The College of
WILLIAM & MARY

The Department of Biology

P.O. Box 8795
Williamsburg, Virginia 23187-8795
757/221-2220, Fax 757/221-6483

24 February 2005

Licensing Assistant Section
Nuclear Materials Safety Branch
U.S. Nuclear Regulatory Commission, Region I
475 Allendale Road
King of Prussia, PA 19406-1415

To Whom it may Concern: 03031466

I have been directed by David Collins in the Region II office to send this renewal to the Region I office.

Please renew the Materials License 45-03499-06, as is, and without any changes from those described in Amendment 10 and dated March 18, 2003.

Specifically, there are no changes to items 6 (byproduct, source, and/or special nuclear material); 7 (chemical and/ or physical form); or, 8 (maximum amount that licensee may possess at any one time under this license). All of the personnel and procedures described in Amendment Number 10, in items 9, 10, 11, 12, 13A,B,C, 14, 15 and outlined in item 16 A and B are unchanged and currently in effect.

For the file, I am enclosing an updated print and an electronic version of the Radiation Safety Manual which incorporates all of the changes previously approved by letter and numbered 9, 10, 11, 12, 13, 14, and 15, as enumerated in License 54-03499-06, Amendment 10.

Should it become necessary, I can be reached by telephone at (757) 221-2220 and by e-mail at: elbrad@wm.edu. Thank you for your help with this renewal.

Sincerely,

Eric Bradley

Eric Bradley
Chair Applied Science
Professor, Biology
RSO, License 45-03499-06

'05 FEB 28 AM 11:04
RECEIVED REGION I

136516
NMSS/RGNI MATERIALS-002

NRC FORM 313 (10-2002) 10 CFR 30, 32, 33, 34, 35, 36, 39, and 40

U.S. NUCLEAR REGULATORY COMMISSION

APPLICATION FOR MATERIAL LICENSE

APPROVED BY OMB: NO. 3150-0120 EXPIRES: 10/31/2005

Estimated burden per response to comply with this mandatory collection request: 7 hours. Submittal of the application is necessary to determine that the applicant is qualified and that adequate procedures exist to protect the public health and safety. Send comments regarding burden estimate to the Records Management Branch (T-6 E6), U.S. Nuclear Regulatory Commission, Washington, DC 20555-0001, or by internet e-mail to infocollects@nrc.gov, and to the Desk Officer, Office of Information and Regulatory Affairs, NEOB-10202, (3150-0120), Office of Management and Budget, Washington, DC 20503. If a means used to impose an information collection does not display a currently valid OMB control number, the NRC may not conduct or sponsor, and a person is not required to respond to, the information collection.

INSTRUCTIONS: SEE THE APPROPRIATE LICENSE APPLICATION GUIDE FOR DETAILED INSTRUCTIONS FOR COMPLETING APPLICATION. SEND TWO COPIES OF THE ENTIRE COMPLETED APPLICATION TO THE NRC OFFICE SPECIFIED BELOW.

APPLICATION FOR DISTRIBUTION OF EXEMPT PRODUCTS FILE APPLICATIONS WITH:

DIVISION OF INDUSTRIAL AND MEDICAL NUCLEAR SAFETY
OFFICE OF NUCLEAR MATERIALS SAFETY AND SAFEGUARDS
U.S. NUCLEAR REGULATORY COMMISSION
WASHINGTON, DC 20555-0001

ALL OTHER PERSONS FILE APPLICATIONS AS FOLLOWS:

IF YOU ARE LOCATED IN:

CONNECTICUT, DELAWARE, DISTRICT OF COLUMBIA, MAINE, MARYLAND, MASSACHUSETTS, NEW HAMPSHIRE, NEW JERSEY, NEW YORK, PENNSYLVANIA, RHODE ISLAND, OR VERMONT, SEND APPLICATIONS TO:

LICENSING ASSISTANT SECTION
NUCLEAR MATERIALS SAFETY BRANCH
U.S. NUCLEAR REGULATORY COMMISSION, REGION I
475 ALLENDALE ROAD
KING OF PRUSSIA, PA 19406-1415

ALABAMA, FLORIDA, GEORGIA, KENTUCKY, MISSISSIPPI, NORTH CAROLINA, PUERTO RICO, SOUTH CAROLINA, TENNESSEE, VIRGINIA, VIRGIN ISLANDS, OR WEST VIRGINIA, SEND APPLICATIONS TO:

SAM NUNN ATLANTA FEDERAL CENTER
U. S. NUCLEAR REGULATORY COMMISSION, REGION II
61 FORSYTH STREET, S.W., SUITE 23T85
ATLANTA, GEORGIA 30303-8931

IF YOU ARE LOCATED IN:

ILLINOIS, INDIANA, IOWA, MICHIGAN, MINNESOTA, MISSOURI, OHIO, OR WISCONSIN, SEND APPLICATIONS TO:

MATERIALS LICENSING BRANCH
U.S. NUCLEAR REGULATORY COMMISSION, REGION III
801 WARRENVILLE RD.
LISLE, IL 60532-4351

ALASKA, ARIZONA, ARKANSAS, CALIFORNIA, COLORADO, HAWAII, IDAHO, KANSAS, LOUISIANA, MONTANA, NEBRASKA, NEVADA, NEW MEXICO, NORTH DAKOTA, OKLAHOMA, OREGON, PACIFIC TRUST TERRITORIES, SOUTH DAKOTA, TEXAS, UTAH, WASHINGTON, OR WYOMING, SEND APPLICATIONS TO:

NUCLEAR MATERIALS LICENSING SECTION
U.S. NUCLEAR REGULATORY COMMISSION, REGION IV
611 RYAN PLAZA DRIVE, SUITE 400
ARLINGTON, TX 76011-8064

030 31466

PERSONS LOCATED IN AGREEMENT STATES SEND APPLICATIONS TO THE U.S. NUCLEAR REGULATORY COMMISSION ONLY IF THEY WISH TO POSSESS AND USE LICENSED MATERIAL IN STATES SUBJECT TO U.S.NUCLEAR REGULATORY COMMISSION JURISDICTIONS.

1. THIS IS AN APPLICATION FOR *(Check appropriate item)*
   - [ ] A. NEW LICENSE
   - [ ] B. AMENDMENT TO LICENSE NUMBER
   - [X] C. RENEWAL OF LICENSE NUMBER 45-03499-06

2. NAME AND MAILING ADDRESS OF APPLICANT *(Include ZIP code)*
College of William & Mary
Department of Biology
Williamsburg, VA 23187-8795

3. ADDRESS WHERE LICENSED MATERIAL WILL BE USED OR POSSESSED
BIOLOGY DEPARTMENT
MILLINGTON HALL
Williamsburg, VA
23187-8795

4. NAME OF PERSON TO BE CONTACTED ABOUT THIS APPLICATION
Eric L. Bradley

TELEPHONE NUMBER
~~800~~ (757) 221-2220

SUBMIT ITEMS 5 THROUGH 11 ON 8-1/2 X 11" PAPER. THE TYPE AND SCOPE OF INFORMATION TO BE PROVIDED IS DESCRIBED IN THE LICENSE APPLICATION GUIDE.

5. RADIOACTIVE MATERIAL
   a. Element and mass number; b. chemical and/or physical form; and c. maximum amount which will be possessed at any one time.

6. PURPOSE(S) FOR WHICH LICENSED MATERIAL WILL BE USED.

7. INDIVIDUAL(S) RESPONSIBLE FOR RADIATION SAFETY PROGRAM AND THEIR TRAINING EXPERIENCE.

8. TRAINING FOR INDIVIDUALS WORKING IN OR FREQUENTING RESTRICTED AREAS.

9. FACILITIES AND EQUIPMENT.

10. RADIATION SAFETY PROGRAM.

11. WASTE MANAGEMENT.

12. LICENSE FEES *(See 10 CFR 170 and Section 170.31)*
FEE CATEGORY
AMOUNT ENCLOSED $ 0

13. CERTIFICATION. *(Must be completed by applicant)* THE APPLICANT UNDERSTANDS THAT ALL STATEMENTS AND REPRESENTATIONS MADE IN THIS APPLICATION ARE BINDING UPON

THE APPLICANT AND ANY OFFICIAL EXECUTING THIS CERTIFICATION ON BEHALF OF THE APPLICANT, NAMED IN ITEM 2, CERTIFY THAT THIS APPLICATION IS PREPARED IN CONFORMITY WITH TITLE 10, CODE OF FEDERAL REGULATIONS, PARTS 30, 32, 33, 34, 35, 36, 39, AND 40, AND THAT ALL INFORMATION CONTANED HEREIN IS TRUE AND CORRECT TO THE BEST OF THEIR KNOWLEDGE AND BELIEF.

WARNING: 18 U.S.C. SECTION 1001 ACT OF JUNE 25, 1948 62 STAT. 749 MAKES IT A CRIMINAL OFFENSE TO MAKE A WILLFULLY FALSE STATEMENT OR REPRESENTATION TO ANY DEPARTMENT OR AGENCY OF THE UNITED STATES AS TO ANY MATTER WITHIN ITS JURISDICTION.

CERTIFYING OFFICER – TYPED/PRINTED NAME AND TITLE	SIGNATURE	DATE
P. Geoffrey Feiss PROVOST	[signature]	2/25/05

FOR NRC USE ONLY

TYPE OF FEE	FEE LOG	FEE CATEGORY	AMOUNT RECEIVED	CHECK NUMBER	COMMENTS
			$		
APPROVED BY				DATE	**NMSS/RGNI MATERIALS-002**

MATERIALS LICENSE

Pursuant to the Atomic Energy Act of 1954, as amended, the Energy Reorganization Act of 1974 (Public Law 93-438), and Title 10, Code of Federal Regulations, Chapter I, Parts 30, 31, 32, 33, 34, 35, 36, 39, 40, and 70, and in reliance on statements and representations heretofore made by the licensee, a license is hereby issued authorizing the licensee to receive, acquire, possess, and transfer byproduct, source, and special nuclear material designated below; to use such material for the purpose(s) and at the place(s) designated below; to deliver or transfer such material to persons authorized to receive it in accordance with the regulations of the applicable Part(s). This license shall be deemed to contain the conditions specified in Section 183 of the Atomic Energy Act of 1954, as amended, and is subject to all applicable rules, regulations, and orders of the Nuclear Regulatory Commission now or hereafter in effect and to any conditions specified below.

Licensee	In accordance with the letter dated **March 18, 2003**
1. College of William and Mary	3. License No. 45-03499-06 is amended in its entirety to read as follows:
2. Department of Biology Williamsburg, Virginia 23185	4. Expiration Date: March 31, 2005
	5. Docket No. 030-31466

6. Byproduct, source, and/or special nuclear material	7. Chemical and/or physical form	8. Maximum amount that licensee may possess at any one time under this license
A. Hydrogen 3	A. Any aqueous solution	A. 1.11 gigabecquerels (GBq) [30 millicuries (mCi)]
B. Carbon 14	B. Any aqueous solution	B. 370 megabecquerels (MBq) [10 mCi]
C. Phosphorus 32	C. Any aqueous solution	C. 1.85 GBq (50 mCi)
D. Sulfur 35	D. Any	D. 2.59 GBq (70 mCi)
E. Iodine 125	E. Any	E. 296 MBq (8 mCi)
F. Phosphorus 33	F. Any	F. 370 MBq (10 mCi)

9. Authorized Use:

A. through F. Laboratory research including animal studies.

MATERIALS LICENSE SUPPLEMENTARY SHEET	
	License No. 45-03499-06
	Docket No. 030-31466
	Amendment No. **10**

CONDITIONS

10. Licensed material shall be used only at the College of William and Mary, Williamsburg, Virginia.

11. The Radiation Safety Officer (RSO) for this license is Eric L. Bradley, Ph.D., or, **in his absence,** Margaret S. Saha, Ph.D., **or Lizabeth A. Allison, Ph.D.,** Alternate RSOs.

12. Licensed material shall be used by, or under the supervision of, Eric L. Bradley, Ph.D., Margaret S. Saha, Ph.D., **or Lizabeth A. Allison, Ph.D.**

13. The licensee is authorized to hold radioactive material with a physical half-life of less than 90 days for decay-in-storage before disposal in ordinary trash provided that:

    A. Radioactive waste to be disposed of in this manner shall be held for decay a minimum of 10 half-lives;

    B. Before disposal as ordinary trash, byproduct material shall be surveyed at the container surface with the appropriate survey meter set on its most sensitive scale and with no interposed shielding to determine that its radioactivity cannot be distinguished from background. All radiation labels shall be removed or obliterated; and

    C. A record of each disposal permitted under this License Condition shall be retained for three years. The record must include the date of disposal, the date on which the byproduct material was placed in storage, the radionuclides disposed, the survey instrument used, the background dose rate, the dose rate measured at the surface of each waste container, and the name of the individual who performed the disposal.

14. Experimental animals, or the products from experimental animals, that have been administered licensed materials shall not be used for human consumption.

15. The licensee shall conduct a physical inventory every six months to account for all sources and/or devices received and possessed under the license.

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		License No. 45-03499-06
MATERIALS LICENSE	**SUPPLEMENTARY SHEET**	Docket No. 030-31466
		Amendment No. **10**

16. Except as specifically provided otherwise in this license, the licensee shall conduct its program in accordance with the statements, representations, and procedures contained in the documents including any enclosures, listed below. The U. S. Nuclear Regulatory Commission's regulations shall govern unless the statements, representations and procedures in the licensee's application and correspondence are more restrictive than the regulations.

A. Application dated December 14, 1989

B. Letters dated:

1) February 20, 1990
2) October 10, 1991
3) December 30, 1991
4) April 15, 1994 with attached Radiation Safety Manual
5) June 14, 1994 [request to add Margaret S. Saha, Ph.D. as alternate RSO]
6) June 22, 1994 [request to dispose of waste material by decay-in-storage.)
7) June 23, 1994 [FAX transmission providing description of training and exp. of Dr. Saha]
8) Revised Radiation Safety Manual [illegible]
9) February 7, 1995 [renewal, no changes]
10) July 1, 1996 [add and delete of authorized places of use, increased I-125 possession limit]
11) March 19, 1998 [add 3 lab spaces, increase possession limit of P-32; and add P-33 use]
12) June 22, 1998 [FAX regarding additional information on a diagram of 3 lab spaces]
13) July 20, 1999 [FAX regarding request to add another lab space for RAM use]
14) November 29, 2000 [add lab space, increase possession limits of P-32 and S-35]
15) **March 18, 2003 [add user and alt. RSO (Dr. Allison)]**

FOR THE U. S. NUCLEAR REGULATORY COMMISSION

DATE MAY 27 2003

BY

Bryan A. Parker
Region II, Division of Nuclear Materials Safety
61 Forsyth Street, S.W., Suite 23T85
Atlanta, Georgia 30303-8931

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RADIATION SAFETY MANUAL

Department of Biology
College of William and Mary
Williamsburg, Virginia

Revised:
June 2004
ELB/MSS/LAA

The policies and procedures discussed in this manual are in compliance with regulations established by the Nuclear Regulatory Commission (NRC) under Title 10, Code of Federal Regulations (CFR), Parts 19, 20, and 30. The License, all records, forms, and operating procedures, as well as copies of the Title 10 regulations are available from the Radiation Safety Officer upon request.

TABLE OF CONTENTS

I. GENERAL

A. INTRODUCTION

This radiation safety manual has been developed to provide all investigators with the information required to ensure their safety and that of the surrounding community with respect to the use of radioactive materials. More specifically, it is designed to familiarize those using radioactive material for their research with the policies of the Biology Department and to ensure that exposure is kept, in compliance with federal policy, as low as reasonably achievable.

B. ORGANIZATION OF THE RADIATION SAFETY PROGRAM

A Radiation Safety Officer (RSO) and one or more Radiation Safety Officers, Alternate (RSO, Alt.) appointed by the Provost will oversee all usage of radioactive material. The RSOs will ensure the safety of users and the surrounding community by monitoring all aspects of radiation safety within the Department.

The RSO has established a Radioisotopes Users Committee. This Committee functions as a mutual-aid and advisory group in order to support the safe and effective use of radioisotopes. All members of the Committee (current Committee membership listed in Section VI) agree to take the responsibility to serve as a designated "first responder" to radioisotope accidents or problems that may develop within the Biology Department. An isotope user may contact any of the Committee members to request aid or report an accident.

Following any first response to an accident, a disposition report must be made to the RSO as soon as possible so that the NRC-required report of the incident may be made for the record.

(1) Granting of Authorized, Restricted, and Supervised User Status

a) Authorized User Status

The RSO and the RSO, Alternates are the Authorized Users designated by the NRC on the License. A person designated as an "Authorized User" may possess and use radioactive material and may also purchase such material in accordance with NRC policy. The Authorized User bears responsibility for the proper maintenance of radioactive materials under his/her authorization and is directly accountable for its proper usage. Granting of this status will require sufficient evidence of both formal and "on the job" training and must also be approved by license amendment from the NRC. Application for Authorized User status and license amendment will be coordinated by the RSO.

b) Restricted User Status

Upon submission of the completed form entitled *Application for Radioisotope User Status*, the RSO will evaluate the formal training and experience of the applicant and may grant "Restricted User" status. Restricted User status will allow persons approved by the RSO to use specified radioactive material under specifically approved conditions as delineated on the *Application for Radioisotope User Status* form (see section VII, Appendix A). Restricted Users may lack the breadth of training and experience to qualify as Authorized Users, but they will have demonstrated specific and extensive training in the particular procedures that have been approved by the RSO. Restricted Users will be supervised by an Authorized User in an on-going way although the physical presence of the Authorized User will not be required at all times. With prior and specific approval of the RSO, a Restricted User may directly supervise previously approved procedures undertaken by "Supervised Users," as defined below. All Restricted Users must successfully complete the Radiation Safety Course at least once each year to maintain their status.

c) Supervised User Status

A "Supervised User" must also complete the *Application for Radioisotope User Status* form to specify the nature of the work to be accomplished, the isotope(s) and amounts to be used, the location of the work and the Name of the Authorized or Restricted User who will supervise the work. Status as a Supervised User will require the successful completion of the Radiation Safety Course each year in addition to providing evidence that the Supervised User is proficient in the handling of radioactive material. A Supervised User will operate under direct supervision of an Authorized User or a specifically approved Restricted User unless a specific exception is granted by the RSO based upon the use of trace amounts of isotope.

(2) Attendance at Training Sessions

All persons who work in or frequent any designated radioisotope work area must successfully complete the Radiation Safety Course at least once per year. This three-hour course will be offered at the beginning of the Fall, Spring, and Summer academic sessions by the RSO and RSO, Alternates and will contain specific instruction both in the theory and practice of handling radioactive materials. Specifically, this course will include instruction in the contents of this manual and a discussion of safe working practices with all licensed isotopes. This will entail a review of area and personal monitoring, safe handling methods, record keeping and other practices as they may be defined by the RSO. Records of attendance in the course and evidence of subject mastery by written examination will be collected and maintained by the RSO for at least three years.

(3) Approval of Projects

The RSO will evaluate the radiological safety aspects of all proposed activities involving the use of radioisotopes at least annually. Each investigator shall present to the RSO, on Part II of the *Application for Radioisotope User Status* form, a description of proposed activities in which radioisotopes are involved prior to the initiation of such activities. If these activities change during the course of the year, the investigator must submit an updated description.

(4) Designation of Radioactive Work Areas

Appropriate work areas in which radioactive isotope work may be conducted are designated by the RSO and approved by the NRC. Approval of a project is contingent upon the availability of adequate laboratory facilities for assignment as work areas. As of June 2004, the approved areas are Millington Hall rooms 4, 203A, 205, 300, 301, 305, 307, 309, 311, and 317.

(5) Procurement of Radioactivity

No requisition or purchase order for any radioactive substance will be accepted for purchase by the College unless specific written approval for that purchase is granted by the RSO or RSO, Alt. This entails the completion of a *Radioisotope Purchase Request* form (see Section VII, Appendix A). If the RSO wishes to submit an order, he/she must first obtain approval from an RSO, Alt.

(6) Oversight of Record Keeping and Inspection

The RSO and RSO, Alts. will ensure that proper records are kept regarding the status of the NRC license and all categories of users, as well as the acquisition, use, and the disposal of radioactive material. In addition, the RSO and RSO, Alts. will ensure that proper surveys of work areas and personnel are performed and that adequate records are kept of these surveys as outlined in section IIIC-IIIG. All of the above records shall be kept pursuant to 10CFR20.2101-2206 and 20.2104 for at least three years.

II. BASIC STANDARDS OF MAXIMUM PERMISSIBLE RADIATION EXPOSURE

(Taken from 10CFR20.1201 to 20.1207. Current standards shall in all cases supersede those listed below.)

A. STANDARDS FOR OCCUPATIONAL RADIATION WORKERS

Occupational dose is defined by the NRC as exposure of an individual to radiation in the course of employment in which individual duties involve exposure to radiation.

(1) External Exposure to Critical Organs

Whole body, head and trunk, active blood-forming organs, eyes, and gonads: The Maximum Permissible Dose (MPD) to the most critical organs, accumulated at any age, shall not exceed 5 Rems multiplied by the number of years beyond 18, and the dose in any 13 consecutive weeks shall not exceed 1.25 Rems. Thus, the accumulated MPD = (N-18) x 5 where N is the age in years and is greater than 18.

(2) External Dose to Other Organs

Skin of whole body: MPD = (N-18) Rems, and the dose in any 13 consecutive weeks shall not exceed 7.25 Rems.

Hands and forearms, feet and ankles: MPD = 75 Rems/year, and the dose in any 13 consecutive weeks shall not exceed 18.75 Rems.

(3) Internal Exposure

The permissible levels from internal emitters will be consistent as far as possible with age-proration and dose principles above. Control of the internal dose will be controlled by limiting the body burden of radioisotopes. This is accomplished in the laboratory by prevention of ingestion, inhalation or transcutaneous absorption of radioactive materials. This is achieved by good housekeeping and work habits and by operation in a laboratory with proper equipment for the handling of radioisotopes, including protective coverings, manipulating devices, suitable ventilation, and waste disposal facilities.

(4) Standards for Pregnant Women

The standards of exposure for pregnant women are 0.5 Rem to the whole body during the entire gestation period. The basis for this limit is described in NRC Regulatory Guide 8.13 and 10CFR20.1208 which is available from the RSO. All females of child-bearing age who intend to work with radioactive material must read this guide before working with radioisotopes.

B. POLICIES DESIGNED TO MINIMIZE EXPOSURE (ALARA)

In order to implement work practices that will keep exposures to radiation "As Low As Reasonably Achievable" (**ALARA**, as defined in 10CFR20.1101), the Department of Biology applies to all users the standards for non-occupational workers that are 1/10 the limits of those specified above for Occupational Workers; i.e., **the maximum allowable dose to the whole body per quarter shall not exceed 0.125 Rem (or 0.5 Rem per year)**.

All persons are expected to apply the three following principles when working with radioactive materials:

- **TIME:** Keep the time of exposure at a minimum.
- **DISTANCE:** Keep human tissues at as great a distance from the radiation source as is practicable.
- **SHIELDING:** Keep adequate shielding materials between the source and human tissue.

C. ALARA PROGRAM ASSURANCE REVIEW

At the end of each academic year the RSOs will meet with a Provost-designated representative of the Campus Safety Office to review the radiation protection program content and implementation as defined in 10CFR20.1101. Pursuant to 10CFR20.2102 a report of those findings will be maintained by the Provost for a period of at least three years and will be available to the NRC upon request.

III. HANDLING OF RADIOISOTOPES AND ASSOCIATED RECORD KEEPING

A. DESIGNATION OF RADIOACTIVE WORK AREAS

All areas involving the use of radioactive material will be pre-approved by the RSO and NRC (see I-B4). Areas in which relatively high energy isotopes such as ^{32}P are used must be adequately shielded and clearly labeled. Areas in which lower energy isotopes are employed should be clearly designated on the area survey map for the room involved. All areas in which radioactive materials are located or are being used shall be posted with appropriate radiation hazard signs. In addition, each User shall have a copy of this manual readily accessible and there shall be posted on the laboratory wall a copy of sections IV and V of this manual. Under no circumstances will food or drink be allowed in ANY area which has been approved for the use of radioisotopes. The presence of food wrappers or soft drink cans, for example, in the trash containers of areas in which radioactivity is used will be taken as evidence of food and drink in radioactive areas.

B. PROCUREMENT OF ISOTOPES

As stated in section I-B5, acquisition of all radioactive material must be pre-approved by the RSO or RSO, Alt. The *Radioisotope Purchase Request* forms (see section VII, Appendix A) are available from the RSO or RSO, Alts. in rooms 104, 308, or 314. No order for radioisotopes may be placed with any vendor until RSO approval is obtained.

C. RECEIPT OF RADIOACTIVE MATERIAL

All radioactive materials shipments for the Biology Department are received in Millington room 116. The carrier shall place the package inside the specially marked holding container and the staff person on duty in the room will sign the carrier's receipt. If the package appears to be leaking or damaged in any fashion, the staff person will immediately contact the RSO or RSO Alt. who will remove the package to a radioactive materials restricted work area and closely examine the package for leaks. If the package appears to be intact, the staff person will directly contact the Authorized User or Restricted User to check in the materials according to the procedures outlined below.

An Authorized or Restricted User shall inspect all incoming shipments immediately after receipt according to the following method pursuant to 10CFR20.1706.

1. Put on gloves

2. Visually inspect package for any signs of damage (e.g., wetness, crushed).

3. Measure exposure rate at 3 feet from package surface--record.

4. Measure surface exposure rate and record: If radiation in excess of 200 mrem/hour is detected at the surface in these steps, stop and notify the RSO immediately so the

appropriate NRC and carrier notifications may be made pursuant to 10CFR 71.47.

5. Open the package (following manufacturer's directions, if supplied) and remove packing slip.

3. Open inner package to verify contents (compare requisition, packing slips, and label on bottle). Check integrity of final source container (inspect for breakage of seals or vials, loss of liquid, discoloration of packing material).

4. Wipe external surface of final source container with a 70% ethanol or isopropanol moistened cotton swab or filter paper held with forceps, assay and record where appropriate.

5. Monitor the packing materials and packages before discarding:

   a. if contaminated, treat as radioactive waste

   b. if not, obliterate radiation labels before discarding in regular trash

6. Once the isotope is properly stored, the *Radioisotope Shipment Receipt Report* must be completed as well a *Radioisotope Inventory Record* form (see Section VII, Appendix A which details subsequent isotope usage and disposal.

D. STORAGE OF ISOTOPES

(1) General

All refrigerators or freezers used for radioactive storage shall be clearly labeled with the appropriate warning sign on the door. A *Radioisotope Inventory Record* is to be posted on the door for each stock in storage in that refrigerator or freezer. Each stock container shall be labeled with the isotope, amount of activity and date, name of user, and chemical form.

All radioactive isotopes will be kept in adequately shielded locations which are appropriately labeled with radioactive hazard signs. These storage areas will be secured when not in use.

(2) Stock sources

Radiation at the surface of the containers of any radioactive materials shall not exceed 200 mRem per hour and the container shall be kept in such a place that the radiation intensity at the nearest occupied area is 0.6 mRem per hour or less. Such containers shall be kept in a place not readily accessible to unauthorized personnel when not in use and shall be conspicuously labeled with radiation hazard signs.

(3) Gaseous Products

Radioactive gases or materials with radioactive gaseous vapors must be stored in gas tight containers, and must be kept in areas with satisfactory ventilation, preferably in approved hoods.

(4) Waste Storage

Radioactive waste will be taken to long-term storage in Millington Room 4B for decay-in-storage or to await shipment for disposal. When waste in temporary storage in work areas is taken to Room 4B it must be done under the direct supervision of the RSO or RSO Alt. Before taking the waste to Millington 4B, the Authorized or Restricted User must complete the "*Room 4 Disposal Record*" (see section VII, Appendix A) which provides detailed information on the type and amount of waste. A copy of this will be secured to the waste and another provided to the RSO and RSO Alt. for the permanent record. Arrangements to transfer such waste must be made in advance with the RSO to ensure that all records are complete.

E. USE OF RADIOACTIVE MATERIAL AND ROUTINE SURVEY PROCEDURES

(1) Survey of Work Areas

Radioactive material will be used ONLY in pre-approved areas (see I-B4) which are appropriately labeled and shielded. All glassware and equipment used in experiments with radioactive materials shall be labeled with radioactive warning tape and kept separate from other equipment and not be used for other work until demonstrated to be free of contamination. Immediately following a procedure involving radioactive material, the laboratory area, as well as any equipment used, will be surveyed for the presence of radioactivity and the results of the survey recorded on the *Radiation Survey Report* (see Section VII, Appendix A) appropriate for that work area.

The survey will consist of:

a. A measurement of radiation levels with a survey meter sufficiently sensitive to detect 0.1 mRem/hr and/or

b. A series of swipe tests to measure contamination levels. This method for performing swipe tests will be sufficiently sensitive to detect 100 cpm above background. Routine swipe tests will be made with either commercially prepared alcohol wipes or with Kim-wipes saturated with 70% ethanol having a surface area of 1 in^2 (6.23 cm^2). A swipe will cover an area of at least 100 cm^2. The swab will be counted in the liquid scintillation counter (LSC) to an error no greater than 20%. A permanent record will be kept of all survey results on the *Radiation Survey Report*, recorded in disintegrations per minute (dpm), including negative results.

The record will include:

a. Location, date, and type of equipment (include monitor number) used to perform the survey.

b. Name of person conducting the survey.

c. Measured exposure rates or contamination levels, keyed to location on drawing (point out rates that require corrective action).

d. Corrective action taken in the case of contamination or excessive exposure rates, reduced contamination levels or exposure rates after corrective action, and any appropriate comments.

All areas or equipment which are above background must be: (a) decontaminated or; (b) contained in a designated shielded radioactive area which is adequately labeled as such and which poses no significant levels of exposure to personnel working in the area. Any significant contamination of any surface which cannot be cleaned and which is not in a designated shielded radioactive area shall be reported to the RSO. An area which emits over 2.0 mRems per hour is seriously contaminated and personnel must not work in the area until it is decontaminated under the direction of the RSO.

(2) Calibration of Survey Meters and Liquid Scintillation Counter

At least annually all survey meters will be calibrated for linearity of response at two points separated by 50% of the scale for each scale in use. The counting efficiency for each isotope in use shall also be determined using sources of known activity. These efficiency values shall be displayed on each counter. Each survey meter is to be checked regularly with the operational check source.

The counting efficiency of the liquid scintillation counter should be checked monthly with the appropriate reference standards. A report of the calibration of all instruments is kept as a part of the RSO records pursuant to 10 CFR20.1501.

(3) Personnel Monitoring/Bioassays

Iodine-125 (or 131). Between 24 and 36 hours following work with more than 10 mCi each person involved will provide a urine specimen. The RSO will assay 3.0 ml of urine in 7 ml of scintillation fluid on a Beckman LS5000CE counter programmed for detection of this isotope. If any counts above background are determined for a person, an immediate referral of the person will be made to the Radiation Safety Office, Medical College of Virginia, Richmond, so that a whole thyroid scan may be made. The results and the recommendations of the MCV Radiation Safety Office will be kept as part of the record pursuant to 10CFR20.x. It will be the responsibility of the RSO to notify the subject concerned of the dose acquired and to outline appropriate actions to minimize subsequent exposure.

Phosphorus-32. Hands, face and body will be monitored with a G-M survey meter after use. If contamination is found, urinalysis will be performed at 24 hours. If activity is detected, further urinalyses will be performed daily. If any of the procedures in a designated work area involve the use of more than 100 microcuries of Phosphorus-32 in a 24 hour period, the user concerned must wear a clip-on and ring film dose monitor approved by the RSO. These devices must be obtained prior to commencing work. Reports of any exposure indicated by these devices are maintained by the RSO and provided regularly to the user concerned.

Hydrogen-3 (tritium). In laboratories where the amount of radionuclide used is greater than 10^{-2} Ci, all workers will have a urinalysis not more than one month prior to work, urinalyses will be made at two-week intervals thereafter during periods when tritium is in use.

Carbon-14, Phosphorus-33, and Sulfur-35. In laboratories where the amount used is greater than 10^{-3}Ci, all workers will have one urinalysis prior to beginning work with biweekly urinalyses during its use, and one urinalysis within one month after termination of use of the radionuclide.

(4) Personnel Monitoring -- External Radiation

If an individual suspects that he or she has received an overexposure of external radiation from any source, he/she should immediately inform the RSO for reference to appropriate medical services. The exposed worker should be removed from areas in which he/she might receive more radiation, and should not be allowed to return to work in such areas until authorized by RSO following medical evaluation. The results of all personnel monitoring will be recorded on the *Personnel Monitor Report.*

F. DISPOSAL OF RADIOACTIVE MATERIAL

(1) General Rules

Radioactive waste shall not be disposed of by the conventional methods of disposing of non-radioactive wastes. This means particularly that contaminated liquid wastes may not be discharged into the sink. Contaminated animals should not be incinerated in general purpose incinerators. Radioactive warning labels must be removed or obliterated prior to disposal in a radioactive waste container (see below).

Transport of isotopes between work areas shall be accomplished in a manner that precludes exposure to any person.

(2) Radioactive Waste Containers

Every laboratory using radioactive isotopes must have at least one container for contaminated solid wastes and one for contaminated liquid waste for each isotope being used. Isotopes may be combined when necessary (e.g. for double labeling experiments), but such waste must be clearly labeled as such. Solid (e.g. $\leq$ 1.5 ml of liquid in a microfuge tube) and liquid contaminated wastes shall be kept separately. The container for solid waste must be lined with a sturdy disposable liner.

For liquid wastes other than scintillation fluid, glass jugs or carboys are probably best for storage, although disposable metal cans may be used. If made of glass or ceramic, it must be kept in such a place that if accidentally broken, the contents will be retained in a small area (e.g., set in a large pan). For scintillation fluid wastes, fluids will be disposed of in the designated waste containers in the fume hood in Millington Rm 305 and disposal recorded on the log sheet. Empy vials with low cpm will be placed in the fume hood for washing, Empty vials with high cpm will disposed of in the User's laboratory in an appropriately lined (and labeled) container with a lid that fits securely. Each waste container must be labeled with a Radioactive Hazard sign and be adequately shielded. Maintenance employees (janitors, etc.) must be instructed never to empty them. A precise record of the disposal of all radioactive waste (which includes the type of isotope, the activity date, the amounts disposed in solid and liquid waste and the date of disposal) will be kept by each User and provided to the RSO as requested.

(3) Ultimate Disposal

All radioactive waste will, with the authorization of the RSO, be regularly deposited in the appropriate barrels in Millington Hall, Room 4B where it will be left to decay or be processed for disposal by a licensed commercial firm. All isotopes with half lives of less than 90 days will be left to decay in Room 4B for at least ten (10) half-lives. If radiation levels are background as judged by G-M Survey Meter monitoring for solid waste and liquid scintillation counting for liquid waste, the waste will be disposed of in the regular trash after the removal and/or obliteration of all labels. If radiation levels are above background, the waste will be left to decay until levels reach background.

All isotopes with half lives longer than 90 days will be disposed of by a licensed commercial firm. All radioactive waste deposited in these barrels must be accompanied by a completed *Room 4 Disposal Record* which records the type of isotope, the activity date, the initial activity as well as the present activity.

G. RECORD KEEPING

Specific forms for various aspects of Radiation Safety record keeping are available from the RSO and RSO, Alts. It is the responsibility of each User to keep records on the appropriate forms and to provide the RSO with regular updates of isotope inventory, monitoring of facilities and personnel. A list of available forms is given below (see Section VII, Appendix A):

1. *Application for Radioisotope User Status*
2. *Radioisotope Purchase Request*
3. *Radioisotope Shipment Receipt Report*
4. *Radioisotope Inventory Record*
5. *Room 4 Disposal Record*
6. *Radiation Survey Report*
7. *Personnel Monitor Report*

To avoid tampering or loss, the RSO and RSO, Alt. shall keep safely archived all completed records listed above and shall have access to all current records kept in each work area.

IV. EMERGENCY PROCEDURES

A. MINOR SPILLS:

1. NOTIFY: Notify persons in the area that a spill has occurred.

2. PREVENT THE SPREAD: Cover the spill with absorbent paper.

3. CLEAN UP: Use disposable gloves and handling tongs. Carefully fold the absorbent paper and pad. Insert into a plastic bag and dispose of in a radioactive waste container. Include all other contaminated materials such as disposable gloves.

4. SURVEY: With a G-M Survey Meter, check the area around the spill, your hands and clothing for contamination. Do not leave the area before monitoring.

5. REPORT: Report incident to the RSO as soon as possible

B. MAJOR SPILLS:

1. CLEAR THE AREA: Notify all persons not involved in the spill to vacate the room.

2. PREVENT THE SPREAD: Cover the spill with absorbent pads, but do not attempt to clean it up. Confine the movement of all personnel potentially contaminated to prevent the spread.

3. SHIELD THE SOURCE: If possible, the spill should be shielded, but only if it can be done without further contamination or without significantly increasing your radiation exposure.

4. CLOSE THE ROOM: Leave the room and lock the door(s) to prevent entry. Do not leave the area without first removing all potentially contaminated clothing.

5. CALL FOR HELP: Notify the RSO IMMEDIATELY.

6. PERSONNEL DECONTAMINATION: Contaminated clothing should be removed and stored for further evaluation by the RSO. If the spill is on the skin, flush thoroughly and then wash with mild soap and lukewarm water.

V. BASIC RULES OF RADIATION SAFETY

1. Do not eat, drink, smoke, or apply cosmetics in any laboratory in which work with isotopes is performed.

2. Wash hands thoroughly before handling any object that will be placed in the mouth or on the face (e.g., before smoking, drinking, putting on spectacles, etc.).

3. ALWAYS wear disposable plastic gloves when working with radioactive material.

4. All work must be performed over table surfaces or trays lined with removable, absorbent paper.

5. NEVER PIPETTE RADIOACTIVE SOLUTIONS BY MOUTH. Use remote measuring devices, such as disposable syringes, automatic pipettes with disposable tips, etc.

6. With the authorization of a member of the Radiation Safety Committee, regularly discard all waste material in special labeled containers in Millington Hall, Room 4B. Solid waste containers must be separate from liquid waste containers. All waste containers must be lined with sturdy plastic bags which can be removed and all containers must have lids which fit securely.

7. All radioactive material must be contained in appropriately shielded and labeled containers.

8. All glassware which contains or has contained radioactive substances must be marked with radiation tape or radiation signs until it has been decontaminated.

9. All containers of radioactive substance, including waste, must be labeled as radioactive and must show the date and the type and activity of the isotopic material contained, with radiation level, if applicable. PRIOR TO DISPOSAL OF WASTE IN THE RADIOACTIVE WASTE CONTAINER, ALL RADIOACTIVE WARNING LABELS MUST BE REMOVED OR OBLITERATED FROM THE WASTE MATERIAL.

10. All areas in which radioactive material is used must be secured when no one is immediately present.

11. Surveys must be completed after EACH procedure and must be recorded in DISINTEGRATIONS PER MINUTE (dpm <u>not</u> cpm).

12. Records of radioisotope inventories, disposal, and area surveys must be kept current and easily accessible.

VI. <u>CONTACT PERSONS</u>

2004-2005 RADIOISOTOPES USERS COMMITTEE

NAME	ROOM	OFFICE PHONE	HOME PHONE
Lizabeth Allison	Rm 308	X12232	[redacted]
Eric Bradley	Rm 302	X12220	[redacted]
Mark Forsyth	Rm 214	X12489	
Paul Heideman	Rm 224	X12239	[redacted]
Margaret Saha	Rm 314	X12407	[redacted]
Patty Zwollo	Rm 324	X11969	[redacted]

RADIATION SAFETY OFFICERS	HOME PHONE	OFFICE PHONE
Eric L. Bradley, RSO	[redacted]	221-2220
Margaret S. Saha, RSO, Alt.	[redacted]	221-2407
Lizabeth A. Allison, RSO, Alt.	[redacted]	221-2232

If unable to contact the RSO, or an RSO, Alt., call the Campus Safety Officer Larry Richards at Campus 911.

VII. APPENDIX A – FORMS

1. *Application for Radioisotope User Status*
2. *Radioisotope Purchase Request*
3. *Radioisotope Shipment Receipt Report*
4. *Radioisotope Inventory Record*
5. *Room 4 Disposal Record*
6. *Radiation Survey Report*

APPLICATION FOR RADIOISOTOPE USER STATUS

Part I:

Name: Social Security No:

Date:

Position (e.g. student, tech ...):

Formal Training:
Describe type(s), date(s) and place(s) of training.

On the Job Experience:
List the type of isotope, amount used, the specific application, the dates and frequency of use, and the institution.

Part II:

Please describe in detail all proposed activities involving radioisotopes. This should include the location of the work area, the type of isotope, the amount to be used in each type for experiment and the specific application (e.g. sequencing, synthesizing a radioactive probe for a Southern blot). *This should obviously be in agreement with the paperwork that your PI already has on file.*

I have read and understood (and know) the contents of the Department of Biology Radiation Safety Manual and I understand the provisions of the referenced NRC documents.

Signature: ______________________________________ Date: _______________________

Part III: ***(to be filled out the by PI)***

Please describe any activities for which the user (e.g. student or tech) is authorized to work without direct supervision, that is, the PI within shouting for help distance.

Signature of PI: ____________________________________ Date: _____________________

RADIOISOTOPE
PURCHASE REQUEST #________________________

NAME________________________
ACCOUNT#________________________

BILL TO:
THE COLLEGE OF WILLIAM AND MARY
DEPARTMENT OF BIOLOGY
P.O. BOX 8795
WILLIAMSBURG, VA 23187-8795
PH 757-221-2207/2208/2209
FAX 757-221-6483

SHIP TO:
THE COLLEGE OF WILLIAM AND MARY
DEPARTMENT OF BIOLOGY
ATTN:
MILLINGTON HALL, ROOM 116
WILLIAMSBURG, VA 23185

CIRCLE ONE: TEACH/RESEARCH/DEPT
CIRCLE ONE: OVERNIGHT/2 DAY/GROUND

VENDOR:________________________
ADDRESS________________________
____
PHONE________________________
FAX________________________
CUSTOMER #________________________
FIN#________________________

CONFIRMATION#________________________
REQUISTION BY:________________________
CUSTOMER SVC REP________________________
DATE____________**TIME**____________

NO.	QTY	UNIT	CATALOG #	DESCRIPTION	PRICE	AMOUNT
1						
2						
3						
4						
5						
6						
7						

Describe the radioisotope protocol(s):

SUBTOTAL__________
S/H __________
TOTAL __________

Laboratory PI: ____

____
RADIATION SAFETY OFFICER OR ALTERNATE
DATE:

RADIOACTIVE SHIPMENT RECEIPT REPORT

PO # ______________________________ Survey Date _____________ Time _________

Vendor ____________________________ Survey by: ______________________________

Condition of package on receipt:
Intact: _______ Broken or Damaged: _____ Describe damage___________________

Shipping package radiation levels: At the Surface _____________________________ mR/hr

3 feet from Surface _________________________ mR/hr

GM Survey meter used: _________________Calibration Date: ________________________

PACKAGE CONTENTS DETAIL

Radioisotope ______________________

Chemical Form ____________________

Amount ______________________ uCi

Describe any discrepancies between packing slip and package contents:

If DOT/NRC/ Carrier notification is required enter details here:

SURVEY OF OPENED PACKAGE AND PRIMARY CONTAINER

Survey with *GM survey meter* if the radioisotope is Iodine 125, Iodine 131, or P32

Record the activity: Packing Material ________mR/h Primary Container ________mR/h

GM Survey meter used: ___________________ Calibration Date: _____________________
--------OR------
If the isotope is H3, C14, S35, or P33 then conduct wipe tests on the shipping container and the primary container with 70% ethanol or isopropanol using *liquid scintillation counting*.

Shipping Package: ____________ CPM _________________ DPM

Primary Container: ____________ CPM _________________ DPM

Final disposition of the shipping package :

RADIOISOTOPE INVENTORY RECORD

Isotope ______________________________ Vendor ______________________________

Date Received ______________________________ Purchase Order # ______________________________

Activity Date ______________________________ Lot # ______________________________

Specific Activity ______________________________ Storage Room ______________________________

Total Volume ______________________________ Location in Room ______________________________

uCi/ul ______________________________

RECORD OF USE

RECORD OF DISPOSAL

						[-------Solid Waste------]				[----Liquid Waste-----]		
User Name	**Date Removed**	**Volume Removed**	**uCi Removed**	**uCi Remaining**		**uCi**	**Date**	**Date to Room 4**		**uCi**	**Date**	**Date to Room 4**

Activity Date: **Isotope:** **Liquid / Solid**

ROOM 4 DISPOSAL RECORD

Date of Disposal in Room 4:

Name of Restricted/Authorized User:

Name of PI:

Name of Person Completing Sheet:

Isotope and Company:

Purchase Order Number:

Lot Number:

Activity of disposed material, as of the activity date of the isotope:
(to be calculated from Inventory Record)

Current Activity (decay corrected for ^{35}S and ^{32}P) as of Room 4 disposal date:

Make three copies of each sheet, one to be attached to the waste bag, one to be given to the RSO, and one for the PIs records)

FINAL DISPOSAL RECORD

Date of Final Disposal:

Number of half-lives (for decay-in-storage isotopes only):

Method for confirming material is at background level for decay-in storage isotopes only (e.g. scintillation counting, GM survey):

Results of counting or survey: Your initials:

Method of Disposal (sanitary sewer, dumpster, commercial pickup):

RADIATION SURVEY REPORT

ROOM # __________

All recordings must be in DPM (not CPM).
For all liquid scintillation wipe test results apply the appropriate efficiency correction for the isotope in use. Correct the CPM readings from a GM Survey meter with the efficiency recorded on the meter. If necessary, attach a map of the room to indicate the location of bench areas, refrigerators, freezers, and other items that are not identified by name.

		DATE	DATE	DATE	DATE
		GM #	GM#	GM#	GM#
ITEM		NAME	NAME	NAME	NAME
Refrigerator 1					
Refrigerator 2					
Freezer 1					
Ultracold					
Centrifuge					
Water bath					
Pipetman					
Bench 1					
Bench 2					
Sink					
Telephone					

VIII. APPENDIX B – FACT SHEETS FOR COMMONLY USED ISOTOPES

TABLE 1. SUMMARY OF PROPERTIES OF COMMONLY USED ISOTOPES

Symbol & Name	Type of Radiation	Energy (MeV)	Distance Traveled in Air	Half-life	Safety Measures	Monitoring Method
^{14}C Carbon-14	Beta	0.156	22 cm (8.6 in)	5730 years	Wear gloves; use 1 cm lucite plastic shielding* when working with source; avoid inhalation of $^{14}CO_2$	Swipe test (LSC)
^{125}I Iodine-125	Gamma (γ) X-ray	γ: 0.035 X-ray: 0.027, 0.031	km (miles)	60.14 days	Use 3 mm lead shielding; wear gloves; work in fume hood for volatile components	NaI detector or GM counter
^{131}I Iodine-131	Beta (β) Gamma (γ) X-ray	β: 0.606 γ: 0.364, 0.637 X-ray: 0.030	Gamma: km (miles) Beta: 165 cm (65 in)	8.04 days	Use 3 mm lead shielding; wear gloves; work in fume hood for volatile components	NaI detector or GM counter
^{32}P Phosphorus-32	Beta	1.71	6 m (20 ft)	14.29 days	Use 1 cm lucite plastic shielding*; wear gloves and eye protection	GM counter
^{33}P Phosphorus-33	Beta	0.249	46 cm (18 in)	25.4 days	Use 1 cm lucite plastic shielding*; wear gloves	Swipe test (LSC)
^{35}S Sulfur-35	Beta	0.167	24 cm (9.6 in)	87.4 days	Wear gloves, use 1 cm lucite plastic shielding* when working with source; ^{35}S methionine may vaporize during incubations.	Swipe test (LSC)
^{3}H Tritium (Hydrogen-3)	Beta	0.019	4.7 mm (0.19 in)	12.28 years	Wear gloves (some compounds can be absorbed through skin).	Swipe test (LSC)

*Use of lead shielding may create Bremsstrahlung radiation.

Carbon-14
Handling Precautions

^{14}C
5730 y
β^- 0.156
No γ
E 0.156

Physical Data

Maximum Beta Energy: 0.156 MeV (100%)[1]

Maximum Range of Beta in Air: 22 cm (8.6 in.)[2]

Occupational Limits[3]

Annual Limit on Intake: 2 mCi (74 MBq).

Derived Air Concentration: 1 x 10^{-6} µCi/ml (37 kBq/m³).

Dosimetry

Millicurie (37 MBq) quantities of ^{14}C do not present a significant external exposure hazard because the low-energy betas emitted barely penetrate the outer dead layer of skin. ^{14}C-labeled compound uptake may be assumed to be uniformly distributed throughout all organs and tissues in the body[4]. Most ^{14}C-labeled compounds are rapidly metabolized and the radionuclide is exhaled as $^{14}CO_2$. Some compounds and their metabolites are eliminated via the urine. Biological half lives vary from a few minutes to 40 days[4].

PerkinElmer has developed the following suggestions for handling Carbon-14 after years of experience working with this low-energy beta emitter.

General Handling Precautions for Carbon-14

1. Designate area for handling ^{14}C and clearly label all containers.
2. Prohibit eating, drinking, smoking and mouth pipetting in room where ^{14}C is handled.
3. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
4. Handle potentially volatile compounds in ventilated enclosures.
5. If enhanced containment is necessary, handle volatile compounds in closed systems vented through suitable traps.
6. Sample exhausted effluent and room air by drawing a known volume through a membrane filter followed by an impinger containing dilute NaOH.
7. Wear disposable lab coats, wrist guards and gloves for secondary protection.
8. Select gloves appropriate for chemicals handled.
9. Maintain contamination and exposure control by regularly monitoring and promptly decontaminating gloves and surfaces.
10. Use pancake or end-window Geiger-Mueller detectors or liquid scintillation counter to detect ^{14}C.
11. Submit periodic urine and breath samples (as appropriate) for bioassay to determine uptake by personnel.

12. Isolate waste in sealed, clearly labeled containers and dispose according to approved guidelines.
13. Establish air concentration, surface contamination and bioassay action levels below regulatory limits. Investigate and correct any conditions that may cause these levels to be exceeded.
14. On completing an operation, secure all ^{14}C; remove and dispose of protective clothing and coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

Some ^{14}C-labeled compounds may penetrate gloves and skin. Handle these compounds remotely, wear two pairs of gloves and change the outer layer frequently. Special caution should be observed when handling ^{14}C-labeled halogenated acids. These compounds can be incorporated in the skin and deliver local dose commitments in the order of 10-100 rad per µCi (3-30 Gy per MBq) deposited.

References

1. Kocher, David C., Radioactive Decay Data Tables, Springfield: National Technical Information Service, 1981 DOE/TIC-11026.
2. Kaplan, Irving, Nuclear Physics, New York: Addison-Wesley, 1964.
3. U.S. Nuclear Regulatory Commission. 10CFR 20 Appendix B – Standards for Protection Against Radiation, 1994.
4. ICRP Publication 30, Part 3, Limits for Intakes of Radionuclides by Workers. Pergamon Press, Oxford, 1981.

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Iodine-125
Handling Precautions

^{125}I
60.14 d
EC
γ 0.035
E 0.177

Physical Data

Principal Radiation Emissions[1]

Gamma:	0.035 MeV (6.5%)
Kα X-ray:	0.027 MeV (112.5%)
Kβ X-ray:	0.031 MeV (25.4%)

Unshielded Exposure Rate for 1 mCi Point Source at 1 cm: 1.4 R/h[2]

Unshielded Exposure Rate from 1 MBq Point Source at 1 m: 0.98 nC/kg/h

Half-Value Layer for Lead Shielding: 0.02 mm (0.001 in.)[2]

Occupational Limits[3]

Annual Limit on Intake: 40 µCi (1.5 MBq) for oral ingestion and 60 µCi (2.2 MBq) for inhalation.

Derived Air Concentration: 3×10^{-8} µCi/ml (1.1 kBq/m^3).

Dosimetry

Gamma and X-ray emissions from ^{125}I can present a penetrating external exposure hazard. Individual iodine metabolism can vary considerably[4]. It may be assumed that 30% of an uptake of iodine is translocated to the thyroid and 70% directly excreted in urine[4]. Iodine in the thyroid is retained with a biological half-life of 120 days in the form of organic iodine. Organic iodine is assumed to be uniformly distributed in all organs and tissues of the body except the thyroid, and retained with a biological half-life of 12 days[4]. 10% of organic iodine is directly excreted in feces and the rest is returned to the transfer compartment as inorganic iodine[4]. Retention in the thyroid is reduced by the short physical half-life of ^{125}I.

Decay Table

Physical Half-Life: 60.14 Days[1]

To use the decay table, find the number of days in the top and left hand columns of the chart, then find the corresponding decay factor. To obtain a precalibration number, divide by the decay factor. For a postcalibration number, multiply by the decay factor.

Days	0	2	4	6	8	10	12	14	16	18
0	1.000	0.977	0.955	0.933	0.912	0.891	0.871	0.851	0.831	0.812
20	0.794	0.776	0.758	0.741	0.724	0.707	0.691	0.675	0.660	0.645
40	0.630	0.616	0.602	0.588	0.574	0.561	0.548	0.536	0.524	0.512
60	0.500	0.489	0.477	0.467	0.456	0.445	0.435	0.425	0.416	0.406
80	0.397	0.388	0.379	0.370	0.362	0.354	0.345	0.338	0.330	0.322
100	0.315	0.308	0.301	0.294	0.287	0.281	0.274	0.268	0.262	0.256
120	0.250	0.244	0.239	0.233	0.228	0.223	0.218	0.213	0.208	0.203
140	0.198	0.194	0.189	0.185	0.181	0.177	0.173	0.169	0.165	0.161
160	0.157	0.154	0.150	0.147	0.144	0.140	0.137	0.134	0.131	0.128
180	0.125	0.122	0.119	0.117	0.114	0.111	0.109	0.106	0.104	0.102
200	0.099	0.097	0.095	0.093	0.090	0.088	0.086	0.084	0.082	0.081
220	0.079	0.077	0.075	0.073	0.072	0.070	0.069	0.067	0.065	0.064
240	0.063	0.061	0.060	0.058	0.057	0.056	0.054	0.053	0.052	0.051

PerkinElmer®
precisely.

PerkinElmer has developed the following suggestions for handling Iodine-125 after years of experience working with this low-energy x-ray emitter.

General Handling Precautions for Iodine-125

1. Designate area for handling ^{125}I and clearly label all containers.
2. Store millicurie (37 MBq) quantities of ^{125}I in containers surrounded by 3 mm (0.125-in.) thick lead.
3. Wear extremity and whole body dosimeters while handling 10 mCi (370 MBq) quantities of ^{125}I.
4. Use shielding to minimize exposure while handling ^{125}I.
5. Use tools to indirectly handle unshielded multi-millicurie (multi-37 MBq) sources and potentially contaminated vessels.
6. Prohibit eating, drinking, smoking and mouth pipetting in room where ^{125}I is handled.
7. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
8. Handle potentially volatile compounds in ventilated enclosures.
9. Handle millicurie (37 MBq) quantities in closed systems vented through activated charcoal traps.
10. Sample exhausted effluent by continuously drawing a known quantity of air through cartridges containing activated charcoal.
11. Wear disposable lab coat, wrist guards and gloves for secondary protection.
12. Select gloves appropriate for chemicals handled.
13. Maintain contamination and exposure control by regularly monitoring and promptly decontaminating gloves and surfaces.
14. Use NaI(Tl) detector or liquid scintillation counter to detect ^{125}I.
15. Submit urine sample for bioassay from 4 to 48 hours after handling ^{125}I to indicate uptake by personnel.
16. Monitor thyroid periodically with a NaI(Tl) detector to determine thyroid dose.
17. Isolate waste in sealed, clearly labeled containers. Store in ventilated enclosure. Consider holding for decay or dispose according to approved guidelines.
18. Establish surface contamination, air concentration, urinalysis and thyroid burden action levels below regulatory limits. Investigate and correct any conditions that may cause these levels to be exceeded.
19. On completing an operation, secure all ^{125}I, remove and dispose of protective clothing and coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

Store $Na^{125}I$ solutions at room temperature because freezing results in subsequent volatilization of radioiodine. Avoid acidic solutions to minimize volatilization. Some radioiodine compounds may penetrate gloves and skin. Therefore, these compounds should be handled indirectly by using tools and wearing two pairs of gloves. The outer layer of gloves should be changed frequently and whenever they are suspected to be contaminated.

References

1. Kocher, David C., Radioactive Decay Data Tables, Springfield: National Technical Information Service, 1981 DOE/TIC-11026.
2. Calculated with computer code "Gamma" utilizing decay scheme data from Kocher(1) and mass attenuation coefficients for lead and mass energy absorption coefficients for air from the Radiological Health Handbook, Washington: Bureau of Radiological Health, 1970. The HVL reported here is the initial HVL for narrow beam geometry.
3. U.S. Nuclear Regulatory Commission. 10CFR 20 Appendix B – Standards for Protection Against Radiation, 1994.
4. ICRP Publication 30, Part 2, Limits for Intakes of Radionuclides by Workers. Pergamon Press, Oxford, 1979.

This document contains general information designed to provide a basic understanding of radiation safety. While we believe the information to be accurate, regulatory requirements may change and information contained herein is not tailored to individual needs. A radiation protection specialist should be consulted for specific applications.

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Iodine-131
Handling Precautions

^{131}I
8.04 d
ß⁻ 0.606
γ 0.364
0.637
E 0.971

Physical Data

Principal Radiation Emissions[1]

Maximum Beta Energies:	0.248 MeV (2.1%)
	0.334 MeV (7.4%)
	0.606 MeV (89.3%)
Gammas:	0.723 MeV (1.8%)
	0.637 MeV (7.3%)
	0.364 MeV (81.2%)
	0.284 MeV (6.1%)
	0.080 MeV (2.6%)
X-Ray:	0.030 MeV (3.9%)

Maximum Range of Beta in Air: 165 cm (65 in.)[2]

Unshielded Exposure Rate at 1 cm from a 1 mCi Point Source: 2.16 R/h[3]

Unshielded Exposure Rate at 1 m from a 1 MBq Point Source: 1.5 nC/kg/h

Half-Value Layer for Lead Shielding: 2.3 mm (0.091 in.)[3]

Occupational Limits[4]

Annual Limit on Intake: 30 µCi (1.1 MBq) for oral ingestion and 50 µCi (1.8 MBq) for inhalation.

Derived Air Concentration: 2 x 10^{-8} µCi/ml (740 Bq/m^3).

Dosimetry

Beta emission from ^{131}I can present an external exposure hazard to skin and eyes. Gamma emissions can present a penetrating external exposure hazard. Individual iodine metabolism can vary considerably[5]. It may be assumed that 30% of an uptake of iodine is translocated to the thyroid and 70% directly excreted in urine[5]. Iodine in the thyroid is retained with a biological half-life of 120 days in the form of organic iodine. Organic iodine is assumed to be uniformly distributed in all organs and tissues of the body except the thyroid, and retained with a biological half-life of 12 days[5]. 10% of organic iodine is directly excreted in feces and the rest is returned to the transfer compartment as inorganic iodine[5]. The committed dose is significantly reduced due to the short physical half-life of ^{131}I[5].

Decay Table

Physical Half-Life: 8.04 Days[1]

To use the decay table, find the number of days in the top and left hand columns of the chart, then find the corresponding decay factor. To obtain a precalibration number, divide by the decay factor. For a postcalibration number, multiply by the decay factor.

Days	0	1	2	3	4	5	6	7	8	9
0	1.000	0.917	0.842	0.772	0.708	0.650	0.596	0.547	0.502	0.460
10	0.422	0.387	0.355	0.326	0.299	0.274	0.252	0.231	0.212	0.194
20	0.178	0.164	0.150	0.138	0.126	0.116	0.106	0.098	0.090	0.082
30	0.075	0.069	0.063	0.058	0.053	0.049	0.045	0.041	0.038	0.035

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PerkinElmer has developed the following suggestions for handling Iodine-131 after years of experience working with this beta, gamma and x-ray emitter.

General Handling Precautions for Iodine-131

1. Designate area for handling ^{131}I and clearly label all containers.
2. Store ^{131}I behind lead shielding.
3. Wear extremity and whole body dosimeters while handling mCi (37 MBq) quantities of ^{131}I.
4. Use shielding to minimize exposure while handling ^{131}I.
5. Do not work over open containers.
6. Use tools to indirectly handle unshielded sources and potentially contaminated vessels.
7. Prohibit eating, drinking, smoking and mouth pipetting in room where ^{131}I is handled.
8. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
9. Handle potentially volatile compounds in ventilated enclosures.
10. Handle millicurie (37 MBq) quantities in closed systems vented through activated charcoal traps.
11. Sample exhausted effluent and room air by continuously drawing a known volume through cartridges containing activated charcoal.
12. Wear lab coat, wrist guards and disposable gloves for secondary protection.
13. Select gloves appropriate for chemicals handled.
14. Maintain contamination and exposure control by regularly monitoring and promptly decontaminating gloves and surfaces.
15. Use pancake or end-window Geiger-Mueller detector, NaI(Tl) detector or liquid scintillation counter to detect ^{131}I.
16. Submit urine sample for bioassay from 4 to 48 hours after handling ^{131}I to indicate uptake by personnel.
17. Monitor thyroid periodically with a NaI(Tl) detector to determine thyroid dose.
18. Isolate waste in sealed, clearly labeled shielded containers and hold for decay.
19. Establish surface contamination, air concentration, urinalysis and thyroid burden action levels below regulatory limits. Investigate and correct any conditions which may cause these levels to be exceeded.
20. On completing an operation, secure all ^{131}I; remove protective clothing and dispose of protective coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

Store $Na^{131}I$ solutions at room temperature because freezing results in volatilization. Avoid acidic solutions to minimize volatilization. Some radioiodine compounds may penetrate gloves and skin. Therefore, these compounds should be handled indirectly by using tools and wearing two pairs of gloves. The outer layer of gloves should be changed frequently and whenever they are suspected to be contaminated.

References

1. Kocher, David C., Radioactive Decay Data Tables, Springfield: National Technical Information Service, 1981 DOE/TIC-11026.
2. Kaplan, Irving, Nuclear Physics, New York: Addison-Wesley, 1964.
3. Calculated with computer code "Gamma" utilizing decay scheme data from Kocher(1) and mass attenuation coefficients for lead and mass energy absorption coefficients for air from the Radiological Health Handbook, Washington: Bureau of Radiological Health, 1970. The HVL reported here is the initial HVL for narrow beam geometry.
4. U.S. Nuclear Regulatory Commission. 10CFR 20 Appendix B – Standards for Protection Against Radiation, 1994.
5. ICRP Publication 30, Part 1, Limits for Intakes of Radionuclides by Workers. Pergamon Press, Oxford, 1979.

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Phosphorus-32
Handling Precautions

^{32}P
14.29 d
β- 1.71
No γ
E 1.71

Physical Data

Maximum Beta Energy: 1.71 MeV (100%)[1]

Maximum Range of Beta in Air: 6 m (20 ft)[2]

Maximum Range of Beta in Water: 8 mm (0.3 in)[2]

Occupational Limits[3]

Annual Limit on Intake: 600 µCi (22 MBq) for oral ingestion and 400 µCi (15 MBq) for inhalation.

Derived Air Concentration: 2 x 10^{-7} µCi/ml (7.4 kBq/m^3)

Dosimetry

The high-energy beta emissions from ^{32}P can present a substantial skin and eye dose hazard. Multi 100-millicurie (multi 3.7 GBq) quantities of ^{32}P can produce significant secondary radiation, presenting a more penetrating external exposure hazard. Uptakes of phosphorus are assumed to be retained with a biological half-life of 0.5 days[4]. Of this phosphorus, 15% is rapidly excreted, 15% is retained in intracellular fluids with a biological half-life of 2 days; 40% is retained in soft tissue with a biological half-life of 19 days; and 30% retained permanently in mineral bone where ^{32}P is reduced by radioactive decay[4].

Decay Table

Physical Half-Life: 14.29 Days[1]

To use the decay table, find the number of days in the top and left hand columns of the chart, then find the corresponding decay factor. To obtain a precalibration number, divide by the decay factor. For a postcalibration number, multiply by the decay factor.

Days	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
0	1.000	0.976	0.953	0.930	0.908	0.886	0.865	0.844	0.824	0.804
5	0.785	0.766	0.748	0.730	0.712	0.695	0.678	0.662	0.646	0.631
10	0.616	0.601	0.587	0.573	0.559	0.545	0.532	0.520	0.507	0.495
15	0.483	0.472	0.460	0.449	0.438	0.428	0.418	0.408	0.398	0.388
20	0.379	0.370	0.361	0.353	0.344	0.336	0.328	0.320	0.312	0.305
25	0.297	0.290	0.283	0.277	0.270	0.264	0.257	0.251	0.245	0.239
30	0.233	0.228	0.222	0.217	0.212	0.207	0.202	0.197	0.192	0.188
35	0.183	0.179	0.174	0.170	0.166	0.162	0.158	0.155	0.151	0.147
40	0.144	0.140	0.137	0.134	0.130	0.127	0.124	0.121	0.118	0.116
45	0.113	0.110	0.107	0.105	0.102	0.100	0.098	0.095	0.093	0.091
50	0.088	0.086	0.084	0.082	0.080	0.078	0.077	0.075	0.073	0.071
55	0.069	0.068	0.066	0.065	0.063	0.062	0.060	0.059	0.057	0.056
60	0.054	0.053	0.052	0.051	0.049	0.048	0.047	0.046	0.045	0.044

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PerkinElmer has developed the following suggestions for handling Phosphorus-32 after years of experience working with this high-energy beta emitter.

General Handling Precautions for Phosphorus-32

1. Designate area for handling ^{32}P and clearly label all containers.
2. Store ^{32}P behind lead shielding.
3. Wear extremity and whole body dosimeters while handling mCi (37 MBq) quantities.
4. Handle millicurie (37 MBq) quantities of ^{32}P behind 1-cm (0.375-in.) thick Lucite® shielding. Where necessary, increase shielding by attaching 3-mm to 6-mm (0.125-in. to 0.25-in.) thick lead sheets to the outside of the Lucite® to reduce secondary radiation.
5. Do not work over open containers.
6. Practice routine operations to improve dexterity and speed before using ^{32}P.
7. Avoid skin exposure by using tools to indirectly handle unshielded sources and potentially contaminated vessels.
8. Prohibit eating, drinking, smoking and mouth pipetting in room where ^{32}P is handled.
9. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
10. Handle potentially volatile chemical forms in ventilated enclosures.
11. If airborne activity is suspected, sample exhausted effluent and room air by continuously drawing a known volume through membrane filters.
12. Use lab coat, wrist guards and disposable gloves for secondary protection.
13. Regularly monitor and promptly decontaminate gloves and surfaces to maintain contamination and exposure control.
14. Use pancake or end-window Geiger-Mueller detectors, NaI(T1) detector or liquid scintillation counter to detect ^{32}P.
15. Submit urine samples for bioassay from two hours to seven days after handling ^{32}P to indicate uptake by personnel.
16. Isolate waste in clearly labeled shielded containers and hold for decay.
17. Establish surface contamination, air concentration and urinalysis action levels below regulatory limits. Investigate and correct conditions that may cause these levels to be exceeded.
18. On completing an operation, secure all ^{32}P; remove protective clothing; dispose of protective coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

The dose rate at the mouth of an open combi-vial containing 1 mCi (37 MBq) of ^{32}P in 1 ml of liquid is roughly 26 rem/hour (260 mSv/hour(5). Since this dose rate will not be attenuated significantly by air, shielding materials should be placed between the source and personnel to absorb most of the radiation. The best shield for a ^{32}P source is a material like Lucite 1-cm (0.375-in.) thick, or other plastic that will absorb the beta particles while generating little secondary radiation. For millicurie (37 MBq) amounts of ^{32}P, thin, high-density shielding, such as lead 3-mm to 6-mm (0.125-in. to 0.25-in.) thick, should be added to the exterior of the Lucite shield to absorb the more penetrating secondary radiation.

A high local dose can be received if the radioactive material is touched and allowed to remain on the skin or gloves. Both the hands and face can receive a considerable dose of radiation near an open container of ^{32}P, particularly if the radioactivity is in a concentrated form. Therefore, never work over an open container of ^{32}P.

References

1. Kocher, David C., Radioactive Decay Data Tables, Springfield: National Technical Information Service, 1981 DOE/TIC-11026.
2. Kaplan, Irving, Nuclear Physics, New York: Addison-Wesley, 1964.
3. U.S. Nuclear Regulatory Commission 10 CFR 20 Appendix B – Standards for Protection Against Radiation, 1994.
4. ICRP Publication 30, Part 2, Limits for Intakes of Radionuclides by Workers. Pergamon Press, Oxford, 1979.
5. Measurements made using Landauer TLD 100 chips extremity badges.

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Phosphorus-33
Handling Precautions

^{33}P
25.4 d
ß⁻ 0.249
No γ
E 0.249

Physical Data

Maximum Beta Energy: 0.249 MeV (100%)[1]

Maximum Range of Beta in Air: 46 cm (18 in.)[2]

Occupational Limits[3]

Annual Limit on Intake: 6 mCi (220 MBq) for oral ingestion and 3 mCi (110 MBq) for inhalation.

Dosimetry

Millicurie (37 MBq) quantities of ^{33}P do not present a significant external exposure hazard because the low-energy betas emitted barely penetrate gloves and the outer dead layer of skin. Uptakes of phosphorus are assumed to be retained with a biological half-life of 0.5 days[4]. Of this phosphorus, 15% is rapidly excreted; 15% is retained in intracellular fluids with a biological half-life of 2 days; 40% is retained in soft tissue with a biological half-life of 19 days; and 30% retained permanently in mineral bone where ^{33}P is reduced by radioactive decay[4].

Decay Table

Physical Half-Life: 25.4 Days[1]

To use the decay table, find the number of days in the top and left hand columns of the chart, then find the corresponding decay factor. To obtain a precalibration number, divide by the decay factor. For a postcalibration number, multiply by the decay factor.

Days	0	1	2	3	4	5	6	7	8	9
0	1.000	0.973	0.947	0.921	0.897	0.872	0.849	0.826	0.804	0.782
10	0.761	0.741	0.721	0.701	0.683	0.664	0.646	0.629	0.612	0.595
20	0.579	0.564	0.549	0.534	0.520	0.506	0.492	0.479	0.466	0.453
30	0.441	0.429	0.418	0.406	0.395	0.385	0.374	0.364	0.355	0.345
40	0.336	0.327	0.318	0.309	0.301	0.293	0.285	0.277	0.270	0.263
50	0.256	0.249	0.242	0.236	0.229	0.223	0.217	0.211	0.205	0.200
60	0.195	0.189	0.184	0.179	0.174	0.170	0.165	0.161	0.156	0.152
70	0.148	0.144	0.140	0.136	0.133	0.129	0.126	0.122	0.119	0.116
80	0.113	0.110	0.107	0.104	0.101	0.098	0.096	0.093	0.091	0.088
90	0.086	0.084	0.081	0.079	0.077	0.075	0.073	0.071	0.069	0.067
100	0.065	0.064	0.062	0.060	0.059	0.057	0.055	0.054	0.053	0.051
110	0.050	0.048	0.047	0.046	0.045	0.043	0.042	0.041	0.040	0.039
120	0.038	0.037	0.036	0.035	0.034	0.033	0.032	0.031	0.030	0.030

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PerkinElmer has developed the following suggestions for handling Phosphorus-33 after years of experience working with this low-energy beta emitter.

General Handling Precautions for Phosphorus-33

1. Designate area for handling ^{33}P and clearly label all containers.
2. Prohibit eating, drinking, smoking and mouth pipetting in room where ^{33}P is handled.
3. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
4. Handle ^{33}P compounds that are potentially volatile or in powder form in ventilated enclosures.
5. If airborne activity is suspected, sample exhausted effluent and room air by continuously drawing a known volume through membrane filters.
6. Wear lab coat, wrist guards and disposable gloves for secondary protection.
7. Maintain contamination control by regularly monitoring and promptly decontaminating gloves and surfaces.
8. Use pancake or end-window Geiger-Mueller detector or liquid scintillation counter to detect ^{33}P.
9. Submit urine samples for bioassay from two hours to seven days after handling ^{33}P to indicate uptake by personnel.
10. Isolate waste in clearly labeled containers and hold for decay.
11. Establish surface contamination, air concentration and urinalysis action levels below regulatory limits. Investigate and correct any conditions which may cause these levels to be exceeded.
12. On completing an operation, secure all ^{33}P; remove protective clothing; dispose of protective coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

References

1. Kocher, David C., Radioactive Decay Data Tables, Springfield: National Technical Information Service, 1981 DOE/TIC-11026.
2. Kaplan, Irving, Nuclear Physics, New York: Addison-Wesley, 1964.
3. U.S. Nuclear Regulatory Commission. 10CFR 20 Appendix B – Standards for Protection Against Radiation, 1994.
4. ICRP Publication 30, Part 1, Limits for Intakes of Radionuclides by Workers. Pergamon Press, Oxford, 1979.

This document contains general information designed to provide a basic understanding of radiation safety. While we believe the information to be accurate, regulatory requirements may change and information contained herein is not tailored to individual needs. A radiation protection specialist should be consulted for specific applications.

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Sulfur-35
Handling Precautions

^{35}S
87.4 d
ß⁻ 0.167
No γ
E 0.167

Physical Data

Maximum Beta Energy: 0.167 MeV (100%)[1]

Maximum Range of Beta in Air: 24 cm (9.6 in.)[2]

Occupational Limits[3]

Annual Limit on Intake: 6 mCi (220 MBq) for oral ingestion and 2 mCi (74 MBq) for inhalation.

Derived Air Concentration: 9×10^{-7} μCi/ml (33 kBq/m^3).

Dosimetry

Millicurie (37 MBq) quantities of ^{35}S do not present a significant external exposure hazard since the low-energy emissions barely penetrate the outer dead layer of skin. The metabolism and retention of sulfur compounds in the body vary considerably for different chemical forms[4]. Sulfur uptakes are assumed to be uniformly distributed throughout all organs and tissues in the body[4]. For uptakes of inorganic sulfur, 15% is assumed to be retained with a 20 day biological half-life and 5% retained with a 2,000 day biological half-life. The remaining 80% is assumed to be rapidly excreted[4].

Decay Table

Physical Half-Life: 87.4 days[1]

To use the decay table, find the number of days in the top and left hand columns of the chart, then find the corresponding decay factor. To obtain a precalibration number, divide by the decay factor. For a postcalibration number, multiply by the decay factor.

Days	0	3	6	9	12	15	18	21	24	27
0	1.000	0.976	0.954	0.931	0.909	0.888	0.867	0.847	0.827	0.807
30	0.788	0.770	0.752	0.734	0.717	0.700	0.683	0.667	0.652	0.636
60	0.621	0.607	0.592	0.579	0.565	0.552	0.539	0.526	0.514	0.502
90	0.490	0.478	0.467	0.456	0.445	0.435	0.425	0.415	0.405	0.395
120	0.386	0.377	0.368	0.359	0.351	0.343	0.335	0.327	0.319	0.312
150	0.304	0.297	0.290	0.283	0.277	0.270	0.264	0.258	0.252	0.246
180	0.240	0.234	0.229	0.223	0.218	0.213	0.208	0.203	0.198	0.194
210	0.189	0.185	0.180	0.176	0.172	0.168	0.164	0.160	0.156	0.153
240	0.149	0.146	0.142	0.139	0.136	0.132	0.129	0.126	0.123	0.120
270	0.118	0.115	0.112	0.109	0.107	0.104	0.102	0.099	0.097	0.095
300	0.093	0.090	0.088	0.086	0.084	0.082	0.080	0.078	0.077	0.075
330	0.073	0.071	0.070	0.068	0.066	0.065	0.063	0.062	0.060	0.059
360	0.058	0.056	0.055	0.054	0.052	0.051	0.050	0.049	0.048	0.046

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PerkinElmer has developed the following suggestions for handling Sulfur-35 after years of experience working with this low-energy beta emitter.

General Handling Precautions for Sulfur-35

1. Designate area for handling ^{35}S and clearly label all containers.
2. Prohibit eating, drinking, smoking and mouth pipetting in room where ^{35}S is handled.
3. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
4. Handle potentially volatile compounds in ventilated enclosures.
5. If enhanced containment is necessary, handle volatile compounds in closed systems vented through suitable traps.
6. Sample exhausted effluent and room air by drawing a known volume through a membrane filter followed by an impinger containing dilute NaOH.
7. Wear disposable lab coat, gloves and wrist guards for secondary protection.
8. Select appropriate gloves for chemicals handled.
9. Maintain contamination and exposure control by regularly monitoring and promptly decontaminating gloves and surfaces.
10. Use pancake or end-window Geiger-Mueller detector or liquid scintillation counter to detect ^{35}S.
11. Submit periodic urine samples for bioassay to indicate uptake by personnel.
12. Isolate waste in clearly labeled sealed containers and hold for decay.
13. Establish air concentration, surface contamination and bioassay action levels below regulatory limits. Investigate and correct any conditions that may cause these levels to be exceeded.
14. On completing an operation, secure all ^{35}S; remove protective clothing and dispose of protective coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

^{35}S may be difficult to distinguish from ^{14}C because the beta emissions are of similar energy. If ^{14}C and ^{35}S are being used in the same area, establish controls that are conservative for both radionuclides. Some ^{35}S compounds, including Methionine, generate volatile fractions particularly during lyophilization or incubation. Check for airborne and surface contamination. Charcoal and copper turnings are effective in absorbing and minimizing airborne contamination.

References

1. Kocher, David C., Radioactive Decay Data Tables, Springfield: National Technical Information Service, 1981 DOE/TIC-11026.
2. Kaplan, Irving, Nuclear Physics, New York: Addison-Wesley, 1964.
3. U.S. Nuclear Regulatory Commission. 10CFR 20 Appendix B – Standards for Protection Against Radiation, 1994.
4. ICRP Publication 30, Part 2, Limits for Intakes of Radionuclides by Workers. Pergamon Press, Oxford, 1980.

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Tritium
Handling Precautions

^{3}H
12.28 y
ß⁻ 0.019
No γ
E 0.019

Physical Data

Maximum Beta Energy: 0.019 MeV (100%)[1]

Maximum Range of Beta in Air: 4.7 mm (0.19 in.)[2]

Occupational Limits[3]

Annual Limit on Intake: 80 mCi (3 GBq)

Derived Air Concentration: 2 x 10^{-5} µCi/ml (740 kBq/m^3).

Dosimetry

Millicurie (37 MBq) quantities of tritium do not present an external exposure hazard because the low-energy beta emitted cannot penetrate the outer dead layer of skin. Exposure to an atmosphere containing tritiated water results in intake of ^{3}H by both inhalation and absorption through the intact skin[4]. Three to four hours after intake, ingested, inhaled or absorbed tritiated water is uniformly distributed in all body water[5]. On average, tritiated water is eliminated with a 10-day biological half-life[4]. Elimination rates can be increased by increasing water intake[5].

Decay Table

Tritium Physical Half-Life: 12.28 Years[1]
To use the decay table, find the number of years in the left hand column and the number of months along the top of the chart, then find the corresponding decay factor. To obtain a precalibration number, divide by the decay factor. For a postcalibration number, multiply by the decay factor.

Years \ *Months*	0	1	2	3	4	5	6	7	8	9	10	11
0	1.000	0.995	0.991	0.986	0.981	0.977	0.972	0.968	0.963	0.959	0.954	0.950
1	0.945	0.941	0.936	0.932	0.928	0.923	0.919	0.915	0.910	0.906	0.902	0.898
2	0.893	0.889	0.885	0.881	0.877	0.873	0.869	0.865	0.860	0.856	0.852	0.848
3	0.844	0.841	0.837	0.833	0.829	0.825	0.821	0.817	0.813	0.810	0.806	0.802
4	0.798	0.794	0.791	0.787	0.783	0.780	0.776	0.772	0.769	0.765	0.762	0.758
5	0.754	0.751	0.747	0.744	0.740	0.737	0.733	0.730	0.727	0.723	0.720	0.716
6	0.713	0.710	0.706	0.703	0.700	0.697	0.693	0.690	0.687	0.684	0.680	0.677
7	0.674	0.671	0.668	0.665	0.661	0.658	0.655	0.652	0.649	0.646	0.643	0.640
8	0.637	0.634	0.631	0.628	0.625	0.622	0.619	0.616	0.614	0.611	0.608	0.605
9	0.602	0.599	0.597	0.594	0.591	0.588	0.585	0.583	0.580	0.577	0.575	0.572
10	0.569	0.567	0.564	0.561	0.559	0.556	0.553	0.551	0.548	0.546	0.543	0.541
11	0.538	0.535	0.533	0.530	0.528	0.526	0.523	0.521	0.518	0.516	0.513	0.511
12	0.509	0.506	0.504	0.501	0.499	0.497	0.494	0.492	0.490	0.487	0.485	0.483

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PerkinElmer has developed the following suggestions for handling Tritium after years of experience working with this low-energy beta emitter.

General Handling Precautions for Tritium [^3H]

1. Designate areas for handling ^3H and clearly label all containers.
2. Prohibit eating, drinking, smoking and mouth pipetting in room where ^3H is handled.
3. Use transfer pipets, spill trays and absorbent coverings to confine contamination.
4. Handle potentially volatile compounds in ventilated enclosures.
5. If enhanced containment is necessary, handle volatile compounds in closed systems vented through suitable traps.
6. Sample exhausted effluent and room air by continuously drawing a known volume through a membrane filter followed by an impinger containing water.
7. Wear disposable lab coat, gloves and wrist guards for secondary protection.
8. Select gloves appropriate for chemicals handled.
9. Maintain control by regular monitoring and prompt decontamination of gloves and surfaces.
10. Use open-window ionization detector or liquid scintillation counter to detect ^3H.
11. Submit periodic urine samples for bioassay to determine uptake by personnel.
12. Isolate waste in sealed clearly labeled containers according to approved guidelines.
13. Establish air concentration, surface contamination, and bioassay action levels below regulatory limits. Investigate and correct any conditions that may cause these levels to be exceeded.
14. On completing an operation, secure all ^3H; remove and dispose of protective clothing and coverings; monitor and decontaminate self and surfaces; wash hands and monitor them again.

Many tritium compounds readily penetrate gloves and skin. Handle these compounds remotely, wear two pairs of gloves and change the outer layer at least every 20 minutes. Tritiated DNA precursors are considered more toxic than tritiated water depending on their route of intake[4][6]. However, they are generally less volatile and do not normally present a significantly greater hazard.

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007047_01 Printed in USA

IX. APPENDIX C – BASIC CONCEPTS

A. UNITS

TERM	UNIT	DEFINITION	CONVERSIONS	RATES
Activity	USA: **Curie (Ci)** International: Becquerel (Bq)	The number of nuclear disintegrations occuring in a given quantity of material per unit time.	1 Ci = 3.7 x 10^{10} dps (2.2 x 10^{12} dpm) 1 mCi = 3.7 x 10^{7} dps (2.2 x 10^{9} dpm) **1 µCi** = 3.7 x 10^{4} dps or **2.2 x 10^{6} dpm** Bq = 1 dps	Disintegration per second (dps) **Disintegration per minute (dpm)**
Specific Activity	**Ci/mmol**	The activity in one gram of pure material.	N/A	N/A
Exposure	Roentgen (R)	A measure of the amount of ionization in air by photons (x- or gamma-radiation)	1 R = 2.58 x 10^{-4} coulombs (C)/kg	R/hr C/kg/sec
Absorbed Dose	USA: **Rad** (Roentgen or radiation absorbed dose) International: Gray (Gy) (1 joule per kg)	The amount of energy absorbed per unit mass.	1 R = 1 Rad in human tissue 1 Gy = 100 Rad	Rads/hr Gy/sec
Dose equivalent	USA: **Rem** (Roentgen equivalent man) International: Sievert (Sv)	Administrative concept related to the relative biological effect (Quality Factor, QF) of the particular radiation. QF is a function of the linear collision stopping power in water at a point of interest and with a specified energy dependence.	Rad x QF = Rem For radioisotopes used in the Biol. Dept., QF = 1; thus, **Rem = Rad** 1 Sievert = 100 Rem	**mRem/hr** mRem/year
Effective dose	**Rem** or Sievert	Used for internal doses related to risk of fatal cancer. Add internal and external doses for total effective dose equivalent (TEDE)	Use weighting factors, based on radiosensitivities of individual organs.	mRem/hr or year

B. MONITORING AND RECORDING ACTIVITY

(1) TERMS

Activity. The number of nuclear distintegrations occuring in a given quantity of material per unit time.

Counter. A device for counting nuclear disintegrations, thereby measuring the amount of radioactivity. The electronic signal announcing distintegration is called a **count.**

Counts per minute (cpm). The rate of nuclear disintegrations as measured by a counter, such as a Geiger-Mueller Counter or a Liquid Scintillation Counter. For record-keeping, **cpm** must be corrected to **disintegrations per minute (dpm)**, based on the efficiency of the instrument.

Distintegration. When a radioactive atom disintegrates, it emits a particle from its nucleus. What remains is a different element. This radioactive decay is measured in disintegrations per second (dps) or disintegrations per minute (**dpm**).

Dosimeter (dose meter). An instrument used to determine the radiation dose a person has received.

Film badge. A piece of masked photographic film worn as a badge for personal monitoring of radiation exposure. It is darkened by penetrating radiation, and radiation exposure can be checked by developing and interpreting the film. The type of masking depends on the type of radiation to be measured.

Geiger-Mueller (GM) Counter (GM Survey Meter). A radiation detection and measuring instrument. It consists of a gas-filled tube containing electrodes, between which there is an electrical voltage, but no current flowing. When ionizing radiation passes through the tube, a short, intense pulse ("counts") of current passes from the negative electrode to the positive electrode and is measured or counted. The number of pulses per second measures the intensity of the radiation field. It was named for Hans Geiger and W. Mueller, who invented it in the 1920s. It is commonly called simply a Geiger counter or a G-M counter, and is the most commonly used portable radiation instrument. It is used for high energy beta- and gamma--irradiation survey measurements. It is especially sensitive to beta-radiation.

Half-life. A means of classifying the rate of decay of radioisotopes according to the time it takes them to lose half their strength (intensity). Half-lives range from fractions of a second to billions of years (see Section VII, Appendix A).

Liquid Scintillation Counter (LSC). Instrument commonly used to detect radioisotopes that emit low energy beta or alpha particles. A sample with an unknown amount of radioisotope is placed into an organic or aqueous solution. This solution, commonly called the "counting cocktail" causes the radioisotope to emit small flashes of light. These flashes are detected and converted to amplified electrical pulses ("counts") by a photomultiplier tube. LSCs can distinguish between different isotopes and different energy types emitted by an isotope.

(2) CONVERSIONS

a. Conversion of cpm to dpm for record-keeping

Activity (dpm) = cpm/instrument efficiency

The efficiency of GM Counters in the Biology Dept. are approximately 10%.

For LSC, efficiency is approximately 50% for ^{35}S and 80% for ^{32}P.

Example: The GM Counter response for ^{32}P on a benchtop scan was 150 cpm. What is the amount of activity on the benchtop?

Answer:
Activity (dpm) = 150 cpm/0.10 = 1500 dpm

b. Half-life ($t_{1/2}$): Radioactive decay calculations

Method 1 (can be performed without using a sophisticated calculator)

$$A_n = A_o(1/2)^n$$

Where... n = number of half-lives
A_n = activity after "n" half-lives
A_o = original activity

Example: If tritium has a half-life of 12 years, how much tritium will remain after 36 years if 100 mCi of tritium were originally present?

Answer:

n = 36 years/12 years = 3 half-lives
A_o = 100 mCi

$A_n = 100 \text{ mCi } (1/2)^3 = 100 \text{ mCi} \times 1/8 = 12.5 \text{ mCi}$

Method 2 (use if you have a calculator with the e^x function)

$$A = A_o e^{-\lambda t}$$

Where ... A = final activity

A_o = original activity

$e = e^x$ on calculator

λ = lambda, the decay constant = $\ln 2/t_{1/2}$

$\ln 2$ = natural log of 2, approx. 0.693

t = elaspsed time

Example: The activity of a sample of ^{32}P, with a half-life of 14.2 days, was 100 mCi on 4/1/2004; what is the activity on 5/21/2004?

Answer:

A_o = 100 mCi, λ = 0.693/14.2 days, t = 50 days

A=100 mCi x $e^{-(0.693/14.2) \times 50 \text{ days}}$ = 100 mCi x $e^{-2.44}$ = 100 mCi x 0.087 = 8.7 mCi

Method 3

Use a decay table! (see Section VII, Appendix A)

C. RADIATION CONCEPTS AND DEFINITIONS

Atomic number. The atomic number is the number of protons (positively charged particles) in the nucleus of an atom. Each element has a different atomic number. The atomic number is also called the charge number.

Atomic weight. The atomic weight is approximately the sum of the number of protons and neutrons in the nucleus of an atom. The sum is also called the mass number.

Background radiation. The radiation coming from sources other than the radioactive material to be measured. Background radiation is primarily a result of cosmic rays, which constantly bombard the earth from outer space. It also comes from such sources as soil and building materials (such as radon). **"Background" in Millington Hall is generally between 0.01 – 0.02 mRem/hr, or ≤ 100 dpm.**

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Radiation is Everywhere...

"For all those who do not like radioactivity, the Earth is no place to live." Dixie Lee Ray, PhD

We are being constantly bombarded by 15,000 radioactive particles per second = 500 billion per year, or 40 trillion in a lifetime. However, the probability that one of those particles will cause cancer or genetic damage is one in 50 quadrillion.

Relative risks: The chance of getting cancer from natural radiation is pretty slim – one in 100. The average incidence of cancer from all causes, environmental, hereditary, and lifestyle is around one in five.

Of the total radiation received by each American **(average of 360 mRem/year)**:

82% comes from Natural Sources:

55%	radon	(200 mRem)
8%	cosmic sources & solar flares	(27 mRem)
8%	terrestrial (uranium, thorium)	(28 mRem)
11%	internal (potassium-40)	(40 mRem)

18% are man-made:

11%	X-rays (medical, dental)	(40 mRem)
4%	nuclear medicine	(14 mRem)
3%	consumer products (cigarettes, smoke detectors)	
1%	all other sources (includes nuclear energy industry, < 0.1%)	

The above are average numbers, they can vary with:

* Location (altitude, soil composition)
* Housing construction (radon)
* Health habits (smoking)

Example: Levels are 2-3 times higher in Denver, CO than they are in Dallas, TX. This difference in the amounts you would receive in Denver vs. Dallas (6.5-12.7 μRem/hr) represents a higher dose equivalent than what the NRC allows the general public to receive from a licensed facility (2 μRem/hour).

The point: These numbers are not meant to alarm or placate you, but to point out that there is natural radiation, and there is "man-made" radiation... and the effects they would have on your body are the same.

(from Envirowin Software, L.L.C., 2001; www.chemsw.com)

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Bremsstrahlung radiation. German word meaning "breaking radiation." The charged particle interacts with the nucleus, causing it to change directions and lose energy. Energy is given off by an X-ray photon which may have as much energy as the incident particle. The fraction of charged particle energy lost to bremsstrahlung is proportional to the atomic number of the absorbing material times the energy of the incident charged particle. This means if you have a high atomic number absorber like lead and a high-energy beta such as the 1.7 MeV from ^{32}P, the proportion of bremsstrahlung will be high. This is why when shielding from ^{32}P we use lucite plastic or some other low atomic number material instead of lead.

Compton effect. The glancing collision of a gamma-photon with an orbital electron. The gamma-photon gives up part of its energy to the electron, ejecting the electron from its orbit.

Electron. A minute atomic particle possessing the smallest possible amount of negative electric charge (−1). Orbital electrons rotate around the nucleus of an atom. Electrons have only about 1/1,820 the mass of protons or neutrons.

Electron volt (eV). A small unit of energy – the amount of energy that an electron gains when it is acted upon by one volt. Radioactive materials emit radiation in energies up to several million electron volts, or **MeV** (1 MeV = 10^6 eV).

Element. All atoms of a given element contain the same number of protons and therefore have the same atomic number. Various isotopes of an element result from a change in the number of neutrons in the nucleus. However, the electrical charge and chemical properties of the various isotopes of an element are identical.

Isotope. Isotopes of a given element contain the same number of protons but a different number of neutrons; i.e., these are nuclei that have the same atomic number (same Z).

Number of PROTONS = ATOMIC NUMBER (Z)
Number of NEUTRONS = NEUTRON NUMBER (N)
Number of NUCLEONS = ATOMIC MASS NUMBER (A)

$A = Z + N$

Nuclide symbol: ${}^{A}_{Z}X$

(example: ${}^{14}_{6}C$ or carbon-14, and ${}^{12}_{6}C$ or carbon-12)

Nucleus. The inner core of an atom. The nucleus consists of neutrons and protons tightly bound together (nucleons).

Neutron. An atomic particle. The neutron weighs about the same as a proton. As its name implies, the neutron has no electrical charge. Neutrons make effective atomic projectiles for the bombardment of nuclei. Neutrons can also present unique external exposure hazards to personnel.

NRC. Nuclear Regulatory Commission

Photon. A class, or quantum, or electromagnetic radiation, such as x-rays, gamma-rays, visible light, and radio waves.

Proton. An elementary particle found in an atom's nucleus. Its positive charge of 1 is opposite that of the electron.

Radioisotopes. A radioactive isotope of an element. A radioisotope can be produced by placing material in a nuclear reactor and bombarding it with neutrons. Many fission products are radioisotopes.

Radiation (ionizing radiation). As defined by the NRC, ionizing radiation means alpha particles, beta particles, gamma rays, X-rays, neutrons, high-speed electons, high-speed protons, and other particles capable of producing ions. It does not include non-ionizing radiation such as radio- or microwaves, or visible, infrared, or ultraviolet light.

The most commonly encountered types of ionizing radiation are:

alpha-particles
beta-particles
x- or gamma-electromagnetic radiation
neutron particles

Radioactive material – any solid, liquid, or gaseous substance, which emits radiation spontaneously

Radioactivity. The distintegration (transformation) of unstable atomic nuclei by the emission of radiation. Radioactive decay is the change in the number of neutrons and protons from an unstable combination to a more stable combination. The nuclide has less mass after decay (mass converted to energy).

The three major forms of radioactivity are alpha (α), beta (β), and gamma (γ):

Alpha-particle (alpha radiation, α). An alpha-particle is made up of two neutrons and two protons that give it a unit charge of +2. It is emitted from the nucleus of a radioactive atom and causes high-density ionization. Alpha-particles transfer their energy in very short distance and are readily deflected by a piece of paper or the top, dead layer of skin. Alpha-radioactivity is therefore primarily an internal radiation hazard.

Example: ${}^{210}_{84}Po \rightarrow {}^{4}_{2}\alpha + {}^{206}_{82}Pb + Q$

α = helium nucleus
Q = energy released by the conversion of mass to energy

Beta-particle (beta radiation, β). Beta particles are small, electrically charged particles emitted from the nucleus of radioactive atoms. They are identical to electrons and have a negative electrical charge of 1. Beta-particles are emitted with various kinetic energies. They pose an internal exposure hazard and are often penetrating enough to cause skin burns.

Example: $^{32}_{15}P \rightarrow {}^{32}_{16}S + \beta^- + \nu + Q$

β^- = electron
ν = neutrino
Q = energy

Gamma-rays (Gamma-radiation, γ). A class of electromagnetic photons emitted from the nuclei of radioactive atoms. Gamma-rays are highly penetrating and present an external radiation exposure hazard. They are indirectly ionizing; the interaction is dependent on radiation energy and atomic number of the absorber.

X-ray. Highly penetrating electromagnetic radiation similar to gamma-ray. X-rays are produced by electron bombardment of target materials. They are commonly used to produce shadow pictures (roentgenograms) of dense portions of objects.

D. CONTROL OF EXPOSURE

ALARA – "As Low As Reasonably Achievable", making every reasonable effort to maintain exposures to radiation as far below the dose limits as is practical (maximum allowable dose to the whole body of 0.125 Rem per quarter or 0.5 Rem per year)

(1) TIME

Dose is directly proportional to time of exposure: halve the time of exposure, halve the dose received:

a. Plan work ahead of time

b. Perform dry-runs using personal protective equipment

c. Plan for emergencies

d. Spend as little time around radioactive materials as possible (limit quantities on hand)

(2) DISTANCE

a. Gammas (Inverse Square Law)

The radiation intensity (I) or exposure from a point source varies inversely as the square of the distance (d) from the source.

$$I_i/I_o = (d_o/d_1)^2$$

Where... I_o = orginal intensity at a point
I_1 = intensity at a second point
d_o = distance from source to original point
d_1 = distance from source to second point

Example: If the intensity of a radiation field 3 meters from a point source is 100 mRem/hr, what is the intensity of the radiation field at 9 meters?

Answer:

I_1/100 mRem/hr = $(3/9)^2$
I_1 = 100 mRem/hr $(3/9)^2$
I_1 = 100 mRem/hr (1/3)
I_1 = 100 mRem/hr x 0.111
I_1 = 11.1 mRem/hr

b. Betas (range in air for 1 MeV beta: 316 cm)

c. Alphas (range is short, range in air for 5 MeV alpha: 3.3 cm)

d. Use tongs or remote handling devices, remove unnecessary sources (ex. waste), restrict access (signage).

(3) SHIELDING

a. Depends on the type and energy of the radiation:

Gammas – lead, concrete
Betas – lucite, glass
Alphas – paper, skin

b. **Half –value layer.** The thickness of a specified substance that, when introduced into the path of a given beam of radiation, reduces the value of the radiation quantity by one-half. It is sometimes expressed in terms of mass per unit area.

The HVL Equation

$$I_n/I_o = (\tfrac{1}{2})^n$$

Where … I_n = intensity of the transmitted radiation (on the other side of the shield from the source)
I_o = original intensity (on the source side of the shield)
n = number of half-value layers

Example: The HVL in lead for a certain gamma-emitting radioisotope is 0.50 inches. The intensity of a source on one side of a two-inch thick lead plate is 150 mRem/hr. What is the intensity of transmitted beam on the opposite side of the shield?

Answer:
n = 2 inches/0.50 inches
n = 4

$I_n/150$ mRem/hr = $(\tfrac{1}{2})^4$
I_n = 150 mRem/hr x 0.0625
I_n = 9.375 mRem/hr

E. BIOLOGICAL EFFECTS OF RADIATION
(from Envirowin Software, L.L.C., 2001; www.chemsw.com)

(1) Molecular or Subcellular Effects

a. Direct energy transfer – ionization of cellular molecules

b. Radiolysis of H_2O (a major constituent of cells)

- direct effect: H_2O may be ionized

- indirect effect: free radicals produced

  - extremely reactive
  - can react with biological or organic molecules (ex. hydrogen peroxide)

(2) Possible Subcellular Targets

a. enzymes, cell membranes, etc.

b. chromosomes (DNA base damage)

- single strand breaks (can be repaired)
- double strand breaks (harder to repair)

(3) Consequences of Radiation Damage to Chromosomes

a. Cell survives with impaired metabolism

b. Cell death

(4) Radiosensitive Tissues

a. Law of Bergonie & Tribondeau - cells where the first effects of radiation damage are noticed:

- are dividing at time of exposure
- undergo numerous divisions in lifetime
- are undifferentiated (i.e. unspecialized)

b. Types of radiosensitive cells

- germinal cells of ovary and testis
- hematopoietic (blood forming) tissues
    - red bone marrow
    - spleen
    - lymph nodes
    - thymus
- epithelium of the skin
- epithelium of gastrointestinal tract
- also: lymphocytes, oocytes

c. Embryo/fetus

- highly radiosensitive (rapidly dividing, unspecialized cells)
- stricter exposure limits for "declared pregnant women" - 1/10 of adult limit

d. Types of radioresistant tissues

- bone
- liver
- kidney
- cartilage
- muscle
- nervous tissue

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: Program Code: 03620
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1. APPLICATION ATTACHED
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   Received Date: 20050228
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   License No.: 45-03499-06
   Action Type: Renewal

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3. COMMENTS

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1. Fee Category and Amount: ______________________

2. Correct Fee Paid. Application may be processed for:
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