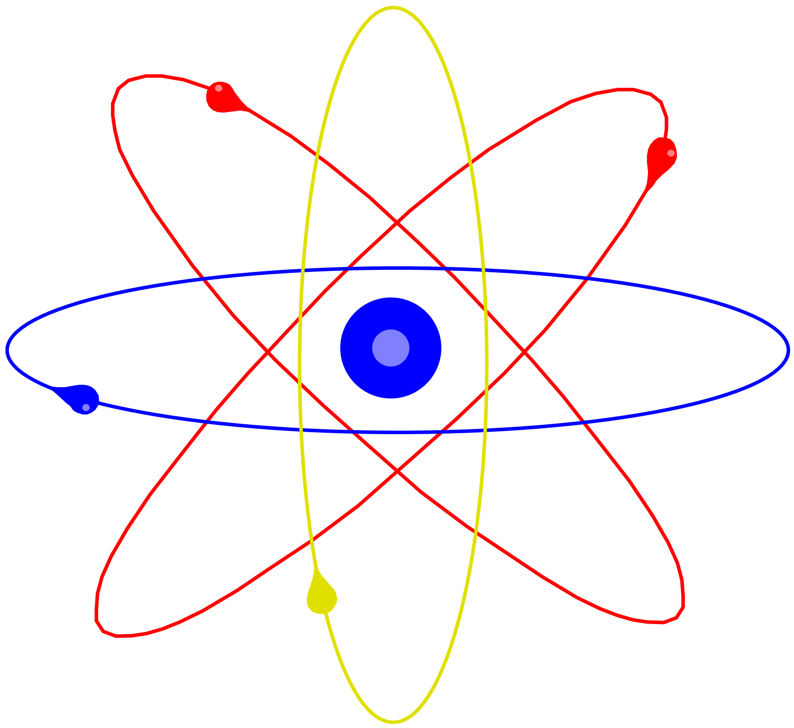
THE SCRIPPS RESEARCH INSTITUTE



RADIATION SAFETY MANUAL

In case of <u>emergency</u> dial x77 from any campus phone.

Revised 2007

TABLE OF CONTENTS

1.0 INTRODUCTION

1.1 Purpose

The purpose of the radiation safety program (RSP) is to ensure that work with radioactive materials (RAM) and radiation-producing machines is conducted in a manner that protects health and minimizes danger to life, property, and the environment. The RSP is based upon the principle that all doses to employees and the public are to be kept as low as reasonably achievable (ALARA).

The purpose of this manual is to communicate administrative policy, organization, operating procedures, and the standards of conduct of the radiation safety program. In addition, it is intended to help everyone using or responsible for the use of radioactive materials to comply with TSRI policy, conditions stipulated in the TSRI Radioactive Materials License, applicable regulations of governmental agencies, and national radiation protection standards.

Principal Investigators (PI) planning to use radioactive materials at TSRI must apply to the Radiation Safety Committee, the ultimate authority for radioactive materials use at TSRI. The application process is detailed in Section 2.0 of this manual. If approval is granted, the PI is assigned a Radiation Use Authorization (RUA) which stipulates the conditions and requirements under which the PI may work with radioactive materials. Future requests to amend or expand the conditions of the RUA must be submitted to the RSC, via the Radiation Safety Officer (RSO), in advance.

Similarly, PIs planning to use or obtain a radiation producing machine at TSRI must submit a "Radiation Producing Machine Registration Form". If approval is granted the PI will be assigned an X-ray Radiation Use Authorization (xRUA) as discussed in Section 9.1 below.

Each investigator who is issued an RUA will be given a copy of this manual. The manual is intended to be a reference and shall be made available to all employees working in laboratories where RAM is authorized for use. Furthermore, a copy of this manual can be found in the Safety Management Plan and on the EH&S website.

Everyone using radioactive materials and radiation-producing machines is expected to be familiar with, and comply with the applicable provisions of this manual.

1.2 Administration and Contact Information

The Radiation Safety Committee (RSC) is responsible for setting policy for the use of radioactive materials (RAM) at TSRI. The RSC works with senior management and the Radiation Safety Officer (RSO) in implementing and overseeing the Radiation Safety Program (RSP). The RSC is responsible for reviewing applications and granting authorization for use of radioactive material and radiation producing machines. The RSC provides final approval for all amendments to RUAs and has the authority to suspend or revoke any authorization previously granted.

The Radiation Safety Officer (RSO) is a member of the Environmental Health & Safety (EH&S) Department and is the Manager of the Radiation Safety Program. The RSO conducts preliminary review of RUA applications and may grant interim approval for routine amendment requests to an existing RUA prior to final approval by the RSC. The RSO has the authority to stop any radioactive materials work deemed a hazard to employees, the public, or the environment.

The Environmental Health & Safety Office, Radiation Safety Staff is managed by the RSO and performs the routine activities required of the radiation safety program. These duties include, but are not necessarily limited to, the following: package receipt, inspection, and delivery; institutional surveys; instrument calibration; bioassays; waste collection and disposal; transportation of RAM; and emergency response.

EH&S CONTACT INFORMATION	
EMERGENCY	x77
Waste Pick-Up Voicemail	x4-4093
Environmental Health & Safety Department	x4-8240
Environmental Health & Safety Department Fax	x4-8490
Environmental Health & Safety Department Mail Drop	TPC-27

TSRI INTRANET RESOURCES
The EH&S website can be found from the main TSRI page via: Campus Services, Research Services, Environmental Health and Safety http://www.scripps.edu/researchservices/ehs/

1.3 Principal Investigator (Radiation Use Authorization Holder)

The Principal Investigator (PI) is responsible for the safe use of radioactive materials under his/her authorization and must agree to comply with the conditions and requirements of the RUA. In general, only faculty members are issued Radiation Use Authorizations. For the sake of radioactive material use in the laboratory, the PI referred to herein is the individual whose name is assigned to the RUA.

1.4 Authorized Users

The individuals using the radioactive materials are responsible for conducting their experiments or procedures in a safe manner by following all applicable radiation safety rules and regulations; this is of central importance to the entire radiation safety program. Everyone who anticipates working with radioactive materials must attend formal radiation safety training and pass a written test.

2.0 APPLICATION TO USE RADIOACTIVE MATERIAL (RUA)

2.1 TSRI Radioactive Materials (RAM) License

The State of California Department of Public Health (CDPH) has issued a radioactive materials license to the institute. TSRI radioactive materials license (#2670-37) allows the RSC to approve applications by individual investigators for nonhuman uses of radioactive materials. This is a great convenience to the institute. Loss of this privilege would result in every minor change requiring approval from the CDPH. Details of the license are discussed further in Section 9.2.3 of this manual.

The radioactive materials license along with other pertinent regulations such as Title 17 of the California Code of Regulations (Title 17 CCR) and the relevant references to the Code of Federal Regulations (10 CFR §20, among others), can be obtained for review at the EH&S office.

2.2 RUA Application

An investigator wishing to be authorized to use radioactive materials must apply to the Radiation Safety Committee by submitting an "Application to Use Radioactive Materials". This form can be obtained online at the EH&S website or by contacting EH&S directly. This application is the applicant's opportunity to show that s/he is qualified by training and experience to be responsible for, and supervise the use of radioactive materials. In addition, the applicant must demonstrate that the laboratory facilities, equipment, and available shielding are adequate for the described project. All personnel who will work with radioactive materials must be listed on the application or amended to it before they begin work. In order to be listed, expectant users must attend formal radiation safety training, pass a written test, and be amended to the RUA at the request of the PI. All forms are to be submitted to EH&S where they will be reviewed by the RSO before being forwarded to the RSC. Detailed instructions for the RUA application are provided below in Section 2.3.

2.2.1 Animal Use
The final authorization to work with any research animals at TSRI must come from the Institutional Animal Care and Use Committee (IACUC). In order to work with RAM in research animals the IACUC will request advice from the RSC. Therefore, an "Application to Use Radioactive Materials in Animals" must be submitted to the RSC. This form can be obtained online at the EH&S website or by contacting EH&S directly.

2.2.2 Radiation Producing Machines Authorizations (x-RUA)
A radiation-producing machine is any high-voltage device that can produce high-energy charged particles and therefore, photons (x-rays) or neutrons. The term includes x-ray machines used in diffraction and fluorescence analysis, electron microscopes, and cyclotrons or other particle accelerators. Devices such as televisions and video display terminals are excluded since they do not produce significant radiation.

Radiation-producing machines must be registered with the CDPH within 30 days of their acquisition and reregistered every two years. Units which are removed from service or transferred off-site must also be reported to the state within 30 days. EH&S can perform these registration functions if notified by the PI. The best way to notify EH&S is by submitting a “Radiation Producing Machine Registration Form”.

The use of diffraction, fluorescent or diagnostic x-ray units must also be approved by the RSC. In order to obtain an x-ray radiation use authorization (xRUA), the PI must submit a “Radiation Producing Machine Registration Form” to EH&S. This form can be obtained online at the EH&S website or by contacting the EH&S office directly.

Further details concerning the use, application, and registration of radiation producing machines can be found in Section 9.1 below.

2.3 Detailed Instructions (Application to Use RAM)

The “Application to Use Radioactive Materials” form is described in further detail below:

Administrative information requested at the top of the application is self explanatory.

A. Training: The RSC wishes to know how much knowledge the applicant has concerning the safe use of radioactive material. Most academic/research institutions require some form of radiation safety training. Please check the items that are most appropriate to your level of training. On the job training implies experience and knowledge passed down from other users of radioactive materials to whom you may have reported to or worked with in the past. Formal training refers to classroom training courses or instruction usually involving some sort of written test.

B. Experience: Further detail the extent of your laboratory work history. Provide the names of institutions where you have worked and what types of radioactive material you have previously used.

C. Staff: List the names of any and all employees that will be working with radioactive materials under your authorization. Each staff member listed, including the PI, will be required to attend a formal safety training class offered by EH&S. Each worker, including the PI, will also need to submit a “Dosimetry Evaluation Form” so that the RSO can determine the need for and type of dosimetry necessary.

D. Location: Provide a brief description and a diagram for all areas where you want to use or store radioactive materials. Highlight or otherwise denote the use areas within a larger laboratory. Describe in detail how the radioactive materials are to be secured from unauthorized access. Questions you should be sure to answer are: How (keys, combination) will the RAM be secured? Who will have access to the keys/combination? Where will they be secured? If other materials are stored in the same freezer, how will access be limited only to the authorized users?

E. Radionuclides to be used: List information concerning each radionuclide to be used. Attach additional pages as needed. The total possession limit is the total amount that will be **allowed in the laboratory** at any one time whereas the activity per experiment is the amount **in use** at any one time. Describe the procedure to the best of your ability. Include how the material will be stored, what chemical and physical forms are involved, how waste will be collected, what shielding will be available for the experiment and the waste containers, etc.

> NOTE: Information concerning typical research radionuclides and procedures has been provided in Appendix A of this manual. Table 1 lists some common radionuclides, sample procedures, limits per experiment, and possession limits that the RSC considers routine. If the radionuclides you are requesting, the procedure, limits per experiment, or total possession limit are not adequate for your needs, please explain in here in Section E.
>
> Table 3 of Appendix A provides general information about the common radionuclides used at TSRI. For each the general physics information, survey instrument requirements, and appropriate shielding is listed.

F. Animal Use: self explanatory

Note: all applications and forms must be signed by the applicant (PI).

2.4 Authorization

Once approved, a copy of the Radiation Use Authorization (RUA) is mailed to the PI. The RUA specifies the following:

- The specific radionuclides allowed.
- How much should be used per experiment.
- The maximum amount that can be in the laboratory(s) at any time.
- Authorized radioactive materials use/storage locations.
- Protective clothing requirements.
- Type(s) of shielding required.
- Radiation dosimetry and bioassays requirements.

The PI named on the RUA is responsible for the use of radioactive materials in the laboratory and must comply with the conditions and requirements of the RUA. The RUA should be posted in the laboratory for reference by all RAM users.

Any changes to the RUA, such as adding new use locations, adding new radionuclides or possession limits, or the addition of new staff must be requested beforehand. Requests for amendment to the RUA can be made by submitting a “Radiation Use Authorization Amendment Request” form. All forms discussed herein can be obtained online at the EH&S website or by contacting EH&S directly.

<u>3.0 ORDERING, TRANSPORTING, AND RECEIVING RAM</u>

3.1 Ordering Radioactive Materials

At TSRI, the laboratory staff is required to contact/purchase radionuclides similarly to any other request for laboratory supplies. Contact the supply company directly. TSRI radioactive materials license number is (#2670-37) and may need to be provided upon ordering. Furthermore, for the timely processing and delivery of radioactive materials packages, it is important that you instruct the supply company to note your RUA number on the packing slip. For example, the attention line should read: "Attn: Dr. Xxxxxxxxx, RUA#0000."

3.2 Radioactive Materials at TSRI

Radionuclide shipments arrive at the TSRI Shipping and Receiving (S&R) department where they will be set aside for EH&S inspection. These radioactive materials packages will be checked for leakage/contamination, excessive exposure rates, and assigned an inventory number by the EH&S staff. The RUA for the recipient will be checked to verify that these radionuclides and amounts are authorized. The omission of pertinent information such as the PI name or RUA number may delay the inspection process.

If a radioactive materials package arrives in your laboratory without an inventory number on it, it has not been inspected by EH&S. Please contact EH&S for instructions if this occurs.

<u>Unauthorized Shipments:</u> If a shipment that is not authorized arrives, it will not be delivered until the RUA has been formally amended either by the RSO or the Radiation Safety Committee. When this happens, the Environmental Health and Safety Department will contact the laboratory and provide options.

<u>Delivery to Laboratory:</u> Once the required safety and inventory checks are performed, the packages are delivered to the laboratories by EH&S or S&R later that same day (typically before 4:00 PM).

3.3 Laboratory Receives Radioactive Materials

Upon receipt of the RAM a laboratory member is required to sign for the material. If no one is present or no one is willing to sign for the material it will be returned to the EH&S processing laboratory. The responsibility falls upon the laboratory staff to obtain this material and ensure that it is stored properly. Upon receipt, the RAM should be stored and secured immediately. Appropriate inventory information shall be documented.

<u>3.3.1 Security</u>
All radioactive materials are to be secured against unauthorized access or under constant surveillance. Any material greater than, or equal to 100uCi must be locked up when not "in use".

3.3.2 Inventory

A complete and accurate inventory must be maintained for each vial. As the material is used, the inventory sheet must be updated. When the vial is empty, discard the vial in the appropriate waste container and indicate on the inventory sheet that the vial has been discarded. Maintain these records for three years. Vials that contain liquid should be poured into the appropriate liquid waste container before being discarded into the dry waste container. Current radionuclide inventories must not exceed the activities authorized on the laboratory's RUA. All authorized investigators are required to maintain an inventory of radioactive materials in their possession.

Sample inventory forms can be obtained online at the EH&S website or by contacting EH&S directly. Radionuclide inventories should at a minimum include the following information:

- Radionuclide.
- Reference (inventory) number.
- Date received.
- Activity received.
- Volume received.

After each time a radionuclide is used, the following information should be added to the inventory records:

- Date used.
- User name.
- Amount of radionuclide used (activity or volume).
- Amount of radionuclide remaining (same units).

Individual laboratory inventories must be combined in order to present an institutional wide inventory. Therefore, each month EH&S sends the RUA holder an inventory based on receipt records. It is the responsibility of the PI to update this form and return it to EH&S.

3.4 Shipping/Transporting RAM

Numerous regulations are involved in the transportation of radioactive materials. Not only do these regulations cover the transportation of RAM between different licensees (from TSRI to another institute or university) but also the internal transfer of RAM within the facility, specifically, whenever RAM is transported across or along public roads. Therefore, it is important that any transfer, transportation, or shipping of radioactive material be approved and coordinated by the Environmental Health and Safety department.

In particular, the following must occur:

- All shipments of RAM to other institutions must be approved and coordinated by EH&S.
- The transfers of radioactive material by motorized vehicles between TSRI facilities must be approved by EH&S.
- The shipping of RAM, whether by personal vehicle or carrier service must be packaged and labeled in accordance with 49 CFR §170-180.
- Inventory records must reflect all (both intra and inter-institution) transfers of radioactive materials.

4.0 SAFE WORK PRACTICES

4.1 PPE

Lab coats, disposable gloves, and safety glasses are required for all work with radioactive materials. Contaminated gloves must be disposed of immediately. Contaminated lab coats must be decontaminated or allowed to decay. Contact EH&S for details.

4.2 Work Areas

If possible, locate the radioactive materials use area away from heavy traffic and entrance ways. This will help minimize disruptions, accidents, and the spread of potential contamination.

Assemble all items necessary for the procedure to avoid delays or leaving hazardous operations unattended.

Expect problems to occur, including spills, and have the appropriate materials close to the work areas (for example extra gloves, absorbent paper (i.e.: paper towels), wipes, plastic bags, a survey meter and decontamination solution). If a spill can be contained immediately, extensive contamination and subsequent decontamination is less likely.

No eating or drinking is allowed in any radioactive materials work area. No eating or drinking is permitted in any laboratory space unless a specific area has been designated as a "Clean Area". A "Clean Area" must be approved by EH&S and must be posted with a sign stating "Clean Area: No Hazardous Materials Permitted."

Bench Tops: Clear ample bench area of unnecessary items and cover with absorbent paper with an impermeable backing. Tape the absorbent material down (absorbent side facing up) and label with "Caution—Radioactive Material" tape. Keep all equipment associated with the use of radioactive materials in this defined area until all manipulations and monitoring for contamination has been completed. At the end of the procedure, the absorbent material should be changed.

Place potentially contaminated equipment; such as pipetters, centrifuges, vial holders, etc.; towards the rear of the bench. Never place pipetters or pipettes used for RAM work on the bench with the tip hanging over the floor.

Hoods: Chemical exhaust hoods are provided throughout the Institute for use with inhalation hazard. Certain RAM compounds fall into this category due to their volatility. Hoods are required in the following instances:

> *Unbound radioiodine* Unbound radioiodine must be used in a specifically designated hood. Never open a vial of unbound radioiodine outside of one of these approved hoods.
>
> NOTE: Iodination procedures must be performed in iodination hoods. Many of these hoods are provided in centralized locations outside of the main laboratories. Consult EH&S to determine the most appropriate "hot lab" for your use. The "hot lab", like any other use location must be listed on your RUA.
>
> *Other volatile RAM compounds* Volatile compounds may present either an inhalation hazard or a potential contamination risk. Procedures involving ^{35}S methionine, some tritiated compounds, phosphorylation nuclides are best performed in a hood and are required in certain cases (for example, >1 mCi ^{35}S methionine). Contact the RSO for details and to discuss options.
>
> *Normally non-volatile RAM compounds* If the material can build up pressure inside the vial during storage or shipment, such as in liquid nitrogen or dry ice storage locations, that container should be opened in a hood.
>
> Whenever working in a fume hood please note the following guidelines:
> - Never remove sashes or alter the hood without EH&S approval.
> - Remove all unnecessary items from the hood to prevent their contamination and to maintain the efficiency of the hood.
> - Keep radioactive materials well inside the sash opening to ensure containment.
> - Never enter the sash opening without wearing a lab coat and gloves. Never place your head inside the hood opening.
> - Avoid using the hood as a storage area; hoods are intended as work areas.

Equipment: Whenever possible, equipment wherein RAM is used (ie: microfuges, pipetters, etc.) or stored should be limited to RAM use only. This equipment must be labeled and surveyed after use. Contamination should be cleaned up immediately.

All radioactive materials must be removed from equipment such as refrigerators, freezers, and centrifuges before equipment may be released from the laboratory's control (for repairs, disposal, etc). The equipment must then be surveyed for contamination by an appropriate method (wipes counted in a liquid scintillation counter (LSC) are preferred) and cleaned as needed. Maintain records of these surveys. It is the laboratory's responsibility to perform these surveys and maintain the appropriate documentation. All radioactive warning labels must be removed, defaced, or otherwise obscured before released for unrestricted access.

4.3 Waste Containers

Place radioactive waste receptacles near the work area so waste can be disposed of as it is generated. A small bench-top waste container may be desirable. A bag hung from the bench is an unacceptable practice because of possible exposure issues and the potential for bag rupture resulting in a spill/contamination requiring clean-up. All waste containers, no matter how small, should be placed in leak-proof containers that can be closed/covered and properly shielded. Large volumes of radioactive liquid, including waste containers, must be placed inside secondary containment that will collect all liquid from the primary container in the event of leakage. Provide shielding to all radioactive waste as appropriate.

4.4 Warning Signs and Symbols

Rooms where radioactive materials are used or stored will be posted with a "Caution—Radioactive Material" sign. Refrigerators, freezers, and other radionuclide storage locations must also be labeled. Potentially contaminated equipment such as centrifuges, hoods, shields, and waste containers are to be labeled as well. Appropriate labels may include "Caution—Radioactive Material" tape, stickers, etc. All radioactive warning labels must be removed, defaced, or otherwise obscured before released for unrestricted access.

Containers must be labeled with a "Caution—Radioactive Material" warning and, if it contains more than 1 μCi, the radionuclide(s) and amount(s).

4.5 Postings

EH&S provides general safety postings for all research laboratories. For those laboratories that use radioactive materials, the postings will also include the following:

RUA -All labs authorized to work with radioactive materials are required to post their Radiation Use Authorization. This document lists who is authorized, what radionuclides are allowed, and where these materials may be used. Furthermore, rules concerning the use of RAM at TSRI are provided on this document for laboratory staff to review.

Notice to Employees - The details of this posting are not provided with this document since it is issued by DHS. This posting is prominently displayed at least once in each main laboratory where radioactive materials are used. It is also posted in various break rooms, common areas, office spaces, campus community bulletin boards, and at entrances to the buildings wherever this seems prudent.

Occupational Radiation Exposure during Pregnancy - All laboratories using radioactive materials are posted with a notice concerning prenatal exposure. The posting reiterates the ALARA principle, by which all radiation use at TSRI is guided, discusses the lower exposure limit for "declared pregnant individuals", defines a "declared pregnant individual", details the need for written notification, and provides contact information.

Title 17 CCR and Radioactive Materials License - This posting details where laws concerning the use of radioactive materials can be found. It notes the actual regulations involved and where a paper copy is kept on campus (the Radiation Safety Office). Furthermore it alerts individuals that a copy of the radioactive materials license, specific radiation safety instructions and operating procedures can also be accessed by employees upon request and where this information is located.

Spills of Radioactive Materials - This posting contains quick access phone numbers to obtain help in the event of a radioactive material spill or emergency and details the level of contamination/spill which needs immediate notification of the RSO. Also contained in this posting are a series of steps to be taken anytime radioactive materials are spilled.

Radiation Rules - This information is posted for each employee to access and is most commonly located directly in the radioactive materials work area as a constant reminder to workers. These rules are detailed below.

General Guidelines for the Safe Use of Radioactive Materials

Storage

- All stock vials and other vials containing greater than 100µCi must be secured when not in use. This is usually accomplished by use of a lock-box secured to the facility/equipment or by storing them in equipment such as a locked refrigerator.
- No food or drink may be stored or consumed in radioactive materials use areas or storage locations.
- Radioactive solutions must be stored in closed, labeled containers. Use secondary containment to prevent contamination.

Use

- The following personal protective equipment must be worn while handling radioactive materials; a lab coat, close-toed shoes, disposable gloves, and safety glasses.
- After each use, monitor your hands, clothing, and work area for contamination. Refer to the radiation safety manual for details.
- NEVER pipette by mouth.
- If dosimeters are issued, wear them at all times while working with radioactive materials. Wear dosimeters on your body where the highest reading would be expected. Whole-body dosimeters should be worn on the trunk of the body above the waist. Finger dosimeters (rings) should be worn with the label toward the radioactive material.

Disposal

- Liquid and solid radioactive waste must be segregated and disposed of in designated receptacles. Refer to the radiation safety manual for details.
- Scintillation vials, well plates, and sharps containing or contaminated with radioactive materials must be segregated from each other and all other wastes.
- Wastes must be segregated by "group" based on the half-life of the material. Refer to section 8.2 for details.
- Lead radionuclide containment vessels (pigs) may be recycled through EH&S. Survey for contamination, if none is found, label as lead waste and EH&S personnel will dispose.
- Always use secondary containment under liquid waste containers to limit contamination.

5.0 EXPOSURES AND DOSE

Personnel who use radioactive material and radiation producing machines at TSRI generally do not require monitoring in accordance with state and federal regulations. These regulations, as stated in 17 CCR and the 10 CFR 20, require monitoring for persons who are likely to receive 10% of the annual dose limit. Historically, the doses received by personnel at TSRI are well below 10% of the annual dose limit and are frequently below recording levels. However, TSRI has set its own criteria for monitoring in order to assess radiation safety practices in accordance with its ALARA policy.

The operating philosophy behind the radiation safety program and TSRI administration is the desire to keep occupational exposures as low as reasonably achievable (ALARA). TSRI has established the policy that any doses exceeding 10% of the regulatory limit will be investigated and corrective actions implemented when possible. All doses above 2% of the regulatory limits will be recorded and monitored for trends.

5.1 Dose Limits

The annual limit is the more limiting of either:

a) The total effective dose equivalent (whole body) being equal to 5 rems (0.05 Sv); or

b) The sum of the deep-dose equivalent and the committed dose equivalent to any individual organ or tissue other than the lens of the eye being equal to 50 rems (0.5 Sv).

The annual limits to the lens of the eye, to the skin, and to the extremities are:

a) An eye dose equivalent limit of 15 rems (0.15 Sv).

b) Shallow dose equivalent of 50 rems (0.5 Sv) to the skin or to any extremity.

c) Radiation dose to a minor (under the age of 18) shall be 10% of the above limits.

5.2 Background Radiation

When discussing radiation dose limits it is important to first discuss background radiation. Naturally occurring radioactive materials and cosmic radiation produce a mean effective radiation dose of approximately 300 mrem to individuals throughout North America. The question often asked is: "Are these levels safe"? Control of radiation dose is based on the assumption that any dose, no matter how small, involves some risk. However, the occupational exposure limits (5 rem per year) are set so low that medical evidence gathered over the past 60 years indicates no clinically observable injuries from radiation exposures will occur among individuals when the established limits are not exceeded.

This was true even for exposures received under the early occupational exposure limits, which were many times higher than present limits. Thus, the risk to individuals at the occupational exposure limits is considered to be very low. However, it is impossible to say that the risk is zero. To decrease the risk still further, TSRI has instituted various policies that are intended to keep actual doses as far below the limits as is reasonably achievable.

5.3 Prenatal Radiation Exposure

Employers of radiation workers shall provide instruction on risks from exposure to radiation. Of special interest is the potential exposure of women workers of child bearing age and risks to the unborn child. Children are more sensitive to radiation than adults. The unborn are generally more sensitive than children, especially during the first trimester. Therefore, the acceptable dose limits are lower than for adults.

The 10 CFR 20, "Standards for Protection Against Radiation", requires that the dose to an embryo/fetus during the entire pregnancy from occupational exposure of a declared pregnant woman does not exceed 500 mrem (5mSv). The 10 CFR 20 also requires the licensee to make efforts to avoid substantial variation above a uniform monthly exposure to a declared pregnant woman that would satisfy the 500 mrem (5mSv) limit.

TSRI adheres to the recommendations of the National Council for Radiation Protection (NCRP) through compliance with the 10 CFR 20. During the gestation period, the maximum permissible dose equivalent to the fetus from exposure to the declared pregnant worker shall not exceed 500 mrem (5mSv).

During initial training of occupational radiation workers, TSRI's policy is presented and the risks are reviewed. It is very important for the worker to disclose her condition confidentially, whether fact or suspicion, at the earliest possible time to ensure that proper action may be taken.

5.3.1 Disclosure Declaration

When the pregnancy has been disclosed by A TSRI employee to the Radiation Safety Officer or supervisor, instruction is provided regarding rights and responsibilities and the option to declare pregnancy or not. A copy of Regulation Guide 8.13, "Potential Health

Risks to Children of Women Who are Exposed to Radiation During Pregnancy" is provided. If the employee declares pregnancy, it must be submitted in writing to the Radiation Safety Officer. The RSO and employee are responsible to ensure the fetus does not receive more than the allowable limits described above. The individual may wish not to declare pregnancy and is then subject to the dose restrictions of all occupational radiation workers. The following facts may aid in the decision to declare pregnancy and assess work conditions:

a) The first trimester of pregnancy is when the fetus is most susceptible to risks from exposure. The decision should be made early.

b) Due to body shielding, the actual dose received by the unborn child will be less than that to the woman in most situations. At TSRI, most occupational exposures are well below the limits recommended for prenatal exposure.

c) The dose to the unborn child can be reduced by decreasing the amount of time spent with radiation, by increasing the distance from the sources and/or shielding the sources from the abdominal area.

d) A pregnant employee may request reassignment to a location where exposure is significantly less or at background levels.

e) When occupational dose is below the 5 rem a year limit the risk to the unborn child is small compared to other day-to-day risks to the unborn. Experts disagree on the exact amount of risk.

f) There is no need to be concerned about sterility (loss of the ability to conceive children). The radiation dose required to produce sterility is more than 100 times greater than the basic dose limit for adults at five rem (50mSv) per year.

<u>5.3.2 Once pregnancy is declared in writing by the worker, the Radiation Safety Office will initiate the following steps:</u>

a) The individual's workload and schedule will be reviewed to evaluate exposures or procedures where the potential exists for radiation exposure.

b) A second dosimeter may be issued in addition to the quarterly whole body dosimeter. The dosimeter will be worn at the abdomen and processed monthly.

c) If the integrated dosimeter reading at the abdomen is greater than 50 mrem during any one month, the workload and procedures will receive a critical review to reduce exposures. When calculated dose to the fetus totals 500 mrem, a transfer to another laboratory or leave is mandatory and the individual shall not use radioactive materials until completion of the gestation period.

5.4 External Dosimetry

Individuals who work with radioactive materials at TSRI in quantities exceeding the amounts in the table below will be issued a whole-body badge and finger ring dosimeter. The determination is perform upon completion of the "Dosimetry Evaluation Form" by the individual wishing to use radioactive material and signed by the PI of the laboratory.

For this Radionuclide	Action level for assigning dosimetry	For this radionuclide	Action level for assigning dosimetry
^{32}P	$\geq$ 1 mCi	**^{131}I**	$\geq$ 0.5 mCi
^{51}Cr	$\geq$ 10 mCi	**^{22}Na**	$\geq$ 1 mCi
^{125}I	$\geq$ 1 mCi	**^{59}Fe**	$\geq$ 0.5 mCi

Dosimeters will not be issued to employees who do not work with radioactive material. Past experience indicates that TSRI employees working with radioactive materials receive average radiation doses insignificant from dose caused by naturally occurring radioactive materials. If the radionuclide is not listed above, the dosimetry requirements will be determined by the RSO based on the estimated potential exposure. Exposure potential is dependent upon the amount of activity handled, how long it is handled, and on the type of radiation emitted and its energy.

Dosimeters provide legal records of radiation dose. Therefore, it is imperative that they only be used as prescribed. They must be worn at all times while working with radionuclides or radiation producing machines. NEVER wear another person's dosimeter. Each dosimeter is assigned to an individual and tracked by the social security number. The EH&S exchanges dosimeters on a quarterly basis. They must be stored in a designated location within the PI's laboratory away from radiation sources and protected against heat, moisture, or contamination.

5.4.1 Lost Dosimetry

Personnel who lose or damage dosimeters will be required to fill out a "Lost Dosimeter Report Form" to properly assess their dose. The report will be forwarded to the responsible department which will be billed for the expense of lost dosimetry.

5.4.2 Positioning

The dosimeter should be worn in the middle of the whole body or as close as practical (see Appendix 1 "whole body"). The finger ring measures extremity dose and shall be worn on the hand most frequently handling radioactive material. The finger ring shall be worn under the glove with the detector facing the palm or inside of hand.

5.4.3 Records and Prior Exposure

The EH&S maintains all dosimetry records for TSRI as required by regulatory agencies and the radioactive materials license. Monitored personnel receive records of their dose history each quarter and an annual report by submitting a signed request to the Radiation Safety Officer.

TSRI employees wishing to use radioactive material are required to complete a "Dosimetry Evaluation Form." Within this form they must indicate locations where previous occupational radiation exposures may have occurred. A letter will be sent to the indicated facilities requesting exposure history with the signed consent of the employee. A reasonable effort will be made to obtain prior lifetime exposure levels.

5.4.4 Verification Level
The TSRI verification level for dose received by an external source and measured by a TLD is 1/50th of the corresponding dose limit. This verification level may appear extremely conservative, however, its selection is commensurate with doses received at TSRI without impacting the laboratory with undue scrutiny while providing reasonable assurance personnel doses are kept ALARA.

5.5 Internal Dosimetry

Bioassays are performed for the assessment of radionuclide intake and deposition in the individual's body, adequacy of radiological controls and determining compliance with occupational dose limits. Bioassay measurements may be made in-vivo or in-vitro depending on the radionuclide. Bioassays should be performed if an individual suspects a potential intake or in the event of an accidental loss of containment with significant activity, if an individual meets routine bioassay requirements, and at the discretion of the Radiation Safety Officer.

5.5.1 Thyroid Bioassays
At TSRI the most common bioassay measurement is for radioactive iodine deposited in the thyroid. A radiation detection probe is placed on the thyroid region of the neck. If measurable activity above background is observed, EH&S can estimate the amount of radioactive iodine present in the body. If an estimate of the time of the original intake can be given, the total amount of radioiodine taken into the body and its dose contribution can be calculated. Non-routine thyroid bioassays are recommended for anyone working with unbound radioiodine. Routine bioassay are mandatory for everyone who works with 10 mCi of unbound radioiodine in any calendar quarter. Call EH&S at 4-8240 to schedule an appointment for your thyroid bioassay.

5.5.2 Bioassays for Tritium
Any individual who introduces into a physical or chemical process at any one time a quantity of tritium that meets or exceeds the quantities listed below must be monitored for internal deposition of tritium. However, prior to use the individual should have a baseline bioassay.

Process Area	Condition A*	Condition B**	Condition C***
Open room or bench top	0.01 Ci	10 Ci	1 mCi/kg
Fume hood	0.1 Ci	100 Ci	10 mCi/kg
Glove box	1 Ci	1000 Ci	100 mCi/kg

*Condition A - HTO and tritiated organics including DNA precursors
**Condition B - Tritium gas in sealed process vessels
***Condition C - HTO mixed with more than 10 kg of inert H_20 or other material
Notes: For declared pregnant workers these values are divided by 10.
For the routine bioassay program the values are multiplied by 10.

5.5.3 Radioactivity Levels for Other Radionuclides Requiring Bioassays
Radionuclides such as ^{32}P, ^{35}S, and ^{14}C historically do not warrant bioassays. An evaluation will be performed during requests for RUAs or RUA amendments. Infrequent use of these radionuclides in significant quantities may require bioassays following initial use to establish effectiveness of controls and compliance with regulatory requirements. These individuals should have a Post-Operational or Confirmatory bioassay at the end of each quarter during infrequent use of significant quantities

5.6 Reducing Exposure to Radiation

It is the policy of TSRI that all necessary provisions will be made to facilitate the safe handling of radionuclides and radiation producing machines, and that all operations will be conducted in such a manner as to maintain exposure As Low As Reasonably Achievable (ALARA).

5.6.1 Controlling External Exposure
There are three general principles for reducing personnel dose from external sources of radiation. These are time, distance and shielding. Typically, more than one of these principles will be applied for reducing dose. Careful evaluation of the anticipated work may dictate which principles will be most effective. For example, shielding will reduce exposure, however excessive shielding may prolong the time an individual spends working with the material resulting in a larger dose. Always bear in mind all three principles when working with radioactive material.

a) Time

Reducing the time you spend handling radioactive materials reduces the dose proportionally. Have your protocol posted or available during the procedure and perform "dry runs" with non-radioactive material during preplanning evaluation of radiation exposure. For all new work, an estimation of radiation dose is a fundamental aspect of good radiation safety practices.

b) Distance

Increasing the distance from the source is frequently the most effective and economical means to reduce radiation exposure from gamma rays and other highly penetrating radiation. The radiation field varies inversely with the square of the distance. For this reason, tongs and other remote handling tools should always be used for manipulating radioactive material emitting significant levels of radiation. Radioactive material should never be handled with the fingers. Low-level sources can be handled with short forceps, which provide a large reduction in exposure when compared with direct skin contact.

c) Shielding

Appropriate shielding of the source may be used in conjunction with time and distance to reduce exposure to levels which are ALARA. Shielding for gamma radiation is accomplished by placing materials of high atomic number and density (Lead) between the source and the area to be shielded.

Beta radiation of significant energy (> 1 MeV) can be shielded by using a solid material such as Lucite™ (acrylic polymer) to absorb the radiation. Beta radiation produces penetrating x rays, called Bremsstrahlung radiation, when it strikes materials of high atomic number. The intensity of Bremsstrahlung radiation varies directly with the square of the energy of the beta radiation and the average atomic number of the shielding material. For this reason, low atomic number materials such as Lucite™ or glass should be used for shielding beta radiation. When working with energetic beta emitters, care must be taken to avoid exposing hands to unshielded material. Dose rates can be on the order of hundreds of rads per minute for commonly used quantities of beta emitters such as ^{32}P. For radioactive materials which emit both beta and gamma radiation, shielding consideration will be determined by the gamma radiation.

5.6.2 Controlling Internal Exposure

Internal deposition of radionuclides is a direct result of mishandling radioactive material. Properly written procedures, evaluation of potential hazards, performing dry runs, and personnel protective clothing all contribute to reducing the potential for dose from internally deposited radionuclides. Time, distance and shielding are not viable methods for protection when the source of radiation is incorporated into the body. The pathways for radioactive material to enter the body are: inhalation, ingestion, injection or absorption through the skin. Potential exposure pathways at TSRI that require safety evaluations are inhalation and ingestion. Absorption, generally observed with tritium, requires its own engineering controls.

Common sense and proper contamination control procedures will prevent ingestion or inhalation of radioactive material in most cases. A common rule for contamination control is “clean to clean” and “hot to hot.” In other words, if you are wearing gloves to prevent your hands from being contaminated, only touch those items which are likely to be contaminated or may be contaminated. Only touch clean items if you have verified with an instrument that your gloves are clean.

6.0 SURVEYS

6.1 Laboratory Surveys

Because most laboratory survey instruments (Geiger Muller tubes and scintillation probes) only indicate the presence of ionizing radiation in count rates, the interpretation of the instrument's indicated response to actual exposure or dose rates is rather complicated. The response from these types of instruments depends on instrument type and the energy of the radiation. More information concerning the response of a typical survey instrument (GM counter with a five cm diameter window) is provided in the Appendix A Table 2.

Frequency: Radiation workers are required to survey themselves and the work area after every use of radioactive materials. This survey should include the general work area, equipment used, lab coats, personnel (skin and clothes), and other objects that may have been touch while working with RAM such as phones, chairs, notebooks, etc. See Appendix A, Table 3 for a list of the acceptable survey methods for monitoring for common radionuclides.

Definition of Contamination: Since background radiation causes a meter response, it is difficult to determine “what is contamination”. A guideline often used is “twice the background reading”. Therefore, a background reading should be taken with the survey instrument and any reading above twice this level should be considered contaminated. Any such contamination must be noted in the survey log, cleaned up, and resurveyed. Once survey readings indicate that contamination is no longer present these readings should be noted in the log as well.

The radioactive materials license defines contamination as 200 disintegrations per minute of removable radioactivity in a 100 square centimeter area. The only way to tell if the activity is removable is to take wipes.

Documentation: Document all surveys performed. There must be documentation of at least one contamination survey every day that radioactive materials are used in a particular area.

Daily survey documentation must have as a minimum the following:

- Description of area surveyed.
- Survey instrument (make, model).
- Background reading (i.e., cpm, cps).
- Results (i.e., 2000 cpm or 33 cps). Remember to document all positive contamination readings before clean-up as well as results after decontamination.
- Name/initials of the person doing the survey.

6.2 Calibration of Instruments

All portable radiation detection instruments must be calibrated on an annual basis and after any major repair work is performed. EH&S can provide this calibration service but does not have the resources to make major repairs. Contact EH&S to arrange for survey meter calibration. Typical turnaround time is one week. It is the individual investigator's responsibility to assure that all of the survey meters are calibrated and properly maintained. If a meter is sent off-site for service or calibration, please send a copy of the calibration certificate to the EH&S office.

6.3 EH&S Confirmatory Surveys

Routinely, but no less frequently than monthly, the EH&S staff will do a wipe and meter survey in areas where radioactive materials are known to be in use. This survey is not intended to determine if the area is free of contamination or is "safe," but to evaluate if the contamination control and monitoring that is being done by the laboratory staff is adequate. If EH&S finds contamination, the laboratory staff is notified. The staff is then required to do more extensive surveys, clean-up, and decontamination. The EH&S technician will return to recheck the contaminated areas after the laboratory has been given time to do the decontamination.

7.0 DECONTAMINATION AND EMERGENCIES

7.1 Contamination

All equipment must be free from radioactive contamination before it is released for unrestricted access. This means that equipment previously used with radioactive materials must be surveyed and confirmed “clean” before it can be removed from the laboratory for repair, disposal, or transfer to another laboratory. It is the laboratory’s responsibility to perform and document these surveys. If assistance is needed, contact EH&S. As stated above for laboratory surveys, contamination is defined as 200 dpm of removable contamination in a 100 square centimeter area as determined by wipe test survey.

Contact EHS& for any contamination that cannot be clean-up to acceptable levels. Any contamination of personnel must be reported to the RSO.

7.2 Spills

All spills involving greater than 1 mCi of radioactivity are to be reported to the RSO immediately. A spill that involves large volumes of radioactive material or the contamination of large areas is also to be reported to EH&S. Furthermore, the radiation safety office suggests that any spill that cannot be easily and immediately cleaned-up be reported. Although it is ultimately the responsibility of the laboratory staff to clean up spills involving RAM, the EH&S staff is available for assistance and guidance.

Any spill that involves the contamination of individuals must be reported to the RSO.

As detailed in the “spills of radioactive materials” emergency posting, the following steps are recommended for any spill of RAM:

- Never delay life saving first aid if needed.
- Contain the spill
- Evacuate the immediate area, consider evacuating the entire laboratory if there is an airborne hazard.

- Prohibit individuals from walking through the spill area.
- Potentially contaminated individuals must be surveyed. If contamination is found, do not allow them to leave the immediate area.
- Notify laboratory staff and EH&S as needed. Request aid as needed. The emergency number x77 may be used even after hours or on weekends.
- Perform decontamination steps and principles (see below).
- Perform a post clean-up survey and report the incident as appropriate.

7.3 Clean-up Procedures

Depending on the extent of the contamination, the physical materials contaminated, and the RAM involved adjustment of the following guidelines may be needed. Proceed conservatively and request assistance as needed.

Work Surfaces (bench tops, fume hoods, floors, etc.): Survey the area to determine the extent of the contamination. Post the contaminated areas with warning tape, signs, or other markings. Assemble the necessary cleanup supplies (gloves, decontamination solution, paper towels, additional survey meters, plastic bags for waste disposal, and other PPE.). Wearing lab coat and double gloves, begin at the outer edges of the contaminated area and work towards the center. All supplies used on the spill must be treated as radioactive waste. Call EH&S if your efforts are unsuccessful.

Equipment: Equipment such as centrifuges or refrigerators often need to be sent out for repairs or defrosting or disposal. As stated above, it is the laboratory's responsibility to ensure that the equipment is "clean" before releasing this equipment to individuals not listed on your RUA. The following steps should be taken.

Survey the equipment to determine the presence and extent of the contamination. It may be necessary to take apart the equipment to ensure that internal surfaces are not contaminated. Wearing lab coat and double gloves, clean all contaminated surfaces. All supplies used on the spill must be treated as radioactive waste. If the equipment is uncontaminated or has been cleaned appropriately, remove or deface any radioactive materials warnings such as stickers or tape. Call EH&S if your decontamination efforts are unsuccessful.

7.4 Contamination of Personnel

If radioactive contamination is found on clothing, remove the contaminated items. If radioactive contamination is found on the skin, note the reading on the survey meter, gently wash with soap and warm water. Resurvey to determine the success of clean-up efforts. Repeat washing as necessary. Use only detergents intended for use on skin. Do not scrub with a brush or other abrasive material. Contact EH&S if decontamination efforts are not successful.

A drop of contamination containing 1 microcurie of ^{32}P on 1 cm^2 area of skin produces an dose rate of 2,000 mrem/hr (2 rem/hr) or 33 mrem/min.

7.5 EH&S Emergency Response

If you have any emergency issues concerning the use of radioactive materials, dial x77 from any campus phone. Tell the Security Officer that a radioactive materials spill has occurred and you need assistance from the Environmental Health and Safety staff. Stay on the line and they will contact EH&S. Two members of the EH&S office are "on-call" at all times including nights and weekends.

8.0 WASTE DISPOSAL

Radioactive waste is very expensive to dispose. However, some things can be done to help alleviate the costs. First, reduce the amounts used. Second, use short-lived radionuclides whenever practical. These can be decayed on site and disposed of as regular trash when no longer radioactive. Third, do not combine different wastes.

Radioactive wastes, depending on the physical form or make-up, are processed differently. The most difficult and expensive wastes to dispose of are called "mixed wastes" containing radioactive wastes commingled with hazardous chemicals or biohazardous wastes. Whenever possible, limit the creation of these problematic mixed wastes. Contact EH&S if you think you will be creating a mixed waste so that options can be discussed.

Radioactive wastes must be segregated by both physical form and radiological half-life as described below.

8.1 Segregation by Physical Form

8.1.1 Liquids

Liquid waste must not contain any solid objects such as tips or filter papers. Do not mix aqueous and organic-based solutions. This produces a "mixed-waste" which can be difficult to dispose of properly. Eight-liter plastic containers are provided by EH&S for the collection or radioactive liquids. If this is not convenient for your lab please contact EH&S for more options. Waste containers must be capped when not immediately "in-use" and stored within secondary containers at all times.

Liquid scintillation vials are a common enough waste that they are collected without needing to be poured into a liquid waste container. Collection boxes lined with double plastic liners can be obtained from EH&S. Do not empty the individual vials. Only vials with scintillation cocktail may be placed in these containers. **NO** plastic bags, vial flats, test tubes, Ependorf tubes, or any other waste may be placed in these containers. If odors are a problem, a 30-gallon drum may be used to help reduce exposure. The new "environmentally benign" cocktails are usually much less of an odor problem and are not classified as flammable liquids. Contact EH&S if you would like to discuss these options.

8.1.2 Solids (Dry Wastes)

"Dry" or "solid" wastes include paper, plastic, unbroken glass (no Pasteur pipettes), and gels. Items such as absorbent pads, disposable gloves, source vials, and plastic pipette tips can be disposed of in a "dry waste" container. No pourable liquids are allowed in dry waste containers. Tubes, bottles, and vials must be emptied of their contents before being placed in the dry waste container. Lead (in containment vessels or shields) is a hazardous material and as such must not be placed into a dry waste container (see Section 8.1.3 "mixed waste".) Serological pipettes are considered dry waste for the purposes of RAM disposal. EH&S supplies two cubic foot cardboard boxes with plastic liners for the purpose of dry waste collection.

Radioactive sharps are any objects that might puncture human skin such as Pasteur pipettes, needles, broken glass, razor blades, etc. These materials must be placed in puncture-resistant, leak-proof containers. EH&S provides one-gallon plastic jars for the collection of radioactive sharps. Never use a biological sharps container to collect radioactive sharps to avoid confusion.

Contaminated *animal carcasses and cage bedding* must be collected and stored in a freezer until they can be picked up by EH&S. They must be contained in plastic bags (preferably zip-lock) and labeled appropriately. If the carcass contains both infectious agent(s) and radioactive materials, contact EH&S.

8.1.3 Mixed Wastes

Mixed wastes are wastes that meet the legal definitions of both hazardous (based on chemical properties) and radioactive material and can be very difficult if not impossible to dispose. Avoid the generation of mixed wastes that contain long-lived radionuclides (half-lives >90 days). Liquid scintillation fluid containing radionuclides can be disposed. A common solid waste is contaminated lead in the form of shields or lead containment "pigs". Collect these wastes separate from all other wastes. If uncontaminated they will be recycled.

Radioactive, infectious waste must be rendered noninfectious before EH&S can pick up the waste. Special autoclave bags are available for handling this type of waste. Common disinfectants such as bleach may be sufficient for this purpose. Call EH&S for instructions on how to handle infectious, radioactive waste.

8.2 Segregation by Radioactive Half Life

Along with the physical segregations discussed above, each radionuclide should be collected separately. This is required because short lived nuclides such as ^{32}P can be "held for decay in storage". This means that the waste can be kept in a storage area, resurveyed after a set period of time, and if no radioactivity can be detected it can be disposed of as regular trash. Since there is a great deal of documentation involved laboratories are not allowed to dispose of wastes in this manner however wastes collected by EH&S that are legally disposable by this method will be.

Since only some radionuclides can be "decayed" for disposal purposes, and those that can decay at differing rates, it is important that laboratories properly segregate their wastes. In order to limit the waste groups to a manageable level the following five categories have been defined.

Group 1	Half-lives of 15 days or less.
Group 2	Half-lives between 15 and 65 days.
Group 3	Half-lives between 65 and 90 days.
Group 4	All others not listed except ^{3}H and ^{14}C.
Group 5	^{3}H and ^{14}C.

Radionuclides that fall into the same category can be stored together however most labs are unlikely to have many radionuclides in the same group.

8.3 Labeling

All radioactive wastes must be labeled with a completed radioactive waste tag. The waste container will also be labeled with a "Caution—Radioactive Materials" sticker and a radioactive Group label that contains a list of radionuclides that can be disposed of in the container.

8.4 Removal from the Laboratory and Obtaining Supplies

When the waste container is approximately ¾ full, close the container/bag, call the waste collection voicemail (4-4093) and leave a message with the information requested. EH&S will collect the waste directly from the laboratory. You can also leave a message on the waste line when you need the following supplies:

- Radioactive sharps container (one-gallon plastic jars)
- Radioactive waste collection boxes (two cubic feet)
- Radioactive waste collection box liners (large plastic bags)
- Radioactive liquid waste container (eight liter)
- Radioactive waste tags and/or group labels

Currently, wastes are picked up on the main (Torrey Pines Road) campus on Monday, Wednesday, and Friday. Waste is picked up from all other buildings on Tuesday.

9.0 MISCELLANEOUS

9.1 Radiation Producing Machines

A radiation-producing machine is any high-voltage device that can produce high-energy charged particles and therefore, photons (x-rays) or neutrons. The term includes x-ray machines used in diffraction and fluorescence analysis, electron microscopes, and cyclotrons or other particle accelerators. Devices such as televisions and video display terminals are excluded since they do not produce significant radiation.

9.1.1 Application

Radiation-producing machines must be registered with the CDPH within 30 days of their acquisition. EH&S can perform these registration functions if notified via a "Radiation Producing Machine Registration Form".

Self-contained machines such as cabinet x-ray units and electron microscopes need no other response.

Open beam machines such as x-ray diffraction/crystallography units and diagnostic/medical x-ray machines have additional requirements. The way in which TSRI ensures that all additional requirements are being met is to issue authorizations similar to the RUAs discussed above. When a "Radiation Producing Machine Registration Form" is submitted for these open beam units it will be forwarded to the RSC. Once authorized, an xRUA will be sent to the PI.

9.1.2 Training

All employees working with x-ray diffraction units are required to take the computer-based safety training available via the EH&S website. At the end of the training is a test which must be taken and passed before an individual is added to the authorized list of users. All employees are required to retake this training and test annually.

If an employee takes this training at any time other than during the initial application, the xRUA will be updated to confirm the addition of the new user and a copy of the amended xRUA is sent to the laboratory.

9.1.3 Emergency Procedures

Emergency procedures are printed on the xRUA which must be posted in the immediate area of the machine. These emergency procedures are also summarized here:

- Turn off the Machine.
- Call the Emergency Line "77".
- Call the Principal Investigator.
- If an exposure to x-rays has occurred, record all important parameters such as kV-peak, mA, nature and duration of the exposure, and approximate distance from the source.

When dealing with x-ray diffraction units, the most common potential accident is the inadvertent exposure of the extremities while aligning the crystal. Extreme caution should be taken to ensure that the beam shutter is closed during this process.

9.1.4 Dosimetry

It has been shown that typical dosimetry is not efficient for detecting exposures from x-ray diffraction units. Self contained machines have built in safe guards that prohibit exposures to employees. Only the medical/veterinary x-ray machine users are currently required to wear dosimetry.

9.1.5 Responsibility
The P.I. must ensure that the project described on the registration form is carried out within the parameters of the application and the specific operation and use requirements stated in the rules and regulations of the governmental agencies and the Radiation Safety Committee.

9.2 Irradiators

Irradiators are not technically radiation producing machines in that the radiation derives not from a flow of electricity but from a sealed radioactive source usually of very large activity. These machines are commonly used for irradiating blood or other laboratory samples. Due to the high radiation levels involved, access and use of these machines is strictly controlled. Special training, access cards or codes, and a background check are required before use is allowed. In order to start the process of becoming authorized to use this equipment contact the Human Resources department.

9.3 Animal Use

As discussed above in the authorization application section (Section 2.2.1), the use of research animals is strictly regulated. Contact the IACUC for details on animal protocol applications. An “Application to Use Radioactive Materials in Animals” must also be submitted to the RSC. This form can be obtained online at the EH&S website or by contacting EH&S directly.

9.4 Regulatory Information and Oversight

For more information regarding rules, regulations, safe work practices and guidance concerning the use of radioactive materials, the following agencies and documents may be informative.

9.4.1 Federal Regulation of Radioactive Materials
The Nuclear Regulatory Commission is responsible for assuring that the use of radioactive materials in the United States does not endanger the public. The most pertinent regulations can be found in 10CFR §20.

9.4.2 State of California
By agreement, the State Department of Public Health, Radiologic Health Branch acts as the de facto “NRC” for the State of California. Regulations pertaining to radioactive materials can be found in Title 17 CCR starting with section 30100.

9.4.3 TSRI Site Specific License Agreements
The TSRI Radioactive Materials License, issued by the Department of Public Health, stipulates who, what, where, why, and how radioactive materials may be used. The TSRI license is a broad-scope research and development license (#2670-37) that does not allow the use of radioactive materials in or on humans. The license does allow the Radiation

Safety Committee to approve individual investigators who have demonstrated that they have adequate facilities and equipment as well as the necessary training and experience to be responsible for the safe use of radioactive materials in their laboratories.

10.0 "HOW DO I…" (FAQS)

A list of frequently asked questions is provided below. The shortest answer to any of these questions is that information is available from the EH&S department. As a support department, the employees of EH&S and in particular the radiation safety staff are available to provide answers to your questions by phone at extension 4-8240.

10.1 How do I obtain, amend, or terminate a Radiation Use Authorization?

- To apply for a RUA follow the instructions in Section 2.3 of this manual. The "Application to Use Radioactive Materials" can be found on line or by contacting EH&S at x4-8240.
- To amend a current authorization, submit an "RUA Amendment Request".
- To terminate a license contact the RSO directly.

All forms are to be submitted to the RSC via the EH&S office. Mail or Fax your forms to EH&S at mail code TPC-27 or x4-8490 respectively.

10.2 How do I obtain application/amendment forms?

Any of the forms referenced in this manual may be found on the EH&S website accessible through the TSRI intranet. EH&S is currently listed under "Research Services". Forms may also be obtained by contacting the EH&S department by phone or fax.

10.3 How do I get trained to work with RAM?

The radiation safety class is currently offered on the first and third Monday afternoons of each month unless a holiday falls on the day in question. The training is presented at 1:00 in the Molecular Biology Building Committee Lecture Hall (2^{nd} floor conference room #220). After the presentation you must complete and pass a written test. Furthermore, non-formal training should be obtained in the laboratory.

If you wish to work with an x-ray diffraction/crystallography unit you must access the on-line training available via the EH&S website. After completing the training you must download a copy of the test and submit it to the EH&S office.

To work with one of the campus irradiators, you will need to be given hands on training for the specific machine. Contact EH&S for details.

10.4 How do I obtain information concerning the risks associated with using radioactive materials or radiation producing machines while pregnant?

There is a posting in each laboratory which provides general information regarding prenatal radiation exposures. As with any major change in health status, it is a good idea to contact the EH&S office and schedule a time to discuss your concerns. In order to enact the lower exposure limit deemed appropriate for pregnant individuals it is necessary for you to “declare” your pregnancy to the EH&S office in writing.

This information will be kept confidential.

10.5 I received a package without an inventory number/tag? What should I do?

Occasionally, a package containing radioactive materials may arrive at your laboratory directly. This infrequently occurs for items such as RIA kits. If this happens you should realize that it hasn’t been seen by the EH&S inspection staff. Although this is a minor issue in most cases, you should do one of the following: 1) contact our office to have the package inspected and entered into the TSRI inventory system, or 2) check the package yourself for any potential leaks of the radionuclide. If everything is in order, all you need to do is send a copy of the packing slip to our office so that the information can be added to the TSRI inventory system.

10.6 How do I perform a proper contamination survey?

Information concerning “when” and “where” surveys are to be performed can be found in Section 6 of this manual. Here are a few helpful tips concerning the “how”. When performing a survey using a hand held portable instrument the following steps should be taken:

1. Select an appropriate meter for the radionuclide being used (see Appendix A).
2. Check the calibration date. If over one year old the meter should not be used.
3. Turn the meter on and perform a battery check. You can’t find contamination if the meter doesn’t work.
4. Start at the lowest scale since all you want to do is find contamination not quantify it.
5. Take and record a background reading.
6. Remove the protective cap if it has one. The cap can shield out radiation.
7. Leave the audio on if available so that you can listen for a change in the count rate while you look at the surfaces where you are surveying.
8. Place the probe/detector close to the surface but do not let the probe touch the contaminated objects.
9. Move the probe slowly (~2 inches per second) over any objects/areas which may have become contaminated
10. If greater than twice the background reading, the area should be cleaned and resurveyed.
11. Document the survey when you are finished. Include before and after clean-up readings.
12. Turn the meter off to save battery power.

When performing a <u>wipe test (LSC)</u> survey for removable contamination the following steps should be taken:

1. While wearing appropriate PPE such as gloves and a lab coat take a piece of filter paper or an LSC wipe and rub it against the surfaces (bench top, floor, equipment, etc. that you wish to survey for contamination.
2. Place the wipe into a scintillation vial.
3. Add scintillation fluid no more than two-thirds of the way up the vial. You may need much less. Consult your LSC user manual for more details.
4. Cap the vial, place it into an LSC rack and run the program. Again, you may want to consult the LSC manual or contact us directly for information on setting up user programs on an LSC.
5. The wipe result should be compared to some background level either preprogrammed into the LSC or by placing a "blank" wipe vial in the counting rack as well.
6. If the results are greater then 200 dpm (make sure the printout is giving you dpm) above background then the area that was wiped is contaminated and clean-up must commence.
7. Resurvey as needed until no contamination can be found.

10.7 How do I get a <u>bioassay</u> performed?

Two types of bioassays are provided by the EH&S department. The most common one is call a "thyroid bioassay" and can detect radioiodine that has been taken into the body by measuring the radiation as it leaves the body. This is a painless, non-intrusive procedure that requires only that we place a detector near the throat (thyroid gland) for one minute and measure the radiation emissions. Anyone working with 10 mCi or more of unbound radioiodine is required to visit our office for this test within 72 hours of the procedure. It can also be performed on an as-needed basis. Contact EH&S for details if you are concerned about a potential exposure.

The other type of bioassay performed in-house is urinalysis. Anyone working with 100 mCi or more of a beta emitting radionuclide should submit a urine sample for analysis. This is rarely necessary but can also be performed on an as-needed basis if an accidental exposure is thought to have occurred.

10.8 How do I get a <u>dosimeter?</u>

All RAM users are required to fill out a "Dosimetry Evaluation Form" before they are authorized for use. Based upon the information provided, dosimetry will be provided on an as needed basis. If you have recently increased your RAM use you may submit a new "Dosimetry Evaluation Form" for review by the RSO. If you would like more information concerning who does and does not need dosimetry contact the RSO.

10.9 How do I get a replacement if I lost my dosimeter?

Contact EH&S at x4-8240 and request a replacement. If your radiation dosimetry is lost or damaged, contact the RSO immediately before continuing work with radiation. A replacement dosimeter will be issued and you will be asked to fill out a form regarding your use of radiation since the lost dosimeter was issued. Your dosimetry record is a permanent legal record of your radiation dose history. It is important for you to keep your record as accurate as possible by reporting lost or damaged dosimetry promptly.

10.10 How can I find out more about the radionuclides I'm working with?

The appendices attached to this manual have a great deal of information specific to the common radionuclides used here at TSRI. If you cannot find what you are looking for please contact the RSO.

10.11 How can I figure out how much a radionuclide has decayed?

In the glossary section of this manual under the definition of "radioactive decay", the simple decay equation is provided. Knowing the initial amount of the material and the amount of time since this initial amount was present, the current activity can be calculated using this equation and by looking up the half-life of the radionuclide. Half-lives and other physical factors concerning commonly used radionuclides can be found in the Appendices of this manual.

10.12 How do I convert cpm to dpm or µCi (microcuries)?

Understand first that cpm (counts per minute) is not an activity, it is simply a count rate. In order to convert from cpm to dpm (desintegrations per minute) you need to know the efficiency of the instrument being used. For LSC counting this can be found by running a known sample such as a calibration source. For a hand held instrument this may be more difficult. Estimates are provided below. The equation used to calculate this activity is given here:

$$dpm = \frac{cpm}{eff}$$

Once the dpm is know it can be converted to becquerrels (Bq=dps) or Curies. Some common conversion rates are given here.

There are 2.2×10^6 dpm in one µCi
There are 37×10^{10} Bq in one Ci
There are 1,000,000 µCi in one Ci

The value obtained is the activity (or estimated activity) of the sample.

10.13 How do I calculate the activity in my waste container?

Actually, you don't. The best way to estimate the activity in a waste container is to keep track of the individual amounts as they are added to the container. If you keep records of what is used in a given experiment you should have a good idea what you are disposing. EH&S supplies waste tags which can be used to log in the waste. Some labs use there own tracking system or log sheets to keep track of their waste totals. Either is acceptable.

10.14 How do I get my radioactive waste disposed?

A voicemail has been set-up at x4-4093. Call this phone number and leave a message including the information requested. In general, the information needed is a description of what waste needs to be picked up, where it is located, and who should be contacted when the technician arrives in the laboratory. This voicemail can also be used to request some supplies such as waste tags, group labels, or additional containers.

Waste pick-ups are performed on the main campus (BCC, IMM, MB, and SR), Monday Wednesday and Friday. Pick-ups at offsite buildings occur on Tuesday.

11. ACRONYMS AND DEFINITIONS

10 CFR §20

Refers to the Code of Federal Regulations, Title 10, Part 20, "Standards for Protection Against Radiation."

17 CCR

Title 17 of the California Code of Regulations. This section of the CCR contains most of the applicable radiation safety regulations for work here at TSRI.

Absorbed Dose

The energy imparted by ionizing radiation per unit mass of irradiated material. The units of absorbed dose are the international unit gray (Gy) or the rad.

Quantity	Name	Symbol	Units	Conversions
Absorbed Dose	gray *rad (old unit)*	Gy *rad*	J Kg^{-1} *100 ergs* $gram^{-1}$	1 Gy = 100 rads 1 cGy = 1 rad

Activity

The rate of disintegration per second (dps), minute (dpm) or decay of radioactive material. The units of activity are the international unit Becquerel (Bq) or the Curie (Ci).

Quantity	Name	Symbol	Unit	Conversions
Activity	becquerel *curie (old unit)*	Bq *Ci*	dps 3.7×10^{10} *Bq*	1 Ci = 3.7×10^{10} Bq

Sub units of the curie are:

millicurie (mCi) = 3.7×10^{7} dps
microcurie(µCi) = 3.7×10^{4} dps
nanocurie (nCi) = 3.7×10^{1} dps
picocurie (pCi) = 3.7×10^{-2} dps

ALARA

Acronym for **A**s **L**ow **A**s **R**easonably **A**chievable. Making every reasonable effort to maintain exposures to radiation as far below the dose limits as practical and 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.

Alpha Particle

Are doubly charged helium nuclei. Alpha-emitting radionuclides are common in nature and include uranium, radium and thorium. From a radiation safety perspective, alpha particles are not an external hazard because they are unable to penetrate the outer layer of skin. Internal deposition of alpha emitters can present a serious radiation hazard.

Becquerel (Bq)

Special name for the SI unit of activity of a radionuclide. One Bq equals one disintegration per second.

Beta Particle

Electrons that are emitted from the nucleus during the transformation of a neutron to a proton. Low-energy beta particles (less than 0.2 MeV) are absorbed in the outer layer of skin and present only a slight external hazard.

Bioassay

The determination of 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

Photons emitted when charged particles, such as beta radiation, decelerate or change direction when passing through matter. The energy of the bremsstrahlung photons depends on the kinetic energy of the incident particle and the density of the absorbing material. High-energy beta particles such as those from ^{32}P can produce a significant amount of bremsstrahlung radiation. To prevent this, low-density material such as plastic is used as a primary shield to protect from the beta particles, and an outer layer of lead foil may be used to absorb the bremsstrahlung photons produced in the primary shield.

Caution—Radioactive Materials

This is the lowest level of radiation posting. It indicates only that radioactive materials may be present and/or used in this space. It does not indicate an exposure hazard. The next lowest posting is the **Caution—Radiation Area** which indicates exposures are possible in amounts that could reach the annual exposure limit if occupied 40 hours a week 50 weeks a year. See "radiation area" for more details.

Contamination

Deposition of radioactive material in any place where it is not desired. The TSRI Radioactive Materials License defines it as any removable radioactivity greater than 200dpm in a 100 cm^2 area.

Curie (Ci)

Unit of radioactivity defined as the quantity of any radionuclide in which the number of disintegrations per second is 3.7×10^{10}.

Diffraction X-ray System

An x-ray system designed for routine analytical work. The primary beam from the target of the x-ray tube emerges from the machine through a collimator and strikes the sample, which diffracts in a characteristic manner. The diffraction pattern is measured with a photographic film or a radiation detector.

Decay (see radioactive decay)

Declared Pregnant Worker

A woman who has voluntarily informed her employer, in writing, of her pregnancy and the estimated date of conception for the purpose of monitoring the radiation dose to the fetus.

Deep Dose Equivalent (DDE)

External whole body exposure that is the dose equivalent at a tissue depth of 1 centimeter (1,000 mg/cm^2).

DHS is now CDPH

California Department of Public Health, the state's licensing and regulatory agency.

Dose Equivalent

The product of the absorbed dose in tissue, quality factor (i.e. rad × Q = rem) or organ dose weighting factors (i.e. Gy × w_T = Sv) and all the necessary modifying factors at the location of interest. The units of dose equivalent are the international unit sievert (Sv) or the rem.

Quantity	Name	Symbol	Unit	Conversions
Dose Equivalent	Sievert *rem (old unit)*	Sv *rem*	$J\ Kg^{-1}$ 10^{-2} *Sv*	100 rem = 1 Sv 1 rem = 1 cSv

EH&S

Environmental Health and Safety

Exposure

A measure of the ionization produced in air by x or gamma radiation. The sum of electric charges on all ions of one sign produced in air when all electrons liberated by photons in a volume of air are completely stopped in air, divided by the mass of the air in the volume. The units of exposure in air are the international unit coulomb per kilogram or the roentgen.

eV

Electron volt. This is the unit used to specify the energy of ionizing radiation and is the energy acquired by an electron in moving freely through a potential difference of one volt. Another common unit is the keV which is equal to 1000eV.

Eye Dose Equivalent (LDE)

External exposure of the lens of the eye that is the dose equivalent at a tissue depth of 0.3 centimeters (300 mg/cm^2).

Gamma and X-Ray Radiation

Electromagnetic radiation. They have no mass or charge. This gives them the ability to penetrate matter more easily than charged particles. The penetrating ability of electromagnetic radiation makes them a potential hazard whether they are internal or external to the body. The range of an X or gamma ray in any material depends on the ray's energy and the density of the absorbing material. In designing shielding for photons, the concept of **half value layer (HVL)** is often used. The HVL is defined as the thickness of a particular material that will reduce the intensity of an X or gamma ray field by a factor of two.

X and gamma rays have identical properties. The difference is the manner in which they are produced. X-rays are emitted by orbital electrons when they undergo transition to lower energy orbits. Gamma rays are emitted by the nucleus of an atom when it drops from one energy level to a lower (usually following charged particle emission).

Gray (Gy)

Special name for the SI unit of absorbed dose, kerma and specific energy imparted. One gray equals one joule per kilogram or 100 rad.

Half-Life, Radioactive

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

High Radiation Area

Any area accessible to individuals that radiation exists at levels such that an individual could receive, in any one hour, a dose equivalent in excess of 100 millirem (1.0 millisievert) at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

Ionizing Radiation

Any electromagnetic or particulate radiation capable of producing ions directly or indirectly in its passage through matter. In general, refers to gamma rays and x-rays, alpha and beta particles, neutrons, protons, high speed electrons and other nuclear particles. Ionizing radiation does not include radiowaves or visible, infrared or ultra-violet light (i.e., non-ionizing radiation).

LSC

Liquid scintillation counter.

NRC

The Nuclear Regulatory Commission (NRC) is the primary federal agency charged with regulating the use of by-product radioactive and special nuclear materials.

Occupational Dose

Occupational dose means the dose received by an employee:

1. In a restricted area or controlled area or;
2. In the course of employment, education, training or other activities that involved exposure to ionizing radiation.

Personnel Dosimetry

Devices that measure the cumulative dose of radiation to an individual. Types of dosimetry include film badges, thermoluminescent dosimeters (TLD), finger rings, and albedo-type for neutron measurements.

Radiation

The emission of energy in the form of particles or photons. Radiation that is capable of directly or indirectly producing ions in matter is referred to as ionizing radiation. Some of the major classes of ionizing radiation are discussed below.

Radiation Absorbed Dose (rad)

The unit of absorbed dose. A dose of one rad means the absorption of 100 ergs of radiation energy per gram, or 0.01 joules per kilogram of absorbing material (cf. SI unit - gray).

Radiation Area

An area accessible to individuals in which radiation exists at such levels that an individual could receive, in any one hour, a dose equivalent to the whole body in excess of 5 mrem (0.05 millisievert) at 30 centimeters from the radiation source or from any surface that the radiation penetrates.

Radiation Producing Machine

Any device capable of producing ionizing radiation when the associated control devices are operated, excluding devices that produce radiation only by use of radioactive materials.

Radiation Safety Committee (RSC)

A committee consisting of TSRI faculty and staff which sets policy regarding use of radioactive material at TSRI consistent with the radioactive materials license.

Radiation Safety Officer (RSO)

The Radiation Safety Officer is responsible for operation of the radiation safety program and assuring that use of ionizing radiation is in conformance with University policies and applicable regulations.

Radiation Use Authorization (RUA)

An authorization issued by the Radiation Safety Committee to conduct specific research using specific radionuclides or ionizing radiation producing machines.

Radioactive Decay

The process by which an excited atom gives off radiation to become more stable. The simple decay equation listed below can be used to calculate the activity of a sample if the other variables are know.

The amount of radioactive material remaining after a period of time is calculated by the equation:

$$A = A_0 e^{\frac{-(\ln 2)(t)}{t_{1/2}}}$$

Where:

A =activity remaining
A_o =initial activity
$t_{1/2}$ =half-life
t =elapsed time in same units as half-life
e =the base of natural logarithms

Radioactive Materials

Any material, solid, liquid or gas that emits ionizing radiation spontaneously.

Radiological Safety Index (RSI)

Each RUA is assigned an RSI to determine the radiological risks associated with each **approved radionuclide, its quantities and the intended use.**

RAM (see radioactive material)

Restricted Area

An area with access limited by radiation safety to protect individuals from undue risk from exposure to radiation and radioactive material. Any radiation area, high radiation area or airborne radioactivity area shall be considered a restricted area.

Roentgen (R)

A unit of exposure to ionizing radiation. The amount of gamma rays or x-rays required to produce ions carrying 1 electrostatic unit of electrical charge in 1 cubic centimeter of dry air under standard conditions. See "Exposure."

> *NOTE: Ion chamber meter readings of beta emitters must be regarded as approximate, since the roentgen, by definition, is a measure only of X or gamma radiation.

Roentgen Equivalent Man (rem)

The unit used to express human dose equivalence as a result of exposure to ionizing radiation. The relation of the rem to other dose units depends upon the biological effect of the radiation under consideration.

RSC (see Radiation Safety Committee)

RSO (see Radiation Safety Officer)

Sealed Source

A radioactive source that is hermetically sealed and not intended to be opened.

Shallow Dose Equivalent (SDE)

External exposure of the skin or an extremity that is the dose equivalent at a tissue depth of 0.007 centimeters (7 mg/cm^2) averaged over an area of 1 square centimeter.

Sievert (Sv)

Special name for the SI unit of dose equivalent. One sievert equals 100 rem.

Somatic Effects of Radiation

Long term effects of radiation to exposed individuals, such as cancer, as opposed to genetic effects to the next generation. Somatic effects may also apply to subsequent unexposed generations beyond the first generation.

Specific Activity

The decay rate per amount of material usually expressed as mCi per milligram or millimole.

S&R

Shipping and Receiving

Survey Meter

Any portable radiation detection instrument designed to determine the presence of radioactive materials and ionizing radiation fields. Survey meters are of two types:

- Count rate meters that detect only the presence of radioactive material. Under certain conditions, the survey meter's reading may be used to determine the exposure rate from a source of radioactive material.
- Dose rate meters used to evaluate the intensity of radiation fields in units such as rem per hour, millirem per hour or sievert per hour.

TSRI

The Scripps Research Institute

Wipe Test (Sample)

A test (sample) made to determine the presence of removable radioactive contamination on a surface. A piece of soft filter paper is wiped over 100 square centimeters of area surveyed and counted for radioactivity with an appropriate instrument.

12.0 APPENDIX A:

Common Radionuclides: Properties and Hazards

The following information is intended as additional information for handling each radionuclide. Remember--any radionuclide can present a hazard if it becomes deposited internally. Numerous other factors may effect real-life situations.

Table 1. Common procedures and limits.

Radionuclide	Procedure	Limit per Experiment	Total Possession Limit
^{14}C	Metabolic labeling	1	10
^{51}Cr	Cell Labeling	5	10
^{3}H	Metabolic labeling	5	40
^{125}I	Chemical labeling	5	10
	Western blot	<1	1
^{32}P	Metabolic labeling	10	50
	DNA sequencing & labeling	1	10
^{33}P	Metabolic labeling	5	20
	DNA sequencing & labeling	1	10
^{35}S	Metabolic labeling	5	20
	DNA sequencing & labeling	1	10

Table 2. Typical pancake probe GM responses.

Radionuclide	Activity	Dose Rate @ 30cm	GM* response at 30cm
None	Background	0.02 mrad/hr	40 cpm
^{14}C, ^{3}H, ^{35}S	N/A	0.02 mrad/hr	40 cpm
^{51}Cr	1 mCi	0.17 mrad/hr	4700 cpm
^{125}I	1 mCi	0.77 mrad/hr	4,000 cpm
^{32}P	1 mCi	0.04 mrad/hr	400,000 cpm
^{33}P	1 mCi	0.02 mrad/hr	150,000 cpm

* These figures are calculated estimates based on idealized conditions. The actual readings produced by particular instruments vary greatly from those above and can only be determined by calibration of the instrument with a known source.

Table 3. Summary of radiological information.

Radionuclide	Primary type of decay	Half-life	Instrument for survey	Shielding required	Range in Air
^{14}C	beta	5730 yrs	GM	N/A, Lucite	8.6”
^{51}Cr	x-rays	28 days	NaI or GM	2cm lead	N/A
^{3}H	beta	12.3 yrs	LSC**	N/A, Lucite	.12”
^{125}I	x-rays	60 days	NaI	1mm lead	N/A
^{32}P	beta	14 days	GM	$3/8^{th}$” Lucite	18’
^{33}P	beta	24 days	GM	N/A, Lucite	2.6’
^{35}S	beta	87 dyas	GM	N/A, Lucite	9”

** LSC is an acceptable method for all radioactive materials but for ^{3}H it is the only approved method.

Individual Radionuclide Information

The specific radionuclides cited in this section represent the majority of those used in the disciplines of biochemistry and recombinant DNA technology. These radionuclides are carbon-14, chromium-51, tritium (^3H), iodine-125, phosphorus-32, phosphorus-33, and sulfur-35. Certain "special function" radionuclides such as calcium-45, iron-59, iodine-131 are used on a limited basis. For more information on these special function radionuclides please contact EH&S.

^{14}C

BIOCHEMISTRY APPLICATIONS

^{14}C possess physical properties that make it suitable as a tracer nuclide. It emits only beta particles, which are sufficiently energetic to make measurements fairly simple, yet weak enough to make shielding unnecessary and to permit fairly good definition in auto-radiography. Its half-life of 5760 years makes it unnecessary to correct for decay.

PHYSICAL CHARACTERISTICS

Carbon-14 has a half-life of 5730 years, emitting beta particles with a maximum energy of 156 keV. The beta particles travel a maximum distance of 10 inches in air.

Periodic Table	
Element Name	Carbon
Atomic Number	6
Atomic Mass Number	14
Atomic Mass	14.003241

Method of Production: ^{14}C is produced by neutron irradiation of beryllium nitride or aluminum nitride [$^{14}N(n,p)^{14}C$]. Because of the low cross section of this reaction and the long half-life of ^{14}C, large amounts of the target material must be exposed to high fluxes over long periods to produce useful quantities. This makes ^{14}C expensive compared to many other reactor-produced nuclides.

Radionuclide Properties	
Mode of Decay	β^- $\left({}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e + 156.5 keV\right)$
Energy of Emission	E_{max} = 156.5 keV E_{ave} = 49 keV
Probability	1.00 (i.e., 100%)
Physical $\tau_{1/2}$	5730 years
Biological $\tau_{1/2}$	12 days
Effective $\tau_{1/2}$	12 days (bound) 40 days (unbound)

METHOD OF DETECTION

Portable Survey Meters: Geiger-Mueller (GM) detectors have an efficiency of ~10%. Beta scintillator detectors have an efficiency of ~5%.

Wipe Test: Liquid scintillation counting is the best readily available method for detecting ^{14}C contamination.

SAFETY CONCERNS

External Exposure: External exposure risk is minimal since low energy emissions barely penetrate skin.

Internal Exposure: Avoid skin contamination (absorption), ingestion, inhalation, and injection (all routes of intake). Many ^{14}C compounds readily penetrate gloves and skin; handle such compounds remotely and wear double gloves, changing the outer pair at least every 20 minutes.

Critical Organ: Fat tissue (most labeled compounds); bone (some labeled carbonates)

Annual Limit on Intake (ALI):
Ingestion $2 \cdot 10^3$ μCi
Inhalation $2 \cdot 10^3$ μCi

Shielding: None required – mCi quantities not an external radiation hazard.

Dosimetry: Urine bioassay is the most readily available method to assess intake (for ^{14}C, no intake = no dose). A urine bioassay is required whenever monthly ^{14}C use exceeds 100 mCi, or after any accident/incident in which an intake is suspected.

^{51}Cr

BIOCHEMISTRY APPLICATIONS

1. Red blood cell survival studies and spleen imaging.
2. Kidney function studies.
3. Quantify gastro-intestinal protein loss.

PHYSICAL CHARACTERISTICS

Chromium-51 is a gamma- and x-ray emitting nuclide with a half-life of 27.7 days.

Periodic Table	
Element Name	Chromium (Cr)
Atomic Number	24
Atomic Mass Number	51
Atomic Mass	50.945

Method of Production: ^{51}Cr is not a naturally occurring nuclide. It is produced in a nuclear reactor via thermal neutron activation. [$^{50}Cr(n,\gamma)^{51}Cr$].

Radionuclide Properties	
Mode of Decay	Electron capture ($^{51}_{24}Cr + ^{0}_{-1}e \rightarrow ^{51}_{23}V + \gamma(320keV)$)
Energy of Emission	γ-ray = 320 keV X-ray = 5 keV Auger electron = 4 keV
Probability	γ-ray = 0.098 (i.e., 9.8%) X-ray = 0.22 (i.e., 22%) Auger electron = 0.68 (i.e., 68%)
Physical $\tau_{1/2}$	27.7 days
Biological $\tau_{1/2}$	616 days
Effective $\tau_{1/2}$	26.6 days (whole body)
Specific Act.	9.24×10^{4} Ci/g max.

METHOD OF DETECTION

Portable Survey Meters: Geiger-Mueller (e.g., TBM-3S) may be used to assess shielding effectiveness. Use a low-energy gamma detector (e.g., Ludlum 44-21) for contamination surveys.

Wipe Test: Liquid scintillation counter.

SAFETY CONCERNS

Radiotoxicity: 0.145 mrem/μCi of ^{51}Cr ingested (CEDE); 0.334 mrem/μCi of ^{51}Cr inhaled (CEDE).

Critical Organ: Lower Large Intestine (LLI).

Intake Routes: Ingestion, inhalation, puncture, wound, skin contamination (absorption).

Radiological Hazard: External and internal exposure; contamination.

Shielding:	Half-Value Layer	Tenth-Value Layer
Lead (Pb)	2 mm	6.6 mm
Concrete	2.8 cm	9.3 cm
Plexiglas	4.8 cm	16 cm

Dosimetry: Always wear radiation dosimetry monitoring badges (body and ring) whenever handling ^{51}Cr.

Special Precautions:

1. Store ^{51}Cr (including waste) behind lead shielding [¼-½ inch thick]; survey (with GM meter) to check adequacy of shielding (accessible dose rate < 2 mR/hr; should be background).
2. Avoid skin contamination [absorption], ingestion, inhalation, & injection [all routes of intake].
3. Use shielding to minimize exposure while handling ^{51}Cr.
4. Use tools to handle ^{51}Cr sources and contaminated objects; avoid direct hand contact.

^{3}H

BIOCHEMISTRY APPLICATIONS

^{3}H is predominantly used in research as a tracer. Tritium is readily available in large quantities, and extremely high specific activities can be obtained. Although the very low energy beta emission may cause difficulties in measurement, it has great advantages in high-resolution autoradiography. ^{3}H possesses a number of physical characteristics that make it an excellent biological tracer. Its half-life is conveniently long, there are no shielding problems, the biological half-life is short, and the radiotoxicity is among the lowest in radioactive materials. A few specific applications are listed below:

1. Studies in ground water flow or tracing reservoir leakage.
2. Pesticide removal studies.
3. Tobacco biosynthesis.
4. ^{3}H labeled thymadine is used as a tracer in cell proliferation experiments.
5. ^{3}H labeled uridine/amino acids for in vitro labeling to follow viral particles in RNA.

PHYSICAL CHARACTERISTICS

Tritium (^{3}H) has a half-life of 12.3 years, emitting beta particles with a maximum energy of 18.6 keV. The beta particles travel a maximum distance of 6mm (~¼-inch) in air.

Periodic Table	
Element Name	Hydrogen
Atomic Number	1
Atomic Mass Number	3
Atomic Mass	3.01605

Method of Production: ^{3}H may be produced by thermal neutron activation of deuterium (^{2}H) [$^{2}H(n,\gamma)^{3}H$], by separation from irradiated ^{3}He [$^{3}He(n,p)^{3}H$], or by a neutron-alpha reaction involving ^{6}Li [$^{6}Li(n,\alpha)^{3}H$].

Radionuclide Properties	
Mode of Decay	β^{-} $\left({}^{3}_{1}H \rightarrow {}^{3}_{2}He + {}^{0}_{-1}e + 18.6 keV\right)$
Energy of Emission	E_{max} = 18.61 keV E_{ave} = 5.7 keV
Probability	1.00 (i.e., 100%)
Physical $\tau_{1/2}$	12.32 years
Biological $\tau_{1/2}$	10-12 days
Effective $\tau_{1/2}$	10-12 days

METHOD OF DETECTION

Liquid scintillation counting is the only readily available method for detecting ^{3}H. Note: Portable survey meters will not detect laboratory quantities of ^{3}H.

The inability of direct-reading instruments to detect tritium and the slight permeability of most material to (tritiated) water and hydrogen (tritium) facilitates undetected spread of contamination. Use extreme care in handling and storage to avoid contamination, especially with high specific activity compounds.

SAFETY CONCERNS

External Exposure: ^{3}H does not pose an external exposure hazard. The weak beta particle is incapable of penetrating the dead layer of the skin.

Internal Exposure: Internal exposure is the primary safety concern while working with ^{3}H. Avoid skin contamination (absorption), ingestion, inhalation, and injection (all routes of intake). Many tritium compounds readily penetrate gloves and skin; handle such compounds remotely and wear double gloves, changing the outer pair at least every 20 minutes.

Critical Organ: Body water or tissue.
Annual Limit on Intake (ALI):
Ingestion $8 \cdot 10^{4}$ µCi
Inhalation $8 \cdot 10^{4}$ µCi

Shielding: None required – not an external hazard.

Dosimetry: Urine bioassay is the only readily available method to assess intake (for tritium, no intake = no dose). A urine bioassay is required whenever monthly ^{3}H use exceeds 100 mCi, or after any accident/incident in which an intake is suspected.

^{125}I

BIOCHEMISTRY APPLICATIONS

1. **NaI:**

- An unbound radioactive iodine molecule usually liquefied by mixture with NaOH. It's kept basic to reduce volatility. Through a process called iodination, this radioiodine can be labeled, or bound to a specific protein. Often used to mark specific antibodies, hormones, or peptides to track there presences or number in biological organisms (cells, blood, or tissues).
  - Radioactive iodine introduced into a sample (cells, blood, liquid mixture)
  - Protein binds chemically to the iodine during an incubation stage.
  - Drain/rinse, separate
  - Count how much iodine was incorporated using a gamma counter.
  - Conclude how much of that protein, antibody, hormone, is present.
- Iodine is preferred over many other nuclides because gamma rays can more easily be detected coming from inside a sample or organism due to their penetrating power. Gamma counters can be used such that the original sample is still available for further testing. LSC would destroy the sample (mixed with solvents).

2. **RIA Kits**

- These kits contain a solution of iodine that has already been bound to a specific protein.
- CONS: Only available for specific proteins. It is more expensive.
- PROS: Much lower risk of exposure to the scientist. It is easier to use and gets quicker results.
- Very commonly used to detect the presence of various hormones in blood samples.
- ^{3}H is another commonly used radionuclide in RIA kits, however, ^{125}I provides much quicker counting times. Furthermore, its relatively short half-life provides easier disposal.

3. **Therapeutic**

- Although not used in routine biochemistry labs for this purpose, ^{125}I has been used for cancer therapy. Seeds implanted for direct radiation exposure to cancer cells. ^{131}I is used for thyroid ablation.

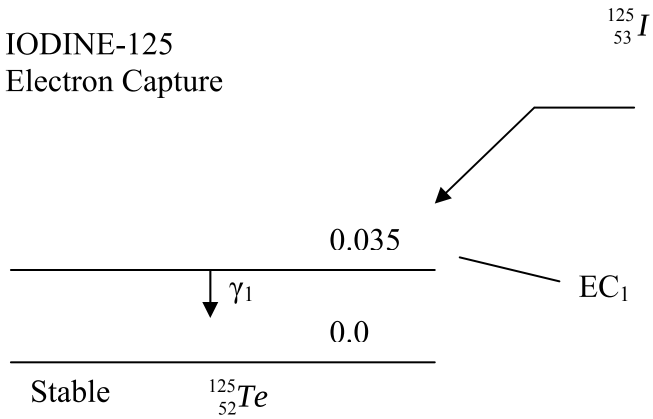
PHYSICAL CHARACTERISTICS

Iodine-125 is a potentially volatile radionuclide with a half-life of 60.14 days, emitting gamma rays with energy of 35.5 keV and x-rays with energies of 27 and 31 keV.

Periodic Table	
Element Name	Iodine
Atomic Number	53
Atomic Mass Number	125
Atomic Mass	124.905

Method of Production: ^{125}I must be created in linear accelerators, cyclotrons or reactors as it is not a naturally occurring material. ^{124}Xe (stable) is bombarded with neutrons becoming ^{125}Xe. ^{125}Xe decays ($\tau_{1/2}$= 17 hours) by electron capture to ^{125}I.

Radionuclide Properties	
Mode of Decay	Electron capture ($^{125}_{53}I + ^{0}_{-1}e \rightarrow ^{125}_{52}Te + \gamma(35.5keV)$)
Energy of Emission	γ-ray = 35.5 keV X-rays = 27 keV, 31 keV
Probability	γ-ray = 0.07 (i.e. 7%) X-ray = 1.13 (i.e. 113%)
Physical $\tau_{1/2}$	60.14 days
Biological $\tau_{1/2}$	120-138 days (unbound iodine)
Effective $\tau_{1/2}$	42 days (unbound iodine)



METHOD OF DETECTION

Preferred method is low-energy gamma scintillator (Ludlum 44-3, 1 inch by 1 mm) with an efficiency of about 19%. Interesting that the 44-17 (2 inch by 2 mm) is only about 20% efficient.

GM (44-9) has a very low efficiency for ^{125}I reported as 2% and 0.1%. To put in perspective, a GM is about 5% efficient for ^{14}C and 32% efficient for ^{32}P.

Gamma counter quoted at >75% efficient.

LSCs are quite efficient yet less convenient (~75%). Found to be quoted at 60% and 70%.

RADIATION SAFETY ISSUES

External Doses: X-ray/gamma rays penetrate. External dose can be significant. Dosimeters required at TSRI when ≥2 mCi are used.

As with all x-rays, a common shielding material is lead. Any highly dense material will do. The half-value layer (HVL) for ^{125}I is 0.02 mm of lead. The TVL is 0.06 mm of lead. A foil of one-sixteenth of an inch should be adequate for all uses.

NaI is characterized by a high vapor pressure that makes the substance very volatile at room temperature. Inhalation hazards are great. Use of fume hood with charcoal filters to catch the effluents is required. Bound iodine is not such a problem.

Internal Doses: Since iodine, radioactive or not, taken into the body system accumulates mostly in the thyroid gland, biological monitoring through thyroid bioassay is simple and non-invasive. Thyroid bioassays required at TSRI when 10 mCi or more are used in a calendar quarter.

By taking non-radioactive iodine supplements (KI) it is possible to flood the thyroid. Then, if radioactive iodine is taken in it cannot accumulate and is quickly flushed from the body.

Annual Limit on Intake (ALI):

Ingestion $4 \cdot 10^1$ μCi
Inhalation $6 \cdot 10^1$ μCi

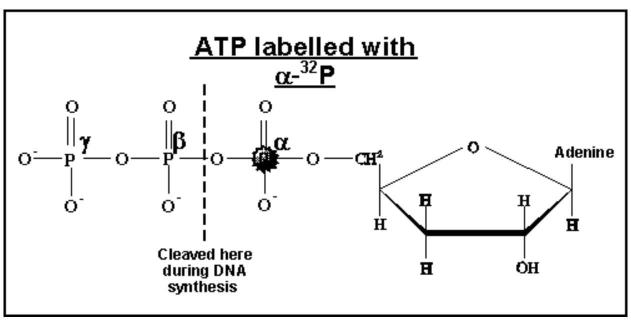
^{32}P

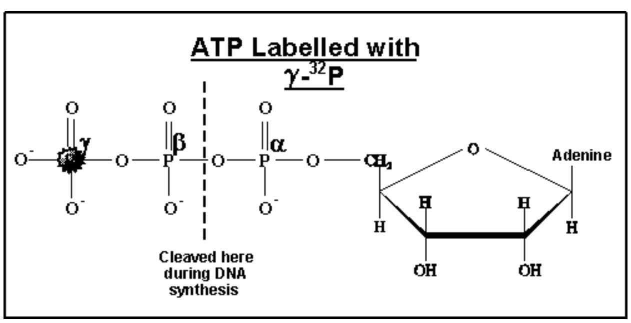
BIOCHEMISTRY APPLICATIONS

^{32}P-labeled compounds have the following Biochemical applications:

1. Inorganic fertilizers for agricultural research; superphosphate-^{32}P is a typical example.
2. Organophosphorus insecticides for studies of their own distribution and metabolism.
3. Compounds used in medical therapy and diagnosis: ^{32}P colloids for therapy, and diisopropyl phosphoflouridate-^{32}P (DFP-P32) for the labeling of blood cells.
4. Labeled pharmaceutical substances for distribution and metabolic studies; cytotoxic drugs such as thiotepa-^{32}P and cyclophosphammide-^{32}P are important examples.
5. Biochemicals, especially nucleotides, such as adenosine-5'-triphosphate-^{32}P.

The DNA molecule is labeled by incorporating nucleotides containing a radioactive phosphorus nuclide ^{32}P. The nuclide can be situated at the alpha or the gamma position of the molecule.





Other molecules labeled in this way include CTP, GTP, UTP, dATP, dCTP, dGTP, and dUTP.

6. Industrial chemicals, such as plasticizers and solvent extraction reagents.
7. Intermediates for further synthetic work; phosphorus halides and sulfides, and phosphorylating agents, such as 2-cyanoethyl phosphate-^{32}P.

PHYSICAL CHARACTERISTICS

Phosphorus-32 has a half-life of 14.3 days, emitting beta particles with a maximum energy of 1.71 MeV. The beta particles travel a maximum of 20 feet in air.

Periodic Table	
Element Name	Phosphorus
Atomic Number	15
Atomic Mass Number	32
Atomic Mass	31.974

Method of Production: ^{32}P is readily produced either by the direct neutron irradiation of elementary red phosphorus [$^{31}P(n,\gamma)^{32}P$] or by separation as carrier-free phosphate from irradiated sulfur [$^{32}S(n,p)^{32}P$].

Radionuclide Properties	
Mode of Decay	β^- (${}^{32}_{15}P \rightarrow {}^{32}_{16}S + {}^{0}_{-1}e + 1.71 MeV$)
Energy of Emission	E_{max} = 1.71040 MeV E_{ave} = 0.694900 MeV
Probability	1.00 (i.e., 100%)
Physical $\tau_{1/2}$	14.290 days
Biological $\tau_{1/2}$	1155 days
Effective $\tau_{1/2}$	14.1 days (bone), 13.5 days (whole body)

METHOD OF DETECTION

A tiny drop of contamination of ^{32}P can be easily detected with a Geiger Counter. GM survey meter with a pancake probe (typical efficiency – 25% to 45%). Low energy NaI probe is used only **to detect bremsstrahlung**. Liquid scintillation counting (typical efficiency – 90%) to detect removable contamination on wipes.

SAFETY CONCERNS

External Exposure: Surface radiation exposure to the skin of the hands. A drop of contamination containing 1 microcurie of ^{32}P on

1 cm^2 area of skin produces an dose rate of 2,000 mrem/hr (2 rem/hr).

Radiation exposure in air over an open vial: The dose rate at the opening of a vial containing 1 mCi of ^{32}P can be as high as 26 rem/hr.

Internal Exposure: 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 phosphorus in the nucleoproteins. ^{32}P is eliminated from the body primarily via urine.

Annual Limit on Intake (ALI):
  Ingestion $6 \cdot 10^2$ μCi
  Inhalation $9 \cdot 10^2$ μCi

Shielding: 3/4 to 3/8 inch thick Plexiglas/Lucite/plastic shielding is required. Do not use lead foil or sheets to shield ^{32}P. Penetrating bremsstrahlung x-rays are produced by dense materials (such as lead) in the vicinity of a ^{32}P source. If quantities of 5 mCi or more are used, a significant level of bremsstrahlung radiation can be produced even in light-weight materials such as Lucite. In such instances, it is desirable to add a thin sheet of lead between the Lucite and the worker to absorb the x-rays.

Half-Value Layer: 2 mm of water/tissue.

Dosimetry: Whole body and finger dosimeters are required if quantities of 1 mCi or more are being used.

^{33}P

BIOCHEMISTRY APPLICATIONS

^{33}P-labeled compounds have a range of applications similar to ^{32}P (see the ^{32}P data sheet for a general overview). Some of the specific biochemistry applications of this nuclide are as follows:

1. Gamma (γ) ^{33}P ATP is used for protein kinase assays (adding phosphates to tissue).
2. Gamma ^{33}P GTP is used for cycle sequencing.
3. Gamma ^{33}P dATP is used for DNA labeling.
4. Alpha (α) dCTP/dGTP are used for DNA sequencing (cutting up DNA).
5. Alpha ATP, CTP, UTP, and GTP are used for RNA labeling.
6. In situ hybridization – this is the technical term for binding tissue cultures in liquids.

^{33}P has a higher specific activity and emits a more energetic beta particle than ^{35}S, thus allowing shorter autographic exposure times. ^{33}P is safer and easier to handle than highly energetic ^{32}P. More importantly the significantly lower energy of ^{33}P's beta particles enables a higher degree of precision when measuring the tightly focused images that may be produced with this nuclide.

PHYSICAL CHARACTERISTICS

Phosphorous-33 has a half-life of 25.3 days, emitting beta particles with a maximum energy of 248.5 keV. The beta particles may travel about 20 inches in air.

Periodic Table	
Element Name	Phosphorous
Atomic Number	15
Atomic Mass Number	33
Atomic Mass	32.972

Method of Production: ^{33}P is not a naturally occurring nuclide and must be artificially produced. ^{33}P is produced when ^{33}S is bombarded by either fast or thermal neutrons [$^{33}S(n,p)^{33}P$].

Radionuclide Properties	
Mode of Decay	β^- (${}^{33}_{15}P \rightarrow {}^{33}_{16}S + {}^{0}_{-1}e + 248.5 keV$)
Energy of Emission	E_{max} = 248.5 keV E_{ave} = 76.4 keV
Probability	1.00 (i.e., 100%)
Physical $\tau_{1/2}$	25.3 days
Biological $\tau_{1/2}$	Bone ~ 1155 days Whole Body ~ 257 days
Effective $\tau_{1/2}$	25.3 days
Specific Activity	156,000 Ci/g max.
Beta Range	Air: 50 cm (~ 20 inches) Water/Tissue: 0.06 cm Plastic: 0.05 cm

METHOD OF DETECTION

Portable Survey Meters: Geiger-Mueller Pancake detectors (e.g., TBM-3S), or Beta Scintillator (e.g., Ludlum 44-21).

Wipe Test: Liquid Scintillation counting works well for counting ^{33}P wipe tests.

SAFETY CONCERNS

Radiotoxicity: 15.6 mrem/µCi (lung) and 2.32 mrem/µCi (CEDE) of ^{33}P inhaled; 1.85 mrem/µCi (Bone Marrow) and 0.92 mrem/µCi (CEDE) or ^{33}P ingested.

Critical Organ: Bone (soluble ^{33}P); Lung (inhalation); GI Tract (ingestion – insoluble compounds).

Exposure Routes: Ingestion, inhalation, puncture, wound, skin contamination absorption.

Radiological Hazard: External exposure – mCi quantities not considered an external hazard. Internal exposure & contamination are the primary concern.

Shielding: None required – mCi quantities not an external radiation hazard.

Dosimetry: Urine bioassay is the most readily available method to assess intake [for ^{33}P, no intake = no dose]. If 100 mCi of ^{33}P are used in one calendar month a urine bioassay is required. No dosimetry badges are needed when working with ^{33}P [beta energy too low to be detected].

Special Precautions:

1. Avoid skin contamination [absorption], ingestion, inhalation, and injection [all routes of intake].
2. ^{33}P is not volatile, even when heated, and can be ignored as an airborne contaminant unless aerosolized.
3. White wine vinegar can be an effective decontamination solvent for this nuclide in most common chemical forms.

^{35}S

BIOCHEMISTRY APPLICATIONS

1. As a radiotracer in the form of labeled amino acids or nucleotides.
2. Used to mark sulfur containing chemical compounds in biological and agricultural research.
3. For use in eukaryotic or bacterial cell labeling studies.
4. For use in protein dynamics studies.

PHYSICAL CHARACTERISTICS

Sulfur-35 has a half-life of 87.4 days, emitting only beta particles with a maximum energy of 0.167 MeV and an average energy of 0.049 MeV. The beta particles from ^{35}S travel a maximum of 24 cm. in air.

Periodic Table	
Element Name	Sulfur
Atomic Number	16
Atomic Mass Number	35
Atomic Mass	34.969

Method of Production: Reactor – daughter product of ^{35}P.

Radionuclide Properties	
Mode of Decay	β^- $\left({}^{35}_{16}S \rightarrow {}^{35}_{17}Cl + {}^{0}_{-1}e + 167keV\right)$
Energy of Emission	E_{max} = 167.47 keV E_{ave} = 48.8 keV
Probability	1.00 (i.e., 100%)
Physical $\tau_{1/2}$	87.44 days
Biological $\tau_{1/2}$	623 days (unbound) 90 days (bound)
Effective $\tau_{1/2}$	44.3 days (bone) 13.5 days (whole body)

METHOD OF DETECTION

1. GM/beta scintillator detection is possible at close range (<2 cm), however, efficiency for both is approximately 4-6%.
2. LSC provides best means of detection (97% efficiency) but cannot detect fixed contamination.
3. Urine bioassays are the most appropriate method to use for assessing intake and dose (required if 100 mCi are used in a calendar month); low energy beta emissions negate effective dosimetry use.
4. ^{35}S is primarily an internal radiation hazard due to weak beta emissions, therefore frequent monitoring of work area an extra handling care are necessary.

SAFETY CONCERNS

Exposure Routes: Ingestion, inhalation, puncture wound, skin absorption.

Skin Contamination Dose Rate: 1200 mrem/1.0 μCi/cm^2/hr. (7.0 mg/cm^2 depth).

Beta Dose Rate: 14.94 rad/h (contact) in air per 1.0mCi; 0.20 rad/h (6 inches) in air per 1.0mCi.

External Exposure: External exposure risk is minimal since low energy emissions barely penetrate skin.

Internal Exposure: Internal exposure risk will depend upon whether it is found in an organic or inorganic compound. Entering the body in an organic form poses a higher retention rate than that entered in an inorganic form. All ^{35}S uptakes are uniformly distributed throughout the body, specifically targeting the testes.

Inhalation Hazard: ^{35}S labeled amino acids (organic compounds) such as cysteine and methionine are inherently volatile and pose both contamination and intake risks. Inhalation of ^{35}S vapors (SO_2, H_2S, CH_3SH) are released when opening thawed vials due to its breakdown during freezing process. These vials should always be opened and used in a fume hood.

Annual Limit on Intake (ALI):
Inorganic (Class W):
- Ingestion $6 \cdot 10^3$ μCi
- Inhalation $2 \cdot 10^3$ μCi

Organic (Class D):
- Ingestion $1 \cdot 10^4$ μCi
- Inhalation $2 \cdot 10^4$ μCi

Shielding: None required since ^{35}S does not pose a significant external hazard.

PPE: Gloves should be changed frequently while working with this radionuclide.