MICHIGAN STATE UNIVERSITY | Environmental Health and Safety

RADIATION SAFETY MANUAL

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Environmental Health & Safety
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ABBREVIATIONS

ALARA- As Low As Reasonably Achievable

Bq- Becquerel

Ci- Curie

cpm- counts per minute

dpm- disintegrations per minute

EHS- Environmental Health and Safety

GM- Geiger-Mueller

Gy- Gray (unit of absorbed dose)

LSC- liquid scintillation count or liquid scintillation counter

NRC- Nuclear Regulatory Commission

PI- Principal Investigator

R- Roentgen

Rad- radiation absorbed dose

Rem- Roentgen equivalent man

RSC- Radiation Safety Committee

RSO- Radiation Safety Officer

Sv- Sievert

1. PREFACE

Michigan State University (MSU) 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 MSU 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 MSU will utilize safe work practices, conduct, and complete all required activities to maintain compliance with these regulations.

2. ADMINISTRATIVE AND REGULATORY ORGANIZATION

The U.S. Nuclear Regulatory Commission (NRC) is the branch of the federal government that 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 for effluent discharges. MSU possesses a radioactive materials license, which contains further conditions of operation.

All 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 their periodic inspections violations will be cited, and penalties may be imposed. Penalties may include civil penalties (which may be fines or criminal prosecution in court), sanctions, suspensions, 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.

2.1 U.S. Nuclear Regulatory Commission (NRC)

The NRC is an independent agency of the U.S. government that is charged with overseeing reactor safety and security, radioactive material licensing, and radioactive material safety. The NRC's mission is to regulate the nation's civilian use of byproduct, source, and special nuclear materials to ensure adequate protection of public health and safety, to promote the common defense and security, and to protect the environment. The use of radioactive material at MSU is licensed through the NRC.

The regulations followed by all persons and organizations that receive NRC approval to use nuclear materials are contained in Title 10 of the Code of Federal Regulations (10 CFR). The sections of 10 CFR that are most important to those working with radioactive material are Part 19 and Part 20. Part 19 includes requirements for keeping workers informed of radiation safety issues. Part 20 has the standards that must be followed for protection against exposure to radiation. The NRC requires licensees to make these parts available to workers. They can be viewed online at the US NRC web site (www.nrc.gov) or through the EHS office.

2.1.1 The Michigan State University Broad Scope License

MSU operates under the U.S. NRC 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. The broad scope license confers authority upon the University to approve, manage, and control the receipt, use, and disposal of radioactive materials. 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. If the license is suspended or terminated for any reason, no individual or principal investigator may use radioactive materials of any kind until the license is reinstated.

2.2 State of Michigan

The Radiation Safety Section for the State of Michigan is responsible for regulating all nonfederal, nontribal machine-produced radiation in the state. Machine-produced radiation includes all x-ray producing machines and particle accelerators.

2.3 MSU Radiation Safety Committee (RSC)

The MSU RSC 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.

RSC members are appointed by the University administration, according to their experience and skills, which enables them to effectively perform their duties. The RSC members have expertise in the wide range of uses of radioactive materials at MSU.

2.4 MSU Radiation Safety Program

MSU has developed and maintains a program for the control and safe handling of radiation and radioactive material. As Low As Reasonably Achievable (ALARA) principles are in effect to ensure that radiation workers, as well as members of the public, are not exposed above the allowable limit from radiation sources.

2.5 Approvals for Use of Radioactive Materials

Approval for the use of radioactive materials is given by the RSC. Information on how to submit an application can be found on the MSU EHS website. Applicants must have faculty status, (assistant professor or greater), experience in the use of radioactive materials, and must be trained by the EHS Office prior to approval. The application will be reviewed by the RSC, wherein approval may be granted.

The RSC may require additional conditions under which the use of material must be conducted. The approved principal investigator (PI) may then order, receive, and use the requested materials, but must do so according to the statements and representations made in the application, any conditions set forth by the RSC, and all applicable 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.

2.5.1 Changes to Radiation Use Approval

Once the RSC has approved the application, the PI shall maintain an up-to-date Radiation Use Approval. All changes and updates to the PIs Radiation Use Approval are to be completed through an Amendment to the Approved Application. Step-by-step instructions on how to submit an Amendment can be requested from the EHS Office. Changes to the PI’s Radiation Use Approval may be subject to RSC review.

2.6 Radioactive Material and Radiation Equipment User

2.6.1 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. If the PI is actively working with radioactive materials or radiation producing equipment, they also are considered a “Radiation Worker.”

2.6.1.1 Responsibilities of the Principal Investigator

Principal investigators are obligated to:

1. Ensure that individuals working under their approval are properly supervised and trained.
2. Maintain control of their radioactive materials/radiation-producing equipment and avoid unnecessary exposure, either to themselves or to other workers.
3. Maintain constant surveillance and immediate control of radioactive materials/radiation producing equipment to prevent unauthorized removal or tampering.
4. Radioactive materials PIs must maintain an up-to-date Radiation Use Approval while Radiation Producing Equipment PIs must maintain up-to-date Machine registrations.

Failure to comply with the rules and regulations set forth above and throughout this manual may lead to disciplinary actions, the cessation of radioactive material shipments, or of radiation-producing equipment experiments. The Radiation Safety Officer (RSO) or the RSC may terminate any radiation 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 scope license.

2.6.1.2 Principal Investigator Absences

PIs 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 and/or radiation-producing machines. 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 PI with the appropriate approvals must be designated and must agree to assume responsibility.

2.6.1.2.1 Radioactive Material

The EHS Office must be notified in writing of an absence duration greater than 60 days and the name of the alternate PI who will oversee the uses of radioactive materials during the absence prior to departure. The stand-in PI must have all the authorizations necessary to oversee the uses of the radioactive materials possessed by the absent PI. During the absence, shipments will still be logged under the absent PI's inventory, but all oversight will be conducted by the stand-in PI. The PI Absence Form can be found on the EHS website

2.6.1.2.2 Radiation-Producing Equipment

The EHS Office must be notified in writing of an absence duration greater than 60 days and the name of the alternate PI/project leader who will oversee the radiation-producing equipment during the PI's absence prior to departure. During the absence, all EHS correspondence regarding the radiation-producing equipment will be directed to the designated alternate PI/project leader. The PI Absence Form can be found on the EHS website.

2.6.1.3 Terminating Employment

If a PI terminates employment at MSU, 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 to determine the presence of unused radioisotope and/or the presence of contamination.

Radiation-producing equipment will need to be either decommissioned or assigned to a different PI/project leader before the termination date. EHS Radiation Safety Staff will need to assist with the decommission or reassignment of the equipment.

2.6.2 Radiation Worker

The term "worker" is used by the university to identify an individual who uses radioactive material or radiation-producing equipment in the course of their employment or study with the university. Workers may be PIs, graduate students, undergraduate students, technicians, post-doctorates, visitors, or any other individual who will handle radioactive material or use radiation-producing equipment.

Individuals who use radioactive materials or radiation-producing equipment 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 are the direct handlers of the radioactive material or the radiation-producing equipment, 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 and/or radiation-producing equipment.

2.6.2.1 Responsibilities of the Radiation Worker

The following items are to be adhered to at all times by radiation workers.

1. Each worker must complete the required safety training class/classes and are prohibited from

handling radioactive materials or using radiation-producing equipment until the required training has been completed. Radiation workers must complete the required annual training.

2. Workers are responsible for adhering to all laws, rules, regulations, license conditions and guidelines pertaining to the use of radioactive materials and/or radiation-producing equipment.
3. Workers must practice ALARA (As Low As Reasonably Achievable) in their work, and minimize the potential for exposure, contamination, or release of radioactive materials.
4. Workers are responsible for maintaining security of radioactive materials and/or radiation producing equipment.

2.6.2.2 Terminating Education/Employment

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

2.6.3 Training

Training and education are the primary means of achieving a safe working environment. Current regulations require that individuals working with sources of ionizing radiation have appropriate training prior to beginning any work. No work can begin unless the individual has received all the appropriate training. EHS makes available the following radiation safety courses. As with all EHS courses, remember to print out and keep a copy of the course registration for your records.

2.6.3.1 Initial Radiation Safety Training

This training covers the proper procedures and safe practices used when handling radioactive material. By law, the Initial Radiation Safety Training covers the minimal required topics listed in Title 10, Code of Federal Regulations, Part 19.12 (10 CFR 19.12), Training for Radiation Workers. This training course concludes with a test requiring 75% to pass. See the EHS website for training dates and times. All radiation users/handlers, including PIs, must attend both the radiation safety and chemical safety parts of the class, as it is impossible to use radioactive materials without also using chemicals routinely or intermittently. Following the completion of the Initial Radiation Safety Training, all users are required to complete the Radiation Safety Refresher training annually.

2.6.3.2 Radiation Safety Refresher

Annual online Radiation Safety Refresher Training courses must be completed within each calendar year following completion of the Initial Radiation Safety Training course.

2.6.3.3 Sealed Source Training

This training course is an online course for individuals that will be working with sources of radioactive materials that are permanently bonded or fixed in a capsule or matrix designed to prevent their release. See Section 5 for further Sealed Source training requirements, policies, and procedures.

2.6.3.4 Analytical X-ray Training

This course meets the State of Michigan requirements for all operators of x-ray devices and other analytical x-ray/radiation-producing equipment. Analytical X-ray Safety is an online course available on the EHS web site. See Section 6 for further Radiation Producing Machine training requirements, policies, and procedures.

2.6.3.5 Site Specific Training

MSU requires safety training for individuals who work with hazardous materials or frequent areas where hazardous materials are used or stored. It is the responsibility of the PI to identify and ensure that their staff is trained according to their responsibilities. The site-specific training can be given by the PI or someone who holds the same training and knowledge regarding the hazardous material as the PI. Site-specific training shall be completed annually and documented for each user. Site-specific training templates that were created by EHS to ensure all required topics are covered during the site-specific training can be found on the EHS website. Use of the template is not required.

3. RADIATION EXPOSURE CONTROL

3.1 ALARA

ALARA is an acronym meaning As Low As Reasonably Achievable. It is a requirement in the law, meaning that 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.

It is not a violation of the law to exceed an ALARA guideline; however, these occurrences alert EHS Radiation Safety Staff and radiation workers to situations that 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 contaminations, exposures, and releases.

3.1.1 Time, Distance and Shielding

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

1. **Time: Minimize the time that radioactive materials are handled**. Since the amount of exposure is 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.
2. **Distance: Maximize the distance from the radioactive materials**. Dose is inversely proportional to distance; therefore, greater distance means lower dose. Do not increase the distance to the point wherein dexterity or control of the materials is jeopardized.
3. **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 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 and/or radiation-producing equipment 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 for specific nuclides in Appendix K or contact the EHS Office.

3.2 Radiation Exposure

3.2.1 Radiation Exposure Units

Radiation exposure quantifies the amount of radiation energy absorbed or deposited in a specific material by a radiation source.

Two sets of units exist for the quantification of radiation dose. They are the standard units (Roentgen, Rad, and Rem) and the SI units (C/kg, Gray, and Sievert). MSU typically reports all exposures in standard units. See Appendix D for further information on units.

3.2.2 Types of Exposure

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. See Appendix E and F for further information regarding radiation effects and exposure types.

3.2.3 Radiation Exposure Limits

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/their exposure to all radiation as low as is reasonable, and to avoid all exposures to radiation when such exposures are unnecessary.

3.2.3.1 Occupational Radiation Exposure Limits

The following table lists the NRC established occupational radiation exposure limits. MSU ALARA limits are 10% of the limits listed in this table.

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

3.2.3.2 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 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, PIs must notify the EHS Office before allowing minors to handle radioactive materials.

3.2.3.3 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 (2.0) mrem in any one hour.

B. 100 mrem in any one year.

3.2.3.4 Pregnant Radiation Workers

If a radiation worker is pregnant, they may notify the Radiation Safety Officer, and then declare the pregnancy in writing for the prenatal exposure limits to take effect. The written declaration is made by completing a Declaration of Pregnancy form, which can be found on the EHS website, and will be maintained in the records by the EHS Office. Declaring pregnancy is strictly voluntary and is not a mandatory requirement. An individual may declare themselves pregnant at any time and may “un-declare” the pregnancy at any time. Both a declaration of pregnancy and an undeclaration of pregnancy must be documented for radiation safety purposes.

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 notification is not made in writing, the radiation exposure limits remain at the occupational level, that is 5,000 mrem per year.

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

See Appendix B for further information relating to pregnant radiation workers.

3.3 Personnel Monitoring

3.3.1 Dosimeters

Radiation detection dosimeters (whole body and extremity) must be worn routinely by personnel when exposure to penetrating radiation is possible. At MSU, this means that workers handling radiation that is energetic enough to cause a measurable dose need to wear a dosimeter. Dosimeters are exchanged quarterly, and in some locations, monthly. Everyone is responsible for seeing that they have a current dosimeter. Radiation detection dosimeters are not required for all users working with Radioactive Materials and/or Radiation-producing equipment. See Appendix A for guidance on dosimeters.

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. If you believe your dosimeter may have been exposed to radiation fields without being on you (e.g., you find it left in a radiation field), or you think it could be compromised (e.g., going through a clothes dryer), you should contact the EHS.

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

Care should be taken to make sure that dosimeters do not become contaminated with radioactive materials. Lost or misplaced dosimeters should be reported immediately to EHS 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 EHS. 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 EHS for their dosimeter results. It typically takes 4 to 6 weeks to have the dosimeters processed. The vender will contact EHS 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 RSO immediately. Potential exposure will be evaluated, and the dosimeter may be sent immediately for an emergency reading. A spare dosimeter will be issued for the interim period. On an emergency basis, results can be obtained within a few days.

3.3.2 Bioassays

A condition of the broad scope license issued by the NRC mandates bioassays for workers using certain types and amounts of radioisotopes. A baseline bioassay shall be completed before completing work that requires a bioassay.

If there appears to be a likelihood that a significant internal exposure has occurred, the RSO may require further bioassays as deemed necessary. EHS also reserves the right to increase bioassay requirements on a case-by-case basis.

Iodine User

The chart below explains when bioassays are required for radioiodine users. When the quantity handled at one time or the cumulative quantity during any 3-month period exceeds the specified amounts, a bioassay is required.

Types of Operations	**Radioactivity Levels in Unsealed Form above Which Bioassay is Necessary (Volatile or Dispersible)**	**Radioactivity Levels in Unsealed Form above Which Bioassay is Necessary (Bound to Nonvolatile Agent)**
Processes in open room or bench, with possible escape of iodine from process vessels	1 mCi	10 mCi
Processes with possible escape of iodine carried out within well-controlled and ventilated areas (i.e., fume hood of adequate design, face velocity, and performance reliability)	10 mCi	100 mCi
Processes carried out within gloveboxes, ordinarily closed, but with possible release of iodine from process and occasional exposure to contaminated box and box leakage	100 mCi	1 Ci

If a bioassay is required, the chart below lists the maximum time duration and type of bioassay that must be completed through the EHS Office.

Isotope	**Maximum bioassay duration from beginning of an operation**	**Type of Bioassay**
^{123}I	1 day	Thyroid count
^{124}I	1 week	Thyroid count
^{125}I	2 weeks	Thyroid count
^{129}I	2 weeks	Urine sample
^{131}I	2 weeks	Thyroid count

Tritium Users

Tritium (^3H) users exceeding the handling limits in the following table at one time or the cumulative quantity during any one-month period 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.

Types of Operations	HTO[a] and Other Tritiated Compounds (Including Nucleotide Precursors)	Tritium (HT or T_2)[b] Gas in Sealed Process Vessels
Processes in open room or bench, with possible escape of tritium from process vessels	100 mCi	100 Ci
Processes with possible escape of tritium carried out within well-controlled and ventilated areas (i.e., fume hood of adequate design, face velocity, and performance reliability)	1 Ci	1,000 Ci
Processes carried out within gloveboxes, ordinarily closed, but with possible release of tritium from process and occasional exposure to contaminated box and box leakage	100 Ci	10,000 Ci

[a]HTO is a symbol for a water molecule in which a tritium atom (T) is present in place of a normal hydrogen atom (H).

[b]A Molecule of hydrogen gas contains two hydrogen atoms. Either one of these atoms may be replaced wit T to form HT, or two T atoms may combine to form T_2 gas.

4. RADIOACTIVE MATERIALS POLICY AND PROCEDURE

4.1 Radioactivity Units

Two sets of units exist for quantifying radioactivity. They are the standard units (Curie) and the SI units (Becquerel). At MSU standards units are typically used. See Appendix D for further information regarding units.

Unit requirements for labeling in the laboratory can be found in Section 4.6.3 Labeling Requirements.

4.2 Radioactive Materials

4.2.1 Ordering Radioactive Materials

Any receipt of radioactive materials must be authorized by EHS. Authorization is based on prior approval by the RSC as described earlier. All requisitions should be sent to the purchasing department directly, who will contact EHS to obtain authorization to order. The information that purchasing needs from the approved user is the name of the PI 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 PIs/project leaders, such as gifts, electron capture devices, or any other device containing a radioactive source or radioactive material must be reported to EHS so that the material may be tracked in the inventory database and summed with the campus totals. This is to prevent an individual PI or the campus from exceeding individual approval or MSU license possession limits.

4.2.2 Receiving and Monitoring Radioisotope Shipments

Shipments of radioactive materials must be delivered directly to EHS unless the lab has received RSO approval to receive shipments. 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.

4.2.3 Transfer of Radioactive Materials

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

To transfer a shipment, call EHS 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.

4.2.4 Inventory of Radioactive Materials

4.2.4.1 Use Logs

Use logs are required in laboratories for nuclides with half-lives ≥ 120 days and for high risk nuclides. To determine what nuclides are high risk, refer to the Laboratory Classification Tables in Appendix I.

The log shall contain records of the amount received, the shipment number, the amounts used, who used them and dates of use for each shipment received. A Use Log template can be found on the EHS website.

4.2.4.2 EHS Inventory

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 EHS. Shipments of radioactive materials are logged into the database for each PI 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.

4.2.5 Shipment of Radioactive Materials

Shipments of radioactive materials leaving the university must have prior authorization of the RSOs at both the sending and the receiving institutions. Federal and State laws require 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. **Contact EHS Radiation Safety 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**. See Appendix N for further shipping and packaging guidance.

4.2.6 Storage

Radioactive materials must be stored in secured 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 to prevent doses to personnel accessing the storage areas. See section 4.3 for security requirements. See section 4.6 for labeling requirements.

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.

4.3 Security of Radioactive Materials

4.3.1 General Security

It is required by U.S. NRC regulations 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 unrestricted 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.

All locations listed as a Radiation Location in the PI’s Radiation Use Approval must be in constant attendance by trained personnel or secured. Non-compliance is viewed as serious and immediate corrective action is required; sanctions may be applied to PIs who fail to maintain security.

EHS reserves the right to increase security requirements on a case-by-case basis.

4.3.2 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. Please contact EHS if your lab if planning on having unattended operations.

4.4 Radioactive Waste

EHS has developed a manual entitled *MSU Waste Disposal Guide,* which is located on the EHS web site. The *MSU Waste Disposal Guide* describes the requirements and specific procedures for correctly managing and disposing of hazardous waste, including radioactive, chemical, biological, and pathological waste. Please use the following sections, the *MSU Waste Disposal Guide* and Appendix O 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.**

4.4.1 Labeling

4.4.1.1 Containers

Radioactive waste containers must display the proper warning/hazard labels. EHS supplies the solid and liquid waste containers with labeling to laboratories upon request. If using waste containers other than the standard cardboard box and liquid waste container, such as plastic bag for Animal wastes or sharp containers, contact EHS for proper warning/hazard labels. 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 surfaces.

4.4.1.2 Waste Tags

Records of radioactive waste disposal must be maintained by the University for NRC review, so labeling or “manifesting” is critical. Radioactive Waste Tags must always be secured to the container and filled out, front and back, as soon as a potentially radioactive waste is placed in the radioactive waste container. EHS supplies the required Radioactive Waste Tags upon request. Any other hazardous constituents, including chemical or biohazardous components shall also be properly manifested.

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

Bench top waste containers are considered part of the experiment, and must be labeled with the trefoil, radioisotope, 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.

4.4.2 Shielding

Laboratories must supply their own shielding for waste that may cause external exposures to workers in the area. Liquid and solid ^{32}P waste should be shielded with Plexiglass. Do not use metal waste containers for ^{32}P waste as this can cause a secondary type of radiation, known as Bremsstrahlung. High energy gamma waste should be shielded with encapsulated lead. Contact EHS with questions regarding required shielding.

4.4.3 Pick-up Request

The Radioactive Waste Pickup request form can be found on the EHS website. EHS reserves the right to decline pickup requests until the following problems are corrected: Containers are overfilled, are contaminated on the outside, have incomplete tag information, and/or improper waste containers.

4.4.4 Specific Packaging procedures

It is required that all radioisotopes be segregated from each other and that each radioisotope be separated according to different types of chemical hazards. For example: you should separate a highly toxic waste from an aqueous buffer waste. Waste containing heavy metals (i.e. mercury) shall also be separated from nonheavy metal waste.

EHS reserves the right to impose monetary charges to the PI for disposal of non-ordinary or high-cost radioactive waste.

4.4.4.1 Radioactive Liquid Waste

Use separate carboys for each radioisotope and separate carboys for aqueous and non-aqueous solutions. Liquid waste containers must have secondary containment, such as a plastic bus tray, to contain leaks or spills.

To the best of your ability, and in accordance with waste minimization requirements, if you are using corrosive materials, adjust the pH of aqueous wastes to between 5.5 and 10.0.

4.4.4.2 Radioactive Solid Waste

Collect contaminated gloves, paper, glassware, etc. in cardboard boxes lined with two plastic bags, which are provided by EHS. Use separate containers for each radioisotope. **Do NOT put liquids into the solid waste container. Do NOT overfill boxes.** The plastic bag in the box must be able to be tied by EHS prior to removal from the lab. Boxes that have overflowing bags will not be handled and removed by EHS. **Do NOT exceed 20 pounds total weight per box. Do NOT put syringes, needles, or broken glass into cardboard boxes. Sharps MUST go into a sharps container.**

4.4.4.3 Radioactive Sharps

Sharps containers that are used to contain radioactive sharps must have a radioactive waste tag attached and completely manifested (front and back) as soon as waste is placed in the container. Disposal of sharps, even radioactive ones, must adhere to the rules and regulations regarding sharps containers. Radioactive sharps can only be stored for 90 days or ¾ full, whichever comes first.

4.4.4.4 Radioactive Scintillation Vials

Make sure all vial caps are tightly closed. **DO NOT mix scintillation vials containing different radioisotopes in the same tray.** Each radioisotope is processed differently, therefore, they must be in separate trays. **Scintillation vials are treated as hazardous waste; therefore, the 90-day storage limit is in effect.**

Place used 20-ml vials in the original trays and in the original box. Tape the box shut and attach a waste tag. If no boxes are available, trays may be taped together in sets of 5 or less. Place 5-ml plastic vials and well plates in a box that is double-lined with plastic bags. Tape the bags shut when the waste is ready for removal.

DO NOT mix flammable scintillation fluid with other aqueous wastes.

4.4.4.5 Animal Wastes Contaminated with Radioisotopes

Animal waste, including carcasses or other biological or pathological wastes contaminated with radioisotopes, will be picked up by EHS. Animal carcasses should be double bagged using opaque, 4-6 mil plastic bags and stored in a refrigerator or freezer for pick-up. Bags are available at MSU Stores in various sizes. A properly completed radioactive waste pick-up tag must be attached.

4.4.4.6 Iodination (Unbound ^{125}I) Waste

Handle all iodination waste material in a fume hood. Waste from iodinations presents an increased health hazard due to the presence of volatile iodine that, if inhaled, will accumulate in the thyroid gland.
Liquid iodination waste should be stored in the back of an approved fume hood in tightly closed containers. Place solid iodination waste in solid waste containers provided by EHS immediately after generation. Collect contaminated needles and place the syringe, with needle attached, in a sharp's container. **NEVER mix liquid iodination waste with other radioactive waste. NEVER mix waste that contains volatile iodine with ^{125}I waste that does not.**

Label all iodination waste as “Free Iodine” in the chemical section of the Radioactive Material Waste Tag. Also, please note on pick-up requests that the waste is free iodine.

4.5 Radiation Laboratories

4.5.1 Food and Drink Policy

Due to the number of NRC violations cited at numerous institutions, including MSU in past violations, the MSU RSC 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 PIs and users.

> *MSU Policy for Food and Drink in Laboratories*
>
> There shall be no food, drink, smoking or applying cosmetics in the laboratories that 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 that 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 PI responsible for the areas.

It is important to be aware that even the presence of empty food and/or drink containers or wrappers 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.

4.5.2 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 MSU 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 EHS Radiation Safety 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 to handle 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.

4.5.3 Protective Equipment

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. Please refer to the MSU Chemical Hygiene Plan, found on the EHS website, for further protective equipment guidance/requirements.

Individuals using radioactive materials shall 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.

4.6 Signage and Labeling

4.6.1 Posting Requirements

Each room and/or Laboratory designated as a Radiation Location in the PI's Radiation Use Approval must bear a label on doors to the room. These labels must have the Radioactive Material hazard label, which includes the radioactive warning symbol and the words "Caution Radioactive Material", and the name and telephone numbers of the PI and one other person who is knowledgeable about the radioactive materials used in the room(s). These labels are for emergency response purposes and should have the non-working hours telephone numbers for the emergency contacts listed.

Each room that bears the Radioactive Material Hazard warning label must also have current copies of NRC Form 3- Notice to Employees and NRC Licensing and Regulation Information posted in the room. PDFs of required postings can be found on the EHS website.

4.6.2 Area Restrictions

At MSU, 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 the time. Members of the public are permitted to be present if they are escorted by a trained worker while in the restricted area or have been trained in radiation safety to work independently. Site-Specific training accomplishes training requirements for workers frequenting the laboratory but not handling radioactive materials. See Section 2.6.3 for Site-Specific Training requirements.

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 that may be present. If this were to occur, the area(s) should be clearly marked and posted with warning signs or barriers.

4.6.3 Labeling Requirements

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

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

4.6.3.1 Work Area and Equipment

Work areas, trays, racks, stock solutions, tools, equipment, etc., which contain radioactive material or are contaminated must be labeled as radioactive material (see 4.6.3). 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 proper labeling).

For contaminated equipment that is in frequent use, the radioisotope, date, and maximum activity that may be present at any given time is to be written on the radioactive warning label.

For equipment that is used for radioactive materials but is not contaminated, a label with the radioactive materials warning symbol, and the words "Caution Radioactive Materials" must be used.

Work areas must be labeled with a “Caution Radioactive Materials” sign or marked with 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.

4.6.3.2 Waste

All Radioactive waste must be properly labeled. Please review section 4.4 for all waste related information.

4.7 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, when applicable, must be calibrated yearly by EHS Radiation Safety staff. It is the responsibility of the Radiation Worker to ensure their instrument is working properly before every use. If you believe there is a problem with your equipment, contact EHS.

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. Liquid scintillation counters (LSC) are used for radioisotopes whose energies are too low to be detected by a beta or gamma probe (i.e. ^{3}H and ^{63}Ni). Ion chambers are commonly used by the Radiation Safety staff in locations where frequent and higher flux external radiation hazards are present; they are typically not used for contamination surveys by laboratory staff. Appendix J provides guidance regarding which monitoring instrument to use based on radioisotope.

4.7.1 Calibrations

Radiation detection instruments used for contamination surveys must be operable and able to detect the radioisotopes used in the laboratory. To assure this, Geiger counters will be calibrated annually by EHS.

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 the efficiency of the instrument. The sources span a range of radiation energies; instruments calibrated then can be evaluated as to their performance and accuracy from the calibration.

After calibrating the instrument, a report of the results will be sent to the PI, 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. The efficiencies listed on the most recent calibration report are to be used by laboratory staff when surveying for radioactive contamination in the work area.

Instruments will be calibrated upon additional request and must be recalibrated after changes to the meter have occurred. This includes meter repair, sending the meter off campus for service, or replacing a cord/probe. Replacing batteries is not cause for recalibration.

EHS currently only offers onsite calibration services for Geiger counters. Please contact EHS for calibration procedures regarding other radiation detection instruments.

4.8 Monitoring and Surveys

4.8.1 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. If appropriate, a survey instrument should be turned on and placed proximal to the work area 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. See section 4.9 for further information regarding contamination.

4.8.2 Surveys

4.8.2.1 Radiation Worker Surveys

Along with monitoring before, during, and after working with radioactive materials, laboratory surveys must be completed and recorded. Surveys are to be conducted by the PI or their designee. Each lab actively using radioisotopes 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. See Appendix L for survey guidelines.

4.8.2.1.1 Survey Frequency

The following table outlines survey frequency requirements for radiation worker surveys. EHS reserves the right to increase survey frequency requirements based on noncompliance and/or the use of high-risk radioisotopes.

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 once per week
No use in a given period	No survey required, keep log in survey book noting dates of non-use

4.8.2.2 EHS Surveys

EHS will make independent surveys of all active radioisotope labs at least quarterly. Such things as inventory assessment, contamination control, personnel monitoring, training, and waste disposal practices will be addressed during these surveys. See Appendix M for compliance requirements.

The MSU RSC may accompany EHS on surveys as deemed necessary for problem laboratories or for purposes of auditing the radiation safety program.

4.8.2.2.1 Sanctions for Non-Compliance

During radiation safety surveys, items of noncompliance may be identified. A report is sent to the PI following the survey, detailing the results of the inspection. If noncompliance is found, the report will explain what corrective actions are required. 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 PI and may require further corrective actions and/or documentation.

Violations are classified into 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 PI, signed, and placed with the radiation safety records for the laboratory.

See Appendix M for further information regarding severity levels and Notice of Violations.

4.9 Radiation Contamination/Incidents/Emergencies

4.9.1 Contamination

When radioactive material is in an unwanted or unplanned location, it is called contamination. A beta/gamma survey meter or a Liquid Scintillation Counter reading of twice background on the surface in question indicates the presence of radioactive contamination and must be addressed. The area must be decontaminated and then re-surveyed and documented. Non-removable contamination should be labeled and shielded whenever possible to maintain ALARA limits. Please refer to the following section, 4.9.2 Incidents, for guidance on responding to differing levels of contamination.

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, proper signage and labeling must be applied. Protective clothing and gloves shall be used when in contact with these areas and in some cases, such as ^{32}P contaminated equipment, shielding is required. See Sections 4.4 and 4.6 for waste and labeling information.

4.9.2 Incidents

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 of 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 arm skin)
- Any injuries, what they are, how serious
- Airborne radioactivity present or not
- What you have done so far
- Principal investigator name
- Name of person reporting
- Telephone number where you can be reached

4.9.3 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, etc. All incidents involving radioactive materials must be reported as soon as possible to the PI. If the PI is not available, notify EHS, who will advise and assist with the problem. When an incident occurs, the worker must first make a judgment as to whether the incident is a **minor incident, major incident, or emergency**. Subsequent actions are based on this decision.

Information regarding decontaminant detergent can be found in Appendix P.

4.9.3.1 Minor Incident

A ***minor incident*** with radioactive materials is an abnormal occurrence involving low amounts of radioactive materials, where the worker handling the contamination and/or spill knows how to clean it up, has the decontamination materials on hand, and is confident they can respond without incurring risk of exposures or spreading within a reasonably short time. In addition, the spill must NOT be detected on individuals, in the air, or on the floor. If contamination is detected in these areas, it is a Major Incident and must be treated as such. See Section 4.9.3.2 for Major Incident instructions.

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

1. Notify the PI and persons in the area that an incident has occurred.
2. Contain the spill. Cover with absorbent paper or dike with absorbent. Document amount of activity spilled before decontamination.
3. Isolate the area to prevent unnecessary spread and personnel exposures.
4. Survey using the appropriate monitoring equipment to evaluate the presence of contamination on an individual's skin and clothing and on lab equipment.
    a. If skin, clothing, or floor contamination is present contact EHS immediately and proceed to Section 4.9.3.2 as a major spill has occurred.
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 effectiveness of absorbent paper. Continue decontaminating if needed.
7. Decontaminate the spill/contamination using decontaminant detergent (available from General Stores), and resurvey.
8. Continue step 7 until the area is fully decontaminated or only non-removable contamination is left (Non-removable contamination must be properly labeled. See Section 4.6.3 for labeling guidance)
9. Document spill in radiation survey logbook.

4.9.3.2 Major Incident

A major incident 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. ***Major spills must be reported to the RSO or his/her designee immediately, as required by federal law. Call EHS during working hours; dial 911 during non-working hours.***

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 PI.
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 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 to prevent entry. Attempt to prevent further contamination or spreading to unrestricted areas. (Hallways, non-radiation laboratories, etc., are unrestricted areas.)
5. Contact EHS 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 EHS.
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.

4.9.3.3 Emergency

An **emergency** is an incident that 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. **DIAL 911 IMMEDIATELY** IF AN EMERGENCY HAS OCCURRED.

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 of the 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.

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 victim(s) will be met by appropriate radiation safety personnel who will monitor the treatment and decontamination procedure.

5. SEALED SOURCE POLICY AND PROCEDURE

A sealed source is a device containing radioactive materials that is permanently bonded or fixed in a capsule or matrix designed to prevent its release. It can be in the form of a solid calibration source or plated to an inner surface as with an electron capture device (ECD). Depending on the radioisotope and activity, periodic leak tests may be required.

All sealed sources, regardless of their size, must be registered with MSU EHS. As with other radioactive materials approval, all applicable training and security requirements must be completed before use can be approved. Sealed sources are approved through the same application process used to apply for dispersible radioactive materials. It is the PI's responsibility to assure that the sources are used according to the laws and regulations pertaining to the source. In particular, leak tests must be performed by the required deadline. If non-compliances are found with sealed sources, sanctions may be imposed.

5.1 Training

All sealed source users must complete the required online EHS sealed source training before working with a sealed source. This training can be found and completed through the EHS website.

Users must also be given site-specific training.

See section 2.6.3 and Appendix A for further training information.

5.2 Security

The same security is required for laboratories housing an ECD as for a radioactive material laboratory, defined in section 4.3.

Contact EHS for security requirements regarding other types of sealed sources.

5.3 Labeling and Postings

5.3.1 Labeling

5.3.1.1 Electron Capture Device (ECD)

Electron Capture Devices must bear a “Caution Radioactive Material” label. Please contact EHS Radiation Safety to obtain the proper label.

5.3.1.2 All other Sealed Sources

Contact EHS for labeling requirements for sealed sources that are not ECDs.

5.3.1.3 Area/Laboratory

Laboratories that house sealed sources such as ECDs, must bear a “Radioactive Material: ECD Only” warning on the door as well as the contact information for two emergency contacts. Laboratory door signs can be requested through the EHS website.

5.3.2 Postings

Each room that bears the “Radioactive Material: ECD Only” Hazard warning label must also have current copies of NRC Form 3- Notice to Employees and NRC Licensing and Regulation Information posted in the room. PDF versions of both required postings can be found on the EHS website.

5.4 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 less than 10 µCi of an alpha emitting material or less than 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 scope license emitting sealed sources must be leak tested every three months.

6. RADIATION-PRODUCING MACHINE POLICY AND PROCEDURE

6.1 Machine Registration

Radiation-producing equipment such as diffractometers, x-ray spectrometers, diagnostic and therapeutic x-ray machines, and transmission electron microscopes are all regulated by the State of Michigan. Equipment of this type must be registered with the State before use. All work done with these machines must be in accordance with Michigan's *Ionizing Radiation Rules Governing the Use of Radiation Machines.*

EHS coordinates all machine/facility registrations with the State of Michigan. EHS will complete machine registration applications with the State on behalf of the PI.

PIs/Project Leaders are responsible for contacting EHS well in advance of executing any action that may affect the Machine Registration, i.e. purchasing, receiving, moving, and/or decommissioning any radiation-producing machine.

6.2 Training

All Radiation Producing Machine users must complete the online EHS Analytical X-ray Training before using a radiation-producing machine.

The user must also receive Site Specific Training.

See section 2.6.3 for further training information.

6.2.1 Standard Operating Procedures

The PI is responsible for ensuring that standard operating procedures (SOPs) are present and available for employee use and are available during inspections. Before using the machine, PIs should review the SOP with workers.

6.3 Signage, postings, and labels

6.3.1 Signage/Labels

6.3.1.1 Area

Any area in which a Radiation Producing Machine is stored and/or used must be properly labeled. This includes an EHS door sign with the “x-ray” hazard warning and at least two emergency contacts with valid contact numbers. EHS door signs can be requested through the EHS website.

6.3.1.2 Equipment/Machine

Any machine that is registered with the State of Michigan as a radiation-producing machine must have the following labels affixed to the machine:

1. Machine Registration Tag: The State of Michigan assigns each registered machine a unique tag number. If needed, EHS can request replacement tags from the State of Michigan.
2. Caution Radiation label: Radiation-producing machines must have hazard warnings visible. Please contact EHS for caution labels.

6.3.2 Postings

The following postings must be displayed in the room with the radiation-producing equipment.

1. Radiation Machine Registration Certificate: This certificate is issued by the State. Please contact EHS for a copy of the Certificate.
2. Section 5 of the State of Michigan's Ionizing Radiation Rules: This posting can be found on the State of Michigan’s website or contact EHS for a copy.
3. Form RH100 (Notice to Employees): This posting can be found on the State of Michigan’s website or contact EHS for a copy.

6.4 Security

Areas in which stationary radiation-producing machines are located shall be secured/securable and access by untrained personnel should be restricted. Radiation-producing machines designed to be portable shall be stored in a locked and properly labeled case with a copy of each required posting.

6.5 EHS Inspections

The EHS staff will periodically inspect radiation-producing machines. EHS reserves the right to conduct unannounced inspections as well as planned inspections. PIs/Project Leaders can request a copy of the latest EHS Inspection from EHS. If violations are found, a copy of the EHS Inspection form will be sent to the PI/Project Leader. A recheck may be conducted in the event problems have been detected that need corrective action. Please refer to Appendix M for compliance requirements.

APPENDIX A - DOSIMETER GUIDE

The following sections can be used as a guide for all dosimetry-related requirements. EHS reserves the right to increase or decrease dosimeter requirements based on user compliance and/or type of work being completed. If you have further questions or concerns regarding dosimetry, please contact EHS.

Users working with Beta Emitters

Beta Emitter	Required Dosimetry
High Energy Emitter (^{32}P, ^{36}Cl, ^{90}Sr) Energies greater than or equal to 0.5 MeV	1. Extremity (ring) dosimeter for persons working with less than 10 mCi per container 2. Body and Extremity (ring) dosimeters for persons handling more than 10 mCi per container
Low Energy Emitters (^{14}C, ^{35}S, ^{3}H, ^{33}P) Energies less than 0.5 MeV	No dosimeter required

Users working with Gamma Emitters

Gamma Emitter	Required Dosimetry
High Energy Emitters (^{51}Cr, ^{22}Na, ^{111}In)	Body dosimeter and extremity (ring) dosimeter required
Low Energy Emitter (^{125}I)	1. Body dosimeter for persons using greater than 0.1 mCi per container 2. No dosimeter required for persons using less than 0.1 mCi per container

Users working with Sealed Sources

Sealed Source	Required Dosimetry
Electron Capture Device	No dosimeter required
All other Sealed Sources	Contact EHS Radiation Safety for requirement

Users working with Radiation-Producing Equipment

The following is a limited list of the possible radiation-producing equipment found at MSU. Please contact EHS for dosimeter requirements if your radiation-producing equipment is not included.

Equipment Type	Required Dosimetry
Closed-Beam analytical x-ray equipment (x-ray fluorescence unit)	No dosimeter required
Open-Beam analytical x-ray equipment (x-ray diffraction unit)	Extremity (ring) dosimeter required
Industrial radiographic cabinet x-ray system of insufficient size to permit human occupancy	No dosimeter required
Industrial radiographic cabinet x-ray system of sufficient size to permit human occupancy	Body dosimeter required
Radiation-Producing Equipment used in Human Medicine (CT, X-ray, Fluoroscopy, Mammography)	Body dosimeter required

Radiation Producing Equipment used in Veterinary Medicine (CT, X-ray, Fluoroscopy)	Body dosimeter required; Extremity (ring) dosimeter may be assigned based on job duties

How to request a dosimeter:

Dosimeter Request forms can be found and completed on the EHS website. Users working with radioactive materials shall use the *Request a Dosimeter* form, while users working with radiation-producing equipment shall use the *Request a Dosimeter (X-ray User)* form. All required EHS training must be completed before requesting a dosimeter.

Updating Personal Information

If the user wishes to update personnel information linked to their dosimeter, the *Change Personal Information* form is available on the EHS website. This would include changes to the user's legal name, MSU NetID, Department/PI, etc.

Returning/Receiving Dosimeters

Users are responsible for coordinating with their PI/Project Leader for returns and receiving. Designated PIs/Project Leaders shall ensure dosimeters are promptly returned to EHS once they receive the new wear period dosimeters for their team. EHS will send out new dosimeters to designated PI/project leaders either monthly or quarterly. Wear period length is determined for each user/group separately depending on what the user is working with and/or frequency of use. Please contact EHS with questions/concerns regarding what wear period you and/or your team has been assigned.

How to report a lost dosimeter

Dosimeters are for monitoring any occupation dose received at MSU and are legal records. MSU is charged for unreturned dosimeters by the vendor. Users should take extra care in preventing lost/misplaced dosimeters. In the case of a lost dosimeter, users must report the lost dosimeter and request a replacement as soon as possible. The *Report a Lost Dosimeter* form can be found and completed through the EHS website. Users are not to work with radioactive material and/or radiation-producing equipment without a dosimeter if they are required to have one.

Discontinue Dosimeter Use

All dosimeters must be returned to EHS following completion of work with radioactive materials or radiation-producing equipment. Users do not need to wait until the end of the wear period to return dosimeters. User can find the *Discontinue a Dosimeter* form on the EHS website. Failure to notify EHS and return dosimeter(s) may result in a charge to the PI or the department.

APPENDIX B - PREGNANT WORKER POLICY

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 RSO 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. At the pregnant worker's request, a meeting may be arranged with a health physics staff member to review 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 dosimeters 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. 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.

APPENDIX C - IONIZING RADIATION THEORY

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 (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 machines, such as cyclotrons. All types of ionizing radiation can remove electrons but they 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 decay constant that relates to the stability of a given radioisotope. As radiation is emitted, the material becomes less radioactive over time, decaying exponentially. The decay rate is generally expressed as the amount of time it takes for half of the total amount of radioactive material to decay, called the 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 ^{99m}Tc has a half-life of 6 hours.

When deposited in the human body, the half-life of the radioactive material present in the body affects the amount of the dose. 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 half-life also greatly impacts costs and concerns in radioactive waste management.

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

$$A = A_0\, e^{-\lambda t}$$

Where: A = Current amount of radioactivity

A_0 = Original amount of radioactivity

e = base natural log ≈ 2.718

λ = the decay constant = $0.693/t_{1/2}$ (where $t_{1/2}$ = half-life)

t = the amount of time elapsed

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

APPENDIX D - UNITS

Units of Exposure and Dose

The Roentgen, abbreviated as "R", is the unit for measuring the exposure from 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 x 10^{-4} coulombs per kilogram of air at STP. 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 approximately equal to tissue dose rate in rads per hour. The EHS, Veterinary Medical Center, 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; 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 a unit of *absorbed dose* and refers to the energy deposited by any type of radiation in any type of material. The international unit for absorbed dose is the Gray (Gy); it is defined as being equal to 1 joule of energy deposition per kilogram of absorber. One rad is equal to 100 ergs of energy deposition per gram of absorber. 1 Gray is equivalent to 100 rads.

The rem (radiation equivalent man) is a unit of human dose called a *dose equivalent*. The international or SI unit for dose equivalent is the Sievert (Sv), which is equal to 100 rem. It takes into account the relative biological effectiveness of different types of radiation; some types of radiation cause more damage to biological tissue than other types. For example, one rad of alpha particles is twenty times more damaging than one rad of gamma rays. To account for these differences, a unit called a quality factor (QF) is used in conjunction with the radiation absorbed dose to determine the dose equivalent in rem:

Dose Equivalent (rem) = rad dose x QF

Some organs/tissues are significantly more susceptible to stochastic radiation effects than others. A modifier called the tissue weighting factor, W_t, is used to account for the radio sensitivity of the tissue receiving the dose. When these weighting factors are applied to an absorbed dose, the resulting dose is called an *effective dose,* in units of rads or Gy. It is much more common to apply W_t to a dose equivalent. If quality factors and tissue weighting factors are both used, the resulting dose is called an *effective dose equivalent*, and is expressed in rem or Sv. 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.

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. Some ion chambers can be useful in estimating dose for beta radiation, but special detectors for alpha or neutron radiation are required.

Units of Activity

The standard 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 radioisotope. The Curie is an amount of radioactive material emitting 2.22 x 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 that 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. Detection instruments are calibrated with known sources with different energy levels to determine the efficiency of the instrument to account for these variables.

Therefore, 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.

CPM/Efficiency = DPM

DPM/2.22 x 10^6 = µCi

Radioactivity Unit Table

Unit	Symbol	Brief Description	Use
Curie	Ci	$3.7\ x\ 10^{10}$disintegrations per second ($2.22\ x\ 10^{12}$DPM)	Standard unit of activity
Becquerel	Bq	1 disintegration per second	SI unit of activity
Roentgen	R	$2.58\ x\ 10^{-4}$C/g (photons in air)	Standard unit of exposure; applies only to gamma and x radiation < 3 MeV
Rad	Rad	0.01 J/kg (100 ergs/g)	Standard unit of dose; applies to any radiation
Gray	Gy	1 J/kg	SI unit of dose
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	Standard unit of human dose equivalent
Sievert	Sv	Gy x Q x any other modifying factors	SI unit of human dose equivalent

Radioactivity Unit Conversions

Activity: $1\ Ci = 3.7\ x\ 10^{10}\ Bq = 2.22\ x\ 10^{12} DPM$

27 µCi = $27\ \mu Ci = 1\ x\ 10^{6} Bq = 1\ MBq$

Exposure: $1\ R = 2.58\ x\ 10^{-4} C/kg$

The standard 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
	1 rad = 0.01 Gy = 10mGy
Dose Equivalent:	100 rems = 1 Sv
	1 rem = 0.01 Sv = 10 mSv

APPENDIX E - RADIATION EFFECTS

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.

1. **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.

2. **Indirect action** occurs when radiation interacts with the medium in which the molecules are suspended. The molecule that 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.

1. **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 burns are an example of a nonstochastic effect (also known as a deterministic effect).

2. **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 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 that receives the exposure.

- Radiosensitive:
  - Breast tissue
  - Bone marrow cells
  - Mucosa lining of small intestines
  - Sebaceous (fat) glands of skin
  - Immune response cells/lymphocytes
  - All stem cell populations
- Radioresistant
  - Heart tissue
  - Large arteries
  - Large veins
  - Mature Blood cells
  - Neurons
  - Muscle Cells

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
10 R; single dose, whole body	Elevated number of chromosomal aberrations in peripheral blood; no other detectable injury or symptoms
25 R; single dose, whole body	Lymphocytes temporarily disappear from circulating blood
100 R; Single dose, whole body	Mild radiation sickness, depressed white blood cell count
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
250 - 500 R; single dose, whole body 50% death rate	Death occurs several weeks after exposure due to damage to bone marrow (Hematopoietic syndrome)
400 - 500 R; local, low energy x-ray	Temporary hair loss
500 - 600 R to skin; local single dose, 200 keV	Threshold erythema in 7 - 10 days, followed by gradual repair and dull tanning
600 - 900 R; local to the eye	Cataracts
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)
1500 - 2000 R to skin; local single dose, 200 keV	Erythema, blistering, residual smooth soft depressed scar
10000 R; single dose, whole body	Death occurs within hours from apparent neurological and cardiovascular breakdown (Cerebrovascular syndrome)

APPENDIX F - ROUTES OF EXPOSURE

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.

There are two routes of exposure: external and internal. The following sections provide overview of each type of radiation exposure

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 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. For humans, the lethal dose where 50% of the exposed population may die from a onetime exposure of the whole body is about 500 rads, assuming no medical intervention.

Exposure to external radiation may be minimized by:

- Time: limiting the working time in the radiation field
- Distance: working at a distance from the source of radiation
- Shielding: inserting shielding between the worker and the source
- Amount Used: 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 absorption/injection.** 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.

APPENDIX G - AIRBORNE RADIOACTIVE MATERIALS

Some work with radioactive materials has 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 iodination or ^{3}H-sodium borohydride may generate airborne radioactivity. Any chemical or physical form that 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 that liberates HCl and $^{35}SO_2$ gas. Airborne radioactivity has resulted in unnecessary intakes and area contamination in laboratories where the users were unaware of this risk and did not take precautions to trap or contain the liberated $^{35}SO_2$.

Heating or incubating may cause evaporation or chemical reactions that 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 that 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.

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. Do not use clean benches (tissue culture hoods) for use of radioactive materials, or any other hazardous material. 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 EHS, 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 EHS. 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.

APPENDIX H - GENERAL RULES FOR RADIATION SAFETY

Good housekeeping is an important component of laboratory safety. Sloppy work habits, incorrect procedures or shortcuts, lack of containment, and crowded or cluttered work areas may cause or contribute to accidents or contamination. The following practices will assist in maintaining effective 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 that will prevent breakage and spillage. Secondary containment is important; when transporting radioactive materials, use trays, and carts. 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.

5. 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.

6. Use ventilation hoods or glove boxes if the radioactivity may become airborne and for high activity uses, such as stock solutions.

7. The individual(s) responsible for any contamination will be required to decontaminate the area of concern. 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 that require them.

10. Wear laboratory coats when working with radioactive materials. Always wear safety glasses.

APPENDIX I - LABORATORY CLASSIFICATION AND ACTIVITY LIMITS

Laboratory Classification Tables

Radionuclides classified according to relative radiotoxicity per unit activity*

Group I: Very high radiotoxicity

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

Group II: High radiotoxicity

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

Group III: Moderate radiotoxicity

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

Group IV: Low radiotoxicity

^{3}H	^{58m}Co	^{71}Ge	^{87}Rb	^{96m}Tc	^{103m}Rh	^{129}I	^{135}Cs	^{187}Re	^{197m}Pt
^{15}O	^{59}Ni	^{85}Kr	^{91}Ym	^{97}Nb	^{113m}In	^{131m}Xe	^{135}Xe	^{191m}Os	
^{37}A	^{69}Zn	^{85m}Sr	^{93}Zr	^{99m}Tc	^{125}I	^{134m}Cs	^{147}Sm	^{193m}Pt	
^{232}Th	^{235}U	^{238}U	NatTh	NatU					

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

Quantity Limit Guide

The following table provides the limitation on activities in various types of working place or laboratory based on level of radiotoxicity.*

Radiotoxicity of radionuclides	Minimum significant quantity	Type C	Type B	Type A
1. Very high	0.1 µCi	≤ 10 µCi	10 µCi - 10 mCi	≥ 10 mCi
2. High	1.0 µCi	≤ 100 µCi	100 µCi - 100 mCi	≥ 100 mCi
3. Moderate	10 µCi	≤ 1 mCi	1 mCi - 1 Ci	≥ 1 Ci
4. Low	100 µCi	≤ 10 mCi	10 mCi - 10 Ci	≥ 10 Ci

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

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APPENDIX J - RADIOISOTOPES COMMON AT MSU

Radioisotope	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

2:2 Gamma: 2” by 2” NaI-scintillator

L.E.G.: Low Energy Gamma 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.

APPENDIX K - FACT SHEETS FOR COMMONLY USED RADIOISOTOPES

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
• Maximum Beta Range in Air:	24.00 cm (10 inches)
• Maximum Beta Range in Water/Tissue*:	0.28 mm (0.012 inches)
• Maximum Beta 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
- Skin Contamination Dose Rate: 1090-1180 mrem per 1.0 µCi/cm^2 (7 mg/cm^2 depth)

Shielding

- None required (≤ 3 mm Plexiglass)

Survey Instrumentation

- G-M survey meter with Pancake Probe; survey meter probe must be at close range (1 cm).
- 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

General Radiological Safety Information

- Urinalysis: Not Required; however, prudent after a ^{14}C radioactive spill or suspected intake.
- Possibility of organic ^{14}C compounds being absorbed through gloves.
- Care should be taken NOT to generate $^{14}CO_2$ gas, which could be inhaled.
- Always wear a lab coat and disposable gloves when working with ^{14}C.
- 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 and 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)
- Physical Half-Life: 27.8 days
- Biological Half Life: 616.0 days
- Effective Half-Life: 26.6 days (whole body)

Radiological Data

- Critical Organ: Lower large intestine (LLI)
- Routes of Intake: Ingestion, inhalation, skin contact
- External & internal exposure and contamination are radiological concerns.
- 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
Half - Value Layer (concrete):	2.8 cm
Half - Value Layer (Plexiglas):	4.8 cm

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 dosimeters required.

Regulatory Compliance Information

- 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 at 1cm: 160.0 mrad/hr

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
- Maximum Beta Range in Air: 0.6 cm
- Maximum Beta Range in Water: 0.006 mm

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
- Annual Limit on Intake (ALI): 80 mCi (ingestion or inhalation) [$^{3}H_2O$]
- Skin Contamination Exposure Rate: 57,900 mrad/hr/mCi (contact)

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 dosimeter or extremity dosimeters: Not needed (beta energy too low)

Regulatory Compliance Information

- Urinalysis (Byproduct License): Required when handling ≥ 100 mCi ^{3}H

General Radiological Safety Information

- Inherent Volatility (at STP): SUBSTANTIAL
- Experimental uses include total body water measurements and in-vivo labeling of proliferating cells by injection of tritium-labeled compounds (i.e., thymidine). Tritium labeling is also used in a variety of metabolic studies.
- Oxidation of ^{3}H gas in air is usually slow (< 1% per day).
- Absorption of ^{3}H inhaled in air is much less when it is present as elemental ^{3}H 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, ^{3}H entering the lung or GI tract is completely absorbed and rapidly dispersed within the body.
- Forcing fluids reduces integrated internal exposures from ^{3}H.
- Always wear a lab coat & disposable gloves when handling ^{3}H.
- Skin contamination, inhalation, ingestion, or absorption through the skin is assumed to be complete and instantaneous. ^{3}H is then rapidly mixed with total body water.
- Detection limit of ^{3}H in urine: $1.08E^{-5}$ µCi/ml (approximately)
- Beta dose rates from 1.0 mCi ^{3}H 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
- Physical Half-Life: 60.1 days
- Biological Half-Life: 120-138 days (unbound iodine)
- Effective Half-Life: 42 days (unbound iodine) - thyroid gland

Physical 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

Shielding

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

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	mrad/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 radioiodine in the body can be assumed to be eliminated quite rapidly via the urine.
- Thyroid Bioassay is required by law when handling > 1 mCi ^{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 iodination. 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 iodination. This prevents puff releases.
- Segregate waste from iodination's (free) from other (bound) ^{125}I waste and store it in the fume hood, in tightly sealed Ziplock bags (solid waste) or screw top containers (liquid waste) until waste pickup.
- Cover test tubes used to count or separate fractions from iodination's 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: 1,155 days
- Effective half-life: 14.1 day (bone) / 13.5 day (whole body)
- 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
- 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	Rad/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%.

Phosphorus-33 [^{33}P]

Physical Data

• Beta energy:	0.249 MeV (maximum) 0.085 MeV (average)
• Physical half-life:	25.4 days
• Biological half-life:	19 days
• 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
- 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-life
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)
• Physical Half Life:	87.4 days
• Biological Half Life:	623 days (unbound ^{35}S)
• 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.

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.
- 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

- Dosimeters 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 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 8.0mCi 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.

APPENDIX L - SURVEY GUIDE

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. Refer to Appendix L or contact EHS Radiation Safety Staff for guidance on appropriate detection equipment.

1. 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, pipettors, and any other equipment that has been used for radioisotope work.

2. Make a record of all laboratory surveys. The record must 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 DPM, the following equation should be used:

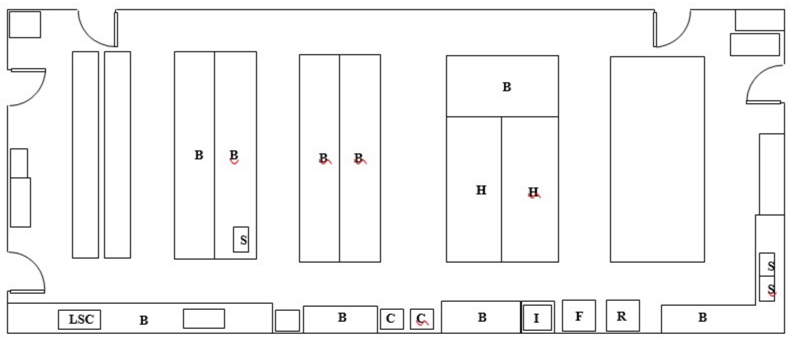
$$\frac{CPM}{Efficiency} = DPM$$

3. To monitor for ^3H, 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.

4. 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 PI.

Survey Form Example

Radiation Survey Map of B228 Anthony Hall



KEY: (B) = Bench, (H) = Hood, (S) = Sink, (R) = Refrigeration Unit, (WA) = Waste Container, (_____) = Wipe Sample Area, (-------) = Meter Survey Area, (X) = Contaminated Area (≤ 100 cm^2 unless stated otherwise).

Survey Instrument Information

Make: ________________ Model: ________________ Serial No.:________________ (Meter)
Make: ________________ Model: ________________ Serial No.:________________ (LSC)
Make: ________________ Model: ________________ Serial No.: ________________

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

Notes:

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 unless stated otherwise. The efficiencies are obtained from the calibrations performed by EHS.
Revised August 2016.

APPENDIX M - VIOLATION INFO

Radioactive material

Severity Level Categories for Radiation Safety Violations

Severity Level I: This is the highest severity level, and results from violations that 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 that 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 noncompliance

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 PI 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 PI from health physicist.
I, II	Letter to PI from RSO; response is required in writing.
I – III	Place restrictions on individual(s) causing non-compliances.
I – III	Suspend shipments of radioactive materials to PI.
I, II	Require PI to appear before committee.
I, II	Decrease scope or limits of radioactive materials approval.
I, II	Require PI to reapply for radioisotope use.
I, II	Confiscate radioactive materials in possession of PI.
I	Permanently terminate approval to use radioactive materials.

Severity levels for violations found during EHS Radiation Laboratory survey

No.	Severity Level	Compliance Requirement
1.	V	Applicable NRC postings are prominently displayed and current.

2.	I – III	Radioactive materials are under constant surveillance and immediate control of licensee, or otherwise secured to prevent tampering or unauthorized removal.
3.	I – III	Radiation users are adequately trained for functions performed.
4.	I – III	Surveyed areas are free of radioactive contamination.
5.	I – IV	Laboratory radiation survey equipment is functional and used correctly.
6.	III – V	Radiation surveys and/or radioisotope use logs are accurate, and frequency is adequate.
7.	I – IV	Food and other consumables are not present in radioisotope/chemical use/storage areas.
8.	I – V	Radioisotope work areas, storage areas and equipment are labeled adequately.
9.	I – IV	Radioisotope sources/stock solutions are labeled adequately.
10.	I – III	Radioisotope waste is manifested in both sides of the tag, 2nd containment for liquids.
11.	I – V	Radioisotope shielding is adequate (material, thickness, positioning).
12.	I – V	Dosimeters and protective equipment are used during radioisotope handling.
13.	I – V	Fume hoods are used properly (sash setting, uncluttered, rated for radioisotope use).
14.	I – III	Contact information is located at the laboratory entrance and is current and correct.

Radiation-Producing Equipment

Compliance requirements for EHS X-ray safety inspections

No.	Compliance Requirement
1.	Radiation area restricted to authorized personnel.
2.	Access secured or securable.
3.	Spaces have limited, or protected spectator access.
4.	Failsafe interlocks or equivalents are present & functional.
5.	Nominal Hazard Zone determined
6.	Shielding and risk assessment completed
7.	State of Michigan Registration current and correct.
8.	Current State of Michigan Notice to Employees is posted.
9.	Current MSU LARA information notice posted.
10.	X-ray-producing machine warning signs & labels posted.
11.	Door signs include correct information, labels, & contact information.
12.	Users have applicable current EHS X-ray safety training.
13.	Users have site specific radiation safety training.
14.	Standard Operating Procedures available.
15.	Dosimeters are issued & utilized.
16.	Personal protective equipment is in good condition & utilized.

APPENDIX N – TRANSPORTATION/SHIPPING GUIDE

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. **EHS must be notified** before any transportation of radioactive materials. This is to ensure that proper procedures are followed, and movement of radioactive material is tracked. Any transfers of radioactive material (possession transferred from one PI to another) must be pre-authorized by EHS.

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 EHS.

Campus Transportation

Whenever radioactive material is transported from one building to another, EHS 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 radioisotope
- The total activity in mCi
- Number of containers
- Phone numbers of responsible persons
- Any special conditions

Walking to another building

Prepare to move your material using an appropriate container (see Package Preparation above). The package must have a radioactive warning label with the radioisotope, activity in DPM, µCi, or mCi and date. Clearly identify the PI 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 EHS if any removable contamination is detected.

Driving to another building

The transportation of radioactive material is regulated by the NRC and DOT. You must not move any radioactive material on a public road without prior authorization by EHS. Remember that all roads on the MSU campus are public. EHS 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). EHS 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 EHS. 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, EHS 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 be obtained from the Radiation Safety Office at that location, preferably the RSO. 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 RSO's (or other staff member) name and phone number
- The nuclide(s) being sent
- The chemical form of each radioisotope
- The total activity in mCi for each radioisotope
- Number of containers in the shipment
- Any special conditions.

Prepare to ship your material using an appropriate container (see Package Preparation above). EHS 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 EHS. Labels will be placed on the package, if required. When the package and paperwork are in order, EHS may provide assistance with sending the package out. Copies of the shipping papers, material return form, and any other paperwork will be made and maintained for review at EHS.

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

APPENDIX O - WASTE

Quantifying Levels of Radioactivity in Waste

Radioactive and other hazardous materials must be completely manifested in the waste. To accurately list levels of radioactivity on the tags, it is necessary to assess the levels that 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:	4,000 ml
Activity in Liquid Waste Sample:	$8 \, x \, 10^{-2}$ µCi/ml
Liquid Waste Total Activity:	$8 \, x \, 10^{-2}$ 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. Multiply the activity of the sample per unit volume by the total volume in the carboy to obtain the total activity in the carboy. Quantify the solid waste as above by subtracting the liquid waste activity.

Pointers for Handling Radioactive Waste

1. Read and understand the MSU Waste Disposal Guide. This document should be 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. EHS only provides waste containers, labs are responsible for secondary containers. Labs are also responsible for obtaining required shielding, if applicable.

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, PI, and the signature of a radiation worker.

4. Record the radioisotope, 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.

5. 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 EHS determine how to route the waste.

6. Fill the liquid container(s) only to four (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.

7. 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.

APPENDIX P - DECONTAMINATING RADIOACTIVE MATERIAL

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 that 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 decontamination method that will work for your surface, nuclide, chemical form, and location. Depending on these factors, effective solutions to the problem will be identified.

Skin Contamination: 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 that contains no abrasives. Remember to notify EHS immediately if personnel contamination occurs or is suspected. Also, note the readings of radioactive contamination detected with the survey instrument and the times that it was discovered and then removed.

GLOSSARY

Activity- The rate of disintegration (transformation) or decay of radioactive material per unit time. The units of activity (also known as radioactivity) are the curie (Ci) and the becquerel (Bq).

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

Adult- An individual 18 or more years of age.

ALARA (As Low As Reasonably Achievable)- Making every reasonable effort to maintain exposures to ionizing radiation as far below the dose limits as 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 positively charged particle ejected spontaneously from the nuclei of some radioactive elements. It is identical to a helium nucleus that has a mass number of 4 and an electrostatic charge of +2. It has low penetrating power and a short range (a few centimeters in air). The most energetic alpha particle will generally fail to penetrate the dead layers of cells covering the skin and can be easily stopped by a sheet of paper. Alpha particles are hazardous when an alpha-emitting radioisotope is inside the body.

Annual Limit on 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 that cannot be divided or broken up by chemical means. It consists of a central core (or nucleus), containing protons and neutrons, with electrons revolving in orbits in the region surrounding the nucleus.

Attenuation- The process by which the number of particles or photons entering a body of matter is reduced by absorption and scattered radiation.

Background Radiation- The natural radiation that is always present in the environment. It includes cosmic radiation that comes from the sun and stars, terrestrial radiation that comes from the Earth, and internal radiation that exists in all living things. The typical average individual exposure in the U.S. from natural background sources is about 300 millirems per year.

Becquerel- One of three units used to measure radioactivity, which refers to the amount of ionizing radiation released when an element spontaneously emits energy as a result of the radioactive decay (or disintegration) or an unstable atom. Radioactivity is also the term used to describe the rate at which radioactive material emits radiation, or how many atoms in the material decay (or disintegrate) in a given time period. As such, 1 Bq represents a rate of radioactive decay equal to 1 disintegration per second, and 37 billion Bq equals 1 Curie (Ci).

Beta Particle- A charged particle that is emitted from the nucleus of a radioactive element during radioactive decay (or disintegration) of an unstable atom. A negatively charged beta particle is identical to an electron, while a positively charged beta particle is called a positron. Large amounts of beta radiation may cause skin burns, and beta emitters are harmful if they enter the body. Beta particles may be stopped by thin sheets of metal or plastic.

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.

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- The adjustment, as necessary, of a measuring device such that it responds within the required range and accuracy to known values of input.

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 (CDE)- The dose to some specific organ or tissue 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 (CEDE)- The sum of the products of the committed dose equivalents for each of the body organs or tissues that are irradiated multiplied by the weighting factors applicable to each of those organs or tissues.

Contamination- Undesirable radiological that is either airborne or deposited in (or on the surface of) structures, objects, soil, water, or living organisms in a concentration that makes the medium unfit for its next intended use.

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

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 period of time. The term is often erroneously used to designate a disintegration, ionizing event, or voltage pulse.

Critical Organ- That part of the body that is most susceptible to radiation damage under the specific conditions under consideration.

Curie- The amount of ionizing radiation released when an element spontaneously emits energy as a result of the radioactive decay (or disintegration) of an unstable atom. Radioactivity is also the term used to describe the rate at which radioactive material emits radiation, or how many atoms in the material decay (or disintegrate) in a given time period. As such, 1 Ci is equal to 37 billion disintegrations per second, so 1 Ci also equals 37 billion becquerels (Bq). A curie is also a quantity of any radionuclide that decays at a rate of 37 billion disintegrations per second (1 gram of radium, for example).

Decay- The spontaneous transformation of one radioisotope into one or more different isotopes (known as “decay products” or “daughter products”), accompanied by a decrease in radioactivity (compared to the parent material). This transformation takes place over a defined period of time (known as a “half-life”), as a result of electron capture; fission; or the emission of alpha particles, beta particles, or photons (gamma radiation or x-rays) from the nucleus of an unstable atom. Each isotope in the sequence (known as a “decay chain”) decays to the next until it forms a stable, less energetic end-product. In addition, radioactive decay may refer to gamma-ray and conversion electron emission, which only reduces the excitation energy of the nucleus.

Declared Pregnant Worker- An individual who is an occupational radiation worker and has voluntarily informed their employer, in writing, of their pregnancy and the estimated date of conception.

Decontamination- A process used to reduce, remove, or neutralize radiological contamination to reduce the risk of exposure. Decontamination may be accomplished by cleaning or treating surfaces to reduce or remove the contamination; filtering contaminated air or water; subjecting contamination to evaporation and precipitation; or covering the contamination to shield or absorb the radiation. The process can also simply allow adequate time for natural radioactive decay to decrease the radioactivity.

Deep Dose Equivalent- The external whole-body exposure dose equivalent at a tissue depth of one centimeter (1000 mg/cm2).

Delayed Health Effects- Radiation health effects that 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.

Department of Transportation (DOT)- A governmental agency responsible for promoting the safe transportation of hazardous materials by all modes (land, air, water).

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 annual limit on intake (ALI).

Disintegration- See decay, radioactive.

Dose or Radiation Dose- A general term, which may be used to refer to the amount of energy absorbed by an object or person per unit mass. Known as the “absorbed dose,” this reflects the amount of energy that ionizing radiation sources deposit in materials through which they pass and is measured in units of radiation-absorbed dose (rad). The related international system unit is the gray (Gy), where 1 Gy is equivalent to 100 rad. By contrast, the biological dose or dose equivalent, given in rems or sieverts (Sv), is a measure of the biological damage to living tissue as a result of radiation exposure.

Dose Equivalent- A measure of the biological damage to living tissue as a result of radiation exposure. Also known as the “biological dose,” the dose equivalent is calculated as the product of absorbed dose in tissue multiplied by a quality factor and then sometimes multiplied by other necessary modifying factors at the location of interest. The dose equivalent is expressed numerically in rems or sieverts (Sv).

Dose Rate- The dose of ionizing radiation delivered per unit time. For examples, rems or sieverts (Sv) per hour.

Dosimeter- A small portable instrument used to measure and record the total accumulated personal dose of ionizing radiation.

Dosimetry- The theory and application of the principles and techniques involved in measuring and recording doses of ionizing radiation.

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 MSU, 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.

Electron- An elementary particle with a negative charge and a mass 1/1,837 that of a proton. Electrons surround the positively charged nucleus of an atom and determine its chemical properties.

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. Radioisotope energy is typically measured in MeV. (million electron volts).

Exposure- Absorption of ionizing radiation or ingestion of a radioisotope. Acute exposure is a large exposure received over a short period of time. Chronic exposure is exposure received over a long period of time, such as during a lifetime. The National Council on Radiation Protection and Measurements (NRCP) estimates that an average person in the U.S. receives a total annual dose of about 0.62 rem (620 millirem) from all radiation sources, a level that has not been shown to cause humans any harm. Of this total, natural background sources of radiation- including radon and thoron gas, natural radiation from soil and rocks, radiation from space and radiation sources that are found naturally within the human body- account for approximately 50%. Medical procedures such as computed tomography (CT scans) and nuclear medicine account approximately for another 48%. Other small contributors of exposure to the U.S. population include consumer products and activities, industrial and research uses, and occupational tasks. The maximum permissible yearly dose for a person working with or around nuclear material is 5 rem.

External Radiation- Exposure to ionizing radiation when the radiation source is located outside the body.

Extremity- The hands, forearms, elbows, feet, knees, leg below the knees, and ankles. Permissible radiation exposures in these regions are generally greater than those for whole body exposure because the extremities contain fewer blood-forming organs and have smaller volumes for energy absorption.

Gamma Radiation- High-energy, short-wavelength, electromagnetic radiation emitted from the nucleus of an atom. Gamma radiation frequently accompanies emissions of alpha particles and beta particles, and always accompanies fission. Gamma rays are similar to x-rays but are very penetrating and are best stopped or shielded by dense materials, such as lead or depleted uranium.

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. It was named for Hans Geiger and W. Mueller, who invented it in the 1920s. It is sometimes simply called a Geiger counter or a G-M counter and is the most used portable radiation instrument.

Gray- One of the two units used to measure the amount of radiation absorbed by an object or person, known as the “absorbed dose,” which reflects the amount of energy that radioactive sources (with any type of ionizing radiation) deposit in materials (e.g., water, tissue, air) through which they pass. One gray (Gy) is the international system of units (SI) equivalent of 100 rads, which is equal to an absorbed dose of 1 Joule/kilogram. An absorbed dose of 0.01 Gy means that 1 gram of material absorbed 100 ergs or energy (a small but measurable amount) as a result of exposure to radiation.

Half-Life, Biological- The time required for the body to eliminate one half of the material taken in by natural biological means.

Half-Life, Effective- The time required for the activity of a particular radioisotope deposited in a living organism, such as a human or an animal, to be reduced by 50% as a result of the combined action of radioactive decay and biological elimination. Effective half-life is related to, but different from, the radiological half-life and the biological half-life.

Half-Life, Radioactive- The time required for half the atoms of a particular radioisotope to decay into another isotope. A specific half-life is a characteristic property of each radioisotope. Measured half-lives range from millionths of a second to billions of years, depending on the stability of the nucleus. Radiological half-life is related to, but different from, the biological half-life and the effective half-life.

Half Value Layer- The thickness of any specified material necessary to reduce the intensity of entering radiation to one-half its original value.

Health Physics- The science concerned with recognizing and evaluation the effects of ionizing radiation on the health and safety of people and the environment, monitoring radiation exposure, and controlling the associated health risks and environmental hazards to permit the safe use of technologies that produce ionizing radiation.

High Radiation Area- Any area with dose rates greater than 100 millirems (1 millisievert) in one hour 30 centimeters from the source or from any surface through which the ionizing radiation penetrates. Areas at licensee facilities must be posted as “high radiation areas” and access into these areas is maintained under strict control.

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.

Ionization- The process of adding one or more electrons to, or removing one or more electrons from, atoms or molecules, thereby creating ions. High temperatures, electrical discharges, or nuclear radiations can cause ionization.

Ionization Chamber- An instrument that detects and measures ionizing radiation by measuring the electrical current that flows when radiation ionizes gas in a chamber, making the gas a conductor of electricity.

Ionizing Radiation- A form of radiation, which includes alpha particles, beta particles, gamma rays, x-rays, neutrons, high-speed electrons, high-speed protons, and other particles capable of producing ions. Compared to non-ionizing radiation, such as radio- or microwaves, or visible, infrared, or ultraviolet light, ionizing radiation is considerably more energetic. When ionizing radiation passes through material such as air, water, or living tissue, it deposits enough energy to produce ions by breaking molecular bonds and displace (or remove) electrons from atoms or molecules. This electron displacement may lead to changes in living cells. Given this ability, ionizing radiation has a number of beneficial uses, including treating cancer or sterilizing medical equipment. However, ionizing radiation is potentially harmful it not used correctly, and high doses may result in severe skin or tissue damage. It is for this reason that the NRC strictly regulates commercial and institutional uses of the various types of ionizing radiation.

Isotope- Two or more forms (or atomic configurations) of a given element that have identical atomic numbers (the same number of protons in their nuclei) and the same or very similar chemical properties but different atomic masses (different numbers of neutrons in their nuclei) and distinct physical properties. Thus, carbon-12, carbon-13, ad carbon-14 are isotopes of the element carbon, and the numbers denote the approximate atomic masses. Among their distinct physical properties, some isotopes (known as radioisotopes) are radioactive because their nuclei emit radiation as they strive toward a more stable nuclear configuration. For example, carbon-12 and carbon-13 are stable, but carbon-14 is unstable and radioactive.

Lethal Dose (LD)- The dose of radiation expected to cause death to 50 percent of an exposed population within 30 days (LD 50/30). Typically, the LD 50/30 is in the range from 400 to 450 rem (4 to 5 sieverts) received over a very short period.

Licensed Material- Source material, byproduct material, or special nuclear material that is received, possessed, used, transferred, or disposed of under a general license or specific license issued by the NRC or Agreement States.

Licensee- A company, organization, institution, or other entity to which the NRC or an Agreement State has granted a general license or specific license to construct or operate a nuclear facility, or to receive, posses, use, transfer, or dispose of source material, byproduct material, or special nuclear material.

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.

Micro (µ)- A prefix that divides a unit into one million parts. Ex. Microcurie (µCi)- a one-millionth of a curie, (1/1,000,000), (0.000001 Ci).

Milli (m)- A prefix that divides a basic unit by 1000. Ex. millicurie (mCi)- a one-thousandth of a curie, (1/1000th), (0.001 Ci).

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 of radiation- Periodic or continuous determination of the amount of ionizing radiation or radioactive contamination in a region. Radiation monitoring is a safety measure to protect the health and safety of the public and the environment through the use of bioassay, alpha scans, and other radiological survey methods to monitor air, surface water and ground water, soil and sediment, equipment surfaces, and personnel.

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

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.

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. Except for the nucleus of ordinary hydrogen, which has only a 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 general term referring to all known isotopes, both stable (279) and unstable (about 2,700), of the chemical elements.

Occupational Dose- The internal and external dose of ionizing radiation received by workers in the course of employment in such areas as fuel cycle facilities, industrial radiography, nuclear medicine, and nuclear power plants. These workers are exposed to varying amounts of radiation, depending on their jobs and the sources with which they work. The NRC requires its licensees to limit occupations exposure to 5,000 mrem (50 mSv) per year. Occupational dose does not include the dose received from natural background sources, doses received as a medical patient or participant in medical research programs, or “second-hand doses” received through exposure to individuals treated with radioactive materials.

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 of this shielding device protect the person handling the container from radiation. Large containers are commonly called casks.

Positron- Particle equal in mass, but opposite in charge, to the electron; a positive electron.

Principal Investigator (P.I.)- A faculty member, assistant professor or higher (no visiting faculty), appointed by the licensee, who has been approved through the RSC for the purchase and use of radioactive materials.

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 or to radioactive material released by a licensee, or to any other source of radiation under the control of a licensee. Public dose does not include occupational dose or dose received from background radiation, from any medical administration the individual has received, from exposure to individuals administered radioactive materials and released in accordance with 10 CFR 35.75, or from voluntary participation in medical research programs.

Quality Factor (Q)- The factor by which the absorbed dose (rad or gray) is to be multiplied to obtain a quantity that expresses, on a common scale for all ionizing radiation, the biological damage (rem or sievert) to an exposed individual. It is used because some types of radiation, such as alpha particles, are more biologically damaging internally than other types.

Rad (Radiation absorbed dose)- One of the two units used to measure the amount of radiation absorbed by an object or person, known as the “absorbed dose,” which reflects the amount of energy that radioactive sources deposit in materials through which they pass. The radiation-absorbed dose (rad) is the amount of energy (from any type of ionizing radiation) deposited in any medium (e.g., water, tissue, air). An absorbed dose of 1 rad means that 1 gram of material absorbed 100 ergs of energy (a small but measurable amount) as a result of exposure to radiation. The related international system unit is the gray (Gy), where 1 Gy is equivalent to 100 rad.

Radiation Area- Any area with radiation levels greater than 5 millirems (0.05 millisievert) in one hour at 30 centimeters from the source or from any surface through which the radiation penetrates.

Radiation Survey- The evaluation of the radiation hazards accompanying the production, use, or existence of radioactive materials under a specific set of conditions. Such evaluation customarily includes a physical survey of the disposition of materials and equipment, measurements or estimates of the levels of radiation that may be involved, and a sufficient knowledge of processes affecting these materials to predict hazards resulting from expected or possible changes in materials or equipment.

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 use of sealed sources of ionizing radiation for nondestructive examination of the structure of materials. When the radiation penetrates the material, it produces a shadow image by blackening a sheet of photographic film that has been placed behind the material, and the differences in blackening suggest flaws and unevenness in the material.

Radioisotope- An unstable isotope of an element that decays or disintegrates spontaneously, thereby emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified.

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

Radionuclide- An unstable isotope of an element that decays or disintegrates spontaneously, thereby emitting radiation. Approximately 5,000 natural and artificial radioisotopes have been identified.

Radio sensitivity- 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.

Rem (Roentgen equivalent man)- One of the two standard units used to measure the dose equivalent (or effective dose), which combines the amount of energy (from any type of ionizing radiation that is deposited in human tissue), along with the medical effects of the given type of radiation. For beta and gamma radiations, the dose equivalent is the same as the absorbed dose. By contrast, the dose equivalent is larger than the absorbed dose for alpha and neutron radiations, because these types of radiation are more damaging to the human body. Thus, the dose equivalent (in rems) is equal to the absorbed dose (in rads) multiplied by the quality factor of the type of radiation. The related international system unit is the sievert (Sv), where 100 rem is equivalent to 1 Sv.

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- Any area to which access is controlled for the protection of individuals from exposure to radiation and radioactive materials.

Roentgen (R)- A unit of exposure to ionizing radiation. It is the amount of gamma or x-rays required to produce ions resulting in a charge of 0.000258 coulombs/kilogram of air under standard conditions. Named after Wilhelm Roentgen, the German scientist who discovered x-rays in 1895.

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- Any radioactive material or byproduct encased in a capsule designed to prevent leakage or escape of the material.

Shielding Material- Any material or obstruction that absorbs radiation and thus tends to protect personnel or materials from the effects of ionizing radiation.

Sievert- The international unit (SI) of dose equivalent equal to 1 Joule/Kilogram. 1 sievert = 100 rem. Named for physicist Rolf Sievert

Somatic Effects of Radiation- Effects of radiation limited to the exposed individual, as distinguished from genetic effects, that may also affect subsequent unexposed generations.

Special Nuclear Material- Plutonium, uranium-233, or uranium enriched in the isotope's uranium-233 or uranium-235.

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- Effects that occur by chance, generally occurring without a threshold level of dose, whose probability is proportional to the dose and whose severity is independent of the dose. In the context of radiation protection, the main stochastic effects are cancer and genetic effects.

Total Effective Dose Equivalent (TEDE)- The sum of the effective 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 that may be incorporated into a sample to allow 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. Because it is chemically identical to natural hydrogen, tritium can easily be taken into the body by any ingestion path. Its decays by emitting beta particles and has a half-life of about 12.5 years.

Unrestricted Area- An area in which a person could not be exposed to radiation levels in excess of 2 millirems in any one hour from external sources.

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 exceed 500 rad (5 gray) in one hour at 1 meter from the source or from any surface that the radiation penetrates.

Whole Body Exposure- Whole body exposure includes at least the external exposure, head, trunk, arms above the elbow, or legs above the knee. Where a radioisotope is uniformly distributed throughout the body tissues, rather than being concentrated in certain parts, the irradiation can be considered as whole-body exposure.

Wipe (smear or wipe test)- A sample made for the purpose of determining the presence of removable radioactive contamination on a surface. It is done by wiping, with slight pressure, a piece of soft filter paper over a representative type of surface area. It is also known as a “swipe” or “smear” sample.

X-rays- Penetrating electromagnetic radiation (photon) having a wavelength that is much shorter than that of visible light. These rays are usually produced by excitation of the electron field around certain nuclei. In nuclear reactions, it is customary to refer to photons originating in the nucleus as x-rays.

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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 NRC. 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.

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