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**University of Arizona  
Moisture Gauge Protection Reference Guide**

**Research Laboratory & Safety Services  
Revised January 8, 2018**

Research Laboratory & Safety Services (RLSS) is the primary coordinating unit responsible for the radiation safety program at the University of Arizona. The Moisture Gauge Protection Reference Guide is maintained at RLSS at 1717 E Speedway Blvd, Suite 1201, Tucson, AZ, and is readily available to anyone via the RLSS website ([rlss.arizona.edu](http://rlss.arizona.edu)).

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## I. Introduction

The Moisture Gauge Protection Reference Guide serves to describe the Moisture Gauge program at The University of Arizona (UA) and to provide information regarding the safe use of moisture gauges and the radioactive sealed sources used in the gauges. The responsibilities of the UA Research Laboratory & Safety Services (RLSS), Approval Holders, Approval Safety Coordinators and Radiation Workers are also described.

The program is intended to:

- Provide a basic introduction to radioactive materials and the hazards associated with their use;
- Provide guidance to Approval Holders and workers authorized under their approvals;
- Provide instruction on the acquisition, safe use, transport, security, transfer, and disposal of sealed sources and gauges;
- Maintain regulatory compliance with applicable state and federal regulations, and
- Inform Approval Holders of the resources available to them through the Research Laboratory & Safety Services (RLSS).

All personnel working with moisture gauges must complete the Moisture Gauge Protection Course prior to using gauges and their sealed sources. Course materials and schedules are available on the RLSS website. Approval Safety Coordinators must also complete an Approval Holders Orientation (provided by RLSS personnel).

## II. Physics

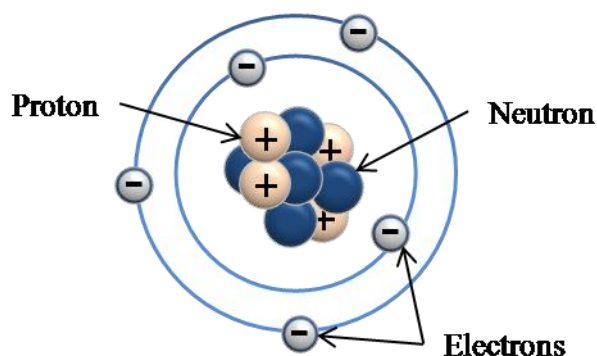
### A. Atomic Structure

The basic unit of matter is the atom. The basic atomic model, as described by Ernest Rutherford and Niels Bohr in 1913, consists of a positively charged core surrounded by negatively-charged shells (see Figure 1). The central core, called the nucleus, is held together by nuclear forces.

Protons ( $p^+$ ) are positively charged particles and neutrons ( $n$ ) are uncharged particles; both are located in the nucleus of the atom. Electrons ( $e^-$ ) are negatively charged particles that travel in structured orbits, or energy shells, around the nucleus.

An atom is electrically neutral if the total electron charge equals the total proton charge. The term ion is used to define atoms or groups of atoms that have either a positive or negative electrical charge. Isotopes are forms of an element that have the same number of protons, but different numbers of neutrons.

**Figure 1: Atomic Structure**



## B. Ionizing Radiation

Radiation is the transfer of energy, in the form of particles or waves, through open space. Radiation with sufficient energy to create ions by physically removing electrons from neutral atoms is referred to as ionizing radiation. Ionizing radiation includes alpha particles, beta particles, electromagnetic waves, and neutrons. Radiation that lacks the energy to cause ionization is referred to as non-ionizing radiation. Examples of non-ionizing radiation include radio waves, lasers, microwaves, and visible light. The following are four main categories of ionizing radiation.

### 1. Alpha Particles

The alpha particle is similar to a helium nucleus, comprised of two protons and two neutrons (without surrounding electrons). Alpha particles are heavier and generally more energetic compared to other common types of radiation; however, typical alpha particles travel less than a few inches in air and are stopped by a sheet of paper or the outermost layer of dead cells which protect the skin.

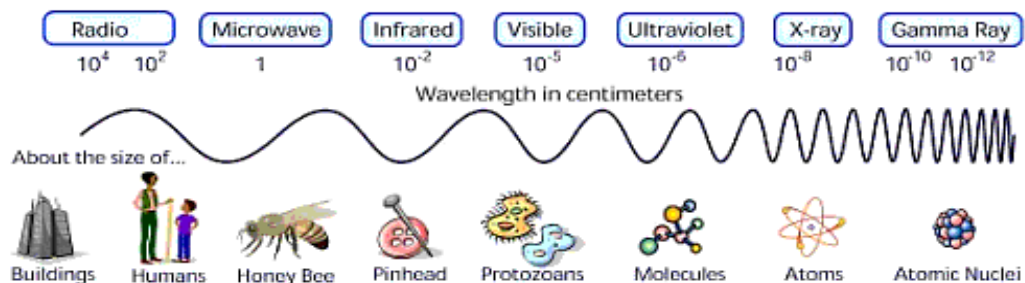
### 2. Beta Particles

Beta particles are charged particles that come in positive and negative forms. When an unstable atom converts a surplus neutron in the nucleus to a proton, it emits an electron. When an unstable atom converts a surplus proton in the nucleus to a neutron, it emits a positive electron (or positron). Positrons, such as those emitted by  $^{18}\text{F}$ , interact with electrons, destroying both and yielding energy (annihilation radiation). That interaction represents a conversion of mass to radiant electromagnetic energy, which can be harmful if not properly controlled. A beta particle has less mass and less charge than an alpha particle, which allows it to travel farther in air, deeper into skin, and through thin shielding and clothing.

### 3. Electromagnetic Waves: Gamma Rays (Gammas) and X-Rays

Gamma and x-rays differ only in their origin. Gammas originate from an unstable atomic nucleus and x-rays originate from accelerated electrons interacting with matter. Unlike alpha and beta particles, gammas and x-rays penetrate deeply into objects because they do not interact as readily with matter. This is due to their extremely small mass and lack of charge. Both are electromagnetic radiation and differ from radio waves and visible light in that they have a much shorter wavelength, higher frequency and higher energy (see Figure 2).

Figure 2: Comparison of Wavelengths



### 4. Neutrons

Neutrons are nuclear particles that have an exceptional ability to penetrate other materials. Of the types of ionizing radiation discussed here, neutrons are the only ones that can make objects radioactive. This process, called neutron activation, produces many of the radioactive sources that are used in medical, academic, and industrial applications (including oil exploration).

Because of their exceptional ability to penetrate other materials, neutrons can travel great distances in air and require very thick hydrogen-containing materials (such as paraffin or water) to absorb them. Neutron radiation primarily occurs inside a nuclear reactor, where many feet of water provide effective shielding.

### C. Principles of a Sealed Source

A radioactive sealed source is radioactive material (RAM) that has either been enclosed in metal or plastic or plated as a thin film onto metal or plastic, or it is a solid element that has become radioactive via exposure to a neutron flux (been activated). These sources come in a variety of shapes and sizes; they can be as small as the tip of a match or as large as a can of paint. Sealed sources may contain radioactive neutron, alpha or beta particle emitting materials.

#### 1. Encapsulated Radioactive Sealed Sources

Encapsulated radioactive sealed sources (see Figure 3) consist of a capsule that is sealed around radioactive compounds. “Special Form” source encapsulations are the most durable type and are specifically designed, tested and certified to withstand extreme heat and pressure. Non-special form source encapsulations may lose their integrity and release radioactive material if twisted or used incorrectly.

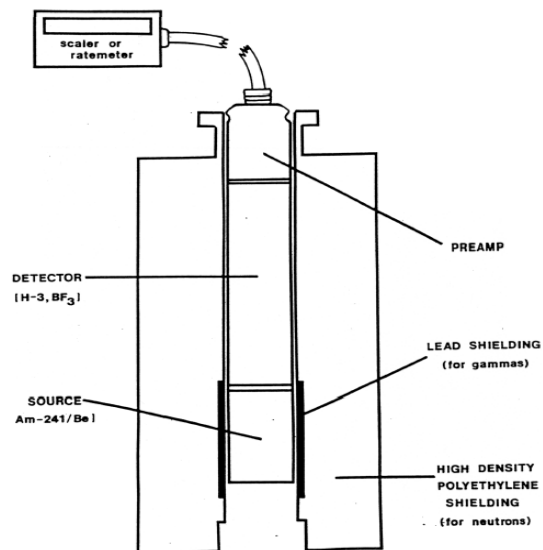
Figure 3: Encapsulated Sources



##### a. Soil Moisture Gauges (see Figure 4):

Radioactive material used in a soil moisture gauge is contained within a sealed, doubly encapsulated stainless steel capsule. Soil moisture gauge sources are classified as “Special Form” sources. The radioactive sealed source is placed into the gauge probe assembly along with a detector. The sealed source emits alpha particles which react with beryllium atoms to create fast neutrons. The system is designed to detect the amount of water in the soil around a probe by counting the amount of neutrons that are reflected back from the soil to the detector. This is commonly referred to as the neutron moderation technique.

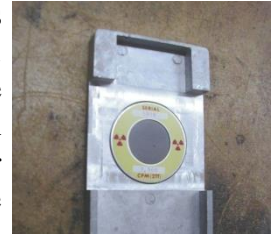
Figure 4: Soil Moisture Gauge System



## 2. Plated Radioactive Sealed Sources

Plated radioactive sealed sources (see Figure 5) have radioactive materials incorporated onto a metal or plastic substrate, usually by electrodeposition. The radioactivity is bonded into the substrate, creating a very thin active layer on the surface. These types of sources are often used for alpha and low energy beta emitting radioactive materials. The common uses for plated sources in the laboratory are for instrument calibration or sample ionization.

Figure 5: Plated Source



## 3. Activated Radioactive Sealed Sources

Activated radioactive sealed sources (see Figure 6) consist of a rod, wire or foil that has been exposed to a neutron flux. The neutron flux irradiates the metal, creating a radioactive isotope of the original material. Sometimes activated sources have a plastic or epoxy coating applied so that the activated material does not separate from the main source body.

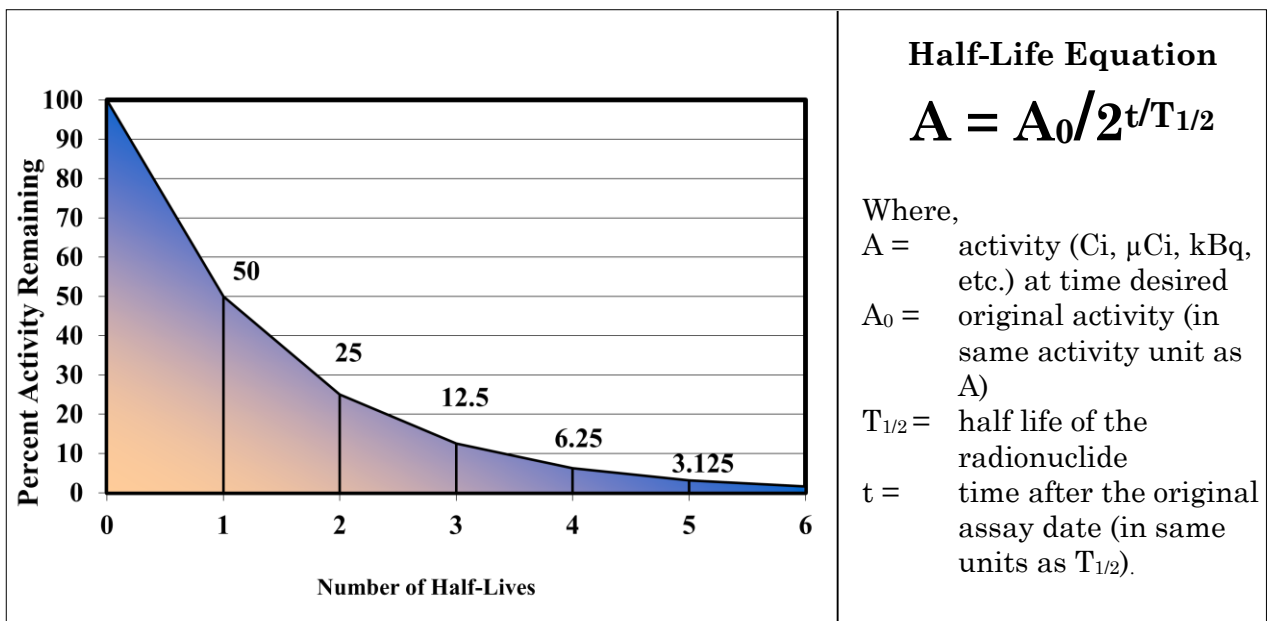
Figure 6: Activated Source



## D. Radioactivity and Units of Radiation Measurement

The energy of ionizing radiation is usually measured in electron volts (eV). The electron volt is defined as the kinetic energy gained by an electron when it accelerates through an electric potential difference of one volt.

Figure 7: Radioactive Decay/Half-Life Equation



## 1. Radioactive Decay

When an unstable atom (or radionuclide) emits energy to become more stable, the radionuclide is said to be "radioactive" and the process of change is called radioactive decay. Radioactive decay is measured in half-life, which is the time required for a radionuclide to lose 50% of its original radioactivity (or activity) by decay. Each radionuclide has a unique half-life ranging from



microseconds to billions of years. Radionuclide vendors provide the assay date and assay activity to users so that the original amount of activity on a specified date is known and the remaining activity on any subsequent date can be determined based on the half-life of the specific radionuclide (see Figure 7).

**2. Radioactivity Units of Measure**

Radioactivity is the rate at which radioactive atoms decay. The quantity of a radioactive material is referred to in relation to its activity rather than its mass (e.g. 2 curies of <sup>32</sup>P, not 2 grams of <sup>32</sup>P).

The two most common units of activity are the curie and the becquerel. One curie is equal to 3.7 x 10<sup>10</sup> (37 billion) radioactive disintegrations per second (dps). The becquerel is the System International (SI) unit of activity and one becquerel is equal to one dps. The curie is a very large amount of activity and the becquerel is a very small amount. To make discussion of common amounts of radioactivity more convenient, millicuries (mCi) and microcuries (μCi) or kilobecquerels (kBq) and megabecquerels (MBq) are used (see Table 1).

<b>Table 1: Units of Radioactivity</b>		
<b>Units</b>	<b>Disintegrations per second</b>	<b>System International (SI) units</b>
1 curie (Ci)	3.7 x 10 <sup>10</sup> (dps)	37 gigabecquerel (GBq)
1 millicurie (mCi)	3.7 x 10 <sup>7</sup> (dps)	37 megabecquerel (MBq)
1 microcuries (μCi)	3.7 x 10 <sup>4</sup> (dps)	37 kilobecquerel (kBq)
1 nanocurie (nCi)	37 (dps)	37 becquerel (Bq)
1 picocurie (pCi)	.037 (dps)	37 millibecquerel (mBq)

**3. Exposure**

Radiation exposure refers to absorption of ionizing radiation or ingestion of a radionuclide. Electromagnetic waves (gammas and x-rays) can produce ionization of air. The unit of measure for ionization of air by electromagnetic waves is the Roentgen (R), where:

$$1 \text{ R} = 2.58 \times 10^{-4} \text{ Coulombs/kg of air}$$

**4. Absorbed Dose**

When predicting biological effects, it is important to determine the energy deposited in human tissue rather than in air or other matter. The total ionizing radiation energy deposited per unit mass of material is the absorbed dose. The rad is the traditional unit of radiation absorbed dose.

$$1 \text{ rad} = 100 \text{ ergs/gram}$$

$$1 \text{ R} = \sim 0.87 \text{ rad (in air); up to } 0.96 \text{ rad (in tissue)}$$

The SI unit of radiation absorbed dose is the gray (Gy).

1 gray = 1 joule/kg

The relationship between the gray and the rad is:

1 gray = 100 rad

### 5. Dose Equivalent

The dose equivalent is used to measure the biological effects of ionizing radiation on the human body. It is a function of the absorbed dose and the type of radiation absorbed. The weighting factor used according to the

type of radiation absorbed is called the quality factor (QF). The rem is the product of the absorbed dose in tissue (the biological dose), calculated by multiplying the rad by a quality factor

(see Table 2). This quality factor is used to address the fact that, for the same absorbed dose, different types of ionizing radiation have differing biological effects in the scope of exposure to low levels of radiation.

Because the quality factor for commonly used ionizing radiation (x-rays, gammas and betas) is one, for radiation safety purposes it may be assumed that:

$$1 \text{ R} = 1 \text{ rad} = 1 \text{ rem}$$

The SI unit for dose equivalent is the sievert (Sv). As it was between the gray and the rad, the relationship between rem and sievert is:

$$1 \text{ Sv} = 100 \text{ rem}$$

**Table 2: Quality Factors for Different Radiations**

<b>Radiation</b>	<b>Quality Factor</b>
X, gamma, or beta radiation and high-speed electrons	1
Neutrons of unknown energy	10
High-energy protons	10
Alpha particles, multiple-charged particles, fission fragments, and heavy particles of unknown charge	20

## III. Biological Effects of Radiation

### A. Origins of Biological Damage from Radiation Exposure

Biological effects can be categorized as direct or indirect based on how cellular damage occurs. An indirect effect occurs when free radicals produced by the ionization of water molecules in the body, interact with other molecules or intracellular structures. Most of the time, free radicals interact with molecules that cells can easily survive without.

Radiation that deposits energy directly into intracellular structures (including DNA) results in a direct effect. Changes to DNA can produce cell death, the inability to reproduce, the inability to function, or a change in the function of the cell (mutation), which could lead to cancer. DNA has the ability to repair itself, reverting to its original state or mutating, depending on the type and extent of the damage.

### B. Exposure Risks

## 1. Acute Radiation Dose Exposure

- a. Acute radiation dose is exposure to a large radiation dose over a short time (the period of exposure is considered short when the dose is delivered so quickly that damaged DNA cannot repair itself). At low levels of radiation exposure, the amount of cell death or mutation that results is usually irrelevant and does not impact the function of an entire organ. With an acute radiation dose, large numbers of cells may die and impact the ability of organs to function. Acute radiation dose results in a specific and prompt effect called acute radiation syndrome (or radiation sickness). The dose at which symptoms occur depends on the sensitivity of various cells to radiation. In general, the faster a cell divides and the less specialized it is (e.g. an immature blood cell is less specialized than a mature one), the more sensitive it is to radiation. Immature blood cells are the most radiation-sensitive cells. Effects and outcomes of the three acute radiation syndromes are shown in Table 3. Soil moisture gauge users are rarely exposed to more than 0.2 rem/year, which is too low to result in acute radiation syndrome.

<b>Table 3: Acute Radiation Syndromes</b>			
	<b>Hematopoietic Syndrome (affects blood cell formation)</b>	<b>Gastrointestinal Syndrome</b>	<b>Central Nervous System Syndrome</b>
<b>Dose (rad)</b>	200-1000	> 1000	> 2000
<b>Time to Death (if fatal)</b>	3-8 weeks	3-10 days	< 3 days
<b>Organ/System Damaged</b>	Bone Marrow	Small Intestine	Brain
<b>Signs &amp; Symptoms</b>	<ul style="list-style-type: none"> <li>• Decreased number of stem cells in bone marrow</li> <li>• Increased amount of fat in bone marrow</li> <li>• Pancytopenia (reduction in red/white blood cells and platelets)</li> <li>• Anemia (reduction in red blood cells)</li> <li>• Hemorrhage (bleeding)</li> <li>• Infection</li> </ul>	<ul style="list-style-type: none"> <li>• Denudation of villi in small intestine</li> <li>• Neutropenia (reduction in white blood cells)</li> <li>• Infection</li> <li>• Bone marrow depression</li> <li>• Electrolyte imbalance</li> <li>• Watery diarrhea</li> </ul>	<ul style="list-style-type: none"> <li>• Vasculitis (inflammation of the blood vessels)</li> <li>• Edema (water-retention)</li> <li>• Meningitis (inflammation of the brain/spinal cord membranes)</li> </ul>
<b>Recovery Time</b>	Dose dependent, 3 weeks to 6 months; some individuals do not survive.	None; fatal	None; fatal

## 2. Chronic Low Level Radiation Exposure

Chronic low level radiation exposure is exposure to low levels of radiation over long periods of time. The dose effects from chronic low level radiation exposure are delayed effects and include an increased risk of cancer and hereditary effects.

Some other effects, such as skin reddening, cataract formation and temporary sterility in males, occur after receiving a threshold dose (the minimum dose that will produce a detectable degree of any given effect); however, none of these effects have been seen at occupational levels. It is important to realize that the potential risks associated with occupational radiation exposure are similar to, and sometimes less than, risks encountered in daily life (accidental death and the impact of lifestyle choices).

### **3. Soil Moisture Gauge Radiation Hazards**

A soil moisture gauge may contain radioactive neutron, alpha, beta, gamma or x-ray emitting materials. Alpha and beta particle exposure is highly unlikely from a soil moisture gauge since only a ruptured or defective, leaking source should cause exposure. Soil moisture gauge

operators are primarily exposed to neutron radiation and to gamma and x-rays (electromagnetic radiations) which may be generated by alpha, beta or neutron particles.

The amount of radiation exposure a user receives varies with different applications. Since radioactive neutrons lack charge, they can escape the capsule and pose an exposure hazard. Therefore, a non-ruptured sealed source in a moisture gauge still presents a neutron and photon radiation hazard.

## **IV. Radiation Exposure and Protections**

Individuals are exposed to radiation in the normal course of everyday life. Sources of radiation exposure can be classified as natural, man-made, and occupational.

### **A. Natural Radiation**

Natural radiation is the background radiation that is always present in the environment. The main sources of natural radiation are: cosmic radiation which comes from the sun and stars, terrestrial radiation which comes from the earth, and internal radiation which exists within all living things.

### **B. Man-Made Radiation**

Man-made ionizing radiation includes medical exposures (such as diagnostic x-rays, fluoroscopy, and other types of imaging, and nuclear medicine diagnostic and treatment procedures), building materials, combustible fuels (including gas and coal), X-ray security systems, smoke detectors, luminous watches, and tobacco.

### **C. Occupational Dose**

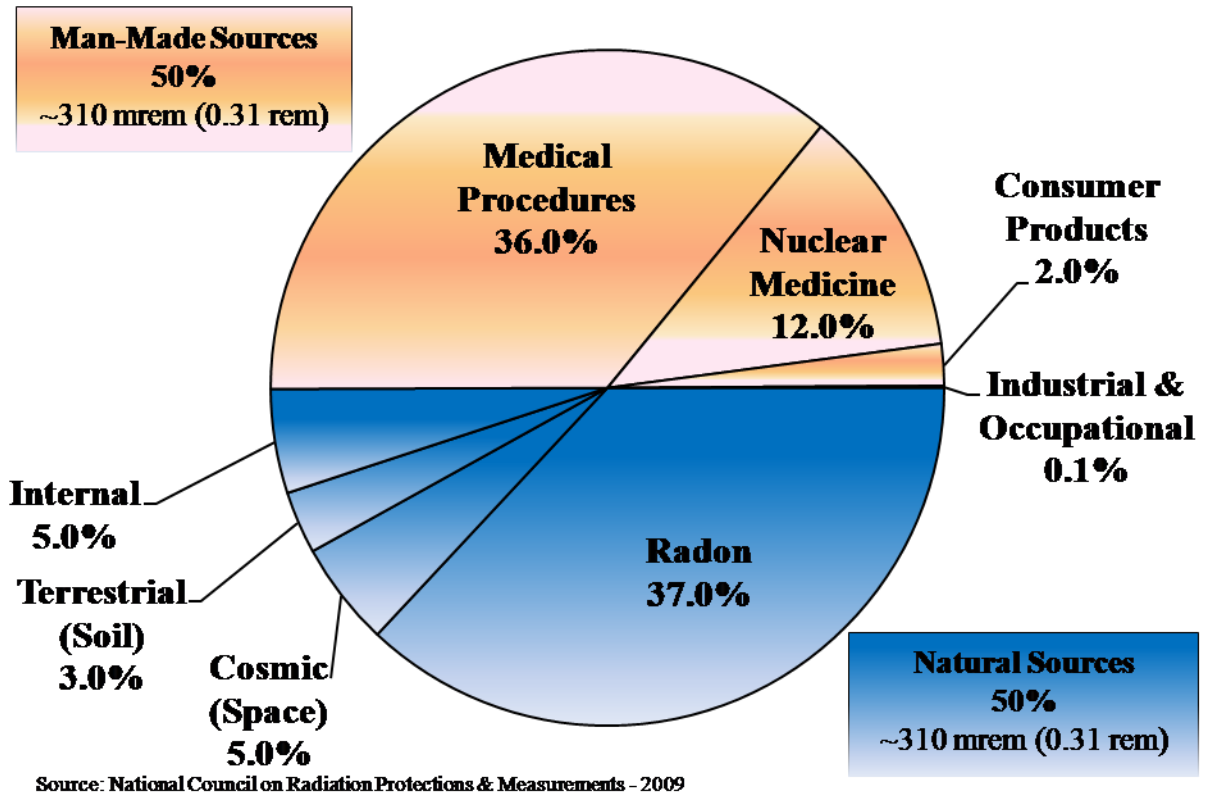
Occupational dose is the total dose received by radiation workers in the course of their work. It is important to note that industrial and occupational exposure accounts for only about 0.1% (0.62 mrem) of the average total radiation exposure experienced by an individual annually.

The average radiation dose received by individuals in the U.S. is about 620 mrem/yr (310 mrem/yr from natural sources and about 310 mrem/yr from human-generated sources, including occupational dose). Previously, the total annual dose was estimated at 360 mrem and the change in the current estimate is mainly the result of increased exposure from medical diagnostic and treatment procedures.

Figure 8 illustrates sources of radiation exposure experienced in the U.S and the percentage each represents of an individual's total annual dose. These are only average doses and an individual's dose can vary depending on geographic location, the amount of medical exposures experienced, and various

lifestyle choices. For example, smoking (30 cigarettes/day) will expose the lungs to the equivalent of 1.5 rem to the whole body.

Figure 8: Sources of Radiation Exposure in the United States



#### D. Occupational Dose Limits

The State of Arizona is a regulatory Agreement State and as such, the U.S. Nuclear Regulatory Commission (NRC) has given the Bureau of Radiation Control (BRC) jurisdiction in regulating work with radioactive materials within the State of Arizona. Limits on occupational doses are based on data regarding known biological effects of ionizing radiation. The International Commission on Radiological Protection and the National Council on Radiation Protection and Measurements publish guidance for setting radiation protection standards. Federal Regulations set regulatory requirements related to radiation exposure and BRC sets regulatory requirements related to radiation protection in the State of Arizona. These limits are set to ensure that the probability of detrimental biological effects from occupational exposure to ionizing radiation is equivalent to what has been observed in other safe industries.

A radiation worker is an individual who has received both general and specific radiation safety training and is authorized to use radioactive materials and/or radiation-producing machines. A non-radiation worker is an individual who is not trained or authorized in the use of radioactive materials and/or

radiation-producing machines. The radiation dose received by radiation workers in the course of their work is defined as occupational dose.

Occupational radiation dose limits set by the State of Arizona for different parts of the body and for minors range from 0.5 rem to 50 rem per year (see Table 4). Occupational radiation dose limits are set well below the exposures that cause acute radiation syndrome. The routine soil moisture gauge user, performing 20 tests/day, 5 days/week, 50 weeks/year would be expected to receive a maximum dose of less than 125 mrem per year. This is well below the 500 mrem threshold for mandatory radiation dose monitoring.

<b>Table 4: Occupational Radiation Dose Limits</b>	
Whole Body	5 rem (5000 mrem)
Lens of Eye	15 rem (15,000 mrem)
Skin of Any Extremity	50 rem (50,000 mrem)
Skin of Whole Body	50 rem (50,000 mrem)
Non-Radiation Worker	0.1 rem (100 mrem)
Minors (personnel under 18 years of age)	10% of adult dose limits
Fetus (total for entire gestation period)	0.5 rem (500 mrem)

**1. Pregnant Women: Dose Limits**

If a radiation worker is planning to become pregnant or is pregnant, it is recommended that she request information from the Research Laboratory & Safety Services (RLSS) concerning radiation exposure to a fetus. A pregnant woman may choose to declare her pregnancy to RLSS. A declared pregnant woman is a woman who has voluntarily informed RLSS in writing of her pregnancy and the estimated date of conception. It is a regulatory requirement that a declared pregnant woman be provided information about the potential risks of radiation exposure to a fetus.

As part of counseling, RLSS will conduct a review of the work situation and previous exposure history of a declared pregnant woman (or a woman planning to become pregnant) and will provide her with information about her potential for fetal exposure. Based on the work situation review, an additional dosimeter to be worn at the waist and monthly urine bioassay samples may be required for a declared pregnant woman. The dose limit to an embryo/fetus is 500 mrem over the entire pregnancy. It is also required that every effort be made to avoid substantial variation above a uniform monthly dose rate of 50 mrem/month.

It is a woman's right to "undeclare" her pregnancy at any time. This decision terminates RLSS's involvement with her pregnancy even though she may still be pregnant and had previously declared the pregnancy.

**2. Minors: Dose Limits**

Occupational dose limits for minors are 10% of the adult limits. The University of Arizona only allows a minor to become a radiation worker as part of an educational experience, not solely for employment.

## E. Protection Against External radiation Exposure

The concept of ALARA (As Low As Reasonably Achievable) is mandated by both Federal and State of Arizona regulations. The ALARA principle is to maintain radiation dose as far below the occupational limits as is reasonably achievable. This regulatory requirement is based on the following:

- No practice shall be adopted unless its introduction produces a net positive benefit;
- All exposures shall be kept as low as reasonably achievable (ALARA), economic and social factors being taken into account; and
- The dose equivalent to individuals shall not exceed the limits recommended for the appropriate circumstances by the regulatory authority.

The ALARA policy is based on the linear, non-threshold (LNT) dose-effect hypothesis. The LNT hypothesis assumes that the known effects of high doses of ionizing radiation may be used to predict the possible effects of long-term, low-dose radiation exposure. According to the LNT hypothesis, there is a relationship between radiation dose and the occurrence of cancer such that any increase in dose, results in an incremental increase in risk. Even though there is disagreement as to whether the LNT hypothesis overestimates or underestimates this risk, Federal and BRC regulations require that The University of Arizona demonstrate that the ALARA principles are being applied.

### 1. Keeping Exposures As Low As Reasonably Achievable (ALARA)

When working with radioactivity, it is essential to keep the radiation exposure to a minimum. The four ALARA principles of time, distance, shielding and minimizing source strength during occupational exposure to radiation are intended to minimize exposure.

#### a. Time

The dose of radiation a worker receives is directly proportional to the amount of time spent in a radiation field. Reducing the amount of time spent in a radiation field by one-half will reduce the radiation dose received by one-half. Workers should always spend as little time as possible around radioactive materials. The following actions may be used to minimize time of exposure:

- plan work carefully
  - read and understand the experiment protocol prior to performing tasks with radiation
  - read and understand gauge manuals, if applicable
- rehearse the work procedure with non-radioactive material (e.g., an inert probe) to identify possible complications
- transport moisture gauges and sealed sources correctly
- have all necessary equipment in one place
- ensure all equipment is in good working condition before work begins
- repeat experiments only when absolutely necessary

#### b. Distance: The Inverse Square Law

Radiation exposure decreases rapidly as the distance between the worker and the radiation source increases. The decrease in exposure from a point source can be calculated by using the inverse square law. This law states that the amount of radiation at a given distance from a point source varies inversely with the square of the distance. Therefore, if the distance to the source is doubled, the exposure decreases by a factor of 4 and if the distance is tripled, the exposure

decreases by a factor of 9. The change in percentage of intensity resulting from an increase or decrease in distance from a radiation source is shown in Table 5.

Although the inverse square law does not accurately describe scattered radiation, distance will still dramatically reduce the intensity from this source of radiation. Maintaining a safe distance, therefore, represents one of the simplest and most effective methods for reducing radiation exposure to workers and non-workers.

**Inverse Square Law**

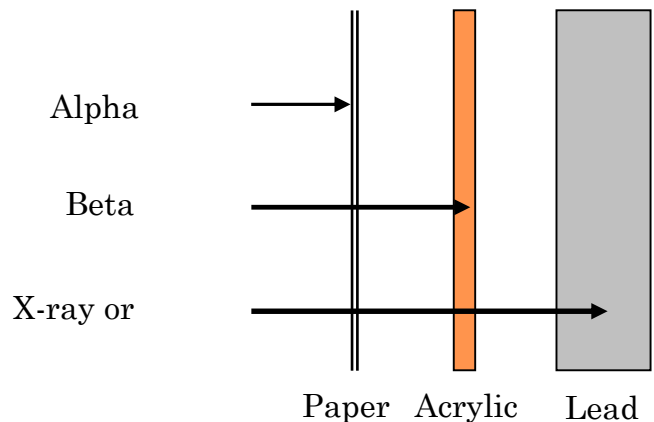
$$I_2 = I_1 (D_1/D_2)^2$$

$I_1$  = original intensity  
 $D_1$  = original distance  
 $I_2$  = new intensity  
 $D_2$  = new distance

Table 5: Effect of Inverse Square Law	
<i>Distance</i>	<i>Intensity</i>
<i>1 foot</i>	<i>100%</i>
<i>2 feet</i>	<i>25%</i>
<i>4 feet</i>	<i>6.25%</i>
<i>10 feet</i>	<i>1%</i>
<i>6 inches</i>	<i>400%</i>

**Figure 9: Shielding Materials**

Shielding is the use of a material or obstruction to absorb radiation and thus protect personnel or materials from the effects of ionizing radiation. The thickness of the required shielding material is dependent on the energy level of the emitted radiation (higher energy requires thicker shielding). The appropriate type and thickness of shielding material must be used in order to reduce the dose rate of different types of ionizing radiation (see Figure 9). Efficacy of shielding is determined by radiation level surveys.



Alpha particles can be completely stopped by almost anything (such as a sheet of paper). Beta particles can be shielded by a sheet of acrylic.

Gamma and x-ray radiation is diminished in intensity by any given absorber but not completely stopped. Lead is an appropriate shield for gamma and x-ray radiation, and for photons. Concrete can also be used as a shield for gamma and x-rays; however, RLSS should be contacted prior to shielding gammas with anything other than lead. Stainless steel or lead- or tin-loaded acrylic viewing windows can also be effective barriers.



Neutrons differ from the ionizing radiation of photons or charged particles in that they are repeatedly bounced and absorbed by light nuclei. Effective shielding material therefore must contain high concentrations of hydrogen, such as is found in water, acrylic, sheets of paraffin, or concrete. The gauge housing provides lead shielding as well and once the probe is out of the shielded housing and about six inches in the soil, the ground shields almost all of the gamma and neutron radiations. Storage areas for multiple gauges may require shielding.

c. Minimizing Source Strength

The less radioactivity used (given everything else remains the same), the less potential dose that will be received. Modern gauges allow researchers to attain their desired results using gauges with less intense sources or lower energy emissions than before.

## F. Measurement of External Exposure to Radiation

Various types of radiation dosimeters (including badge, extremity or ring, and supplemental/secondary dosimeters) are used to measure an individual's external exposure to radiation; badge dosimeters cannot measure the absorbed dose from alpha or low energy beta particles because of their low energy. The need for personal dosimeters is dependent on the frequency, quantity and specific nuclides used. Individuals who are likely to receive at least 10% of the occupational dose limit will be assigned a dosimeter. Badge, extremity and supplemental/secondary dosimeters are issued free of charge by RLSS. Whether or not a dosimeter is assigned, or whether bioassays are required (for monitoring internal exposure), is determined by a health physicist. Soil moisture gauge users, except for pregnant women or minors, are typically not assigned a dosimeter.

### 1. Badge Dosimeters

Badge dosimeters (see Figure 10) are the primary type of whole body personal dosimeter provided by RLSS. These dosimeters are typically collected by RLSS on a bimonthly basis and sent to their manufacturers to be analyzed. The dosimeter should not be exposed to temperatures above 150° F, as this may affect the exposure measurements that are obtained.

**Figure 10: Badge Dosimeter  
(showing front of unit  
and front/back of holder)**



## 2. Extremity (Ring) Dosimeters

Extremity (ring) dosimeters are used to measure exposure to the hands when whole body exposure and hand exposure could differ significantly (see Figure 11). The “chip side” of the finger ring must be aimed towards the palm and must be worn on the designated hand.

## 3. Supplemental/Secondary Dosimeters

Pocket ion chambers and electronic personal dosimeters are two types of supplemental/secondary dosimeters. An ion chamber is 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. A pocket ion chamber is an ion chamber the size of a fountain pen and is used to detect gamma or neutron ionizing radiation exposure. It provides the user with an immediate measurement of exposure.

**Figure 11: Extremity (Ring) Dosimeter**



An electronic personal dosimeter is an electronic unit capable of measuring gamma, beta and x-radiation exposure. It provides the user with immediate feedback as to the current rate of exposure as well as exposure over a specified period of time (see Figure 12).

**Figure 12: Electronic Personal Dosimeter**



Pocket ion chambers and electronic personal dosimeters are only issued on an as needed basis and proper use requires additional training and documentation. The number of available units is limited due to high cost.

## G. Protection Against Internal Exposure to Radiation

Radioactive material can be damaging to the body if absorbed, inhaled, or ingested (swallowed). Although it is uncommon for a sealed source to leak, there is a low risk of internal exposure due to improper use or leakage.

- Absorption

Skin should be protected against the potential absorption of radioactive material from a leaking source. Laboratory coats, gloves, eye protection and other types of coverings should be used to reduce the risk of absorption. It is also recommended that open wounds be covered.

- Inhalation

When a source is leaking, there is a potential for inhalation of radioactive material; therefore, maintaining a distance of at least 10 feet from the source will minimize this risk.

- Ingestion

When a source is leaking, there is the potential for ingestion of radioactive material; therefore, maintaining a distance of at least 10 feet from the source and minimizing contact with mouth and potentially contaminated surfaces (including hands) will minimize this risk.

## H. Measurement of Internal Exposure to Radiation

The amount of radioactive material incorporated into the body may be measured through a bioassay. Bioassays are not commonly performed for moisture gauge users, but may be required if exposed to a leaking source. A bioassay is a test to determine the kind, quantity, or concentration (and sometimes the location) of radioactive material in the human body, either by direct measurement or by evaluation of bodily fluids or tissue.

### 1. Urine Bioassay

Urine bioassays are used by RLSS to determine the presence of radioactive material in the body. Bioassays can be used to measure the internal levels of most radioactive isotopes.

## V. Laboratory Practices

All individuals working with moisture gauges should be aware of the location of the necessary documents, records, and guidelines that pertain to use approvals. A visiting RLSS or state inspector may ask to view this information at any time.

### A. Education and Training

Individuals may not work with moisture gauges until they have received appropriate training. In conjunction with RLSS, this is a two-part process that includes gauge specific training and completion of the Moisture Gauge Protection Course. Course schedules and registration information are located on the RLSS website. Gauge transport is taught in this course and users under approvals that include transport of gauges must receive Transport Refresher training every three years. RLSS notifies Approval Holders and Approval Safety Coordinators via email when source users are due for refresher training.

RLSS training must be completed before an individual begins working in a new laboratory or under an additional approval.

### B. Approval to Use Moisture Gauges/Radioactive Sealed Sources

An 'Approval to Use Radioactive Sealed Sources' is granted to an individual for the use of moisture gauges after the Radiation Safety Committee reviews and approves an Application for New Sealed Source Approval. The radionuclides that will be used, their activity, the protocols, the rooms where the material will be used and stored, and off-site locations must be specified in the application.

In order to obtain readings at depths of over 20 feet, the Approval Holder must obtain specific approval by the Radiation Safety Committee. Submitted plans must include that all sample holes will be cased and that will use either a kellem's grip for the probe, a secondary support line, or an inert probe of the same dimension as the live probe (see Figure 13) will be deployed to and retrieved from the required reading depth before using the live probe. RLSS can assist with drafting the plan for the Radiation Safety Committee review.

**Figure 13: Inert Probe**



To change approved protocols, add radionuclides, raise activity limits, modify routine transport plans, change or add storage locations, or modify the encapsulation or device in which the source is

contained, an Approval Holder is required to submit an Application for an Amendment to Sealed Source Approval for review and approval by the Radiation Safety Committee.

In addition to RLSS approval, proposed experiments may require additional regulatory approvals from the Institutional Animal Care Use Committee (IACUC), the Institutional Review Board (IRB) at the Human Subjects Protection Program office, or the Institutional Biosafety Committee (IBC).

### C. Posting and Labeling of Areas Containing Radioactive Materials

Once a room is approved for gauge use or storage (includes confirming appropriate radiation levels in surrounding areas), RLSS will post the required signs. Moisture gauges may not be used/stored in these areas until the signs have been posted.

#### 1. Room and Area Entrances

"Caution Radioactive Materials" (see Figure 14)

#### 2. Notice to Employees (Form ARRA-6)

This document summarizes the rights and responsibilities of State radiation workers, and radiation exposure protections required by the BRC.

#### 3. Radiation Emergency Procedures Form

This form provides brief information for emergency situations, phone numbers for Approval Holders and Approval Safety Coordinators approved to use the posted area, and RLSS and UAPD phone numbers.

#### 4. Adjacent RAM Work Area Notice

This notice is only posted in areas that have been designated for use of RAM in an open bay laboratory. The Approval Holder is responsible for training non-radiation workers in these areas.

#### 5. Labeling of Gauges and Containers

In addition to the signage provided by RLSS, it is the responsibility of all radiation workers under the approval to provide appropriate labeling for gauges and gauge cases.

- "Caution Radioactive Material" (CRM) signs must be posted on storage cabinets within a laboratory.
- Gauge transport containers and gauge housings must also be clearly labeled.

Figure 14: Sample Sign



### D. Dosimetry Use

The measurements obtained by a dosimeter are a legal record of a person's individual radiation exposure and RLSS maintains these records for personnel using RLSS-issued dosimeters. Personal dosimeters issued by RLSS may not be shared or exposed to any source of radiation outside of the specific work assignment for which they were issued. Monitoring is typically not required for soil moisture gauge users, however declared pregnant workers or minors may be issued a dosimeter. If a dosimeter is issued, it must be worn whenever working with radioactivity in the work assignment.

A lost or damaged badge should be reported immediately to RLSS. A worker may not perform any work with radioactive materials until a new badge has been obtained. RLSS will immediately replace any damaged or lost dosimeter; however, a replacement fee may be charged to the department for lost dosimeters; the department may pass the charge on to the responsible individual. Current information pertaining to the use of dosimeters, monitoring and documentation of exposure is located on RLSS web site.

## **E. Receipt, Inventory, Storage & Security of Radioactive Sealed Sources**

All incoming and outgoing radioactive sealed sources and gauges must be routed through RLSS.

### **1. Receipt**

All incoming soil moisture gauges are surveyed for leakage of the sealed source by RLSS, assigned an RMR# (radioactive material receipt number) and source ID#, and entered into the inventory database. The shipment is then delivered to the requesting laboratory along with the packing slip.

### **2. Inventory**

Once the soil moisture gauge or sealed source is delivered, the Approval Holder is required to maintain records of its use on the Soil Moisture Gauge Use Log or an equivalent log sheet. The date checked in and out, person checking out the gauge, and use location must be logged for each use.

Transfer of any soil moisture gauge, whether internally to another Approval Holder, or externally to another institution must be done via RLSS. Prior to any internal transfers, RLSS must be contacted to assure that the radionuclide and the transfer amount are permitted under the recipient's current approval. At the same time, the radionuclide, amount and assay date of the source that is to be transferred must be reported to RLSS for inventory purposes. RLSS will provide a record of the transaction to both Approval Holders.

For transfer to an external site, RLSS must be notified at least 24 hours before scheduling the transfer so that the appropriate paperwork may be completed in advance. A copy of the NRC/State license must be obtained from the intended recipient and may be faxed directly from the recipient company or institution to RLSS. Transfer of soil moisture gauges to other countries may sometimes take months to arrange.

All Department Of Transportation required hazardous materials (HAZMAT) shipping labels, forms and paperwork are available from RLSS. Transport supplies such as braces, chains, locks and/or cases must be purchased by the Approval Holder. Contact RLSS in advance before attempting to order, transfer, ship, or receive a new gauge or sealed source.

### **3. Permanent Storage Sites**

Permanent storage (as identified in the approval) must meet the following conditions:

- a. The gauge must be stored in a locked manufacturer's transport case and the case must be locked in a closet or room that is not readily accessible to the public.
- b. The source may not expose personnel to any dose rate that is three times the natural background rate from any location of high occupancy (e.g. desks, work stations or a residence).
- c. The storage location must be under the exclusive control of the Approval Holder or users listed under that approval.
- d. The storage area must be appropriately labeled (contact RLSS for replacement postings if labels are missing).

#### 4. Temporary Storage Sites

Gauges must either remain under direct supervision at all times when in a temporary storage location or must be under two levels of security, not including the locked transport case. Temporary locations could include long term analysis sites, overnight in a motel room, or while in transit.

#### 5. Off-Site Storage

Approval Holders must notify RLSS at least 30 days in advance when planning to store gauges and sources outside of Arizona or on private property.

##### a. Outside of Arizona

Gauge use or storage is restricted outside of the State of Arizona. Reciprocity agreements with other regulatory agencies may be required to use or store gauges outside the State of Arizona (a fee may be required). The possession and use of the gauge while under a reciprocity agreement must adhere to the conditions set by the BRC and RLSS as well as by the regulations of the host state or nation.

##### b. On Private Property

Gauge use or storage on private property is restricted. If cooperative work with private entities requires the storage of gauges on private property, a written agreement that coordinates the use, security and storage of the gauges must be signed between the land owner and The University of Arizona via RLSS prior to source storage.

#### 6. Transportation of Soil Moisture Gauges

Shipping by common carrier (Federal Express, Yellow Freight, etc.) must be coordinated through and shipped by RLSS. All moisture gauge vehicle transport must be in accordance with DOT rules and regulations. Approval Holders are responsible for ensuring that all gauge users are trained and equipped to transport radioactive materials.

- a. Moisture gauges require two levels of security while in transport. The primary, most desirable level of security is direct observation. Locks, chains or cables are required to fulfill the secondary level of security. Lock shanks must either be shrouded or the lock itself must be a shankless design.
- b. Moisture gauge transport cases must be properly labeled for transport. Prior to each transport, workers must inspect the container labels and confirm that they are all legible and present. Labels must not overlap or have tears or excessive fading. Labels that are not vinyl should be covered with transparent tape to protect them from the weather. Contact RLSS for replacement labels or forms. Prior to each transport, workers must confirm that the following items are present on the case:
  - 1) Two “Do Not Load in Passenger Aircraft” stickers (see Figure 15);

Figure 15



Figure 16



Figure 17



- 2) Two yellow “Radioactive II” stickers with the radionuclide contents, activity (in megabecquerels) and transport index information written in permanent marker (see Figure 16);
- 3) Two “RQ” stickers (see Figure 17);
- 4) Two “UN 3332 Special Form” stickers (see Figure 18);
- 5) One “Package Orientation” sticker; and
- 6) Two “In Case of Emergency” stickers, providing phone numbers of the BRC, the UAPD and the UA RLSS.

Figure 18



- c. Before transporting gauges and sources, workers must ensure that the container or box has no cracks, missing latches, missing internal packaging or broken internal/external pieces. Contact RLSS before attempting to ship a moisture gauge in a damaged case.
- d. One copy of the Bill of Lading/Emergency Response laminated form (if applicable) must be attached to the gauge case and another copy must be available within reach of the driver and visible from outside the vehicle during transit.
- e. The gauge case must be braced so that it cannot move more than one inch while in transport. Obtaining necessary equipment (such as transport braces, which are available locally) is the responsibility of the Approval Holder; contact RLSS for recommendations.
- f. The gauge may not be transported in the passenger compartment of cars or the cab of trucks. The gauge must be secured as far away from passengers as possible.
- g. The gauge transport container must be locked.
- h. Transport guidelines by vehicle type:
  - 1) Cars with a trunk
    - The gauge container must be locked to the trunk suspension or vehicle body with a cable or chain.
  - 2) Cars without a trunk
    - The gauge container must be locked to the hatchback suspension or vehicle body with a cable or chain.
  - 3) Pickup trucks with locked camper shell, bed cover or Nux type case.
    - The gauge container and camper shell/bed/Nux cover must be locked shut. The shell/bed/Nux cover must be permanently affixed to the truck bed.
    - The gauge container must be locked to the truck bed frame with a cable or chain.
  - 4) Open bed pickup trucks.
    - The gauge container must be locked to the truck bed frame with a cable or chain.
    - Gauge transport in an open bed pickup truck requires that the gauge remain under constant surveillance.
    - Regulators highly recommend the use of a nuclear gauge containment system for open bed truck transport of soil moisture gauges.
    - Transport in an open bed pickup truck is the least desirable method of transportation.

## 7. Security

It is the responsibility of the Approval Holder to ensure that radioactive sealed sources (in moisture gauges) are secure from unauthorized use or theft. All individuals who are authorized to enter a radiation use area have the responsibility to adhere to source security measures. These individuals may include radiation workers, non-radiation workers or others who are authorized to enter the radiation use laboratory (including University support personnel).

Unless determined otherwise by RLSS or the Radiation Safety Committee, radioactive sealed sources must be secured by:

- keeping them under constant “line of sight” surveillance by a radiation worker (authorized under that approval), or
- by locking the approved permanent storage sites, or
- by placing them in approved locked, permanent storage (such as a cabinet with a lock) within an approved use or storage site, or
- by locking them in approved transportation modes according to Department of Transportation (DOT) rules and regulations (e.g., in a locked car trunk, attached to suspension or body of vehicle without a trunk or in open truck bed, inside locked camper shell or bed cover of truck).

Under the following conditions, sealed sources must be secured in a locked storage container (such as a cabinet with a lock) whenever not under constant “line of site” surveillance by a radiation worker.

- Approvals for a total of 50 mCi or more of sources, or
- approvals for storage of gauges in open bay laboratories.

Sealed sources classified as exempt by RLSS may have reduced security and control requirements; however, written instructions for exempt source use will be provided.

The physical securing of radioactive sealed sources must be combined with preventing unauthorized entry into the laboratory. Visitors must be questioned as to their purpose for being in a radiation laboratory. Visitors and outside contractors shall be under constant supervision by a radiation worker when in radiation use areas unless all sources have been. UA Facilities Management personnel and custodial staff have been trained to work safely around radioactive sources, so supervision is not required.

Any known or suspected loss or theft of sources or gauges must be reported immediately to RLSS.

### F. Disposal of Gauges/Radioactive Sealed Sources

Disposal or disposition of all gauges/radioactive sealed sources must be coordinated with and conducted by RLSS.

## VI. Emergency Procedures

Radiation workers should familiarize themselves with the Emergency Procedures document posted in each laboratory approved for work with RAM. The Approval Safety Coordinator is the designated person, other than the Approval Holder, who can provide information about source use in the laboratory in case of an emergency.



## **A. Leaking Sealed Sources**

If a gauge's sealed source is damaged, the source capsule is ruptured, or if the source capsule integrity cannot be determined, there is a potential for contamination. RLSS must be notified immediately of suspected leaking sources and will coordinate decontamination efforts. Decontamination must not be attempted without instruction from RLSS personnel.

The initial steps taken in the event of a spill are represented by the acronym, SWIM.

**S**top the spill

**W**arn other personnel

**I**solate the area

**M**inimize exposure to radiation and contamination

### **1. Actions**

In the case of a potentially leaking source, the following actions should be taken by laboratory personnel as soon as possible:

- Notify people to leave the immediate area, but to remain nearby as a group so that they can be surveyed for contamination.
- Leave the immediate area quickly and lock the door. Remove potentially contaminated gloves, shoes and laboratory coats before leaving the area.
- Notify RLSS immediately. If after business hours or if no answer at the RLSS telephone number, call University Police.
- Remain nearby to ensure that no one enters the area and to provide information when help arrives.

## **B. Fire Emergencies Involving Radioactive Materials**

- In case of fire, call '911' from a University telephone, notify dispatcher that radiation is involved, pull the nearest fire alarm, and vacate the building.
- Call RLSS (if after business hours or if no answer at the RLSS telephone number, call University Police).

## **C. Loss or Theft of Gauges/Sealed Sources**

Suspected loss or theft of a moisture gauge or radioactive sealed source must be reported immediately to the Approval Safety Coordinator and/or Approval Holder, and RLSS. If after business hours or if no answer at the RLSS telephone number, call University Police.

## **VII. Responsibilities By Role**

The responsibility for maintaining radiation doses to workers and the public under the ALARA principles is shared by, the Approval Holder, the Approval Safety Coordinator, and each radiation worker.

### **A. Approval Holder Responsibilities**

Approval Holders are the individuals ultimately responsible for the safe use of gauges and radioactive sealed sources under their control and listed on their approval. Approval Holder Orientation is provided by RLSS at the time of approval, during audits, and/or at a minimum of every three years. Approval Holders have the responsibility to:

- Comply with the rules, regulations and approval conditions administered by the University Radiation Safety Committee or the Medical Radiation Safety Committee, RLSS, and the BRC;
- Properly train radiation workers to handle, secure, transport and dispose of gauges and radioactive sealed sources under their approval in accordance with the Radiation Training Policy and requirements for transportation of Radioactive Sealed Sources;
- Provide in-house training;
- Ensure that RLSS is notified of new proposed radiation workers;
- Provide adequate supervision of authorized radiation workers;
- Maintain a written documentation of gauge use;
- Confirm gauge storage locations and workers under the approval on a quarterly basis via the online RLSS Approval Review;
- Participate in annual RLSS audit or ensure that Approval Safety Coordinator is available to participate during the audit.
- Respond to information requests by RLSS in a timely manner;
- Notify RLSS immediately if source leakage has occurred or is suspected;
- Maintain all required postings and labeling for gauges and their storage areas;
- Provide and ensure proper use of personal protective equipment, if required;
- Notify RLSS prior to relocation or transfer of gauges or sources (to internal or external sites), other than to previously approved sites or as part of approved routine transport;
- Notify RLSS if the Approval Holder will be absent from the institution for an extended time that will reduce the effective oversight of laboratory operations. If an extended absence is planned, an agreement must be reached with an appropriate substitute to oversee the use of the approved gauges while the Approval Holder is away.

## **B. Radiation Safety Coordinator Responsibilities**

Some Approval Holders may not have the time or resources to personally monitor the day-to-day operation of a laboratory. Therefore, Approval Holders may appoint an Approval Safety Coordinator to operate under their approval, but the ultimate responsibility for use of the gauges remains with the Approval Holder. The Approval Safety Coordinator, in addition to attending the Moisture Gauge Protection Course will receive an Approval Holder Orientation from RLSS personnel (initially, during audits, or at a minimum of every three years). At the direction of the Approval Holder, the Approval Safety Coordinator may be assigned extra responsibilities such as those in the above list.

## **C. Radiation Worker Responsibilities**

Radiation Workers have the responsibility to:

- Complete the Moisture Gauge Protection Course and any other required training prior to beginning work;
- Notify RLSS if transferring to a new Approval Holder's group or laboratory;
- Comply with the requirements for the safe use, transport and security of moisture gauges, and for proper disposal of the sealed source used in the gauges;
- Document each use or transport of the moisture gauges; if the approval includes routine transportation of gauges, transport refresher training must be completed every three years;
- Report all accidents and exposures (known or suspected) to the Approval Safety Coordinator and/or Approval Holder, and to RLSS.

#### **D. Research Laboratory & Safety Services (RLSS) Responsibilities**

RLSS has responsibility to:

- Provide training (e.g., Moisture Gauge Protection Course, Approval Holder's Orientation, Transport Refresher training);
- Receive shipments of radioactive sealed sources and moisture gauges and inspect for leakage prior to delivery to requesting laboratory and at periodic intervals;
- Maintain a current inventory of approved gauges and sealed sources;
- Coordinate state reciprocity agreements;
- Ship or dispose of gauges/sources, as needed;
- Calibrate survey instruments;
- Perform dose rate surveys in work areas surrounding source storage areas;
- Provide signs for entrances to use areas and for labeling of storage areas;
- Provide DOT required gauge/source transport documentation;
- Provide personnel dosimeters and area monitors, if necessary;
- Maintain exposure records for Radiation Workers;
- Perform audits and laboratory inspections (at least annually);
- Provide assistance in contamination surveys and decontamination procedures, as needed.

#### **VIII. Purchasing Moisture Gauges and Sealed Sources**

Prior to purchasing moisture gauges/radioactive sealed sources, the Approval Holder must notify RLSS of the planned purchase. RLSS confirms that the purchase is appropriate under the current approval and license, whether there are any special requirements related to the particular source, and whether an amendment to the current approval is necessary. Once cleared, the Approval Holder generates a Purchase Requisition (see requirements below). Departmental Purchasing Cards may not be used to purchase RAM; this violates University mandated Policy Restrictions that apply to the Purchasing Card.

The purchase requisition must contain all of the following items (applies to new and replacement shipments).

- Approval Holder name
- Approval Number
- Radionuclide
- Activity being ordered in mCi or  $\mu$ Ci
- Chemical form and Catalog number
- Protocol Number
- Object Code 5240

All incoming shipments of gauges must be delivered to:

Attn: Research Laboratory & Safety Services  
Medical Receiving Dock  
1501 N Campbell Ave  
Tucson, AZ 85724

OR

Research Laboratory & Safety Services  
University of Arizona  
College of Medicine, Phoenix Campus  
425 N 5th Street  
Phoenix, AZ 85004