INTRODUCTION TO RADIATION SAFETY

FOR

RESEARCH PERSONNEL

RADIATION SAFETY OFFICE
OKLAHOMA STATE UNIVERSITY

Structure of the Atom

Dense nucleus composed of neutrons (0 charge) and protons (+ charge) and surrounded by orbital electrons **(-** charge). Neutrons and protons firmly held in the nucleus while electrons are very loosely held and are easy to remove. When electrons are removed from the atom, two charged particles (ions) are produced the positively charged atom and the negative electron. Energy is absorbed to remove the electron from the atom.

Atomic Notation

Chemical symbols such as C for carbon, H for hydrogen, and Cs for cesium are used to identify each type of atom. The atomic number of the element is designated as Z and the mass number is designated as A. The atomic number is always equal to the number of protons in the atom. The mass number is equal to the sum of the number of protons and number of neutrons. The mass number (A) is always written as a superscript, as in ^{14}C (carbon-14) or as C-14. The atomic number is written as a subscript when used as in $_6C$ (carbon- 14). However, since the chemical symbol identifies the element it is redundant to include the atomic number, so it is rarely used. Carbon-14, therefore, would be written as ^{14}C or C-l4.

Unit of Radiation Energy

The electron volt (eV) is an extremely small unit and is equal to only 1.6 X 10^{-12} ergs. It is only used in radiation safety to express radiation energy. The electron volt is such a small unit that it is usually written as mega- or kilo- electron volts which is a million electron volts (MeV) or a thousand electron volts (keV), respectively.

Radioactivity

The atoms of all elements will exist in two categories with respect to their stability. Some atoms have too much mass-energy within the nucleus and exist in an unstable form. The unstable atoms are moved toward attaining stability much like an unstable car on top of a hill rolls to the bottom to become more stable. The process of going from an unstable to a more stable form is the process that is called radioactive decay (also referred to as radioactivity).

An atom which stabilizes by radioactive decay always forms a different element. For example, radioactive carbon-14 decays into nitrogen-14, a different element.

The stable atoms, on the other hand, are not moved to attain more stability and undergo no such process. These atoms would be referred to simply as non-radioactive atoms.

Families of elements exist for all of the atoms and all members of a family are the same element. For example, the hydrogen family consists of H-1, H-2, and H-3. Hydrogen-1 and hydrogen-2 are not radioactive, but hydrogen-3 is radioactive. All three members are isotopes of each other but hydrogen-3 is a radioisotope.

It is important to remember that it can not be assumed that if radioactive decay occurs that a non-radioactive element will be produced for every element. The decay product may or may not be non-radioactive. It depends on the particular elements undergoing decay. For example, P-32 decays to non-radioactive S-32 while Sr-90 decays to radioactive Y-90.

Rate of Radioactive Decay

All radioactive elements do not decay at the same rate because they usually have a different degree of instability. Elements which are highly unstable decay at a very fast rate. Those that are only slightly unstable decay at a very slow rate.

The rate at which radioactive atoms decay is defined in terms of something known as a half-life ($T_{1/2}$). The half- life of an element is the amount of time required for one-half of all the atoms in the sample to decay. Therefore, if the half-life of iodine-131 is 8.05 days then it will decay at a much faster rate than carbon-14, which has a half-life of 5730 years. Half of any iodine-131 in possession will be gone in 8.05 days but only after 5730 years would half of the carbon-14 be gone.

There is no typical half-life of an element. Half-lives range from billions of years to seconds. For example potassium-40 has a half-life of 1.3 billion years while oxygen-14 has a half-life of 72 seconds.

The undecayed atoms remaining in a sample decreases by one-half during each length of time equal to the half-life. With iodine-131, after 8.05 days, half of the sample is decayed and one-half remains. After two half-lives, one- fourth of the sample remains undecayed and three-fourths will have decayed as indicated in the table below.

Number of Half-lives Passed	Fraction Remaining	Fraction decayed
1 *(8.05 da.)*	1/2	1/2
2 *(16.1 da.)*	1/4	3/4
3 *(24.15 da.)*	1/8	7/8
4 *(32.2 da.)*	1/16	15/16
5 *(40.25 da.)*	1/32	31/32
6 (48.30 da.)	1/64	63/64
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10 *(80.5 da.)*	1/1024 or 9.8 X 10^{-2}%	1023/1024

It can be seen that after 10 half-lives the fraction remaining has been reduced to 0.098 %. If 5 millicuries of I-131 is purchased and allowed to decay through 10 half-lives or *80.5* days then only 4.9 microcuries would remain at this time. So the quantity has decreased from a moderate amount of radioactivity to a very small amount. This method may be used as a means of waste disposal by holding a sample of radioactive material for decay until no activity is detectable with a radiation instrument.

EXPRESSING THE QUANTITY OF RADIOACTIVE MATERIAL

Quantities of radioactive material are not commonly expressed in grams. The reason is that the material is purchased for the radiation-producing decays and expressing the weight in grams bears only an indirect relationship to the radioactivity. The shorter the element half-life the higher is the decay rate per gram (specific activity) and the longer the half-life the lower is the decay rate. For example, the decay rate of a gram of phosphorus-32 (half-life of 14.3 days) is about 30 times faster than a gram of hydrogen-3 (half-life of 12.3 years). Therefore, it is usually more useful to express in terms of a decay rate.

The curie (abbreviated Ci) is an older unit which has been used for many years to express the quantity of a radioactive material as a decay rate. One curie is equal that amount of radioactive material which has 3.7 X 10^{10} atoms decaying per second (dps) or 2.22 X 10^{12} atoms decaying per minute (dpm).

The curie is a very large quantity of material for many types of use so prefixes such a milli- (1/1000) or micro- (1/1,000,000) are used to express smaller quantities. The millicurie is written as mCi and the microcurie is written as :Ci (: = Greek letter micro). The microcurie should never be written any other way, especially as mCi or MCi. Many problem have resulted from the improper expression of the microcurie. In some types of use the kilocurie (1000 X the curie) is more convenient to use.

Remember: 1 :Ci = 3.7 X 10^4 dps = 2.22 X 10^6 dpm
1 mCi = 3.7 X 10^7 dps = 2.22 X 10^9 dpm
1 mCi = 1000 :Ci
1 :Ci = 0.001 mCi
1 kCi = l000Ci

Example 1: How many millicuries are in 1.2 curies?

X = (1.2 Ci)(1000 mCi/Ci) = 1,200 mCi

Example 2: How many :Ci are in 5 mCi?

X = (5 mCi)(1000 :Ci/mCi) = 5000 :Ci

Example 3: What decay rate in dpm would be expected from 2.5 :Ci of a radioactive sample?

X = (2.5 :Ci) (2.22 X 10^6 dpm/:Ci) = 5.55 X 10^6 dpm

Example 4: A radioactive sample is producing a decay rate of 5.43 X 10^8 dpm. What is the radioactivity in mcuries?

X = (5.43 X 10^8 dpm) / (2.22 X 10^9 dpm/mCi)

X = 0.244 mCi

With the implementation of the SI system of measurements the curie was scheduled to be phased out and replaced by a unit called the becquerel (abbreviated Bq) which is equal to 1 dps. However, at the present time the curie is still legal for use except in transportation labeling. There is really no timetable for the conversion so the becquerel or curie may be used presently. The becquerel will usually be required if the data goes into a publication which is distributed internationally. The becquerel is in use essentially worldwide except in the United States.

Example 1: A sample is producing 3.4 X 10^8 dps. How many becquerels are in this sample?

X = (3.4 X 10^8 dps)(1 Bq/dps) = 3.4 X 10^8 Bq

Example 2: How many Bq in 20 mCi?

X = (20 mCi)(3.7 X 10^7 dps/mCi)(1 Bq/dps) =

X = 7.4 X 10^8 Bq = 0.74 gigabecquerels

RADIOACTIVE DECAY CORRECTIONS

In the course of doing research with unsealed radioactive materials it is common to purchase labeled material days if not weeks in advance. As is characteristic with radioactive material the radioactivity would decrease with passage of time. As was discussed earlier in this chapter the rate at which the radioactivity decreases is dependent upon the half-life of the material. For example, a radioisotope with a half-life of 14 days will have one-half of its radioactivity after 14 days. On the other hand, a radioisotope with a half life of 60 days will have one-half of its radioactivity after 60 days. The fraction of a radioactive sample remaining after a length of decay is expressed by the following equation:

$$f_r = e^{-0.693 \times t / T_{1/2}}$$

Where 0.693 = constant
t = elapse time
$T_{1/2}$ = half-life

So if a radioactive sample, with a half-life of 12 days, initially contained 4 mCi (A_o) then the amount of radioactivity remaining (A) after 5 days could be calculated by the following equation:

$$A = A_o \times f_t$$

$$A = A_o e^{-0.693 \times t / T_{1/2}}$$

$$A = 4 \text{ mCi } e^{-0.693 \times 5 \text{ days } / 12 \text{ days}}$$

$$A = 4 \text{ mCi} \times 0.749 = 2.997 \text{ mCi}$$

Example: 1 A sample of 10 mCi of H-3 was purchased on October 4, 1999. How many mCi of radioactivity on October 4, 2002. The half-life of H-3 is 12.3 years.

$$A = A_o e^{-0.693 \times t / T_{1/2}} = 10 \text{ mCi } e^{-0.693 \times 3 \text{ years } / 12.3 \text{ yrs}} = 8.44 \text{ mCi}$$

Example: 2 A sealed source of Co-60 which was purchased with an activity of 5 curies. The source has been use for 20 years. What activity remains in the source if the half-life of C0-60 is 5.2 years.?

$$A = A_o e{-0.693} \times t / T_{1/2} = 5 \text{ curies } e^{-0.693 \times 20 \text{ yrs } / 5.2 \text{ yrs}} = 0.348 \text{ curies}$$

TYPES AND ORIGIN OF RADIATION

As discussed previously the excess mass-energy of the nucleus drives it to absorb or emit particles so that the more stable state is achieved. If this process does not achieve required stability then a form of electromagnetic radiation known as gamma rays carries away the excess. The decay process of some atoms involve gamma emission whereas others involve only particles.

ORBITAL ELECTRON CAPTURE

Orbital electron capture (EC) is also known as K-capture since the process involves the capture of a K-shell electron which is absorbed into the nucleus. The absorbed electron remains in the nucleus so no particles are involved.

The vacancy left in the orbital shell by the removal of the electron is immediately filled by higher energy electrons. The transition from higher energy shells to lower energy shells causes the production of “characteristic” X-rays. Therefore, the only type of radiation emitted from these atoms are rather weak X-rays. Iodine-125 and chromium-51 are examples of atoms which decay by this process.

Some atoms decay by both positron decay and electron capture. Typically you might have 10 % positron decay and 90 % electron capture or perhaps 40 % decay positron and 60 % electron capture. Regardless of which decay mode occurs the decay element is the same, however. Sodium-22 is an example of an element which decays by both positron decay and electron capture with neon-22 produced as the decay product for both modes of decay.

BETA DECAY

The term beta decay refers to negative beta decay which is an electron identical to those found in nature. The beta particle is emitted from the nucleus with energies ranging from a few tenths of an MeV to usually not more than about 3.0 MeV.

The beta particle is emitted with a spectrum of energies. The energy of the particle may be cited in references as either the maximum energy (E_{max}) or the average energy (E_{avg}). The average energy is usually calculated as 1/3 of the maximum energy. For example, the maximum energy of P-32 is 1.71 MeV_{max} the average energy would be (1/3) (1.71 MeV) or 0.57 MeV_{avg}

The beta particle travels a considerable distance in air. The rule of thumb is a distance of about 12 feet per MeV in air. Therefore, a P-32 beta particle with an energy of 1.71 MeV_{max} would travel maximally about (12)(1 .71 MeV) or 20.52 feet in air. For tissue, the rule of thumb is about 0.36 cm per MeV so it can be seen that a P-32 beta would travel about 0.6 cm into tissue. The dead protective layer of tissue is only 0.007 cm thick so most of the penetration is in living tissue.

An energy of at least 0.07 MeV is required to penetrate the dead protective layer of the skin. So it can be seen that tritium (H-3) betas with an energy of 0.0186 MeV_{max} cannot penetrate this layer. Carbon- 14, with an energy of 0.156 MeV_{max} is a borderline case. Most of the beta particles cannot penetrate the protective layer of the skin but a low percentage can.

When beta particles penetrate materials a rather unusual type of event occurs. The beta energy is converted to a form of electromagnetic energy called bremsstrahlung (Gr. braking radiation) which is nothing more than weak X-rays. The X-rays produced are very similar to medical and dental X-rays. The extent of production is linked to the atomic number of the material through which the beta is penetrating and the energy of the beta. The higher the atomic number and the more energetic the beta particle then the more bremsstrahlung is produced.

It should be remembered that when using beta sources the only concern is not just the beta particle but there must also be concern for the production of significant amounts of bremsstrahlung.

RADIATION UNITS

There are two systems of units used to express the damaging effects of exposure to different types of radiation. One can simply be referred to as the Old Metric System and the other the new International System, the SI. There are three units in each system which expresses the different ways in which the radiation dose is defined.

OLD METRIC SYSTEM

1. The Roentgen (R)

The roentgen unit came into use after the discovery of the X-ray machine because many individuals were suffering damage and there was no system to indicate when too much had been received.

The roentgen was defined to be measured in air in the vicinity of an individual for whom the dose was desired. Since this was not a direct measure of the tissue dose the unit was referred to as an “air dose” or an “exposure dose” and is defined as follows:

$$1\ \text{R} = 2.58 \times 10^{-4}\ \text{coulombs/kg (air)}$$

This unit is basically used only for expressing exposure doses with survey meters and pocket-type dosimeters.

2. The Radiation Absorbed Dose (rad)

Since the roentgen was defined for an air dose many researchers were not pleased with the unit and wanted a replacement. Their desire was to have a unit to measure the absorbed dose in any kind of material. A new unit called the “rad” was actually developed and implemented and was defined as follows:

1 rad = 100 ergs of radiation energy absorbed / gram of any material.

The rad is normally not used in radiation safety compliance but is used only in research and almost exclusively in medical areas. The original intent was for it to be used in compliance also but it turned out to be a faulty unit. One rad of beta dose, for example, did not produce the same damaging effects as one rad of alpha dose so the unit was inconsistent. A unit was needed which would give the same effect for any type of radiation with a unit dose.

3. Roentgen Equivalent Man (rem)

To correct the situation produced by the rad a new unit called the “rem” was devised. This corrected the error by multiplying the rad by a “fudge factor” to make up for the discrepancy. The fudge factor was called the quality factor (Q.F.)

Rem = rad x Q.F.

When the dose is expressed in rems equal doses of any type of radiation produces the same biological effect. It is for this reason that the unit is referred to as the “equivalent dose” or the “dose equivalent”. It is the only unit normally used for record-keeping. All governmental regulations as well as film badge results are reported in units of rems.

INTERNATIONAL SYSTEM

The radiation units which are part of the International System of Measurement are in use essentially world wide but the Nuclear Regulatory Commission is not presently requiring their use in the U.S. However, any publication which is international will require the use of these units.

1. Coulomb Per Kilogram (C/kg)

The plan is to replace the roentgen with the unit coulombs/kg (air) which will mean that the way in which the dose is used has not changed but only the way in which it is defined. The C/kg is a large unit so a prefix of micro- or milliC/kg is appropriate for low dose rates.

2. Gray (Gy)

The gray will replace the rad and has the same basic definition of energy per gram of a material but the unit of gray is 100 times larger than the rad so the unit is converted as follows:

1 gray = 1 joule/kg = 100 rads

3. Sievert (Sv)

The sievert will replace the rem and is defined in the same way. For example:

sievert = gray x Q.F.

Since the sievert is a larger unit than the rem it is more appropriate to express the dose in microsieverts or millisieverts.

BIOLOGICAL EFFECTS OF RADIATION

GENETIC AND SOMATIC EFFECTS

There are two types of biological effects which are studied, researched, and reported in the literature. These are genetic and somatic effects. Genetic effects are those effects which are inherited from generation to generation as a result of information carried in the reproductive material. Somatic effects are those effects which arise from the damaging effects of energy deposited in general body tissue such as muscle tissue. Somatic effects are not inherited from one generation to another.

Genetics effects are carefully considered when the population dose limits (170 mrem/yr) are set. However, with all of the studies it has never been shown unequivocally that radiation produces a genetic effects in humans. Genetic effects certainly occur in lower forms of life and these have been amply reported.

ACUTE AND CHRONIC EXPOSURE

There are two ways in which a radiation exposure may occur; either acute or chronic. Acute exposure refers to a high dose rate for a short or long period of time such as occupational conditions. Chronic exposure refers to a low dose rate over a long period of time such as environmental conditions.

The reason for classifying the exposures separately is that the biological effect is different and requires a different timetable to appear. Biological effects from radiation exposure do not appear immediately. All cases have a latent period (no symptoms) between exposure and biological effect. The lower the total dose the longer is required for the symptoms to appear. With chronic exposure, for example, the time required for symptoms to appear may be as long as 20 to 25 years. At very high total doses, as in acute exposure, the latent period will disappear altogether.

With high doses of radiation (greater than several hundred rems) some effects would be seen immediately and would consist of a decrease in circulating blood cells and gastrointestinal damage, while at thousands of rems there could be damage to the central nervous system, primarily the brain.

With chronic exposure the primary biological effect would be cancer induction. The elapse time before the symptoms appear would vary with the total dose but could be as long as 20 to *25* years. The average latent period is 15 years. However, the chances of developing cancer from the amount of exposure received at OSU is practically zero. Very few workers receive a measurable dose in all of the time they work here. When the effects from medical and dental X-rays are considered the effects from OSU exposure is very small.

PERSONNEL DOSIMETER

A personnel dosimeter is a device which is worn on the individual to measure the radiation dose. The aluminum oxide dosimeter (Luxel) is worn as a badge, for this purpose, at OSU.

The aluminum oxide dosimeter functions by absorbing the energy (radiation) which is emitted from a radiation source as the dosimeter is worn. The aluminum oxide crystal stores the energy in the trapping centers within the crystal. The energy stored within the crystal is proportional to that absorbed by the body tissue so when the energy dose to the crystal is measured the dose to the tissue can be determined. To “read” the dose the aluminum oxide crystal is subjected to a laser beam which stimulates a specific population of trapping centers to release energy in the form of visible light. Since there are several populations of trapping centers, the dosimeter may be read several times if there is a need. The dosimeter has a case, which is a part of the measuring system, and an open window to the film and a special area inside the case for the aluminum oxide material. The badge cover will have a special background scene for your particular college or department. A human figure on the badge indicates with a small dot where the badge should be worn.

The routine for using a dosimeter badge consists of starting with a new badge at the first of each month. The deep dose (whole body) badge is worn in the chest area with the open window facing outward. The open window along with another area of the badge allows the beta dose (shallow dose) to be determined. The finger badges are of course worn as a ring on the fingers

The chest badge will measure all types of radiation except alphas and very weak beta particles. The weak betas in C-14, H-3, and S-35 are not energetic enough to penetrate the badge wrapper so they cannot be monitored with a badge. Therefore, no badges are assigned for pure beta emitters like C-14, H-3, and *S-35*. If the weak beta source also emits gamma radiation, then a badge would be used.

Remember that any medical or dental exposure is not part of your work and the exposure should not be recorded on your film badge. In addition, this badge is assigned to one individual and others should not use it.

SURVEY METERS

Survey meters are portable instruments which each department will have which consists of a radiation sensitive detector and a scaling device to display the count rate or dose rate. The count rate (CPM) scale indicated the number of radiation interactions in the detector per minute. The dose rate scale (mR/hr) indicates the dose rate in mR/hr (**valid for X- & gamma rays only**) which is equivalent to mrem/hr. Some departments have meters which do not have a mR/hr scale so a graph is available providing a conversion from CPM to mR/hr. For meters which have both scales, the detector window should be open for the CPM scale and the window closed for the mR/hr scale.

RADIATION PROTECTION

Radiation protection is necessary from two different perspectives; external and internal. External radiation protection is the process of minimizing the dose from sources which are outside the body. Internal, on the other hand, is protection from radioactive material which has made its way into the body. The method of protection is not the same for external as for internal.

EXTERNAL RADIATION PROTECTION

There are three methods used to protect from external sources. These are (1) time, (2) distance, and (3) shielding.

1. Time

    The total radiation dose is directly dependent upon the dose rate and the time spent around the source. So protection can be afforded by reducing the dose rate. This can be done by using smaller amounts of radioactive material. However, in many cases there is a minimal amount which must be used to get desired results. So, to reduce the total dose under any circumstances just don’t spend any more time doing a procedure than is necessary.

2. Distance

If the time spent in an area cannot be reduced by doing a procedure more quickly then distance may be relied on for protection. The basic premise is to move away from the source of radiation. The radiation emitted from most work arrangements will follow the so-called "inverse square law". This means that if the distance increases by a certain factor then the dose rate will decrease by the square of that factor. So what if a worker is working 2 feet from a source and then decides to move to a distance of 10 feet from the source. The distance has increased by a factor of 10 / 2 or 5. The corresponding dose rate will then decrease by a factor of $(5)^2$ or 25. The following inverse square equation can be used by simply entering all of the variable.

$$(\text{1st distance})^2 (\text{Drl}) = (\text{2nd distance})^2 (\text{Dr2})$$

Where: Dr = dose rate 1 and 2

Example 1: A worker is receiving a dose rate of 20 mrem/hr when 2 m from a source of radiation. What will be the dose rate at 6 m?

The distance has increased by a factor of 6 / 2
or 3 so the dose rate will decrease by $(3)^2$ or 9.

$$\text{Dr} = 20 \text{ mrem/hr} / (6/2)^2 = \mathbf{2.22\ mrem/hr}$$

Example 2: Repeat of Example 1 using the inverse square equation.

$$(2 \text{ m})^2 (20 \text{ mrem/hr}) = (6 \text{ m})^2 (\text{Dr2})$$

$$\text{Dr2} = (4 / 36)(20 \text{ mrem/hr}) = \mathbf{2.22\ mrem/hr}$$

3. Shielding

If neither of the two previous methods of radiation protection are effective then the source must be shielded. This involves placing an appropriate shielding material between the worker and the source.

For beta emitting sources lucite, plexiglass or low atomic numbered materials in general are necessary for shielding and the lessening of bremsstrahlung production. A thickness of one-half inch is suitable for all beta particles which will be encountered.

For gamma and X-ray shielding a layer of lead which is appropriate for the photon energy is necessary. At least 1/8 inch thick layer of lead is necessary for the weak photons from Cr-51 and 1-125. For Cs-137, a lead thickness of 1/4 inches is needed to reduce the beam by one-half. For more energetic photons such as Co-60, 1/2 inches of lead is needed to reduce a beam by one-half. However, the more lead that can be used the better since it will progressively lower the dose rate received by the worker.

INTERNAL RADIATION PROTECTION

The principles of internal radiation protection take the form of an old adage, “an ounce of prevention is worth a pound of cure”. The rationale is to provide a clean work environment so that radioactive material is not ingested, breathed, or absorbed through the skin or a wound.

To prevent uptake through the lungs the air must be free of any radioactive gases or vapors. Any radioactive material which has the possibility of producing a gas should definitely be used in a hood which has proper flow so that it does not flow back into the lab. Iodine-125 and S-35 are two radioisotopes which have a high likelihood of producing some gas or vapor.

Uptake by ingestion can occur by several blatantly incorrect activities such as pipetting radioactive material by mouth. This should never be done under any circumstances or for any reason. The second way in which radioactive material may be ingested is by eating, drinking, and smoking in the lab. No food or drinking material should be present in the lab. The Oklahoma Department of Environmental Quality might take this to indicate that food and drink is probably being consumed in the lab and they could issue a citation. Licensees have also been cited for having an empty coffee pot in the lab.

The control of material so that excessive internal deposition does not occur is accomplished by limiting the concentration in air, water, and food.

Control of excessive uptake utilizes limits such as the Annual Limits on Intake (ALI) and the Derived Air Concentration (DAC). There are two Annual Limits on Intake, one for ingestion and one for inhalation. An Annual Limit on Intake is the quantity of radioactive material in :Ci, which may be taken into the body by either of the two processes per year. The Derived Air Concentration, which is the maximum allowable air concentration, is calculated by dividing the ALI for inhalation by the annual air intake to yield :Ci/ml. It may be seen then that control of excessive uptake is achieved by regulating the environmental levels.

There is also a limit on the quantity of radioactive material which may be released to the sewers. This is referred to as the Monthly Average Sewer Concentration and is expressed in :Ci/ml. This is the highest concentration of radioactive material which may be released into the sewer when the monthly sewer dilution is considered. The sewer dilution occurs by the release of normal sewer water during month. In other words, the concentration may be averaged over one month.

Measures can be taken in the laboratory to minimize the concentration in air by placing all solid waste in plastic lined trash containers. The containers must have a secure lid to prevent drying of the waste and suspension in the room air. Waste containers should also be labeled as containing radioactive material and not produce a dose rate greater than 2.0 mrem/hr.

There should be one sink which is dedicated to the use of radioactive material for disposal and clean-up. This sink should be labeled as containing radioactive material.

All equipment, such as stirrers and centrifuges, which are used on a routine basis for radioactive material should be labeled as such.

LABORATORY CLASSIFICATIONS

Laboratories are classified within four types depending on the potential for internal uptake of radioactive material. The potential for uptake is expressed as a function of the annual limit on intake (ALI) which determines the frequency of surveys, laboratory facilities, and specialized equipment. The classification scheme is shown in the table below:

(a) Type-1 (<1 ALI)	Lockable lab and storage area functional work bench + sink and running water	**Refer to facts sheets for ALI values. Use the most limiting value.**
(b) Type-2 (1-20 ALIs)	Type-1 lab requirement	
(c) Type-3 (>20 ALIs)	Type-2 lab requirement + exterior exhausting hood or a filtered interior exhausting hood.	
(d) Type-4 (Sealed Sources)	Lockable lab and storage area	

REGULATORY CONTROL

LICENSING

In order to possess and use a radioactive material the University must possess an appropriate license for the material to be used. Practically all of the materials used at OSU are covered by a license known as a Byproduct Material License. The license is issued by the Oklahoma Department of Environmental Quality (ODEQ) with oversight by the Nuclear Regulatory Commission (NRC) for a period of *9* years in past years after which an application is required for its renewal. The most recent licenses were issued for a period of 10 years.

The license states specifically which radioisotopes may be used and in what quantities and how the University may use them. Any action in contradiction to the license conditions could result in an enforcement/corrective action by the ODEQ (NRC). This may include fines, liability suits, and loss of the OSU Broadscope Radioactive Materials License.

Radioactive material is classified in two broad categories for compliance purposes. These are (1) chemical sources of radioactive material and (2) sealed sources of radioactive material. Chemical sources of radioactive material would be a radioactive chemical like $^{22}NaCO_3$ in a vial which would look like any non-radioactive compound. A sealed source of radioactive material would be a compound of Cs-137 which is encapsulated in water-tight stainless steel so that the chemical compound does not leak out of the capsule.

LABELING OF LABORATORIES

Each laboratory cleared for the use of radioisotopes should have each entrance labeled appropriately by the RSO. The label should indicate CAUTION: RADIOACTIVE MATERIAL or RADIATION AREA.

Every lab which is labeled for use of radioisotopes must also have these items posted:

(a) Instruction to Workers", which is the ODEQ Form 64
(b) A copy of Section 206 of the Atomic Energy Act of 1*954*
(c) Instructions Concerning Prenatal Exposure
(d) Emergency Procedures
(e) Decontamination Procedures
(f) List of Authorized Radioisotopes
(g) List of Trained Workers

The Forms will be posted inside the laboratory. They provide information the ODEQ (NCR) considers important with respect to having a safe working environment. If any of these items are not posted, call the Radiation Safety Office at *744-8721 (7890).*

ALARA

Although the NRC sets limits for various purposes it still expects that all doses and levels will maintained As Low As Reasonably Achievable (ALARA). A laboratory is not in compliance if doses and levels are not as low as they could be with a reasonable amount of effort and experiment planning.

PREGNANCIES

If anyone working in a radioisotope lab should become pregnant, this fact should be communicated to the faculty supervisor and to the RSO (Cordell 226 or *744-8721 (7890)),* immediately. The NRC considers the first 17 weeks of pregnancy to be the most critical so care should be taken to avoid exposure during this time.

The pregnant individual has the option of becoming a “Declared Pregnant Woman” by completing paperwork provided by the ODEQ (NRC). This classification reduces the allowance dose rate to 500 mrem during the entire pregnancy.

RADIOISOTOPE AUTHORIZATION

Each researcher who uses radioisotope must be authorized by the University to do so. The authorization is obtained by first accessing the Radiation Safety website for a Radioisotope Authorization Request Form. (www.vpr.okstate.edu/radiology) The form is completed by the applicant and approved by the Department Head and returned to the RSO. The application is then approved by the Radiation Safety Committee and the Vice-President for Research*. A certificate indicating authorization and the authorized quantity is then mailed to the applicant. The authorized quantity* is the purchase limit for individual order.

RADIOISOTOPE PURCHASES

The purchase of all radioisotopes must be pre-approved by the Radiation Safety Office. The process begins by the researcher filling out the required form obtained from* and signing it. The form is then forwarded to the RSO for University approval. When the approved form is returned to the Department then the purchase may be made. Phone order approvals are not allowed but researchers may FAX the order to the RSO office for approval (FAX 744-2542). Purchases which do not have prior approval will not be delivered by University Mailing Service.

All purchases of radioisotopes must have each layer of containment (including the outside) checked for contamination before it is placed in storage. This method is described in Appendix A of this manual.

RADIOISOTOPE STORAGE

When radioisotopes are received they must be placed in a secure storage area where unauthorized removal cannot occur. They may be placed in a locked cabinet or refrigerator or within any area with a locking outer door. During times when the lab is unattended the area should be securely locked. The storage area should be labeled with an appropriate label which is usually “Caution Radioactive Material”.

The storage container should be labeled with a “Caution Radioactive Material” label which provides such information as quantity of radioactivity and date of estimate, radiation levels, if any, and kind of material.

WASTE DISPOSAL

Chemical sources of radioactive material invariably produce a waste product when used for research. The waste may be legally released into the sewer so long as the limits described previously are not exceeded and it is water soluble.

If the radioactive material is placed in bags or vials for liquid scintillation counting it may contain an organic solvent such as toluene and cannot be released into the sewer.

If the liquid scintillation counting material is C-l4 or H-3 and the concentration is 0.05 :Ci/ml or less then it may be treated as though it was not radioactive. If the bags or vials contain an organic solvent then it must be treated as an organic chemical. There should be no radioactive labels on the bags or vials. This type of waste is classified as List A waste.

If C-14 or H-3 waste has a concentration of 0.05 :Ci/ml or less but is <u>not</u> a liquid scintillation fluid it must be classified as List B. Both ListA & B Forms are available on the Radiation safety office website (www.vpr.okstate.edu/radiology).

Liquid scintillation fluids, other than H-3 and C-14, whether they contain an organic solvent or not, would be considered as radioactive and classified as List B waste.

All solid material such as wipes, gloves, and pipettes would be classified as List B waste, even H-3 and C-14. Also, solutions containing radioisotopes, other than H-3 and C-14 in concentrations as described above, would be classified as List B. These radioisotope should be packaged separately.

For short-lived radioactive material, such as I-125, Cr-51, P-32, S-35, and P-33, which will be held for decay, each should be packaged separately and the information placed on List B Forms. No radioactive labels are to be placed inside the boxes containing this material.

Information concerning the specific packaging procedures for disposal is available on the backside of List A and B Forms. To dispose of radioactive material, follow these specific instructions and send the List A and B Forms to the RSO at Cordell 398.

INCOMING PACKAGES

All packages containing radioactive material must be tested for radioactive contamination as the package is opened, unless it contains only a gas or a sealed source. The test is done with a small filter paper by simply wiping to remove any loose contamination. Each level of containment, <u>including</u> the outside, is wipe-tested and counted as the package is opened. Except for P-32, I-125, and Cr-51, the count done on the different layers should be counted on an appropriate counter rather than by use of a survey meter. If significant contamination is found the RSO should be notified. A record of the counting results of each layer of containment should be kept for inspection by the RSO and the NRC. The minimum sensitivity, also referred to as the minimum detectable activity (MDA) and the minimum detectable count rate (MDCR) of the counting system , the counting efficiency, and the background count should also be kept as part of the record (Appendix A). The test for contamination may be done as either count rate or activity, however, all data expressing the quantity of contamination must be either in DPM/cm^2 or :Ci/cm^2

The MDCR is calculated by the following equation. The MDA is the MDCR divided by the counting efficiency (CPM/DPM).

$$\text{MDCR} = 3\sqrt{2R_b / t_b}$$

Suppose a swipe had a background count rate (Rb) of 25 CPM and was counted for 2 minutes. The sample count rate (Rs) was 40 CPM and was also counted for 2 minutes. Is the sample contaminated or is the difference just due to the random nature of sample and background?

The MDCR, calculated from the equation above yields, 15 CPM. The net count rate (RsRb) yields 15 CPM. **If the net CPM** is equal to **or greater than the MDCR then it may** be **concluded that there is contamination. If the net CPM** is less than **the MDCR then there is no contamination.** It can be seen that the net count rate (15 CPM) is equal to the MDCR *(15* CPM) therefore the wipe is contaminated. Since the wipe is contaminated the activity must be entered in DPM/ cm^2 or :Ci/ cm^2

Had the wipe-test activity been 30 CPM then the wipe would not be contaminated (15 CPM >3O CPM-25CPM) at the 99.7% C.L. The tests for contamination may be made in CPM but all data expressing contamination of wipe-tests must be either in DPM / cm^2 or microcuries / cm^2.

ROUTINE LABORATORY SURVEYS

Wipe tests and area surveys of the work area should be performed according to the following routine:

Lab Type-1	Weekly when radioisotopes are in use.
Lab Type-2	Daily when radioisotopes in use.
Lab Type-3	Daily when radioisotopes in use.
Lab Type-4	Whenever sealed sources are in use.

These procedures are performed at the appropriate intervals to detect any contamination which may be left behind. The wipes are done by wiping an area of approximately 100 square centimeters where the work surface is flat. If the surface is very irregular then the surface area requirement is not necessary. The wipes are counted in an appropriate counter (not a survey meter) and the records are kept for inspection by the RSO and the NRC. The minimum sensitivity (MDA) of the counting system, counting efficiencies, and the background count should also be kept as part of the record. Use the same procedure to test for contamination of laboratory wipe-tests as was described in the latter section for packages. Surveys with a meter may replace the wipes for gamma and high energy beta emitters like P-32, Cr-51, I-125,and I-131.

Each laboratory must show on an annual basis that members of the public (non-radiation workers) did not receive a dose in excess of 10 mrem/year from air contamination emanating from their laboratories.

RADIATION DOSE RECORDS

Records of the film badge results are maintained by the RSO in Cordell S. 392. An annual summary of the radiation dose for each monitored individual is provided on a yearly basis. These are usually sent out around July 1 and will be mailed to your campus address.

LEAK TESTING OF SEALED SOURCES

Any sealed sources which are owned by the researcher must be leak tested twice a year (April 1 & October 1) if required by the OSU license. Any beta/gamma emitting sealed sources do not require leak testing if the activity is equal to or less than 100 microcuries. For alpha emitting sources the value is equal to or less than 10 microcuries.

The leak test procedure involves wiping the source with a filter paper to remove any loose contamination and counting in an appropriate counter. Around April 1 and October 1 of each year the RSO sends out the wipe test materials (filter paper) and a notice that the leak testing must be done on the first of the month. The wipes may be returned to the RSO for counting. A record of the wipe test results are maintained for inspection by the ODEQ (NRC).

MEMBERS OF THE PUBLIC

Members of the public or so-called non-occupational workers are those individuals who are employed in areas where radioisotopes or radiation sources are used but do not actually participate themselves. These individuals are not monitored on a continual basis but we still have to insure that they do not exceed the limits set for them. There is a yearly limit and an hourly limit set for them with respect to deep dose exposure. The yearly limit is 1/50 of the occupational limit or 100 mrem/yr. This dose is about the same as natural background in Oklahoma. The hourly dose limit is set at 2.0 mrem in any one hour. If any gamma, x-ray or bremsstrahlung sources are used in the laboratory the annual dose must be determined for them.

TRANSPORTATION

Radioactive material may need to be transported from one location to another, such as a building- to-building transfer. If it is not carried on public roadways then the radioactive material (loose or sealed) must be secured against spillage or leakage, labeled with respect to radioactivity, and monitored for the dose rate. The dose rate limit is 2.0 mrem/hr if it is where members of the public might come in contact with the container.

If the radioactive material is moved on public roadways then the workers involved must be HazMat trained. The ruling from the NRC is that all roads on Campus are public. If you package for transport, label, load , drive, etc., then Hazmat training is required. Contact the Radiation Safety Officer before you involve yourself in this type of transportation.

REPORTING

If it is known or suspected that a violation of the regulations is occurring or if it is felt that the area is not as safe as it should be then report this to the RSO at the following address:

Daniel Van Gent
Radiation Safety Officer
Cordell North 219, OSU
744-8721 (45716)