RADIATION SAFETY MANUAL

College of William and Mary
Williamsburg, Virginia

Revised:
Department of Biology
June 2004; May 2005; September 2008 - ELB/LAA/MSS

Main Campus
February 17, 2010 - ELB

The policies and procedures discussed in this manual are in compliance with regulations established first by the Nuclear Regulatory Commission (NRC) under Title 10, Code of Federal Regulations (CFR), Parts 19, 20, and 30. This manual reflects the subsequent transfer of this authority to the Virginia Radioactive Material Program (VRMP) as an "Agreement State," in April 2009. The program is conducted in accordance with Chapter 481, "Virginia Radiation Protection Regulations" The current License, all records, forms, and operating procedures, as well as copies of the regulations are available from the Radiation Safety Officer.

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 applicable policies for the use of radioactive materials on the Main Campus of the College of William and Mary. All approved operations are designed to ensure that exposure is kept, in compliance with federal policy, as low as reasonably achievable (ALARA).

B. ORGANIZATION OF THE RADIATION SAFETY PROGRAM

The Virginia Radioactive Materials Program (VRMP) has granted a license to the College of William and Mary for the use of specified nuclear by-products, as well as accelerator-produced and naturally occurring radioactive materials. This license provides for the possession and use of an array of small (under 100uCi) sealed sources of radioactive materials with atomic numbers 1 through 96, except in a few specific cases where larger amounts have been permitted. Under the terms of this License there are also permitted mCi amounts of specific byproduct materials that are not sealed and are in a form for use in chemical and biological synthesis. The details of the isotopes permitted and the specific limits for each may be found in the current license (830-065-1; expiring May 31, 2010).

A Radiation Safety Officer (RSO) and one or more Radiation Safety Officers, Alternates (RSO, Alt.) appointed by the Provost to oversee all usage of radioactive material on the Main Campus (note: the College of William and Mary School of Marine Science in Gloucester Point Virginia holds a separate radioactive materials license). The RSO will ensure the safety of users and the surrounding community by monitoring all aspects of radiation safety. The current RSO is Eric L. Bradley, Ph.D., Biology Department.

All work with licensed sealed sources will be supervised by RSO, Alt, Todd D. Averett, Ph.D., Department of Physics. The sealed-source inventory can be checked out only to approved Supervised, or Restricted, or Authorized Users, and all items must be returned to inventory when not in active use.

All work with unsealed byproducts will be supervised by the RSO, Eric L. Bradley, Ph.D., Biology Department. In addition, the RSO has established a Radioisotopes Users Committee in the Biology Department to function as a mutual-aid and advisory group in order to support the safe and effective use of un-sealed 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 with un-sealed radioisotopes. 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 a proper report of the incident may be made to the Virginia Radioactive Materials Program (VRMP) for the record, if necessary.

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

a) Authorized User Status

The RSO and the RSO, Alternates are the Authorized Users and are designated by the VRMP 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 VRMP 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 VRMP. Application for Authorized User status and license amendment must 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 and supervised 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 College Radiation Safety Course (or an RSO-approved equivalent) 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.

(2) Attendance at Training Sessions

All persons who work in or frequent any designated radioisotope work area in a manner that is likely to expose them to unsealed radioisotopes must successfully complete the Radiation Safety Course at least once per year. This three-hour course is customarily 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 the safe 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 course 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. Persons working only with sealed sources may be exempt from the annual Radiation Safety Course only if they have equivalent and up-to-date Jefferson Laboratory Radiation Safety certification.

(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 For Un-Sealed Radioactive Materials

Appropriate work areas in which radioactive isotope work may be conducted are designated by the RSO and approved by the VRMP. Approval of a project is contingent upon the availability of adequate laboratory facilities for assignment as work areas. As of February 2010, the approved areas for un-sealed radioisotope work are Integrated Science Center Rooms 0036, 3024, 3030, 3033, 3034, 3040, 3042, 3044, 3060, 3063, 3066.

(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 VRMP 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 VRMP regulations for at least three years.

II. BASIC STANDARDS OF MAXIMUM PERMISSIBLE RADIATION EXPOSURE

Current standards shall in all cases supersede those listed below.
(Excerpts taken from 10CFR20.1201 to 20.1208.)

A. STANDARDS FOR OCCUPATIONAL RADIATION WORKERS

§ 20.1201 Occupational dose limits for adults.

(a) The licensee shall control the occupational dose to individual adults, except for planned special exposures under § 20.1206, to the following dose limits.

(1) An annual limit, which is the more limiting of--

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

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

(2) The annual limits to the lens of the eye, to the skin of the whole body, and to the skin of the extremities, which are:

(i) A lens dose equivalent of 15 rems (0.15 Sv), and

(ii) A shallow-dose equivalent of 50 rem (0.5 Sv) to the skin of the whole body or to the skin of any extremity.

(b) Doses received in excess of the annual limits, including doses received during accidents, emergencies, and planned special exposures, must be subtracted from the limits for planned special exposures that the individual may receive during the current year (see § 20.1206(e)(1)) and during the individual's lifetime (see § 20.1206(e)(2)).

(c) The assigned deep-dose equivalent must be for the part of the body receiving the highest exposure. The assigned shallow-dose equivalent must be the dose averaged over the contiguous 10 square centimeters of skin receiving the highest exposure. The deep-dose equivalent, lens-dose equivalent, and shallow-dose equivalent may be assessed from surveys or other radiation measurements for the purpose of demonstrating compliance with the occupational dose limits, if the individual monitoring device was not in the region of highest potential exposure, or the results of individual monitoring are unavailable.

(d) Derived air concentration (DAC) and annual limit on intake (ALI) values are presented in table 1 of appendix B to part 20 and may be used to determine the individual's dose (see § 20.2106) and to demonstrate compliance with the occupational dose limits.

(e) In addition to the annual dose limits, the licensee shall limit the soluble uranium intake by an individual to 10 milligrams in a week in consideration of chemical toxicity (see footnote 3 of appendix B to part 20).

(f) The licensee shall reduce the dose that an individual may be allowed to receive in the current year by the amount of occupational dose received while employed by any other person (see § 20.2104(e)).

[56 FR 23396, May 21, 1991, as amended at 60 FR 20185, Apr. 25, 1995; 63 FR 39482, July 23, 1998; 67 FR 16304, Apr. 5, 2002]

§ 20.1207 Occupational dose limits for minors.

The annual occupational dose limits for minors are 10 percent of the annual dose limits specified for adult workers in § 20.1201.

§ 20.1208 Dose equivalent to an embryo/fetus.

(a) The licensee shall ensure that the dose equivalent to the embryo/fetus during the entire pregnancy, due to the occupational exposure of a declared pregnant woman, does not exceed 0.5 rem (5 mSv). (For recordkeeping requirements, see § 20.2106.)

(b) The licensee shall make efforts to avoid substantial variation above a uniform monthly exposure rate to a declared pregnant woman so as to satisfy the limit in paragraph (a) of this section.

(c) The dose equivalent to the embryo/fetus is the sum of--

(1) The deep-dose equivalent to the declared pregnant woman; and

(2) The dose equivalent to the embryo/fetus resulting from radionuclides in the embryo/fetus and radionuclides in the declared pregnant woman.

(d) If the dose equivalent to the embryo/fetus is found to have exceeded 0.5 rem (5 mSv), or is within 0.05 rem (0.5 mSv) of this dose, by the time the woman declares the pregnancy to the licensee, the licensee shall be deemed to be in compliance with paragraph (a) of this section if the additional dose equivalent to the embryo/fetus does not exceed 0.05 rem (0.5 mSv) during the remainder of the pregnancy.

[56 FR 23396, May 21, 1991, as amended at 63 FR 39482, July 23, 1998]

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 College 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 shall not exceed 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 Radiation Safety Committee 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 VRMP upon request.

III. HANDLING OF RADIOISOTOPES AND ASSOCIATED RECORD KEEPING

A. DESIGNATION OF RADIOACTIVE WORK AREAS

All areas involving the use of un-sealed radioactive material will be pre-approved by the RSO and VRMP (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 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. No order for radioisotopes may be placed with any vendor until RSO approval is obtained.

C. RECEIPT OF RADIOACTIVE MATERIAL

All un-sealed radioactive materials shipments must be received in the Integrated Science Center Room 3035. 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. An Authorized or Restricted User shall inspect all incoming shipments immediately after receipt according to the method pursuant to 10CFR20.1706 (below).

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. In the event of a leak, the RSO must file the appropriate reports with the DOT and VRMP. 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.

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 VRMP 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 Integrated Science Center Room 0036 for decay-in-storage or to await shipment for disposal. When waste in temporary storage in work areas is taken to Room 0036 it must be done under the direct supervision of the RSO or RSO Alt. Before taking the waste to Room 0036, the Authorized or Restricted User must complete the "*Room 0036 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) <u>Calibration of Survey Meters and Liquid Scintillation Counter</u>

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 at the time of each survey using 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, (or another equivalently equipped and staffed facility) so that a whole thyroid scan may be made. The results and the recommendations of the consulting Radiation Safety Office will be kept as part of the record. It will be the responsibility of the RSO to notify the subject 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. ≤ 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 Integrated Science Center Room 3063 and disposal recorded on the log sheet. Empty 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 comtaomers in Integrated Science Center 1, Room 0036 where it will be left to decay in storage, 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 0036 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 containers must be accompanied by a completed *Room 0036 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 0036 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 for at least three years.

IV. EMERGENCY PROCEDURES

A. MINOR SPILLS FROM UNSEALED CONTAINERS:

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 OR LOSS OF SEAL-INTREGRITY IN A SEALED-SOURCE:

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

2. PREVENT THE SPREAD: Cover the spill (or broken source container) 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 (our source) 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 Integrated Science Center 1, Room 0036. 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. CONTACT PERSONS

RADIATION SAFETY OFFICERS	HOME PHONE (all 757)	OFFICE (all 757)	CELL (all 757)
Eric L. Bradley, RSO	253-2472	221-2220	897-1034
Unsealed Radioisotopes:			
Margaret S. Saha, RSO, Alt.	253-2472	221-2407	876-2873
Lizabeth A. Allison, RSO, Alt.	258-4624	221-2232	876-3843
Sealed Radioisotopes and Accelerator-Produced Materials			
Todd D. Averett, RSO alt.	229-3377	221-3534	561-6702

UNSEALED RADIOISOTOPES USERS COMMITTEE:

NAME	OFFICE/LAB	OFFICE PHONE
Lizabeth Allison	ISC 3035b/3030	X12232
Eric Bradley	ISC 3048/3060	X12220
Mark Forsyth	ISC 3051/3066	X12489
Margaret Saha	ISC 3046/3040	X12407
Patty Zwollo	ISC 3043/3024	X11969

If unable to contact the RSO, or any RSO, Alt., in the event of a radiological emergency then contact the Director of Environmental Health & Safety, Sandra Prior at Campus 911, or 221-2146.

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 0036 Disposal Record*
6. *Radiation Survey Report*

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.

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 = 3.7×10^{10} dps (2.2×10^{12} dpm) 1 mCi = 3.7×10^{7} dps (2.2×10^{9} dpm) **1 µCi =** 3.7×10^{4} dps or **2.2×10^{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 = 2.58×10^{-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) <u>CONVERSIONS</u>

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.

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

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

b. Half-life ($t_{½}$): Radioactive decay calculations

<u>Method 1</u> (can be performed without using a sophisticated calculator)

$$A_n = A_o(½)^n$$

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

<u>Example:</u> 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?

<u>Answer:</u>

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

A_n = 100 mCi $(½)^3$ = 100 mCi x 1/8 = 12.5 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

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

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 Integrated Science Center 1 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.

<u>Relative risks:</u> 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)

<u>Example:</u> 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).

<u>The point:</u> 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.

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

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. For the College of William and Mary this is a 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. Gamma (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. Beta (range in air for 1 MeV beta: 316 cm)

c. Alpha (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

$$I_n/I_o = (½)^n$$

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 = $(½)^4$
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