RADIATION SAFETY TRAINING MANUAL

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VIRGINIA POLYTECHNIC INSTITUTE
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ENVIRONMENTAL, HEALTH AND SAFETY SERVICES
RADIATION SAFETY OFFICE

PREFACE

The Radiation Safety Training Manual has been developed by the Virginia Tech Radiation Safety Office and is supplemented with the Radioactive Material Safety Program (requirements for use of radioactive material) and three videos relating to contamination control, contamination detection and decontamination.

The training program is designed to explain the fundamentals of radiation, the safe use of radioactive materials, and the Federal, State, and University rules and regulations that control their use. The primary purpose of the training program is to limit unnecessary internal and external radiation exposures, by ensuring that each individual knows how to work safely with radioactive material. In order to document that each person has received this training, and understands the information, a written test must be passed after the training program has been completed.

If there is a question about any of the material in this manual, or for inquiries concerning the use of ionizing radiation, please contact the Radiation Safety Office at (540)231-5364.

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FUNDAMENTALS OF RADIOACTIVITY

THE ATOM

An atom is the smallest division of matter that still displays the chemical properties of an element. Atoms are composed of an extremely small, positively charged nucleus, which is surrounded by a cloud of negatively charged electrons. In neutral atoms the positive and negative charges are equal. Most nuclear effects involve only the nucleus, which is made up of protons and neutrons. The proton has a mass of 1.007897 atomic mass units (AMU) and a single positive unit of charge, while the neutron has a mass of 1.009268 AMU and has no charge. The electrons circle the nucleus in distinct orbits, called energy shells. These shells are labeled alphabetically, starting with the letter K, and going outward.

THE DECAY PROCESS

The simplest nucleus is that of hydrogen, which consists of a single proton. The second simplest nucleus belongs to another type of hydrogen called deuterium, consisting of a proton and neutron. Since the charge is what characterizes an element, nuclei with different numbers of neutrons in the nucleus, but the same number of protons, are called isotopes of that element. For example, there are three isotopes of hydrogen that have none, one, or two neutrons in the nucleus. The two lightest isotopes of hydrogen are stable, while the third is unstable. These means that the third isotope, called tritium, can spontaneously decay and change into another isotope. When this happens a negative electron, called a beta (β^-) particle is emitted and one of the two neutrons becomes a proton:

$$_1{}^3\mathrm{H} \rightarrow \beta + {}_2{}^3\mathrm{He}$$

so that an unstable isotope has decayed into a stable one, an isotope of helium. The beta particle is similar to ordinary electrons, except that it has kinetic energy to ensure conservation of energy.

Stable isotopes with light nuclei tend to have equal numbers of neutrons and protons. As the number of neutrons and protons increase, the stable isotopes begin to have more neutrons than protons. This is because the protons are confined in a very small space and strongly repel each other due to their like charges. Since neutrons have no charge, more of them can be close together. However, nuclear forces prevent too many from being in a stable nucleus. The largest stable nucleus that has equal numbers of protons and neutrons is an isotope of calcium with 20 of each.

There can be both stable and unstable isotopes for a given element. Tin has the most stable isotopes, 10, while there are no completely stable isotopes for elements with atomic numbers greater than 83. Unstable isotopes decay until the decay product is stable. This may take more than one step. For example, in a chain decay one unstable isotope will decay to another unstable one, which will then decay to a stable one. There are many different ways in which an unstable isotope decays. The following list depicts the primary decay modes for the radioisotopes used at the University.

- ALPHA DECAY - this occurs when an isotope emits an alpha particle (α). An alpha particle is a helium nucleus made up of 2 protons and 2 neutrons, so that it has a mass of approximately 4

AMU and a positive charge of 2 units. Many heavy isotopes decay by this means. Alphas are emitted with discrete energies (monoenergetic), and typically have energies of 4 to 9 million electron volts (MeV). An example of an alpha emitter is ^{241}Am.

- BETA DECAY - this happens when a nucleus emits a particle similar to an electron (β). This particle has a unit charge which may be negative or positive. In the latter case they are called positrons. They are very light, with a mass of approximately 1/1837 AMU. Their maximum energies range from 0.015 to 3 MeV. They are not monoenergetic, but are emitted with an energy which can vary up to a maximum value for a given isotope. Beta emitters include ^{3}H, ^{14}C, ^{32}P, ^{32}P, ^{35}S, ^{36}Cl, and ^{45}Ca.

- GAMMA DECAY - these isotopes decay by emitting electromagnetic radiation called gamma rays (γ) which are like radio, TV, or visible light, but are of very short wave length. They have no mass or charge. Their energies are monoenergetic and range from a few thousand electron volts (keV), up to approximately 3 MeV. Isotopes that decay by this process include ^{51}Cr, ^{57}Co, ^{60}Co, ^{109}Cd, ^{125}I, and ^{131}I.

- ELECTRON CAPTURE - sometimes isotopes decay by capturing an electron from the orbital cloud around the nucleus. In such a case x-rays are emitted with energies comparable to low energy gamma rays. ^{125}I can decay in this way.

Some isotopes can decay by more than one process, such as ^{125}I listed above, which can decay by gamma emission and electron capture. Other examples are ^{134}Cs and ^{137}Cs, both of which emit betas and gammas. The types of decay listed above are the ones of primary concern for the isotopes in use at the University. Another source of radiation associated with the emission of the betas is called **bremsstrahlung** or braking radiation. When a beta particle passes close to a nucleus, the strong attractive forces cause it to deviate sharply from its original path. This deviation requires considerable kinetic energy loss. Since energy must be conserved x-rays are emitted. The intensity of the bremsstrahlung depends on the energy of the emitted particle and the atomic number of the material it is passing through. A lead container would be a much stronger source of bremsstrahlung than an aluminum one, due to its much greater density.

RADIOACTIVE BEHAVIOR

A radioisotope decays spontaneously. There is no way to speed up or delay the decay of a given atom. The radioactive decay process is purely statistical. The likelihood of a given atom decaying at any time can be determined by the use of a statistical constant. If an atom is very unstable and likely to decay quickly, this constant is large. If it decays slowly the constant is small. This does not mean that all unstable isotopes of a given element will decay at a given instant, the constant simply states the probability of a given atom of that element decaying in a unit of time.

The total number of atoms decaying at a specific time for a specific isotope depends on the decay constant and the number of atoms present. This can be expressed mathematically as:

$$A = \lambda N$$

where: A = activity
λ = decay constant
N = number of atoms present

This equation is not very useful, since the number of atoms there are at any given moment is rarely known. However, there are instruments which are calibrated to determine activity. As time passes the activity decreases as the atoms decay. The amount of activity present at any time can be calculated from the amount that was initially present using the following equation:

$$A_t = A_o e^{-\lambda t}$$

where: A_t = activity after a period of elapsed time
A_o = original activity
e = base of the natural log, 2.718
λ = decay constant
t = time elapsed
- sign indicates that the number of atoms is decreasing

The decay constant (λ), represents the fraction of the atoms that decay per unit of time, with the actual value being 0.693/half-life of the isotope. The half-life is the time required for the initial activity to decrease one half. Since activity is directly related to the number of atoms present, the following table illustrates the decay process of 1000 radioactive atoms:

TIME (units of half-life)	number of radioactive atoms
0	1000
1	500
2	250
3	125
4	62.5

According to the table, after four half-lives there are 62.5 radioactive atoms remaining. This is an impossibility, but it shows the statistical nature of radioactive decay. There might actually have been 503 atoms left after one half-life, 245 after two, 126 after three, 64 after four, and so on until no radioactive atoms are left.

The previously mentioned chain decay, where the daughter product is unstable, is rarely encountered at the University. In these cases the single decay equation is not correct for the second unstable isotope. The equation for a two member chain decay is not required knowledge for this course, but it is shown to help illustrate the effects of a chain decay.

$$A_2(t) = A_1(o)[e^{-\lambda 1t}/(\lambda_2-\lambda_1) + e^{-\lambda 2t}/(\lambda_1-\lambda_2)]$$

The subscript 1 refers to the first unstable atom and subscript 2 to the second. If the parent half-life is shorter than the daughters', the activity A_2 will increase for a time, until there are more type 2

atoms decaying than are being replaced by decaying type 1 atoms. When the half-life of the first member of the chain is longer than the second, eventually both isotopes will reach equilibrium and decay at the same rate.

An example of the longer parent half-life is the medical use of an isotope of technetium. It has a mass of 99 AMU with a half-life of 6 hours. It is formed by the decay of a molybdenum isotope of the same mass, with a half-life of 66 hours. The favorable relationship of the half-lives makes it possible for the parent to be made in a reactor and shipped over substantial distances with low decay losses. Once at the hospital the short lived daughter can be chemically separated, administered to the patient, and then allowed to decay away in a short period of time. From a radiation protection standpoint, it is very desirable to have the isotopes decay and become stable after they have served their purpose. Short-lived isotopes should be used whenever possible.

A common rule of thumb is: after 10 half-lives have elapsed, all activity is effectively gone. This is based on the fact that the activity decreases by a factor of 2 as each half-life passes. After 10 half-lives have elapsed the activity has been diminished by a factor of 1024, or to less than 0.1%. However, if there was originally a large amount of activity, there may still be considerable activity remaining even after 10 half-lives. For example, if there were originally 1 Curie of an isotope there would still be approximately 1 mCi remaining after 10 half-lives.

UNITS OF ACTIVITY

In order to describe a specific amount of activity, a unit called the Curie is used. The Curie is defined as 3.7×10^{10} disintegrations per second (dps). It refers to a fairly large amount of activity. In most cases the amounts of activity used in an experiment would be in the range of a few microcuries to a few millicuries. Below are some of the derivative units based on the Curie:

UNIT	SYMBOL	DISINTEGRATIONS PER SECOND	DISINTEGRATIONS PER MINUTE
Curie	Ci	3.7×10^{10}	2.22×10^{12}
MilliCurie	mCi	3.7×10^{7}	2.22×10^{9}
MicroCurie	µCi	3.7×10^{4}	2.22×10^{6}
NanoCurie	nCi	3.7×10^{1}	2.22×10^{3}
PicoCurie	pCi	3.7×10^{-2}	2.22

Another unit of activity is the Becquerel which is used in most countries outside of the United States. This unit will not normally be used at this University, but a basic understanding is important because the Becquerel is often the only unit used in research publications. The following table depicts convenient multiples of the Becquerel:

UNIT	SYMBOL	DISINTEGRATIONS PER SECOND	DISINTEGRATIONS PER MINUTE
Becquerel	Bq	1.0	6.0×10^{1}
Kilo Becquerel	kBq	1.0×10^{3}	6.0×10^{4}
Mega Becquerel	MBq	1.0×10^{6}	6.0×10^{7}
Giga Becquerel	GBq	1.0×10^{9}	6.0×10^{10}
Tera Becquerel	TBq	1.0×10^{12}	6.0×10^{13}

Specific activity (SpA) is an important concept in experimental design and is defined as the concentration of activity. SpA is expressed in units of Ci/g, mCi/ml, mCi/mm, etc. For example, for 1 mCi of ^{125}I with a SpA of 10 mCi/ml then the total volume would be 0.1 ml.

UNITS OF DOSE

Units of activity are intensity units. An activity of a radioisotope in millicuries or microcuries does not translate easily into exposure effects to the worker. A standard unit of exposure is the roentgen (R). **A roentgen is defined as the amount of x or γ radiation which will cause ionization of one electrostatic unit of charge in one cubic centimeter of dry air at standard temperature and pressure.**

The roentgen defines a radiation field, but it does not provide a measure of absorbed dose in ordinary matter or tissue. To take absorption properties of the exposed material into account, a dose unit called the rad (rad) is used. **The rad is defined as an amount of absorbed radiation dose of 100 ergs per gram of matter.**

A method to remember the concept of a rad is, **R**adiation **A**bsorbed **D**ose. The rad is not greatly different from a roentgen. An exposure of one roentgen would yield an absorbed dose of 87.6 ergs/gm of air or 95 ergs/gm of tissue.

In terms of human exposure another factor must be taken into account. Exposures to equal activities of different types of radiation do not cause equal amounts of damage to humans. In order to take these varying effects into account, a unit called the rem (rem) is used. **The rem stands for Radiation Equivalent Man, and the dose in rems is equal to the dose in rads times the quality factor.**

The quality factor takes into account the varying effects when assessing doses to tissue. Quality factors for different types of radiation are given below.

QUALITY FACTOR

TYPE OF RADIATION	QUALITY FACTOR
Alphas	20
Betas	1
Gammas	1
X-rays	1
Thermal neutrons	3
Fast neutrons	10
Fission fragments	20

NUCLEAR REACTIONS

Many radioisotopes commonly used in research are artificially produced by nuclear reactions. One of the most common reactions is to cause a neutron to interact with a natural element. This is shown symbolically as:

$$n + X \rightarrow (Y)^{**} \rightarrow Y^{*} + a$$

where:	n	=	incident neutron
	X	=	atomic nucleus of target element
	Y**	=	compound nucleus
	Y*	=	reaction product in excited state
	a	=	secondary particle

At the time of the formation of a compound nucleus, several prompt gamma rays are usually emitted. This compound nucleus is very short-lived and only present for a fraction of a second. The asterisk (*) on the product nucleus Y* indicates that it is left in an excited state and will decay by emitting alpha, beta and/or gamma radiation. An example is given below with the compound nucleus stage omitted.

$$n + {}^{31}P \rightarrow {}^{32}P^{*} + \gamma$$

The unstable $^{32}P^{*}$ decays with a 14.28 day half-life to the stable isotope ^{32}S by emitting a 1.710 MeV beta. An example of a different reaction is:

$$n + {}^{14}N \rightarrow {}^{14}C^{*\prime} + \rho$$

The ^{14}C decays with a 5730 year half-life to stable ^{14}N when a 0.156 MeV beta is emitted. Another type of neutron induced reaction is the fission reaction, shown below when thermal neutrons are captured by ^{235}U.

$$n_{th} + {}^{235}U \rightarrow X^{*} + Y^{*} + \textit{neutrons}$$

X and Y are the fission products with mass numbers of approximately 90 and 140.

Some commonly used radioisotopes can be obtained by reprocessing used nuclear fuel and separating the useful fission fragments (e.g. ^{90}Sr, ^{131}I and ^{137}Cs).

Not all artificially generated radioisotopes are created by neutron irradiation. An example of a radioisotope produced by a charged particle reaction is ^{22}Na, which is produced in a cyclotron.

$$\rho + {}^{25}Mg \rightarrow {}^{22}Na^{*} + \alpha$$

The ^{22}Na decays with a 2.6 year half-life to ^{22}Ne by emitting a 0.545 MeV β^+ and a 1.275 MeV gamma. Annihilation radiation (0.511 MeV gammas) is associated with ^{22}Na decay as well due to the positrons emitted.

INTERACTIONS OF RADIATION WITH MATTER

The two different kinds of radiation are particulate (alphas, betas and neutrons) and electromagnetic radiation (gamma rays, x-rays and bremsstrahlung). Each type of radiation interacts with matter in a unique way.

Charged particles have an electric field, similar to the orbital electrons of an atom. As a charged particle passes an atom the influence of its electric field can either remove an electron from the atom or raise an electron to an excited orbital state. The first process creates an ion pair while the second leaves the atom intact. Both types require energy which is derived from the kinetic energy of the incident particle. The kinetic energy of the particle is reduced by the amount of energy transferred during the interaction. These interactions continue until the particle loses all of its energy.

ALPHAS

An alpha particle is a relatively large subatomic particle (4 AMU) that has a charge of +2. This causes the ionization per unit length (linear energy transfer) to be high and the range of the particle to be very short. An alpha loses about 35 electron volts (eV) for each ion pair it creates in air or soft tissue. A typical alpha creates more than 100,000 ion pairs before all of its energy is lost. The alpha particle loses most of its energy near the end of its path. Because these particles are monoenergetic, they have well defined ranges in matter. To illustrate its penetrability, a 4 MeV alpha has a range of approximately 2.3 cm in air and 0.003 cm in tissue. This is much less than the thickness of human skin which is approximately 0.1 cm. The greatest hazard posed by alpha radiation is from ingestion or inhalation, which allows the radionuclide to be deposited in tissue.

BETAS

Since beta particles are also charged particles they interact with matter in basically the same way as alpha particles. Due primarily to the much smaller mass of the beta (1/1837 AMU), there are some differences. For a given energy, their speeds are much greater which causes them to spend less time in the vicinity of an atom. This results in fewer interactions per unit distance. Since they have the same mass as the orbital electrons, a larger portion of their energy can be given up to a target electron. Consequently, they can be scattered through relatively large angles so that their paths are not as well defined. They can also lose energy by bremsstrahlung as their paths are bent by the electric fields of the nucleus and orbital electrons.

The absorption of betas also differs from alpha particles because they are not monoenergetic. Betas are emitted with energies ranging between 0 and a maximum value. The average energy is usually about 1/3 of the maximum energy. The beta energies vary because a neutrino is emitted along with the beta and the maximum energy is shared between them. Since interaction between the uncharged neutrino and matter is so slight, it does not transmit appreciable energy to any material it passes through.

Although a beta will penetrate much more deeply in matter than an alpha, the range is still not great. For example, the 1.71 MeV beta of ^{32}P has a range of about 0.8 cm in tissue (1/3 inch). In

air the ^{32}P beta has a much greater range of 610 cm (20 feet). The advantage of using low energy beta emitters can be illustrated by comparing ^{14}C and ^{32}P. The ^{14}C 0.156 MeV beta has a range in tissue of 0.04 cm (1/25 inch) and a range in air of 31 cm (1 foot). Shielding is not necessary for ^{14}C while considerable shielding is necessary for ^{32}P.

Bremsstrahlung is another energy loss mechanism for betas in which the beta energy is converted into X-rays. This occurs when the attractive forces from an atom cause the beta to rapidly decelerate and change its path. The quantity of bremsstrahlung increases as the shield density increases. The X-ray energies are determined by the incident beta energy, but their average energy is 1/3 of the maximum beta energy. The use of low atomic number shields (e.g. plastic) minimizes the production of bremsstrahlung.

Some isotopes decay by emitting positrons (positive charged betas, β^+). These particles have a very short lifetime because they rapidly combine with electrons in an annihilation process. This process creates two 0.511 MeV gammas.

In summary, betas are more penetrating than alphas, however the most serious hazards are posed by ingestion or inhalation.

NEUTRONS

Since neutrons are not charged, they interact differently with matter than charged particles. They may either be scattered or absorbed by the nucleus of the target atoms. Fast neutrons can disrupt chemical bonds in scattering due to their mass. Enough recoil energy can be transmitted to the target nucleus to break the bonds. When neutrons are absorbed in a nuclear reaction, prompt gammas are emitted and charged particles may be emitted. Additionally the element may be changed when the residual nucleus decays by either alpha or beta decay along with gammas in some instances. Since all of these processes can be highly disruptive to the chemical bonds of the material, neutrons can cause severe radiation damage.

GAMMAS AND X-RAYS

Gammas and x-rays are electromagnetic radiation which is not electrically charged. These photons interact with matter differently from particles. Gammas and x-rays are identical in nature, but are different in origin. Gammas are produced in processes that involve the nucleus of an atom, while x-rays are produced by interactions that take place outside of the nucleus. X-rays are emitted with discrete energies or with a broad spectrum of energies, while gammas are always released with discrete energies. There are three processes by which these photons interact with matter: the photoelectric effect, Compton scattering, and pair production.

In the photoelectric effect a gamma ray interacts with an orbital electron and transfers essentially all of its energy to it. The reaction involves the entire atom and usually affects the most tightly bound orbital electrons. After the interaction the gamma ray no longer exists and the electron is ejected from the atom to interact with the material as a beta particle.

In Compton scattering a gamma ray interacts with a free or very loosely bound electron. The gamma ray cannot give up all of its energy to the electron. This causes the electron to be scattered in one direction, while a lower energy gamma is scattered in another direction. The electron (β^-) and gamma will then continue to interact with matter. The energy of the scattered beta is the difference between the energies of the original and scattered gammas.

In pair production the energy of the incident gamma is sufficient to create one negative and one positive beta. The gamma must have an energy of at least 1.022 MeV. When this process occurs, the original gamma disappears with its kinetic energy shared between the electron and positron. These particles will interact as betas.

In all of the mechanisms by which a gamma ray interacts with matter, the original gamma disappears, but no energy loss occurs until the reaction takes place. This is their primary distinction from particles. Gammas have no finite range in matter. They diminish in number as they penetrate material, but theoretically some will exist at any depth. An example using the 0.661 MeV gamma emitted by ^{137}Cs will illustrate the penetrability of gammas. The thickness of several materials to reduce the number of gammas transmitted by a factor of ten (tenth value) would be: 2 cm (0.8 inches) of lead, 6.6 cm (2.6 inches) of iron, or 24 cm (9.5 inches) of concrete. Additional tenth values can be used to further reduce the number of gammas transmitted through matter. This example also shows that high density materials shield gamma emitters better than low density materials.

RADIATION DETECTION INSTRUMENTATION

There are many devices available to detect radiation, several of which are used in laboratories where either isotopes or x-ray producing equipment is used. They are used for personnel monitoring or area and equipment monitoring.

Personnel monitoring devices integrate radiation exposure over a period of time, providing a record of that exposure. Four commonly used devices are: the pocket dosimeter, the film badge, the thermoluminescent dosimeter (TLD) and the optically stimulated luminescent dosimeter (OSLD). The first of these is usually employed to provide monitoring over a few hours or a day, while the other three are used for longer periods such as a month or quarter.

POCKET DOSIMETERS

The pocket dosimeters used at the University are direct reading. This pencil shaped device has a fine gold coated quartz fiber that is charged to a potential of about 200 volts. The fiber is repelled from a similarly charged electrode. The unit is discharged by ion pairs created by radiation interacting with the gas between the fiber and the electrode. The fiber is viewed by the user through a lens. Superimposed in the field of view is a scale calibrated so that the change in location of the fiber corresponds to a given exposure. A typical pocket dosimeter detects gammas and X-rays with an energy of .060 - 2 MeV, and a dose range of 0-200 milliroengten (mR).

FILM BADGES

Film badges rely on the sensitizing of the silver halide in photographic film caused by ionizations from incident radiation. The film will detect both betas and gammas. Neutrons can be detected when a special film emulsion is used. The film is not energy dependent except for gamma radiation from about 0.04-0.2 MeV. Below about 0.04 MeV the cover on the film affects the sensitivity. Selective filtration of various parts of the film provides information about the type of radiation. A badge will normally have an open window, and areas with one or more filters of materials such as aluminum, copper, silver, and lead. Beta doses can be read from the open window area, and x-rays or different energy gammas can be distinguished by looking at the relative darkening under the different filters. The energy dependence of the film must be taken into account when film badges are used to monitor for x-rays. An advantage of these badges is that the film darkening can be reread if an error in reading is suspected. The film badges at the University are used to detect and differentiate between primary and scattered x-rays, and are changed on a monthly basis. These badges are used to determine whole body, lens and skin doses.

THERMOLUMINESCENT DOSIMETERS

The thermoluminescent dosimeters (TLDs) in use at the University have lithium fluoride (LiF) crystals. The TLD crystals can be used in the form of powder, as small chips, or impregnated in plastic. The incident radiation creates excited states in the crystals which trap electrons. This energy is released in the form of light by heating the chip in a carefully controlled heating cycle.

The amount of light released is proportional to the integrated radiation exposure. The chips are used in badges, similar to those for film, with filters to characterize the radiation.

A TLD can be used many times to provide accurate and reliable radiation readings. Unlike film, the process of reading destroys the information, so a badge can only be read once. There are two types of TLD badges in use at the University. The first is called a body badge which is used to determine whole body, lens and skin doses. The second is called a ring badge and is used for extremities, specifically the hands. These badges are changed on either a monthly or quarterly basis. They are sent to an outside company for processing to determine personnel doses.

OPTICALLY STIMULATED LUMINESCENT DOSIMETERS

The optically stimulated luminescent dosimeters (OSLDs) in use at the University have aluminum oxide (Al_2O_3) crystalline material. Strips impregnated with Al_2O_3 are stimulated with selected frequencies of laser light causing them to luminesce in proportion to the amount of radiation exposure and the intensity of stimulation light. The strips are used in badges, similar to those for TLDs, with filters to characterize the radiation. These dosimeters can be reanalyzed numerous times to confirm the accuracy of the measurement. Most of the body badges at Virginia Tech are OSLDs. The badges are changed on either a monthly or quarterly basis and are sent to an outside company for processing to determine personnel doses.

SURVEY INSTRUMENTS - THEORY OF OPERATION

Most commonly used area survey instruments are based on the collection of ion pairs in a gas filled enclosure. Many designs use a cylinder that has a very fine central wire as the positive electrode (anode) and the wall of the cylinder as the negative electrode (cathode). The negative ions (electrons) are collected by the anode while the positive ions are collected by the cathode. A complete detector system must have an external circuit, including a high voltage supply and a high valued resistor.

At very low voltages some of the ions may recombine before they are collected by the electrodes. This area is called the recombination region. As the voltage is increased, a point will be reached when recombination becomes negligible and all of the ions created by the incident radiation are collected. This is known as the saturation region.

If the voltage continues to be raised, another increase in the number of ions collected is observed. This occurs when the light and easily accelerated electrons gain enough energy to interact with the gas near the anode, and cause secondary ionizations. This process is called an avalanche which results in the collection of more ions per event than were originally created by the incident radiation. The increase is dependent on the voltage, due to the avalanche spreading along the anode with increasing voltage.

The voltage will reach a point where the avalanche has spread along the entire anode, and enough positive ions have been created to reduce the electric field below the point at which multiplication can take place. All radiation events, regardless of energy, will then result in the same number of

ions being collected. This is the Geiger-Mueller (GM) region. Most survey instruments operate in this region. If the voltage is increased further a continuous discharge between the electrodes can occur, independent of the presence of incident radiation, and the detector can be damaged.

Time is required to collect the charge and for the interelectrode potential to return to normal through the external circuit. The anode potential decreases as the charges are collected and begin to return to normal as the external battery supplies current through the external circuit. The result is a negative pulse appearing at the output for each event. If the detector is operated in the GM region, the charge collection time is appreciable and the counter is insensitive during this collection interval. Until enough positive ions are collected to permit additional avalanches to occur the detector is dead. For another period of time, smaller pulses than normal result from an interaction. The time required for the detector to be able to distinguish two separate events is called the resolving time or dead time. A typical GM counter will have a dead time of 100 microseconds or more. The fill gas is often a mixture of argon with a quenching gas of either a halogen or a hydrocarbon. The quenching gas eliminates secondary avalanches. The hydrocarbons are permanently destroyed, while the halogen molecules can recombine and remain useful.

A typical GM counter can be employed to count either betas or gammas. The betas enter the gas through a fragile thin window, typically located at the end of the cylinder. The window is as thin as 1.5 mg/cm^2. The counter would be able to detect betas with energies as low as 0.030 MeV and would even be useful for counting alphas. If the window is covered by a shield to prevent charged particles from entering, the response of the counter can be limited to gammas. This permits characterization of the radiation field.

The long resolving time of the GM counter is a serious limitation, since it results in many events not being detected. At high levels of radiation, a GM counter might even indicate zero. Typically, GM counters are used to measure dose rates of 200 mR/hr or less.

Higher dose rates can be measured by operating a counter in the ionization region, using a very high resistance, and measuring the voltage developed across this resistor with an electrometer. Dose rates of up to 10,000 R/hr can be measured with a counter operated in this manner. However, ionization counters are sensitive to humidity and temperature due to leakage through circuit components other than the resistor.

Betas from ^3H cannot be adequately monitored by any gas filled devices because of their very low energies. However, an alternate method is to wipe the area or equipment with a piece of filter paper and analyze it in a liquid scintillation counter.

Liquid scintillation counters make use of the fluorescent properties of certain materials when exposed to radiation. Material from the swipes is either dissolved or suspended in a solution, and almost all of the emitted radiation passes through some portion of the scintillator. Therefore, counting efficiencies can approach 100%.

The light from the detection of a single event is very weak. In order to obtain a useful signal, the light is allowed to fall upon a photomultiplier tube which incorporates a light sensitive surface that emits electrons. The initial electrons are accelerated through a potential of approximately 100 to

200 volts and are collected at an anode. At the anode each electron causes several more electrons to be emitted so that the number of electrons is multiplied. This process is repeated by placing several anodes in series with each at a successively higher voltage. Amplification factors of a million or more are achieved. The resulting electrical pulse can be further amplified and counted.

Although liquid scintillators do not offer good energy resolution, they do have a light output related to the energy of the betas. Pulses of specific energies can be selected so that a liquid scintillation system can differentiate betas of different energies.

Generally, gammas are not detected well by a liquid scintillation counter. A gamma counter can be used to detect activity on swipes with high efficiencies. This system is similar to the liquid scintillation counter except solid scintillators (NaI) are connected to the photomultiplier tubes. Liquid or dry samples can be put into the gamma counter.

SURVEY INSTRUMENTS - PRACTICAL

The least expensive and simplest type of survey instrument is a Geiger counter. This type of instrument uses a gas filled detector which operates in the GM region. The detector is used with the following configurations: a side window, a thin end window or a pancake type probe with a thin window. The side window detector has a relatively thick window which the radiation must penetrate. Typically, betas of less than 200 keV would not be energetic enough to be detected, and no alphas would penetrate the window. This detector would not be satisfactory for ^{3}H, ^{14}C or ^{35}S, since their beta energies do not exceed 200 keV. The 1.71 MeV betas of ^{32}P could be detected but better probe designs are normally used. This type of detector is effective for gammas with energies greater than 50 keV. Betas and gammas can be differentiated by sliding a built-in metal shield over the window to completely block out the betas.

The next detector type has a thin end window. The window on this tube permits betas with energies as low as 40 keV to be detected, still not adequate to allow ^{3}H to be detected. This detector type can be used to detect the betas from ^{14}C, ^{35}S and ^{32}P with efficiencies ranging from 5% (^{14}C) to 10% (^{32}P). Alphas with energies greater than 4 MeV are detectable. Some beta/gamma discrimination can be achieved by covering the window with a shield which only gammas can penetrate.

The last type of GM detector has a large pancake shaped probe. This probe will detect alphas, betas and gammas similar to the thin end window detector. The pancake probe has a greater sensitivity than the end window type because the probe's active surface area is about 2 times larger than the end window achieving efficiencies ranging from 10% (^{14}C) to 25% (^{32}P).

IONIZATION CHAMBERS

Another type of instrument uses an ionization chamber detector. It has a detector constructed similar to a GM detector except a typical ion chamber is air filled and vented to the atmosphere. Another difference is that it operates in a current mode rather than in a pulse counting mode. The current (flow of electrons) going through the meter is a direct measure of the total number of ion pairs created by the incident radiation. Since one ion pair is produced per ionization event, the

instrument is relatively ineffective for measuring rates less than 1 mR/hr. For this reason ion chambers are primarily used in areas of high radiation intensity. Because the chamber is vented to the atmosphere, position and temperature changes can affect the radiation measurement. The large front window allows for the detection of betas with energies of at least 300 keV. A removable shield allows the instrument to differentiate between betas and gammas. Typically, gamma and X-ray energies over 50 keV are detectable.

SCINTILLATION DETECTORS

Scintillation detectors use a crystal that scintillates or releases light when exposed to x-rays or gamma rays. The crystal is coupled to a photomultiplier tube (PMT) that converts the light flashes to amplified electrical pulses. The number of pulses is directly proportional to the intensity, and the size of the pulse is directly proportional to the energy of the incident radiation.

Since scintillation crystals are solid, rather than gaseous, their higher density makes scintillation detectors very efficient and sensitive instruments for the measurement of x-rays and gamma rays. Portable scintillation detectors are more sensitive than Geiger counters because of their increased efficiency. Two of the types of scintillation detectors are: a thin crystal and a thick crystal. They are used primarily to detect gamma radiation. The thin crystal can detect gamma and x-rays with an energy range of approximately 10-60 keV, while the thick crystal has a range from about 50 keV to 1 MeV.

NONPORTABLE INSTRUMENTS

The use of portable survey instruments is normally coupled with contamination surveys analyzed by more sensitive instrumentation. The two types of nonportable equipment used are: a liquid scintillation counter and a gamma counter. They are used to analyze filter paper that has been wiped on surfaces or equipment to determine if removable contamination is present. Liquid scintillation cocktail is added to each sample vial to allow for appropriate analysis.

The liquid scintillation counter is primarily used for detection of beta contamination. Detection efficiencies range from approximately 50% (for ^{3}H) to almost 100% (^{32}P). The instrument can also detect alpha (up to 100% efficiency) or gamma (approximately 20% efficiency) contamination.

The gamma counter is used for detection of gammas. This instrument has a higher detection efficiency (up to 75%) than a liquid scintillation counter. The principal advantage to this instrument is that virtually no sample preparation is necessary. This instrument will count assay tubes and requires no cocktails.

RADIATION MONITORING TECHNIQUES

Two types of instruments are commonly used for monitoring contamination of personnel, equipment or areas. Portable survey instruments provide direct measurement capabilities. Fixed instruments such as liquid scintillation counters provide an indirect means to determine contamination by analyzing paper wipes of test areas. While portable instruments allow for faster and more thorough assessment, the fixed instruments allow for greater sensitivity.

Before each use of a portable instrument, several quality checks must be made. The calibration sticker must be checked to ensure that the instrument is not due for recalibration. The batteries must be checked to ensure the instrument will be powered properly. Finally, the instrument response must be tested with a check source. The survey instrument would now be ready for use.

Most instruments have a response time selector. This will vary the response from slow (10-15 seconds to reach 70% of true readings) to fast (1-3 seconds). The fast response times will greatly reduce the survey time. After the proper response time is selected, turn on the instrument to its most sensitive scale (e.g. x1 or x0.1) and determine the background readings for that scale. Once the background is determined, the monitoring must be performed slowly at a rate of approximately 1 – 3 inches per second and very close to the surface without touching. If the probe has a window, this must be directed at the surface being monitored. However, small or pointed objects can puncture the thin windows if care is not exercised. If a reading above background is indicated, the probe movement should be stopped to determine the extent over background. Since the clean limit is 220 DPM, the actual value can be calculated as in the following example:

Gross CPM - Background CPM = Net CPM
Net CPM times the Efficiency (a multiplier specific to the isotope and instrument used) = DPM

500 CPM – 200 CPM = 300 CPM; 300 CPM x 10 = 3000 DPM

The exact determination of DPM values is not usually required for portable survey instrument use. Consider a CPM measurement that is at least twice the background to be contaminated and to require decontamination.

The other method of monitoring requires that paper wipes are analyzed in a fixed instrument such as a liquid scintillation counter (LSC). A piece of dry filter paper is rubbed on the area to be tested with moderate pressure. An area of 100 cm^2 (a little larger than the size of your palm) should be tested. An effective swipe test is done by randomly wiping the test area instead of wiping a small square area. To analyze the filter paper, it must be: placed in a LS vial, have LS fluid added, and be counted by the LSC. The results are calculated in the same manner as with the portable instrument except counting efficiencies are usually much better.

BIOLOGICAL EFFECTS OF RADIATION

Exposure of the human body to ionizing radiation can result in harmful biological effects. The nature and severity of the effects depends on the dose of radiation absorbed and the rate at which it is received. The biological effects of ionizing radiation are generally grouped into three categories: somatic, genetic, and teratogenic effects.

SOMATIC EFFECTS

ACUTE SOMATIC EFFECTS: Observable changes in the exposed individual are called somatic effects and can be classified as either short or long term. Short term effects occur after exposure to large doses of radiation in a short period of time, usually greater than 100 Rem to the whole body in a few hours. However, transient somatic effects can be observed for exposures as low as 25 Rem.

The sequence of events that follow exposure to high levels of radiation is termed the "acute radiation syndrome". Symptoms can become apparent within a few hours or days depending on the dose received. The first stage of the acute radiation syndrome is usually characterized by nausea, vomiting and diarrhea. Following this initial period of sickness the symptoms may subside and the individual may feel well. This stage can last from hours to weeks and while no symptoms are present, changes are occurring in the internal organs. Severe illness, which may lead to death, follows this asymptomatic period. Depending on the dose initially received, hematological, gastrointestinal and/or neuromuscular symptoms will appear. Hematological symptoms can include fatigue, progressive anemia, and the inability to resist infection. Gastrointestinal and neuromuscular symptoms include vomiting, severe diarrhea, dehydration, disorientation, respiratory and cardiovascular collapse. The radiation dose to the whole body at which 50% of those exposed will die within 30 days, if untreated, is approximately 400-500 Rem.

Another effect which results after an acute over-exposure to the skin of greater than 100 Rem is erythema or reddening of the skin. Because the skin is on the surface of the body it can absorb greater doses of radiation than other tissues. This is especially true for low energy X-rays. Large exposures may lead to other changes in the skin such as pigmentation changes, blistering, and ulceration.

CHRONIC SOMATIC EFFECTS: Personnel can be exposed to small doses of radiation over long periods of time resulting in delayed effects that may become apparent years after the initial exposure. Delayed effects may include life span shortening, premature aging, and chronic fatigue. However, the principal somatic delayed effect from chronic exposure to radiation is an increased incidence of cancer. Radiation is a well known carcinogenic agent in animals and humans and has been implicated as capable of inducing all types of human cancers. Those types of cancer with the strongest association with radiation exposure include leukemia, cancer of the lung, bone, female breast, liver, skin, and thyroid gland.

It is not known how radiation induces cancer. However, several theories have been proposed to explain the carcinogenic properties of radiation. Cancer is characterized by an over-proliferation of cells in any tissue. According to one theory, radiation damages the chromosomes in the nucleus of

a cell resulting in the abnormal replication of that cell. Another theory postulates that radiation decreases the overall resistance of the body and allows existing viruses to multiply and damage cells. A third theory suggests that as a result of irradiation of water molecules in the cell, highly reactive and damaging agents called "free radicals" are produced which may play a part in cancer formation.

Evidence that ionizing radiation can induce cancer in humans has been demonstrated among radiation workers exposed to high doses of radiation, children exposed *in-utero* to diagnostic X-rays, patients receiving therapeutic X-rays and internal radiation exposure, individuals exposed to fallout, and the Japanese A-bomb survivors. Some of these are summarized below:

- Increased incidences of cancer have been noted among several groups of radiation workers. Among these were the early radiologists, uranium miners and radium watch dial painters.

- Increased incidences of leukemia were demonstrated in children x-rayed *in-utero*. An increase in breast cancer was noted among women with tuberculosis who received repeated fluoroscopic examinations.

- Exposure to therapeutic X-rays has resulted in increased incidences of cancer among patients treated for ringworm of the scalp, arthritis of the spine, and enlargement of thymus glands.

- Residents of the Marshall Islands were accidentally exposed to fallout from a nuclear bomb test in 1954. Increased incidences of thyroid carcinoma have been demonstrated in these individuals.

- The strongest evidence for radiation induced carcinogenesis has come from studies of the Japanese A-bomb survivors. These data have suggested that radiation may be a general carcinogenic agent in humans. Increased incidences of leukemia, cancer of the breast, respiratory organs, digestive organs, and urinary organs have been reported.

Increases in cancer have not been clearly demonstrated at levels below the occupational limit of 5000 mRem/year. However, the cancer risks associated with these levels have been extrapolated from the observable effects on those populations exposed to large doses of radiation.

The Nuclear Regulatory Commission (NRC) has adopted a linear model for calculating the cancer risks associated with low level radiation exposure. According to the NRC, this model neither seriously underestimates nor overestimates the risks involved from radiation exposure. Under the linear model, the risks decrease proportionally to the dose of radiation. Thus, a worker who receives 5000 mRem/yr is assumed to have incurred ten times the risk as a worker who receives 500 mRem/yr.

Approximately 25% of all adults between the ages of 20 and 65 will develop cancer from all causes during their lifetime. It is not known what an individual's chances are of getting cancer from exposure to ionizing radiation. However, risk estimates can be made based on statistical increases in the incidence of cancer among large populations. Based on linear extrapolation from high doses, the best risk estimates available today are that an additional 300 cancer cases would occur among a

population of one million individuals exposed to 1000 mRem each of radiation. Therefore, in a group of 10,000 workers not exposed to radiation on the job, 2500 cancer cases would be expected to occur. An additional 3 cancer cases would result in a group of 10,000 radiation workers exposed to 1000 mRem each.

GENETIC EFFECTS

Radiation exposure to the genetic material in the reproductive cells can alter the genetic code and result in mutations in future generations. Genetic mutations resulting from radiation have been clearly demonstrated in animals, but genetic mutations have not been observed in human populations exposed to radiation.

Based on irradiation of animals the following inferences can be made regarding genetic effects in humans:

- Radiation is a powerful mutagenic agent and any amount of radiation can potentially damage a reproductive cell.

- The vast majority of genetic mutations are recessive. Both a male and female must possess the same genetic alteration in their chromosomes in order for the mutation to be expressed.

- Most genetic mutations are harmful. Therefore, genetic mutations tend to decrease the overall biological fitness of a species.

- Because genetic mutations may decrease the viability of the human species it is desirable that the level of genetic defects in the population be kept as low as possible. This can be accomplished by avoiding any unnecessary radiation exposure to the reproductive cells.

TERATOGENIC EFFECTS

Malformations induced in the embryonic or fetal stages of development are termed teratogenic effects. The sensitivity of cells to radiation damage is directly related to their reproductive activity and inversely related to their degree of specialization. Thus, a developing embryo or fetus, whose cells are rapidly dividing and unspecialized, is very sensitive to radiation damage.

There is no time during the development of the unborn child when it can be exposed to radiation without incurring some risk of biological damage. The human fetus is particularly sensitive to radiation damage during the first trimester, and especially during the first few weeks when the organs are forming. It is during this time that a woman may not even be aware that she is pregnant. Radiation damage to the fetus during the first two weeks results in a high risk of spontaneous abortion. The second through sixth weeks are the most critical with respect to the development of visible abnormalities. Exposure during the second and third trimesters has also been associated with abnormal growth and development of the fetus.

These observations are based on studies performed on experimental animals and from human epidemiological (population) studies. Visible abnormalities in animals have been produced from

exposure of the embryo to doses as low as 25 Rem. Subtle changes in the nerve cells of rats have been observed from exposures to short term doses in the range of 10 to 20 Rem. Abnormalities in animals resulting from exposure to doses below 10 Rem have not been conclusively shown. Chronic exposures of up to one Rem per day over a large part of the period before birth have shown no radiation induced changes in experimental animals.

Although it is difficult to extrapolate the results from animal experiments to humans, the data suggest that a human embryo would have to be exposed to at least 25 Rem before visible malformations would occur. This level is considerably above the whole body occupational limit of 5 Rem/year. Animal studies further suggest that doses of approximately 10 Rem to the human embryo may produce small alterations in intelligence or behavior.

In humans, epidemiological studies of children who were exposed to radiation while inside the womb have shown an increased incidence of abnormal growth and development. These data come primarily from the Japanese A-bomb survivors and women who received diagnostic x-rays during their pregnancies. Among the children of the Japanese A-bomb survivors, increased risk of mental retardation, small head size and a generally smaller body size than normal have been observed. Doses received by these children were above 50 Rem. It has been theorized, although not yet proven, that less severe effects on intelligence and behavior may have occurred at doses considerably below 50 Rem.

The primary concern from exposure of the unborn child to ionizing radiation is an increased incidence of childhood cancers, especially leukemia, during the first ten years of a child's life. An increased incidence of leukemia and other childhood cancers has been associated with radiation exposure to the fetus during all stages of development. However, the carcinogenic effect is greatest for exposure during the first trimester. Recent studies have shown that the risk of leukemia and other cancers in children increases if the mother was exposed during pregnancy to estimated radiation doses averaging 2 Rem, with a range of 0.2 to 20 Rem. One study involved the follow-up of 77,000 children exposed to diagnostic x-rays before birth. Another study followed 1292 children who were exposed before birth during the bombing of Hiroshima and Nagasaki. The evidence from these studies suggests an association between exposure of the unborn child and an increased risk of childhood cancer.

Based on these studies the incidence of leukemia among children from birth to 10 years of age in the U.S. could rise from 3.7 cases per 10,000 children to 5.6 cases per 10,000 children if the children were exposed to 1 Rem of radiation before birth. An equal number of other types of cancer could result from this level of radiation. Other studies, however, have suggested a much smaller effect from exposure of the unborn child to radiation.

The evidence from animal studies and human epidemiological studies indicates that the embryo and fetus are more sensitive to radiation than adults. The effects produced are strongly related to the developmental stage during which the radiation was received, with the unborn child becoming more resistant to radiation as it develops.

Adult radiation workers are permitted to receive 5000 mRem/yr. Since the unborn child is more sensitive to radiation injury, a pregnant radiation worker may want to limit her exposure to below

this amount. To minimize potential biological injury to the unborn child, it is recommended that the occupational exposure of the expectant mother not exceed 500 mRem during the course of her pregnancy.

It is the employer's responsibility to take all practical steps to reduce radiation exposure to its employees. It is the responsibility of the expectant mother to decide if she wishes to continue to work with radioactive materials or equipment. If a woman decides that she wishes to limit her exposure to below 500 mRem, she should contact the Radiation Safety Officer to review radiation levels in the work area. If it is likely she will receive a dose in excess of 500 mRem she may:

- Decide not to continue working in the area.
- Ask for reassignment to areas involving less radiation exposure.
- Attempt to decrease her exposure through the proper application of time, distance, and shielding.
- Continue to work in the area with the full awareness that she is doing so at some small increased risk to her unborn child.

The following facts should be noted in making a decision:

- Because the first three months of the pregnancy are the most critical, a decision should not be delayed.
- The actual dose received by the unborn child will probably be less than the dose recorded for the mother because some of the dose will be absorbed by the mother's body.
- The actual risk to an unborn child at the present occupational limit of 5000 mRem is small, but experts disagree on the exact amount of risk.
- Doses received by personnel that work with radiation at Virginia Tech are very low. The average dose to radiation workers is less than 50 mRem per year, it is very rare to see doses over 1000 mRem per year, and less than five individuals exceed 500 mRem per year.

Pregnant radiation workers who decide to continue to work with radioactive material or equipment shall:

- Wear an extra whole body personnel monitoring device worn on the lower abdomen if working with penetrating beta, x or gamma radiation sources.
- Be informed of her radiation exposure on a quarterly basis.
- Wear a pocket dosimeter if there is a reasonable probability of receiving a dose in excess of 500 mRem.

Pregnant radiation workers should:

- Notify the Radiation Safety Officer as soon as her pregnancy is known (confidentiality will be maintained if requested).
- Consider voluntary declaration of the pregnancy to their supervisor.

- Limit her exposure to less than 500 mRem during the course of the pregnancy.

- Keep her exposure to the very lowest practical level by reducing the amount of time spent in a radiation area, increasing the distance from a radiation source, and using shielding.

FEDERAL, STATE, AND UNIVERSITY REGULATIONS

FEDERAL REGULATIONS

An individual authorized to use radioisotopes or ionizing radiation must comply with all regulations and procedures established in order to protect both the user and other personnel from unnecessary exposure to radiation. These rules have been incorporated into the Radioactive Material Safety Program document. The Nuclear Regulatory Commission (NRC) is the federal agency that develops the regulations for the use of radioactive material. The NRC has establised regulations that govern the use of special nuclear material, source material, byproduct material, naturally occurring material and accelerator produced materials. Special nuclear material (SNM) is defined as: plutonium, uranium-233, or uranium enriched in the isotope 233 or 235. Source material is defined as: uranium or thorium in any physical or chemical form or ores that contain by weight at least 0.05% of uranium or thorium. Source material does not include SNM. Byproduct material is either fission products from SNM, or materials made radioactive in a reactor that utilizes SNM. Radium-226 is an example of a naturally occurring material and sodium-22 is an example of accelerator produced material.

The regulations of the NRC are published in title 10 of the Code of Federal Regulations. This document is very comprehensive, however only some of the parts concern the University's use of material. Those parts are:

- Part 19: Notices, Instructions, and Reports to Workers; Inspections
- Part 20: Standards for Protection Against Radiation
- Part 33: Specific Domestic Licenses of Broad Scope for Byproduct Material
- Part 40: Domestic Licensing of Source Material
- Part 61: Licensing Requirements for Land Disposal of Radioactive Waste
- Part 70: Domestic Licensing of Special Nuclear Material
- Part 71: Packaging and Transportation of Radioactive Material

The most applicable sections are in 10 CFR Part 19 and 10 CFR Part 20. The full text of these parts is available for review at the following web site: www.nrc.gov in the electronic reading room.

Part 19 is primarily concerned with the rights of employees. Each worker must be informed of the radiation risks and hazards associated with their working conditions. Any employee may request an inspection by the NRC for any working conditions that may be unsafe. The employee is protected from any discriminatory actions by the University. Any worker can request their own radiation exposure history at any time.

Part 20 is the basic regulation that establishes the standards for protection against ionizing radiation. This regulation addresses the following areas:

- Permissible doses, levels and concentrations - this section sets the exposure limits to authorized personnel, members of the public, and minors. Limitations on air and water concentrations of radioactivity are provided as well.

- Precautionary procedures - this section establishes the requirements for radiation surveys, personnel monitoring, warning signs and labels, and receipt of packages.

- Waste disposal - This section requires the proper disposal of waste and allows for release into the sanitary system as well as incineration.

- Records, reports, and notification - this section requires that records of radiation surveys, personnel monitoring, and waste disposal be maintained. Reports on theft or loss of material and overexposures or excessive levels or concentrations are also required.

STATE REGULATIONS

The Commonwealth of Virginia became an Agreement State on March 31, 2009. This status means that Virginia has assumed regulatory authority from the NRC for University activities. The applicable regulations are found in the *Virginia Radiation Protection Regulations* found in Chapter 12VAC5-481 of the Virginia Administrative Code. The most applicable parts are:

- Part III: Licensing of Radioactive Material

- Part IV: Standards for Protection Against Radiation

- Part V: Notices, Instructions, and Reports to Workers; Inspections

- Part XI: Licensing Requirements for Land Disposal of Radioactive Waste

- Part XIII: Transportation of Radioactive Material

The Commonwealth of Virginia has issued a license to the University which contains a number of conditions that must be met. The terms of the license state such things as:

- the chemical and physical form of the radioisotopes,

- the limits of possession to include all the radioisotopes in storage, in use, or in waste,

- the locations where use may occur such as the main campus or the Equine Medical Center in Leesburg,

- sealed sources must be tested for leakage every 6 months and if excessive leakage is detected, the Commonwealth must be notified,

- radioactive waste with no more than 120 day half-lives can be held for decay and then discarded as ordinary trash if after at least 10 half-lives the waste is surveyed to ensure at background, and has any radiation labels obliterated, and

- licensed material cannot be used in or on humans.

UNIVERSITY REGULATIONS

Based upon the Federal and State regulations, the Radioactive Material Safety Program document has been prepared. This document contains the specific rules that must be followed for use of radioactive material at the University. It is important that all personnel review this document prior to beginning work with radioisotopes at Virginia Tech.

LABORATORY DESIGN, OPERATIONS AND SAFETY PROCEDURES

The design of a laboratory plays an important role in the safe use of radioisotopes. The ideal wet chemistry laboratory has two exits, remote from each other. This separation should allow for a safe exit in the event of an emergency. Conversely, emergency response personnel would be able to gain access to the laboratory without passing through the hazardous area. For emergency treatment of spills or personnel, a deluge shower and eye wash station should either be in the laboratory or in the immediate vicinity.

A fume hood rated for radioisotope use should be located in a low traffic area of the laboratory, away from windows or air intakes for the room. Make up air for the hood should be sufficient to provide six or more air changes per hour. Since a number of laboratory operations cause aerosol production, work with radioisotopes should be done in the hood to control aerosol dispersion. When hood use is not possible, the planned bench work should be evaluated by the Radiation Safety Office. The bench tops should be constructed of an impervious material such as stainless steel or Formica. During the actual work the bench top should have extra protection by using a plastic backed absorbant paper. This paper can be discarded as solid radioactive waste rather than necessitating the decontamination of bench tops. The bench tops should be designed with smooth corners and no cracks, to reduce areas in which radioactive materials can be trapped.

The floor should be of seamless construction of an impervious design or covered with vinyl or other similar material. The edges should not form a sharply defined crack, but should curve upward for ease of cleaning up any contamination.

If the radioisotopes are used in conjunction with flammable solvents, refrigerators must be rated for flammable material storage. Large volumes of flammable material must be stored in a flammable material storage cabinet. Whether radioisotopes are stored in a refrigerator or cabinet, the storage unit must be lockable, so that all radioactive material can be secured.

A waste storage area must be designated, to keep all radioactive waste. Occasionally the waste may present hazards in addition to radiation (e.g. flammable). The waste storage must comply with the appropriate chemical safety rules.

Protective clothing should be available and used when appropriate. Goggles or safety glasses, gloves, and lab coats may be required. Disposable gloves are the minimum protection required.

PROPER MARKING OF LABORATORIES, AREAS AND EQUIPMENT

The laboratories at the University are involved in many functions. Not all individuals that frequent these laboratories are trained in Radiation Safety. The appropriate use of warning labels is necessary to inform all people about the location of radioactive material in the laboratory.

Any laboratory that contains radioisotopes must have the warning label posted on the door. This immediately informs a visitor of the presence of radioactive material. Storage areas such as refrigerators and cabinets must also be labeled. Any equipment that may be contaminated must be

labeled. Some examples are: centrifuges, vortex units, flasks and traps, a filtering apparatus, pipetters, forceps, scissors, and tube racks.

The warning label must be put on any container of radioactive material. This label must also state the isotope, activity and date measured. Containers are not required to be labeled if: the activity is less than the exempt quantity value in Appendix 1 or the material is used in the constant presence of the user.

RECOMMENDED EQUIPMENT AND WORK SURFACES

Bench tops should be constructed of an impervious material such as stainless steel or stoneware (when ^{32}P is used bench tops should have lower density surfaces such as Formica or working in cafeteria style trays). The integrity of these surfaces leads to easy decontamination. To avoid unnecessary decontamination activities, work areas should be covered with plastic backed absorbent paper.

The house vacuum lines should not be used for radioactive work unless no other alternative is present. If these lines must be used, traps and filters must be incorporated into the apparatus to protect the vacuum system. The ideal vacuum system would consist of a vacuum pump exhausting into a fume hood.

The use of equipment dedicated for isotope work reduces the potential for spread of contamination and avoids the potential exposure of personnel not working with isotopes. Examples of such designated equipment are: microfuges, water baths, incubators, pipetters, electrophoresis equipment, and filtering equipment.

The majority of radioactivity is contained in the isotope stock vials. Adequate storage is critical to preventing contamination problems. The use of a secondary enclosure for these stocks is an effective control, such as using Rubbermaid products. Storage areas should be lined with absorbent paper.

One sink should be designated for decontamination activities. This area must be monitored frequently to ensure no residual contamination.

CONTAMINATION SURVEILLANCE

The RSO performs a contamination check on the outside of each box received from manufacturers prior to delivery to laboratories. Each laboratory must check the inside of the outer packaging and deface any radioactive markings or symbols prior to disposal as clean trash. The intermediate container for the stock vial should also be checked for contamination to avoid spread in the storage area. The stock vial must always be treated as contaminated unless shown to be clean.

Periodic laboratory surveys must be performed to show control of contamination. The immediate work areas must be checked at least once daily when active use of radioisotopes has occurred. Weekly or monthly comprehensive surveys must be performed to include the work areas, equipment used, phones, door knobs, handles, floors, etc. Weekly surveys are required when at

least 200 μCi is removed from a stock vial at any time while monthly surveys are required when less than 200 μCi is used. The recommended surveillance technique is to perform the daily checks with a portable survey instrument (tritium labs must always conduct swipe surveys), while the weekly/monthly checks would be done with swipe tests analyzed in scintillation counters. Whenever radioactive contamination is found, it must be cleaned immediately.

Once equipment has been used with radioactive material, no alternate uses are allowed until it is shown to be clean. The equipment cannot be serviced in the lab, sent back to manufacturers or repair shops, or sent as surplus until proven to be clean.

DECONTAMINATION

PERSONNEL

Removal of skin contamination (excluding wounds or near body openings) can be accomplished by using a wide variety of methods. The simplest and safest technique is with ordinary soap and cool water. It is important to thoroughly monitor affected areas prior to cleaning to determine the effectiveness of decontamination activities. The soap should be worked into a good lather to wash the affected areas for several minutes. After rinsing and drying, the area should be monitored to determine progress. This process should not be repeated more than 3 times, but a soft brush can also be used. Caution should be exercised to prevent spread to noncontaminated areas and to prevent defating of the skin. More aggressive methods can be employed while under supervision of the RSO.

Decontamination of the eyes, ears, nose and mouth or wounds is a more sensitive procedure and should be done in the presence of medical personnel as well as the RSO. Flushing with water is the most acceptable means of decontaminating the body openings and wounds.

EQUIPMENT

A number of decontamination techniques can be used to clean equipment. The two basic types of decontamination methods are corrosive and noncorrosive. Corrosive techniques are less desirable because surface removal is often caused. This results in a surface that is harder to decontaminate in the future. The size of equipment, extent and chemical form of contamination and construction of equipment can dictate the technique used. If short half-life isotopes are used, storage of contaminated equipment for 7-10 half lives can be an effective decontaminant especially when radiation levels pose a hazard.

Washing equipment with a special decontaminating solution (e.g. Radiacwash, Count-off, Lift-away) is recommended. A several hour to 24 hour soak in this solution can often remove more stubborn contamination. After the equipment has been cleaned, it must be dried before a final survey can be performed. The use of sprays such as Fantastik or Windex may be an effective decontaminant.

Organic solvents such as ethanol could be used by wiping the equipment. Harsher methods involve soaking in dilute acids or bases. One additional method uses abrasives such as steel wool or

sandpaper. Abrasives usually remove the surface layer which will increase the difficulty of future decontamination efforts. When the equipment cannot be cleaned below the limits, disposal as radioactive waste is necessary.

AREAS

Any areas such as bench tops or floors that become contaminated must be cleaned up promptly. Initially, a detailed survey must be performed to determine the extent of contamination. The affected area can be outlined with a wax pencil or magic marker. For very small areas with dry contamination, masking or duct tape pressed on the area and removed may decontaminate effectively. For larger areas cleanup is best accomplished by applying a decontamination solution to the area and working from low activity areas to high activity areas. If scrubbing with towels or sponges aren't sufficient, a brush should be used. Other methods involve organic solvents, acids, bases, and abrasives in a similar fashion to equipment cleaning. These later steps must be performed under RSO supervision only. Widespread contamination or high activities must be cleaned under RSO supervision. Area contamination must be cleaned to below the limits. Removal of surfaces such as floor tile may be necessary if contamination cannot be cleaned adequately.

RADIOACTIVE WASTE DISPOSAL

Radioactive waste is classified according to the half-life of the isotope. For isotopes with half-lives no more than 120 days, the waste is stored at the University until it decays for 10 half-lives. After the decay period, the waste is surveyed and discarded as clean trash if found to be at background. This category is segregated into two groups: less than 30 days – e.g. ^{32}P, ^{33}P, ^{51}Cr and 30 – 120 days - e.g. ^{125}I, ^{35}S. Another category includes isotopes with half-lives over 120 days - e.g. ^{3}H, ^{14}C. This category is shipped from the University for disposal.

The waste must be collected according to its physical form as solid, liquid or biowaste. The solid waste is primarily composed of absorbent paper, gloves, plastic or glass. No liquid other than trace amounts can be put into the solid waste. Capped tubes or vials must be emptied into liquid waste prior to disposal as solid waste. This waste is collected in 5 gallon, 20 gallon or 55 gallon containers provided by the RSO.

The liquid waste consists of bulk liquids, stock vials and liquid scintillation fluids. ^{14}C and ^{3}H liquid waste should be segregated from other isotopes. The bulk liquid must be segregated as aqueous or non-aqueous. This waste is either shipped off site for disposal or poured into the sanitary system by the RSO. Bulk liquids must be collected in 1 gallon or 2.5 gallon containers provided by the RSO. Only liquid waste can be in the containers, solid waste such as pipette tips must be put in solid waste containers. All original solutions and first rinses must be collected as waste. Other rinses or equipment decontamination water can be released into the sanitary system only if several criteria are met. The liquid must be readily soluble or dispersible in water. The maximum release cannot exceed 1 uCi per day. Any release must be flushed with copious amounts of water.

Liquid scintillation vials are collected in 5 gallon or 55 gallon containers. Safer cocktails (less than 150^{o} C flashpoint) must be segregated from conventional cocktails (toluene, xylene base). The use of the safer cocktails (e.g. Econosafe, Scintiverse BD, Ecolume, Ecoscint) is recommended due to greater personnel safety. Specific activities less than 0.05 uCi/ml of cocktail must be kept separate from others. Additionally, ^{3}H and ^{14}C must be separate from all others. Reuse of vials is discouraged due to the additional personnel exposure to the chemicals in the fluid. The intact closed vials should be placed in the waste container. This waste is shipped from the University for reprocessing at a licensed facility.

Stock vials must be segregated from other liquid waste because of the high concentrations of activity present. These vials must be collected in 5 gallon containers.

Biowaste (e.g. animal carcasses and excreta) is the last form of waste to discuss. Biowaste must be collected in plastic bags and maintained frozen until removal by the RSO. It must be segregated by specific activity with ^{3}H and ^{14}C less than 0.05 uCi/g kept separate from any other isotopes. Biowaste is shipped from the University for incineration.

Radioactive waste is regularly removed from laboratories every Wednesday. Prior to removal of any waste, a radioactive waste label must be properly completed for each container. The activity section is very important and must be determined as accurately as possible. The activity in biowaste can be determined from the initial dose given to them. Liquid waste activities can be determined by analysis of aliquots of the waste. By using the calculated dpm/ml and multiplying by the total volume of waste, the activity can be calculated by determining the total dpm in the container and dividing by 2.2×10^{6} dpm/µCi. Liquid scintillation activities can be determined by either adding all counts of vials up or estimating by average. Once the counts are converted to dpm, the value can be converted to microcuries. The solid waste activities are the most difficult to determine. The simplest method is to infer by subtracting all other waste forms from the total activity used. All activities reported must be corrected for decay for all isotopes with half-lives less than 2 years.

Biohazardous radioactive wastes must be autoclaved or chemically inactivated. The preferred method is by chemical treatment (e.g. bleach or Lysol) specific to the biohazard. Any syringes used must have the needles removed and capped before disposal to avoid a puncture hazard.

All containers used for radioactive waste must be labeled with either "Caution - Radioactive Material" or "Caution - Radioactive Waste". The standardized waste containers provided by the RSO (1 gallon or 2.5 gallon jugs, and 5, 20, 55 gallon drums) must be used at all times. In addition to labeling of the primary collection containers, all secondary containers such as beakers must also be labeled.

Before any waste containers will be removed from a laboratory a contamination check must be performed. If a swipe of the outer container surfaces shows in excess of 220 dpm, the container must be cleaned and rechecked to ensure it is below 220 dpm. However, if a container cannot be decontaminated, special arrangements can be made by the RSO. Waste **will not** be removed if the contamination check has not been done.

PERSONNEL MONITORING

External and internal radiation monitoring is performed on University personnel. OSLD and TLD badges are the principal types of monitoring devices used. A body badge can be issued to monitor exposure to the whole body, eyes and the skin. This badge must be worn on the outer clothing usually on the lab coat pocket or collar.

A finger badge can be issued to monitor hand exposure. This badge should be worn on the hand expected to receive the highest exposure and worn with the label facing inward. Generally, a right handed person will receive more exposure to the left hand because more holding is done with the left hand. The ring badge should always be worn under gloves to avoid contamination.

Badges are normally issued only to users of high energy beta, or medium to high energy x-ray or gamma emitting isotopes such as ^{32}P, ^{51}Cr, ^{131}I or ^{137}Cs. Personnel that use ^{3}H, ^{14}C, ^{35}S or ^{125}I are not issued badges. Individuals that are issued badges must wear them anytime isotopes are received, handled or otherwise used. The personnel monitoring badges **must not** be worn during non-occupational exposures such as dental x-rays.

Any lost or damaged badges should be reported to the RSO promptly. A replacement will be acquired and a dose assignment will be determined. Normally badges will be exchanged by the RSO every 3 months (January, April, July and October). The old badges are sent to a commercial laboratory for determination of the radiation dose.

Periodically, bioassays are performed to determine any uptakes of radioactive material. Generally, if an uptake is suspected, the individual would provide a urine specimen to the RSO. These specimens are analyzed by a commercial laboratory to determine if personnel are internally contaminated. Individuals that use ^{125}I or ^{131}I have thyroid scans performed after iodinations of proteins or other compounds or work with any unbound radioiodine. The scans are done between 24 - 72 hours after the procedure.

RECORD KEEPING

The receipt, usage and disposal of all radioactive material must be documented by laboratory personnel. The "Radioactive Material Usage and Survey Record" is a daily usage record that must be maintained. This form is used to track the activity remaining in the stock vial, the activity used on a given day, the division of activity put into waste, and any activity left in experiments. Daily surveys are documented on this form by initialing the line entry. The proper use of these forms is very important to demonstrate appropriate use and disposal of all isotopes. In order to simplify record keeping, no decay corrections should be performed on these records.

Contamination surveys must be documented by laboratory personnel. The "Contamination Survey Record" is used to document the weekly and monthly swipe surveys and to show success of decontamination efforts when applicable. It is helpful to use a sketch of the lab numbered at the survey points so that the actual survey record can have numbers referenced to simplify the record completion.

INSTRUCTIONS TO CLEANING PERSONNEL

Custodial personnel must not be involved in the clean-up of radioactive material. These people must be informed by lab personnel of areas to avoid. The following guidelines are provided to custodians:

- Any room marked with the special symbol may contain radioactive material or radiation from a machine. Ask the person in charge to show you the possibly dangerous areas and explain any special safety steps that need to be followed.

- Most radioactive materials used in laboratories are dangerous only if they enter the body through the mouth, nose or cuts. If you do not handle them, they should not cause any harm. Do not handle any container marked with the radiation symbol.

- Radioactive materials which could cause harm without entering the body are kept in special containers or used in protected areas. These containers and areas are always marked with the radiation symbol.

- All radioactive waste is placed in special containers that are marked with the radiation symbol. Do not ever remove these containers or their contents, which are in yellow bags, from any area.

- If yellow bags or anything else marked with the radiation symbol are found in normal trash, do not remove this trash. The person in charge of the lab and the Radiation Safety Officer should be contacted. These people will take action to correct the situation.

- Spilled radioactive materials must never be cleaned up by custodians. Do not clean up **ANY** spills in areas marked with the radiation symbol.

- Do not clean bench tops, hoods, refrigerators or sinks. This is the responsibility of laboratory personnel.

SECURITY OF AREAS AND RADIOACTIVE MATERIAL

Radioactive material must be protected from removal by unauthorized personnel. Visitors must be protected from exposure to radiation emitted from the radioisotopes used in the laboratory. Storage areas of stock vials such as refrigerators must be locked when not in use or unattended by authorized personnel. The lab must be locked whenever an authorized user is not present. This precaution ensures that radioactive waste or radioactive experiments in progress are protected from unauthorized access.

PERSONNEL PROTECTIVE EQUIPMENT

The use of protective equipment is always required when isotopes are used in an unsealed form. The extent of equipment is determined by the potential hazards. The minimum protection required is gloves. Double gloves would be advisable when higher levels of activity are used. Because various chemical forms are used, the choice of glove composition should be made according to chemical resistance. For example, latex gloves provide resistance to acids, bases, salts and ketones. PVC gloves provide similar protection including aromatics such as toluene or xylene. Polyethylene gloves provide excellent protection from toluene. Generally, neoprene and nitrile gloves perform better than other types of disposal gloves. Go to www.showabestglove.com to determine the glove selection suited for the specific compounds to be used.

A laboratory coat is recommended to provide protection to exposed skin and personal clothing from spills. Eye protection is required in many situations; this includes safety glasses, goggles or a full face shield. Generally, the hazards associated with these requirements are: flying glass, liquid splashing or spattering, and fumes or particles. Contact lenses should not be worn during chemistry operations due to the risk of eye injury without the ability to remove the lenses.

Respiratory protection may be necessary when the generation of fumes, mists or particles cannot be controlled by an enclosure. A dust mask can be used for protection from particulates in the air. Exposure to fumes, mists and fine particulates can only be controlled by wearing a half-face respirator. The respirator must be equipped with filters capable of removing the specific hazard. Respirators are issued to individuals by the Environmental, Health and Safety Services Department. Prior to issuance the individual must pass a pulmonary function test to ensure that the person is physically capable of using a respirator.

REDUCTION OF EXPOSURE TO THE WORKER

Because any amount of radiation is potentially harmful every effort should be made by personnel to reduce their doses to a level **as low as reasonably achievable**. This is known as the **ALARA** concept. The University Administration fully supports the use of appropriate controls to limit radiation exposures to ALARA.

Time, distance, and **shielding** represent the most practical methods that laboratory personnel can use to minimize external radiation exposure. The dose of radiation received is directly proportional to the amount of time spent in a radiation field. Reducing the time spent in a radiation field by half would also reduce the dose by half. A very effective method to reduce time is job preparation.

Before any work with radioactive material is done, the individual must be very familiar with the procedure to be used. Often, a full scale run of the experiment without radioactive material present can provide an effective means for familiarization of the procedure. This also ensures that the person will be completely prepared for the work.

Radiation exposure decreases rapidly as the distance between the worker and the source of the radiation increases. Maximizing distance represents one of the simplest and most effective methods for reducing radiation exposures. The exposure from a small source of X-ray or gamma radiation is inversely proportional to the change in distance. This relationship is called the inverse square law. For example, if the dose rate at one foot from a source is 20 mR/hr, then the dose rate at two feet (twice the distance) will be 5 mR/hr ($R_1 \times D_1^2 = R_2 \times D_2^2$ where D is the distance from the source and R is the dose rate). This example illustrates the importance of maximizing distance from a radioactive source. The use of tongs or long-handled forceps allows a distance separation when containers or tubes must be manipulated.

In contrast to x or γ radiation, β particles have a finite range in air. Low energy β emitters such as ^{3}H, ^{14}C, or ^{35}S do not pose an external radiation exposure problem when the material is handled in containers. Higher energy β emitters such as ^{32}P do pose an external hazard. Since the energy distribution of betas is from zero to some maximum (dependent upon the isotope), the average energy is approximately one-third of the maximum. Once the distance from a beta source exceeds 4 inches, dose rate reduction follows the inverse square law as the separation distance increases.

Radiation exposure can also be decreased by placing a shielding material between a worker and the source of radiation. The shielding used can take many forms ranging from bench top shields to shielded holders for test tubes, ependorf tubes and waste containers. Shielding attenuates the quantity of gammas emitted from a source. Materials with high densities are the most effective shielding choice for gammas. As the energy of the gammas increase, the thickness of shielding must also increase to provide comparable stopping power. Lead bricks, lead sheets, lead foil and leaded glass are commonly used, while steel or concrete may be used occasionally as shielding materials. An example of a shielding device is a bench top shield. The upright portion shields the whole body while an angled top piece of leaded glass shields the face. This angled top feature allows for optimum viewing while maintaining exposures low. This type of shield would be used when stock solutions of gamma emitters such as ^{65}Zn or ^{59}Fe are manipulated. When low energy gamma emitters are used, lead foil can effectively reduce the emissions. For example, a column used for purification of a freshly made ^{125}I hormone can be totally shielded with a layer of lead foil. The tenth value layer (TVL) is useful for developing shielding plans. The TVL reduces the dose by a factor of 10. Appendix 2 provides tenth value layers for a number of isotopes and various shielding materials.

The shielding principles applied to gamma radiation are different from the principles for beta radiation. Since beta particles have a finite range, shields are designed to totally stop all betas from the isotope in use. While gamma shields rely on high density, beta shielding materials must be low density. If beta shields are composed of materials with an atomic number higher than aluminum (13), the incidence of, "bremsstrahlung" increases to unacceptable levels. The bremsstrahlung phenomenon causes beta energy to be converted into x-rays because of interactions with atoms. These secondary x-rays can pose a greater hazard than the original betas. Shields are commonly

composed of plexiglass, glass or aluminum. Water can also be used to effectively shield betas. Refer to Appendix 3 for a list of the minimum thicknesses of several materials that would be required to stop the betas emitted from various isotopes. A number of shielding devices can be used. Plexiglass bench top shields provide protection to the body and eyes, plexiglass or aluminum blocks for tube holders protect hands, several thicknesses of tygon tubing provide excellent hand shielding when a tube must be held, and plexiglass cylinders or PVC pipe shield liquid waste or other containers of radioactive solutions.

Efforts should also be made to keep internal radiation exposures ALARA. Radioactive material can be internally deposited if there is: skin contact, inhalation or ingestion. The use of good cleanliness practices coupled with adequate contamination surveillance can avoid skin contamination problems and the associated ingestion or skin absorption hazard. Airborne radioactivity can pose a significant inhalation problem. Procedures that generate aerosols or produce volatile or gaseous products should be performed in a closed apparatus. For instance, capped tubes should be vortexed and closed systems should be used in conjunction with filters or traps when volatile or gaseous products are expected. If absolute containment is not achievable, the work must be performed in a fume hood.

The isotope selection process is another effective method to reduce potential radiation exposures. The areas to be considered are: the radioactive half-life, the energy and type of emissions, the quantity of isotope, and the chemical form of the isotope. The half-life of the isotope selected can affect waste management. Generally, shorter lived isotopes are preferred over longer lived. Since the University stores waste with half-lives up to 120 days until decayed to background, this category of waste causes minimal monetary and environmental impact because it is not buried in a radioactive waste disposal facility.

The energy and type of emissions from the perspective isotopes must be considered. Selection of low energy beta or gamma emitters is preferred because radiation hazards are proportionally related to the energy. Beta emitters are preferred over gamma emitters because betas require less shielding. The radiation hazard is also proportionally related to the quantity (radioactivity) of the isotope to be used. The use of small activities is preferred. The chemical form selected for the experiment can also affect the radiation hazards associated with the work. It is preferred to avoid the use of compounds that are or produce volatile or gaseous compounds.

Several examples can be used to illustrate the selection process. When considering the use of phosphorus, two isotopes are feasible. ^{32}P has a short 14 day half-life but emits high energy betas (1.710 MeV). ^{33}P has a longer half-life (25 days) but emits low energy betas (0.248 MeV). ^{33}P would be the most desirable isotope to use, however, availability is limited and cost may be an issue. Another substitute for use in some molecular biology procedures is ^{35}S, with its 87 day half-life and low 0.168 MeV beta. The low energy improves resolution of autoradiographs and requires no shielding or remote handling.

A common use of iodine involves studies with iodinated hormones. Two isotopes of iodine, ^{125}I and ^{131}I, are feasible. The low x and gamma radiation of ^{125}I makes it more acceptable than ^{131}I (high energy beta and gamma emitter). Another decision making level is chemical form. The iodinated hormone can either be made at the University or purchased premade. The use of

available kits is preferable to production within the University. The iodination process begins with the very volatile form of Na ^{125}I. Additional precautions are advisable including work within a charcoal filtered hood. Thus it is much safer to work with bound iodine rather than unbound iodine.

APPENDIX 1: EXEMPT QUANTITIES

Americium-241 (^{241}Am)	0.01	uCi
Cadium-109 (^{109}Cd)	10	uCi
Calcium-45(^{45}Ca)	10	uCi
Calcium-47(^{47}Ca)	10	uCi
Carbon-14(^{14}C)	100	uCi
Cerium-141(^{141}Ce)	100	uCi
Cesium-134(^{134}Cs)	1	uCi
Cesium-137(^{137}Cs)	10	uCi
Chlorine-36(^{36}Cl)	10	uCi
Chromium-51(^{51}Cr)	1000	uCi
Cobalt-60(^{60}Co)	1	uCi
Hydrogen-3(^{3}H)	1000	uCi
Iodine-125(^{125}I)	1	uCi
Iodine-131(^{131}I)	1	uCi
Iron-55(^{55}Fe)	100	uCi
Iron-59(^{59}Fe)	10	uCi
Manganese-54(^{54}Mn)	10	uCi
Mercury-203(^{203}Hg)	10	uCi
Molybdenum-99(^{99}Mo)	100	uCi
Nickel-63(^{63}Ni)	10	uCi
Phosphorus-32(^{32}P)	10	uCi
Plutonium-239(^{239}Pu)	.01	uCi
Strontium-90(^{90}Sr)	0.1	uCi
Sulfur-35(^{35}S)	100	uCi
Technetium-99m(^{99m}Tc)	100	uCi
Thorium(natural)	100	uCi
Uranium(natural)	100	uCi
Zinc-65(^{65}Zn)	10	uCi

APPENDIX 2: TENTH VALUE LAYERS FOR GAMMA EMITTING ISOTOPES

Isotope	Principle Gamma	Concrete		Steel		Lead	
	keV	inches	cm	inches	cm	inches	cm
^{51}Cr	320	3.8	9.7	1.1	2.8	0.3	0.8
^{54}Mn	835	5.6	14.2	1.8	4.6	1	2.5
^{55}Fe	6			0.0008	0.002	0.0002	0.0005
^{57}Co	122	2.7	6.9	0.4	1	0.02	0.06
^{59}Fe	1292	7.3	18.5	1.8	4.6	1.4	3.6
^{60}Co	1332	8.2	20.8	2.7	6.9	1.6	4
^{65}Zn	1116	7	17.8	2.1	5.3	1.3	3.3
^{75}Se	401	4.2	10.7	1.3	3.3	0.4	1
^{85}Sr	514	4.8	12.2	1.4	3.6	0.6	1.5
^{86}Rb*	1077	6.8	17.3	2	5.1	1.3	3.3
^{99}Mo*	739	5.4	13.7	1.7	4.3	0.9	2.3
^{99m}Tc	141	2.8	7.1	0.5	1.3	0.03	0.08
^{109}Cd	88			0.2	0.6	0.01	0.03
^{125}I	35			0.02	0.06	0.003	0.007
^{131}I	723	5.4	13.7	1.7	4.3	0.9	2.3
^{134}Cs	1365	8.2	20.8	2.7	6.9	1.6	4
^{137}Cs	662	6.2	15.7	2.1	5.3	0.8	2.1
^{141}Ce*	145	2.8	7.1	0.5	1.3	0.03	0.08
^{144}Ce*	134	2.8	7.1	0.5	1.3	0.03	0.08
^{203}Hg	279	3.6	9.1	1	2.5	0.2	0.5
^{226}Ra	1764	9.2	23.4	2.9	7.4	2.2	5.5

* Should consider beta shielding on inside of gamma shielding

APPENDIX 3: THICKNESSES TO STOP BETAS FROM VARIOUS ISOTOPES

	Principle Beta	Values in Inches			
Isotope	keV	Water	Plexiglass	Glass	Aluminum
^{14}C	156	0.014	0.010	0.006	0.005
^{32}P	1710	0.320	0.250	0.150	0.125
^{33}P	249	0.025	0.020	0.012	0.009
^{35}S	167	0.015	0.011	0.006	0.005
^{36}Cl	710	0.096	0.079	0.043	0.036
^{42}K	3521	0.820	0.650	0.360	0.300
^{45}Ca	259	0.027	0.022	0.012	0.009
^{47}Ca	1988	0.370	0.290	0.170	0.150
^{86}Rb	1744	0.320	0.260	0.150	0.125
^{90}Sr	546	0.070	0.055	0.031	0.025
^{99}Mo	1214	0.195	0.160	0.083	0.070
^{144}Ce	580	0.075	0.060	0.033	0.028
^{141}Ce	318	0.035	0.027	0.016	0.013

APPENDIX 4: ISOTOPE CHART

Isotope	Half-Life*	Radiation Type**	Average Energy (keV)	Maximum Energy (keV)
^{3}H	12.3y	β^-	6	19
^{14}C	5730y	β^-	49	156
^{22}Na	2.6y	β^+ γ	216 1275	546
^{32}P	14d	β^-	695	1710
^{33}P	25d	β^-	77	249
^{35}S	87d	β^-	49	167
^{36}Cl	3×10^5y	β^-	251	710
^{42}K	12h	β^- γ	1564 1525	3521
^{45}Ca	163d	β^-	77	257
^{47}Ca	4.5d	β^- γ	817 1297	1988
^{51}Cr	28d	γ	320	
^{54}Mn	313d	γ	835	
^{55}Fe	2.7y	x	6	
^{57}Co	271d	γ	122	
^{59}Fe	45d	β^- γ	149 1292	466
^{60}Co	5.3y	β^- γ	96 1332	318
^{63}Ni	100.1y	β^-	17	66
^{64}Cu	13h	β^+ β^- γ	278 190 1345	653 578
^{65}Zn	244d	β^+ γ	143 1116	330
^{75}Se	120d	γ	401	
^{85}Sr	65d	γ	514	
^{86}Rb	19d	β^- γ	709 1077	1774
^{90}Sr	28.6y	β^-	196	546
^{90}Y	64 h	β^-	935	2284
^{99}Mo	66h	β^- γ	443 739	1214
^{99}Tc	2.1×10^5y	β^-	85	294

* Hours - h
Days - d
Years - y

** Alpha particle - α
Beta particle - β^-
Positron particle - β^+
Gamma ray - γ
X-ray – x

Isotope	Half-Life*	Radiation Type**	Average Energy (keV)	Maximum Energy (keV)
^{99m}Tc	6h	γ	141	
^{109}Cd	464d	γ	88	
^{123}I	13h	γ	159	
^{125}I	60d	x γ	31 35	
^{131}I	8d	β^- γ	192 364	606
^{134}Cs	2.1y	β^- γ	210 796	658
^{137}Cs	30.2y	β^- γ	157 662	511
^{141}Ce	33d	β^- γ	181 145	580
^{144}Ce	284d	β^- γ	91 134	318
^{203}Hg	47d	β^- γ	58 279	212
^{226}Ra	1600y	α γ	4785 1764	
^{232}Th	1.4 x10^{10}y	α	4010	
^{235}U	7 x 10^8y	α γ	4598 205	
^{238}U	4.6 x 10^9y	α	4196	
^{238}Pu	87.8y	α	5499	
^{239}Pu	24,131y	α	5155	
^{241}Am	432y	α γ	5486 60	

* Hours - h
Days - d
Years - y

** Alpha particle - α
Beta particle - β^-
Positron particle - β^+
Gamma ray - γ
X-ray – x

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GLOSSARY

Activity: the number of atoms decaying per unit of time.

Airborne radiation area: any room, enclosure, or operating area where airborne radioactive materials exist in concentrations above the maximum permissible concentration (MPC) specified in 10 CFR 20; or any room enclosure or operating area where airborne radioactive material exists in concentrations that, averaged over the number of hours in any week when individuals are in the area, exceed 25% of the MPC's specified in 10 CFR 20.

Alpha: a helium nucleus consisting of two neutrons and two protons, with a mass of 4 AMU and a charge of +2.

As low as reasonably achievable (ALARA): basic radiation protection concept to reduce doses to the lowest possible levels through the proper use of time, distance and shielding.

Atom: the smallest division of matter that still displays the chemical properties of an element.

Atomic mass unit (AMU): one twelfth of the arbitrary mass assigned to carbon 12. It is equal to 1.6604×10^{-24} gm**.**

Becquerel: a unit of activity equal to one diintegration per second.

Beta: a charged particle emitted from the nucleus of an atom, with a mass and charge equal to that of the electron.

Bremsstrahlung: a german word for **braking radiation**. It is incidental photon radiation caused by the deceleration of charged particles passing through matter.

Chain decay: a process by which an unstable atom decays to another unstable atom, repeating the process until the atom becomes stable.

Code of Federal Regulations (CFR): title 10 contains the regulations established by the NRC. Part 19 deals with the rights of employees to be informed of any radiation hazards associated with their working conditions, and the rights of the worker to complain about any working conditions that may be unsafe. Part 20 is the basic regulatory guide which establishes the standards for protection against ionizing radiation.

Compton scattering: interaction process for x or gamma radiation where an incident photon interacts with an orbital electron of an atom to produce a recoil electron and a scattered photon with energy less than the incident photon.

Curie: a unit of activity equal to 3.7×10^{10} disintegrations per second.

Decay, radioactive: the disintegration of the nucleus of an unstable atom caused by the spontaneous emission of charged particles and/or photons.

Decay constant: represents the fraction of atoms that decay per unit of time, with a value equal to 0.693/half-life of the isotope.

Electron: elementary particle with a unit negative charge and a mass of 1/1837 AMU.

Energy shells: labels given to the different orbits of the negatively charged electrons circling the nucleus of an atom.

Gamma: electromagnetic radiation with a very short wave length and no mass or charge.
Half-life: the time required for the initial activity to decrease by half.

High radiation area: any area accessible to personnel where there exists radiation at such levels that a major portion of the body could receive a dose over 100 mR in any one hour.

Isotopes: atoms with the same number of protons, but different numbers of neutrons.

Monoenergetic: where all the particles or photons of a given type of radiation (alpha, beta, neutron, gamma, etc.) originate with and have the same energy.

Neutrino: a particle with no mass or charge, but has energy associated with it.

Neutron: an atomic particle with a mass of 1.009268 AMU, and no charge.

Nuclear Regulatory Commission (NRC): Federal agency charged with the responsibility of regulating the use of radioactive material.

Nucleus: the central part of an atom that has a positive charge, and is composed of protons and neutrons.

Pair production: an absorption process for x and gamma radiation where the incident photon is annihilated in the vicinity of the nucleus of the absorbing atom, producing an ion pair (beta and positron). This process only occurs for incident photon energies exceeding 1.02 MeV.

Photoelectric effect: process by which a photon ejects an electron from an atom. All the energy of the photon is absorbed in ejecting the electron and in imparting energy to it.

Photon: energy emitted in the form of electromagnetic radiation, such as x-rays and gamma rays.

Positron: particle equal in mass to the electron and having an equal but positive charge.

Proton: a particle with a positive charge and a mass of 1.007897 AMU.

Quality factor: a term to express the varying effects of different types of radiation when assessing doses to tissue.

Rad: an amount of absorbed radiation dose of 100 ergs per gram of matter.

Radiation area: any area accessible to personnel where there exists radiation at such levels that a major portion of the body could receive a dose of over 5 mR in one hour or a dose over 100 mR in any 5 consecutive days.

Rem: stands for radiation equivalent man, and the dose in rems is equal to the dose in rads multiplied by the quality factor.

Restricted area: any area where access is controlled by the University to protect individuals from exposure to radiation and radioactive materials. Residential quarters cannot by included in a Restricted Area.

Roentgen: the amount of x or gamma radiation which will cause ionization of one electrostatic unit of charge in 1 cubic centimeter of dry air at standard temperature and pressure.

Specific activity: total activity of a given nuclide per gram of a compound, element, or radioactive nuclide.

Tenth value: the thickness of a given material that will decrease the amount of radiation to one-tenth of the original value.

X-ray: penetrating electromagnetic radiation similar to visible light, but having extremely short wave lengths.