# LAMAR UNIVERSITY

# RADIATION SAFETY MANUAL

**REVISED AUGUST 2006**
**LAST REVIEWED AUGUST 2013**

**George Irwin**
**Radiation Safety Officer**

**In case of emergency involving radioactive materials, contact the University Police Department 880-8311. The Police Department will contact the Radiation Safety Officer and/or other knowledgeable person.**

## Record of reviews and amendments:

| Date | Person making review/amendment | Signature | Section(s) amended. |
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RADIATION SAFETY IN THE LABORATORY AND IN USE

A. The Radiation Safety Officer will be in charge of all radioactive materials and will have authority to control their use in all programs that come under this license. At the present time, the only materials in use are the Ni-63 Electron Capture Detectors in two gas chromatographs in the Environmental Chemistry Laboratory located in the Chemistry building in rooms 202 and 206, sealed sources (as detailed in item K below) used by and under supervision of Dr. George M. Irwin (whose lab is in room 212A of the Geology building), and aqueous solutions of P-32-labelled nucleotides in the possession of Dr. Maxim V. Soukhodolets (in room 218 of the Chemistry 2 Building). This safety program will address these three users and the care of the storage area. Additional programs will be addressed when and if they are to be added.

B. All radioactive materials will be ordered with the approval of the Radiation Safety Officer. This should ensure that the limit of the license not be exceeded. Access to these materials will be limited to the Radiation Safety Officer, Dr. George Irwin, Dr. Maxim V. Soukhodolets, or the Risk Manager. No materials should be delivered to the University during off hours. If perhaps they are, notify the campus police. The police will notify the Radiation Safety Officer, Dr. Irwin, Dr. Soukhodolets, or the Risk Manager.

C. When radioactive materials are received, the package will be surveyed by the Radiation Safety Officer, or Dr. Irwin, or Dr. Soukhodolets at the receiving department with one of the surveying meters. Rubber or plastic gloves will be worn until it is confirmed that no contamination is present. If contamination is indicated, wipe test will be made in a manner as described in Section E of this section. If removable contamination is 22,000 dpm per 100 sq cm on the external surface or greater, the final carrier and the Bureau of Radiation Control will be immediately notified. Telephone, telegraph or other rapid means of communication will be used for notification. The tests should be made as soon as possible and not later than three hours after the materials are received.

D.

1. Training for users of the gas chromatographs with Ni-63 containing Electron Capture Detectors will consist of warning not to in any way remove, damage, or revise the Ni-63 sources and that the cells will be leak tested by the Radiation Safety Officer every six months. (Microtec Services, Inc, 110 Charles Street, Pasadena TX 77506 will count the swabs). If there is any indication that the cell might be leaking, this must be reported immediately to the Radiation Safety Officer. Training may be carried out by the Radiation Safety Officer, by Dr. David Cocke, or by Dr. John Whittle.

2. The safety of the materials and student training in Dr. Irwin's lab will be done by him, using Chapter 3 of "Techniques For Nuclear Physics Experiments" (Springer-Verlag) to teach the students safety. At the completion of training, a test will be given. When they pass this to his satisfaction, they are permitted to help in the experiments. In any case Dr. Irwin is in complete charge and possession of the materials in his lab. These materials are either in the lead pig or in the locked cabinet. Dr. Irwin's experience, training, materials, and his expectations for his students are listed below.

3. The safety of the materials and student training in Dr. Soukhodolets's lab will be done by him, in a way similar to that was established earlier for Dr. Irwin's lab (see above, in section D2). The source vials containing P-32-nucleotides will be stored in a locked freezer at all times. Dr. Soukhodolets is in complete charge and possession of the radioactive materials in his lab. The solid and liquid P-32-containing waste will be treated and disposed as described below, in sections O-R.

4. Appropriate training programs will be developed and approved before any use is made of any other radioactive materials.

E. Surveys are to be made every six months in Dr. Irwin's and Dr. Soukhodolets's labs, and around exterior of their labs. If the exterior of the labs shows more background than accepted for a low-radiation area, more shielding must be added. If radiation is detected in unexpected locations or at unexpectedly high level, a wipe test of the indicated area is to be carried out. A diagram of the room should be used to show the survey results, and the location of any areas that were wipe-tested. All surveys will be made with the calibrated survey meter. Wipe tests will be made over an area of 100 sq cm withy cotton swab or filter paper. If the area to be tested is less than that, the whole body of the object will be wiped. If the wipes indicate more than 1,000 dpm, the area is to be cleaned with designated decontaminant until it is below that count. Surveys are to be made with the calibrated PUG1 meter. Contaminated materials must be stored in specified areas of the lab.

F. Previous records have shown that no individual monitoring devices are needed in the lab. Also, years of monitoring records of the Radiation Safety Officer indicates that he doesn't need any either. (Landauer). Documentation that the maximum possible annual exposure will not exceed 50 mR shall be prepared annually for the Radiation Safety Officer, for Drs. Irwin and Soukhodolets, and for each student involved in Dr. Irwin's and Dr. Soukhodolets's labs. Exposure calculations shall be carried out using the method described in Appendix II of this manual.

G. Aqueous solutions containing P-32-labelled nucleotides.

H. Inventories of materials are to be made of all radioactive materials every six months.

I. Survey instruments are to be calibrated once each year, by Microtec Services, Inc. (110 Charles Street, Pasadena, TX 77506).

J. Summary of Records to be Kept (all records must be dated and signed by the person making the record):

1. Inventories of materials every six months.
2. Calibration of the survey instrument once each year.
3. Receipt and disposal of all materials.
4. All occupationally absorbed dose.
5. Surveys and wipe tests in the lab.

K. Isotopes to be used by Dr. Irwin:

| Isotope | Form | Origin | Maximum Quantity |
|---|---|---|---|
| Co-57 | Sealed | Isotope Product Labs, Inc.<br>Idaho State University | 40 mCi |
| U-233 | Sealed | Idaho State University | 1 mCi |
| Th-229 | Sealed | Idaho State University | 0.015 mCi |
| Eu-134 | Sealed | Idaho State University | 0.005 mCi |

L. Protocols for Use of Isotopes Listed in Section K. (The abovementioned isotopes will be used only by Dr. George M. Irwin and selected undergraduate research assistants as part of a faculty and student research program and lab course work).

1. Co-57 Mossbauer Effect Sources. The Co-57 Mossbauer Effect Source will be used in a Mossbauer Effect Spectroscopy system for a variety of materials science research projects, including analysis of geological samples, magnetic materials, and the development of a novel surface imaging system. The maximum limit stated allows for two sources with initial activity of 20 mCi to be used.

2. U-233 Sources. The U-233 Sources obtained from Idaho State University will be used to continue an active research program concerning observation of optical radiation from sealed (quartz-covered) sources. These studies are related to a low-lying level in the Th-229 nucleus which is populated in the alpha-decay of the U-233 parent. The current sources have a total activity of 0.5 mCi, and the maximum limit stated above will allow for further sources to be used in the research.

3. Th-229 Sources. The Th-229 sources obtained from Idaho State University are also part of an active research program concerning studies of a low-lying nuclear state in this isotope which will involve excitation of the low-lying level from the ground state with optical means. The sources have an activity <0.002 mCi, but the maximum limit stated above will allow for the use of more sources in the future.

4. Eu-154 Sources. A 0.004 mCi Eu-154 source obtained from Idaho State University will be used for calibration and educational

purposes. The maximum limit stated above reflects the fact that no additional Eu sources will be required.

M. Experience of the primary users of the isotopes listed in section K.

In 1990 Dr. George K. Irwin received a Ph. D. in Physics from the Ohio University, where he routinely used Co-57 Mossbauer Effect Sources for his doctoral research. Following doctoral work, he was employed for two years at the Idaho National Engineering Laboratory (INEL, now the Idaho National Engeneering and Environmental Laboratory, INEEL) where he received detailed training in Radiation Safety. Following employment at INEL, Dr. Irwin held the position of Assistant Professor at Idaho State Univesity where he used a Co-57 Mossbauer Effect Source identical to the one to be obtained from Isotope Products Laboratories, and received further radiation safety training and gained considerable experience in the handling of these radioisotopes. Also at ISU, he was involved in research which included the U-233, Th-229, and Eu-154 sources which will eventually be used in continued research at Lamar University. Dr. Irwin has published results of his research with these sources in Physical Review.

N. Safety and training for isotopes listed in Section K.

1. *Safety.* All radioactive sources to be used by Dr. Irwin are sealed sources with minimal risk of leakage and contamination. Therefore the main radiological safety risks are due to gamma-radiation. No disposal of radioactive materials will be necessary as part of the work. Complete safety precautions will be taken for storage and use of the indicated radioactive sources, including, but not limited to:

   - Radioactive sources will be stored in the locked drawers in Dr. Irwin's research laboratory when not in use, with access limited to Dr. Irwin and the Lamar University Radiation Safety Officer.

   - To limit exposure to gamma-radiation from the Co-57 Mossbauer Effect source, the source will be stored in a lead box containing the Mossbauer Effect Spectrometer source transducer with a beam hole allowing only the passage of radiation necessary, for completion of experiments. Removal of the source from this semi-permanent storage position will be done only in the event that the apparatus is modified, in which the source will be stored in locked drawer in a suitable lead "pig" housing. All Co-57 sources will be stored in lead pigs in the locked drawer when not in use.

- Personnel working in the lab will not be exposed to more than or equal to 5 R/year [The annual TRCR limit per TRCR 21.201 (a)(1)(i)]. Therefore the use of radiation safety badges will not be required. Calculations and measurements to verify that maximum possible exposure meets the requirements for continued exemption from monitoring will be performed annually, and at any other time that a significant change in the sources of radiation occurs. Further support for not using personnel badges comes from Dr. Irwin's own radiation exposure record from Idaho State University where all of the above mentioned isotopes have been used in identical circumstances as requested at Lamar University (personnel at ISU were routinely badged as it was fiscally sound due to the large number of personnel in the department involved in radiation and radioactive materials).

2. *Training.* All persons using or handling the radiation sources will receive training from Dr. Irwin with the oversight of the Lamar University Radiation Safety Officer.

3. *Site of Radiation Material Use and Storage.* All experiments involving the use of radioactive materials, whether for research or educational purposes, will be performed in Room 212A of the Geology building at Lamar University.

4. *Waste Disposal.* All radioactive sources to be used are permanently sealed and no routine disposal of radioactive waste will be necessary. Even after the Co-57 has decayed such as to no longer be useful for research purposes (half-life 270 days), the source will be valuable for educational purposes. The relatively exotic U-233 and Th-229 sources will also not require disposal as future work, with approval at appropriate time, may require the isotopes to be put in other physical and chemical forms.

O. Isotope(s) to be used by Dr. Maxim V. Soukhodolets

| Isotope | Form | Origin | Maximum Quantity |
|---|---|---|---|
| P-32 | Aqueous Solution of P-32-labeled nucleotide | Amersham/Pharmacia | 20 mCi |

P. Protocols for use of isotopes listed in section "O".

The P-32 –labeled nucleotides will be utilized in *in vitro* transcription and labeling experiments. The labeling of nucleic acids with P-32 essentially gives the researcher means of detecting and identifying nucleic acids and/or their fragments;

typically, following the *in vitro* labeling, the P-32-labeled polynucleotides are separated by electrophoresis. The procedure of labeling nucleic acids with P-32 and the following electrophoretic separation is routinely carried out in most biochemistry/molecular biology laboratories. The procedure generates two types of P-32-containing waste: solid waste (polyacrylamide gels containing the P-32-labeled nucleic acids) and liquid waste (aqueous buffer containing the unincorporated label).

Q. Experience of Primary Users of isotope(s) listed in section "O".

After obtaining his Ph.D. degree from Moscow State University in 1992, Dr. Maxim V. Soukhodolets was employed for two years at Washington University in St. Louis, where he received detailed training in Radiation Safety. In 1995 Dr. Soukhodolets started his work at the National Cancer Institute (NIH), initially as a Visiting Fellow (1995-1999), and later as a Research Fellow (2000-2004). During his employment at NIH, Dr. Soukhodolets received additional detailed training in Radiation Safety and was an authorized user (NIH authorized user #031480) of radioactive isotopes, including P-32, for eight and a half years. Dr. Soukhodolets has extensively utilized existing protocols for P-32 labeling of nucleic acids and proteins, and has also developed multiple novel/modified biochemical protocols utilizing P-32; the results of Dr. Soukhodolets's research activity, including detailed protocols utilizing radioactive isotopes, have been published in peer-reviewed scientific journals and books such as *Methods in Enzymology*, *Genes and Development*, *Molecular and Cellular Biology, Journal of Biological Chemistry, Biochemistry, etc.* Dr. Maxim Soukhodolets joined Lamar University in August 2004 as an Assistant Professor, and his research activity in the Biochemistry Laboratory of the Department of Chemistry and Physics is a continuation of the research projects described in the publications cited below.

R. Safety and training for isotopes listed in section "O".

1. *Safety.* P-32 is primarily a beta-emitter with a relatively short half-life of approximately two weeks. Therefore, the safety precautions for handling aqueous solutions of P-32 deal primarily with (i) preventing/minimizing exposure to P-32-containing solutions *via* extensive shielding, typically utilizing 3/8 in. laminated (acrylic)-glass shields, which completely absorb the beta-emission, (ii) preventing spills of P-32-containing aqueous solutions - utilizing polyethylene-covered paper towels to cover the workbench surfaces (if accidental spills of P-32-containing aqueous solutions do occur, these disposable towels are simply discarded and treated as radioactive waste), and (iii) extensive monitoring of the laboratory with hand-held detectors before and after experiments with P-32-labeled nucleotides. Standard safety measures for handling P-32-labeled compounds will include (but will not be limited to): (a) storage of radioactive sources in

dedicated shielded containers in a locked –20˚C freezer (and the radioactive waste in designated containers placed in locked, 3/8 in. acrylic glass boxes) located in a single research laboratory (Room 118 in Chemistry 2 building), that is locked at all times with access limited to authorized personnel such as Dr. Soukhodolets or the Lamar University Radiation Safety Officer, (b) exposure of the personnel working in the lab to not more than 5 R/year [The annual TRCR limit per TRCR 21.201 (a)(1)(i)]. With the particularly short, 2-week half-life of P-32, and the planned purchase/utilization of approximately 5 mCi/year (typical monthly purchases will be in the range of 0.25-0.5 mCi), the actual exposures will be significantly lower than the aforementioned limit of exposure.

2. *Training.* All persons using or handling P-32-labeled materials will receive extensive training from Dr. Soukhodolets with the oversight of the Lamar University Radiation Safety Officer.

3. *Site of radiation material use and storage*. All experiments involving the use of radioactive materials, whether for research or educational purposes, will be performed in Room 118 of the Chemistry 2 building at Lamar University. All P-32-containing materials (source vials, liquid waste, and solid waste) will be kept at all times in appropriately shielded containers in locked boxes (a locked freezer in the case of the source vials containing aqueous solutions of P-32 labeled nucleotides) in the locked laboratory.

4. *Waste disposal.* Expected use of P-32 is approximately 5 mCi annually, and will not exceed 10 mCi under any circumstances. The half-life of P-32 is approximately two weeks. Five mCi held for two months will have decayed to 0.0195 mCi, and after 6 months to less than 0.000003 mCi (0.003 µCi). Liquid waste will be collected in approximately 20-liter polyethylene bottles, shielded by placing them in locked, high-capacity acrylic glass boxes; Daigger catalog #PX23602CX). Solid waste (polyacrylamide gels) will be collected in locked acrylic glass waste containers (Daigger catalog #PC23602DX). All waste will be stored in locked containers in locked, appropriately labeled cabinet for a minimum of six months. Every six months one set of shielded waste containers will be sealed, and stored in the locked cabinet for a further six months. All P-32 will be in the form of phosphate salts or esters, before and after use in experiments. The Beaumont Campus of Lamar University produces a sanitary sewer waste stream of approximately 3.25 million gallons per month. The permitted monthly average limit (Section 289.202(ggg)) for P-32 is $9 \times 10^{-5}$ µCi/ml. The

maximum possible amount of undecayed P-32 in a waste container after storage for 6 months, 0.003 µCi, in any volume in excess of approximately 33 ml of waste water will be below this limit. The liquid waste will be discarded to the sanitary sewer and will be at concentrations several orders of magnitude below the maximum permitted release. Records will be kept of all material disposed off in the sanitary sewer. The maximum possible amount of undecayed P-32 in solid waste that has been stored for 6 months, 0.003 µCi, will not produce radiation that is detectable over background. This will be verified by surveying the container and contents. This concentration of undecayed P-32 will be many orders of magnitude lower than the 10 $\mu Ci/m^3$ required to be labeled under Section 289.202(ggg)(7). The polyacrylamide gels do not constitute a hazardous waste, and will not contain radioactivity detectable above background. They will therefore be discarded in the University's regular trash disposal containers for transfer to a Class I landfill. Should any hazardous waste that could potentially contain p-32 be produced in any future experiments, the solid waste, after storage for at least 6 months, will be included in the University's next regular hazardous waste disposal contract. Records will be kept of all material disposed off in this manner. All laboratory equipment used for radioactive work will be segregated and labeled with radioactivity warning signs. Any equipment to be discarded will be stored for at least 6 months, surveyed to check for absence of detectable radiation, and then discarded in trash disposal. All radioactive warning labels will be removed or obliterated prior to disposal.

# I. THEORY OF ELEMENTS

Any material is made of atoms. Atoms are the smallest identifiable part of any material. Often in a gas , one atom is completely separate from every other atom. Helium is one such gas. However, even in gases, groups of atoms combine to ,act together to form molecules. Each molecule then acts like an independent particle. We usually call this a compound. oxygen is an example of a gas that acts this way, since two oxygen atoms bind together to form the molecule. Gas molecules pay no attention to each other except when they collide. Liquids are certainly more complicated than gases and the atoms and molecules have some reaction to each other. Water is a molecule that is made of two hydrogen atoms and one oxygen atom. Solids are more complicated than liquids. Table salt or sodium chloride is a solid compound. that is made of one atom of sodium and one of chlorine. Atoms interact strongly with each other in solids and are characterized by an organized structure with each chlorine and each sodium atom having its specified place. This structure is called crystalline structure.

Each atom is made of electrons and a nucleus. The nucleus, in turn, is made of protons and neutrons. The proton has one kind of electricity on it, and the electron has another kind. The kind of charge on the electron is usually called negative, and that on the proton is usually called positive. The neutron is neutrally charged, that is, it has no electrical properties. In an atom there are just as many protons as there are electrons or the atom has a net charge of zero. The number of electrons in an atom determines the chemical properties of the element and permits the elements to be arranged in the periodic chart according to their chemical properties. The number of electrons in an atom is the atomic number, which is designated by the letter Z.

The nucleus is made of the same number of protons as the atom has electrons and varying numbers of neutrons. In small atomic number elements, the number of protons and neutrons is the same or nearly the same. Oxygen has eight protons and eight neutrons. For large atomic number elements' there are more neutrons than protons in the nucleus. The nuclei that have the same atomic number, but have different numbers of neutrons are called isotopes of each other. A nucleus is designated in the following way:

$${}_{Z}X^{A}{}_{A\text{-}Z} \quad \text{or} \quad {}^{A}{}_{Z}X_{A\text{-}Z}$$

X is the element nucleus; Z is the atomic number or number of protons in the nucleus; and A is the number of nucleons (sum of the number of protons and neutrons in the nucleus). That makes A-Z the number of neutrons in the nucleus. Examples of nuclei with this notation follow:

HYDROGEN, ${}_{1}H^{1}{}_{0}$; LITHIUM ${}_{3}Li^{6}{}_{3}$; ${}_{92}U^{238}$

Many times the A-Z is not designated.

Isotopes have the same chemical properties, but their nuclei are different. Protons and neutrons have nearly the same amount of matter (mass). They are about 1840 times as massive as electrons. The nucleus has a diameter of about $10^{-15}$ meters while the atom is much larger. Its diameter is approximately $10^{-10}$ meters. Nearly all the mass of an atom is contained in the nucleus and this indicates that most of the volume of all matter is free space. The number of protons plus the number of neutrons is called the mass number. The symbol for the mass number is A. Some examples of groups of isotopes follow:

1) isotopes of Hydrogen: $_1H^1$; $_1H^2$; $_1H^3$

(2) There are seventeen isotopes of samarium:

$_{62}Sm^A$ with A = 141 - 157 etc.

# II. RADIOACTIVITY

Radioactivity is the spontaneous changing of the nucleus in some way. They change by emitting alpha, beta, and gamma particles. In alpha decay, the nucleus gives up an alpha particle. The alpha particle is identified as the helium nucleus, a helium atom without its electrons. This means that the parent nucleus has its atomic number lowered by two and the mass number is lowered by four. The alpha particle has a net charge of two times that of the proton and the amount of material about four times that of a proton. When these particles come out of the nucleus, they have energy of motion and, in general, they leave the residual or daughter nucleus with a good deal of internal energy that it must give up in some other way. A couple of alpha decays are:

$$_{84}Po^{212} \rightarrow {}_{82}Pb^{208} + \text{alpha}$$

$$_{83}Bi^{212} \rightarrow {}_{81}Tl^{208} + \text{alpha}$$

The beta particle has the same mass (amount of matter) as an electron that comes from the atom. it is found that two different particles exist that have the same mass as the electron. One is exactly the electron (beta -); however, the other has a charge that is the same as the proton (beta +).In the case of each of the beta decays the mass number of the daughter remains the same as the parent. The atomic number of the daughter nucleus of beta negative decay increases by one, while that for the beta positive decay decreases by one. Again, the daughter nucleus may have excitation energy that it wants to lose. Some examples of beta decay are:

$$_2He^6 \rightarrow {}_3Li^6 + \beta^-$$

$$_6C^{14} \rightarrow {}_7N^{14} + \beta^-$$

$$_{7}N^{13} \rightarrow {}_{6}C^{13} + \beta^{+}$$

$$_{13}Al^{28} \rightarrow {}_{14}Si^{28} + \beta^{-}$$

There are several ways that a nucleus might give up its excess energy. The most common of these is by gamma decay. In gamma decay the mass number does not change and neither does the atomic number. A gamma ray is emitted, and it is just electromagnetic energy. This usually permits the nucleus to rest in its lowest energy state, which is referred to as the ground state. Examples of this are:

$$_{13}Al^{27} \rightarrow {}_{13}Al^{27} + \text{(gamma ray)}$$

$$_{92}U^{232} \rightarrow {}_{92}U^{232} + \text{(gamma rays)}$$

$$_{49}In^{115} \rightarrow {}_{49}In^{115} + \text{(gamma rays)}$$

The alpha particles that are emitted appear in several different groups, each group characterized by the same kinetic energy. Beta particles on the other hand may appear in several groups but they appear in each group as a continuum of energies from zero to a maximum energy that characterizes the beta decay.

A radioactive nucleus is characterized not only by the type of change that occurs but also how fast the change happens. Some nuclei change very rapidly while others change very slowly. The rate of change of one nucleus into another is characterized in the statement of the half life of that nucleus. The half life of a nuclear species is just the time that it takes for half the nuclei that exist now to change into different nuclei. Some nuclei and their half lives are Am-241 433 yr; Na-22 2.60 yr;. Cs-137 30.2 yr; Sm-155 22.4 min; Ag-108 2.4 min; and Pu-239 24,100 yr.

## III. INTERACTION OF PARTICLES OF RADIOACTIVITY WITH MATTER

One must be protected from these emissions as they can affect the health of the person. The energy of the particles is transferred to the body tissue by ionization or excitation of atoms or molecules. When charged particles of high enough energy move through air or other materials, electrons are removed from the atom or molecule. This process of removing electrons from molecules and atoms is called ionization. Water molecules breakup under the influence of these charged particles and chemicals that are detrimental to biological materials are formed. The injury to the body depends on how much ionization takes place.

Alpha particles ionize many atoms along their paths but are very easy to shield against. Very high energy alpha particles can be stopped by an ordinary sheet of paper. Alpha particles constitute almost no external hazard. In the work that is done at Lamar there is no internal use of alpha emitters. One can simply protect himself or herself by being very neat and clean in the work area. Beta particles, being charged particles, ionize atoms along their path, but are not as efficient as the alpha particles. Many low to medium energy beta particles offer no hazard if they are in their bottle or other container. In some cases they are a hazard to the skin, and if the skin becomes contaminated with beta activity, it is a surface hazard to the skin. Also, if the skin is treated with some materials, it will absorb the beta particles. DMSO is one such material. These materials should never be used when there might be beta contamination. Some time, shielding may be needed. Low atomic number materials should be used, if possible, since beta particles interact. with heavy nuclei to give off x-rays; and if one uses materials with high atomic numbers, one gets rid of the beta problem but creates one with x-rays. Plastics are usually a good choice.

Gamma and x-rays, on the other hand, constitute an internal hazard. They are very penetrating and shielding may be necessary. Heavy or high atomic number materials make the best shields against these particles. Iron and lead seem to be good shielding materials. Gamma-rays and x-rays may miss your tissue altogether, but if they don't, they will interact with it in one of three ways: (1) the photoelectric effect, (2) the Compton effect, and (3) pair production. In each case, the results are ion pairs with addition of electrons with energy to move in the material. These electrons will then ionize the materials of the tissue.

The photoelectric effect occurs when the gamma-ray gives up all its energy to an electron in one encounter.

The Compton effect occurs when the gamma ray gives up only part of its energy in one encounter and then may interact with other electrons to eventually lose all its energy or to escape with some of it left.

Pair production happens only with gamma rays of more than 1.02 Mev energy. In this process the gamma energy is given up to creating an electron and a positron. Energy above 1.02 Mev will appear as energy of motion of the created pair. An electron volt is a unit of energy and it is the amount of energy that a one charge particle gains in falling through a one volt potential difference. One Mev is one million times this energy.

The best defense against exposure is involved with time and distance. Limit the TIME that you are in the presence of the radioactive materials. The other is DISTANCE. Most sources can be considered to be point sources, and from point sources, the particles go out equally in all directions. This spherical symmetry leads to an inverse square fall-off in intensity. This means that doubling the distance from the source will lead to a reduction of number of particles per second per square meter by one quarter. Always keep time of exposure to a minimum and do work as far away from the source as is practical.

# IV. UNITS OF RADIATION

The units used in radiation are of at least three kinds: (1) the rate of decay of the radioactive material; (2)the reaction of the material that absorbs the radiation; and (3) the effect that it has on living tissue.

(1) The Curie (Ci) is the unit that gives the decay as required by the Bureau of Radiation Control. It is defined as 3.7 x $10^{10}$ disintegrations per second. Some sub units of this are the millicurie (mCi) or 1/1000 of a Ci and a microcurie (μCi) or 1/1000 of a mCi. One mCi is equal to 3.7 X $10^{7}$ disintegrations per second and one μCi is equal to 3.7 X $10^{4}$ disintegrations per second. The SI unit for decay rate is the Becquerel (Bq) which is one disintegration per second. There are 3.7 X $10^{10}$ Becquerels in one Curie.

(2) A unit of exposure is the roentgen (R). It is defined as the absorption in air of enough x- and or gamma-radiation to cause the creation of 1.61 X $10^{15}$ ion pairs per kg of air. This represents the absorption of 0.00869 J/kg of air. The exposure of one R in tissue is about 0.0096 J/kg:. Absorbed dose is a measurement of energy deposit ion in any medium, by all types of ionizing radiation. The unit that measures this is the rad. A rad is defined as the deposition of 0.01 J/kg. One R in air is equivalent to 0.869 rad in air and 0.96 rad in tissue. The SI unit is the Gray (Gy) and is defined as the absorption of one J/kg. One Gray is equivalent to 100 rad.

(3) Since tissue is affected in different ways by different radiation, dose equivalent units are used. The dose equivalent unit is the product of absorbed dose and a quality factor Q. This unit is called the rem. The dose equivalent (rem) = absorbed dose (rad) x Q. The SI unit is the sievert (Sv). It is equal to the absorbed dose (Gy) x Q. One sievert is equivalent to 100 rem. The Q factor depends on the ability of the radiation to cause ionization. The Q factor for electrons, positrons, and x- and gammarays is one. Thermal neutrons have a Q factor of about 3 and fast ones have a Q factor of 10. Alpha particles and other multicharged particles have a Q factor of 20. Another quantity of interest is the dose rate. It is dose equivalent per unit time. often these units are expressed as m rem/hr or mSv/hr. The dose is found by multiplying the dose rate times the time of exposure.

# V. BIOLOGICAL EFFECTS OF RADIATION

Biological effects of radiation are of two kinds (1) somatic and (2) hereditary. The somatic effects are the damages that appear in the irradiated person and the hereditary effects are those that arise in the offspring of the irradiated person. These hereditary effects come from Radiation damage to the germ cells in the reproduction organs - the gonads.

The radioactive substances enter the body through the circulatory, respiratory and digestive-systems. Radioactive materials usually come into the body through eating or breathing. The circulatory system then picks up the radioactive materials from the lungs or liver and carries it to all the parts of the body. Some materials might be absorbed through the skin. Some of the materials may be expelled from the body as solid waste (feces) and as liquid waste (urine). Some may be expelled through breathing. While these radioactive nuclei are being wheeled about in the body, they are invading the tissue. Cells of the body are made up of a cell membrane, nuclear membrane, cytoplasm, and the nucleus. The nucleus contains the DNA molecules that carry the information which determines the characteristics of the daughter cells.

Cells reproduce in two ways. one is known as mitosis and the other as meioses. In the mitosis process the chromosomes split lengthwise and divide into two new cells that are identical to the original cell. Meioses occurs during the formation of sexual reproduction cells, sperm of -the male and ovum of the female. This occurs only once in a cell's life cycle and the male and female chromosomes combine to form a new cell that contain the genetic material from each parent.

The emissions from the Radioactive Materials have the ability to ionize the water molecules and the process of damage has several steps.

(1) $H_2O$ + radiation $\rightarrow$ $H_2O$+ +e- (~$10^{-16}$s)

called the initial physical stage.

(2) $H_2O \rightarrow$ H*r + OH

$H_2O + e^- \rightarrow H_2O^-$ (~$10^{-6}$s)

$H_2O^- \rightarrow H + OH^-$

called the physio-chemical stage

The products of these reactions are $H^+$, $OH^-$, $H^\bullet$ and $OH^\bullet$ . $H^+$ and $OH^-$ ordinarily occur in water and have no real part in the damaging chemistry. On the other hand, $H^\bullet$ and $OH^\bullet$ are called free radicals (they have unpaired electrons) and are highly reactive. Hydrogen peroxide is formed in the following way:

$$OH^\bullet + OH^\bullet \rightarrow H_2O_2$$

and it is a strong oxidizing agent.

(3) chemical stage (a few seconds). The reaction products interact with important organic molecules. The free radical may attack the molecules that form the chromosomes and break the chain.

(4) The biological stage that might last from minutes to years. The cells may react in several ways:
   (a) it may have an early death.
   (b) The cell may not divide, or at least may not divide when it should.
   (c) The cell might have a permanent modification that is passed onto the daughter cell.

The overall effects to the body come from the sum of the cell damages.

## The Somatic Effects Of Radiation

These effects occur within a few hours to a few weeks of radiation received over a period of a few hours. These effects are caused by a major depletion of cell population in major organs. Damages would be to (1) bone marrow, (2) gastrointestinal systems or (3) neuromuscular systems. The overall effect depends on the dose received. About 1 Gy gives way to nausea and vomiting. This is known as radiation sickness, and usually occurs a few hours after exposure. This results from damage to the cells lining the intestine. Doses above 2 Gy can lead to death in about 10 to 15 days.

No specific dose insures no death or death. Exposures below 1.5 Gy usually gives a person a chance to survive while 8 Gy and above gives a person little chance to survive. From 3 to 10 Gy, exposure causes infections because the white blood cells are killed. These deaths are usually referred to as the region of infection death. In doses above 10 Gy death comes soon because of the gross damage to the lining of the intestines and massive invasion of bacteria. In higher doses, damage may come to the central nervous system. Reddening of the skin may also occur in large dose exposures.

Evidence indicates that lower levels of exposure cover long periods of time lead to a higher risk of various kinds of cancer. There is some indication that people exposed to low levels of radiation over longer periods of time may have shorter life expectancy even if there is no indication of cancer present. There probably are no safe levels of long period radiation exposure.

There are naturally occurring radioactive elements that are always present. Potassium-40 is always present in naturally occurring potassium. In some areas the thorium chain is prevalent while in others uranium is present. Some locations in the world certainly have higher levels of background radiation than others.

It appears that there are ways to reduce radiation exposure and that care should be exercised to reduce the levels as low as possible.

At Lamar University, it is not likely that there will be any exposure much above background.

## APPENDIX II – MODEL PROCEDURE FOR CALCULATING ANNUAL EXPOSURE TO VERIFY CONTINUED EXEMPTION FROM PERSONNEL MONITORING

This procedure is tailored for workers who will work in Geology Room 212A – Dr. Irwin's Mossbauer Spectroscopy lab. However, in consultation with the Radiation Safety Officer, it may be modified for exposures that may arise in any other area in the future.

1. A separate calculation must be carried out for each individual.

2. Estimate the maximum possible number of occasions where the subject, or any part of the subject's body, may be in an area where the radiation levels measureably exceed background, and the length of time of each exposure . If, for example, it is necessary to place a hand nearer to a source, and thus in an area where radiation level are higher for a different period of time, a calculation should first be done for the whole body and then a separate additional calculation for the hand area.

3. Assuming the source is unshielded, calclulate the exposure rate using the formula

   exposure rate = $\Gamma A/d^2$

   where $A$ is the activity of the source (in mCi)
   $d$ is the distance from the source (in cm)

   For Co-57, the factor $\Gamma$ = 13.2 R·cm/hr·mCi

4. Multiply the exposure rate (which is in rems per hour) by the number of hours estimated exposure.

5. Repeat 3 and 4 if some parts of the body are subject to more radiation than others.

6. Add all the annual exposures thus estimated to give a total annual exposure.

7. Determine the effectiveness of the shielding. In the case of the Co-57 source, it has been determined that the shielding reduces radiation outside the shield to less than 1/1000th of that calculated assuming an unshielded source.

8. Multiply the annual exposure calculated in 6 by the fraction of radiation that is not stopped by the shielding.

If the annual exposure thus estimated is less than 0.050 rems, the requirement that less than 10 percent of the allowable annual exposure is expected is satisfied, and individual monitoring is not required under the exemption in §289.202(q)(2).

NOTE: All factors entering into this calculation must be reviewed each year, and a new calculation performed if any factor has changed. New calculations must be performed if at any time a new source is obtained or changed shielding arrangements are effected.

A sample calculation is attached.

SAMPLE
CALCULATION

**Individual Exposure Calculation**

**Name** __George M. Irwin__ **Date** __9-20-03__

Archer 116

The following dose calculation must be performed for all radiation workers in Archer 116. It is to ensure that no worker will acquire more than 50 mrem dose total in all laboratory activities per year. The calculation is done assuming a completely unshielded source, to achieve a conservative upper limit on total exposure.

Cobalt-57 Mossbauer Source

Assume a source activity of 20mCi. The Exposure Rate at distance d is

$$ER = \frac{\Gamma A}{d^2} \qquad \Gamma = 13.2\frac{R\cdot cm^2}{hr\cdot mCi} \text{ For } ^{57}\text{Co}$$

Dose Rate to whole body: @ 100 cm : 26.4 mrem/hr

Dose Rate to hand at close proximity: @ 20 cm : 660 mrem/hr

Estimated number of usages: __50__

Time per exposure: 20 seconds :whole body
3 seconds :hand

| | | | | | |
|---|---|---|---|---|---|
| Total Exposure time: | 1000 s | = | 2.22 | hr | Whole body |
| | 150 s | = | .00417 | hr | Hand |

Total Exposure (rem): __58.6__ mrem whole body

__2.75__ mrem hand

These estimates are for a completely unshielded source. Shielding reduces exposure by a measured factor of 1000. Hence total exposure is estimated to be:

Whole Body __58.6×1e-3__ mrem

Hand __2.75 ×1e-3__ mrem

9-20-03

Individual Exposure Calculation p.2

Summary

Total Dose : 0.006 mrem/yr (whole body), 0.003 mrem/yr (hand)

Since the total dose in one year does not exceed 50 mrem/yr (10% of the maximum allowable dose of 500 mrem/yr) exemption from dosimetric monitoring is warranted.

Signature [signature] Date 9-20-03

APPENDIX III -- LETTER FORMALLY ESTABLISHING DUTIES OF RADIATION SAFETY OFFICER

**LAMAR UNIVERSITY**
**A Member of the Texas State University System**

OFFICE OF RISK MANAGEMENT
P.O. Box 10807
Beaumont, Texas 77710-0807

August 29, 2006

Dr. George Irwin
Radiation Safety Officer
Lamar University

Re: Duties required by Bureau of Radiation Control

Dear George:

We thank you for being willing to continue to serve as Radiation Safety Officer for the University, and note that you will continue to perform the following duties and actions to meet the requirements of the Texas Regulations for the Control of Radiation ("The Regulations"):

1. Inspect and audit all the laboratories and storage areas in which radioactive materials are used and stored. Such inspections should verify the security of these areas, verify that required postings are present, review the user logs to ensure only trained users are using radioactive materials or instruments containing same, and generally review all activities involving radioactive materials in these areas. Such inspections are to be made at your discretion but in no event less frequently than once per quarter.

2. At the request of the Director of Risk Management, or of any authorized user listed on the Radioactive Materials License, assist the University in complying with The Regulations in whatever manner is necessary, including but not limited to helping solve problems or concerns.

3. Review and/or supervise the training of students and other new users who will use radioactive materials under the supervision of an authorized user.

4. Ensure that a listing is maintained of trained users who are then authorized to use radioactive materials under the supervision of an authorized user. The master listings shall be maintained along with all other records pertaining to Radioactive Materials in Room 117B of the John Gray Center. However, copies of such records should also be maintained near the instruments and materials so that they can be readily accessed at those locations.

5. Ensure that access to The Regulations is readily available at all locations where radioactive materials are used. (It is noted that all computers connected to the University network have web access to The Regulations on the TDH Web Site.)

6. Ensure that all sealed sources required to be leak tested are tested at intervals not exceeding those authorized. Certifications of the results of the tests shall be maintained along with all other records pertaining to Radioactive Materials in Room O-95 of the Maes Building.

7. Ensure that the University's radiation meter is calibrated at intervals not to exceed one year, and that certification of the calibrations are maintained in Room O-95 fo the Maes building. A copy should be kept with the meter.

8. Review all proposed purchases of radioactive material, including but not limited to instruments containing radioactive material, for compliance with The Regulations, and, if found in compliance, countersign the requisition thus authorizing the Purchasing Department to proceed. Copies of all approved requisitions shall be maintained in Room O-95 of the Maes Building.

9. Review all proposed transfers and disposals of radioactive materials to others, and, if found in compliance with The Regulations, countersign the requisition or other shipping document. Copies of such documents shall be maintained in Room O-95 of the Maes Building.

10. Ensure that all required records relating to Radioactive Materials are maintained and retained for the required retention times, and stored in Room O-95 of the Maes Building.

11. Ensure that routine radiation surveys are performed in all areas where radioactive materials are used and stored, and that special surveys are performed as necessary, including but not limited to surveys required to release areas back for regular "public" use.

12. Be present when Texas Department of Health inspectors request to inspect the University's radioactive materials program and/or facilities, equipment and materials, and act as the University's representative during such inspections.

13. Advise the University on all matters involving compliance with The Regulations.

14. Perform any other function and provide any other service as requested as being necessary to maintain compliance with The Regulations.

15. Respond and assist in the event of any emergency involving radioactive materials or suspected radioactive materials on or in the vicinity of the campus.

Attached are copies of instructions to the Purchasing Department, to the Shipping Department, and to the Chair of the Department of Chemistry and Physics (with copies to authorized users of radioactive materials) reiterating the requirements for your prior approval of any purchase, transfer or moving of radioactive material. You are hereby authorized to enter any location where radioactive materials are stored or used at any reasonable time.

Sincerely,

John A. Whittle
Director of Risk Management

APPENDIX IV -- MEMO ESTABLISHING PROCEDURE FOR PURCHASE OF RADIOACTIVE MATERIAL

**LAMAR UNIVERSITY**
**OFFICE OF RISK MANAGEMENT**
**Box 10807 Telephone ext. 8276 Fax ext. 7977**
**email: john.whittle@lamar.edu**

**INTERNAL MEMORANDUM**

To: Mr. Jack Tenner
Director, Purchasing

From: John A. Whittle
Director of Risk Management

Date: August 28, 2006

Subject: Ordering of Radioactive Materials

This memo will serve to update the standing instructions in respect of ordering radioactive materials.

In order to comply with the Texas Regulations for the Control of Radiation, it is necessary that the University's Radiation Safety Officer approve all acquisitions of radioactive material. Therefore please be advised that no purchase or other acquisition of radioactive materials may be processed unless the requisition is approved by the Radiation Safety Officer. Our Radiation Safety Officer is currently Dr. George Irwin. Dr. Irwin will countersign requisitions that he approves as complying with the Regulations.

Cc: Vice President Mike Ferguson

APPENDIX V -- MEMO ESTABLISHING PROCEDURE FOR MOVING AND SHIPPING OF RADIOACTIVE MATERIAL


**LAMAR UNIVERSITY**
**OFFICE OF RISK MANAGEMENT**
**Box 10807 Telephone ext. 8276 Fax ext. 7977**
**email: john.whittle@lamar.edu**


**INTERNAL MEMORANDUM**

To: Mr. Gerald McCaig
Director, Facilities Management

From: John A. Whittle
Director of Risk Management

Date: Augsut 28, 2006

Subject: Moving and Shipping of Radioactive Materials

This memo will serve to update the standing instructions in respect of radioactive materials.

In order to comply with the Texas Regulations for the Control of Radiation, it is necessary that the University's Radiation Safety Officer approve all moving, transfer and disposition of radioactive material. This includes instruments which contain sealed sources of radioactive material. Therefore please be advised that no moving, shipping or other disposition of radioactive materials may be effected unless the request, requisition or shipping document is approved by the Radiation Safety Officer. Our Radiation Safety Officer is currently Dr. George Irwin. Dr. Irwin will countersign requests that he approves as complying with the Regulations, and will assist in complying with shipping regulations.

Cc: Vice President Mike Ferguson

APPENDIX VI -- MEMO ESTABLISHING PROCEDURE FOR MOVING AND RELOCATING OF RADIOACTIVE MATERIAL

**LAMAR UNIVERSITY**
**OFFICE OF RISK MANAGEMENT**
**Box 10807 Telephone ext. 8276 Fax ext. 7977**
**email: john.whittle@lamar.edu**

**INTERNAL MEMORANDUM**

To: Dr. Keith Hansen
Chair, Department of Chemistry and Physics

From: John A. Whittle
Director of Risk Management

Date: August 28, 2006

Subject: Moving and/or Relocation of Radioactive Materials and Instruments containing Radioactive Material

This memo will serve to update the standing instructions in respect of radioactive materials, previosly communicated to Dr. Richard Lumpkin when he was Chair of the department..

In order to comply with the Texas Regulations for the Control of Radiation, it is necessary that the University's Radiation Safety Officer approve all moving and relocation of radioactive material. This includes instruments which contain sealed sources of radioactive material. Therefore please be advised that no moving or relocation of radioactive materials may be effected unless approved in writing by the Radiation Safety Officer. Our Radiation Safety Officer is currently Dr. George Irwin.

Cc: Dean Brenda Nichols

APPENDIX VII- EMERGENCY CONTACT INFORMATION

**LAMAR UNIVERSITY**
**OFFICE OF RISK MANAGEMENT**
**Box 10807 Telephone ext. 8276 Fax ext. 7977**
**email: john.whittle@lamar.edu**

**INTERNAL MEMORANDUM**

To: Chief Dale Fontenot
Lamar University Police Department

From: John A. Whittle
Director of Risk Management

Date: August 28, 2006

Subject: Contact Information for Radiation Emergencies

This memo will serve to update your records in respect of contact information for emergencies involving radioactive materials.

In the event of an emergency involving radioactive materials or suspected to involve radioactive materials, contact the following individuals and offices.

During normal working hours

Radiation Safety Officer Dr. George Irwin, 880-8243 (Archer 233) or personal cell phone 409-553-7139

**and**

Office of Risk Management ext. 8008 or 8276

Outside Normal Working Hours (or if no contact above)

Call the following in order until someone is reached:
Radiation Safety Officer Dr. George Irwin 409-553-7139 (home – is a cell phone)
Director of Risk Management John Whittle 409-722-4193 (home), 409-782-1010 (cell);
Dr. Max Soukhodolets 409-880-7905 (Chemistry 121Q) or 409-755-1509 (home)
Texas Department of Health, Bureau of Radiation Control 512-458-7460 (emergency only)

Cc: Vice President Mike Ferguson

# APPENDIX VIII

## Allowable Contamination Limits Applicable to P-32

Per 25TAC§289.202(ggg)(6) last amended March 1998 (P-32 users should check the Bureau of Radiation Control Website periodically for any changes)

AVERAGE 5,000 dpm beta-gamma/100 $cm^2$
MAXIMUM 15,000 dpm beta-gamma/100 $cm^2$
REMOVABLE 1,000 dpm beta-gamma/100 $cm^2$

As used above, dpm (disintegrations per minute) means the rate of emission by radioactive material as determined by correcting the counts per minute observed by an appropriate detector for background, efficiency, and geometric factors associated with the instrumentation.

Measurements of average contamination level should not be averaged over more than 1 square meter. For objects of less surface area, the average should be derived for each object.

The maximum contamination level applies to an area of not more than 100 $cm^2$.

The amount of removable radioactive material per 100 $cm^2$ of surface area should be determined by wiping that area with dry filter or soft absorbent paper, applying moderate pressure, and assessing the amount of radioactive material on the wipe with an appropriate instrument of known efficiency. When removable contamination on objects of less surface area is determined, the pertinent levels should be reduced proportionally and the entire surface should be wiped.

The average and maximum radiation levels associated with surface contamination resulting from beta-gamma emitters should not exceed 0.2 mrad/hr at 1 centimeter and 1.0 mrad/hr at 1 centimeter, respectively, measured through not more than 7 $mg/cm^2$ of total absorber.