MICHIGAN STATE UNIVERSITY

RADIATION SAFETY MANUAL

Environmental Health & Safety

Engineering Research Complex
1449 Engineering Research Court C125
East Lansing, MI 48824-1326
Phone: (517) 355-0153
Fax: (517) 353-4871
E-Mail: ehs@msu.edu

October 2013

NOTICE TO RADIOACTIVE MATERIALS USERS

The Radiation Safety Manual and further radiation safety information can be found or viewed at the following locations:

- Principal investigator
- Department safety representative
- EHS Home Page http://www.ehs.msu.edu
- EHS Office 355-0153

Table of Contents

Preface

Michigan State University is committed to its employees, students, visitors and patients to provide a safe and healthy work, study and treatment environment. The primary objective of this document is to provide a general guide for handling radioactive materials at Michigan State University and meet the requirements of Federal, State and local regulations.

The Environmental Health & Safety Office (EHS) is responsible for implementing the University's radiation safety program as defined by the Radiation Safety Committee, the Nuclear Regulatory Commission Broad Scope license, and applicable state and federal regulations. It is expected that all users of radioactive materials at Michigan State University will utilize safe work practices, and conduct and complete all required activities to maintain compliance with these regulations.

The Michigan State University Broad Scope License

Michigan State University operates under the U.S. Nuclear Regulatory Commission License Number 21-00021-29. This license is a large scale non-fuel cycle Type A broad scope license. Type A broad licenses may only be given to large facilities who have a long history of radioactive materials use with a good safety record. It allows Michigan State University the privilege of using large varieties of radioactive materials. Large amounts of activity are authorized and may then be used in many locations, with many procedures and users that change frequently. The broad license confers authority upon the University to approve, manage and control the receipt, use and disposal of radioactive materials. In fact, the University acts to police itself under the authority given in a broad license.

The broad license has one feature which must always be remembered by each radioactive materials user: **there is only one license for the entire university, and any individual or action which jeopardizes the license endangers the permission of all researchers to utilize radioactive material at MSU**. If, for any reason, the license is suspended or terminated, no individual or principal investigator may use radioactive materials of any kind until the license is reinstated. Therefore, this license places significant responsibility on each individual who uses radioactive materials to conform to safe work practices, and to conduct and complete all required compliance duties, however large or small they may be.

The Radiation Safety Committee

The Michigan State University Radiation Safety Committee is comprised of faculty, administrators and staff who have been delegated responsibility for radiological health, safety and compliance at the University. Approval for use of radioactive materials, reviewing policy and campus radiation safety, advising the university administration in radiation safety issues and programs, and auditing the operations and activities of the EHS Health Physics staff are some of the functions performed by the RSC.

Radiation Safety Committee members are appointed by the University administration, according to their experience and skills, which enable them to effectively perform their duties. Radiation Safety Committee members' qualifications are reviewed by the NRC, then members are named in our broad license as being responsible for oversight and review of campus radiation safety. The Radiation Safety Committee members have expertise in the wide range of uses of radioactive materials at Michigan State University.

Current members of this committee are listed in the campus telephone directory, which is updated each year.

Approvals for Use of Radioactive Materials

Approval for the use of radioactive materials is given by the Radiation Safety Committee for a period of one year, and is reviewed annually. Approval may be obtained by submitting a brief application describing the requested material and quantity to be used, the location, individuals who will handle the material, the training and experience of the applicant, the training of workers, the protective equipment to be used, if any, monitoring equipment, a brief description of experimental procedures with emphasis on potential safety concerns, and waste disposal information. Applicants must have faculty status, assistant professor or greater, experienced in the use of radioactive materials and must be trained by the EHS Office prior to approval. The application will be reviewed by RSC members, wherein approval may be granted.

The RSC may require additional conditions under which the use of the material must be conducted. The approved principal investigator may then order, receive and use the requested materials, but must do so according to the statements and representations made in the application, and any conditions set forth by the safety committee and all applicable local, state and federal laws, regulations and license conditions. Violations or infractions of these conditions may be cause for suspension or termination of the approval to receive and use radioisotopes.

For most applications to use radioactive materials, interim approval may be given by the Radiation Safety Officer (RSO) until the Radiation Safety Committee gives final approval. This precludes a long waiting period for approval. Principal investigators who are currently approved and have a good safety record may be given verbal interim approval to initiate a new use, except for work that involves a significantly higher risk. Applications for new principal investigators must be approved directly by the Radiation Safety Committee, regardless of previous approvals at other institutions.

New applications are required for the use of a new radionuclide, for a change in experimental procedures which have an impact on safety, a change in chemical or physical form of a material previously approved, and for substantial increases in the quantity. Amendments to current approvals are given for slight increases in quantity or moderate changes in chemical form, and may be obtained by submitting a short memo stating the desired change and the reason for the change, referencing to the original approved application to be amended. Applications for approval or amendments should be directed to the MSU Radiation Safety Officer.

Responsibilities of the Principal Investigator

Principal investigators are directly responsible for compliance with all regulations governing radiation safety in the laboratory, and for safe practices of individuals working under their supervision. Principal investigators are obligated to:

1. Ensure that individuals working under their control are properly supervised and trained to enable safe working habits and prevent exposures to themselves and others and/or contamination of the work areas or environment. Inadequate supervision and lack of training

have been cited as indicative of negligence in lawsuits involving radiation.

2. Be aware of the potential radiation hazards inherent in a proposed activity; be responsible for instructing personnel in safe practices or directing personnel to sources of information concerning safe practices.
3. Maintain inventory and knowledge of the various forms (physical and chemical) and quantities of radiation which are present in their work areas.
4. Avoid any unnecessary exposure, either to themselves or to other workers.
5. Understand the risks associated with the possession, use and shipment of all radioactive materials. Federal and state regulations control the use and shipping of radioactive materials and certain other hazardous materials.
6. Keep current records of the receipt and the disposition of radioactive material in their possession including use in research, waste disposal, transfer, storage, etc.
7. Maintain constant surveillance and immediate control of radioactive materials to prevent unauthorized removal or tampering, and/or assure that all of the workers occupying the area maintain security.
8. Post warnings and restrict entry to areas that contain potentially hazardous radioactivity or chemicals. Label radioactive use equipment and work areas.
9. Notify the EHS Office of any personnel changes, including addition or termination of employees, or changes of areas where radioactive materials may be used or stored.
10. Assure instruction of female radiation workers of the risks associated with working with radioactive materials during pregnancy. (NRC Reg. Guide 8.13).
11. Assure designation of a responsible individual to oversee radioisotope work during short absences and of a stand-in principal investigator with the required committee approvals during extended absences (greater than 60 days).
12. Ensure that radiation safety surveys and audits in the laboratory are conducted, and maintain records for review.
13. Be aware of regulations and requirements pertaining to the use of radioactive materials; maintain compliance and a safe working area.
14. Use radioactive materials according to statements, representations and conditions set forth in the radioactive materials use approval given by the Radiation Safety Committee. **Changes from the approved procedures must be approved by the Committee in an amendment or new application prior to the implementation of the change.**
15. Maintain use logs for radioisotopes with half-lives of ≥ 120 days.

Failure to comply with the rules and regulations set forth above and throughout this manual may lead to disciplinary actions and/or the cessation of radioisotope shipments and experiments. The Radiation Safety Officer and/or the Radiation Safety Committee may terminate any radioisotope use and/or research if deemed necessary. Suspension or termination of approval to use radioactive materials may result from situations jeopardizing health and safety, the environment or the MSU broad license.

Radioactive shipments which are ordered during a principal investigator's absence will be tracked under the absent principal investigator's inventory.

Responsibilities of the Worker

Individuals who use radioactive materials assume certain responsibilities in their work. The individual worker is the "first line of defense" in protection of people and the environment against undue risks of radiation exposure and/or contamination. Since the workers, themselves, are the direct handlers of the radioactive material, the final responsibility lies with them for safety and compliance with laws and regulations. For this reason, it is critical that they be aware of the risks, safe practices and requirements for use of radioactive materials.

The term "worker" is used by the university to identify an individual who uses radioactive material in the course of his/her employment or study with the university. Workers may be principal investigators, graduate students, undergraduate students, technicians, post-doctorates, visitors, or any other individual who will handle radioactive material. The following items are to be adhered to at all times by radiation workers.

1. Each worker must attend the all required safety training classes, including radiation and chemical safety. Workers are prohibited from handling radioactive materials until this class has been completed. Radiation workers must attend a refresher session each year.

2. The worker must complete the radiation safety examination and pass with a score of 75% or better. Workers are prohibited from handling radioactive materials until this has occurred.

3. Workers are responsible for adhering to all laws, rules, regulations, license conditions and guidelines pertaining to the use of radioactive materials.

4. Workers must wear their assigned radiation dosimeter during uses of radioactive materials. (See Personnel Monitoring for details on dosimeter requirements.)

5. Workers must practice ALARA (As Low As Reasonably Achievable) in their work, and minimize the potential for exposures, contamination or release of radioactive materials.

6. Radiation work areas must be monitored by the user after each use of radioactive material. If contamination is found, it must be cleaned up.

7. No changes in experimental procedures using radioactive materials are to occur without the approval of the principal investigator. Do not take short cuts. Changes in experimental procedures impacting upon safety (higher quantities, higher risk, use in animals, etc.) must be approved by the MSU Radiation Safety Committee.

8. Any abnormal occurrence must be reported immediately to the principal investigator, such as spills, significant contamination, equipment failure, loss of radiation dosimeters and unplanned release. If the principal investigator cannot be reached, contact the EHS Health Physics staff.

9. It is the responsibility of the worker to clean any contamination or spills that occur in their work area. DO NOT LEAVE IT FOR ANOTHER PERSON TO CLEAN UP.

10. Workers are responsible for returning the radiation dosimeter on time and reporting any loss or contamination of the dosimeter to the EHS Office.

11. Workers are responsible for informing the EHS Office of any exposures which have occurred at a previous employer when beginning employment at MSU. They are also responsible for notifying EHS of termination of employment and returning the radiation dosimeter at the end of their employment.

12. Workers are responsible for maintaining security of radioactive materials. (See section on Security of Radioactive Materials).

Sanctions for Non-Compliance

During radiation safety surveys, noncompliance may be identified. A report is sent to the principal investigator following the survey, detailing the results of the inspection, and explaining what corrective actions are required within the radioisotope use area. If the problems are corrected, no further actions will be required. If the problems are not corrected, a Notice of Violation may be sent to the principal investigator, and may require further corrective actions and/or documentation.

Violations are classified in five severity levels based on NRC definitions. The most severe is a level I violation, which could result in a researcher losing the privilege to use radioactive material, and the least severe is a level V. If violations are found, actions that may be taken are geared to these severity levels. A given instance of noncompliance may result in multiple actions, depending on specific circumstances, whether the incident is an isolated occurrence or is part of a repetitive pattern, etc.

The Notice of Violation identifies severity levels, assigns sanctions and documents that instructions were given concerning violations found. It is to be reviewed by the principal investigator, signed and placed with the radiation safety records for the laboratory.

SEVERITY LEVEL CATEGORIES FOR RADIATION SAFETY VIOLATIONS

Severity Level I: This is the highest severity level, and results from violations which cause immediate risk or danger to safety, health, release to the environment of reportable quantities, doses of substantial amounts to humans, or place the NRC license in jeopardy (i.e., an incident reportable to NRC).

Severity Level II: Not as serious as Level I, but also presents any of the above risks or threats to health, safety, the environment or licenses.

Severity Level III: A serious violation, but does not present immediate risk to health, safety, the environment or the license.

Severity Level IV: A violation, but not serious. Poses little risk to health, safety, environment or license.

Severity Level V: A minor violation; typically something in lesser technical matters, such as record keeping errors of minor impact. Poses no immediate risk to health, safety, environment or license, but is a compliance issue which may lead to increased concerns or is a minor technical violation.

Note: Any violation, when seen repeatedly, may be escalated to a higher severity level. Repeat violations can be interpreted as a disregard for safety regulations and must be dealt with quickly and effectively to avoid undue risks of exposure to individuals or the NRC broad license.

SANCTION ACTIONS FOR NONCOMPLIANCES IN RADIATION SAFETY

Severity Level	Possible Resulting Action
I -V	Violations noted on EHS surveys and sent to PI. All violations handled this way.
I -V	Written corrections required of PI and maintained in laboratory record books for review.
IV, V	Health physicist contacts principal investigator and discusses problem(s) and correction.
I - V	Require that involved personnel attend safety class again.
I - V	Increase EHS surveillance.
I -V	Increased surveillance required of laboratory staff.
I - V	Letter to principal investigator from health physicist.
I, II	Letter to principal investigator from Radiation Safety Officer; response is required in writing.
I-III	Place restrictions on individual(s) causing non-compliances.
I-III	Suspend shipments of radioactive materials to principal investigator.
I, II	Require principal investigator to appear before committee.
I, II	Decrease scope or limits of radioactive materials approval.
I, II	Require principal investigator to reapply for radioisotope use.
I, II	Confiscate radioactive materials in possession of principal investigator.
I	Permanently terminate approval to use radioactive materials.

SEVERITY LEVELS FOR VIOLATIONS FOUND IN RADIATION SAFETY INSPECTIONS

Severity Level	No.	Compliance Requirement
V	1.	NRC "Notice To Employees" and "Licensing and Regulation Information" are posted.
I -III	2.	Radioactive materials are under the constant surveillance and immediate control of licensee, or otherwise secured to prevent tampering or unauthorized removal.
I -III	3.	Radiation users are adequately trained for the functions performed.
I -III	4.	Surveyed areas are free of contamination.
I - IV	5.	Laboratory equipment is functional and is used correctly.
III- V	6.	Laboratory radiation surveys are accurate and frequency is appropriate.
I - IV	7.	Food and other consumable items are not present in the radioisotope and chemical use/storage areas.
I - V	8.	Radioisotope work and storage areas and equipment are labeled adequately.
I - IV	9.	Radioisotope sources/stock solutions are labeled adequately.
I -III	10.	Radioactive waste is manifested on both sides of the tag, secondary containment for liquids.

I -V	11.	Shielding is adequate (material, thickness, positioning).
I -V	12.	Dosimeters, if assigned, and appropriate protective equipment are used during radioisotope handling.
I -V	13.	Fume hoods are used properly (sash setting, uncluttered, rated for radioisotope use).

Training

It is mandatory that all workers, including principal investigators, be certified prior to the use of radioactive materials. Certification is obtained by attending the introductory EHS training class and passing the radiation safety examination. All radiation users/handlers, including principal investigators, must attend both the radiation safety and chemical safety parts of the class, since it is impossible to use radioactive materials without also using chemicals routinely or intermittently.

Initial training must contain minimally the items listed in Title 10, Code of Federal Regulations, Part 19.12 (10 CFR 19.12), Training for Radiation Workers. The EHS Office offers a training class in radiation safety; this covers the necessary topics. Annual retraining is required for all users of radioactive materials and is available online at the EHS Office web site.

Individuals who frequent areas where radioactive materials are present and radiation workers must be trained by the principal investigator according to the functions performed. This training may be evaluated during inspections, either by discussions with individuals present or by written records, if they are used. A checklist (See PI Training Checklist Appendix) has been developed which may be used to assist with the clarity and uniformity of the principal investigator training records.

Registration is required in advance for introductory safety training classes; dates of available training sessions may be obtained by calling the EHS Office and/or by checking the Training Hotline, 2-SAFE (432-7233) or the EHS Web Page, http://www.EHS.msu.edu. Advance registration is not required for refresher training, since dates, times and locations are announced in advance, and attendees register during the class.

Ionizing Radiation Theory

Ionizing radiation has the ability to remove electrons from atoms, creating ions; hence, the term "ionizing radiation". The result of ionization is the production of negatively charged free electrons and positively charged ionized atoms. There are four types of ionizing radiation involved that can be classified into two groups: 1) photons, such as **gamma** and **x-rays**, and 2) particles, such as **beta** particles (positrons or electrons), **alpha** particles (similar to helium nuclei, 2 protons and 2 neutrons), and **neutrons** (particles with zero charge, electrically neutral). Photons are electromagnetic radiation having energy, but no mass or charge; whereas particles have typically mass and charge as well as energy. Neutrons have mass and energy, but no charge, and are typically produced by man with machines, such as cyclotrons. All types of ionizing radiation can remove electrons, but interact with matter in different ways.

Particles are more highly ionizing; excitation and ionization are the primary interaction with matter, and potential for ionization increases as mass and charge increase. The range in tissue (depth to which the radiation may penetrate) for particles decreases as mass and charge increase. Photons, because they have no mass or charge, are less ionizing but more penetrating in matter.

Ionized atoms (free radicals), regardless of how they were formed, are much more active chemically than neutral atoms. These chemically active ions can form compounds that interfere with the process of cell division and metabolism. Also, reactive ions can cause a cascade of chemical changes in the tissue. The degree of damage suffered by an individual exposed to ionizing radiation is a function of several factors: type of radiation involved, chemical form of the radiation, intensity of the radiation flux (related to the amount of radiation and distance from the source), energy, and duration of exposure.

Radioactive Decay

Radioactive materials have an associated half-life, or decay time characteristic of that isotope. As radiation is emitted, the material becomes less radioactive over time, decaying exponentially. Since it is impossible or impractical to measure how long one atom takes to decay, the amount of time it takes for half of the total amount of radioactive material to decay is used to calculate half-life. Some radioisotopes have long half-lives; for example, ^{14}C takes 5,730 years for any given quantity to decay to half of the original amount of radioactivity. Other radioactive materials have short half-lives; ^{32}P has a two week half-life, and $^{99}Tc^{m}$ has a half-life of 6 hours.

This is important for many reasons. When deposited in the human body, the half-life of the radioactive material present in the body affects the amount of the exposure. If the radioactive material contaminates a workbench or equipment, and is not removable, the amount of time before the contaminated items may be used again is determined by the radioactive half-life. Radioisotope decay using half-life minimizes costs and concerns in radioactive waste management.

The equation which is used to calculate radioactive decay is shown below.

$$\mathbf{A = A0\ e^{-\lambda t}}$$

Where: A = Current amount of radioactivity
A0 = Original amount of radioactivity
e = base natural log ≈ 2.718
λ = the decay constant = 0.693/t1/2 (where t1/2 = half-life)
t = the amount of time elapsed from A0 to A

It is important to be careful of the units used for the time. Days, hours and years must not be mixed in the calculation.

Radiation Units

Two types of units are used for radiation, units of activity and units of exposure (dose). Units of activity quantify the amount of radiation emitted by a given radiation source. Units of exposure quantify the amount of radiation absorbed or deposited in a specific material by a radiation source.

In the world today, two sets of units exist. They are the Special units (Curie, Roentgen, Rad and Rem) and the SI or International Units (Becquerel, Gray and Sievert). In the United States, the Special units must be used as required by Federal law. Therefore, in our discussions the units used will always be the Special units. SI units are defined and described in the appendix on units.

Units of Activity

The unit of activity for radiation is the Curie, abbreviated Ci. Most laboratory facilities use only millicurie (mCi, 0.001 Ci) or microcurie (μCi, 0.000001 Ci) amounts of radioactive materials, since reliable data can only be obtained using low levels of activity for a given isotope. The Curie is an amount of radioactive material emitting 2.22×10^{12} disintegrations (particles or photons) per minute (DPM). (The international, or SI, unit for radioactivity is the Becquerel, defined as one disintegration per second.) Activity can be measured with an appropriate radiation detection instrument. Most of these measurements are made with a liquid scintillation counter, gamma well counter or Geiger-Mueller (GM) survey meter with appropriate detection probes. These instruments detect a percentage of the disintegrations and display in counts per minute (CPM).

It is important to note that the CPM readings from survey instruments are not the true amount of radiation present, since there are factors which decrease the detection capability of even the most sensitive instruments. Two factors influence radiation detection sensitivity: the geometry of the counting system and the energy of the radionuclide being measured. Lower energy radionuclides are detected with lower efficiencies than higher energy radionuclides. Detection instruments are calibrated with known sources with different energy levels to determine the efficiency of the instrument in order to account for these variables.

Therefore, in order to correct for the above sources of error in the measurements, a calculation must be made to standardize the units of activity used in all facilities licensed by the NRC. **It is required by NRC law that all records relevant to NRC licensed activities must be maintained in units of DPM or microcuries.** To make the necessary conversion to the microcurie unit, the following formula must be used in all records of surveys, waste materials or radioactive solutions generated within the facility.

$$\text{CPM/Efficiency} = \text{DPM}$$

$$\text{DPM}/2.22 \times 10^{6} = \mu\text{Ci}$$

Units of Exposure

The Roentgen, abbreviated as "R", is the unit for measuring the quantity of x-ray or gamma radiation by measuring the amount of ionization produced in air. One Roentgen is equal to the quantity of gamma or x-radiation that will produce ions carrying a charge of 2.58×10^{-4} coulombs per kilogram of air. An exposure to one Roentgen of radiation with total absorption will yield 89.6 ergs of energy deposition per gram of air. If human tissue absorbs one Roentgen of radiation, 96 ergs of energy will be deposited per gram of tissue. (The international units do not include the Roentgen, but simply use the amount of energy deposited in air as the descriptive term.)

The Roentgen is easy to measure with an ion chamber, an instrument that will measure the ions (of one sign) produced in air by the radiation. The ion chamber has readouts in Roentgen per hour or fractions thereof, and is an approximation of tissue exposure. The EHS Office, Veterinary Medicine clinics, National Superconducting Cyclotron Laboratory (NSCL) and other departments with the potential for external radiation exposures use ion chambers for measuring exposure. It is a useful instrument for gamma radiation; however, it is not quantitatively accurate for alpha, beta or neutron radiation.

The rad and the rem are the two main radiation units used when assessing radiation exposure. The rad (radiation absorbed dose), is the unit of absorbed dose, and refers to the energy deposition by any type of radiation in any type of material. (The international unit for absorbed dose is the Gray; it is defined as being equal to 100 rads.) One rad equals 100 ergs of energy deposition per gram of absorber.

The rem (radiation equivalent man) is the unit of human exposure and is a dose equivalent (DE). (The international or SI unit for human exposure is the Sievert, which is defined as equal to 100 rem.) It takes into account the biological effectiveness of different types of radiation. The target organ is important when assessing radiation exposures and a modifying factor is used in radiation protection to correct for the relative biological effectiveness (RBE or quality factor). Also, the chemical form of the radiation producing the dose is of critical importance in assessing internal doses, because different chemicals bind with different cell and/or organ receptor sites.

Additionally, some types of radiation cause more damage to biological tissue than other types. For example, one rad of alpha particles is <u>twenty times more damaging</u> than one rad of gamma rays. To account for these differences, a unit called a <u>quality factor</u> (QF) is used in conjunction with the radiation absorbed dose in order to determine the dose equivalent in rem:

rem dose = rad dose x QF x other modifying factors

Tissue weighting factors, Wt, are used for incorporating the actual risk to tissues for different radioisotopes and tissues in dose calculations. These weighting factors assign multiplication factors for increasing or decreasing the actual biological risk to a given tissue.

Another way to evaluate risk to an individual for internal intakes of radioactive material is the use of body retention class, D, W or Y. These classes stand for Days, Weeks or Years of retention time in the human body and are specified in the Title 10 CFR 20 limits in the Appendix B. This classification is based on the chemical form of the radioactive material, which affects the biochemical pathway and resultant target organ, therefore determining the retention time.

The dose rate is proportional to the radiation flux (number of particles or photons/square centimeter/second) and is expressed in rem/hour or mrem/hour. (Radiation dosimeter readings are reported in mrem units). The dose rate can be estimated by using an ion chamber when the radiation source is a gamma or x-ray emitter. The ion chamber is useful in estimating dose for beta radiation, but special detectors for alpha or neutron radiation are required.

Biological Effects of Ionizing Radiation

Injury due to irradiation is caused mainly by ionization within the tissues of the body. When radiation interacts with a cell, ionizations and excitations are produced in either biological macromolecules or in the medium in which the cellular organelles are suspended, predominantly water. Based on the site of interaction, the radiation-cellular interactions may be termed as either direct or indirect.

> **Direct action** occurs when an ionizing particle interacts with and is absorbed by a macromolecule in a cell (DNA, RNA, protein, enzymes, etc.). These macromolecules become abnormal structures which initiate the events that lead to biological changes.
>
> **Indirect action** involves the absorption of ionizing radiation in the medium in which the molecules are suspended. The molecule which most commonly mediates this action is water. Through a complex set of reactions the ionized water molecules form free radicals that can cause damage to macromolecules.

The most important target for radiation in the cell is DNA in the nucleus. Biological effects result when DNA damage is not repaired or is improperly repaired. Extensive damage to DNA can lead to cell death. Large numbers of cells dying can lead to organ failure and death for the individual. Damaged or improperly repaired DNA may develop into lymphoma and cancers in somatic cells. Two kinds of effects may result.

> **Acute, or nonstochastic**, effects are health effects, the severity of which varies with the dose and for which a threshold is believed to exist. Radiation-induced cataract formation is an example of a nonstochastic effect (also known as a deterministic effect).
>
> **Delayed, or stochastic**, effects are health effects that occur randomly and for which the probability of the effect occurring, rather than the severity, is assumed to be a linear function of the dose without threshold. Genetic effects and cancer incidence are examples of stochastic effects.

Tissue and Cell Sensitivity to Radiation

Various degrees of sensitivity to radiation exist due to the type of tissue which receives the exposure, and are shown below:

Radiosensitive	**Radioresistant**
Breast tissue	Heart tissue
Bone marrow cells	Large arteries
Mucosa lining of small intestines	Large veins
Sebaceous (fat) glands of skin	Mature blood cells
Immune response cells	Neurons
All stem cell populations	Muscle cells
Lymphocytes	

It is important, when considering the real versus the perceived risk of radiation exposures, to be aware of the acute effects of large radiation exposures. Without this information, one has no comparison to determine whether the radiation one is handling presents an actual risk, or does not. Often, fears exist that because the radiation is present and is measurable, a serious risk is present. The fact that we cannot see, smell, hear or feel the radiation sometimes magnifies the fears. The table below shows the effects of various types of high radiation exposures.

Effects of Acute Radiation Exposures in Humans

Radiation Exposure	Effects
10000 R; single dose, whole body	Death occurs within hours from apparent neurological and cardiovascular breakdown (Cerebrovascular syndrome)
500 - 1200 R; single dose, whole body	Death occurs within days and is associated with bloody diarrhea and destruction of the intestinal mucosa. (Gastrointestinal syndrome)
250 - 500 R; single dose, whole body 50% death rate	Death occurs several weeks after exposure due to damage to bone marrow (Hematopoietic syndrome)
50 - 350 R and higher; single dose, whole body	Can produce various degrees of nausea, vomiting, diarrhea, reddening of skin, loss of hair, blisters, depression of immune system
100 R; Single dose, whole body	Mild radiation sickness, depressed white blood cell count
400 - 500 R; local, low energy x-ray	Temporary hair loss
600 - 900 R; local to the eye	Cataracts
500 - 600 R to skin; local single dose, 200 keV	Threshold erythema in 7 - 10 days, followed by gradual repair and dull tanning
1500 - 2000 R to skin; local single dose, 200 keV	Erythema, blistering, residual smooth soft depressed scar
25 R; single dose, whole body	Lymphocytes temporarily disappear from circulating blood
10 R; single dose, whole body	Elevated number of chromosomal aberrations in peripheral blood; no other detectable injury or symptoms

External and Internal Radiation Exposures

There are two potential primary exposure types connected with work involving radioisotopes: external and internal exposure to radiation. Each must be carefully evaluated prior to working with radioactive materials, and precautions must be taken to prevent these exposures.

External Radiation Exposure

External hazards arise when radiation from a source external to the body penetrates the body and causes a dose of ionizing radiation. These exposures can be from gamma or x-rays, neutrons, alpha particles or beta particles; they are dependent upon both the type and energy of the radiation.

Most beta particles do not normally penetrate beyond the skin, but when sufficiently intense, can cause skin and/or eye damage. Very energetic beta particles, such as those emitted by ^{32}P, can penetrate several millimeters into the skin. Shielding is needed in order to reduce the external radiation exposure. Typically, a maximum of 1/2 inch thick sheet of Plexiglas is an effective shield for most beta particles.

Alpha particles, because of higher mass, slower velocity, and greater electrical charge compared to beta particles, are capable of traveling a few inches in air and rarely penetrate the outer dead skin layer of the body. Therefore, alpha particles typically are not an external radiation hazard.

X and gamma rays, along with neutron radiation, are very penetrating, and are of primary importance when evaluating external radiation exposure and usually must be shielded.
The onset of first observable effects of acute radiation exposure, diminished red blood cell count, may occur at a dose of approximately 100 rads of acute whole body radiation exposure. The LD_{50} for humans (lethal dose where 50% of the exposed population may die from a one time exposure of the whole body) is about 500 rads, assuming no medical intervention.

Exposure to external radiation may be controlled by limiting the working time in the radiation field, working at a distance from the source of radiation, inserting shielding between the worker and the source, and by using no more radioactive material than necessary.

Internal Radiation Exposure
Radioactive materials may be internally deposited in the body when an uptake occurs through one of the three routes of entry: inhalation, ingestion and skin contact. These exposures can occur when radioactive material is airborne; is inhaled and absorbed by the lungs and deposited in the body; is present in contaminated food, drink or other consumable items and is ingested; or is spilled or aerosolizes onto the skin and absorbed or enters through cuts or scratches. Internal deposition may also result from contaminated hands, with subsequent eating or rubbing of eyes.

Internal exposures arise when radiation is emitted from radioactive materials present within the body. Although external hazards are primarily caused by x-rays, gamma rays, high energy betas and neutrons, all forms of radiation (including low energy betas, gammas and alphas) can cause internal radiation exposures. Alpha particles create a high concentration of ions along their path, and can cause severe damage to internal organs and tissues when they are inhaled, ingested or are present on the skin. Once these particles get into the body, damage can occur since there is no protective dead skin layer to shield the organs and tissues. Internal exposures are not limited to the intake of large amounts at one time (acute exposure). Chronic exposure may arise from an accumulation of small amounts of radioactive materials over a long period of time.

It is known that many substances taken into the body will accumulate in certain body organs, called target organs. For example, iodine will accumulate in the thyroid gland. When iodine is inhaled or ingested, the body cannot distinguish stable iodine from radioactive iodine; a significant portion of the inhaled iodine will be deposited in the thyroid gland within 24 hours.

Other elements, such as calcium, strontium, radium and plutonium accumulate in the bones. Here, high doses to bones can occur over very long periods of time, since the body eliminates these materials very slowly once they are incorporated into the bone structure. The blood forming organs, such as the bone marrow, are very radiosensitive, since bone marrow cells are in the S-phase of mitotic activity more often than other cells. Hence, if there is a significant long-term exposure to radioisotopes, chronic diseases such as leukemia and/or osteosarcoma can occur. The induction time for the onset of these types of diseases is typically in excess of 20 years.

Laws and Regulations Concerning Radiation

The U.S. Nuclear Regulatory Commission is the branch of the federal government which regulates the licensing, use and disposal of radioactive materials. A multitude of laws set forth by the NRC must be obeyed. The State of Michigan also has laws, guidelines and regulations. In some cities, local regulations governing radioactive materials uses also exist, primarily with effluent discharges. Michigan State University possesses a radioactive materials license which contains further conditions of operation.

All of the above laws, guidelines and regulations must be obeyed. If any of the regulating agencies or authorities determine that the laws or conditions are not complied with during the periodic inspections which they conduct, violations will be cited, and penalties may be imposed. Penalties may include civil penalties (which may be fines or criminal prosecution in court), sanctions, suspension or termination of the license. For this reason, it is imperative that all principal investigators, workers and support staff involved in the receipt, use, disposal or records of radioactive materials be aware of and comply with these laws.

The Code of Federal Regulations, Title 10, Parts 19 and 20, are legal requirements set forth for all radioactive materials licensees. In particular, Part 20 contains the general practices, requirements and conditions by which all users of radioactive materials must abide.

ALARA

ALARA is an acronym meaning **As Low As Reasonably Achievable**. It is a requirement in the law, meaning all facilities possessing radioactive materials licenses must have a formal ALARA program. It may be defined as a professional standard of excellence, and is practiced by keeping all doses, releases, contamination and other risks as low as reasonably achievable. The regulatory guideline and our license requires managing programs and procedures to achieve ≤ 10% of applicable legal limits, such as air and water release limits, exposure limits or contamination limits for radiation use facilities.

Michigan State University has not needed to change its management practices significantly with the implementation of this new law, since ALARA was written into the license previously and has been practiced here for many years. MSU has attempted to incur no exposures, releases or contamination, but since this is not feasible or practical in radiation use facilities, they are kept beneath 10% of the legal limits.

It is not a violation of the law to exceed an ALARA guideline; however, these occurrences alert radiation safety staff and radioactive materials users to situations which need to be reviewed to determine whether the practices may be modified to better reflect ALARA management practices. Practical measures to incorporate ALARA into work practices are included in this manual to assist radiation workers. Some simple concepts and easy precautions may prevent contamination, exposures and releases.

Maximum Permissible Exposure

Exposure standards have been established by the NRC and set at a level where apparent injury due to ionizing radiation during a normal lifetime is unlikely. This limit is called the "maximum permissible exposure". However, personnel should not completely disregard exposures at or below these limits. It is the responsibility of each individual to keep his/her exposure to all radiation as low as is reasonable, and to avoid all exposures to radiation when such exposures are unnecessary.

The exposure limit for whole body exposures is lower than that for a single organ because all organs and tissues are exposed in a whole body exposure, while only a single organ is involved in the single organ exposure limits. The risk to the organ is incorporated in the exposure calculations which must be done if organs or tissues are exposed. Maximum permissible exposure limits to external radiation for adult and minor radiation workers are given in the table below.

OCCUPATIONAL RADIATION EXPOSURE LIMITS

Part of Body	Adult Yearly (mrem)	Minors Yearly (< 18 yrs. age) (mrem)	Adult ALARA Yearly (mrem)
Whole Body, Head and Trunk, Active Blood Forming Organs **(TEDE)**	5,000	500	500
Lens of Eye **(LDE)**	15,000	1,500	1,500
Extremities **(SDE)** (Elbows, Forearms, Hands, Knees, Lower Legs, Feet)	50,000	5,000	5,000
Single Organ Dose **(TODE)**	50,000	5,000	5,000
Skin of Whole Body **(SDE)**	50,000	5,000	5,000

Notice that each of the following quantities are types of dose equivalents. The following definitions describe the new quantities. (Note: the types of doses are quantities; the units used for these quantities are the rem or the Sievert.)

DE: Dose Equivalent. The product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and Sievert.

CDE: Committed Dose Equivalent. Means the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive materials by an individual during the 50 year period following the intake.

EDE: Effective Dose Equivalent. It is the sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

CEDE: Committed Effective Dose Equivalent. It is the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

DDE: Deep Dose Equivalent. Applies to external whole-body exposure. It is the dose equivalent at a tissue depth of 1 centimeter (1000 mg/cm^2).

TODE: Total Organ Dose Equivalent. The sum of the CDE and DDE for the maximally exposed organ.

SDE: Shallow Dose Equivalent. Applies to the external exposure of the skin or an extremity, is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7 mg/cm^2), averaged over an area of 1 square centimeter.

LDE: Lens of Eye Dose Equivalent. Applies to the external exposure of the lens of the eye and is taken as the dose equivalent at tissue depth of 0.3 centimeter (300 mg/cm^2).

TEDE: Total Effective Dose Equivalent. The sum of the deep dose equivalent (for external exposures) and the committed dose equivalent (for internal exposures).

Personnel Monitoring

Radiation detection dosimeters (rings and badges) must be worn routinely by personnel when exposure to penetrating radiation is possible. At Michigan State University, this means that workers handling radiation that is energetic enough to penetrate and lead to exposures need to wear a dosimeter. Dosimeters are exchanged quarterly, and in some locations, monthly. Each individual is responsible for seeing that they have the current dosimeter.

Dosimeters provide legal documentation of external radiation exposure received while working with radioactive materials at a given facility. They are not to leave your immediate work area; they are not to be taken home or to any other location, since non-occupational exposures may occur (e.g., a dentist's office or another laboratory). Dosimeters are heat and light sensitive, and if left in a car where the temperature may be high, a false exposure will be recorded.

Radiation detection dosimeters are not assigned for work with certain radionuclides, since the energies are beneath the detection limits. This is not a risk to the worker, however, because these kinds of radiation are not penetrating enough to cause a deep radiation dose. Examples of these radionuclides are ^{3}H, ^{14}C, ^{35}S, ^{45}Ca, ^{33}P and ^{63}Ni. For those individuals who use x-ray equipment and/or high energy beta or gamma emitters, both body and ring dosimeters must be used.

The ring dosimeter is worn on the hand most likely to receive the heist exposure, which is usually the dominate hand with the name tag facing the radiation source. The whole body dosimeter is worn on the torso with the name tag facing the suspected source of radiation. It is important to return your badge at the proper time. Delays in processing and reading the badge may invalidate the results. Chances of the badge being lost are increased with late badge returns.

Care should be taken to make sure that dosimeters do not become contaminated with radioactive materials. Lost or misplaced badges should be reported immediately to the EHS Office in order to receive a replacement. Under no circumstances should workers wear a dosimeter belonging to another individual. It is a legal requirement that doses be tracked for the worker to whom the dosimeter is assigned.

When terminating employment with the university, dosimeters must be returned to the EHS Office. A termination report will be supplied on request, since the next place of employment must be supplied with this report before the individual will be allowed to work with radioactive materials.

At any time, individuals can contact the EHS Office for their dosimeter results. It typically takes 4 to 6 weeks to have the dosimeters processed. The vendor will contact the EHS Office to report any doses that are significantly higher than normal (i.e., greater than 200 mrem) and the worker will be notified by a Health Physicist. **If you suspect that you have received a significant exposure, contact the Radiation Safety Officer immediately**. Potential exposure will be evaluated, and the badge may be sent immediately for an emergency reading. A spare badge will be issued for the interim period. On an emergency basis, results can be obtained within a few days.

Minors Working With Radioactive Materials

Radiation exposure limits exist for minors, (individuals under 18 years of age) who work with radioactive materials. These limits are 10% of all of the occupational limits for adult radiation workers. For these workers, safety training must be completed prior to work with radioactive materials as with other occupational workers. It is university policy that an informed parental consent form must be completed and kept on file for purposes of liability and risk management.

Due to university policy and legal requirements, principal investigators must notify the EHS Office before allowing minors to handle radioactive materials.

Pregnant Radiation Workers

A special situation arises when a radiation worker becomes pregnant. Under these conditions, radiation exposure could also involve exposure to the embryo or fetus. A number of studies have indicated that the embryo or fetus is more sensitive than the adult, particularly during the first four months of pregnancy. This can be a problem since many workers are unaware of their pregnancy during the first month or two of gestation. Hence, the NRC and the State of Michigan require that all occupationally exposed workers be instructed concerning the potential health protection problems associated with prenatal radiation exposure.

The maximum permissible exposure for a declared pregnant worker during the gestation period is 500 mrem. There are relatively few research laboratories where radiation levels are high enough that a fetus would receive this dose before birth. If a radiation worker is pregnant, she may notify the Radiation Safety Officer, and then declare the pregnancy in writing in order for the prenatal exposure limits to take effect. The pregnant radiation worker will then meet with a health physics staff member, and a complete assessment of her radiation exposure potential will be made. The written declaration is made by completing a Declaration of Pregnancy form, which is maintained in the records by the EHS Office.

If notification is not made in writing, the radiation exposure limits remain at the occupational level, that is, 5 rem per year. An individual may "un-declare" her pregnancy at any time, but this also should be documented.

Declared pregnant workers (DPW) will be assigned two badges, one for the whole body, normally worn on the torso and one for the fetus, normally worn on the abdomen. The badges will be exchanged on a monthly basis. Exposures must be maintained beneath a cap of 50 mrem per month in order to prevent exposure spikes.

Exposure Limits for the General Public

Visitors to a radiation laboratory who are not classified as radiation workers by their employers, laboratory workers who are not trained in radiation safety, custodial staff, and any other non-radiation workers are all members of the general public under the law. They must not receive a radiation dose in excess of either:

A. Two mrem in any one hour.
B. 100 mrem in any one year.

Since most radiation use facilities frequently have members of the general public visit their work areas, Michigan State University has elected to maintain unrestricted area contamination limits as part of the ALARA program.

Area Restrictions

All rooms or areas in which licensed quantities of radioactive materials are used or stored must be posted with a "Caution Radioactive Material" sign, an "NRC Licensing and Regulation Information Bulletin" sign, and a "Notice To Workers" sign. Door signs must include the principal investigator's name and phone number, and where he or she can be reached in the event of an emergency. Postings can be obtained from the EHS Office.

The following chart definitions are set forth in the federal law for area restrictions.

DEFINITION OF AREA RESTRICTIONS 10 CFR 20.1003

Unrestricted Area
An area, access to which is neither controlled nor restricted by the licensee.

Restricted Area
An area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. A restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be used as a restricted area.

Controlled Area
An area, outside of a restricted area but inside of the site boundary, access to which can be limited by the licensee for any reason.

Radiation Area
An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 5 mrem in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

High Radiation Area
An area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 100 mrem in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

Very High Radiation Area
An area, accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads* in 1 hour at 1 meter from a radiation source or from any surface that the radiation penetrates.

*The exposure rates for Very High Radiation Areas are in rads, rather than rems, because potentially life threatening exposures could result in areas with these fluxes of radiation.

At Michigan State University, most of the radiation use areas on campus are managed as restricted

areas. Most radiation use areas are open to the public, and may have both radiation workers and other individuals present often or all of the time. Members of the public are permitted to be present, as long they are escorted by a trained worker while in the restricted area or have been trained in radiation safety to work independently. Principal investigator training accomplishes training requirements for workers frequenting the laboratory but not handling radioactive materials.

Within the restricted area, it is imperative that strict surveillance be maintained to assure that significant exposure levels are not present, whether in the form of contamination, airborne levels of radiation or external exposure levels. For this reason, unrestricted area limits for contamination, exposures and/or releases are to be adhered to at all times, rather than restricted area limits. We have been using the unrestricted area limits for several years at Michigan State University as a part of our ALARA program management.

Another very important requirement for restricted areas is the security of radioactive materials. It is the responsibility of all workers frequenting a restricted area to maintain security. This is discussed in the section on security of radioactive materials.

Other radiation area restriction categories (radiation area, high radiation area, etc.) exist only in a few specific locations, which are typically not accessible to the general public. In the event of emergency or other unusual situations, any of the restricted areas may be restricted to a more secure level to protect against radiation or any other hazard which may be present. If this were to occur, the area(s) would be clearly marked and posted with warning signs or barriers.

Warning signs and labels are available from the EHS Office. Indiscriminate use of warning signs and/or labeling of non-radioactive materials with "Radioactive" stickers or labels is prohibited.

Labeling Requirements

Work areas, trays, racks, stock solutions, tools, equipment, etc., which contain radioactive material or are contaminated must be labeled with radioactive materials tape. The label must contain the radioisotope present, date, and the total activity in disintegrations per minute (DPM) or microcuries. It is not reasonable to expect that each tube or vial be labeled, but the container, tray or rack that holds them must be labeled. (For example, scintillation vials do not need to be individually labeled, but the tray or box that they are stored in must have the above described label).

For contaminated equipment which is in frequent use, the isotope, date and maximum activity which may be present at any given time is to be written on the radioactive warning label. For equipment which is used for radioactive materials, but is not contaminated (equipment which the staff wishes to identify for radioactive use), a label with the radioactive materials warning, "Caution, Radioactive Materials", may be used. Labels are not required if the equipment is not contaminated.

All radioactive waste must be similarly labeled with the above described information. Bench top waste containers are to be labeled in the same method as for radioactive materials in use or storage. As soon as radioactive waste is placed in the radioactive waste container, all information on the waste tag must be filled out.

Work areas must be labeled with the “Caution Radioactive Materials” sign, or marked off with the radioactive warning label tape. If the area is seldom used for radioactive materials, the area may be labeled only for the duration of the use, providing that it is surveyed for contamination and is free of contamination before the labels are removed. If the work area is frequently used, it is best to label the area permanently. For work areas frequently used for radioactive materials work, and which may contain contaminated equipment, the area may be labeled with a maximum reasonable amount of activity, the radioisotope, the date and the "Caution Radioactive Materials" warning.

Each room in which radioactive materials are used must bear a label on doors to the room. These labels must have the radioactive warning symbol, and the name and telephone numbers of the principal investigator and one other person who is knowledgeable about the radioactive materials uses in the room(s). These labels are for emergency response purposes, and should have the nonworking hours telephone numbers where a responsible and knowledgeable individual may be reached in the event of emergency. These labels must not be disposed in the regular trash.

Bioassays

Conditions of the broad license issued by the Nuclear Regulatory Commission (NRC) mandates that bioassays are required for workers using certain types and amounts of radioisotopes.

Individuals performing iodinations with any free form of radioactive iodine are required to obtain a thyroid scan after the iodination or use of the sodium iodide or potassium iodide stock solution. A baseline thyroid scan should be conducted on workers who have not previously used these types of isotopes at Michigan State University. Individuals must receive a thyroid scan bioassay with the EHS Office at least 24 hours after each iodination or use of free radioiodine, but not more than one week afterwards.

Also, individuals handling $\geq$ 100 mCi of tritium (^{3}H) must submit a urine sample to the EHS Office for bioassay within 24 hours of the handling. This bioassay must be performed each time this amount of tritium is handled. Contact the EHS Office for further details prior to urine bioassays.

If there appears to be a likelihood that a significant internal exposure has occurred, the Radiation Safety Officer may require further bioassays as deemed necessary.

Ordering Radioactive Materials

Any receipt of radioactive materials must be authorized by the EHS Office. Authorization is based on prior approval by the Radiation Safety Committee as described earlier. All requisitions should be sent to the purchasing department directly, who will contact the EHS Office to obtain authorization to order. The information that purchasing needs from the approved user is the name of the principal investigator ordering the material, account number, element and mass number, chemical form, activity and company from which the radioisotope will be purchased.

Each shipment received by project leaders, such as gifts, electron capture devices, or any other device containing a radioactive source or radioactive material must be reported to the EHS Office so that the material may be tracked in the inventory database and summed with the campus totals. This is to prevent an individual principal investigator or the campus from exceeding individual approval or MSU license possession limits.

Receiving and Monitoring Radioisotope Shipments

Shipments of radioactive materials must be delivered directly to the EHS Office. The shipments are monitored by the EHS staff, and records of monitoring are maintained for review. Results are indicated on the shipping papers delivered to the laboratory with the shipment.

Transfer of Radioactive Materials

Transfer of radioactive material between investigators of different projects must be reported prior to the transfer by telephoning the EHS Office. These transfers must be between committee approved principal investigators, and within the limits of the approved quantities. The transfer should not take place until the authorization has been given.

It is required that we document any transfers of radioactive materials by reassigning the shipment in our inventory database. To transfer a shipment, call the EHS Office and supply the information to the Health Physics staff, who will confirm approval to transfer the material and document the change in the inventory database.

Radioactive materials must never be transferred to individuals who are not certified or approved. Certified workers are trained and have passed the certification examination.

Food and Drink Policy

Due to the number of NRC violations cited at numerous institutions, including MSU in past violations, the MSU Radiation Safety Committee and the Office of the Vice-President for Research and Graduate Studies have developed a policy regarding food and drink. The following policy must be adhered to by radioisotope principal investigators and users.

Michigan State University Policy for Food and Drink in Laboratories

> There shall be no food, drink, smoking or applying cosmetics in the laboratories which have licensable radioactive materials, biohazardous materials or hazardous chemicals present. There shall be no storage, use or disposal of any "consumable" items in laboratories (including refrigerators within laboratories). Rooms which are adjacent, but are separated by floor to ceiling walls, and do not have any chemical, radioactive or biohazardous agents present, may be used for food consumption or preparation at the discretion of the principal investigator responsible for the areas.

It is important to be aware that even the presence of empty food and drink containers in the normal trash may cause a violation, since it is construed as "evidence of consumption" by regulators and the burden of proof to the contrary then lies with the licensee. Please also note that gum and tobacco chewing are prohibited in laboratories.

Floor to ceiling enclosures must separate food areas from hazardous materials areas, due to the potential for release of a hazardous material into the air, and then into a food area when only partial barriers are present.

If empty food or drink containers are used for storage or disposal of laboratory waste, pipette tips, or other laboratory equipment, reagents or materials, they must be clearly labeled. If used for disposal of items contaminated with radioactive materials, the containers must be clearly labeled with the radioactive materials warning symbol, and the nuclide, quantity of activity and date.

Security of Radioactive Materials

Federal law requires that NRC licensed material must be under the immediate control and constant surveillance of the licensee, or otherwise be locked and secured to prevent tampering or unauthorized removal. The NRC has cited many facilities, including MSU, for violations of this law; therefore, precautions must be taken to prevent this from occurring. This means that radioactive materials in storage or unattended should be kept in locked containers or in areas that are not readily accessible to unauthorized individuals.

When working with radioactive materials, the room must be secured whenever a radiation worker is not present, or the radioactive materials must themselves be secured. Refrigerators or cabinets containing radioactive materials that are located outside a lockable room must be locked to prevent access. **Any loss of radioactive materials must be reported to the MSU Radiation Safety Officer immediately**.

The personnel present in the laboratory may provide security for radioactive materials by challenging unauthorized entry into the room. Staff member who are not radiation workers may be among those in immediate control of the materials if they are trained by the principal investigator according to the items on the PI Training Checklist.

Inventory of Radioactive Materials

The NRC requires that all licensees maintain records tracking the receipt, use and disposal of radioactive materials. This is done with an inventory maintained in a database at the EHS Office. Shipments of radioactive materials are logged into the database for each principal investigator ordering the material. Additionally, workers names, training dates, use locations, monitoring equipment and radioisotope approvals are maintained in the database. Periodically, a printout of information for a project leader will be sent to the laboratory, and information must be updated and corrections made. This information is a legal record subject to inspection by any regulatory agency; efforts must be made to keep records as accurate and complete as possible to prevent NRC violations.

Use logs are required in laboratories for nuclides with half-lives $\geq$ 120 days and for high risk nuclides. The log should contain records of amounts used, who used them and dates of use for each shipment received. To determine what nuclides are high risk, refer to the Laboratory Classification Tables in the appendix.

Shipment of Radioactive Materials

Shipments of radioactive materials leaving the university must have prior authorization of the Radiation Safety Officers at both the sending and the receiving institutions. Federal and State law requires that the shipper must obtain the receiver's approval and the respective Nuclear Regulatory License number or the State License number prior to the shipment of the material.

All shipments must be in accordance with the packaging and labeling requirements set forth by the Department of Transportation (DOT); an appropriate record must be made of the radiation levels on contact with the package and at three feet from the package using an ion chamber. Also, the record must contain information on the shipper, receiver, nuclide(s) and activity, phone numbers of shipper and receiver, and performance of a survey for removable radioactivity. <u>Contact a Health Physicist well in advance of the desired shipping date to assure that all the required license exchanges, shipping papers and monitoring records are completed, as the package will not be shipped until these requirements are met</u>.

Terminating Employment

If a principal investigator terminates employment at Michigan State University, the EHS Office should be notified at least two weeks beforehand. Arrangements must be made to remove or reassign any radioactive materials according to the requirements of the EHS Office. Before the termination date, the radiation safety staff will conduct a final radiation survey of the radioisotope laboratory in order to determine the presence of unused radioisotopes and/or the presence of contamination.

Radiation workers who terminate their education and/or employment at the university shall notify the EHS Office, and their dosimeters must be returned. Michigan State University maintains dosimeter reports for all radiation workers. To meet this requirement at future locations, this information will be supplied to a worker upon request.

Leak Tests of Sealed Sources

Each sealed source containing licensed material (other than tritium) with a half-life greater than thirty days, and in any form other than gas, shall be periodically tested for leakage. The test shall be capable of detecting 0.005 μCi. Sources are exempt from testing if they contain <10 μCi of an alpha emitting material or <100 μCi of a beta or gamma emitting radionuclide.

Sources that are being stored and not being used must be tested at least once every ten years, with the exception of alpha emitting sources. Alpha emitting sources must be tested every quarter, regardless of use.

A stored source is one that has not been used for six months, and will not be used in the coming six months. It must be removed from its functional position (i.e., electron capture devices removed from gas chromatographs) and secured. Stored sealed sources must be leak tested before being returned to service. The broad license requires that sealed beta or gamma emitting sources are leak tested every six months. Alpha emitting sealed sources must be leak tested every three months.

Principal investigators must have approvals to possess and use sealed radioactive sources. Users must have training, sources must be labeled, and security must be in place. It is the principal investigator's responsibility to assure that the sources are used according to the laws and regulations pertaining to the source. In particular, the leak tests must be performed by the required deadline. If non compliances are found with sealed sources, sanctions may be imposed.

Radiation Safety for Machine Produced Radiation

Radiation producing equipment such as diffractometers, x-ray spectrometers, diagnostic and therapeutic x-ray machines, and electron microscopes are all regulated by the Michigan Department of Licensing and Regulatory Affairs (LARA), Radiological Safety Division. Equipment of this type must be registered with the State of Michigan. A copy of this registration must be displayed in the room with the radiation producing equipment. Posted information shall also include a copy of Section 5 of the State of Michigan's Ionizing Radiation Rules and form RH100 (Notice to Employees). It is required that all work done with these machines will be in accordance with the rules set forth by the Michigan Department of Radiological Health Ionizing Radiation Rules.

Personnel who use radiation generating equipment must use whole body and extremity radiation badges. Signs warning of radiation must be posted near radiation producing equipment.

The principal investigator possessing the machine is responsible for training all workers operating radiation producing machines, and this training must be documented. The EHS Office also offers special training classes in radiation safety for radiation producing machines upon request.

Principal Investigator Absences

Principal investigators may be occasionally absent from the laboratory for various reasons. During such absences, another individual must be named to assume the responsibility for the correct usage and management of radioactive materials. When the absence is less than 60 days, a responsible graduate student or technician may be appointed to assume responsibility. If the absence is greater than 60 days, an alternate principal investigator with the appropriate radioisotope approvals must be designated, and must agree to assume responsibility.

The EHS Office must be notified in writing of the absence duration and the name of the alternate principal investigator who will oversee the uses of radioactive materials during the absence prior to departure. The stand-in principal investigator must have all the authorizations necessary to oversee the uses of the radioactive materials possessed by the absent principal investigator. The EHS Office must be notified in advance of the intended absence. During the absence, shipments will still be logged under the absent principal investigator's inventory, but all oversight will be conducted by the stand-in principal investigator.

Radiation Laboratories

Laboratory Design and Equipment

Working with radioactive materials requires the use of specially designed laboratories and equipment, and may not be conducted in offices or other unapproved locations. In fact, rooms to be used for such work must be examined and approved for the use of the types and quantities of radioactive materials to be used. This is part of the approval process. Most laboratories at Michigan State University meet the requirements for use of radiation.

Smooth, contiguous, non-absorbent surfaces such as stainless steel or linoleum are preferred in a radiation work area. A properly working chemical fume hood with flow rates of at least 100 feet per minute is required if fume hoods will be used for containing radioactive materials. Special filters and/or design are not generally necessary, but may be prudent in special cases. The rooms used must be capable of security, or in other words must be able to be locked to maintain the security requirements for radioactive materials.

In areas where contamination is likely, surfaces should be covered with absorbent and disposable material, such as poly-backed absorbent lab paper. (The paper should have the plastic side down, absorbent side up.) If you are in the process of designing a radioisotope lab, consult the Health Physics staff for information regarding design and vendor catalogues. Work areas should be localized to minimize the possibility of contamination spread, and also because surveys must be conducted for all areas where radioactive materials are used, stored or disposed.

Equipment such as glassware, tools, syringes, etc. used in the handling of radioactive materials should not be used for other work or allowed to leave the lab unless it can be shown that the equipment is free from removable contamination. It is strongly recommended that a designated and labeled storage area be used to store this equipment. Fume hoods with flow rates of at least 100 linear feet per minute should be used whenever working with radioactive materials where the potential for vaporization/volatilization exists (as is the case during iodination), or in handling stock solutions of radiotracers, because of the high activity concentration.

Clean Laboratory Conditions and Containment

Good housekeeping is an important component of laboratory safety. Sloppy work habits, incorrect procedures or shortcuts, lack of containment, crowded or cluttered work areas and similar situations may cause or contribute to accidents or contamination. The following practices will assist in maintaining effective safety.

1. Maintain neat and clean work areas. Clutter, debris and crowded conditions interfere with the careful handling required in hazardous materials use.
2. Follow experimental procedures carefully. Radioisotope approvals are contingent upon following the procedures, statements and representations made in the principal investigator's approval. Departures from the procedures may place the approval in jeopardy.
3. Use absorbent poly-backed laboratory paper, with the plastic side down, to protect surfaces from inadvertent spills or splashes. Laboratory benches, fume hoods, trays containing samples, waste areas and floors in the radioactive work areas are some of the locations where absorbent paper is useful.
4. Use secondary containment for all radioactive solutions, samples, liquid waste or any other hazardous materials which may be spilled. Use trays, boxes, bus trays and other types of secondary containment to catch spills, splashes and possible container ruptures.
5. When transporting radioactive materials, use a cart; this will prevent accidentally dropping or tipping the container.
6. Clean up the work areas and survey for contamination after work is finished. If contamination is present, decontaminate or dispose of the contaminated materials.
7. Use tightly sealed or capped containers when moving, heating, centrifuging or vortexing. Spills, evaporation, gases, container breakage or splashes may occur in any procedure where energy is put into the system.
8. Label all radioactive materials and areas where radioactive materials are used, stored or disposed.

Unattended Operations

An experiment is considered to be unattended if there is no one present who is knowledgeable of the operation and of the shutdown procedure to be followed in the event of an emergency.

- Experiments that are left unattended must have overriding controls with automatic shutdown devices to prevent system failure that could result in fire or explosion, for example, the loss of cooling water, overheating, flooding, and pressure buildup. Permanent piping, and shields or barriers if necessary, should be provided.
- Warning signs must be used if radiation, toxic fumes, or other hazardous conditions are present. Custodians, utility, or security personnel need to be warned of them.
- The laboratory entrance door should display an Emergency Notification sign naming the people to contact in case of trouble.
- Burners, induction heaters, ovens, and furnaces must be located away from areas where temperature-

sensitive and flammable materials are handled.

- Post a notice on your equipment describing possible malfunctions, emergency shutoff procedures, and the nature of the hazards.
- Bunsen and other gas burners without approved flame-failure devices must not be left on overnight. Gas pressure often fluctuates; an increase in pressure will cause a taller, hotter flame, overheating equipment and perhaps causing a fire. If the pressure decreases the flame may go out. Upon resumption of gas flow unburned gas will accumulate to create a fire or explosion hazard.
- Use permanent piping if you must supply water to an overnight experiment. A sudden rise in pressure due to water fluctuations may rupture plastic or rubber experimental apparatus and cause flooding of lower floors. Floor flooding also takes place when water is left running into sinks to maintain a desired level and the drain becomes blocked or plugged. Consideration should be given to the use of standing overflow devices, which make drain plugging less likely.
- Electrical extension cords shall never be left plugged in while unattended (they are for temporary use while working with portable equipment in rooms where receptacles are not available).

Monitoring Instruments

Every laboratory using radioactive materials must possess or have available for immediate use appropriate radiation monitoring equipment. This equipment must be in good working order, and must be calibrated yearly by EHS Health Physics staff. Results of this calibration will be forwarded to the project leader. Equipment that has not passed this annual examination must be removed from service until it is repaired or replaced. If you believe that there is a problem with your equipment, contact the EHS Office and arrange a time when the equipment can be inspected and calibrated.

Radioactive monitoring instruments must be capable of detecting the radioisotope being monitored at or below the contamination limits listed in the section on Radiation Surveys. To calculate the sensitivity of the survey instrument, the following formula may be used.

(Background of instrument x 2) ÷ (Efficiency* for the isotope being measured) = Minimum Detectable Activity in DPM

**Note that efficiencies are given in the EHS Office calibration results.*

There are several types of monitoring instruments commonly used in teaching and research laboratories. The most widely used instrument is the Geiger counter, a portable instrument capable of detecting beta or gamma radiation, providing the appropriate detector is used. The Geiger counter is the least expensive, fastest and generally the most reliable means of detecting and measuring radioactive contamination.

The beta pancake detector is used with the Geiger counter for finding and measuring beta radiation, and will detect all beta radioisotopes used at Michigan State University except ^{3}H and ^{63}Ni. It does not detect those nuclides because their betas are too low in energy to penetrate the window of the detector. Radioisotopes which may be detected reliably with the beta pancake are ^{14}C, ^{35}S, ^{33}P, ^{32}P, ^{45}Ca, ^{36}Cl, and other beta emitting nuclides.

The low energy gamma (LEG) probe is used with the Geiger counter to detect and measure gamma radioisotopes of various energies. It is most efficient for ^{125}I, but will perform adequately for ^{51}Cr, ^{111}In, ^{60}Co and other gamma emitting nuclides. These detectors will also detect low energy x-rays, such as those emitted by beta emitters producing Bremsstrahlung radiation.

Another instrument in common use is the liquid scintillation counter. It is necessary to use it in radiation safety surveys for ^{3}H and ^{63}Ni, since no other instrument will detect these nuclides. Liquid scintillation counters work for both beta and gamma nuclides for quantifying what is in a sample. It is not an adequate primary method of evaluating contamination surveys; however, since samples measured consist of wipes of the areas of suspected contamination. *If the contamination is not removable, the wipe will not pick it up, and contamination will not be detected*. It is also possible for only part of the contamination present to come up on a wipe, not giving an accurate measurement of the contamination present.

A third instrument which may be used to evaluate contamination is the gamma well counter. Again, this is used to gather data in samples, but for the same reasons as the liquid scintillation counter, it is not a good radiation survey instrument.

Ion chambers are used commonly by the Radiation Safety staff and in locations where frequent and higher flux external radiation hazards are present; they are typically not used for contamination surveys by laboratory staff. These instruments measure the ions produced in air (of one sign) by gamma radiation, and are a good indicator of radiation exposure fields. They are useful for exposure potential screening on shipments, activated parts at the Cyclotron, drums of waste at the Radioactive Waste Building, packages prior to shipment and sources and stocks of radioactive materials.

Other more sophisticated instruments used to detect and quantify radiation are the gamma spectrometer or multi-channel analyzer, neutron detectors, alpha detectors, and a wide array of electronic dosimeters, area monitors, and even portal monitors (which a person walks through to detect any contamination on the body or clothing; these are used at reactors).

For effective and accurate data gathering in radiation, follow a few simple guidelines:

1. Survey at the proper geometry. Hold the detector about 1 cm. or 1/2 inch above the surfaces monitored. If the detector is too far away, serious underestimation of activity or no detection of activity present may occur. If the detector is too close, contamination of the detector may occur.

2. Use the correct detector. Do not survey for beta radiation with a gamma probe or for gamma radiation with a beta probe. NO GEIGER COUNTER WILL DETECT TRITIUM; LIQUID SCINTILLATION TECHNIQUES MUST BE UTILIZED.

3. Survey slowly; do not race the detector over the surface or wave it like a magic wand; the sensitivity of the detection is inversely proportional to increasing survey speed.

4. Do not cover the detector while surveying; covers decrease or eliminate detection, since they act as a shield.

Calibrations

Radiation detection instruments used for contamination surveys must be operable and capable of detecting the radioisotopes used in the laboratory. To assure this, radiation detection instruments will be calibrated annually by the EHS Office. Calibrations are conducted using a set of sealed radiation check sources containing known amounts of activity. The percentage of the known activity that the instrument detects is known as the efficiency of the instrument. The sources are for a range of radiation energies; instruments calibrated then can be evaluated as to their performance and accuracy through the calibration.

After calibrating the instrument, a report of the results will be sent to the principal investigator, who should then place the report in the radiation safety record book maintained in the laboratory. Instrument background, efficiencies for various appropriate nuclides used in the laboratory, and comments are on the record. This information is to be used by laboratory staff when surveying for radioactive contamination in the work area.

Instruments will be calibrated upon request, and must be recalibrated after repair.

Radiation Surveys

The EHS Office will make independent surveys of all active radioisotope labs at least quarterly. Such things as inventory assessment, contamination control, personnel monitoring, and training and waste disposal practices will be addressed during these surveys. (See the survey checklist used by the EHS Office in the Appendix).

Copies of the results of surveys will be forwarded to the principal investigator, and a recheck may be conducted in the event problems have been detected that need corrective action. The MSU Radiation Safety Committee may accompany the EHS Office on surveys as deemed necessary for problem laboratories or for purposes of auditing the radiation safety program.

Surveys are to be conducted by the project investigator or his/her designee in conjunction with the EHS surveys. Each lab that is actively using isotopes must conduct radiation surveys weekly, monthly or quarterly, depending on the types and quantities of radioactive materials present in the laboratory. By doing this, the potential for exposures can be evaluated and reduced, if necessary. Records of these surveys must be maintained for review.

When removable radioactivity is found, the area must be decontaminated and then re-surveyed and documented. Detectable levels of removable contamination should be removed, and non-removable contamination should be labeled and shielded whenever possible in order to maintain ALARA limits.

It is understood that certain areas may be routinely contaminated, such as internal parts of equipment and the inside areas of glassware, and that it may not be practical to decontaminate these surfaces. If this occurs, signs must be posted and protective clothing and gloves should be used when in contact with these areas. In some cases, such as ^{32}P contaminated equipment, shielding is required.

Limits for removable contamination are listed in the table below. Radioactive contamination found at or above these levels must be decontaminated or shielded and labeled. (Therefore, one of the advantages of using disposable lab paper on the benches is that one only has to dispose of the contaminated area of the paper in the radioactive waste, rather than decontaminating or shielding.)

RADIOACTIVE CONTAMINATION LIMITS
AT MICHIGAN STATE UNIVERSITY

Type of Area	Alpha Emitters (DPM/100 cm^2)	High Risk Beta or Gamma Emitters (DPM/100 cm^2)	Low/Moderate Risk Beta or Gamma Emitters (DPM/100 cm^2)
Unrestricted Areas	22	220	2,200
Controlled Areas	22	220	2,200
Restricted Areas	220	2,200	22,000
Personal Clothing Outside Restricted Areas	22	220	2,200
Skin	22	220	22,000

Most of the radioisotope use areas on campus are treated as restricted areas, and are characterized as locations with controlled access and have proper radiation safety controls in place. **Contamination limits for surveys are the controlled and unrestricted area limits, due to the ALARA programs required of licensees**.

Radioisotopes classified as high risk include ^{45}Ca, ^{22}Na, and ^{60}Co. Low/moderate risk radioisotopes include ^{32}P, ^{3}H, ^{14}C, ^{35}S, ^{125}I, ^{51}Cr and ^{111}In. **Remember that the ALARA requirement must be adhered to in the above limits, meaning 10% of the limits, where possible.** (For some radionuclides, it is impossible to achieve less than the contamination limits, since the instrumentation and normal backgrounds prevent any increased sensitivity. For others, sensitivity may exist where it is realistic to achieve 10% of the contamination limits.)

Practical Radiation Protection

Routes of Exposure to Radiation

Minimizing the amounts of radioactive materials handled in all cases will reduce exposure potential, since exposure is directly related to the amount used and how it is handled.

The three routes of entry into the body for radioactive materials are **inhalation**, **ingestion** and **absorption/injection**. Precautions should be taken to avoid each of these means of internal exposure to radiation.

External radiation exposure is possible with certain kinds of radiation. Methods of minimizing this potential are **time**, **distance**, **shielding and minimizing the amount used**. Precautionary measures are discussed further in the following sections.

Monitoring Operations Involving Radioactive Materials

Due to the potential for contamination of work areas during use of radioactive materials, it is necessary to monitor as much as possible the operations performed. Work areas should be checked before use to determine background or prior contamination. The survey instrument should be turned on and placed proximal to the work area in order to check radiation levels, and to alarm the worker if radiation levels rise significantly. Hands should be checked frequently for presence of contamination due to splashing or aerosols. At the end of the use of the work area, or each day, work areas should be monitored to determine the presence of contamination. Note that worker clothing and shoes should also be monitored. If contamination is found, the area or equipment must be decontaminated.

Time, Distance and Shielding

Three primary means of eliminating or reducing radiation exposures exist. They are:

Time: Minimize the time that radioactive materials are handled. Since the amount of exposure occurs as a function of duration of exposure, less time means less exposure. This may be achieved by conducting "dry runs" (practicing the procedures to be performed, with all of the steps and manipulations performed without the hazardous materials). Conduct the work quickly and efficiently, but do not rush.

Distance: Maximize the distance from the radioactive materials. Dose is inversely proportional to distance, therefore, greater distance means less dose. Do not increase the distance to the point wherein dexterity or control of the materials is jeopardized.

Shielding: Use shielding wherever it is necessary to reduce or eliminate exposure. By placing an appropriate shield between the radioactive source and the worker, radiation is attenuated and exposure may be completely eliminated or reduced to an acceptable level. The type and amount of shielding needed to achieve a safe working level varies with the type and quantity of radioactive material used. The HVL (half-value layer) may be used as a guide to the thickness of the shielding necessary to block the radiation. The HVL is the thickness of the shielding necessary to reduce the radiation dose rate to half of the original or unshielded dose rate. Refer to the HVL information in the appendices on specific nuclides.

Protective Equipment

In order to prevent contamination of skin, eyes or personal apparel, protective equipment should be utilized during use of radioactive material. The specific types of protective equipment needed are dictated by the nuclide, level of activity, chemical form and experimental procedures.

Two main categories of protective equipment are personal protective equipment and engineering controls. Personal protective equipment is protective equipment worn by the worker. Examples are gloves, laboratory coats and safety glasses. Engineering controls are external equipment designed to protect the worker, or are a part of the design of the work area. Examples are fume hoods, biological safety cabinets, building ventilation systems and shields.

Individuals using radioactive materials must wear laboratory coats, gloves and eye protection. Additional protective equipment may be necessary or prudent. Contact a Health Physicist if you have questions about protective equipment.

Airborne Radioactive Materials

Some work with radioactive materials have the potential for release into the air, causing the worker to have an uptake of the material through one or more of the routes of entry into the body, particularly inhalation.

Contamination present in a room may create airborne radioactivity by simple movement of the air over the contamination, spreading it around in the air. Most radioisotopes will be picked up by air and spread through this mechanism. This is one more good reason to keep areas free of contamination.

Use of **volatile forms of radionuclides**, such as ^{125}I for iodinations or ^{3}H-sodium borohydride may generate airborne radioactivity. Any chemical or physical form which readily volatilizes or evaporates into the air must be considered a potential airborne radioactivity risk.

Chemical reactions may generate radioactive gases or other airborne contaminants. An example is the labeling reaction for ^{35}S methionine, which generates a methyl mercaptan reaction which liberates HCl and $^{35}SO2$ gas. Airborne radioactivity has resulted in unnecessary intakes and area contamination in laboratories where the users were unaware of this risk and have not taken precautions to trap or contain the liberated $^{35}SO2$.

Heating or incubating may cause evaporation or chemical reactions which release radioactive materials into the air. **Aerosols** (tiny droplets or particles) are present with all materials, and pose an increased risk when handling stock solutions or other high concentrations of radionuclides. Use chemical fume hoods or biological safety cabinets for high activity, concentrated or potentially volatile radioactive materials manipulations.

Materials which have been frozen may release substantial quantities of aerosols or gaseous radioactive material when the containers are opened. There have been numerous incidents at MSU and other institutions where this has occurred and has caused significant contamination of work areas, equipment and clothing of the worker opening the containers.

Another cause of airborne radioactivity is media or solutions containing **cells, bacteria or other living organisms**. The living organisms metabolize the radioactive substrates and may produce radioactive gases or vapors as a byproduct.

When **hazardous chemical forms of the radionuclides** are used, such as radiolabeled carcinogens or toxins, increased risks are presented by the vapors, aerosols or gases present or generated in the use. In this case, the hazard present is not only radioactive, but may also pose airborne chemical risks.

In order to prevent uptake in these increased risk situations, fume hoods, biological safety cabinets or other containment must be used to protect the worker from uptake and internal deposition. <u>Do not use clean benches (tissue culture hoods) for use of radioactive materials, or any other hazardous material</u>. While the product is kept sterile by these hoods, the hazardous material present in the materials used are blown into the face of the worker, and into the room. Therefore, there is no protection for the worker.

In certain rare cases, respiratory protection may be necessary for certain radioisotope uses. However, respiratory protection should only be used when other means of control and containment do not provide enough protection. Respirators must be chosen carefully to ensure the proper fit and type of cartridge, and the use must be monitored carefully. For this reason, use of respirators for radioactive materials use must be pre-approved by the EHS Office, documented and monitored. Prior to using respirators for any reason, fit testing and medical monitoring are required.

If you are concerned that an intake has occurred, contact the EHS Office. Bioassays (urine samples) or other investigational methods may be employed to determine whether an intake has actually occurred and to recommend ways to avoid such undesirable situations in the future.

Disposal of Radioactive Waste

The EHS Office has developed a manual entitled Michigan State University Waste Disposal Guide, which is located on the EHS web site. This manual describes the requirements and specific procedures for correctly managing and disposing of hazardous waste, including radioactive, chemical, biological and pathological waste. Please use this guide when preparing waste for disposal. All radioactive waste shall be separated from non-radioactive waste. **Under no circumstances is it permissible to dispose of any radioactive material into the non-radioactive trash or into any drains.**

Radioactive waste must be properly manifested for the isotope and activity, and any other hazardous constituents, including chemical or biohazardous components. Complete waste disposal instructions may be found in the Michigan State University Waste Disposal Guide and online at the EHS web site.

Radioactive waste must be completely labeled at all times, from the time it is deposited into a container until final disposal. Records of radioactive waste disposal must be maintained by the University for NRC review, so this labeling or "manifesting" is critical. Tags must be completely filled out at all times after any radioactive waste is placed in the container.

The EHS Office supplies the solid and liquid waste containers to laboratories upon request. It is the responsibility of the laboratory to supply secondary containers, such as a plastic bus tray, to prevent the waste from leaking or contaminating the surfaces. Laboratories must supply their own shielding for waste that may cause external exposures to workers in the area.

Bench top waste containers are considered part of the experiment, and must be labeled with the isotope, activity in DPM or μCi and the date. It is not necessary to attach a waste tag until the waste is placed in the permanent waste container.

It is required that all radioisotopes are segregated from each other and that each isotope be separated according different types of chemical hazards. For example: you would separate a highly toxic waste from an aqueous buffer waste.

Since radioactive waste must be stored for some period of time prior to disposal, it is critical that the date(s) the waste was deposited in the container be present; radioactive decay is one means of effectively managing and minimizing radioactive waste.

Quantifying Levels of Radioactivity in Waste

Radioactive and other hazardous materials must be completely manifested in the waste. In order to accurately list levels of radioactivity on the tags, it is necessary to assess the levels which are disposed in both liquid and solid waste. Suggestions on methods to quantify the waste follow.

1. During a given experiment it is known that a certain quantity of radionuclide is used. At the end of each of several similar experiments, take a sample of liquid waste and count it with the appropriate counting equipment. The activity in the sample per unit volume is then multiplied by the total volume of the liquid waste generated. For the solid waste, the quantity of radioactivity in the liquid is subtracted from the total quantity used in the experiment, and the

remainder is then the quantity in the solid waste.

Example:

Total Used in experiment:	500 μCi
Liquid Sample Volume:	1 ml
Total Liquid Waste Volume:	4000 ml
Activity in Liquid Waste Sample:	8 E^{-2} μCi/ml
Liquid Waste Total Activity:	8 E^{-2} μCi/ml X 4000 ml. = 320 μCi in liquid waste
Solid Waste Total Activity:	500 μCi - 320 μCi = 180 μCi in solid waste

2. After the first few experiments, or when the waste carboy is full, take a sample of the pooled liquid waste, and count it as above. <u>Multiply the activity of the sample per unit volume by the total volume in the carboy</u> to obtain the total activity in the carboy. Quantify the solid waste as above by subtracting the liquid waste activity.

General Rules for Radiation Safety

1. Do not eat, drink or smoke in radiation use, storage or disposal areas. "Eating" includes gum, candy, beverages and chewing tobacco. Do not apply cosmetics in the laboratory. Do not consume medication in radioisotope laboratories. Do not dispose of food, empty food wrappers or containers anywhere in the laboratories.
2. Gloves should be worn during any and all operations in which contamination of the hands is possible.
3. Never pipette radioactive liquids by mouth.
4. Store and transport radioactive materials in containers which will prevent breakage and spillage. Secondary containment is important; when transporting radioactive materials, use trays and carts.
5. Use ventilation hoods or glove boxes if the radioactivity may become airborne and for high activity uses, such as stock solutions.
6. The individual(s) responsible for any contamination will be required to decontaminate the area of concern.
7. Regularly check your hands, clothing and shoes for contamination prior to leaving the work area after working with radioactive material.
8. Always dispose of radioactive waste in a radioactive waste container.
9. Always wear your assigned radiation dosimeters when working with radioactive materials.
10. Wear laboratory coats when working with radioactive materials.
11. Always wear safety glasses.

Radiation Incidents/Emergencies

The following are the reporting information necessary to evaluate and respond properly to an abnormal occurrence involving radioactive materials.

- Radionuclide involved
- Amount of radioactivity
- Chemical form of released material, other hazardous chemicals involved

- Volume or released material
- Location of incident (building and room number)
- Persons contaminated or exposed, estimate of amount (e.g., 2,000 CPM, ^{32}P, 10 cm^2 on skin of arm)
- Any injuries, what they are, how serious
- Air borne radioactivity present or not
- What you have done so far
- Principal investigator name
- Name of person reporting
- Telephone number where you can be reached

Some radiological incidents involve serious risk to life, health or property. In the event of serious injury coupled with exposure to radiation, fire, explosion, major release of health threatening materials or serious radiation exposure, an ambulance may be dispatched, and victims will be transported to a hospital for treatment. Upon arrival at the hospital, the victims(s) will be met by appropriate radiation safety personnel who will monitor the treatment and decontamination procedure.

Handling Radioactive Incidents/Emergencies

Incidents may occur during the use of radioactive materials, such as spills, accidental releases into the air, contamination of the worker or the work area, and numerous other possible problems. When an incident occurs, the worker must first make a judgment as to whether the incident is a <u>minor incident, major incident or emergency</u>. Subsequent actions are based on this decision.

A <u>*minor incident*</u> with radioactive materials is an abnormal occurrence involving low amounts of radioactive materials, where the worker handling the spill knows how to clean it up, has the decontamination materials on hand, and can respond without incurring risk of exposures or spreading within a reasonably short time.

A <u>*major incident*</u> is an abnormal occurrence involving high amounts of radioactive materials, high risk nuclides, large areas contaminated, contamination of the skin, airborne radioactivity, or any situation where contamination may have been spread outside the authorized area. <u>Major spills must be reported to the Radiation Safety Officer or his/her designee immediately, as required by federal law. Call the EHS Offce during working hours; dial 911 during non-working hours.</u>

An <u>*emergency*</u> is an incident which involves serious injury or death, fire, explosion, or significant release of a health or life threatening material, which is or may be coupled with a minor or major radiological incident. <u>DIAL 911 IMMEDIATELY</u> IF AN EMERGENCY HAS OCCURRED!!

In the event of a **MINOR** incident, these procedures should be followed:

1. Notify the principal investigator and persons in the area that an incident has occurred.
2. Contain the spill. Cover with absorbent paper or dike with absorbent.
3. Isolate the area to prevent unnecessary spread and personnel exposures.
4. Survey using the appropriate monitoring equipment in order to evaluate the presence of contamination on an individual's skin and clothing and on lab equipment. If skin or clothing contamination is present, a major spill has occurred. Contact the EHS Office immediately.
5. Using disposable gloves, carefully fold up the absorbent paper and pad and deposit in an appropriate radioactive waste container.
6. Survey the area of the spill to determine the extent.

7. Decontaminate the spill using decontaminant detergent (available from General Stores), and resurvey.
8. Continue step 7 until the area is decontaminated completely.
9. Document spill in radiation survey log book.

In the event of a **MAJOR** incident, the following procedure should be instituted:

1. Notify all persons in the area that a major spill or incident has occurred and evacuate unnecessary personnel. Notify the principal investigator.
2. If possible, prevent the spreading of the radioactive material by using absorbent paper. Do not attempt to clean it up. Confine all potentially contaminated individuals in order to prevent the further spread of contamination.
3. If possible, shield the source, but only if it can be done without significantly increasing your radiation exposure.
4. Leave the affected room and lock the doors in order to prevent entry. Attempt to prevent further contamination or spreading to unrestricted areas. (Hallways, non-radiation laboratories, etc., are unrestricted areas.)
5. Contact the EHS Office if the spill occurs during normal work hours. Call the Department of Police and Public Safety, 911, after normal working hours.
6. Remove all contaminated clothing and await instructions concerning cleanup from the EHS Office.
7. If skin contamination has occurred, measure levels of contamination with a survey meter, record, and begin decontamination by gentle washing with warm water and soap, washing downwards towards extremities, not upwards.

In the event of an **EMERGENCY** in which radioactive materials are involved, the following procedure should be instituted:

1. Notify all persons in the area that an EMERGENCY has occurred and evacuate the area if a risk to persons present exists.
2. Dial 911 and NOTIFY of the nature emergency, using the reporting guidelines previously listed in this section.
3. AWAIT THE EMERGENCY RESPONDERS who will assist and provide direction, as well as contact any other necessary responders.

All incidents involving radioactive materials must be reported as soon as possible to the principal investigator. If the principal investigator is not available, notify the EHS Office, who will advise and assist with the problem.

Decontaminating Radioactive Material

When radioactive material is in an unwanted or unplanned location, it is called contamination. This may be floors, equipment, work areas, storage areas, people or areas outside the authorized radiation use laboratory. Fortunately, most radioactive contamination and/or spills are easy to clean to background levels in a reasonable time and with reasonable cost. Some methods of decontamination are as follows:

Liquid Radioactive Decontaminant: Concentrated liquid decontaminating agents are available from General Stores and most scientific suppliers. This detergent is diluted with water and rapidly and easily cleans radioactive contamination without excessive effort. Mild wiping or scrubbing will remove most contamination using this detergent. Note that these detergents contain a carcinogen, so the Material Safety

Data Sheet should be read by new radiation users so that they are aware of the hazards. In dilute liquid form, radioactive decontaminants do not present a significant hazard to handlers unless ingested or splashed in eyes. Avoid prolonged skin contact with the concentrated material.

Foam Spray Decontaminant: A variety of foam spray decontamination products are available which are marketed as radioactive decontaminants. However, many other foam cleaning products accomplish decontamination just as effectively at a much lower cost; most of these are marketed in any store as bathroom or kitchen cleaning agents. Spray the foam on the contaminated areas, let sit for a few minutes, and then wipe off with a dry paper towel.

Other Decontaminating Agents: Many other agents will work to clean radioactive contamination that has been resistant to the above methods. Contact a Health Physicist for assistance with difficult to remove contamination. We will help identify a method of decontamination which will work for your particular surface, nuclide, chemical form and location. Depending on these factors, effective solutions to the problem will be identified.

Contamination on Skin: Use lukewarm (not hot or cold) water and a mild cleaning agent, such as soap. Do not rub hard or scrub with abrasives, which may break the surface of the skin. Clean the affected area in a downwards fashion, with the grain of the skin and hair, not against it, and towards the tips of extremities, not upwards. Check the area after gentle drying. If still contaminated, use a cream hand cleaner which contains no abrasives. <u>Remember to notify the EHS Offcie immediately if personnel contamination occurs or is suspected</u>. Also, note the readings of radioactive contamination detected with the survey instrument and the times that it was discovered and then removed.

PI Number_________
(For EHS use only)

APPLICATION FOR APPROVAL TO OBTAIN AND USE RADIOACTIVE MATERIALS AT MICHIGAN STATE UNIVERSITY

Please complete the requested information and send to:

Radiation Safety Officer
Environmental Health & Safety
C124 Research Complex - Engineering
Campus

Please call 355-0153 if you have questions.

1. Name of Principal Investigator:____
Title:___________________________Department:______________________________
Office Location:_____________________________Telephone:______________________
Date of Application:__________________________ Fax Number:____________________

2. Radioisotope(s) requested in this application:

Nuclide	**Physical and Chemical Form**	**Maximum Possession Amount (mCi)**

3. Radioisotopes for which previous approval was granted:
Location of previous approval:____

Nuclide	Physical and Chemical Form	Maximum Amount (mCi)

4. Describe your formal experience handling radioactive materials, including locations, radioisotopes and amounts handled.

____
____
____
____
____

List the safety training courses you have attended.

Name of Course	Location (Institution)	Mo./Yr.

5. List the location(s) where the radioactive material will be used (building and room number).____

Describe the storage facilities and security for radioactive materials that will be used.

____
____
____

6. Describe the personnel (dosimeters) monitoring, laboratory monitoring (survey and any other) and protective equipment that will be used for each nuclide.

Dosimeters:____

Monitoring Equipment:

Make__________________Model__________Detector__________________

Make__________________Model__________Detector__________________

Protective Equipment:

Lab Coats ☐ Eye Protection ☐

Gloves ☐ Fume Hood ☐

Shield ☐ Type of Shield____________________Thickness:_________

Other (Describe): ____

7. Describe the experimental procedures that will be utilized with the requested isotope. Emphasize aspects that pertain to safety issues. A brief description of materials and methods is usually adequate. (Add more pages if necessary.)

•What amount of radioactivity will be used in a typical experiment? ______________________

•What is the frequency of experiments?____

8. Describe the types of waste that will be generated in this research, including physical and chemical forms. List any other hazardous constituents, such as hazardous chemical, biological hazards, etc. Identify the amounts, volumes and rates of disposal of the waste.

____
____
____
____
____
____
____
____

9. Please describe any special hazards associated with the use(s) of radioactive materials requested in this application.

____
____
____
____
____
____
____
____
____

Applicant's Signature____

Department Chairperson's Signature____

CARBON - 14
[^{14}C]

PHYSICAL DATA

• Beta Energy:	156 keV (maximum) 49 keV (average) (100% abundance)
• Physical Half-Life:	5730 years
• Biological Half-Life:	12 days
• Effective Half-Life:	12 days (bound)
• Effective Half-Life:	40 days (unbound)
• Specific Activity:	4460 mCi/gram

• Maximum Beta Range in Air:	24.00 cm = 10 inches
• Maximum Beta Range in Water/Tissue:	*****0.28 mm = 0.012 inches
• Maximum Range in Plexiglas/Lucite/Plastic:	0.25 mm = 0.010 inches

*****Fraction of ^{14}C beta particles transmitted through dead layer of skin: At 0.007 cm depth = 1%

RADIOLOGICAL DATA

- Critical Organ: Fat Tissue
- Routes of Intake: Ingestion, Inhalation, Skin Contact
- External exposure: Deep dose from weak ^{14}C beta particles is not a radiological concern
- Internal exposure & contamination: Primary radiological concerns

- Committed Dose Equivalent (CDE): 2.08 mrem/µCi (ingested)
  (Fat Tissue) 2.07 mrem/µCi (puncture)
  2.09 mrem/µCi (inhalation)

- Committed Effective Dose Equivalent (CEDE): 1.54 mrem/µCi(ingested)

- Annual Limit on Intake (ALI)*: 2 mCi (ingestion of labeled organic compound) 2000 mCi (inhalation of carbon monoxide) 200 mCi (inhalation of carbon dioxide)

  *****[1.0 ALI = 2 mCi (ingested C- 14 organic compound) = 5,000 mrem CEDE]

- Skin Contamination Dose Rate: 1090-1180 mrem per 1.0 µCi/cm^2 (7 mg/cm^2 depth)
- Dose Rate to Basal Cells from Skin Contamination, 1.0 µCi/cm^2 = 1400 mrad/hour.
- Immersion in ^{14}C Contaminated Air = 2.183E^7 mrem/year per µCi/cm^3 at 70 um depth of tissue and 4.07E^6 mrem/year per µCi/cm^3 value averaged over dermis.

SHIELDING

- None required (≤ 3 mm Plexiglas)

SURVEY INSTRUMENTATION

- Can detect ^{14}C using a thin-window G-M survey meter; survey meter probe **must** be at close range (1 cm.)
- G-M survey meters have very low counting efficiency for ^{14}C (5%).
- Liquid scintillation counter (indirect counting) may be used to detect removable ^{14}C on wipes.

RADIATION MONITORING DOSIMETERS

- Not needed (beta energy too low).
- ^{14}C Beta Dose Rate: 6.32 rad/hr at 1.0 cm. in air per 1.0 mCi ^{14}C
- Skin Contamination Dose Rate: 13.33 mrad/hr per μCi on skin
- Dose Rate from a 1 mCi isotropic point source of ^{14}C:

Distance	Rad/Hr
1.0 cm	1241.4
2.0 cm	250.4
15.2 cm	0.126
20.0 cm	0.0046

GENERAL RADIOLOGICAL SAFETY INFORMATION

- Urinalysis: Not Required; however, prudent after a ^{14}C radioactive spill or suspected intake.
- Inherent volatility (at STP): Not Significant.
- Possibility of organic ^{14}C compounds being absorbed through gloves.
- Care should be taken NOT to generate $^{14}CO2$ gas which could be inhaled.
- Internal Dose is the concern: Skin contamination, ingestion, inhalation, and puncture.
- Always wear a lab coat and disposable gloves when working with ^{14}C.
- The concentration of carbon in adipose tissue, including the yellow marrow, is about 3 times the average whole body concentration. No other organ or tissue of the body concentrates stable carbon to any significant extent.
- The fractional absorption of dietary carbon (uptake to blood) is usually in excess of 0.90. •
- Three main classes of carbon compounds may be inhaled: organic compounds, gases (CO or CO_2), and aerosols of carbon containing compounds such as carbonates and carbides.

Organic Compounds - most organic compounds are NOT very volatile under normal circumstances; the probability of these being inhaled as vapors is therefore small. In circumstances where such substances are inhaled, it would be prudent to assume that once they enter the respiratory system they are instantaneously and completely translocated to the systemic circulation without changing their chemical form.
Gases - the inhalation of CO and its retention in body tissues has been studied extensively. Since gas has a relatively low solubility in tissue water, doses due to absorbed gas in tissues are insignificant in comparison with doses due to the retention of CO bound to hemoglobin. CO_2 in the blood exists mainly as a bicarbonate.
Carbonates & Carbides - It is assumed that inhaled or ingested ^{14}C labeled compounds are instantaneously and uniformly distributed throughout all organs & tissues of the body where they are retained with a biological half-life of 12-40 days.

CHROMIUM - 51
[^{51}Cr]

PHYSICAL DATA

Gamma Energy: 320 keV (9.8% abundance) *
X-ray Energy: 5 keV (22% abundance) *
*[Percent of disintegration resulting in this radiation being emitted]

No Betas Emitted

Specific Gamma Constant: 0.017 mR/hr per mCi at 1.0 meter

Physical Half-Life: 27.8 days
Biological Half Life: 616.0 days
Effective Half-Life: 26.6 days (whole body)

Specific Activity: 92,000 Curies/gram
Specific Activity (microspheres): 63.56 mCi/gram

RADIOLOGICAL DATA

- Critical Organ: Lower large intestine (LLI)
- Routes of Intake: Ingestion, inhalation, skin contact
- External & internal exposure and contamination are radiological concerns.

Committed Dose Equivalent (CDE): 0.15 mrem/μCi (ingested/gonad)
(gonad & lung) 1.41 mrem/μCi (inhalation/lung/Class W)

Committed Dose Equivalent (CDE): 1.20 mrem/μCi (ingested/GI tract/LLI)
0.22 mrem/μCi (inhaled/LLI Wall/Class D)

Committed Effective Dose Equivalent (CEDE): 0.107 mrem/μCi (ingested)
0.211 mrem/μCi (inhalation/Class D)
0.211 mrem/μCi (inhalation/Class W)

Annual Limit on Intake (ALI)*: 20 mCi (inhalation/Class W & Y)
52 mCi (inhalation/Class D/soluble)
40 mCi (ingestion)

*[1.0 ALI = 40 mCi (^{51}Cr ingested) = 5,000 mrem CEDE (Whole Body)]

SHIELDING

- Use 1/4" - 1/2" lead shielding for ^{51}Cr

Half - Value Layer (lead): 2.0 mm = 0.07"
Half - Value Layer (concrete): 2.8 cm = 1.10"
Half - Value Layer (Plexiglas): 4.8 cm = 1.90"

Tenth - Value Layer (lead): 5.6 mm = 0.22"
Tenth - Value Layer (concrete): 9.3 cm = 3.66"
Tenth - Value Layer (Plexiglas): 17.2 cm = 6.80"
Maximum range in lead: 7 mm. = 0.5"
Maximum range in Plexiglas: 65 cm. = 22.0"

SURVEY INSTRUMENTATION

- Survey meter equipped with a NaI scintillation probe is recommended.
- Survey meter equipped with a G-M pancake/detector or standardized cylindrical probe is very **inefficient** for the detection of ^{51}Cr (very low counting efficiency).
- Smears or wipes counted in a liquid scintillation counter (indirect) is best for the detection of **removable** ^{51}Cr surface contamination.

PERSONAL RADIATION MONITORING DOSIMETERS

Whole body & extremity badges required.

REGULATORY COMPLIANCE INFORMATION

- Derived Air Concentration (DAC): (inhalation)
  - $2.0E^{-5}$ μCi/cc (Class D)
  - $1.0E^{-5}$ μCi/cc (Class W)
  - $8.0E^{-6}$ μCi/cc (Class Y)

- Airborne Effluent Release Limit*:
  - $6.0E^{-8}$ μCi/cc (Class D)
  - $3.0E^{-8}$ μCi/cc (Class W & Y)

* Applicable to the assessment & control of dose to the public (10 CFR 20.1302). If this concentration was inhaled continuously for over one year the resulting TEDE would be 50 mrem.

- Urinalysis : Not required; however, may be requested in the event of a spill of ^{51}Cr.

- Whole Body Bioassay: May be prudent in the event of a suspected intake of ^{51}Cr through ingestion, inhalation, skin absorption, or a wound.
- Gamma (photon) exposure rates from 1.0 mCi ^{51}Cr point source:

Distance	mrad/hr.
1.0 cm	160.0
5.0 cm	6.4
10.0 cm	1.6
100.0 cm	0.016

- Inherent Volatility (STP): Insignificant/Negligible

HYDROGEN - 3
[^{3}H]

PHYSICAL DATA

- Beta Energy: 18.6 keV (maximum)
  5.7 keV (average) (100% abundance)
- Physical Half-Life: 12.3 years
- Biological Half-Life: 10 - 12 days
- Effective Half-Life: 10 - 12 days *

* Forcing liquids to tolerance (3-4 liters/day) will reduce the effective half-life of ^{3}H by a factor of 2 or 3. (Relatively easy to flush out of system with fluids.)

- Specific Activity: 9640 Ci/gram
- Maximum Beta Range in Air: 6 mm = 0.6 cm = 1/4"
- Maximum Beta Range in Water: 0.006 mm = 0.0006 cm = 3/10,000"
- Penetrability in Matter or Tissue: Insignificant*
  *[0% of beta particle energy transmitted through dead layer of skin]

RADIOLOGICAL DATA

- Least radiotoxic of all radionuclides
- Critical Organ: Body Water or Tissue
- Routes of Intake: Ingestion, Inhalation, Puncture, Wound, Skin Contamination (Absorption)
- External exposure from weak ^{3}H beta energy - not a radiological concern
- Internal exposure & contamination are primary radiological concerns
- Committed Dose Equivalent (CDE): 64 mrem/mCi (ingested)
  64 mrem/mCi (inhaled)
  64 mrem/mCi (puncture)
- Committed Effective Dose Equivalent (CEDE): 90 mrem/mCi (ingested)
  63 mrem/mCi (inhaled)
- Annual Limit on Intake (ALI)*: 80 mCi (ingestion or inhalation) [^3H_2O]
  * [1.0 ALI = 80 mCi (^{3}H) = 5,000 mrem CEDE]
- Skin Contamination Exposure Rate: 57,900 mrad/hr/mCi (contact)*
  * Exposure rate to dead layer of skin only
  * Skin contamination of 1.0 μCi/cm^2 = 0 mrad/hr dose rate to basal cells
- Rule of Thumb: 0.001 μCi/ml of ^{3}H in urine sample is indicative of a total integrated whole body dose of approximately 10 mrem (average person) if no treatment is instituted (i.e., flush with fluids) [NCRP-65, 1980]

SHIELDING

- None required

SURVEY INSTRUMENTATION

- **CANNOT** detect ^{3}H using a G-M or NaI survey meter
- Liquid scintillation counter (indirect) is the only monitoring method

RADIATION MONITORING DOSIMETERS

- Whole Body Badge or Finger Rings: Not needed (beta energy too low)

RADIOACTIVE WASTE

- Solid, liquids, scintillation vials, pathological materials, animal carcasses

REGULATORY COMPLIANCE INFORMATION

- Derived Air Concentration (DAC) : 2.0 E^{-5} μCi/cc (occupational)
- Airborne Effluent Release Limit: 1.0 E^{-7} μCi/cc *

  * [Applicable to the assessment & control of dose to the public (10 CFR 20.1302). If this concentration was inhaled continuously for over one year the resulting TEDE would be 50 mrem.]
- Controlled Area Removable Contamination Limit: 2,200 dpm/100 cm^2
- Urinalysis (Byproduct License): **Required** when handling ≥ 100 mCi ^3H

GENERAL RADIOLOGICAL SAFETY INFORMATION

- Inherent Volatility (at STP): **SUBSTANTIAL**
- Experimental uses include: total body water measurements & in-vivo labeling of proliferatory cells by injection of tritium-labeled compounds (i.e., thymidine). Tritium labeling is also used in a variety of metabolic studies.
- Oxidation of ^3H gas in air is usually slow (< 1% per day).
- Absorption of ^3H inhaled in air is much less when it is present as elemental ^3H than as tritiated water (HTO).
- Tritium penetrates the skin, lungs, and GI tract either as tritiated water or in the gaseous form.
- As gaseous hydrogen, ^3H entering the lung or GI tract is completely absorbed and rapidly dispersed within the body.
- Some ^3H is incorporated into cellular components and has a long turnover rate.
- Forcing fluids reduces integrated internal exposures from ^3H.
- Monitor for ^3H contamination using only wipe-testing (bench tops, floors, refrigerator/freezer handles, phone, etc.).
- Always wear a lab coat & disposable gloves when handling ^3H.
- Skin contamination, inhalation, ingestion, or absorption through the skin is assumed to be completely and instantaneously absorbed and rapidly mixed with total body water.
- The volume of total body water (standard man) is 42,000 ml.
- The concentration of ^3H in urine is assumed to be the same as in total body water.
- Detection limit of ^3H in urine: 1.08E^{-5} μCi/ml (approximately)
- For a continuous inhalation exposure at a rate of 1/365 of an ALI per day, the equilibrium concentration of ^3H in urine is
- 0.073 μCi/ml. [NOTE: 1/365 of 80 mCi (ALI) = 219 μCi]
- The predicted concentration activity normalized to unit intake from inhalation is 2.204 E^{-5} μCi/ml/μCi of ^3H.
- Beta dose rates from 1.0 mCi ^3H point source:

Distance	Rad/hr
0.25 cm	10,293.00
0.50 cm	28.12
0.56 cm	1.12

IODINE - 125
[^{125}I]

PHYSICAL DATA

• Gamma Energies:	35.5 keV	(7% abundance/93% internally converted, gamma)
(No betas emitted)	27.0 keV	(113%, x-ray)
	27-32 keV	(14%, x-ray)
	31.0 keV	(26%, x-ray)

- Specific Gamma Ray Constant: 0.27 to 0.70 mR/hr per mCi at 1 meter
  (Current literature indicates 0.27 mR/hr per mCi at 1 meter)

- Physical Half-Life: 60.1 days
- Biological Half-Life: 120-138 days (unbound iodine) - thyroid elimination
- Effective Half-Life: 42 days (unbound iodine) - thyroid gland

- Specific Activity: 17,400 Ci/gm (theoretical/carrier free)
- Intrinsic Specific Activity: 22.0 Ci/millimole

RADIOLOGICAL DATA

- Critical Organ (Biological Destination): Thyroid
- Routes of Intake: Ingestion, inhalation (most probable), puncture, wound, skin contamination (absorption)
- External and internal exposure and contamination concerns exist in use of ^{125}I

- Committed Dose Equivalent (CDE): 814 mrem/mCi (thyroid/inhalation/class "D")
  (Organ Doses) 1185 mrem/mCi (thyroid/ingestion/NaI form)
  910 mrem/mCi (thyroid/inhalation)
  1258 mrem/mCi (any organ/puncture/adult)

- Committed Effective Dose Equivalent(CEDE): 24 mrem/mCi (whole body/inhalation)

SHIELDING

- Lead foil or sheets (1/32 to 1/16 inch thick): 0.152 mm lead foil
- Half Value Layer: 0.02 mm = 0.008 inches

SURVEY INSTRUMENTATION

- Survey meter equipped with a low energy NaI scintillation probe is necessary.
- Survey meters equipped with GM pancakes or end window GM probes are inefficient. These probes are not useful for contamination monitoring; they are only about 0.1% efficient.

DOSE RATES
(from unshielded 1.0 mCi isotropic point source)

Distance	mrads/hr.
1.00 cm	156 - 275
10.00 cm	15.5 -27.5
100.00 cm	0.156 -0.28
6.00 in	6.5

(Some literature indicates 0.7 mrad/hr per mCi at 100 cm.)

- Individuals who will be using ^{125}I in the NaI or KI chemical form are required to obtain a thyroid scan to be used as a baseline reference prior to use.

- The thyroid gland accumulates 20 - 30% of the soluble radioiodine taken in by the body. All radioiodines in the body can be assumed to be eliminated quite rapidly via the urine.

- Thyroid Bioassay is **required by law** when handling $\geq$ 1 mCi in the ^{125}I in the sodium or potassium iodide chemical form. In accordance with the NRC license and MSU's commitment to ALARA, the threshold amount is taken to be 0.1 mCi. The thyroid scan is to be obtained not less than 24 hours but not more than one week after the handling or use of that quantity and form of ^{125}I. In addition, all workers who assist or observe in manipulations of the above quantity and type of ^{125}I, or are sufficiently close to the process so that intake is possible (within a few meters and in the same room) are required to obtain thyroid scans under the same conditions listed above.

- Fume hood sash glass provides adequate shielding for most iodinations. Extra shielding is not recommended, since it impedes air flow into the hood.

- Shielding is not required for most uses of this nuclide due to the low energy and low amounts typically used.

- Use a cannula adapter needle to vent stock vials of ^{125}I used for iodinations. This prevents puff releases.

- Segregate waste from iodinations (free) from other (bound) ^{125}I waste and store it in the fume hood, in tightly sealed ziplok bags (solid waste) or screw top containers (liquid waste) until waste pickup.

- Cover test tubes used to count or separate fractions from iodinations with parafilm or other tight caps to prevent release while counting or moving outside the fume hood.

PHOSPHORUS - 32
[^{32}P]

PHYSICAL DATA

• Beta energy:	1.709 MeV (maximum)
	0.690 MeV (average, 100% abundance)
• Physical half-life:	14.3 days
• Biological half-life:	1155 days
• Effective half-life:	14.1 days (bone) / 13.5 days (whole body)

• Specific activity:	285,000 Ci/gm
• Maximum range in air:	610 cm = 240 inches = 20 feet
• Maximum range in water/tissue:	0.76 cm = 1/3 inch
• Maximum range in Plexiglas/Lucite/plastic:	0.61 cm = 3/8 inch
• Half-Value Layer (HVL):	2.00 mm (water/tissue)

RADIOLOGICAL DATA

- Critical organ (biological destination) (soluble forms): Bone
- Critical organs (insoluble forms or non-transportable ^{32}P compounds): Lung (inhalation) and G.I. tract/lower large intestine (ingestion)
- Routes of intake: Ingestion, inhalation, puncture, wound, skin contamination (absorption)
- External and internal exposure from ^{32}P

• Committed Dose Equivalent (CDE):	32 mrem/ μCi (ingested)
(Organ Doses)	37 mrem/ μCi (puncture)
	96 mrem/ μCi (inhaled/Class W/lungs)
	22 mrem/ μCi (inhaled/Class D/bone marrow)
• Committed Effective Dose Equivalent (CEDE):	7.50 mrem/ μCi (ingested/WB)
	5.55 mrem/ μCi (inhale/Class D)
	13.22 mrem/ μCi (inhale/Class W)

- Skin contamination dose rate: 8700-9170 mrem/ μCi /cm^2/hr. (7 mg/cm^2 or 0.007 cm depth in tissue).
- Dose rate to basal cells from skin contamination of 1.0 μCi/cm^2 (localized dose) = 9200 mrad/hr.
- Bone receives approximately 20% of the dose ingested or inhaled for soluble ^{32}P compounds.
- Tissues with rapid cellular turnover rates show higher retention due to concentration of phosphorous in the nucleoproteins.
- ^{32}P is eliminated from the body primarily via urine.
- Phosphorus metabolism; see ^{33}P Fact Sheet.

SHIELDING

- ≤ 3/8 inch thick Plexiglas/acrylic/Lucite/plastic/wood.
- Do not use lead foil or sheets! Penetrating Bremsstrahlung x-ray will be produced!
- Use lead sheets or foil to shield Bremsstrahlung x-rays only **after** low density Plexiglas/acrylic/Lucite/wood shielding.

SURVEY INSTRUMENTATION

- GM survey meter and a pancake probe.
- Low-energy NaI probe is used **only to detect Bremsstrahlung x-rays.**
- Liquid scintillation counter (indirect counting) may be used to detect removable surface contamination of ^{32}P on smears or wipes.

DOSE RATES

(from unshielded 1.0 mCi isotropic point source)

Distance	Rads/hr
1.00 cm	348
15.24 cm	1.49
10.00 ft	0.0015

- 78,000 mrad/hr at surface of 1.0 mCi ^{32}P in 1 ml liquid.
- 26,000 mrad/hr at mouth of open vial containing 1.0 mCi ^{32}P in 1.0 ml liquid.

GENERAL PRECAUTIONS

• Because it is a bone seeker, special precautions must be taken to minimize any chance of introducing into the body.

• Airborne contamination can be generated through drying (dust), rapid boiling, or expelling solutions through syringe needles and pipette tips, due to aerosols.

• Personnel radiation monitors (whole body and finger rings) are **required** when handling > 1.0 mCi of ^{32}P at any time.

• Never work directly over an open container; avoid direct eye exposure from penetrating ^{32}P beta particles.

• Always wear a lab coat and disposable gloves when handling ^{32}P.

• Monitor personnel work areas and floors using a GM survey meter equipped with a pancake (beta) probe for surface contamination.

• Monitor for removable surface contamination by smearing or wiping where ^{32}P is used.

• Use low-density (low atomic number) shielding material to shield ^{32}P and reduce the generation of Bremsstrahlung x-rays. The following materials are low atomic number materials: Plexiglas, acrylic, Lucite, plastic, wood, or water.

• Do NOT use lead foil, lead sheets, or other high density materials (metals) to shield ^{32}P directly. Materials with atomic number higher than that of aluminum (Z = 13) should NOT be used. Penetrating Bremsstrahlung x-rays will be generated in lead and other high density shielding material.

• Safety glasses or goggles are recommended when working with ^{32}P.

• Typical GM survey meter with pancake probe efficiency is ≥ 45%. Typical liquid scintillation counter counting efficiency for ^{32}P (full window/maximum) ≥ 85%.

• Typical detection limit of ^{32}P in urine specimens using a liquid scintillation counter = 1.1 E^{-7} μCi/ml.

PHOSPHORUS - 33
[^{33}P]

PHYSICAL DATA

- Beta energy: 0.249 MeV (maximum, 100% abundance)
  0.085 MeV (average)

- Physical half-life: 25.4 days
- Biological half-life: 19 days (40% of intake; 30% rapidly eliminated from body, remaining 30% decays)
- Effective half-life: 24.9 days (bone)
- Specific activity: 1,000 - 3,000 Ci/millimole
-
- Maximum beta range in air: 89 cm = 35 inches = 3 feet
- Maximum range in water/tissue: 0.11 cm = 0.04 inch
- Maximum range in Plexiglas/Lucite/plastic: 0.089 cm = 0.035 inch
- Half-Value Layer (HVL): 0.30 mm (water/tissue)

RADIOLOGICAL DATA

- Critical organ (biological destination) (soluble forms): Bone marrow
- Critical organs (insoluble forms or non-transportable ^{33}P compounds): Lung (inhalation) and G.I. tract/Lower large intestine (ingestion)
- Routes of intake: Ingestion, inhalation, puncture, wound, skin contamination (absorption)
- Internal exposure and contamination are the primary radiological concerns
- Committed Dose Equivalent (CDE): 0.5 mrem/mCi (inhalation)
- Skin contamination dose rate: 2,910 mrem/hr/μCi/cm^2 (7 mg/cm^2 or 0.007 cm depth in tissue)
- Fraction of ^{33}P beta particles transmitted through the dead skin layer is about 14%.
- Tissues with rapid cellular turnover rates show higher retention due to concentration of phosphorus in the nucleoproteins.
- ^{33}P is eliminated from the body primarily via urine.
- Phosphorus metabolism: 30% is rapidly eliminated from body
  40% has a 19-day biological half-
  60% of ^{33}P (ingested) is excreted from body in first 24 hrs

SHIELDING

- Not required; however low density material is recommended, e.g., 3/8 inch thick Plexiglas, acrylic, Lucite, plastic or plywood.

SURVEY INSTRUMENTATION

- GM survey meter with a pancake probe.
- Liquid scintillation counting of wipes may be used to detect removable surface contamination.

PERSONNEL DOSIMETERS

- Are not required, since they do not detect this low energy nuclide.

GENERAL PRECAUTIONS

- Inherent volatility (STP): Insignificant
- Skin dose and contamination are the primary concerns.
- Drying can form airborne ^{33}P contamination.
- Monitor work areas for contamination, using smears or wipes to check for removable contamination.

SULFUR - 35

[^{35}S]

PHYSICAL DATA

- Beta energy: 167 keV (maximum)
  53 keV (average) (100% abundance)

- Physical Half Life: 87.4 days
- Biological Half Life: 623 days (unbound 35S)
- Effective Half Life: 44 -76 days (unbound 35S)
- Specific Activity: 42,400 Ci/g

- Maximum Beta Range in Water or Tissue: 0.32 mm. = 0.015 in.
- Maximum Beta Range in Plexiglas or Lucite: 0.25 mm. = 0. 01 in.
- Fraction of ^{35}S betas transmitted through dead layer of skin = 12%

RADIOLOGICAL DATA

- Critical organ: Testis
- Routes of Intake: Ingestion, inhalation, puncture, wound, skin contamination (absorption)
- External exposure (deep dose) from weak ^{35}S beta particles is not a radiological concern.
- Internal exposure and contamination are the primary radiological concerns.

- Committed dose equivalent (CDE): 10.00 mrem/ μCi (ingested)
  0.352 mrem/ μCi (puncture)
- Committed Effective Dose Equivalent (CEDE): 2.6 mrem/ μCi (ingested)*
  *(Assumes a 90 day biological half life)
- Annual Limit on Intake (ALI)*: 10 mCi (ingestion of inorganic ^{35}S compounds)
  6 mCi (Ingestion of elemental ^{35}S)
  8 mCi (ingestion of sulfides or sulfates/LLI)**
  10 mCi (inhalation of ^{35}S vapors)
  20 mCi (inhalation of sulfides or sulfates)
  2 mCi (inhalation of elemental ^{35}S)

*1.0 ALI = 10 mCi (inhaled ^{35}S vapors) = 5,000 mrem CEDE
** 1.0 ALI = 8 mCi (ingestion sulfides/sulfates LLI) = 50,000 mrem CDE

- Skin Contamination Dose Rate: 1,170 - 1, 260 mrem/μCi/cm^2/hr. (7.0 mg/cm^2 depth)
- Beta Dose Rates for ^{35}S: 14.94 rad/h (contact) in air per 1.0 mCi
  0.20 rad/h (6 inches) in air per 1.0 mCi

SHIELDING

- None required (≤ 3 mm Plexiglas shields; shielding optional).

SURVEY INSTRUMENTATION

- can detect using a thin window G-M survey meter (pancake), however, probe **MUST** be at close range, recommend 1 cm distance.
- G-M survey meter has low efficiency, usually 4 - 6%.
- Liquid scintillation counter (wipes, smears) may be used for secondary, **but will NOT detect non-removable contamination!**

RADIATION MONITORING DEVICES

- (Badges): Not needed, because ^{35}S beta energy is too low, and is not an external radiation hazard
- Dose Rate from a 1 millicurie unshielded isotropic point source of ^{35}S:

Distance	Rad/hr
1.0 cm	1173.6
2.5 cm	93.7
15.24 cm	0.2
20.00 cm	0.01

GENERAL RADIATION SAFETY INFORMATION

- Urinalysis: Not required, but may be requested by Health Physics staff after a spill or personnel contamination involving ^{35}S.
- Inherent volatility (STP): **SIGNIFICANT** for ^{35}S methionine and cysteine.
- Radiolysis of ^{35}S amino acids (cysteine and methionine) during storage and use may lead to the release of volatile impurities. Volatile impurities are small (≤ 0.05%).
- Metabolic behavior of organic compounds of sulfur (cysteine and methionine) differs considerably from the metabolic behavior of inorganic compounds.
- Organic compounds of sulfur (cysteine and methionine) become incorporated into various metabolites. Thus, sulfur entering the body as an organic compound is often tenaciously retained.
- The fractional absorption of sulfur from the gastrointestinal tract is typically > 60% for organic compounds of sulfur. Elemental sulfur is less well absorbed from the GI tract than are inorganic compounds of the element (80% for all inorganic compounds and 10% for sulfur in its elemental form). Elemental sulfur is an NRC inhalation Class W (meaning it is retained for weeks in the body).
- Inhalation of the gases SO_2, COS, H_2S, and CS_2 must be considered. Sulfur entering the lungs in these forms is completely and instantaneously translocated to the transfer compartment; from there, its metabolism is the same as that of sulfur entering the transfer compartment following ingestion or inhalation of any other organic compound of sulfur.
- Contamination of internal surfaces of storage and reaction vessels may occur (rubber stoppers, gaskets or o rings).
- Vials of ^{35}S labeled cysteine and methionine should be opened and used in ventilated enclosures (exhaust hoods).
- The volatile components of ^{35}S labeled amino acids should be opened and used in ventilated enclosures (exhaust hoods).
- The volatile components of ^{35}S labeled cysteine and methionine are presumed to be hydrogen sulfide (H_2S) and methyl mercaptan (CH_3SH), respectively.
- ^{35}S vapors may be released when opening vials containing labeled amino acids, during any incubating of culture or cells containing ^{35}S, and the storage of ^{35}S contaminated wastes.
- Excessive contamination can be found on the inside surfaces and in water reservoirs of incubators used for ^{35}S work. Most notable surface contamination can be found on rubber seals of incubators and centrifuges.
- Radiolytic breakdown may occur during freezing processes, releasing as much as 1.0 μCi of ^{35}S per 8.0 mCi vial of ^{35}S amino acid during the thawing process.
- ^{35}S labeled amino acids work should be conducted in an exhaust hood designated for radiolytic work.
- Vent ^{35}S amino acid stock vials with an open-ended charcoal-filled disposable syringe. Activated charcoal has a high affinity for ^{35}S vapors.
- Place an activated carbon or charcoal canister, absorbent sheet, or tray (50-100 grams of granules evenly distributed in a tray or dish) into an incubator to passively absorb ^{35}S vapors. Discard absorbers which exhibit survey meter readings above normal area background levels in the solid radioactive waste.

Directions for Conducting a Radiation Safety Survey

Radiation safety surveys must be conducted on a weekly to monthly basis in each laboratory where radioactive materials are used. Appropriate detection equipment must be used for each nuclide monitored. Examples are as follows:

^{3}H	Beta	.018 MeV	Liquid Scintillation Counter (Wipe Samples)
^{14}C	Beta	.156 MeV	Geiger Counter with Beta Pancake Probe Geiger Counter
^{35}S	Beta	.167 MeV	Geiger Counter with Beta Pancake Probe Geiger Counter
^{33}P	Beta	.248 MeV	Geiger Counter with Beta Pancake Probe Geiger Counter
^{32}P	Beta	1.71 MeV	Geiger Counter with Beta Pancake Probe Geiger Counter
^{125}I	Gamma	.027 MeV To .035 MeV	Geiger Counter with Low Energy Gamma Probe
^{51}Cr	Gamma	.320 MeV	Geiger Counter with Low Energy Gamma Probe

1. Use a Geiger counter rather than liquid scintillation counter for monitoring all nuclides except ^{3}H. Geiger counters detect both removable and non-removable contamination, whereas wipes and liquid scintillation counting detect only removable contamination. ^{3}H cannot be detected by any Geiger counter, so liquid scintillation counting is the only method to conduct a survey for that nuclide.
2. You must survey in all areas where radioisotopes are used, stored or disposed, and the floors adjacent to those areas. This includes centrifuges, incubators, cold rooms, sealing equipment, pipetters and any other equipment which has been used for radioisotope work.
3. Make a record of all laboratory surveys. The record should include a map of the room, marks to identify where you surveyed, nuclides surveyed for, equipment identification, background of the equipment, efficiency for each nuclide monitored, and results of the survey. Results include area of contamination, nuclide, CPM reading, DPM, μCi amount and corrective action taken. To convert CPM to μCi, the following equation should be used:

   $$\text{CPM/Efficiency} = \text{DPM} \qquad \text{DPM}/2.22\ E^{6} = \mu\text{Ci amount}$$

4. To monitor for ^{3}H, wipes of the area must be taken. Follow these steps:
   a. Use a cotton tip applicator dipped in methanol to wipe the work area being checked. You may wipe a large area, then count. If you find contamination, take wipes of smaller areas until you localize the contamination.
   b. Place the cotton tip applicator in a liquid scintillation vial.
   c. Add counting cocktail.
   d. Let the sample desorb for 30 minutes.
   e. Count in a liquid scintillation counter for 1 minute.

f. Record the results on the laboratory survey record.

5. To monitor all other radioisotopes, use a Geiger counter with the correct probe. Follow these steps:

   a. Turn the meter on and first check the batteries by looking at the battery check reading. If the batteries are low, replace them before surveying. You may survey with the audio on or off. However, significant rate changes are easily detected by the audio.

   b. Set the meter to read on the lowest possible setting, e.g., .1X or 1X the count rate. Set the response to fast response.

   c. Check and record the background reading. (Note: Fast response mode gives a background range, which is needed to determine when contamination is present.)

   d. Slowly scan the area to be surveyed with the probe. Hold the probe about half an inch above the areas to maximize detection.

   e. If the needle reads above twice (rule of thumb for surveying) background, switch the response to slow response to accurately quantify the contamination. Check the suspected source of contamination from more than one direction to confirm the source of the response. The meter response may be due to waste, samples or other radioactive materials in the area, not to contamination.

   f. Record the results of the survey on the record form.

   g. Decontaminate or dispose of the contamination in the radioactive waste. If the contaminated area or equipment cannot be decontaminated, shield and label the contamination with the nuclide, date and activity in DPM or μCi.

   h. Remember to turn the meter off after each use to save batteries.

   i. If major contamination is found, report immediately to the principal investigator.

SURVEY FREQUENCY GUIDE

Amount Use	Documented Survey Frequency
Always less than 200 μCi in shipment	Monthly
≥ 200 μCi in shipment	After each use of ≥ 200 μCi (means each handling of shipment, even if using much less than 200 μCi), but not more than one per week, unless EHS deems otherwise (certain high risk uses require more frequent surveys)
No use in a given period	No survey required, keep log in survey book noting dates of non-use

LABORATORY CLASSIFICATION TABLE
RADIONUCLIDES CLASSIFIED ACCORDING TO RELATIVE RADIOTOXICITY PER UNIT ACTIVITY*

<u>Group I: Very high radiotoxicity</u>

^{210}Pb	^{226}Ra	^{227}Th	^{231}Pa	^{233}U	^{238}Pu	^{241}Pu	^{243}Am	^{244}Cm	^{249}Cf
^{210}Po	^{228}Ra	^{228}Th	^{230}U	^{234}U	^{239}Pu	^{242}Pu	^{242}Cm	^{245}Cm	^{250}Cf
^{223}Ra	^{227}Ac	^{230}Th	^{232}U	^{237}Np	^{240}Pu	^{241}Am	^{243}Cm	^{246}Cm	^{252}Cf

<u>Group II: High radiotoxicity</u>

^{22}Na	^{56}Co	^{95}Zr	^{124}Sb	^{126}I	^{140}Ba	^{170}Tm	^{207}Bi	^{228}Ac
^{36}Cl	^{60}Co	^{106}Ru	^{125}Sb	^{131}I	^{144}Ce	^{181}Hf	^{210}Bi	^{230}Pa
^{45}Ca	^{89}Sr	$^{110}Ag_m$	$^{127}Te_m$	^{133}I	^{152}Eu	^{182}Ta	^{211}At	^{234}Th
^{46}Sc	^{90}Sr	$^{115}Cd_m$	$^{129}Te_m$	^{134}Cs	^{154}Eu	^{192}Ir	^{212}Pb	^{236}U
^{54}Mn	^{91}Y	$^{114}In_m$	^{124}I	^{137}Cs	^{160}Tb	^{204}Tl	^{224}Ra	^{249}Bk

<u>Group III: Moderate radiotoxicity</u>

^{7}Be	^{48}Sc	^{65}Zn	^{91}Sr	^{103}Ru	$^{125}Te_m$	^{140}La	^{153}Gd	^{183}Re	^{199}Au	^{233}Pa
^{14}C	^{48}V	$^{69}Zn_m$	^{90}Y	^{105}Ru	^{127}Te	^{141}Ce	^{159}Gd	^{186}Re	^{197}Hg	^{239}Np
^{18}F	^{51}Cr	^{72}Ga	^{92}Y	^{106}Rh	^{129}Te	^{143}Ce	^{165}Dy	^{188}Re	$^{197}Hg_m$	
^{24}Na	^{52}Mn	^{73}As	^{93}Y	^{103}Pd	$^{131}Te_m$	^{142}Pr	^{166}Dy	^{185}Os	^{203}Hg	
^{38}Cl	^{56}Mn	^{74}As	^{97}Zr	^{109}Pd	^{132}Te	^{143}Pr	^{166}Ho	^{191}Os	^{200}Tl	
^{31}Si	^{52}Fe	^{76}As	$^{93}Nb_m$	^{105}Ag	^{130}I	^{147}Nd	^{169}Er	^{193}Os	^{201}Tl	
^{32}P	^{55}Fe	^{77}As	^{95}Nb	^{111}Ag	^{132}I	^{149}Nd	^{171}Er	^{190}Ir	^{202}Tl	
^{35}S	^{59}Fe	^{75}Se	^{99}Mo	^{109}Cd	^{134}I	^{147}Pm	^{171}Tm	^{194}Ir	^{203}Pb	
^{41}A	^{57}Co	^{82}Br	^{96}Tc	^{115}Cd	^{135}I	^{149}Pm	^{175}Yb	^{191}Pt	^{206}Bi	
^{42}K	^{58}Co	$^{85}Kr_m$	$^{97}Tc_m$	$^{115}In_m$	^{135}Xe	^{151}Sm	^{177}Lu	^{193}Pt	^{212}Bi	
^{43}K	^{63}Ni	^{87}Kr	^{97}Tc	^{113}Sn	^{131}Cs	^{153}Sm	^{181}W	^{197}Pt	^{220}Rn	
^{47}Ca	^{65}Ni	^{86}Rb	^{99}Tc	^{125}Sn	^{136}Cs	^{152}Eu	^{185}W	^{196}Au	^{222}Rn	
^{47}Sc	^{64}Cu	^{85}Sr	^{97}Ru	^{122}Sb	^{131}Ba	^{155}Eu	^{187}W	^{198}Au	^{231}Th	

Group IV: Low radiotoxicity

^{3}H	$^{58}Co_m$	^{71}Ge	^{87}Rb	^{97}Nb	$^{103}Rh_m$	^{129}I	$^{134}Cs_m$	^{187}Re	$^{197}Pt_m$	^{235}U
^{15}O	^{59}Ni	^{85}Kr	$^{91}Y_m$	$^{96}Tc_m$	$^{113}In_m$	$^{131}Xe_m$	^{135}Cs	$^{191}Os_m$	^{232}Th	^{238}U
^{37}A	^{69}Zn	$^{85}Sr_m$	^{93}Zr	$^{99}Tc_m$	^{125}I	^{135}Xe	$^{147}S_m$	$^{193}Pt_m$	^{Nat}Th	^{Nat}U

* From Safe Handling of Radionuclides, IAEA Safety Standards, 1973

TABLE II: LIMITATION ON ACTIVITIES IN VARIOUS TYPES OF WORKING PLACE OR LABORATORY*

Radiotoxicity of radionuclides	Minimum significant quantity (μCi)	Type C	Type B	Type A
1. Very high	0.1	10 μCi or less	10 μCi - 10 mCi	10 mCi or more
2. High	1.0	100 μCi or less	100 μCi - 100 mCi	100 mCi or more
3. Moderate	10.0	1 mCi or less	1 mCi - 1 Ci	1 Ci or more
4. Low	100.0	10 mCi or less	10 mCi - 10 Ci	10 Ci or more

Type C, Type B and Type A have the meanings normally used in the classification of laboratories for handling radioactive materials. Type C is a good quality chemical laboratory. Type B is a specially designed radioisotope laboratory. Type A is a specially designed laboratory for handling large activities of radioactive materials. In the case of a conventional modern chemical laboratory with adequate ventilation and fume hoods, as well as polished, easily cleaned, non-absorbing surfaces, etc., it would be possible to increase the upper limits of activity for Type C laboratories towards the limits for Type B laboratories for toxicity groups 3 and 4.

*From Safe Handling of Radionuclides, IAEA Safety Standards, 1973

CHECKLIST FOR TRAINING WORKERS IN RADIATION LABORATORIES

Revised 6/1/95

The following is a list of information which should be reviewed by the principal investigator with all individuals frequenting any work area where there are radioactive materials. Please write a Yes, No, or NA (Not Applicable) in the box provided next to the training item.

		Y/N/NA
1.	Right to Know Training has been completed.	
2.	EHS Radiation Safety Training has been completed.	
3.	EHS Chemical/Biological Safety Training has been completed.	
4.	EHS Bloodborne Pathogen Training has been completed.	
5.	The exposure limits for radiation have been reviewed with the worker (Refer to instruction sheet for table).	
6.	Radiation warning symbols and their meanings have been reviewed with the worker.	
7.	The locations of radioactive materials, hazardous chemicals and biohazardous agents present in the laboratory have been pointed out to the worker.	
8.	The relative risks of being near to or using the hazardous agents present in the laboratory have been reviewed with the worker.	
9.	The location and types of wastes and containers for the wastes have been identified with the worker.	
10.	The proper procedures for emergencies which may arise in the laboratory have been reviewed with the worker. This information includes the location of emergency spill kits, emergency response telephone numbers and immediate persons to contact in the laboratory if an emergency arises.	
11.	Security requirements for radioactive material have been reviewed with the worker.	

The following safety documents and/or safety manuals were reviewed by the worker. Note below.

a. Radiation Safety Manual
b. Chemical Hygiene Plan
c. Waste Disposal Guide
d. Other (Please list). ___________________________________

Worker Consent: I certify that I have been provided with and understand the information indicated above. I understand that this is a certification of principal investigator training and informed consent, and does not constitute a waiver of my rights. I understand that I am responsible for adhering to all safety practices, laws, rules and guidelines.

____

Worker Signature | Date | Title/Function

Principal Investigator: I certify that the above information was reviewed with or provided to the above certified worker.____

Principal Investigator Signature | Date

INSTRUCTIONS FOR PRINCIPAL INVESTIGATOR TRAINING

1. Individuals frequenting an area where radioactive materials are used, stored or disposed should receive principal investigator training. This training may be documented with this checklist.
2. Training is function specific and site specific, meaning the content and depth of training is related to the duties of the person and the scope of the hazards present in the work area.
3. Exposure limits must be explained to workers. For persons who are not certified radiation workers, the exposure limits are General Public, or 100 mrem per year. For radiation workers, the limits are the occupational limits set forth in the 10 CFR 20 laws, or 5 rem per year TEDE (whole body), 50 rem per year to an organ, 15 rem per year to the lens of the eye, 50 rem per year for the skin of the whole body and/or extremities. Radiation workers must have received introductory safety training at the EHS Office, and must attend annual refreshers for radiation and hazardous waste.
4. Copies of the training records may be kept in the safety notebook.
5. Security and control of radioactive materials must be provided at all times, either with persons present or locking or securing to prevent tampering or unauthorized use or removal. Persons who are not radiation workers may provide this control if they are appropriately trained by the PI and/or the EHS Office radiation safety training class.
6. This document serves as informed consent of the worker.

Pointers for Handling Radioactive Waste

1. Read and understand the Michigan State University Waste Disposal Guide. This document should be located in your laboratory.
2. If you need an empty container, go to the EHS web site and fill out a pick-up request stating the types and number of containers you need.
3. As soon as you receive the containers in your lab, fill out the bottom part of the back side of the waste tag. This information identifies your laboratory, including room number, building name, phone number, principal investigator and the signature of a radiation worker.
4. A separate container must be used for each isotope you will be using.
5. You must separate the solids and the liquids. Under no circumstance should liquids be placed in the solid waste or solid material placed in the liquid waste.
6. You must have secondary containment for your liquid radioactive waste container(s), in case of a leak or there is some spillage when filling the container, or rupture of the container.
7. Record the isotope, activity, date and initials every time material is added to the waste container(s). Each pair of gloves or pipette tip need not be manifested, but there should be an entry for each experiment or day that material is added.
8. Be sure to list the chemical components of the liquid waste on the back of the waste tag. Put the chemical name followed by the percent "by volume" or other units to quantify that chemical. This helps the EHS Office determine how to route the waste.
9. Fill the liquid container(s) only to 4 inches from the top. Overfilling the containers could present a hazard to the lab as well as the EHS personnel. When the container is full, go to the EHS web site and complete and submit a pick-up request.
10. Mixed waste (waste that is both radioactive and chemically hazardous), must be disposed of within 90 days of filling in accordance with the Environmental Protection Agency and the Department of Natural Resources regulations. This includes scintillation vial waste that contains flammable cocktail or liquids that are more than 15% of a listed chemical waste.

NOTE: Containers that are overfilled, are contaminated on the outside, have incomplete tag information and/or improper waste containers will not be picked up until the problem is corrected.

Pregnant Radiation Worker Policy at MSU

Requirements are:

1. The limit for radiation exposure for a declared pregnant radiation worker is 500 mrem for the entire gestation period.
2. There is now a separate limit for the fetus of 500 mrem for the entire gestation.
3. Exposures to the fetus must be uniform, and will be maintained at or below 50 mrem per month.
4. Declaration of pregnancy is optional. Pregnant radiation workers must declare their pregnancy in writing to the Radiation Safety Officer for the fetal and prenatal limits to take effect. If no written declaration is made, the limits remain at the occupational limit (5 rem per year).
5. If exposures have occurred between the time of conception and the declaration date, the exposures will be subtracted from the permitted exposure limits, and the balance will be prorated over the remaining months.
6. A meeting will be scheduled with the pregnant worker and a health physics staff member to review the previous exposures, discuss any particular concerns and review any special precautions or particular concerns in radiation uses.
7. Pregnant radiation workers will be supplied with two radiation dosimeters, one for the mother (whole body), and one for the fetus (abdomen). These badges will be exchanged monthly in order to assure that an exposure spikes do not occur, and to document that exposures do not exceed the 50 mrem/month cap.
8. Exposure records for the fetus will be tracked separately from the mother. This eliminates confusion and assures that the accumulated dose wraps into the next year if the pregnancy carries into that year.

There are relatively few research laboratories where radiation levels are high enough that a fetus would receive 500 mrem before birth. The likelihood of any dose to the fetus is almost nonexistent at Michigan State University with the types and quantities of radioactive materials used. Most nuclides pose little risk of external radiation to the worker. For those who work with ^{32}P, the risk is also very small; although ^{32}P is a high energy beta nuclide, it can only penetrate the tissue 7 - 10 millimeters, and thus not to the depth of the fetus.

If you are pregnant, planning to become pregnant or simply would like more information, please call a Health Physicist, and we will arrange a meeting with you to review information and answer questions.

Properties of Some Commonly Used Beta Emitters

Property	^{3}H	^{14}C	^{45}Ca	^{32}P	^{90}Sr
Half Life	12.3 y	5730 y	163 d	14.3 d	28.1d
Max beta energy (MeV)	0.0186	0.156	0.257	1.71	2.27[a]
Average beta energy (MeV)	0.006	0.049	0.077	0.70	1.13[b]
Range (cm) in unit density material	0.00052	0.029	0.06	0.8	1.1

HVL (cm), unit density absorber	---------	0.0022	0.0048	0.10	0.14
Dose rate from 100 beta particles/cm^2sec^{-1} (mrad/hr)[c]	---------	56	33	11	11
Fraction transmitted through dead layer of skin (0.007 cm)	---------	0.11	0.37	0.95	0.97
Dose rate (mrad/hr) to basal cells[d] of epidermis per mCi/cm^2	---------	1,400	4,000	9,200	17,000[e]

a. From the ^{90}Y decay product. ^{90}Sr emits 0.55 MeV (max) beta.
b. ^{90}Sr (0.196) + ^{90}Y (0.93).
c. The dose rate for 100 b particles/cm^2-sec is for a parallel beam.
d. The dose rate to basal cells of the epidermis is from beta particles emitted in all directions equally from contamination on the surface of the skin. Basal cells are considered to be 0.007 cm below the surface.
e. The dose rate to basal cells of the epidermis listed for ^{90}Sr includes the ^{90}Y contribution. Data for half-lives and maximum and average beta energies taken from MIRD, 1975.

(J. Shapiro, *Radiation Protection--A Guide for Scientists and Physicians*)

Tissue Dose Rate (rads/hr) at Various Distances Around a 1 μCi Particle of Various Beta Emitters (Range in Tissue 1 - 10 mm.)

um	mm	^{14}C	^{90}Sr	^{32}P	^{90}Y
10	-	2,000,000	530,000	380,000	270,000
100	0.1	1,500	5,000	3,700	2,700
200	0.2	40	1,100	930	680
400	0.4	0.03	200	230	160
600	0.6	0	60	100	70
1,000	1.0	0	10	30	26
10,000	10.0	0	0	0	0.02

(From NATO AMedP-6, Part 1, 1973)

RADIOLOGICAL UNITS

Unit	Symbol	Brief Description	Use
Curie	Ci	3.7×10^{10} disintegrations per second (2.22×10^{12} DPM)	Special unit of activity
Becquerel	Bq	1 disintegration per second	SI unit of activity
Roentgen	R	2.58×10^{-4} C/kg. (photons in air)	Special unit of exposure; applies only to gamma and

			x radiation
Rad	Rad	0.01 J/kg (100 ergs/g)	Special dose unit; applies to any radiation
Gray	Gy	1 J/kg.	SI unit of dose (Equals 100 rads)
Dose Equivalent	H	Dose x Q x any other modifying factors	Radiation protection
Quality Factor	Q	Biological effectiveness related to type of radiation	Radiation protection
Rem	Rem	Rad dose x Q x any other modifying factors	Special unit of human dose equivalent
Sievert	Sv	Gy x Q x any other modifying factors	SI unit of human dose equivalent (Equals 100 rem)

Activity: 1 Ci = 3.7 x 1010 Bq = 2.22 x 1012 DPM

Exposure: 1 R = 2.58 x 10-4 C/kg.
The special unit for exposure is the Roentgen. There is no SI unit for exposure; it is simply expressed in C/kg.

Dose: 100 rads = 1 Gy

DoseEquivalent: 100 rems = 1 Sv

KeV: Kilo (1000) electron volts

MeV: Mega (1,000,000) electron volts

1 MeV = 1000 keV
1 KeV = .001 MeV
1 Ci = 3.7 x 1010 Bq = 37 GBq
27 µCi = 1 x 106 Bq = 1 MBq
1 rad = 0.01 Gy = 10 mGy
1 rem = 0.01 Sv = 10 mSv

RADIOISOTOPES COMMON AT MSU

Isotope	Half-Life	Counting Method	Typical Efficiency*	Energy, MeV (b)	Energy, MeV (g)
^{3}H	12.35 years	L.S.C.	50%	0.0186	None
^{14}C	5730 years	L.S.C., Pancake	75%, 5%	0.157	None
^{22}Na	2.6 years	2:2 Gamma, 1:1 Gamma	30%, 15%	0.546	0.511, 1.27
^{32}P	14.3 days	Pancake	50%	1.71	None
^{33}P	25.3 days	Pancake	15%	0.248	None
^{35}S	87.5 days	L.S.C., Pancake	75%, 5%	0.167	None
^{36}Cl	3.0 E^{5} years	Pancake	30%	0.709	None
^{40}K	1.28 E^{9} years	Pancake	50%	1.33	1.46
^{45}Ca	163 days	Pancake	15%	0.258	0.012 (x-ray)
^{46}Sc	84 days	Pancake, 1:1 Gamma	20%, 15%	0.357	1.12, 0.889
^{51}Cr	27.7 days	L.E.G.	20%	None	0.320
^{55}Fe	2.7 years	Pancake	15%	0.232	None
^{63}Ni	100 years	L.S.C.	50%	0.0669	None
^{65}Zn	243.8 days	1:1 Gamma, Pancake	15%, 15%	0.325	1.116
^{85}Sr	64.8 days	L.E.G.	15%	None	0.514
^{86}Rb	18.6 days	Pancake, 1:1 Gamma	50%, 20%	1.775	1.0771 (9% abundance)
^{111}In	2.8 days	L.E.G.	20%	None	0.245, 0.171
^{125}I	60 days	L.E.G.	50%	None	0.036
^{203}Hg	46.6 days	L.S.C., Pancake	25%, 10%	0.213	0.279

KEY
L.S.C.: Liquid Scintillation Counter
1:1 Gamma: 1" by 1" NaI – scintillator
L.E.G.: Low Energy Gamma Scintillator
2:2 Gamma: 2" by 2" NaI - scintillator
Pancake: Beta Pancake Detector

***These are not the efficiencies to use for your own laboratory surveys. Obtain the correct efficiencies for your survey meter from the most recent calibration report supplied by the EHS Office.**

Security and Storage of Radioisotopes

Security

It is required by U.S. Nuclear Regulatory Commission law that security of radioactive materials must be in place at all times. Violations of this regulation are frequently cited at institutions utilizing radioactive materials, and place the license to use such materials in jeopardy. The Code of Federal Regulations, Title 10, Part 20.1801 and 20.1802, Storage and Control of Licensed Materials in Unrestricted Areas, reads:

(a) The licensee shall secure from unauthorized removal or access licensed materials that are stored in controlled or unrestric0ted areas.

(b) The licensee shall control and maintain constant surveillance of licensed material that is in a controlled or unrestricted area and that is not in storage.

This means that all locations where radioactive materials are present must be in constant attendance by the trained user, or otherwise locked or secured to prevent unauthorized removal or tampering.

Storage

Storage of radioactive materials shall be in secured or locked cabinets, refrigerators, freezers or waste areas, unless attended by the licensee. Radioactive materials shall be stored in sealed containers in such a way as to prevent accidental spillage or breakage, and to prevent release into the air. If the nuclide requires shielding, it shall be stored in shielded containers in order to prevent doses to personnel accessing the storage areas.

If the radioactive material has been stored in a freezer or ultra-freezer, it is imperative that the material be thawed, opened and handled in a certified fume hood or biological safety cabinet. Aerosols from stored radioactive materials may cause contamination of adjacent areas and doses to personnel if not handled in the proper way after storage.

All radioactive materials, whether in storage, waste or use, must be labeled with the radioactive warning symbol, the words "Caution, Radioactive Materials", the isotope, the date and the amount of radioactivity in DPM or microcuries.

The EHS Office will store radioactive materials for principal investigators upon request. Contact a Health Physicist to arrange for storage of radioactive materials.

EHS RADIOISOTOPE LABORATORY SURVEY

Location_____________________________Isotopes Used_________________Date______________

Project Leader_______________________________Contact Person_________________________

CHECKLIST: (Items marked "No" require corrective action.)

	Yes	No	NA	
1.	____	____	____	NRC "Notice to Employees" and "Licensing and Regulatory Information" is posted.
2.	____	____	____	Radioactive materials are under constant surveillance and immediate control of licensee, or otherwise secured to prevent tampering or unauthorized removal.
3.	____	____	____	Radiation users are adequately trained for functions performed.
4.	____	____	____	Surveyed areas are free of radioactive contamination.
5.	____	____	____	Laboratory radiation survey equipment is functional and used correctly.
6.	____	____	____	Laboratory radiation surveys are accurate and frequency is appropriate.
7.	____	____	____	Food and other consumables are not present in radioisotope and chemical use/storage areas.
8.	____	____	____	Radioisotope work areas, storage areas and equipment are labeled adequately.
9.	____	____	____	Radioisotope source /stock solutions are labeled adequately.
10.	____	____	____	Radioisotope waste is manifested on **both** sides of the tag, 2^o containment for liquids.
11.	____	____	____	Radioisotope shielding is adequate (material, thickness, positioning).
12.	____	____	____	Dosimeters, if assigned, and protective equipment is used during radioisotope handling.
13.	____	____	____	Fume hoods are used properly (sash setting, uncluttered, rated for radioisotope use).

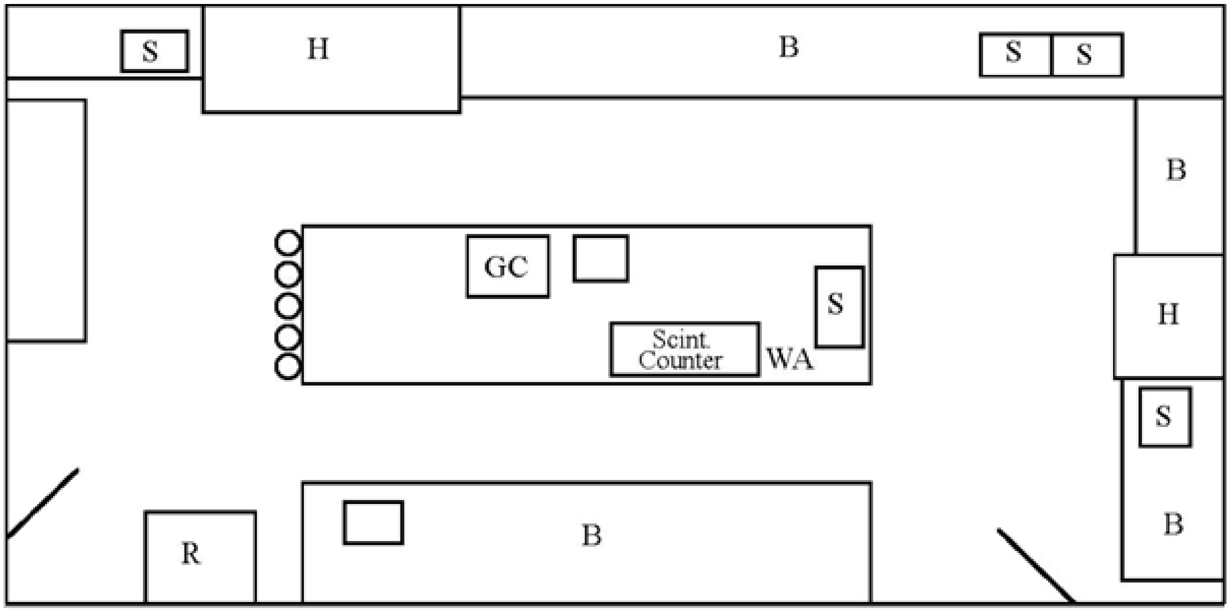
#: Not observed; no radioactive work at time of survey or no radiation workers present in laboratory.

Comments:

SURVEYED BY:____

(EHS Representative)

RADIATION SURVEY MAP OF ROOM C32B ENGINEERING RES.



KEY	(B)=Bench, (H)=Hood, (S)=Sink, (R) =Refrigeration unit, (WA)=Waste container, ( )=Wipe sample area, (----)=Meter survey area, (X)=Contamination area (≤ 100cm2 unless stated otherwise)

Survey Instrument Information

Make:________________ Model: _________________ Serial No:_______________(Ratemeter)

Make:________________ Model:__________________Serial No:_______________ (Ratemeter)

Detection Sensitivity Information

Nuclide B.G. (CPM) Eff.(%)

_______________ _______________ _______________

_______________ _______________ _______________

_______________ _______________ _______________

_______________ _______________ _______________

Survey Results

I.D.	Area Description	Nuc.	CPM	DPM	μCi	Corrective Action

Date of Survey: _______________Signature:____

Note: All areas surveyed are less than twice background levels above unless stated otherwise. The efficiencies are obtained from the calibrations performed by the EHS Office.

Transportation Instructions for Radioactive Material

Requirements for the transportation of radioactive material on campus and to other institutions must comply with both the NRC and DOT regulations. Transporting may involve walking or driving radioactive material across campus, or shipping off campus. The EHS Office must be notified before any transfers take place. This is to insure that proper procedures are followed and movement of radioactive material is tracked. Any transfers of radioactive material (possession transferred from one principal investigator to another) must to be pre-authorized by the EHS Office.

Package Preparation

All packages used to transport radioactive material must be strong, tight containers that will not leak under normal transportation conditions (such as dropping, jarring or temperature extremes). If liquid is shipped, use at least twice the amount of absorbent needed to contain the entire volume, in case the container should break or leak. If you are not sure whether the container you plan to use is adequate, contact the EHS Office.

Transportation on Campus

Whenever radioactive material is transported from one building to another, the EHS Office must be notified of the following information:

- When the material will need to be moved
- The names of the person sending and receiving the material (if different)
- The sending and receiving locations
- The nuclide(s) being moved
- The chemical form of the isotope
- The total activity in mCi
- Number of containers
- Phone numbers of responsible persons
- Any special conditions

<u>Walking to another building</u> Prepare to move your material using an appropriate container (see Package Preparation above). The package must have a radioactive warning label with the isotope, activity in DPM, μCi or mCi and date. Clearly identify the principal investigator and one other contact in case of an accident or loss of the package. The package must be tested for removable contamination before it leaves its place of origin and after it reaches its destination. Contact the EHS Office if any removable contamination is detected.

<u>Driving to another building</u> The transportation of radioactive material is regulated by the Nuclear Regulatory Commission (NRC) and the Department of Transportation (DOT). **You must not move any radioactive material on a public road without prior authorization by the EHS Office.** Remember that all roads on the MSU campus are public. The EHS Office will prepare documentation and transport your material. The sender's responsibility is to make contact in advance, and properly package the radioactive material.

Prepare to move your material using an appropriate container (see Package Preparation above). The EHS Office will determine what package labeling is required. Do not seal the package. The condition of the package must be checked and a leak test performed by the EHS Offcie. A radiation worker must be present at the receiving location to take possession of the material at the arranged time.

Shipping Radioactive Material

When preparing to ship radioactive material, whether it is radioactive samples or a piece of equipment being returned for repairs, the EHS Office must be informed in advance. **Do not expect to send shipments out immediately**. Federal regulations must be followed regardless of the quantity being sent.

Shipments can only be made to institutions that are licensed to possess radioactive material. When shipping to another licensee, it is required that prior authorization is obtained from the Radiation Safety Office at that location, preferably the Radiation Safety Officer. License information must be on record or obtained before the shipment can be sent. To initiate this process, the person sending the material must have the following information:

- The name of the person sending the material
- Facility name and address
- The name of the person receiving the material
- The Radiation Safety Officer's (or other staff member) name and phone number
- The nuclide(s) being sent
- The chemical form of each isotope
- The total activity in mCi for each isotope
- Number of containers in the shipment
- Any special conditions.

Radioactive material is sent from this university through the MSU Stores mail room. A material return (MR) form must be filled out by the department **and** completed by MSU Purchasing. Purchasing will then assign an MR number to the shipment. The Stores mail room will not send the package without this number.

Prepare to ship your material using an appropriate container (see Package Preparation above). The EHS Offcie will determine what package labeling is required. Do not seal the package, as the condition of the package must be checked and a leak test performed by the EHS Office. Labels will be placed on the package, if required. When the package and paperwork are in order, the EHS Office will transport the package to the MSU Stores mail room. Copies of the shipping papers, material return form, and any other paperwork will be made and maintained for review at the EHS Office.

Remember that shipments of radioactive material must be planned well in advance; allow at least two weeks prior to the desired shipping date.

References and Other Resources

SELECTED BIBLIOGRAPHY

(and additional sources of information)

Brodsky, A. 1978. CRC Handbook of Radiation Measurement and Protection. Boca Raton, FL: CRC Press, Inc.

Cember, H. 1996. Introduction to Health Physics. (3rd Edition) New York: McGraw-Hill.

Cobb, Charles E., Jr., and Karen Kasmauki. 1989. Living With Radiation. National Geographic, 175: 402 (36).

Cohen, Bernard L. 1991. Radiation Standards and Hazards. IEEE Transactions on Education, 34: 260-265.

Henry, Hugh. 1969. Fundamentals of Radiation Protection. New York: Wiley-Interscience.

Martin, Alan, and Samuel A. Harbison. 1986. An Introduction to Radiation Protection. New York: Chapman and Hall.

Miller, Kenneth L. 1992. CRC Handbook of Management of Radiation Protection Programs. Boca Raton, FL. CRC Press, Inc.

Moeller, Dade. 1992. Environmental Health. Cambridge, MA: Harvard University Press.

Shleien, Bernard, ed. 1992. The Health Physics and Radiological Health Handbook. Silver Spring, MD: Scinta Inc.

Shapiro, Jacob. 1990. Radiation Protection. Cambridge, MA: Harvard University Press.

Yalow, Rosalyn S. 1994. Concerns with Low-level Ionizing Radiation. Mayo Clinic Proceedings, 69: 436-440.

Fundamentals of Radiological Protection. 1993. Radiation Safety Associates Publications, 19 Pendleton Drive, P.O. Box 19, Hebron, CT 06248. (203) 228-0824

Radiological Health Handbook. 1970. Compiled and edited by the Bureau of Radiological Health and The Training Institute, Environmental Control Administration. Washington, D. C.: Government Printing Office.

Chart of the Nuclides. 14th edition. Available as wall chart (50" x 29") or booklet (8 1/2" x 11") from: GE Nuclear Energy, General Electric Company, Nuclear Energy Operations, 175 Curtner Ave, M/C 397, San Jose, CA 95125. Cost: approx. $12.

The Medical Internal Radiation Dose Committee (MIRD) of the Society of Nuclear Medicine publishes a series of pamphlets giving methods and data for absorbed dose calculations. The pamphlets may be purchased from MIRD Committee, 404 Church Ave., Suite 15, Maryville, TN 37801.

The National Council on Radiation Protection and Measurements (NCRP) issues reports providing information and recommendations based on leading scientific judgment on matters of radiation protection and measurement. Reports are available from NCRP Publications, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814.

The International Commission on Radiation Units and Measurements (ICRU) issues reports concerned with the definition, measurement, and application of radiation quantities in clinical radiology and radiobiology. Reports are available from ICRU, 7910 Woodmont Ave., Suite 800, Bethesda, MD 20814.

The International Commission on Radiological Protection (ICRP) issues reports dealing with the basic principles of radiation protection. The reports may be obtained from Pergamon Press, Maxwell House, Fairview Part, Elmsford, NY 10523.

The International Atomic Energy Agency issues many publications pertaining to the nuclear science field, including the proceedings of symposia, a Safety Series covering topics in radiation protection, a Technical Reports Series, a Bibliographical Series, and a Review Series. A complete catalog of publications may be obtained from the Publishing Section, International Atomic Energy Agency, Karnter Ring 11, P. O. Box 590, A1011 Vienna, Austria. Publications may be ordered from UNIPUB, Inc., P. O. Box 433, New York, NY 10016.

National Consensus Standards relating to radiation protection provide information and guidance, and are often incorporated into the regulations of the Nuclear Regulatory Commission. The major national organization issuing such standards is the American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018.

The U. S. Nuclear Regulatory Commission issues guides that describe methods acceptable to the NRC staff for implementing specific parts of the Commission's regulations. Request information from the U. S. Nuclear Regulatory Commission, Washington, D. C. 20555, Attention: Director, Office of Nuclear Regulatory Research.

Health Physics, the official journal of the Health Physics Society, is a valuable source of information in radiation protection.

Health Physics Society Newsletter, a publication of the Health Physics Society, 8000 Westpark Dr., Ste 130, McLean, VA 22102.

Radiation Protection Management: The Journal of Applied Health Physics. RSA Publications, 19 Pendleton Drive,

P. O. Box 19, Hebron, CT 06248.

OTHER REFERENCE RESOURCES

Excellent resources are available on the computer internet. Several are listed below.

EHS Home Page: http://www.ehs.msu.edu

U.S. Nuclear Regulatory Commission Home Page: http://www.nrc.gov/

Health Physics Society Home Page: http://www.hps.org

Safety Mother Lode (Comprehensive safety listings): http://www.sas.ab.ca/biz/christie/safelist.html#web

Radiation Biology Home Page: http://www.science.ubc.ca/departments/physics/radbio/HomePage.html

Glossary

Absorbed Dose

the amount of energy imparted to matter by ionizing radiation per unit mass of irradiated material. The unit of absorbed dose is the rad, which is 100 ergs/gram.

Absorption

the phenomenon by which radiation imparts some or all of its energy to any material through which it passes.

Activation
the process of making a material radioactive by bombardment with neutrons, protons, or other nuclear radiation.

Activity
the number of nuclear disintegrations occurring in a given quantity of material per unit time.

Acute Exposure
the absorption of a relatively large amount of radiation (or intake of radioactive material) over a short period of time.

Acute Health Effects
prompt radiation effects (those that would be observable within a short period of time) for which the severity of the effect varies with the dose, and for which a practical threshold exists.

Adult
an individual 18 or more years of age.

ALARA
(acronym for As Low As Reasonably Achievable) making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical consistent with the purpose for which the licensed activity is undertaken, taking into account the state of technology, the economics of improvements in relation to state of technology, the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to utilization of nuclear energy and licensed materials in the public interest.

Alpha Particle
a strongly ionizing particle emitted from the nucleus during radioactive decay having a mass and charge equal in magnitude to a helium nucleus, consisting of 2 protons and 2 neutrons with a double positive charge.

Alpha Ray
a stream of fast moving helium nuclei (alpha particles), a strongly ionizing and weakly penetrating radiation.

Anion
a negatively charged ion.

Annual Limit of Intake (ALI)
the derived limit for the amount of radioactive material taken into the body of an adult worker by inhalation or ingestion in a year. ALI is the smaller value of intake of a given radionuclide in a year by the reference man that would result in a committed effective dose equivalent of 5 rems (0.05 Sv) or a committed dose equivalent of 50 rems (0.5 Sv) to any individual organ or tissue.

Atom
smallest particle of an element which is capable of entering into a chemical reaction.

Attenuation
the process by which a beam of radiation is reduced in intensity when passing through some material. It is the combination of absorption and scattering processes and leads to a decrease in flux density of the beam when projected through matter.

Background Radiation
ionizing radiation arising from radioactive material other than the one directly under consideration. Background radiation due to cosmic rays and natural radioactivity is always present. There may also be background radiation due to the presence of radioactive substances in other parts of the building, in the building material itself, etc.

Becquerel

the international (SI) the unit for radioactivity in which the number of disintegrations is equal to one disintegration per second. A charged particle emitted from the nucleus of an atom during radioactive decay.

Beta Particle

charged particle emitted from the nucleus of an atom during radioactive decay. A negatively charged beta particle is identical to an electron. A positively charged beta particle is called a positron.

Beta Ray

a stream of high speed electrons or positrons of nuclear origin more penetrating, but less ionizing than alpha rays.

Bioassay

the determination of kinds, quantities or concentrations, and, in some cases, the locations of radioactive material in the human body, whether by direct measurement (in vivo counting) or by analysis and evaluation of materials excreted or removed from the human body.

Body Burden

the amount of radioactive material which if deposited in the total body will produce the maximum permissible dose rate to the critical organ.

Bremsstrahlung electromagnetic (x-ray) radiation produced by the deposition of charged particles in matter.

Secondary photon radiation (x-ray) produced by the deceleration of charged particles through matter. Usually associated with energetic beta emitters, e.g., ^{32}P.

Calibration

determination of variation from standard, or accuracy, of a measuring instrument to ascertain necessary correction factors. The check or correction of the accuracy of a measuring instrument to assure proper operational characteristics.

Cation

a positively charged ion.

Charged Particle

an ion. An elementary particle carrying a positive or negative electric charge.

Chronic Exposure

the absorption of radiation (or intake of radioactive materials over a long period of time), i.e., over a lifetime.

Committed Dose Equivalent

the dose equivalent to organs or tissues of reference that will be received from an intake of radioactive material by an individual during the 50-year period following the intake.

Committed Effective Dose Equivalent

the sum of the products of the weighting factors applicable to each of the body organs or tissues that are irradiated and the committed dose equivalent to these organs or tissues.

Contamination, Radioactive

deposition of radioactive material in any place where it is not desired, and particularly in any place where its presence may be harmful. The harm caused may be a source of excessive exposure to personnel or the validity of an experiment or a procedure.

Controlled Area

an area, outside of a restricted area but inside the site boundary, access to which can be limited by the licensee for any reason.

Cosmic Radiation

penetrating ionizing radiation , both particulate and electromagnetic, originating in space. Secondary cosmic rays, formed by interactions in the earth's atmosphere, account for about 45 to 50 millirem annually.

Coulomb

the meter-kilogram-second unit of electric charge, equal to the quantity of charge transferred in one second by a constant current of one ampere.

Count

the external indication of a device designed to enumerate ionizing events. It may refer to a single detected event or to the total registered in a given period of time. The term is often erroneously used to designate a disintegration, ionizing event, or voltage pulse.

Critical Organ

the organ or tissue, the irradiation of which will result in the greatest hazard to the health of the individual or his descendants.

Curie

the quantity of any radioactive material in which the number of disintegrations is 3.7×10^{10} per second. Abbreviated Ci.

Daughter Products

isotopes that are formed by the radioactive decay of some other isotope. In the case of radium-226, for example, there are ten successive daughter products, ending in the stable isotope lead-206.

Decay, Radioactive

disintegration of the nucleus of an unstable nuclide by the spontaneous emission of charged particles and/or photons.

Declared Pregnant Worker

a woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception.

Delayed Health Effects

radiation health effects which are manifested long after the relevant exposure. The vast majority are stochastic, that is, the severity is independent of dose and the probability is assumed to be proportional to the dose, without threshold.

Decontamination

the reduction or removal of contaminating radioactive material from a structure, area, object, or person. Decontamination may be accomplished by (1) treating the surface to remove or decrease the contamination, (2) letting the material stand so that the radioactivity is decreased as a result of natural decay, and (3) covering the contamination to shield or attenuate the radiation emitted.

Deep Dose Equivalent

applies to external whole-body exposure and is the dose equivalent at a tissue depth of one centimeter (1000 mg/cm^2).

Department of Transportation (DOT)

a governmental agency responsible for promoting the safe transportation of hazardous materials by all modes (land, air, water).

Depleted Uranium

uranium having a percentage of uranium-235 smaller than the 0.7% found in natural uranium. It is obtained from spent (used) fuel elements or as byproduct tails, or residues, from uranium isotope separation.

Derived Air Concentration (DAC)

the concentration of a given radionuclide in air which, if breathed by the reference man for a working year of 2,000 hours under conditions of light work (inhalation rate 1.2 cubic meters of air per hour), results in an intake of one ALI.

Disintegration

see decay, radioactive.

Dose or Radiation Dose

a generic term that means absorbed dose, dose equivalent, effective dose equivalent, committed dose equivalent, committed effective dose equivalent, or total effective dose equivalent, as defined in other paragraphs of this section.

Dose Equivalent (H_T)

the product of the absorbed dose in tissue, quality factor, and all other necessary modifying factors at the location of interest. The units of dose equivalent are the rem and the sievert (Sv). The ICRP defines this as the equivalent dose, which is sometimes used in other countries.

Dose Rate

the radiation dose delivered per unit of time. Measured, for example, in rem per hour.

Dosimeter

a portable instrument for measuring and registering the total accumulated exposure to ionizing radiation. (see dosimetry.)

Dosimetry

the theory and application of the principles and techniques involved in the measurement and recording of radiation doses. Its practical aspect is concerned with the use of various types of radiation instruments with which measurements are made (see film badge; thermoluminescent dosimeter; Geiger-Mueller counter).

Effective Dose Equivalent

the sum of the products of the dose equivalent to the organ or tissue and the weighting factors applicable to each of the body organs or tissues that are irradiated.

Efficiency (radiation detection instrument)

a measure of the probability that a count will be recorded when radiation is incident on a detector. Usage varies considerably so be aware of which factors (window, transmission, sensitive volume, energy dependence, etc.) are included in a given case. At Michigan State University, we are referring to the percent of total activity present for a given nuclide detected by the radiation detection instrument being used.

Electromagnetic Radiation

a traveling wave motion resulting from changing electric or magnetic fields. Familiar electromagnetic radiations range from x-rays (and gamma rays) of short wavelength, through the ultraviolet, visible, and infrared regions, to radar and radio waves of relatively long wavelength. All electromagnetic radiations travel in a vacuum with the velocity of light (see photon).

Electron

negatively charged elementary particle which is a constituent of every neutral atom. Its unit of negative electricity equals 4.8 x 10^{-19} coulombs. Its mass is 0.000549 atomic mass units.

Electron Capture

a mode of radioactive decay involving the capture of an orbital electron by its nucleus. Capture from the particular electron shell is designated as "K-electron capture," "L-electron capture," etc. X-rays are produced.

Electron Volt

a unit of energy equivalent to the amount of energy gained by an electron in passing through a potential difference of 1 volt. Abbreviated eV. Radioisotopic energy is typically measured in MeV. (million electron volts).

Erg

the unit of energy or work in the centimeter-gram-second system; the work performed by a force acting over a distance of one centimeter so as to result in a one gram mass being accelerated at a rate of one centimeter per second each second.

Exposure

(1) Being exposed to ionizing radiation or radioactive material. (2) a measure of the ionization produced in air by x or gamma radiation. It is the sum of the electrical charges on all ions of one sign produced in air when all electrons liberated by photons in a volume element of air are completely stopped in air, divided by the mass of air in the volume element. The special unit of exposure is the Roentgen.

External Dose

that portion of the dose equivalent received from radiation sources outside the body.

Extremity

hand, elbow, arm below the elbow, foot, knee, or leg below the knee.

Eye Dose Equivalent

applies to the external exposure of the lens of the eye and is taken as the dose equivalent at a tissue depth of 0.3 centimeter (300 mg/cm^2).

Film Badge

a packet of photographic film used for the approximate measurement of radiation exposure for personnel monitoring purposes. The badge may contain two or more films of differing sensitivity, and it may contain filters which shield parts of the film from certain types of radiation.

Fission

the splitting of a nucleus into at least two other nuclei and the release of a relatively large amount of energy. Two or three neutrons are usually released during this type of transformation.

Gamma Ray

very penetrating electromagnetic radiation of nuclear origin. Except for origin, identical to x-ray.

Geiger-Mueller (G-M) Counter

a radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of radiation.

Gray

The international (SI) unit of absorbed dose in which the energy deposited is equal to one Joule per kilogram (1 J/kg).

Half-Life, Biological

time required for the body to eliminate 50 percent of a dose of any substance by the regular processes of elimination. This time is approximately the same for both stable isotopes and radionuclides of a particular element.

Half-Life, Effective

time required for a radioactive nuclide in a system to be diminished by 50 percent as a result of the combined action of radioactive decay and biological elimination.

$$\text{Effective half-life} = \frac{\text{Biological half-life x Radioactive half-life}}{\text{Biological half-life + Radioactive half-life}}$$

Half-Life, Radioactive

time required for a radioactive substance to lose 50 percent of its activity by decay. Each radionuclide has a unique half-life.

Half Value Layer

the thickness of any specified material necessary to reduce the intensity of an x-ray or gamma ray beam to one-half its original value.

Health Physics

a term in common use for that branch of radiological science dealing with the protection of personnel from harmful effects of ionizing radiation. The science concerned with the recognition, evaluation and control of health hazards from ionizing and non ionizing radiation.

High Radiation Area

an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.1 rem (1 mSv) in one hour at thirty centimeters from the radiation source or from any surface that the radiation penetrates.

Hot Spot

the region in a radiation/contamination area in which the level of radiation/contamination is noticeably greater than in neighboring regions in the area.

Individual Monitoring Devices

devices designed to be worn by a single individual for the assessment of dose equivalent such as film badges, thermoluminescent dosimeters (TLDs), pocket ionization chambers, and personal air sampling devices.

Intake

quantity of material introduced into the body by inhalation, ingestion or through the skin (absorption, puncture, etc.)

Inverse Square Law

the intensity of radiation at any distance from a point source varies inversely as the square of that distance. For example: if the radiation exposure is 100 R/hr at 1 inch from a source, the exposure will be 0.01 R/hr at 100 inches.

Ion

an atom that has too many or too few electrons, causing it to be chemically active; such as an electron that is not associated (in orbit) with a nucleus. Ions may be positively or negatively charged, and vary in size.

Ionization

the process by which a neutral atom or molecule acquires either a positive or a negative charge.

Ionizing Radiation

any radiation capable of displacing electrons from atoms or molecules, thereby producing ions. Examples, alpha, beta, gamma, x-rays, neutrons and ultraviolet light. High doses of ionizing radiation may produce severe skin or tissue damage.

Ionization Chamber

an instrument designed to measure the quantity of ionizing radiation in terms of the charge of electricity associated with ions produced within a defined volume.

Ionizing Radiation

alpha particles, beta particles, gamma rays, x-rays, neutrons, high speed electrons, high speed protons, and other particles or electromagnetic radiation capable of producing ions.

Isotopes

nuclides having the same number of protons in their nuclei, and hence having the same atomic number, but differing in the number of neutrons, and therefore in the mass number. Almost identical chemical properties exist between isotopes of a particular element.

Kinetic Energy

the energy that a body possesses by virtue of its mass and velocity, the energy of motion.

Joule

the meter-kilogram-second unit of work or energy, equal to the work done by a force of one Newton when its point of application moves through a distance of one meter in the direction of the force.

Labeled Compound

a compound consisting, in part, of labeled molecules. By observations of radioactivity or isotopic composition this compound or its fragments may be followed through physical, chemical or biological processes.

LD50/60

the dose of radiation expected to cause death within 60 days to 50 percent of those exposed.

Licensed Material

source material, special nuclear material, or byproduct material received, possessed, used, transferred or disposed of under a general or specific license issued by the Nuclear Regulatory Commission.

Licensee

the holder of the license.

Limits

the permissible upper bounds of radiation exposures, contamination or releases.

Member of the Public

an individual in a controlled or unrestricted area (who is not a radiation worker). However, an individual is not a member of the public during any period in which the individual receives an occupational dose.

Microcurie (μCi)

a one-millionth of a curie. (1/1,000,000), (0.000001 Ci) (See Curie.)

Millicurie (mCi)

a one-thousandth of a curie. (1/1000th), (0.001 Ci) (See Curie.)

MilliRoentgen (mR)

a sub multiple of the Roentgen equal to one-thousandth (1/1000th) of a Roentgen. (see Roentgen.)

Minor
an individual less than 18 years of age, as pertains to radiation exposure limits, works with radioactive materials (not a member of the general public).

Molecule
a group of atoms held together by chemical forces. A molecule is the smallest unit of a compound that can exist by itself and retain all its chemical properties.

Monitoring
the measurement of radiation levels, concentrations, surface area concentrations or quantities of radioactive material and the use of the results of these measurements to evaluate potential exposures and doses.

Natural Radiation
ionizing radiation, not from manmade sources, arising from radioactive material other than the one directly under consideration. Natural radiation due to cosmic rays, soil, natural radiation in the human body and other sources of natural radioactivity are always present. The levels of the natural radiation vary with location, weather patterns and time to some degree.

Neutron
elementary particle with a mass approximately the same as that of a hydrogen atom and electrically neutral. It has a half-life in minutes and decays in a free state into a proton and an electron.

Non-Removable Contamination
contamination adhering to the surface of structures, areas, objects or personnel and will not readily be picked up or wiped up by physical or mechanical means during the course of a survey or during decontamination efforts.

NARM
any naturally occurring or accelerator produced radioactive materials. It does not include byproduct, source, or special nuclear material.

Neutron
an uncharged elementary particle with a mass slightly greater than that of the proton, and found in the nucleus of every atom heavier than hydrogen.

NORM
naturally occurring radioactive materials.

Nuclear Regulatory Commission (NRC)
an independent federal regulatory agency responsible for licensing and inspecting nuclear power plants, universities and other facilities using radioactive materials.

Nucleus
the small, central, positively charged region of an atom that carries essentially all the mass. Except for the nucleus of ordinary (light) hydrogen, which has a single proton, all atomic nuclei contain both protons and neutrons. The number of protons determines the total positive charge, or atomic number; this is the same for all the atomic nuclei of a given chemical element. The total number of neutrons and protons is called the mass number.

Nuclide
a species of atom characterized by its mass number, atomic number, and energy state of its nucleus, provided that the atom is capable of existing for a measurable time.

Occupational Dose

the dose received by an individual in the course of employment in which the individual's assigned duties involve exposure to radiation and to radioactive material from licensed and unlicensed sources of radiation, whether in the possession of the licensee or other person. Occupational dose does not include dose received from background radiation, as a patient from medical practices, from voluntary participation in medical research programs, or as a member of the general public.

Particle Accelerator

any machine capable of accelerating electrons, protons, deuterons, or other charged particles in a vacuum and of discharging the resultant particulate or other radiation into a medium at energies usually in excess of 1 MeV. The National Superconducting Cyclotron Laboratory is a particle accelerator.

Photon

a quantum (or packet) of energy emitted in the form of electromagnetic radiation. Gamma rays and x-rays are examples of photons.

Pig

a container (usually lead or plastic) used to ship or store radioactive materials. The thick walls protect the person handling the container from radiation. Large containers are commonly called casks.

Pocket Dosimeter

a small ionization detection instrument that indicates radiation exposure directly. An auxiliary charging device is usually necessary.

Positron

particle equal in mass, but opposite in charge, to the electron; a positive charge.

Principal Investigator (P.I.)

a faculty member, assistant professor or higher (no visiting faculty), appointed by the licensee, who has been approved through the Radiation Safety Committee for the purchase and use of radioactive materials.

Protective Barriers

barriers of radiation absorbing material, such as lead, concrete, plaster and plastic, that are used to reduce radiation exposure.

Proton

an elementary nuclear particle with a positive electric charge located in the nucleus of an atom.

Public Dose

the dose received by a member of the public from exposure to radiation and to radioactive material released by a licensee, or to another source of radiation. It does not include occupational dose or doses received from background radiation, as a patient from medical practices, or from voluntary participation in medical research programs.

Quality Factor (Q)

a modifying factor that is used to derive dose equivalent from absorbed dose. It corrects for varying risk potential due to the type of radiation.

Rad

the special unit of absorbed dose. One rad is equal to an absorbed dose of 100 ergs/gram or 62.4 X 10^6 MeV per gram.

Radiation Area

an area, accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in one hour at thirty centimeters from the radiation source or from any surface that the radiation penetrates.

Radiation Worker

an individual who uses radioactive materials under the licensees control. Individuals must be trained and have passed a radiation safety examination prior to beginning work with radioactive materials.

Radiography

the making of shadow images on photographic film by the action of ionizing radiation.

Radioisotope

a nuclide with an unstable ratio of neutrons to protons placing the nucleus in a state of stress. In an attempt to reorganize to a more stable state, it may undergo various types of rearrangement that involve the release of radiation.

Radiology

that branch of medicine dealing with the diagnostic and therapeutic applications of radiant energy, including x-rays and radioisotopes.

Radionuclide

a radioactive isotope of an element.

Radiosensitivity

the relative susceptibility of cells, tissues, organs, organisms, or other substances to the injurious action of radiation.

Radiotoxicity

term referring to the potential of an isotope to cause damage to living tissue by absorption of energy from the disintegration of the radioactive material introduced into the body.

Reference Man

a hypothetical aggregation of human physical and physiological characteristics arrived at by international consensus. These characteristics may be used by researchers and public health workers to standardize results of experiments and to relate biological insult to a common base.

Relative Biological Effectiveness

for a particular living organism or part of an organism, the ratio of the absorbed dose of a reference radiation that produces a specified biological effect to the absorbed dose of the radiation of interest that produces the same biological effect.

Rem

the special unit of dose equivalent. The dose equivalent in rems is numerically equal to the absorbed dose in rads multiplied by the quality factor, distribution factor, and any other necessary modifying factors.

Removable Contamination

contamination deposited on the surface of structures, areas, objects or personnel that can readily be picked up or wiped up by physical or mechanical means during the course of a survey or during decontamination efforts.

Restricted Area

an area, access to which is limited by the licensee for the purpose of protecting individuals against undue risks from exposure to radiation and radioactive materials. Restricted area does not include areas used as residential quarters, but separate rooms in a residential building may be set apart as a restricted area.

Roentgen (R)

the quantity of x or gamma radiation such that the associated corpuscular emission per 0.001293 gram of dry air produces, in air, ions carrying one electrostatic unit of quantity of electricity of either sign. Amount of energy is equal to 2.58×10^{-4} coulombs/kg air. The Roentgen is a special unit of exposure.

Scintillation Counter

a counter in which light flashes produced in a scintillator by ionizing radiation are converted into electrical pulses by a photomultiplier tube.

Sealed Source

radioactive material that is permanently bonded or fixed in a capsule or matrix designed to prevent release and dispersal of the radioactive material under the most severe conditions which are likely to be encountered in normal use and handling.

Shallow Dose Equivalent

applies to the external exposure of the skin or an extremity and is taken as the dose equivalent at a tissue depth of 0.007 centimeter (7 mg/cm^2) averaged over an area of one square centimeter.

Shielding Material

any material which is used to absorb radiation and thus effectively reduce the intensity of radiation, and in some cases eliminate it. Lead, concrete, aluminum, water and plastic are examples of commonly used shielding material.

Sievert

The international unit (SI) of dose equivalent (DE, human exposure unit), which is equal to 100 rem. It is obtained by multiplying the number of grays by the quality factor, distribution factor, and any other necessary modifying factors.

Site Boundary

that line beyond which the land or property is not owned, leased, or otherwise controlled by the licensee.

Somatic Effects of Radiation

effects of radiation limited to the exposed individual, as distinguished from genetic effects, which may also affect subsequent unexposed generations.

Source Material

1. uranium or thorium in any combination of uranium and thorium in any physical or chemical form; or
2. ores that contain, by weight, one-twentieth of 1 percent (0.05%), or more, of uranium, thorium, or any combination of uranium and thorium. Source material does not include special nuclear material.

Special Nuclear Material

1. plutonium, uranium-233, uranium enriched in the isotope 233 or in the isotope 235, and any other material that the Nuclear Regulatory Commission determines to be special nuclear material, but does not include source material; or
2. any material artificially enriched by any of the foregoing but does not include source material.

Specific Activity

total radioactivity of a given nuclide per gram of a compound, element or radioactive nuclide.

Stable Isotope

an isotope that does not undergo radioactive decay.

Stochastic Effects

health effects that occur randomly and for which the probability of the effect occurring, rather than its severity, is assumed to be a linear function of dose without threshold. Hereditary effects and cancer incidence are examples of stochastic effects.

Survey

an evaluation of the radiological conditions and potential hazards incident to the production, use, transfer, release, disposal or presence of radioactive material or other sources of radiation. When appropriate, such an evaluation includes a physical survey of the location of radioactive material and measurements or calculations of levels of radiation, or concentrations or quantities of radioactive material present.

Terrestrial Radiation

the portion of the natural radiation (background) that is emitted by naturally occurring radioactive materials in the earth.

Thermoluminescent Dosimeter (TLD)

crystalline materials that emit light if they are heated after being they have been exposed to radiation.

Total Effective Dose Equivalent (TEDE)

the sum of the deep dose equivalent (for external exposures) and the committed effective dose equivalent (for internal exposures).

Tracer, Isotopic

the isotope or non natural mixture of isotopes of an element which may be incorporated into a sample to make possible observation of the course of that element, alone or in combination, through a chemical, biological, or physical process. The observations may be made by measurement of radioactivity or of isotopic abundance.

Tritium

a radioactive isotope of hydrogen (one proton, two neutron). Because it is chemically identical to natural hydrogen, tritium can easily be taken into the body by any ingestion or inhalation path. Decays by beta emission. Its radioactive half-life is about 12.5 years.

Unrestricted Area

an area, access to which is neither limited nor controlled by the licensee.

Unstable Isotope

a radioisotope.

Uptake

quantity of material taken up into the extracellular fluids. It is usually expressed as a fraction of the deposition in the organ from which uptake occurs.

Very High Radiation Area

an area accessible to individuals, in which radiation levels could result in an individual receiving an absorbed dose in excess of 500 rads (5 grays) in one hour at one meter from a radiation source or from any surface that the radiation penetrates.

Weighting Factor (WT)

for an organ or tissue (T) is the proportion of the risk of stochastic effects resulting from irradiation of that organ or tissue to the total risk of stochastic effects when the whole body is irradiated uniformly. Presently, the organ dose weighting defined by the NRC and the ICRP differ.

Whole Body

for purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knee.

Wipe (smear or wipe test)

a procedure in which a swab, e.g., filter paper or cotton tipped applicator, is rubbed on a surface and its radioactivity measured to determine if the surface is contaminated with loose (removable) radioactive material.

X-rays

penetrating electromagnetic radiations having wave lengths shorter than those of visible light. They are usually produced by bombarding a metallic target with fast electrons in a high vacuum. In nuclear reactions it is customary to refer to photons originating in the nucleus as gamma rays, and those originating in the extranuclear part of the atom as x-rays. These rays are sometimes called Roentgen rays after their discoverer, W.C. Roentgen.