable atoms; unstable atoms will emit particles or energy to become stable and are referred to as radioactive.

Types of radiation

Radiation is classified as either ionizing or non-ionizing. Ionization occurs when enough energy is supplied to an atom and an electron is removed from the atom. The resulting atom will have a positive charge. Non-ionizing radiation includes radiant heat, radio waves, ultraviolet radiation, and light.

Ionizing radiation includes:

- Alpha
- Beta
- Gamma
- Neutron
- X-ray

Alpha radiation

Alpha particles are the largest particles emitted from the nucleus of an atom. Because of their relatively low velocity and large charge, chances are that soon after alpha particles are emitted they will quickly interact with an atom and lose their energy. Alpha particles travel only a few centimeters in the air. A piece of paper, normal work clothes, or the dead layer of skin on a human body can stop an alpha particle. Because of their high energy, alpha particles can deposit a significant internal dose if inhaled or ingested.

Beta radiation

Beta particles are much smaller in mass than alpha particles and are less likely to collide with surrounding atoms. Therefore, they can travel much farther than alpha particles (up to several meters in air) and can penetrate some materials, including human tissue. Certain materials can stop beta particles, such as a thin piece of metal or a few centimeters of wood, plastic, or glass. Beta radiation presents a health hazard to the skin of the entire body, the eyes, and the internal

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organs if ingested or inhaled.

Gamma radiation

Gamma radiation is by far the most penetrating of the three common types of radiation (alpha, beta, gamma). Gamma rays have no mass or charge and are considered to be pure energy. They can travel great distances and have the ability to pass through the human body and interact with living cells. Lead, concrete, and other dense materials are used to attenuate (not to stop) gamma rays.

X-ray radiation

X-rays differ from gamma radiation only in their origin and the fact that they tend to be less energetic. Whereas gamma radiation originates in the nucleus of an atom, x-rays are generated by the shell transition of orbital electrons. They are also formed from the deceleration of electrons interacting with matter (this is known as bremsstrahlung).

Neutron radiation

In the past, neutron radiation normally was found only in the immediate vicinity of a nuclear reactor or nuclear weapons burst. Today we are seeing more industrial use of neutron-emitting radionuclides. Neutron-emitting radionuclides are being used in some specialized radiographic procedures, in well logging and soil moisture analysis. If accelerator energy is above 8 MeV, neutrons may be an important component of the radiation generated.

Neutron radiation is extremely difficult to detect. Because neutron radiation is extremely penetrating, protecting workers is equally difficult. Effective shielding for neutron radiation usually involves a material that has a high hydrogen atom concentration. Such shielding might employ several feet of soil, paraffin (materials saturated with hydrogen atoms), or concrete.

NATURE OF RADIATION SOURCES

Unsealed or sealed sources containing radionuclides

Unsealed Sources used in many laboratories are easily dispersed, may cause contamination of the skin, and may be taken into the body.

Non-dispersible Sources are normally encapsulated or sealed. These are often enclosed in their own shield containers, but can still produce large radiation fields. If the shielding is damaged or the source is otherwise exposed, increased

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radiation intensities may be present. If the source capsule is ruptured, serious contamination is also possible.

Radiation Generators

X-ray machines - a device that converts electrical energy into X -ray energy.

Accelerators - device used to impart kinetic energy to electrically charged particles such as electrons, protons, deuterons, or other heavy ions.

QUANTITIES AND UNITS

Radioactivity

Activity

Activity is the rate of disintegration (transformation) or decay of radioactive material.

- 1) Becquerel (Bq) = one disintegration per second
- 2) Curie (Ci) = 3.7×10^{10} Bq.

Because the Ci is so large and the Bq is so small, we often use prefixes to define levels of activity. Examples of these prefixes follow:

(m) milli (10^{-3})	(K) kilo (10^3)
(μ) micro (10^{-6})	(M) mega (10^6)
(n) nano (10^{-9})	(G) giga (10^9)
(p) pico (10^{-12})	(T) terra (10^{12})

Half Life ($t_{1/2}$)

The amount of time that it takes for a radionuclide to be reduced by one half of its value through the process of radioactive decay.

The radioactivity decay equation is expressed as follows:

$$A = A_i \exp(-\lambda T) = A_i \exp(-0.693T / t_{1/2})$$

where,

A_i , is the initial activity of the source;
 λ , is the decay constant ($\lambda = 0.693/t_{1/2}$);

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T, is the elapsed time from the initial decay; and
 $t_{1/2}$, is the half-life of the radioactive material.

Dosimetry

Dose and dose rate

- dose is the amount of energy per unit of mass
- dose rate is the dose divided by the time in which the dose is received

Roentgen (R)

- Is the unit of exposure to ionizing radiation and applies only to gamma and x-rays.
- Corresponds to the generation of approximately 2.58×10^{-4} C/kg in dry air at standard temperature and pressure (STP).
- Does not relate biological effects of radiation to the human body.
- 1R = 1,000 milliroentgen (mR)

Rad (unit of absorbed dose)

- Is the amount of energy from any type of radiation deposited in the unit mass of any material.
- Measures absorbed dose on different types of material but does not take into account the effect that different types of radiation have on the body.

Rem (unit of dose equivalent)

- Takes into account the energy absorbed in tissue as well as the biological effect on the body that different types of radiation have (dose equivalent).
- 1 rem = 1,000 millirem (mrem)

Gray/Sievert

These are the SI units equivalent to rad and rem.

1 Gy = 100 rad

1 Sv = 100 rem

BIOLOGICAL EFFECTS

Introduction

Since we do not precisely know what the risks are at low levels of radiation exposure, we can only accept the risks associated with working around radiation

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by comparing it to other daily risks.

Average estimated days lost due to daily activities

health risk	days lost
Unmarried male	3,500
Cigarette smoker (1 pack/day)	2,250
Unmarried female	1,600
Coal miner	1,100
25% overweight	77
Alcohol (U.S. average)	365
Construction worker	227
Driving a motor vehicle	207
100 mrem/year for 70 years	10
Drinking coffee	6

This next table addresses the estimated days lost of life expectancy due to radiation exposure at radiation-related facilities as compared to other industries.

Average estimated days lost due to daily activities

health risk	days lost
Mining	328
Construction	302
Agriculture	277
Radiation dose of 5,000 mrem/year for 50 years	250
Transportation/Utilities	164
All industry	74
Government	55
Service	47
Manufacturing	43
Trade	30
Radiation accidents (deaths from exposure)	<1

The basis of our knowledge on biological effects is due to the past studies on:

- Early radiation workers
- Radium dial watch painters
- Accident victims
- Nuclear weapons testing/use
 - a. The survivors of Hiroshima and Nagasaki

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- b. Those exposed accidentally during Bikini Island tests
- Persons undergoing nuclear medicine treatment (the largest group).

SOURCES OF EXPOSURE

Natural exposure

The average annual radiation dose to a member of the general population from natural radiation sources is about 360 millirem (mrem).

The four major sources of natural radiation exposures are:

- Cosmic radiation
- Sources in the earth's crust (terrestrial radiation)
- Sources in the human body (internal sources)
- Radon

Medical exposure

X-ray Procedure

	<u>Average Dose*</u>
Normal chest examination	10 millirem
Normal dental examination	10 millirem
Rib cage examination	140 millirem
Gall bladder examination	170 millirem
Barium enema examination	500 millirem
Pelvic examination	600 millirem

**Variations by a factor of 2 (above and below) are not unusual.*

Nuclear medicine procedures tend to deliver even higher doses.

Occupational exposure

Any individual whose official duties or authorized activities include handling, operating or working in the presence of any type of radiation source or radiation producing device is a subject to occupational exposure.

TYPES OF RADIATION EXPOSURE

Chronic radiation exposure involves low levels of ionizing radiation over a long period of time. Among the possible effects of chronic exposure are the increased risk of developing delayed somatic effects such as cancer and cataracts. Also, research indicates possible genetic effects in humans from radiation damage to

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sperm and egg cells. Genetic damage may result in birth defects passed along to future generations.

- **Somatic effect** is the biological effect that occurs on the exposed individual.
- **Genetic effect** refers to biological changes on the descendants of the exposed individuals due to mutation of their genetic materials.
- **Hereditary effect** is a genetic effect that is inherited or passed onto an offspring
- **Teratogenic effects** are birth defects, experienced when an embryo or fetus is exposed to **large** doses of radiation. Radiation induced genetic abnormalities have not been identified in human populations. However, they have been observed in less genetically complex species.

Acute radiation exposure is delivered in a short period of time. Larger acute exposures are often associated with deterministic effects. The following possible outcomes can be produced as a result of a **large** acute exposure:

25 - 100 rads	Minor blood changes, some illness anticipated
100 - 300 rads	Illness (lowering of the white blood cell count, nausea, bacterial infections, vomiting, loss of appetite, diarrhea, fatigue, hair loss, and possible sterility), at the end of this range death may occur but this is infrequent and would be associated with those individuals undergoing simultaneous physiological stress. These are the classic signs and symptoms of the radiation sickness syndromes.
300 - 450 rads	Anticipated death of 50% of population within 30 days (at 450 rad LD _{50/30}), if medical assistance is not provided. Death caused by complications associated with radiation sickness syndromes.

When severely exposed, the victim may suffer fever, abdominal pains, explosive diarrhea, internal bleeding, infection, shock, convulsions, coma, and ultimately death. Acute exposure delivering 300 rads and above in a short period of time could possibly produce these outcomes.

Radiosensitivity is a term that describes how sensitive a given cell is to radiation damage. Scientists have found that the rate of mitosis and the degree of cellular differentiation determine radiation sensitivity.

The possible effects that could occur due to radiation exposure to cells are:

- There is no cell damage

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- Cells repair the damage and operate normally and/or cannot reproduce.
- Cells are damaged and operate abnormally.
- The cells die as a result of the damage.

The following cells are considered to be the most radiosensitive because of their reproductive rate:

- Cells of the unborn child.
- Blood and blood producing organs.
- Reproductive cells (sperm/egg).
- Digestive tract cells.
- Immature white blood cells.

Those, which reproduce slowly and are considered the least radiosensitive are nerve, muscle and bone cells. Of course, radiation affects each person differently depending on such factors as total dose, dose rate, type of radiation, the area of body exposed, cell sensitivity, individual sensitivity, age, medical history, and physiological condition.

INDIVIDUAL DOSE LIMITS

Federal and State Authorities establish legal dose limits that an employee should not exceed in a calendar year. Administratively, ISU establishes more conservative values than allowed by Federal and State authorities and the ALARA goals (explained in the next section) are set and self imposed by the ISU Radiation Safety Committee in order to minimize personnel exposure.

NRC occupational annual dose limits

The annual adult (persons 18 years of age or older) occupational dose limit established by the United States Nuclear Regulatory Commission is the more limiting of:

- The total effective dose equivalent being equal to 5,000 mrem (5 rem); or
- The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50,000 mrem (50 rem).
- An eye dose equivalent of 15,000 mrem (15 rem), and
- A shallow dose equivalent of 50,000 mrem to the skin or to each of the extremities (50 rem).

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The Idaho State University's Administrative Occupational Dose Limits (legal limits set by ISU) are as follows:

The annual adult occupational dose limit is the more limited of:

- The total effective dose equivalent being equal to 2,000 mrem (2 rem); or
- The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue, being equal to 10,000 mrem (10 rem).

ISU's administrative occupational dose limits are far less than the occupational dose limits set by the NRC or the State of Idaho.

Idaho Quarterly Occupational Dose Limits (applies to X-ray and accelerator users only)

- Whole body; head and trunk; active blood-forming organs; lens of eye or gonads 1,250 mrem/calendar quarter.
- Hands and forearms; feet and ankles 18,750 mrem/calendar quarter.
- Skin of whole body 7,500 mrem/calendar quarter.

General Public Dose Limits

The dose limit for members of the general public, including all persons who are not classified as radiation users, is a total effective dose equivalent not to exceed 100 mrem per year. The State limit is actually 500 mrem per year, however, we use 100 mrem to be consistent with the Nuclear Regulatory Commission (NRC).

Fetal Dose

The embryo-fetus may be more susceptible to radiation effects than an adult and is, therefore, subject to a lower dose limit. The dose limit for the embryo-fetus is 500 mrem (5 mSv) during the entire gestation period. As a further precaution, this limit should not be experienced in an acute fashion, but rather distributed relatively uniformly during the gestation period if it is to be experienced (Regulatory Guide 8.13). This degree of protection for the embryo-fetus can only be achieved with the cooperation of the employee. It is recommended that she notifies her supervisor or the RSO as soon as the pregnancy is known. In order for a pregnant worker to take advantage of the lower exposure limit and dose monitoring provisions, the woman may declare her pregnancy in writing to the TSO. This notification is optional, and at the discretion of the employee the TSO encourages the act of notification, when appropriate. Unless a woman declares her pregnancy, ISU can not set special dose equivalent limits for her. A sample letter for declaring a pregnancy is available on the TSO web page.

Dose Limits for Minors

The dose limits for minors (persons under 18 years of age) are 10% of the adult occupational dose limits.

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ALARA POLICY

Policy

Idaho State University is committed to an effective radiation protection program to eliminate unnecessary exposures to radiation and to reduce all exposures to levels that are **As Low As Reasonably Achievable (ALARA)**, **taking into account social and economic considerations**. The ALARA principle is a formal requirement of the U.S. Nuclear Regulatory Commission and the Idaho Department of Health and Welfare. The ALARA principle is implemented by a comprehensive radiation protection program that includes specific requirements and procedures for:

1. training of all radiation users,
2. safety evaluations of proposed facilities or projects utilizing radiation in any way,
3. regular surveys of work areas for contamination and exposure rates,
4. monitoring of radiation exposures to groups and individuals,
5. investigations of all exposures that exceed predetermined levels, and
6. reviews of the program by the Radiation Safety Committee.

Idaho State University's ALARA Goals

The ALARA goals for Idaho State University are set by the Radiation Safety Committee (RSC). The RSC reviews the University's goal at least annually to verify all exposures at ISU are consistent with the ALARA policy of the NRC.

ALARA Goals for the Radiation Technology Program:

- Total effective dose equivalent being equal to **600 mrem/year (150 mrem/calender quarter)**.

ALARA Goals for All Other Radiation Safety Programs:

- The total effective dose equivalent being equal to **100 mrem/year (25 mrem/ quarter - notification level)**.

If an ALARA goal is exceeded, the TSO will perform an investigation. The TSO's investigation is intended to determine if the personnel are following good radiation protection practices and if the ALARA goals are appropriate for the particular activity. Appropriate action will be taken based upon the results of the TSO's investigation.

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TRAINING

Each individual working with or in the presence of radioactive materials or other radiation sources is required to receive training or provide documentation showing they have received training, in the applicable provisions of regulations and license conditions, in the potential health problems associated with exposure to radiation, in the precautions and procedures required for safe use of radiation, and in the proper use of protective and measurement devices (10CFR19.12). The extent of the training is to be commensurate with the potential risk of radiation exposure to the individual.

Students who use small, non-dispersible radiation sources shall receive appropriate training by the laboratory instructor provided:

1. The use of the source is a part of a scheduled laboratory course under the supervision of an instructor who is either a qualified "Responsible User" or designated by the Responsible User for use of the source, AND;
2. The student will not receive more than 10% of the public dose limit of 100 mrem from the use of the source.

The primary responsibility for providing adequate training for radiation users rests with their responsible users or supervisors. Except for students in regularly scheduled laboratory courses discussed above, the responsible user or supervisor will generally fulfill this responsibility by assuring that each person participates in the appropriate training program offered by the RSO.

Following the initial training, each radiation user/responsible user is required to take on-line refresher training annually.

Users of analytical x-ray machines and particle accelerators, in addition to the training outlined for normally exposed radiation users, must receive instruction on proper use of shutters, interlocks and other safety devices, and on the requirement for a safety survey following room re-entry or any machine's modification or repair.

Users of soil densometers, in addition to the training outlined for normally exposed radiation users, must receive instruction on soil densometer transport requirements and theory of operation.

CLASSIFICATION OF AREAS

Controlled Area: Any area, to which access is limited for any reason. X-ray rooms and accelerator rooms are controlled administratively by the personnel who operate the equipment. Laboratories using radioactive materials are

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controlled by posting and locking for the purpose of preventing unauthorized removal of these materials. Exposure to radioactive materials is prevented by controlling the materials, and by limiting normal access to the laboratory when it is open and attended.

Restricted Area: an area, to which access is limited for the purposes of protecting individuals against undue risks from exposure to radiation and radioactive materials. It is an area that is defined by a responsible user to the purposes of working with radioactive materials. An area must be posted as a Restricted Area if the dose rate is **>2 mrem/hr** or it contains **> 0.02 ALI** of dispersible radioactive material. A Restricted Area will have some type of marked or physical boundary so that untrained personnel will be prevented from accessing the area.

Radiation Area: Any accessible area in which an individual could receive a dose equivalent **exceeding 5 mrem in 1 hour at 30 cm** (1 ft) from the source or from any surface the radiation penetrates.

High Radiation Area: Any accessible area in which an individual could receive a dose equivalent **exceeding 100 mrem in 1 hour at 30 cm** (1 ft) from the source or from any surface the radiation penetrates.

Very High Radiation Area: Any accessible area, in which radiation absorbed dose exceeds **500 rad in 1 hour at 1 meter** (3.28 ft) from the source or from any surface the radiation penetrates.

EXTERNAL EXPOSURE

Careful planning of work, good handling techniques and thorough monitoring are all necessary to minimize external exposure. Adequate shielding and distance from sources are also important factors in reducing exposure.

Workers can apply three principles to protect themselves from ionizing radiation exposure:

- Time
- Distance
- Shielding

Time

Obviously, the less time a person spends in a radiation field, the less exposure he/she will receive. Keep in mind that exposures to radiation are additive in their effect.

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Methods to minimize time of exposure to a radiation field:

- Preplan the task thoroughly prior to entering the area. Use only the number of people required for the job.
- Have all the necessary tools prior to entering the area.
- Work efficiently but swiftly.
- Do the job right the first time
- Perform as much work outside the area as possible.

Distance

The greater the distance you are from a source the smaller the exposure. Staying away from a radiation source, even a few feet, will greatly reduce worker exposure.

The radiation dose rate from point sources can be calculated using the following formula:

$$\text{Dose rate} = \Gamma A / (d^2) \quad [\text{R/h}]$$

where:

- Γ is a constant that depends on the radionuclide [$\text{Rm}^2/\text{Ci}\cdot\text{h}$]
- A is the activity in (Ci)
- d is the distance from the source in (m)

From the above formula for two distances d_1 and d_2 results that:

$$E_2 = E_1 \cdot (d_1)^2 / (d_2)^2$$

where,

E_1 = initial exposure rate at distance d_1

E_2 = final exposure rate at distance d_2

Methods to maximize distance:

- Be familiar with radiological conditions in the area.
- During work delays, move to lower dose rate areas.

Shielding

Shielding places protective materials between the worker and the source; for example, walls, barriers, or protective clothing.

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Proper uses of shielding

- Take advantage of permanent shielding.
- Erect temporary shielding as necessary.

Monitoring of External Exposures

External exposures are monitored by using individual monitoring devices. These devices are required to be used if the worker is likely to receive an external exposure that will exceed 10 percent of your allowed annual dose. The most commonly used monitoring devices are:

- Thermo-Luminescent Dosimeter (TLD)-(modern technology often uses *Optically Stimulated Luminescence (OSL) Dosimeters*)
 - Whole body badge
 - Finger ring
- Direct Reading Dosimeter (DRD)
 - pocket dosimeter
 - electronic dosimeter

The Whole body badge is worn to measure the exposure to the whole body (i.e., between the neck and the waist), finger rings are worn on the work hand and underneath a glove so as not to contaminate the ring, the DRDs are worn adjacent to the Whole body badge.

Dosimeter use and storage

Dosimetry devices issued from ISU's Radiation Safety Office are used to monitor the exposure that you receive while performing work at ISU only, and cannot be used at any other facility. It is important that they are returned to their proper storage location when they are not in use. This ensures that the badges are only recording your exposure from work performed at ISU, and also minimizes the chance of the badges being misplaced or lost.

If you are personally receiving radiation exposure for diagnostic or therapeutic purposes, **DO NOT** wear your dosimeter. Contact the RSO to discuss this situation. Be certain to contact RSO/TSO if you are exposed to radiation at other institutions.

The dosimeters will be picked up and replaced every three months for processing. Personnel that fail to return dosimeters, or return them to their proper storage locations, will be restricted from continued radiological work at ISU.

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Temporary Dosimeters

Temporary dosimeters will be issued on a case by case basis only. The professor in charge of the lab or facility will be responsible for the radiological actions of the potentially exposed individual. Temporary badges will not be issued as a vehicle to circumvent training requirements.

INTERNAL EXPOSURE

The presence of radioactive substances inside the human body generates internal exposure. Surface contamination can generate airborne contamination (particle re-suspension) that in turn, is ingested or inhaled.

Radioactive contamination may be *fixed or removable/transferable*.

Fixed contamination is not easily transferred from one place to another. It usually becomes fixed by physical or chemical absorption or by entrapment in physical irregularities of the surface material. If only fixed surface contamination is present, it can be quantified. Typically this is done using a Geiger Muller (GM) detector. Often those are referred as GM pancake probes. The information displayed on the meter's scale is in counts per minute (cpm). However, because cpm is strongly dependent on the radionuclide and a source to detector distance, one should compute the surface contamination in disintegration per minute (dpm) which is independent of the type of contaminant. The contamination in dpm is equal to the value in cpm divided by the efficiency (ϵ) of the detector for that type of radiation:

$$dpm = cpm / \epsilon$$

It is important to emphasize that the evaluation of contamination depends on the knowledge of two quantities cpm and ϵ . We can read cpm on the meter's scale but we have to know efficiency (ϵ) from the calibration. Because ϵ has values between 0 and 1 results that $dpm > cpm$. Only for an efficiency of 100% (hard to be obtained) $dpm = cpm$.

Portable meters are not of much help in case of low beta energy radionuclides (^{14}C and ^{32}S) and inapplicable in case of tritium (^3H).

Removable/transferable contamination may readily be transferred among objects. Cleanup activities where radioactive dust or dirt is present may lead to

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airborne contamination due to the mechanical action of sweeping or bagging activities. Examples of transferable contamination include (1) surface contamination, which can be spread by contact; (2) airborne contamination, which can be spread by grinding or burning, by air currents, and by evaporation; and (3) hot particles, which are small pieces of radioactive material with a very high radioactivity level. Hot particles may be especially hazardous to the skin or the extremities due to their short range and the intensity of the radiation emitted.

In research facilities, no removable contamination shall be tolerated indefinitely, therefore a **Removable Contamination Limit (RCL)** is established for each lab. The RCL in **dpm per 100cm²** (shipping regulations use dpm/300cm² or Bq/cm²) is the maximum amount of removable contamination allowed for each individual radioisotope. The removable contamination is measured by rubbing a filter paper over a 100 cm² area of the suspected contaminated surface. This survey is referred to as a swipe or smear test. If both fixed and removable contamination are present, the swipe test will give the removable component only and the GM pancake meter will give the total contamination (fixed plus removable). The RCL is also based on the **Annual Limit on Intake (ALI)**.

If a worker becomes contaminated, a health physicist should be consulted for proper decontamination procedures. The process is **NOT** the same as chemical decontamination. The decontamination methods used depend upon the location and the form of the contamination. Normal cleaning techniques for external decontamination usually involve washing with soap and lukewarm water, although the aid of other techniques and medical personnel may be needed. Reduction of internal contamination depends on the **radioactive half-life** of the particular contaminant and the normal biological elimination processes such as urination, exhalation, defecation, and perspiration. These processes can be enhanced under proper medical supervision.

Prevention of intake of radioactive material

Ingestion of radioactivity must be prevented by avoiding mouth contact with any items handled in a radioactive material laboratory (pipettes, pencils, etc.), by prohibiting eating, drinking and smoking in radionuclide handling areas and by careful attention to personal hygiene.

MONITORING OF INTERNAL EXPOSURES

Internal exposures - Bioassay

Bioassay measurements used for demonstrating the compliance with the occupational dose limits should be conducted often enough to identify any

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quantify potential exposure, during any year, are likely to collectively exceed 0.1 times the ALI (Reg. Guide 8.9, 10CFR20).

A bioassay is required whenever personal contamination or injury caused by a contaminated object occurs, or if airborne radioactivity may have been inhaled. Routine bioassays, at intervals determined by the radionuclides used, are required from each user who handles more than certain threshold quantities of dispersible radioactive materials. A routine bioassay may be waived when appropriate surveys for contamination, conducted during and after each use of radioactive material according to recommended procedures, demonstrate that there was essentially no exposure to unconfined, dispersible radioactive material and as authorized by the RSO.

A radiation user who handles a cumulative quantity of radioactive materials in dispersible form of less than 1 ALI per month, averaged over the bioassay interval, is unlikely to experience an annual intake of 0.1 ALI and does not require routine bioassays. If a worker is exposed to contamination exceeding the levels specified under "Conditions Requiring Bioassays", however, a non-routine bioassay will be required.

At ISU, a radiation user who handles a cumulative quantity of radioactive materials in dispersible form of more than 1 ALI per month, averaged over the bioassay interval, is considered to be potentially exposed to an annual intake of more than 0.1 ALI. Such an individual must perform or obtain bioassays routinely unless the records of contamination surveys of both the user and the RSO verify that there was no exposure to unconfined radioactive materials exceeding the levels specified.

Individuals who handle dispersible radioiodine compounds may be required to obtain in vivo measurements of radioiodine in the thyroid, performed by the RSO, at specified intervals. Individuals who handle other radionuclides in dispersible forms may be required to perform assays of radioactivity in urine on a routine basis to document the absence of radioactivity in the body or to determine the magnitude of any exposure. Other types of assays may be utilized if, in the judgment of the RSO, such assays will meet the intent of this policy more effectively.

The optimum time for performing a bioassay is within a few days after a potential exposure, and therefore **each user will perform** a screening assay within a few days after handling any unusually large quantities, or after performing any procedure involving a greater than usual opportunity for exposure. Subsequent routine bioassays would not be required again until the end of another full bioassay interval unless another unusual exposure situation occurred. The

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Technical Safety Office will notify users when a bioassay is due (upon delivery of the radioactive material), i.e. the expiration of the bioassay interval, but it is the responsibility of the user to complete the bioassay promptly.

- A bioassay is required within 5 days for each individual having contamination of the skin or hair exceeding 10 RCL.
- A bioassay is required within the normal bioassay interval for any individual having skin or hair contamination exceeding 1 RCL.
- A bioassay is required within 5 days for each individual involved in a spill, or other uncontrolled release, of >0.5 ALI of radioactive material outside of a properly functioning fume hood or >5 ALI inside a hood.
- A bioassay is required within 5 days for each individual who was present in an area during a time when removable contamination exceeding 100 RCL was present on any readily accessible surface.
- A bioassay is required within the normal bioassay interval for each individual who was present in an area during a time when removable contamination exceeding 10 RCL was present on any readily accessible surface.
- A bioassay is required within the normal bioassay interval for personnel who work in laboratories that have >1 ALI of cumulative quantity handled, averaged over the bioassay intervals. The determination of the cumulative quantity handled will be based primarily on records of receipts and disposals of radioactive materials, with adjustments for individual work assignments as defined by the responsible user. Routine bioassays may be waived at the discretion of the RSO if the records of contamination surveys of both the user and the RSO verify that there was no exposure to unconfined radioactive materials exceeding the levels specified above and no incidents of personal contamination since the last bioassay. When mixtures of radionuclides are present in the laboratory, the necessity of a bioassay will be based upon a sum of the fractions evaluation.

RECORDS AND REPORTS

All the records of surveys, measurements and individual monitoring are maintained at the TSO. Records of the doses to individuals are reported, at least annually to the workers in a format required by the NRC. If a dose received by a

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worker exceeds any of the annual dose limits, any occupational exposure will be prohibited for the overexposed individual for the rest of that year (Reg. Guide 8.29, 10 CFR 20.2106).

Upon the request of a former ISU worker, the dose report for the period of time that the individual was engaged in ISU activities will be furnished to the worker (10 CFR 19.13).

If the workers are concerned about safety issues in their workplace, they may request that the NRC conduct safety inspections.

LABORATORY SAFETY PROCEDURES

Responsibilities

Each person who works with unsealed or dispersible radioactive materials is responsible for:

- knowing the basic properties of the radioactive materials to be used, e.g. the half-life of the radionuclide(s), the type(s) of radiation emitted, the annual limit on intake (ALI) and the type and quantity of the appropriate regional shielding.
- following the instructions or procedures provided by the responsible user and the RSO, or provided in the Radiation Safety Policy Manual.
- surveying of gloves, clothing, equipment and work area frequently during procedures in which more than 1 ALI is manipulated, and surveying of hands and personal clothing before leaving the laboratory.
- providing a urine sample, or obtaining a thyroid count or other bioassay measurements, at intervals specified by the RSO.
- recording the results of all radiation surveys and screening bioassays promptly, completely and accurately.

Posting

Each room containing more than 10 times the Reference Quantity values given in 10CFR20, Appendix C and RPR10 must be labeled with a "CAUTION RADIOACTIVE MATERIALS" label. For rooms containing X-ray machines "CAUTION X-RAY EQUIPMENT" label should be used.

If any dose rate exceeds **2 mrem in any one hour** at 30 cm (1ft.) from an accessible source or surface, the room shall be posted as a "RESTRICTED AREA" to prevent entry of unauthorized individuals. If any dose rate exceeds **5 mrem in any one hour** at 30 cm (1ft.) from an accessible source or a surface, the room must be labeled with a "CAUTION RADIATION AREA" sign.

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A "NOTICE TO EMPLOYEES", available from the RSO, must be posted in a location clearly visible to anyone entering the laboratory.

All containers of radioactive materials should be labeled with the "CAUTION, RADIOACTIVE MATERIAL" or "DANGER, RADIOACTIVE MATERIAL" sign.

Survey instruments

The responsible user shall ensure that instruments used for determining exposure rates or for direct detection of contamination are calibrated biannually and capable of responding appropriately to the types of radiation anticipated. The user must know the detection efficiency (e.g. % efficiency for the radionuclides being used in the laboratory, cpm/dpm) for each contamination survey instrument and record it with all survey results.

PHYSICAL SECURITY OF RADIOACTIVE MATERIALS

Policy

According to the provisions of 10CFR20 the licensee shall: (i) secure from unauthorized removal or access licensed materials that are stored in controlled or unrestricted areas (10CFR20.1801) AND (ii) control and maintain constant surveillance of licensed material that is in a controlled or unrestricted area and that is not in storage (10CFR20.1802). These security requirements apply to radionuclides in any form, sealed or non-sealed, and to radionuclides in original containers, anywhere in the experimental process, and in waste containers. Only those persons who are qualified to work with radioactive materials have access to those materials. Administration at Idaho State University is extremely sensitive regarding this policy and strongly encourages its employees to strictly adhere to the policy because of problems discovered during recent NRC inspections.

ISU Security Requirements

All Responsible Users at Idaho State University are required to maintain security of the licensed radioactive material in their possession. This includes but is not limited to: radionuclides in original containers, reagents and test materials, and waste in waste containers.

1. The presence of authorized personnel in the laboratory will be sufficient to meet the NRC security requirement (at least one authorized individual must

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continuously be present in the laboratory when radioactive materials are not secured).

2. When there are no authorized personnel in the laboratory, the following conditions apply:

- a) One or more physical barriers will be maintained for licensed material above the exemption level of Schedule B of 10 CFR 20.
- b) Two or more barriers will be maintained for all radioactive material in excess of 100 times the levels of Appendix C of 10 CFR 20.
- c) No exceptions to the two barrier rule for material in excess of 1000 times the levels of Appendix C of 10 CFR 20 will be granted by the Radiation Safety Officer or the Radiation Safety Committee. Responsible users who desire an exception to this policy may appeal to the P-VPAA.

Common safe storage measures are recommended for all radioactive material below the levels specified above. A physical barrier is defined as some form of fixed locked storage. The door to the laboratory is considered to be one barrier if it is maintained in a locked condition when the lab is unoccupied. Other barriers may be: a fixed locked cabinet, locked refrigerator, locked fume hood sash or similar fixed locked storage.

Responsible Users

The responsible user must ensure that:

- the licensed radioactive materials that are stored in controlled or unrestricted areas are secured from unauthorized removal or access.
- the licensed radioactive material that is stored in a controlled or unrestricted area and that is not in storage is constantly controlled and surveyed.
- all radiation users have received the required radiation safety and security instruction.
- radioactive materials are secured against theft, misuse and access by unauthorized personnel.
- all radioactive materials will be logged in and out.
- radioactive wastes are segregated properly and placed in appropriate containers (**DO NOT** generate mixed hazardous waste). The containers are to be provided by the user; labels and clear plastic bags are available from the TSO. The TSO is contacted for the disposal of radioactive wastes.
- accurate records of acquisitions and dispositions of radioactive materials are maintained.
- the RSO is notified promptly of any accident or abnormal incident involving radioactive materials.

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- prior to any extended absence of the responsible user, another individual is authorized by the Radiation Safety Committee (or temporarily authorized by the Radiation Safety Officer) to assume the preceding responsibilities, or the use of radioactive materials is suspended or terminated.

To order and receive radioactive materials from stores, the laboratory supervisor should fill a purchase order which must be signed by the RSO.

Radioactive materials may be shipped from the University to another organization or individual ONLY after verification by the RSO that all transfer, packaging, labeling and transportation requirements have been met.

Any responsible user who is planning to transport radioactive material between University buildings or to ship to another institution must first contact the TSO.

All transportation of radioactive materials ON campus must be conducted by the TSO.

Only DOT exempt sources may be transported in private vehicles. To assure that all requirements for shipment are met, and that appropriate records are maintained, a written authorization form and one or more check lists must be prepared by the TSO before the shipment is made. The instructions and forms for various applications are contained in the ISU Radiation Safety Manual.

RADIATION EMERGENCY

Any accident, injury or loss of control of a radiation source or radiation producing device that could cause an excessive or uncontrolled radiation exposure to any individual is referred to as a radiation emergency. Each user of radiation sources should be familiar with the basic emergency responses listed below and methods for applying them in his or her own work area.

In case of a spill of radioactive material, you must respond in a timely manner to minimize your exposure and take appropriate actions. Employees are expected to clean up, survey and document their own spills **if** it is in their capability. The TSO offers assistance in spill clean-up if so requested. If you enter a lab with a spill and do not know what the material is or feel uncomfortable with decontamination procedures, you should contact the TSO for assistance.

Workers are not permitted to enter rooms with X-ray machines and accelerators while the beam is on. Inadvertent entry into X-ray machine rooms or accelerator rooms is prevented by engineering and administrative controls. All the safety

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systems must meet **fail-safe characteristics**. This is a design feature that causes beam shutters to close, or otherwise prevents emergence of the primary beam, upon failure of a safety or warning device.

1. Protect People

The first consideration is to assist injured persons and to prevent any further injury. If the situation involves a radiation-producing machine, the machine should be turned off (if it is in your capability). Except for the usual precautions for moving an injured person, individuals should immediately leave the room or area until the extent of the radiological hazard has been evaluated. However, all individuals should remain available in the vicinity until they are checked for contamination and their exposure has been assessed. If you are qualified to render first aid, do so without regard to the presence of radioactivity.

2. Get Help

Each individual using radiation sources or radiation producing devices should know in advance whom to call in case of a radiation emergency. If fire injury or other emergency conditions are involved, first call the appropriate numbers listed on the 1st page of the Campus Directory.

Dial 911 immediately for medical assistance, and report the nature of the illness or injury. Inform the 911 dispatcher that the injured individual may be contaminated with radioactive material (generally not the case for X ray machines and accelerators).

Next notify the Technical Safety Office at extensions 2310 or 2311 during normal working hours OR notify Public Safety, at 282-2515 during off duty hours. Public Safety will notify the TSO.

When reporting any emergency, be sure to state the exact nature of the emergency then give your name and the phone number from which you are calling, the exact location of the emergency (building, room, nearest entrance, etc.) and the name of the Responsible User, if known. Do not hang up! Let the person you called end the conversation after all pertinent information is clearly understood.

3. Contain the Hazard

Any of the following actions appropriate to the situation should be performed provided they can be carried out safely:

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1. Turn off radiation producing machines.
2. Cover containers of radioactive materials.
3. Place absorbent material on spilled liquids.
4. Close the sash on fume hoods, but do not turn off hood exhaust fans.
5. Close doors to the area and post signs or guards to prevent unauthorized entry.
6. Allow no one to leave the area without being checked for contamination.

4. Follow-up Action

Any necessary decontamination or repairs required after a radiation emergency shall be performed only under the direction of the Radiation Safety Officer (RSO) or his designee. Reentry or re-occupancy must be authorized by the RSO. The RSO shall evaluate, record and report, as necessary, any radiation exposures to personnel, loss of radioactive material, or damage to radiation facilities resulting from the emergency. If required by the RSO, individuals involved in a radiation emergency shall submit specimens for bioassay, surrender personal clothing or other articles for decontamination or assay, and provide pertinent information.

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RADIONUCLIDE DATA

Low-energy beta or electron emitters with negligible external exposure potential.

Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
H-3	12 years	1,000	80
C-14	5,730 years	100	2
S-35	87 days	100	6
Cl-36	3×10^5 years	10	2

High-energy beta emitters with negligible gamma emission but capable of significant bremsstrahlung¹ production if not properly shielded. Emphasis is on control of doses to extremities and prevention of intake.

Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
P-32	14.3 days	10	0.6
Sr-Y-90	29.12 years	0.1	0.03

Radioiodines are treated as a separate category for exposure evaluation. Emphasis is on prevention of intake by ingestion or inhalation.

Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
I-125	60 days	1	0.04
I-129	1.57×10^7 years	1	0.005
I-131	8 days	1	0.03

Noble gases present minimal exposure potential or waste disposal problems.

Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
Kr-85	10.7 years	1,000	N/A
Xe-133	5.2 days	1,000	N/A

Naturally occurring radionuclides are primarily alpha emitters. Emphasis is on prevention of intake by ingestion or inhalation.

Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
Th-232	1.4×10^{10} years	100	0.0007
U-238	4.5×10^9 years	100	0.02

Radionuclides which emit gamma rays of substantial energy and with ALI greater than or equal to 1 millicurie; emphasis is on external exposure control and monitoring.

¹ Bremsstrahlung radiation is electromagnetic radiation emitted by swiftly moving charged particles as they de-accelerate.

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Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
Na-24	15 hours	100	4
Mn-54	312 days	100	2
Mo-99	2.8 days	100	1
Tc-99m	6 hours	1,000	80
Au-198	2.7 days	100	1

ALL OTHER RADIONUCLIDES not included in one of the above groups are assumed to have potentials for both external and internal exposures and must be evaluated individually.

Nuclide	Half Life	Reference Quantity (μCi)	Ingestion ALI (mCi)
Na-22	2.6 years	10	0.4
Co-60	5.27 years	1	0.2
Zn-65	244 days	10	0.4
Ir-192	74 days	1	0.9
Hg-203	47 days	100	0.5