RADIATION SAFETY IN THE LABORATORY
TRAINING MANUAL

A Short Course Offered by:

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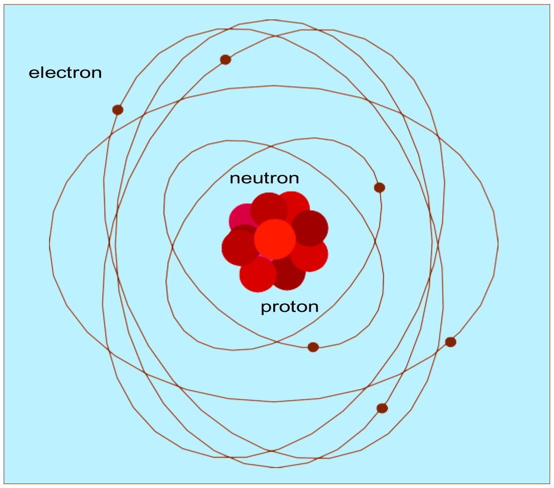
LESSON 1:
ATOMIC COMPOSITION AND STRUCTURE



The atom consists of two regions: the nucleus which contains positively charged particles called protons and electrically neutral particles called neutrons and the area around the nucleus called the orbital region where electrons are found. In an electrically stable atom, there are an equal number of protons and electrons. Atoms can be either stable or unstable. Unstable atoms have the capacity to release radioactive emissions from its nucleus as particles in the form of alpha particles, beta particles or neutrons. They can also release electromagnetic energy from the nucleus in the form of gamma rays. Radioactive emissions can also originate from the electron orbitals in the form of x-rays.

The nucleus is made up of positively charged protons and neutrons with no charge. The majority of the mass of an atom is found in the nucleus. The atom could not exist if it contained only protons, since the positive nature of the protons would cause them to repel each other just like the same poles of two magnets repel each other. Neutrons have an affinity for just about anything and they impart the stability to the nucleus. For small atoms, there are an equal number of protons to neutrons. In larger atoms, there are more neutrons than protons. This is necessary to have proper stability. However, there are times when too many neutrons are present and thus the atom becomes unstable or as we call it – radioactive. The second law of thermodynamics states that matter in the universe moves from unstable states to stable states. In the case of an unstable atom, matter or energy is released to achieve a more stable configuration and we call this a radioactive emission. This phenomenon can be exploited by researchers in many ways such as using them in tracer studies or for irradiating things.

The electrons that orbit the nucleus have negative charges but are of much lesser mass than the protons or neutrons. When electrons are displaced from their normal predicted locations, x-radiation will be released. X-rays are a form of electromagnetic radiation and differ from gamma rays only in their point of origin.

TERMS TO KNOW

- **Atomic Number (Z):** The atomic number refers to the number of protons in the nucleus. It is often abbreviated with a capital "Z". The atomic number defines the elemental nature of the particular atom. An atom with an atomic number of 1 is always hydrogen. An atom with an atomic number of 6 is always carbon.
- **Mass Number (A):** The atomic mass refers to total number of neutrons and protons in an atom. It is abbreviated with a capital "A". When we speak of a specific type of radioactive atom, we include the atomic mass. For instance, we can identify an atom of phosphorus-32 with 32 being the atomic mass.
- **Neutron Number (A-Z=N)**: The number of neutrons in the nucleus can be calculated.
  $^{A}_{Z}X$ Whenever you see a radioactive material or nuclide written in this way, the "X" represents the element (hydrogen, phosphorus etc.). The subscript is the atomic number and the superscript is the atomic mass.
  Examples: Here are some examples of radioactive atoms – hydrogen-3(also known as tritium), carbon-14, cobalt-60 and cesium-137. Each nuclide is referred by its atomic mass.

  $$^{3}_{1}H \qquad ^{14}_{6}C \qquad ^{60}_{27}Co \qquad ^{137}_{55}Cs$$

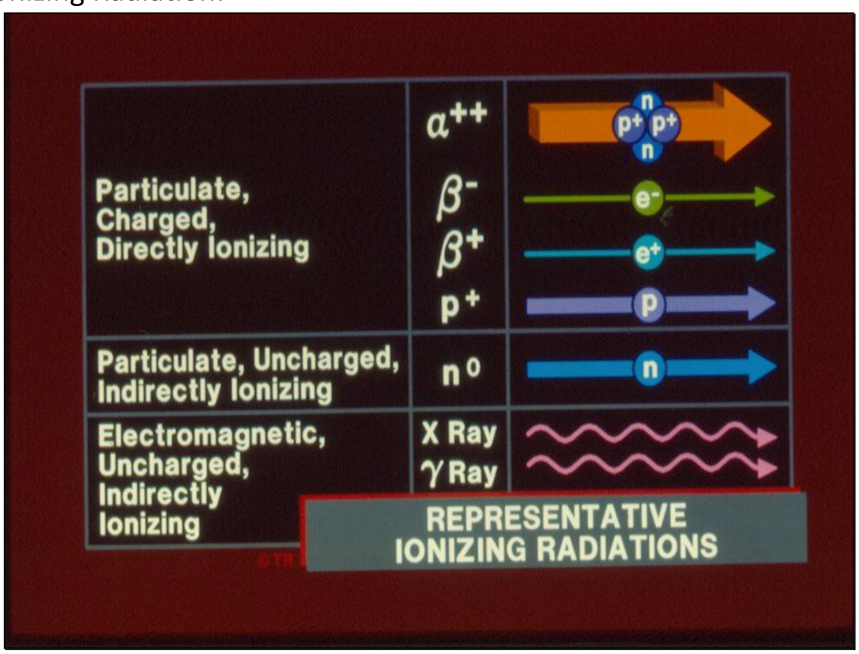
- **Isotope:** Isotopes are a group of nuclides having the same atomic number (Z). I-123, I-125, I-131 are examples of isotopes of Iodine, with a Z of 53. Iodine-127 is the stable form of iodine, which means it has no radioactive emissions. But iodine has isotopes ranging from I-117 to I-139. Now in your research, you can use any of the radioactive iodine isotopes. They all react chemically the same way. However, their physical properties can be quite different. For instance, Iodine 131 emits a number of gamma rays with various energies. However, the principle gamma that is emitted 82% of the time is one that is 364 kilo-electron volts. (That's 364 thousand electron volts). It also emits beta particles less than 1% of the time. Now iodine-125 emits a gamma ray of 35 kev with no beta particles emitted.
- **Radioactive Decay:** Another difference between isotopes is the rate at which they emit radiation. We refer to this as the rate at which the radioactive material "decays". The decay rate is also called the half-life of an isotope. The half-life refers to the amount of time it takes for the original amount of radiation to decay by one-half. Half-lives of isotopes can vary from a less than a second to millions of years. The half-life of I-131 is 8 days and the half-life of I-125 is 60 days. I mention these two isotopes because they are readily available commercially. Most people working in laboratories will buy I-125 because it has a long half-life and will last a lot longer. Since the gamma ray that it emits is relatively weak, it can be shielded with a very thin piece of lead. Shielding is simply material that is placed between the radiation source and yourself to absorb the radiation before it has a chance to be absorbed by you. Now I-131 is not used in research so much anymore because it has a shorter half-life and the gamma rays it emits require shielding

with a piece of lead that is the thickness of a standard sized brick. However, I-131 is used in the diagnosis and treatment of human diseases in the nuclear medicine departments of hospitals. The short half-life is ideal since it reduces the amount of overall dose to the patient.

IONIZING RADIATION

Ionizing radiation consists of either electromagnetic or particulate radiation that when it comes in contact with a target atom is capable of removing an electron from the atom which results in the formation of an ion pair, that is one negatively charged electron and a slightly positive atom. This is the only type of radiation that can do this. Now if that atom I am talking about is component of an hereditary gene in your chromosome, it can result the that particular gene being expressed differently than what nature had intended. This could result in the cell in which this gene resides to become cancerous. We know through studies that ionizing radiation is a carcinogen.

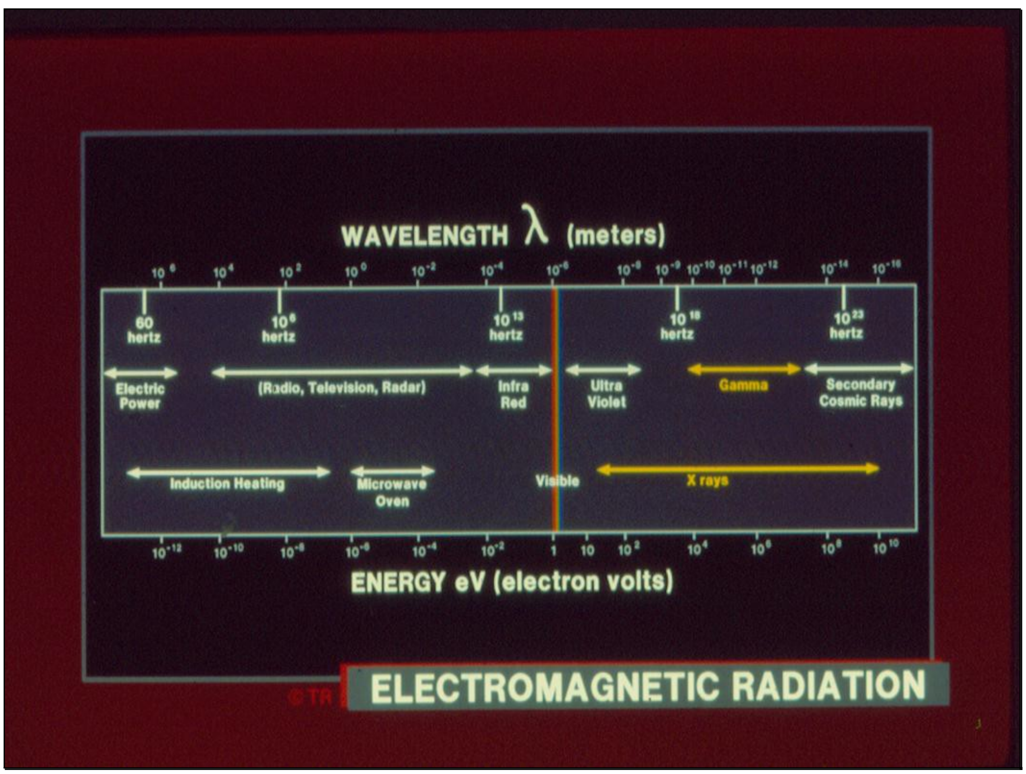
Two Types of Ionizing Radiation:



- Particulate radiation- Energy emitted from an unstable atom or nucleus in the form of particles. These particles have mass and a charge. Particulate radiation consists of alpha particles (a^{++}). Alpha particles have a plus 2 charge and they have a significant amount of mass. Beta particles (B^+ or B^-) can either have a minus one or a plus one charge. They have the mass of an electron. The most prevalent type is the negatively charged particle also referred to as a negatron. Another type of radioactive emission is the uncharged neutron. Neutrons can be spontaneously emitted from an atom like an alpha or beta emitter but that is a rare occurrence. Most neutrons are emitted by combining an alpha emitter or a gamma emitter with a non-radioactive target material which then results in the emission of neutrons. You probably heard the expression of someone exposed to radiation as “glowing in the dark”. This can only happen if you are exposed to a large neutron field. Remember what I said in an earlier slide that neutrons have an affinity for anything so they would attach to the atoms of your body thus making them unstable or radioactive. This is how many of the isotopes used in your lab are made. They will take a target material and bombard them with a strong neutron field and produce the isotopes for your research.

- Electromagnetic radiation is radiation that is emitted from a nucleus or electron orbitals in the form of waves. These waves are made up of a basic unit called photons. There are 2 types of electromagnetic radiation discussed– gamma rays and x-rays. Remember that these types of radiation have no mass or charge and generally are more penetrating than particulate radiation of comparable energy.

ELECTROMAGNETIC SPECTRUM



Above is a chart of the entire electromagnetic spectrum. The top of the chart is a scale for wavelength. Electromagnetic energy travels in waves. The number of wave crests that pass a certain point would be a measure of its frequency. At the bottom of the slide is a scale for photon energies in electron volts. Notice that the photon energy will increase as the wavelength decreases and the frequency increases. At about 100 electron volts, you are in the upper ultraviolet range or the lower x-ray energy range. This is where ionization begins to take place.

As the photon energies increase on the chart to the right, the degree of ionization will also increase. This is the area where gamma rays are located. This is the part of the spectrum where the principle biological effect to humans would be cancer.
Other parts of the electromagnetic spectrum can have potential biological effects. The upper edge of the ultra-violet region can cause ionization. The two primary biological effects associated with the UV range are skin cancer and skin aging. Skin aging is probably the result of being exposed to the lower ranges of the UV spectrum.

Notice that visible light is located to the right of center on the chart. The photon energies of visible light are around the 1-2 electron volt range. This is about 100 – 100,000 times less energy that ionizing radiation. There are no known biological effects from exposure to visible light although if you stare at an intense light source for an extended period of time, you will do serious damage to the retina of your eye. Part of the damage could be attributed to the UV component of light.

Infra-red radiation, located to the left of visible light, has a photon energy range of 0.1 to 1 electron volt. Exposure to infra-red radiation can cause the molecules in the exposed area to vibrate and produce heat. Infra-red lamps are often used in the treatment of injured muscles. They are also used in industry for the heating and drying of glues.

Microwave ovens emit photons in the range of one one-thousandth of an electron volt. In this range, the water molecules of the affected material will begin to actually rotate and cause a heating effect.

The photon energy of a standard cell phone is one one-millionth of an electron volt or one one-thousandth the energy of a microwave oven. In this range, no rotation of water molecules occurs thus no heating can occur. There is not known biological effect in this range. Ionizing effects **cannot** occur in this range. It would take anywhere from 1 to 10 million photons of cell phone radiation hitting the same molecule instantaneously to cause the same effect of one photon of x-radiation. Quantum mechanics does not support the notion that energy from cell phones can cause cancer.

RADIOACTIVE QUANTITY
There are many different terms for radioactive quantity. Probably the most familiar quantity to you is the curie named after Madame Curie, an early researcher with radioactive materials. A curie is equal to 3.7×10^{10} disintegrations per second. If you have a large amount of radioactive material, it is going to decay and give off some form of radiation. If the number of atoms released from this large amount of radioactive materials is 3.7×10^{10} per second, then a curie of radiation is present. This number is actually based on the decay of one gram of Radium-226 which decays at this rate. But anything that decays at this rate is considered a curie.
A Becquerel is a new international unit that is replacing the curie. One Becquerel is equal to one disintegration per second. This unit is slowly being adopted by the United States and it will be beneficial to learn the conversation rates.

Conversion Charts:
1 Curie (Ci) = 3.7 x 10^{10} disintegrations per second (dps)
1 Becquerel (Bq)= 1 dps = 27 pCi
1 Ci = 37 GBq = 37 x 10^9 Bq

In laboratory research at USC, we do not often use curies of radiation. Another common unit of radiation quantity is the millicurie which is one one-thousandth of a curie. Researchers often purchase tritium and sulfur-35 in millicurie quantities. Also, the microcurie is a common unit. A microcurie is equal to one one-millionth of a curie or one one-thousandth of a millicurie. Phosphorus-32 is often ordered in microcurie quantities.

Some useful conversions of Curies to Becquerels:

1 TBq = 10^{12} Bq	1 pCi= 37 mBq
1 GBq= 10^9 Bq	1 nCi= 37 Bq
1 MBq = 10^6 Bq	1 uCi= 37 kBq
1 mCi = 10^{-3} Ci	1 mCi=37 MBq
1 uCi = 10^{-6} Ci	1 Ci= 37 GBq
1 nCi= 10^{-9} Ci	1 kCi= 37 TBq
1 pCi = 10^{-12} Ci	

RADIOACTIVE DECAY AND DECAY RATE

The decay property of radioactive materials was discussed in a previous section. The decay rate or half-life formula can be of some benefit to you in your daily work with radioactive materials. It can be a helpful planning tool in determining if you have enough radiolabel to successfully complete your experiments. For example, if you plan to label bacteria cells that are growing in a large flask and you know for a fact that the optimum growth period for the cells is going to be a week or so from now, will you have enough of radiolabel in the freezer to label those cells successfully? This formula can be a useful tool for you in such a situation.

The formula is $A=A_oe^{-.693t/T1/2}$

A_o = the activity or number of atoms originally present
A= the activity or number of atoms after a certain time (t) has elapsed
t= the time elapsed from A_o to A
T1/2 = half-life of the isotope

EXAMPLE:

On April 1, you have 10mCi of P-32. What will be the activity of May 1?

First of all, the time elapsed (t) is 30 days. The half-life of P-32 is 14.3 days. You can look up the half-lives of various isotopes or perhaps use the search engine on your computer.

$A=(10mCi)e^{-.693(30)/14.3}$
$A=(10mCi)(.233)$
$A=2.33\ mCi$

The general decay formula can be used to get an exact number but an estimate can also be . You know for a fact that on April 1, you had 10 mCi of P-32. On April 14 (one half-life) you would have 5mCi. On April 28(another half-life passes) you would have 2.5 mCi. So after 30 days, you would have a little less than 2.5 millicuries.

INTERACTION OF RADIATION WITH MATTER
How radiations interact with matter after they are released from an unstable atom

- Alpha Particles-
  When an alpha particle is released, its range is rather short since it has a plus 2 charge and a relatively large mass. Its effect is considered local. Alpha particles are not considered much of an external hazard. By external hazard, I am referring to a source located outside of the human body that emits radiation and causes one to receive a dose from the shine coming off of the source. It would require an alpha particle of 7.5 million electron volts just to penetrate the dead layers of skin. If you would get some alpha particles on the skin, this could result in some "hot spots" that could give the affected area a large dose to an extremely small area. Normally, the residence time of alpha particles would not be very long since repeated washing of the affected area and the sloughing off of the dead skin cells would cause the particles to be removed.

  The greater concern with alpha particles is if the sources of alpha particles happen to end up inside of your body. For instance, if you were to inhale an alpha emitting particle that was of a size that it would end up in the deeper recesses of the lung in the alveolar regions, these particles are considered below the level at which your body can easily remove them and they stay there for years. The cells immediately surrounding the alpha particles would receive a significant radiation dose over time and could possibly become cancerous. So, you would want to avoid inhaling alpha particles. Individuals, who work with this type of material, normally perform their work in a glove box and might also have further protection of the breathing zone by wearing a respirator.
  In summary, alpha particles:
  1. Have large Mass and a +2 charge
  2. Range is short and effect is local
  3. Not an external Hazard
  4. Can be a serious internal hazard
  5. Avoid inhalation of alpha particles

- Beta Particles-
  Beta particles are generally more penetrating than alpha particles of comparable energy. Betas can have either a minus one charge or a plus one charge. Now the low energy beta particles such as H-3, C-14, S-35 and Ca-45 are not considered an external hazard. No shielding is required to work with these isotopes. However, they can be an internal hazard if inhaled, ingested or absorbed. These isotopes will accumulate in the body wherever these elements are normally found. Tritium and C-14 will end up in just about every cell since these two elements are a component of most cells. S-35 will gravitate to proteins. If you recall from your basic biology instruction, the tertiary structure of proteins are held together by disulfide bonds. Ca-45 is a bone seeker. It would also become a component of your blood since calcium is important in the clotting process.

  High energy beta particles such as P-32 or Sr-90, are considered both an external and an internal hazard. Internally, P-32 and Sr-90 would seek out the bones of your body. P-32 could also end up as part of the backbone of the DNA molecules. P-32 has a very high specific activity which means that just a small amount can be very radioactive. Whenever it is handled, P-32 can impart a significant local dose to the skin and subcutaneous regions. Great care should be taken to avoid prolonged exposure to P-32.

  In summary, beta particles:
  1. More penetrating than alpha particles
  2. Low energy particles- not an external hazard (H-3,C-14,S-35,Ca-45)
  3. High energy particles- both internal and external hazard (P-32, Sr-90)

- Gamma and X-ray Interactions-
  Gamma rays and x-rays are more highly penetrating since they are forms of electromagnetic energy and have no mass or charge like alpha or beta particles. Very low energy gamma rays and x-rays would not penetrate the body very much and can impart a significant local dose much like high energy beta particles. Higher energy rays are obviously more deeply penetrating and can deposit dose easily to the internal regions of the body.

  In summary, gamma and x-ray radiations:
  1. Highly penetrating (no mass or charge)
  2. Very low energy rays can impart a significant local dose
  3. Higher energy rays are much more penetrating
  4. Greater range in air

PROPERTIES OF COMMONLY USED RADIOISOTOPES

Each radionuclide is unique in terms of what types of radiation it emits. Some give off just beta particles such as phosphorus-32. Some give off alpha particles and gamma rays such as Americium-241. And some can give off alpha, beta and gamma radiations like uranium-235. You can categorize each radionuclide by the type of radiation it emits, the energy of the particles or photons in electron volts, kilo-electron volts(thousand) or mega-electron volts(million). And each radionuclide has a rate of emission that we refer to as the half-life.

Two videos are available on our web site titled “A Demonstration of the Various Types of Radioactive Materials” and “Safety Precautions when Using Specific Types of Isotopes”. These videos were created to actually show you the various types of radioactive materials that were just discussed and present some of the safety precautions that are taken when working with these radioisotopes.

It is important for you to know that which isotopes are considered weak or high energy beta emitters. By knowing the category an isotope, you can then apply certain safety precautions when working with that material. For instance, if you are working with Phosphorus-32, you should know that it is a high energy beta emitter and that Plexiglas shielding is needed as well as a whole body and ring dosimeter. You would also need to have your Geiger counter handy to survey your work area during and after your experiment.

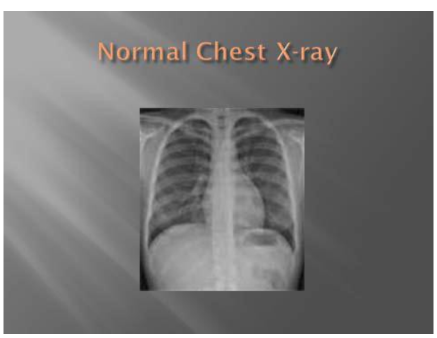
LESSON 2:
Dose Units and Biological Effects

As you recall, the units that are used for radiation quantity are the Curie and the Becquerel. There are a few other terms related to radiation field strength and radiation dose that you need to be familiar when working with radiation.

The first term is the **Roentgen (R)** which was named after William Conrad Roentgen who discovered x-rays in 1895. A roentgen is a measure of radiation exposure in air. It specifically refers to x-rays or gamma rays but is often used to quantify other types of radiation, as well. A roentgen measures the strength of a radiation field. In other words, if you had a source that was emitting radiation, you could measure that field using a Geiger counter. The units on a typical Geiger counter are milli-roentgens (mR) per hour. A milli-roentgen is a thousandth of a roentgen. The roentgen unit does not correlate directly with the amount of dose that a human can receive from a radiation source.

Another unit was developed called the radiation absorbed dose or the **RAD**. The energy of the radiation and the density of the material that absorbs the radiation are two important factors in determining dose. Radiation energy is directly correlated with the degree of penetration in a human body. More energetic radiations are more penetrating. The denser tissues of the body will absorb more radiation.

The RAD is a unit of absorbed dose, considers the energy of the radiation and the density of the absorbing material. 1RAD = absorbed dose when 100 ergs of energy per gram is transferred to the absorbing material.



When x-rays come in contact with photographic film, they have the ability to darken the film. Notice in this slide that the ribs come out lighter on the film than the areas in between the ribs. The ribs are much denser than the soft tissue between the ribs and so therefore, they absorb more radiation, get more dose and appear lighter on the film.

Radiation Absorbed Dose (RAD) – Proportionality Constants

kv	Filter mm of Al	constant (RAD/R) air	water	muscle	bone
100	5.5	0.87	0.91	0.94	3.10
250	3	0.87	0.96	0.96	1.42
400	nil	0.87	0.97	0.97	1.11

If you could measure the radiation quantity at the surface of the body in roentgens, you could then determine the amount of absorbed dose in RADS using the proportionality constants in this table. The very far left column lists the energy of the radiation in kv (kilovolts) from 100 to 400 kv. Now as you move from left to right in the table you seen columns for increasing material densities from air (least dense) to bone (most dense). In summary, you can take the number for skin entrance exposure and multiply it by the appropriate proportionality constant to obtain a value for absorbed dose in RADS.

Another term associated with dose is the roentgen equivalent man or the **REM**. A REM is a measure of radiation dose equivalent. As discussed, radiations can differ: some have plus charges, some have negative charges, some have no charges or mass. As the result of these differences, they affect living systems differently. For example, if you had a 1 MEV alpha particle and a 1 MEV gamma ray penetrating your body, each would behave differently as it passed through you. The 1 MEV gamma ray, since it has no mass or charge, would pass through your body rather easily. If you could measure the gamma ray as it exited your body, it would probably be less than 1MEV in energy because of collisions with atoms. If you look at the path of the 1 MEV alpha particle, it would only penetrate possibly a few layers of skin. Now if you could measure the amount of radiation that is deposited in each cell from both types of radiation, you would discover that there is far more energy deposition from the alpha particle since it deposited most of its energy over a much shorter range. As a result of this phenomenon, we can say that the alpha particle has a higher biological effectiveness than does the gamma ray. The table provides the QF for the different type radiations.

Radiation Type	Quality Factor
X-rays or gamma rays	1
Beta Particles	1
Neutrons	10
Alpha Particles	20

NEW INTERNATIONAL UNITS

In 1975, the International Commission on Radiological Units (ICRU) adopted new units applicable to radiation protection that are consistent with the International System of Units (SI System). The **Gray** (Gy) has replaced the RAD. One gray is equal to 100 RAD's. And the **Seivert** (Sv) has replaced the REM. One seivert is equal to 100 REM. Most countries of the world have adopted the new units. However, they are still not widely used in the United States and Russia, but there is much movement to adopt these units. So, it is important to know both sets of terms. If you look at the scientific literature, you will find the Gray and Seivert used. If you visit most countries, you will find the new units used in discussions about radiation dose.

Gray (Gy) replaces RAD
1 Gy = 1 joule/kg = 100 RAD

Seivert (Sv) replaces REM
1 Sy = 100 REM

DOSE LIMITS- TOTAL EFFECTIVE DOSE EQUIVALENT (TEDE)

Everyone is exposed to a certain amount of radiation from the environment (cosmic, radon, terrestrial…) which is called the background radiation dose. In SC, the average background radiation level is between 100- 500 mrem per year. Once you begin to use radiation in our laboratories, you will be considered a “radiation worker” by the regulatory authorities. And as a radiation worker, it is expected that you will receive some dose from your activities. The regulatory authorities allow radiation workers to receive a certain amount of dose related to their work activities. The dose limit for radiation workers is referred to as the **Total Effective Dose Equivalent or TEDE**. The TEDE includes radiation shine from external sources such as an x-ray machine or a bottle of radiolabel. It is referred to as the Deep Dose Equivalent or DDE. The deep dose equivalent is obtained from radiation dosimeters worn by workers. The second component of dose is what can be received from internal deposition of radiation in the body. This is referred to as the Committed Effective Dose Equivalent of CEDE. The CEDE really tries to address the deposition of long-lived isotopes that may have a long residence time in your body. There are 3 main routes of entry for radioactive materials in the body: **ingestion, inhalation, and absorption**. If you can get a measure of the amount of radiation that is deposited internally, then you can project how much dose that source of radiation will cause over a 50 year work period. It would be rare to have this type of radiation deposition by working with the isotopes that we normally use at USC. The only isotope that is capable of causing an internal dose under normal conditions is I-125 in a free form of sodium iodide. If you were to open a vial of this form of Iodine-125, it has a relatively high vapor pressure and will be volatile. The radioactive atoms could easily permeate your work space just by opening the vial. Employees who work with I-125 for the purpose of tagging another organic molecule will be required to work in the laboratory fume hood. This protects the worker from inhaling the radioactive atoms. Now if you happen to be boiling a radioactive solution, this could possibly result in airborne atoms and this activity should also be performed in a fume hood. We measure internal deposition of iodine by measuring radiation emissions from the thyroid since iodine is accumulated almost exclusively in the thyroid.

If you are working with just an x-ray machine, there is no possibility of having an internal dose – only an external dose. So, your TEDE would just consist of DDE readings from the personnel dosimeter.

Summary:
Total effective dose equivalent – sum of the deep dose equivalent (DDE) from external exposures and the committed effective dose equivalent (CEDE) from internal doses to any organ or tissue.
TEDE= DDE+CEDE

The annual limits are:
5 rem - total effective dose equivalent
50 rem - total organ dose equivalent to any single organ or tissue
15 rem – total dose to lens of the eye

It should be pointed out that these limits do not imply a safe level of radiation dose. The biological effects from low doses of radiation are not well known. As a result, the regulatory bodies have taken the position that radiation doses must be kept as low as reasonably achievable (ALARA) which will be discussed below.

LIMITS DURING PREGNANCY
The dose to the embryo/fetus over the entire gestation period (9 months) must not exceed 0.5 rem. The dose should be delivered at a fairly uniform rate over the entire period of pregnancy and not delivered in a few large doses. The rule permits an additional 0.05 rem if the pregnant woman has greater than 0.45 rem at the time of notification. Abdominal dosimeters will be issued to the employee, if applicable, who has declared her pregnancy in writing to the Radiation Safety Office. A more detailed discussion of this topic can be found later in this manual.

ALARA
It is important to note that the dose limits listed are believed to be a safe level based on studies of the biological effects of ionizing radiation. However, we cannot say beyond the shadow of a doubt that they are safe for everybody. Humans have varying degrees of sensitivity to radiation. For example, the very young are more sensitive to radiation. Young folks are growing rapidly and they experience rapid cell reproduction. Cells that are actively diving are more sensitive to radiation therefore there are more stringent limits during pregnancy. Also, older humans are more radiosensitive because their immunity systems are not as strong and radiation exposure or exposure to any kind of physical stressor could upset the homeostatic balance of the body.

As a result of this, the regulatory authorities state that even though there is an established radiation limit, we should strive to keep all doses to a minimum or as is stated on this slide – **AS LOW AS REASONABLY ACHIEVABLE**. The University policies are developed with ALARA in mind.

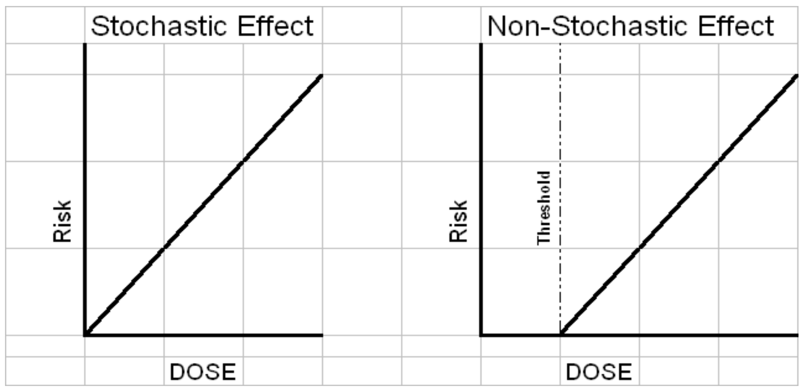
BIOLOGICAL EFFECTS

Obviously, ionizing radiation has definite biological effects or there would be no need for you to be taking this course. There are two types of biological effects associated with ionizing radiation: **deterministic** or **non-stochastic and stochastic**.

- In a **deterministic** effect, the severity of the disease to the individual is directly related to the amount of radiation dose received. The higher the dose, the greater will be the biological effect. A certain amount of dose above a threshold level would cause skin reddening. A much higher dose would possibly cause skin lesions or burns. It has been shown that threshold levels do exist for diseases such as cataracts, skin damage and lower red blood cell counts.

- A **stochastic** effect results in a certain fraction of an exposed human population developing a disease. The severity of the disease does not depend on the radiation dose. You either get the disease or you don't. For instance, the survivors of the atomic bombs that were dropped on Japan at the end of World War II received doses that caused a fraction of the surviving population to be afflicted with leukemia after about 5 years. This same population had a higher incidence of lung and bone cancers about 10 years after the event. Increases in other cancer rates were noted 20-25 years after.

Dose Response Curve



There are two different types of dose response curves. As you can see, in the curve showing the stochastic effect, the curve crosses the x-y axis at zero. In other words, there can be a small risk from a very small dose. This type of response could be associated with carcinogenesis or mutagenesis. In the other curve showing the non-stochastic effect, there is a definite point below which there appears to be no risk. This is known as the threshold point. Skin reddening and cataracts appear to require a threshold level of radiation before the effect can appear.

FACTORS AFFECTING BIOLOGICAL EFFECTS

Dose rate is an important factor to consider. The faster the dose is delivered, the greater will be the biological effect. If you received 1000 RAD to the whole body at once from a highly penetrating radiation, it would be fatal to you. However, if you received 1000 RAD over a period of months or years, then the dose would not be fatal. The explanation for this is that the body has the ability to repair damage to the chromosomes in between episodes of radiation exposure and thus the body can tolerate more radiation.

The **area of exposure** to the body is also critical. 1000 RADs to the whole body at once would kill you but 1000 RADs to your finger would not kill you.

Humans have shown to have varying degrees of **sensitivity to radiation**. The very young and the very old cannot tolerate as much radiation as someone who is past puberty and has stopped growing vertically. In young people, you have rapid growth periods and rapid cell turnover or cell reproduction. Cells that are actively dividing are more radiosensitive than cells in the resting phase.

In older people, any kind of outside stress can disrupt the homeostatic mechanisms of the body and in the case of radiation it would make you less tolerant to those stresses. As a result, we borrow a unit from toxicology called the **LD_{50}** to express the radiation effect. LD refers to the lethal dose and the number 50 refers to the dose that would kill 50% of a human population – assuming that it includes both young and old members. The LD_{50} dose for humans from a highly penetrating type of radiation is 400-450 Rem (4-5 Sv).

Cell sensitivity is also a factor. Cells that are more actively dividing are more **radiosensitive**. Less differentiated cells are more radiosensitive, as well.
Cells such as erythroblasts and spermatagonia are considered highly radiosensitive.
They are relatively undifferentiated.

RADIOSENSITIVE CELLS:	BONE MARROW CELLS EPIDERMAL STEM CELLS BLOOD-FORMING CELLS IMMUNE SYSTEM CELLS REPRODUCTIVE STEM CELLS

But cells such as muscles and nerves are highly **radioresistant**. Muscles and nerves don't reproduce much once you reach maturity. They are very highly differentiated. The function of muscle cells is to contract and cause body movement while the nerve cells function to send electrochemical impulses through the body to the muscles and cause movement.

RADIORESISTANT CELLS:	BRAIN CELLS NERVE CELLS MUSCLE CELLS

DOSE vs. EFFECT

When considering radiation dose effects, distinct differences can be noted between acute and chronic levels of radiation exposure. **Acute doses** are large doses received over a short period of time such as a few minutes to a few hours. The effects are immediate and can easily be associated with the radiation event. **Chronic doses** are smaller doses delivered more frequently and over a longer period of time. In this case, there is a latent period between when the dose was received and the appearance of a biological effect. It is often more difficult to associate exposure to the radiation events and a biological effect due to the latency period. Latency periods may be anywhere from 5 to 25 years. You also have confounding factors that can contribute to the same biological effect. For instance, you inhaled a significant dose of radiation while working in a fume hood that suddenly malfunctioned. Twenty years from now, you are diagnosed with lung cancer. In considering the etiology of this disease, was the cancer caused by the radiation exposure or was it caused by the fact that you are a chronic cigarette smoker?

Acute Doses- When someone receives an acute radiation dose, here are some of the organ systems that would be affected:

- The hematopoietic system is responsible for blood formation in the body. Large doses of radiation impair the body's ability to produce new blood cells. When someone receives and acute dose of radiation, one of the things that medical personnel will do is take your blood samples over a period of time to see if the cell counts are changing. Your body is constantly producing new cells and destroying older cells. If you can no longer produce new cells, then this could become a very serious problem.

- The gastrointestinal tract is part of your digestive system and the duodenum which is part of the small intestine is lined to the side facing the digested food with tiny cells called micro-villa. Micro-villa is hair-like projections of the cell which increase the surface area of the cell and increase the cell's absorption efficiency. These cells are very radio-sensitive and large doses of radiation to your gut would kill these cells and severely impair your ability to obtain nutrition.

- Large doses of radiation can cause your hair to fall out. This is usually a reversible condition once the radiation event has passed.

- The skin can be affected by large doses of radiation. The type of radiation that normally is involved with skin effects are beta particles or weak energy gamma or x-rays. They cause a more local effect – usually skin burns. These types of burns are not of the charring type like you would receive from a fire but rather are more like a blistering, swelling and exuding of pus. If the skin burn is serious enough, then skin grafts may be required to treat the area.

- You can also have general systemic effects such as radiation sickness. Symptoms include nausea, vomiting, diarrhea. The central nervous system can also be impaired. Large doses can affect the capillaries which feed the nerve fibers and this would be a serious problem.

Chronic Effect- chronic effects occur many years after an initial acute dose or from exposure to small amounts of radiation over a longer period of time. These types of effects occur at much lower doses. These are the types of chronic effects associated with radiation exposure.

- Genetic mutation- would occur in your germ cells. In males, the sperm would be altered and in females, the eggs would be altered. You would probably experience no signs of radiation exposure but if you decided to pro-create, your children could possibly show signs of radiation damage.

- Somatic mutation- would occur in cells of your body that are not germ cells such cells that make up your lungs or other internal organs. In this case, you could experience the biological effects from radiation exposure in your generation.

- Carcinogenesis – radiation is a carcinogenic agent to a wide variety of tissues in both experimental animals and humans.

- In utero effects – radiation is considered a teratogenic agent which causes developmental abnormalities in fetuses. Two factors controlling teratogenic effects are the dose to the embryo/fetus and the stage of development at the time of the exposure.

LESSON 3:
BASIC PROTECTION MEASURES/DECONTAMINATION

The goal of any radiation safety class is to teach you how to reduce your radiation dose. By applying some rather simple concepts, radiation dose can be reduced substantially. Dose can be reduced through the use of time, distance and shielding.

- **Time**: Obviously, the less time you spend near a radiation source, the less will be your dose. Now in our laboratory setting, how can you do this? Well, you can first carefully plan your experiments. Study the protocol that you will use and then perhaps do an initial trial run of that protocol WITHOUT introducing the isotope. Usually, the more times that you perform a repetitious series of steps, the more proficient you become at the individual tasks and therefore, less time will be required to carry out those tasks.

- **Distance:** The further you are away from a radiation source, the less will be your dose. Now for gamma rays, x-rays and high energy beta particles, we can employ something called the **inverse square law**. The inverse square law states that dose rate is inversely proportional to the square of the distance.
  $I_1 D_1^2 = I_2 D_2^2$ In this formula, the letter "I" refers to exposure rate and the letter "D" is the distance.

  EXAMPLE:
  If the exposure rate is 10 mR/hr at one foot, what is the exposure rate at 2 feet?
  $I_1D_1^2 = I_2 D_2^2$
  $(10 \text{ mR/hr})(1 \text{ foot})^2 = (?)(2 \text{ feet})^2$
  $10 = 4x$
  $x = 2.5 \text{ mR/hr}$
  Let's look at this example. You can see that I_1 is 10 mR/hr and D_1 is one foot. Of course one squared is one and the left side of our equation comes out to 10. Our unknown is I_2 – the exposure rate at distance 2 and our second distance is two. Two squared is 4 and the right side of our equation is 4x. And x would equal 2.5 mR/hr. So, you see that by doubling your distance from a radiation source, you reduce the exposure rate by a factor of four. If you are in a laboratory setting where radiation is present, by observing a safe distance from the source, you can reduce your dose.

- **Shielding**: Shielding is simply a material barrier that is placed between the radiation source and yourself that serves to attenuate the radiation. Shielding is used when storing radioactive materials. It can also be used while you are working with radioactive materials. You can work behind the shield and extend your arms around the shield to manipulate your experimental materials. For alpha emitting radioactive materials, no shielding is needed. If you recall, alpha particles are not very penetrating and can be stopped by placing a few sheets of paper over the material. For beta emitting radioactive materials, we must consider the energy of the emitted beta. For weak energy beta emitters, no shielding is required. Weak energy beta particles are not very penetrating. The isotopes in this category are H-3, C-14, S-35 and Ca-45. For high energy beta emitters such as phosphorus-32, shielding is required. The type of shielding needed in this application would be one that is of low molecular weight to reduce the incidence of production of Bremmstralung x-rays. The type of material most often used is Plexiglas. Bremmstralung x-rays can be produced when high energy electrons penetrate heavy shielding material. The use of a thin lead shield could be a worse application than using no shield at all.

When shielding for gamma or x-ray emitters, a dense material such as lead is the most appropriate material to use. If you recall, gamma rays and x-rays are a form of electromagnetic energy with no mass or charge associated with them. They are generally more penetrating than other types of radiation and so a dense shield where the atoms are tightly packed together is the material of choice. Now the thickness of the lead that is required would depend on the activity of the radiation source as well as the energy of the source. Rays that are more energetic require thicker shields. If you are trying to shield for iodine-125, a thin piece of lead is all that is needed since the energy of the emitted gamma rays is only 35 kilo-electron volts. If you are trying to shield for iodine-131 or cesium-137, the shielding material needs to be as thick as a brick.

This is a picture of a Plexiglas shield that would be used for phosphorus-32 applications. Your work area would be on the back side of the shield on the base or on the lab bench beyond the base of the shield. One nice thing about Plexiglas shields is their transparency. You can easily work behind the shield yet be able to see through the shield to manipulate your experimental products.

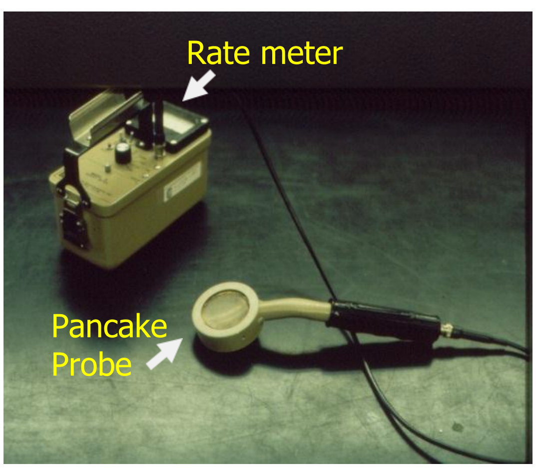
This shield is used for gamma emitters. The base and the side of the shield is made of thick steel and the viewing window is leaded glass. Leaded glass has a yellow tint and is very heavy.

Here is some shielding material used for higher energy gamma emitters. Notice how thick these pieces are compared to the shields in the previous slides.

RADIATION DETECTORS

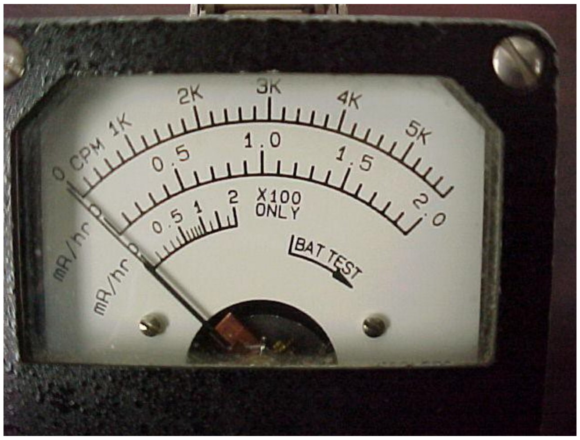
There are two types of radiation detectors used in our laboratories – the Geiger Counter and the Liquid Scintillation Counter. A Geiger counter is a portable device used to assess the strength of radiation fields or to find radioactive contamination. The liquid scintillation counter is not portable. It is a lab bench instrument used to accurately count your radioactive research samples and is also used to count contamination wipes.

- **Geiger Counter**: A Geiger counter can detect all types of radioactive materials including alpha emitters of a certain minimal energy, betas, gammas, x-rays and neutrons. The low beta emitter that cannot be detected with a Geiger counter is tritium or hydrogen-3.

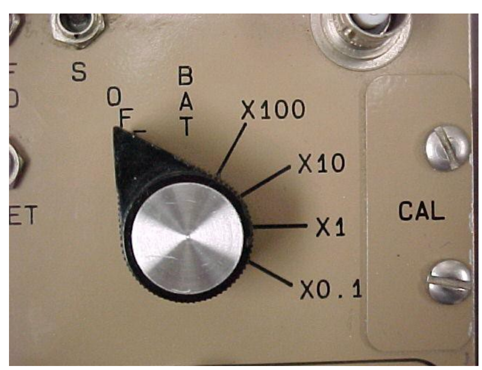


The probe of a GM contains a counting gas and the detecting area of the probe has a very thin Mylar window on it that is covered by a thin screen. The screen is there to protect the thin Mylar covering. The presence of the screen does reduce the instrument's sensitivity somewhat.

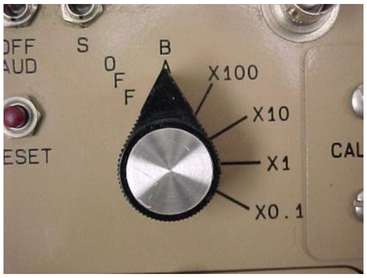
OPERATION OF GM



This is a view of the meter face. Notice that there are three scales. The uppermost scale is the CPM scale. CPM refers to counts per minute. On this scale, you will get a value for the number of counts that are being emitted from the radiation source over a period of one minute – a rate per unit time if you will. The middle scale measures in mR/hour. The lower scale measures in mR/hr as well but is used only on the 100x scale. When the unit is switched to the 100x scale, the pancake probe is bypassed for another probe that is located in the base of the rate meter. One of the limitations of a Geiger counter is that the response of the counter is dependent on the energy of the radiation that is being measured. When measuring high energy radiation around 800-900 kev, the instrument under responds to the amount of radiation present. In other words, there is more radiation present than can be accurately measured. When measuring lower energy radiation around 200 kev, the instrument over responds to the amount of radiation present. In this case, the meter is actually counting more radiation than is actually present. So, as a result of this limitation, you really can't accurately measure the radiation using the units of mR/hr unless you calibrate the instrument using a source that emits energy similar to the radioactive material that you are surveying. The CPM scale is what should be used. All we can say is that the radiation is emitting a certain number of radiation counts in a minute. However, most people use the mR/hour scale all the time but understand that it may not be very accurate.

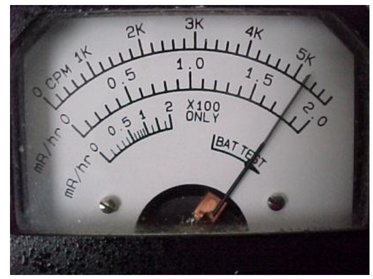


The selection dial has four numerical options plus a battery check option. The four numeric options are just different sensitivities of scales for the unit. The 0.1x scale is the most sensitive. In this case, you just multiply the numeric value that you view on the meter face by 0.1. For example, if you observe a numeric value of 2 mR/hr, you are actually getting a measured value of 0.2 mR/hour. If you set the dial to the 1x scale, the numeric value you observe is exactly as you see it. On the 10x scale, the correct reading would be 20 mR/hour.



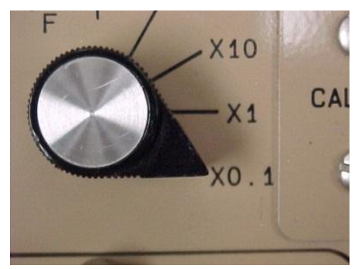
Whenever you turn on the instrument, the first selection should be the “bat” setting. As I said, the “bat” stands for battery and what you are doing here is measuring the strength of your battery.

The needle on the meter face must be within the battery test range or you will have too weak of a battery to use the instrument. Notice that the needle on this meter face is located within the “bat test” range and therefore it has enough energy to adequately power the unit.



If the batteries need to be replaced on this unit, just simply pop the latch located under the handle and put two new d-cell batteries in the unit.

When beginning a survey, you will want to set the selection dial to the most sensitive scale. In this case, the most sensitive scale is the x 0. 1 scale. The reason that you want to select this scale is that if there is just a very small quantity of radiation present, it will be measured. If you were on the less sensitive 10x scale, the needle on the faceplate may not move at all. However, if you are on the most sensitive scale and the meter needle goes to the maximum level, then just move the dial up to the next scale and obtain a measurement.



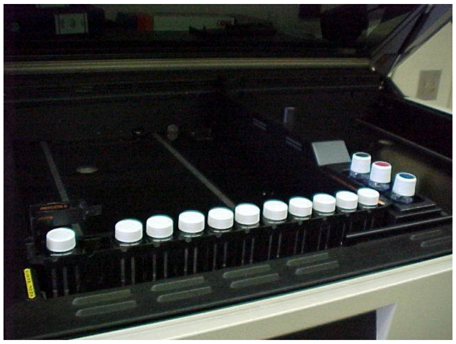
There is a switch in the upper left corner of the picture that allows you to turn the audio response on or off. When you measure a radiation field with this instrument, you not only get a visual representation of the radiation quantity, but the instrument also responds with an audio pulse. The pulse becomes more pronounced when more radiation is present. In the lower left corner of this picture, there is a reset button that can be pushed to quickly return the needle to the zero position. The needle will fall back after removing the probe from the radiation field but the reset button reset the needle instantaneously. The last switch allows you to select between an F and S setting. This controls how quickly the needle responds to the radiation field that is present. Normally, you would want to keep in on the fast response. However, if you are in a varying radiation field such as might be the case with some x-ray machines, the strength of the radiation field could be quite erratic and the meter needle will respond erratically, as well. If you move the selector to the “s” or slow response, the meter will no longer behave erratically in the radiation field and you can thus get a more accurate quantity of the radiation present.

- **Liquid Scintillation Counters:** As you can see, it differs from a Geiger counter in that it is certainly not portable. It is a tabletop instrument that is capable of accurately counting beta emitters including tritium. It will also count some gamma emitters but with much less efficiency.

  In liquid scintillation counting, you actually place the sample that you wish to count in a 20 ml vial along with a counting medium called a fluor or scintillation cocktail. The liquid cocktail will actually fluoresce when in the presence of a radioactive material. Now you can’t actually see the fluorescing action but it will be picked up inside the dark chamber of the counting unit. On either side of the vial there will be two photomultiplier tubes which will convert the light flashes to electronic pulses and then be converted to counts. Obviously, the more fluorescence you have, the more radiation that is present.

  A liquid scintillation counter will count tritium at about 50% efficiency, carbon-14 at about 90% efficiency and phosphorus-32 at about 99% efficiency. When I refer to efficiency, I mean the instruments ability to count all of the radiation that is emitted from a source. You might think that an instrument would count everything that is present but that is not the case. For instance with tritium, since it is such a weak energy beta emitter, some of the radiation will be absorbed by any solid material present in the medium or some of it could be just self-absorbed in the liquid itself. If you know that you have tritium in a quantity that is emitting 100,000 dpm, then the instrument will be able to count approximately 50,000 of those disintegrations. However, this is no problem if you know the exact efficiency of your instrument using radioactive standards, you can then determine how many dpm is present just simply by taking your cpm and dividing by the instrument efficiency.



This is a picture of the liquid scintillation counter with the top in the open position. Notice that the vials with the little white caps can be placed in a tray of twelve and counted in sequence. You can also have multiple trays of samples present.

Actual scintillation vial up close with a small filter paper inside the vial usually used for conducting wipe tests. It is important to select a liquid cocktail that best works for the type of sample that you are using. If you have an organic substance such as living tissue, you may want to select a cocktail that will be most efficient for counting this type of sample. I would consult the supply house catalogues that have very detailed descriptions of each type of cocktail and what they are best suited for. One thing that we ask of our users of radioactive materials here at USC is that you select a **scintillation cocktail that is considered "bio-safe"**. Bio-safe means that there are no hazardous chemical components that would make it more of a challenge to dispose of the materials as hazardous waste.

Operation of a Liquid scintillation counter is specific to that type unit so please refer to the operator's manual.

RADIATION VS CONTAMINATION

There is a definite difference between a radiation field and contamination. Both can result in the reception of a dose. Contamination is simply radioactive materials that are found on the skin that causes dose to the skin. And a radiation field can impart a dose from an external source such as an x-ray machine or a vial of radioactive material.

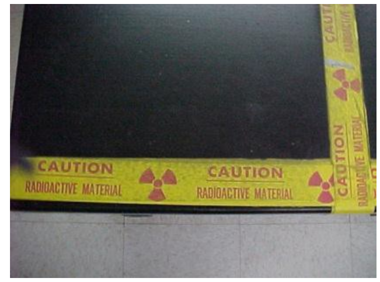
One important way to control radioactive contamination is through the conduction of **surveys** and **wipe tests** or your work area.

- A **survey** is a check of your work area using a Geiger counter. You would want to survey your work area before, during and after your activities with radioactive materials. In conducting a survey, what you are looking for are areas in your work area that are above background levels. By background, I'm referring to the naturally occurring radiation that we are constantly exposed to from cosmic sources and naturally occurring isotopes in the ground or in building materials. When you turn on your Geiger counter, you will hear a slight clicking noise with beats that may occur every few seconds. When radiation is present from your work activity, the clicking is more frequent and pronounced. This is an indication that something other than background radiation is present. This is an area that you will need to clean to remove the contamination.

- A **wipe test** is used to find loose contamination in your laboratory. A wipe test is accomplished by taking a piece of filter paper or other type of absorbent paper and wiping a potentially contaminated surface to see if any radioactive material can be removed from the surface. A wipe test must be done after each work interval using tritium and weekly when using other radioactive materials in the lab. The difference here is that you can't pick up tritium with a Geiger counter so it is good to be cautious and check for any contamination you might have in your work area. In doing weekly wipe tests, you will want to wipe various surfaces in your lab where you think that contamination might be present. You may want to wipe 10 areas and count these wipes on a liquid scintillation counter. One of the wipes should be just a plain vial with scintillation cocktail to get a count of the background for that day. If any of the wipes exceed three times the counts you obtained for background, then that particular area must be cleaned to remove the contamination. A written record must be kept for your weekly wipe tests. This is probably the most important record that you keep since it is an indication of the extent of contamination present in the lab.

Another important way to reduce the spread of contamination is using the **personal protective equipment** that is required when working with radioactive materials.

- The lab coat will protect your street clothes from becoming contaminated. It is best to have a couple of lab coats so that if one becomes contaminated, you will have a back-up to use to complete your work.
- Wear latex or other rubber gloves. They provide sufficient protection from the absorption of radioactive materials into the skin.
- Safety glasses should be worn to protect eyes from splashes of radioactive materials.



Designate a radioactive work area. When working with radioactive materials, you should dedicate a certain bench or a part of a bench for the isotope work. The idea is to prevent the spread of radioactive materials to non-radioactive work areas in the lab. It is appropriate to delineate the radioactive work area with tape that has the radioactive caution warnings on it.

In a lab where radioactive materials are used, one sink is designated as the **hot sink**. This is where any personnel decontamination should take place or where equipment is to be cleaned. This is not where liquid radioactive waste should be poured. Liquid waste must be stored in plastic containers and removed from the lab by radiation safety personnel. When cleaning glassware, the first two rinses of soapy water must be poured into the plastic carboys or containers. After that, any additional rinses can be poured down the drain. Our experience is that after two rinses, the amount of radioactive materials that are adhering to the glassware is minimal. The hot sink should be part of your weekly wipe test program. We do allow for wipes to be above three times background in the hot sink considering the activities that take place there. However, if the wipe test of the sink is in the 10,000 to one million count range, the sink must get a thorough cleaning.

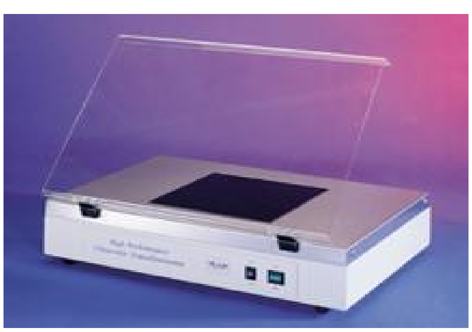
A **plastic liquid waste container** used for the accumulation of your liquid waste will be provided to the lab. Notice that is has the radiation warning label attached to it. The radioactive waste – both solids and liquids – should be stored in an area of the lab where human traffic is at a minimum. The exposure rate, measured by using a Geiger counter, should not exceed 2mR/hr near the waste. If it is greater than this, then shielding must be used to reduce the radiation levels. If additional shielding is not available, then request a special waste pick-up to remove the materials from your lab.

Each laboratory is equipped with a **fume hood**. A fume hood is connected to the building's ventilation system and it draws air from inside the room through the hood and up through the stack. A fume hood is essential when you are working with volatile materials or boiling materials that would increase the volatility of those materials. In the case of radioactive materials, work with iodine-125 or I-131 in a free, untagged form must be carried out in the fume hood. Radioactive iodine in free form, that is, sodium iodide, is volatile at room temperatures. If you opened a vial of radioiodine, its vapor pressure is great enough to permeate a laboratory room within a very short period of time. So, the fume hood is essential in working with this material. A fume hood used for radioactive material work must have the radioactive warning label affixed to the hood lip. Fume hoods must have a certain **capture velocity** to be approved for radioactive material work. The capture velocity is the velocity of the air moving into the hood at the face of the hood with the sash lowered to about 12 inches. The capture velocity must be between 125 – 150 linear feet per minute. We measure capture velocity with an instrument called a "velometer". Each year, an employee of the University's health and safety program will measure the hood to see if it has the proper capture velocity. You will notice that a calibration sticker has been affixed somewhere on the front of the hood. If the hood does not have the proper capture velocity, it will be the responsibility of the researcher or lab manager to put in a work order to USC's Operational Services to have the hood serviced.

Each tool used for radioactive work is labeled as radioactive. This is to warn everyone in the lab that these tools are potentially contaminated with radioactive materials and should be treated with caution.

OTHER RADIATION SOURCES IN A LABORATORY

A piece of equipment that emits a different type of radiation that can be a potential hazard in the laboratory is a trans-illuminator which is used as a facilitator in processing DNA gels. DNA gels are often cut into smaller slices and the trans-illuminator allows the researcher to see them more easily. It does this using an ultraviolet light source.



The light source will be emitted in the black square area on the top of the illuminator. Notice that there is also a Plexiglas screen attached to the illuminator with two hinges. This screen is there to protect the user from excessive exposure to ultraviolet light. Exposure to high levels of ultraviolet light can result in skin irritation, skin burns and conjunctivitis of the eyes. I'm mentioning this because we have had a few instances over the past few years where some users have gotten too much exposure and have ended up in the local hospitals with serious skin burns and eye irritations. So, be aware that these devices can emit enough ultraviolet radiation to cause harm. Users who have fair skin are more vulnerable to ultraviolet radiation exposure. When working with the trans-illuminator, please use the Plexiglas screen as a shield. Additional protection should be employed when working with trans-illuminators. Goggles will protect the eyes. However, this type of goggles will not protect the rest of your face and if you do receive excessive ultraviolet exposure, you could end up looking like a raccoon. The use of a full-face shield which is what you need when working in this environment. This will protect the entire face. In addition to eye protection, you will want to wear a lab coat with the sleeves covering as much of the arms and wrists as possible. Don't roll up the sleeves! Latex gloves will protect your hands and sun screen applied to the exposed skin surfaces is a good protective measure. The SPF factor for the sunscreen should be at least 30.

CONTAMINATION

If contamination is found in only in one area or a few areas, then laboratory personnel can clean up the contaminated areas. The action level that requires you to decontaminate an area is any wipe test that is three times the background levels. If you find that contamination is more widespread in the laboratory and you are getting wipe test results that are over 20,000 dpm, contact the radiation safety office for assistance.

If you are involved with a decontamination effort, you will want to

- localize the area that is contaminated;
- eliminate traffic in the area if the floor is contaminated. You don't want to spread the contamination to wider areas of the lab and hallway.
- Setting up a step-off area is a good practice. A step-off area is just simply a line (it could be an imaginary line) that separates the contaminated zone from the non-contaminated zone. You would use a Geiger counter or wipe tests to determine where the step-off area should be located. When you step into this area, your shoes or protective shoe covers must be removed and left on the contaminated side of the step-off area.
- You will also want to monitor anyone who was in or near the contaminated zone. Survey the persons with a Geiger counter.
- In the decontamination process, you will want to use cleaners such as Radcon (which is a foamy aerosol) or alcohol based cleaners. Use paper towels to wipe up the contaminated surfaces. Place all paper towels and other cleaning products in the radioactive trash.
- One other thing to remember is that you should have personal protective equipment on when decontaminating the lab. It may require repeated cleaning to remove contamination from lab surfaces – particularly if the contamination is high.

Skin Decontamination: If you or other lab personnel are contaminated, you will want to go to a sink and clean the affected area with warm water and mild soap. Repeated washings may be necessary. A soft bristled brush could be useful, as well. Soap with a mild abrasive such as Lava hand soap may be necessary.

Hair Decontamination: If your hair is contaminated, shampoo the affected area and be careful to keep the head deflected away from the face to prevent contamination of your eyes. A 3% citric acid solution may be useful in removing contamination from the hair. Repeated washing may be necessary. If just a small part of your hair is contaminated, clipping it off with the scissors may be the best approach to take.

Eye Decontamination: If you have some contamination in your eyes, then spread the eyelids and irrigate the eye surface. A bottle of isotonic solution that you would use for contact lenses might be good to have in the lab as a precaution. Obviously, you would want to rinse away from the nose to prevent the spread of contamination to the other side of the face.

Whole Body Decontamination: If you have contamination over most of your body, you will need assistance from someone in the lab or from radiation safety personnel. You will want to remove your clothing and get to a shower. Repeated washing in the shower may be necessary. Monitor with a Geiger counter. Make sure the shower is thoroughly cleaned afterward. Don’t worry about the amount of contamination that is going down the drain. This is allowed in emergency situations.

Treating Wounds: A wound is a break in the skin that would be an open route to your circulatory system. If you are wounded while using radioactive materials, rinse the affected area with running water in the hot sink. Delimit the wound with tape and plastic to prevent the spread of contamination to the surrounding areas. Decontaminate the skin around the wound and apply a sterile dressing. Contact the radiation safety office for assistance, if necessary.

Internal Contamination: Internal contamination can be the result of wounds or accidental needle sticks with a radioactive syringe. If this should happen to you, go directly over to the hot sink and rinse the affected area. Apply a little pressure to bleed the area before the contamination can get into your system. Call Radiation Safety for assistance.

If you have a serious episode of internal contamination – maybe from an explosion or other calamity and you require medical attention – go to a hospital that has a trauma center. In Columbia, SC, Palmetto Richland Hospital has a trauma center. The attendants will want to know when you had the accident, what type of uptake it was, the radionuclide involved, the chemical nature of the contaminant and the approximate amount of radioactivity that was involved. This information is important in your proper treatment. The physician attending to you may wish to administer a chelating agent which will chemically trap the radioactive material before it has a chance to become fixed in your system.

Information to provide an EMS worker if contamination is involved in a serious incident:

- Time of incident
- Type of uptake (ingestion, open wound, inhalation)
- Radionuclide involved
- Chemical Nature
- Approximate activity if available.

LESSON 4:
LABORATORY SAFETY/SIGNAGE

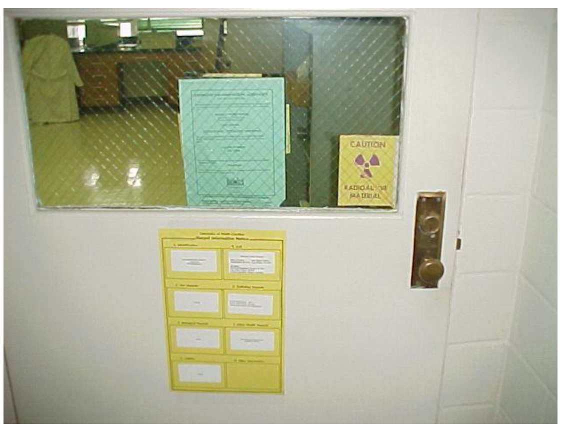
Here are some general safety measures that you must follow when working with radioactive materials.

- Personal protective equipment is a necessity. This includes a laboratory coat, rubber gloves, protective eyewear and your personal dosimeter(s).
- All radioactive materials must be secured against theft. If you are the last person leaving the laboratory, make sure that you lock the door. If this is not possible, then make sure that radioactive materials are kept in a locked container or in a refrigerator/freezer with a lock on the doors.
- Use radioiodine compounds in a fume hood if they are of the volatile form.
- Conduct your experiments in a tray such as a cafeteria tray if possible. This is to ensure that if a spill occurs, then the contents would be contained in the tray. Use absorbent paper with a backing that is plastic. The plastic backing prevents any spilled liquids from permeating the surface below the paper.
- If you administer radioactive materials to animals, those animals will begin to excrete waste products very shortly after the administration. USC's Animal Care facility does not house radioactive animals. So, the animals must remain under your watch until they are no longer radioactive or until you sacrifice the animal. All animal bedding must be treated as radioactive waste. When requesting a waste pick-up, be sure to place the bedding material in double plastic bags to prevent the possible breakage of the waste during transport.
- Never pipette radioactive solutions by mouth.
- Do not eat, drink or smoke in a laboratory where radioactive materials are used.
- Do not store your lunch in a refrigerator where radioactive materials are stored. You can keep your food in a refrigerator in the lab but it cannot have radioactive materials in it. Remember, you can't eat your lunch in the lab. If your lab is equipped with a break room separate from the work areas, it is permissible to eat there.
- Label all of the glassware and other utensils that you use for radioactive materials work with the "caution-radioactive materials" tape.
- If you have been assigned a radiation dosimeter, make sure that you store in a low background area in the lab when you are not using it.
- Your laboratory must be equipped with the proper shielding.
- Monitor yourself frequently when working with radioactive materials.
- Any radioactive waste products must be handled properly. At no time should radioactive waste be disposed of in the regular trash.

- Any decontamination efforts in your laboratory must be done by you or with the assistance of radiation safety staff. At no time should you ask housekeeping personnel to assist you in a clean-up of a radioactive spill. Housekeeping personnel are not trained in how to handle radioactive materials.
- Remember to monitor anyone who might possibly become contaminated using a Geiger counter.
- In addition to these radiation safety rules, you must also abide by general safety rules set down by OSHA (Occupational Safety and Health Act). Each laboratory is inspected yearly by personnel from USC's Health & Safety Program. They are looking for things such as fire hazards, tripping hazards, chemical storage, waste storage and many other matters.

RADIOACTIVE SIGNAGE

When walking into a USC laboratory building, you will see a number of warning signs.

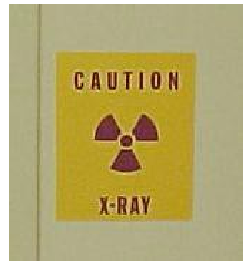


On the outside of each laboratory door, you will see the yellow sign identical to the one on the lower half of the door shown here in this slide. The laboratory doors in the Graduate Science Research Center have a different style of sign but contain the same information. This is a "**hazard information notice"**. It contains information about who resides in the lab. It will also have contact information for after hour emergencies. The notice also lists all of the major chemical, biological and radiological hazards in the lab. This notice is for emergency personnel such as fireman or police. This information is useful to these people if they have to enter to put out a fire or other emergency. The information on this sign must be kept current by someone on your laboratory.

You will also notice a radiation sign in the lower right portion of the door window. This sign reads "Caution – Radioactive Materials" and must be placed on the outside door of any lab where radioactive materials are present. The green sheet ("**Emergency Radiological Assistance"**) in the middle of the window lists emergency phone numbers for the radiation safety office, the USC Police and the SC Bureau of Radiological Health. This sign must be posted somewhere in the lab. It does not have to be posted on the door. Perhaps you can place it on a bulletin board or tape it to a wall where general information is normally hung. In the event of an emergency, during office hours, you may contact the Radiation Safety Office. Call 911 or 7-9111 if an emergency occurs after hours and inform the police if radioactive materials are involved. The other sign required to be posted in the lab is a **"Notice to Employees"** which states your rights as a radiological worker. Make sure you read this form when you begin work in the lab.

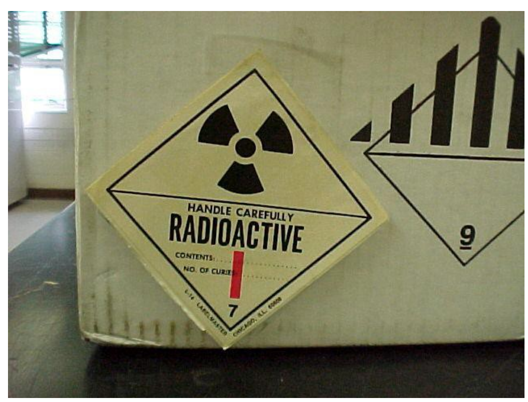
Once you enter a lab where radioactive materials are used, you will also see the "Caution – Radioactive Materials" sign anywhere radiation is stored.

This caution sign must also be placed on radioactive waste containers and if you store radioactive stock materials in a refrigerator, it must be posted with the warning sign, as well.



This sign must be posted on a door leading to where an x-ray machine is present. Unlike radioactive materials, the x-ray machine will only produce radiation when it is energized and a red caution light on the top of the unit is lit.

Whenever you order radioactive materials, they will normally come in a box like the one shown here. There may be some radioactive warning labels on the package or in a case such as the one shown here, there are none. The amount of isotope ordered may be low enough to be exempted from external labeling. The package will contain a bill of lading which will list the contents. Before you receive a package such as this, it is first delivered to the radiation safety office. We check the contents of the package against what is ordered by the researcher and we also wipe the package and the contents to check for loose contamination. If contamination is present, we will decontaminate it before it is taken to your laboratory.



This is a US Dept. of Transportation label that can be found on some radioactive packages. This is a **Radioactive I** label and if you look closely, you will see that the label lists the contents and activity. One very important step after receiving a radioactive package with a DOT label on it is to deface or remove the label after the contents are removed. If the box ends up in the trash with the label on it, it could result in a situation where someone thinks it actually contains radioactive material and it becomes a headache for the University and the radiation safety office.

This label is different from the previous one. It is a **Radioactive II** label and notice that the upper part of the diamond is colored yellow. It also has a rectangular box in the bottom of the diamond that is called a **transport index** box. A number is placed in the box by the shipper. It represents the radiation exposure rate at one meter from the package. A more intense radiation source is found in a package with a radioactive II label on it.

This is a **Radioactive III** label. In a package with this label on it, the exposure rate at one meter from the package can be up to 10mR/hr and the surface reading can be 200 mR/hr. If you have a source of radiation that exceeds these limits, it can't be shipped in the US. Additional shielding must be used to get the exposure rate to within these limits. Of course, additional shielding will result in the cost of shipping to be much higher. All of these DOT labels are designed for the shippers of the radioactive packages. Employees of Federal Express and other shippers are trained to recognize these labels and take appropriate action in handling them. By the way, the US Postal Service and the United Parcel Service will not ship radioactive materials.

PERSONNEL DOSIMETRY

Employees working with radioactive materials may be issued personnel dosimeters. These dosimeters are to be worn when working with radioactive materials. Not everyone working with radioactive materials will be issued badges. If you are working with beta emitters of less than 200 kev, this type of radiation is too weak to penetrate the badge and is of no benefit to the wearer. This includes tritium, C-14, S-35 and Ca-45.

There are two types of badges issued to USC employees – a whole body badge and a ring badge. A whole body badge measures the dose to the head, neck, trunk, upper arms and upper legs. It should be worn where you think the greatest potential exposure will be to the body. That way when get a badge report back from our vendor, we will know that the dose was the worst possible dose that the user could have received. A ring badge is worn by employees who work with phosphorus-32. Phosphorus-32 has a high specific activity and since it is a beta emitter, it is not deeply penetrating. Therefore, it can impart a significant local dose to the hands and fingers. Once again, you would select a hand and a particular finger where you think the maximum dose would be.

Practices that you should follow when wearing radiation dosimeters:

- Always wear your badge in a restricted area. A restricted area is defined as a laboratory that has the "Caution – Radioactive Materials" sign on the outside of the lab door. This type of lab is considered a restricted area.
- Place the badge on your body nearest the radiation source.
- Do not take your badge home. You may forget it the next day and then you would not have the badge with you when you work with isotopes.
- Never intentionally expose your badges to radiation. The badges are issued to you and are designed to measure your dose while working in a University lab. Excessive doses on your badge could result in loss of permission to use radioactive materials.
- Do not wear your badge while you are being exposed to radiation for medical purposes. If you are interested in finding out how much dose you receive from a particular medical exam, ask the technologist. More than likely, the hospital is accredited by the JCHMO and one of the requirements of the certification is that patients must be told the approximate dose they will receive if the patient is interested in that information.
- Don't tamper with the badge packet. It contains filters that may be disrupted if you mess with them and result in an erroneous reading.
- Protect your badge from excessive heat and moisture. Washing machines are not good for radiation badges. And leaving your badge on the dashboard of your car in middle of summer in Columbia, SC can result in erroneous readings, as well.
- Notify Radiation Safety if you have any changes.

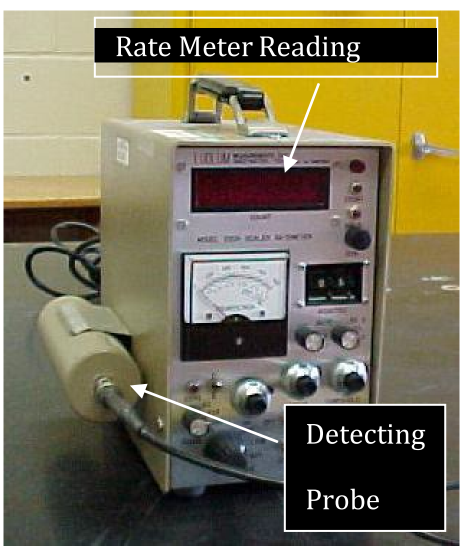
Notice that she is sitting at a table and she has the badge on her collar.

If she were standing up, she might wish to place the badge on her belt buckle.

This illustrates the proper location of the ring badge used when working with phosphorus-32. When wearing a ring badge, always place the badge under the latex glove. Placing it on the outside of the glove would result in the badge becoming contaminated. If this happens, then doses will be measured constantly – even when the badge is not being worn and large doses will be recorded.

WORKING WITH IODINE-

If you are working with free radioactive iodine – iodine in the form of sodium iodide – in levels of one milli-curie or more, you will need to monitor your thyroid for the presence of the isotope. If you receive iodine internally, it will accumulate in the thyroid gland. So, the gland could receive a significant dose from the uptake. If you are working with radioactive iodine that is already tagged to another molecule like you would get from an RIA kit, it is not necessary to monitor your thyroid. You would need to monitor your thyroid before you begin your work and between 6-48 hours after completion of your work.



Please call the radiation safety office to obtain a monitor such as the one pictured. Notice that is has a rather large rate meter and on the left side of the rate meter, the monitoring probe is attached.

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Demonstrating the proper monitoring procedures.

Notice that she has the probe held up to the lower part of the neck and she will monitor the thyroid for a period of five minutes. You will also take a five minute background count by either monitoring her leg or just holding up the monitor in the air. You will be required to keep a written record of the monitoring results. The results that are recorded are just simply the red numbers that appear on the monitor. If there is a significant difference (hundreds of counts) between the thyroid measurements and the background measurements, notify the radiation safety office immediately. You may have had an uptake of radioiodine.

DOSE TO EMBRYO/FETUS

We discussed the dose limits placed on radiation workers by the State regulations. There is also a limit that is placed on pregnant radiation workers and it is more restrictive than employees who are not pregnant. The dose limit is 0.5 rem or 500 mrem for the entire period of pregnancy which in humans of course is 9 months. The University has a pregnancy Policy. It is Radiation Safety Policy Number 11 which can be found in the radiation safety manual which is located with the records in your laboratory. The policy states that a pregnant employee does not have to tell us of her pregnant condition. It is voluntary. But if a pregnant employee wishes to declare her pregnancy, she can fill out a "**Declaration of Pregnancy**" form found at the end of Policy # 11. If the employee declares her pregnancy in writing, we will issue an additional abdominal dosimeter if she is working with an isotope that can be picked up with a dosimeter. We will also be available to answer any questions.

CONTROL OF RADIOACTIVE MATERIALS

- **Ordering:** If you wish to order radioactive materials, you must do so through the radiation safety office. You can't order directly from a vendor. We must place the orders to demonstrate to the SC Bureau of Radiological Health that we have complete control over the materials from the time that they are ordered until we dispose of the material as waste. You can place the orders by sending us an e-mail at: radsafe@mailbox.sc.edu. Please give us the following information: the company you wish to order from, the isotope, the quantity in millicuries or microcuries, the model number of the isotope and any special instructions that you wish to have included such as when you want to receive the materials.

- **Waste Handling:** Radioactive waste generated by your laboratory must be treated with caution. It cannot be placed in the regular laboratory trash. In order to better utilize our employee's time, radioactive waste will be picked up on the downtown campus every Tuesday. Waste from the Medical School campus will be picked up every Thursday. Now if you have some waste that is very radioactive and you do not feel comfortable having the waste in the lab, we will make special pick-ups in cases such as this.
- **Waste Pick-up Procedure:** If you wish to have the waste removed from your laboratory please send us an e-mail at the same address where you placed the orders for isotopes: radsafe@mailbox.sc.edu. Identify the type of waste such as solids, liquids or animal carcasses. List the radioactive materials in the waste stream as well as the approximate activity in millicuries or microcuries. We understand that it is difficult to approximate the amount of activity that has adhered to solid waste such as pipettes or paper waste but give us your best estimate. This is an important piece of information for us because when we dispose of the waste through our waste broker, we must list what isotopes are in the waste drum as well as the amount of radioactivity. If you need any additional supplies, please list that in your request, as well.
- **Solid Waste:** Solid radioactive waste must be placed in a covered trash container that is lined with a reasonably thick plastic bag. The waste container should have the "Caution – Radioactive Materials" sign on the outside of it. It is imperative that you not put any liquid waste in with the solid waste. These must be kept separate. We had an entire shipment of waste rejected at the disposal site once because there was some liquid in with the solid waste drum. If you have any waste that has sharp edges such as pipettes, needles, razors etc., they must not be placed in the bagged waste. Put them is a cardboard box. This will prevent our employee who is removing the waste from getting stuck by these items. We are charged for waste disposal by volume so we try to get as much waste into one drum as possible. We use an industrial waste to compact the waste after it is placed in each drum. These drums will be sent to a licensed waste facility and super compacted. This process smashes the drums into much smaller volumes called pucks and they are then placed in a cement vault and buried under ground.
- **Liquid Waste:** Use the plastic jugs or carboys supplied by our office. Please try to avoid the generation of mixed waste. Mixed waste is waste that contains radioactive materials as well as hazardous components that are listed under the Resource Conservation and Recovery Act (RCRA). The problem with this type of waste is that the facilities licensed to receive radioactive materials will not accept the RCRA waste. And the facilities that are licensed to accept RCRA waste will not have anything to do with radioactive waste.

There are one or two facilities that will accept mixed waste in this country and they charge an exorbitant amount of money for the disposal. Normally, we are not able to cover these types of charges in our budget and the researcher who generates the waste must bear the full cost of the disposal. When we review the researchers' protocols submitted to us when they applied for an authorization, we look for any type of waste product that might possible contain mixed waste. If we find some, we will contact the researcher and see if there are some non-hazardous chemicals that can be substituted in the protocols. Please keep the short lived isotopes separate from the long lived isotopes. Tritium and C-14 can be combined in a waste carboy but do not add things like phosphorus-32 or sulfur-35. We do store your liquid waste with short half lives in a designated room and hold them for a period of time to allow for radioactive decay to reduce the activity to a minimum before we dispose of them.

- **Scintillation Vial Waste:** If you generate scintillation vial waste, please give them to us in the cardboard trays (with the dividers) in which they were purchased. The vials can leak particularly if the caps are not tightened properly. If they are placed in plastic bags, the liquid can leak out of the bags and onto the floor of your lab. Also, please keep tritium and carbon-14 vials separate from other isotope vials. This allows us to take advantage of lower waste disposal charges.
- **Animal Carcasses**: We also store animal carcasses in this freezer until we get enough for disposal. If you are giving us radioactive animal carcass waste, please let us know how much activity is present in each animal and the weight of each animal. This is required by the vendor who disposes of the waste for us. Once you are done with the animal carcasses, please store them in your freezer until we can come to your laboratory and remove them.

REGULATORY MANDATES

The University has a license with the SC Bureau of Radiological Health, a division of DHEC, to possess radioactive materials and use them in research, teaching and in medical applications. We are required to follow the SC State regulations contained in **SC Radioactive Materials Regulation 61-63**. This regulation is also referred to as **Title A**. A copy of Title A can be found in each departmental central office. We are inspected periodically by DHEC. They will review all of our records and visit some of the labs where radioactive materials are used. So, you may see them in your lab some time. Please be kind and courteous to them.

In order to complete the requirements of the course, you must take an examination to demonstrate that you have successfully mastered the material. The exam will be offered at the radiation safety office which is located at 302 of Benson School. Just call 777-5269 and make an appointment. Someone is in our office from 7:30 in the morning to about 4:00 in the afternoon.

What to bring with you to the exam:

(1). Bring a pen or a pencil to use for the exam.

(2). Bring a calculator that has an exponential function key. This will be important in figuring out the decay correction problem that is on the exam. If you don't have a calculator, don't worry. We have one that we can lend you.

(3), bring your University ID card or driver's license with you. Obviously, we need to verify that the person taking the exam is actually the person who is in need of the training.

If you are not familiar with where Benson School is located, go to: www.sc.edu/uscmap/ and enter either Benson or building #159. Parking is available in the upper lot but your vehicle needs to be registered with Parking Services or you may be ticketed. Room 302 is located on the third floor. Enter the third level through the middle door of the building, turn to your right and go down the hall.

If you ever have a question concerning radiation, please feel free to contact our office at 777-5269. Good luck to you in your work at USC and please work safely.