UNIVERSITY OF CENTRAL FLORIDA

RADIATION SAFETY MANUAL

2010 Edition

TABLE OF CONTENTS

I. Introduction

The University of Central Florida (UCF, the University) uses sources of ionizing radiation for a variety of educational and research applications. UCF has established a radiation safety program (RSP) to ensure that work with radioactive materials and radiation machines is conducted in a manner that protects health and minimizes danger to life, property and the environment. This radiation safety manual is a guide to the safe use of radiation sources at the University. Its purpose is to describe some of the basic aspects of health physics (the science of radiation protection) and practical application of radiation safety principles in the laboratory, as well as the University's radiation safety polices and procedures.

II. Regulatory Authorities

The State of Florida Department of Health (FDOH) is granted regulatory authority by the U.S. Nuclear Regulatory Commission to oversee the acquisition and use of radioactive materials and radiation producing machines within the state. The University holds an academic broad scope radioactive materials license issued by the FDOH Bureau of Radiation Control (BRC) Radioactive Materials Program in Tallahassee, and our radiation machines are registered with the BRC Radiation Machine Program in Jacksonville. The state's radiation control regulations are found in Chapter 64E-5, Florida Administrative Code (FAC). The parts of Chapter 64E-5, FAC that apply to the University's operations are listed below. The FDOH BRC performs inspections of our facilities, can issue citations and levy fines for violations of its regulations, and has the authority to suspend or revoke UCF's license and/or registration with due cause.

The University also complies with U.S. Department of Transportation (DOT) regulations governing the shipment of hazardous materials, including radioactive materials, which are found in Title 49, Code of Federal Regulations (49 CFR). Both the U.S. DOT and FDOH BRC enforce the hazardous materials regulations.

III. Licensing and Registration Requirements

A. Radioactive Materials Licensing Requirements

FDOH licensing requirements are found in Part II of Chapter 64E-5, FAC. There is a three-tier hierarchy associated with licensing of radioactive materials. The first tier is exempt sources, which are not subject to regulatory control as a result of their low activity and/or concentration, or because of the low risk associated with their use. Part II describes exemptions for specified concentrations, quantities and items (such as smoke detectors and exit signs). The second tier is generally licensed sources, which are considered sufficiently hazardous to warrant limited controls of varying degrees depending on the source.

Examples of "GL sources" include calibration/reference standards, static eliminators, *in vivo* and *in vitro* test kits, and low-activity gauges and other measuring devices. Some sources are distributed as GL sources even though their activity would otherwise make them exempt, so it is important to know the licensing status of any source possessed. The third tier is specifically licensed sources, which are subject to strict controls. Authorization to possess "SL sources" requires submittal of a license application, establishment of a radiation safety program, and demonstration of appropriate facilities, equipment, procedures and qualified personnel before the license is issued by FDOH. The University holds an academic broad scope specific license authorizing use of various radioactive materials for education, research and development. Note: Authorization for certain GL sources is included in the University's specific license.

License Amendments. Radiological activities must be confined to the locations and purposes approved by the license and the UCF radiation safety committee. Prior to implementing any major change in licensed activities, a request to amend the license must be submitted to and approved by the FDOH BRC. Examples of changes that require a license amendment are new use locations, policy/procedure changes, adding additional isotopes, and increasing isotope possession limits. Changes that could increase radiation exposures require revision to the UCF public dose limits compliance study. Amendment requests should reference the license number and must be dated and signed by a certifying official (a person authorized to make legally binding statements on behalf of the University). The UCF broad scope license authorizes the radiation safety committee to internally authorize new personnel and radiological projects within the restrictions imposed by the license.

B. Radiation Machine Registration & Reporting Requirements

Radiation-producing machines must be registered with the FDOH BRC Radiation Machine Program within 30 days of acquisition, using Form DH-1107. An annual fee covering registration and inspection costs is due within 30 days after acquiring a machine, and by Oct. 28 thereafter. If the machine is acquired within 120 days before the Oct. 28 annual renewal date, the registration fee is due on Oct. 28, as is the renewal fee.

Within 15 days of assembly/installation of an X-ray machine, a Form DH-1114 (Report of Assembly of Non-Certified X-ray Systems) must be submitted. The form must be signed by a registered radiation machine vendor, certifying that all components were installed in accordance with state requirements and were adjusted and tested per the manufacturer instructions.

The BRC must be notified within 15 days of the sale, lease, transfer, relocation, loan, assembly, installation or disposal of an X-ray machine or major component, using DOH Form DH-1114. If the system contains certified components, FDA Form 2579 must be used.

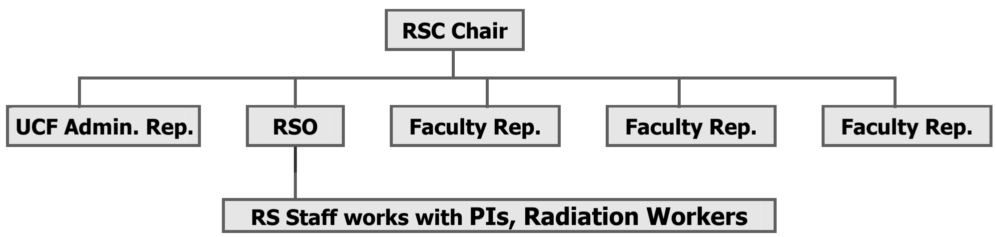
The BRC must be notified in writing within 30 days any changes to the information in the Certificate of Registration. Reports are required for a change of address, or receipt, sale, transfer and/or disposal of a machine or major components.

IV. Radiation Safety Program

A. Radiation Safety Program Organization

The University has established a radiation safety program (RSP) describing how safe radiological operations and compliance with regulatory requirements are achieved. The program is administrated by the radiation safety officer (RSO), who may be assisted by radiation safety support staff. UCF faculty with appropriate radiation safety training and experience are designated as Principal Investigators (PIs). PIs are responsible for supervision of their lab personnel designated as radiation workers. Oversight of the program is provided by the radiation safety committee (RSC).

UCF Radiation Safety Program Organization Chart



B. Radiation Safety Committee (RSC)

The RSC is made up of six members; RSO (ex-officio, voting), four principal investigators experienced in the safe use of radioactive materials, and an administrative representative appointed by the University president (ex-officio, non-voting). Since there are few qualified candidates, there is no routine rotation of members.

RSC Composition

Seat	Department/Represents	Vote
1	Chair (Faculty Representative)	Yes
2	University Administration Rep.	No
3	Faculty Representative	Yes
4	Faculty Representative	Yes
5	Faculty Representative	Yes
6	Radiation Safety Officer	Yes

The Chairperson is appointed from one of the PI members who have served on the Committee for at least two years immediately prior to their appointment as Chairperson. A committee quorum of at least three voting members and the administrative representative is required to conduct business. At least three committee members' signatures are required for the approval of each proposed use of radioactive material, and at least three voting members must agree to suspend a proposal or establish radiation safety policies.

When there is a Committee membership vacancy, the RSO makes the vacancy known to the chairperson. A replacement is then selected, with his/her consent, from a department that is involved in radiation-related research. Upon acceptance by the new member, a letter of appointment is prepared for the signature of the University president.

The Committee is responsible for ensuring that the UCF radiation safety program complies with all internal and external rules and regulations, without placing undue burdens on the University's educational and research activities. The Committee formulates institutional radiation safety policies, reviews and audits the content and effectiveness of the program, and provides guidance to the RSO on the operational uses of RAM/radiation. A summary of RSC duties is listed below.

- Determine policy for the radiation safety program.
- Advise the RSO on technical, and regulatory matters.
- Conduct periodic or discretionary reviews or evaluations of the radiation safety program.
- Review and approve or disapprove new proposals for the use of radioactive materials or ionizing radiation producing equipment under the jurisdiction of the University, after the RSO has conducted a preliminary review.
- Review and approve or disapprove amendment requests to existing authorizations following review by the RSO, including interim approval prior to final approval by the Committee during the next RSC meeting.
- Prescribe special conditions, as may be necessary; such as additional training and/or instructions, designated or limited areas of use, disposal methods, etc.
- Suspend or revoke user privileges if the Committee determines such action is warranted, and direct the RSO to impound radiation sources or suspend their use.
- Review occupational radiation safety exposures and incidences to determine cause and corrective action.
- Review all reports submitted to the Committee by the RSO.
- Hold Committee meetings semi-annually. Meetings may be called by any member at any time. Meeting minutes will be recorded and maintained. These shall include, but not limited to, attendance, discussions, actions, recommendations, and numerical results of all votes taken.
- Routine review of new proposals and authorizations may be conducted via email as needed.

C. <u>Radiation Safety Officer</u> (RSO)

The RSO is responsible for implementation of the radiation safety program and for ensuring safe radiological working conditions. The goal is to protect radiation-related research by maintaining the integrity of the license/registration and addressing radiation-related safety issues. The RSO is empowered to immediately revoke any radiation use authorization and impound radioactive materials and/or radiation machines if there is evidence warranting such actions. RSO duties, which are listed below, may be delegated to the radiation safety support staff.

- Ensure compliance of all terms and conditions of the license, registration and regulations.
- Ensure that all personnel are properly trained, read and understand University radiation safety, operating and emergency procedures.
- Emphasize the ALARA philosophy (see Sec. IV) to workers and provide guidance on ways to minimize radiation exposures.

- Ensure that radioactive materials and radiation producing machines are used only by personnel authorized by the license/registration, and that they wear dosimetry and other personal protective equipment as required.
- Ensure that radioactive materials and radiation machines are properly secured against unauthorized access or removal.
- Ensure that the sealed sources are leak tested at required intervals and as prescribed by the manufacturer or the license.
- Ensure that radiation survey instruments are calibrated by a licensed and qualified vendor at least annually and following service/repair.
- Conduct annual reviews of the radiation safety program's content and implementation.
- Maintain all required records, including those pertaining to training, personnel monitoring, inventories, leak tests, and radioactive material receipt/transfer/disposal.
- Serve as a contact with the FDOH BRC for events such as the loss, theft or damage of radioactive material or radiation machines.

The University has designated the RSO position as that of a certifying official; i.e., the RSO is authorized to make legally binding statements on behalf of UCF.

The FDOH BRC must be notified in writing within 30 days of a change of RSO. A license amendment is required to formally designate the new RSO, and the amendment request must include documentation of the new RSO’s qualifications for the position.

D. Authorized Users, Associate Investigators & Radiation Workers

Basic Criteria for Authorized Users

Authorization to use radioactive material and/or radiation generating equipment may be granted to any faculty or visiting faculty member that successfully completes the application, meets the requirements for training, meets the facility and equipment requirements, and passes the UCF RSC review process.

The **Principal Investigator (PI)** shall complete appropriate use applications. At UCF, a PI must have either a terminal degree (i.e. Ph.D., M.D.) in an appropriate field and one-year experience using radioisotopes in research or written exemption from the RSC. **The PI is the person who is primarily responsible for the research operations, the authorized use, supervision, and training of their laboratory personnel**.

Each candidate PI:

- Must read, be familiar with, and follow the procedures outlined in this manual.
- Shall submit a completed Form RC-3 "Radioactive Material Use Application" and a proposal with the description of the procedures and techniques involving radioisotopes or, Form RC-4 "Radiation Machine Use Application" (as applicable) to the RSO. The application must be approved by the RSC before the work may begin. The responsible PI must sign all proposals. The RSO will assist in completion of the form and will present the application to the RSC for evaluation and signature if approved. Approval will be granted if the Committee agrees that the proposed use satisfactorily meets University and regulatory requirements.

- Must submit to the RSO a completed Form RC-1 "Statement of Radiation Safety Training and Related Experience" for the authorized user and each person working as an associate investigator, and describe the training and experience of any additional radiation workers conducting activities authorized by the application.
- Must obtain an amendment to their application, approved by at least the Committee chairperson and the RSO, before substantially deviating from the kinds of radioisotopes, the maximum activities, the areas of use, or the experiments described on the proposal. The RSO may approve minor changes in the proposal, including the addition of up to one millicurie in the amount of activity authorized.
- An authorization is issued for a period not to exceed five years, at which time the application may be resubmitted for another review by the Committee.

The Committee will approve applications only if sufficient evidence is provided that the user is competent in performing all applicable phases of the proposed experiments and adequate facilities and equipment are available. If, after reviewing the application and supporting information, the Committee members have questions about the safety of the proposed use, they may require:

- A personal interview with the applicant for specific details of the experiment.
- That the users first make trial runs of the experiment using non-radioactive materials.
- Specific types of equipment and techniques to be used under certain conditions.

The **Associate Investigators (AI)** are lab personnel designated as supervisors for work with radioactive material and/or radiation generating devices under an authorized PI. AI's shall be an experienced user (at least 6 months work experience) of radioactive material (or radiation machines, as applicable) and considered competent in directing the proposed activities.

- Shall observe all applicable safety recommendations, rules and regulations, and any special conditions required by the UCF RSC.
- Shall immediately, report to the RSO any incident involving radioactive material or radiation producing machine.
- Shall notify the RSO of all shipments or transfers of radioactive material and/or radiation machines to and from the University.
- Shall be listed on the application for use (RC-3).
- Shall review applicable parts of this manual.
- Attend basic UCF radiation awareness training.

Radiation Workers (directly supervised)

The position of Radiation Worker is established primarily for personnel who will be working with very low levels of radioactive materials involving minimal hazards. Direct supervision is required. Direct supervision means that the supervisor (Principal Investigator or Associate Investigator) must work closely with the individual, physically demonstrate the procedures, and give instruction on the hazards of the experiment. The supervisor should be physically present, unless convinced that the worker understands the procedures and can safely perform the assigned duties. The supervisor should be readily available for the worker to contact in case of need.

If the person has had no experience working with radioactive materials, that person, before conducting radioactive experiments, must work as a trainee for an initial period with the supervisor physically present. The trainee should make trial runs, when necessary, using non-radioactive materials until the worker can safely conduct or assist in conducting the radioactive experiments.

Must attend UCF basic radiation safety training.

Special Instructions for Maintenance and Janitorial Workers

- Maintenance personnel. Maintenance personnel who are required to work in labs where possible radiation hazards exist must be informed of the hazards and be supervised when necessary. Radiation safety staff should be notified by the PI/authorized user or their designee before the maintenance work begins, so that proper oversight and safety measures are provided as necessary.

  The following are examples of projects that should be reported to the RSO before work is begun:

  - Changing filters in hoods or glove boxes in radiological labs.
  - Work on drains of sinks that have been used for disposal of radioactive materials.
  - Work on lab equipment that is likely to be contaminated with radioactive material.

- Janitorial personnel. Janitorial workers must be advised of any radiation hazards present and as to the meaning of warning signs and labels. Radiation safety staff provides such instructions on an as-needed basis.

V. ALARA Policy

Part III of Chapter 64E-5, FAC establishes standards for protection against radiation hazards. Section 64E-5.303, FAC requires use (to the extent practical) of procedures and engineering controls based on sound radiation protection principles to achieve occupational and public doses that are as low as reasonably achievable (ALARA). The concept of the ALARA philosophy is that unnecessary exposure to radiation should be avoided, even though occupational dose limits pose a very low risk of injury. The objective is to reduce radiation doses as far below regulatory limits as is reasonably achievable through good radiation protection planning and practice, as well as by a management commitment to policies that deter departures from good practices.

The University's administration is committed to the ALARA philosophy of maintaining occupational and public radiation doses as low as reasonably achievable. The RSO has been delegated authority to ensure adherence to ALARA principles.

The administration will support the RSO in instances where this authority must be asserted. All reasonable modifications will be made to procedures, equipment and facilities to reduce exposures, unless the cost is unjustified. The administration is prepared to describe the reasons for not implementing modifications that have been recommended.

As noted in Section IV, the RSO is tasked with leading the implementation of ALARA principles and practices. The RSO's annual program reviews include an evaluation of equipment, procedures, contamination control records, inspection findings and incidents to assess the program's success and are used to determine if any program modifications are needed to ensure doses are kept to a minimum. A summary of the findings, including a description of any actions proposed and taken, will be documented, submitted to the RSC for review, and available to all personnel for review.

Authorized users and radiation workers are instructed to apply ALARA principles and good work practices to minimize their radiation exposures, and to strictly adhere to UCF radiation safety policies and procedures in order to keep their exposures as low as practical.

VI. Radiation Safety Training Program

Handling and use of radioactive material (RAM) and ionizing radiation-producing equipment at UCF is restricted to trained personnel.

The University's radiation safety training program has two components: initial and refresher training. Initial training covers the two training requirements specified in Florida radiation control regulations: radiation awareness training (instructions to workers) described in section 64E-5.902, Fla. Administrative Code (FAC) and authorized user training described in section 64E-5.1307, FAC. In addition, hazmat employee training is provided to any worker with job functions related to shipment and receipt of packages containing RAM.

PI's that can document sufficient hands on and formal training at another institution will not be required to complete UCF's radiation awareness training. The RSO will present a one-on-one session with the PI covering UCF specific program requirements and PI responsibilities.

A. Initial Radiation Safety Training

Completion of initial radiation safety training is a prerequisite for working with RAM or radiation machines and is a requirement for designation as a radiation worker or Associate Investigator. The appendices of the UCF radiation safety manual are the primary training references, and a copy of the manual is supplied to each lab. The RSO conducts radiation safety classes. Attendees are instructed to read the radiation safety manual prior to attending the class. The training covers the topics listed in 64E-5.902(1) and 64E-5.1307(1), and FAC, which are summarized below.

- Information on the storage, transfer, and use of radiation sources at UCF.
- Principles and fundamentals of radiation protection and safety practices, including ALARA principles, precautions and procedures for minimizing radiation exposures.
- Biological effects of radiation exposure, including internal and external radiation hazards;
- Radiation detection, measurement and monitoring techniques.
- Applicable provisions of Florida radiation control regulations and the University's radioactive materials license, machine registration and radiation safety program.
- Personnel monitoring, occupational and public dose limits, and occupational radiation exposure reporting requirements.
- Lab policies and procedures, including workers' responsibility to report any unsafe conditions in the workplace.
- Requirements for shipping and receipt of radioactive materials.
- Radioactive waste processing and disposal.
- Procedures for responding to radiological incidents and emergencies.

The duration of training is generally about 2 hours, but may vary based on attendees' comprehension of the topics covered. A question and answer session is held at the end of the training period, and attendees are encouraged to request clarification as necessary during the presentation. The class concludes with a quiz covering all training topics.

Upon completion of the initial training class, personnel with previous experience working with the types and quantities of radioactive materials or machines they will be using at UCF can document this experience using Form RC-1 "Statement of Radiation Safety Training and Related Experience". The PI will submit the form to the RSO requesting that the person is formally designated as Associate Investigators under that PI's authorization.

Personnel without appropriate prior experience are designated as radiation workers and are required to obtain practical experience with use of their radioactive materials or machines under the supervision of PI or AI. The duration of the directly supervised hands-on training will be determined by the PI, based on the scope of work performed and each individual's performance.

B. Radiation Safety Refresher Training

Radiation workers and AI's are required to attend radiation safety refresher training at least every 7 years. The RSO conducts the class and determines the topics to be covered. Topics may include deficiencies found during lab inspections, violations, radiation policies, exposures, new subject material and concerns from employees.

C. Hazmat Employee Training

In accordance with U.S. Department of Transportation (DOT) regulations (49 CFR Part 172, Subpart H), workers with job functions that directly affect radioactive material transportation safety must complete hazmat training prior to performing such work. Exception: employees can work for 90 days without the training, provided a hazmat-trained employee directly supervises them. Refresher hazmat training is provided at least once every 3 years. Most UCF employees are not designated as hazmat employees; typically, the designation is limited to the RSO, radiation safety staff, and to personnel in the shipping/receiving department.

Hazmat training includes the following topics: general awareness/familiarization, function specific, safety, and security awareness training. It is provided by the RSO or by a qualified third party, and may be conducted concurrently with other radiation safety training. Documentation of hazmat training includes the following:

- Employee name and date of most recent training completed.
- Description, copy or location of training materials used.
- Name and address of the person providing the training.
- Certification that the employee has been trained and tested as required.

D. Radiation Safety Training for Radiation Machine Operators

Personnel using radiation machines complete an "X-ray edition" of the initial radiation safety training described in VI.A. In addition to completing the initial training, such personnel are required to read the device manual and receive supervised hands-on instruction on the instrument's use prior to being allowed to operate it independently.

E. Radiation Safety Staff Training

The RSO, as a minimum, must meet the requirements of 64E-5.1305(2), FAC, which states that the individual must have sufficient training and experience to be a user of the radioactive materials authorized by the license. Training must include practical experience in use of radioactive materials and knowledge of procedures, facilities and equipment. The RSO need not be an expert in all areas covered by the program, but must have sufficient training and experience to perform the duties required for the position. RSO qualifications should be a combination of formal education and relevant experience with the types and quantities of radiation sources possessed by UCF.

In addition to completing the initial training required for all radiation workers, UCF radiation safety staff receives instruction from the RSO regarding the responsibilities of radiation safety technical staff and supervised hands-on instruction on performance of radiation safety program-related tasks, with emphasis on lab inspections, instrumentation, records and radwaste processing.

VII. Radiation Safety Policies and Procedures

A. Responsibilities

PI and staff are responsible for ensuring compliance with UCF policies and procedures in their lab.

B. Lab Posting

A restricted area is defined as any lab or room where radioactive materials are used or stored. Lab and equipment room doors posted with a "Caution – Radioactive Material(s)" sign signify a restricted area. Only trained and approved workers are permitted to work in restricted areas without supervision.

All labs must be posted with:

- UCF Radiation Safety Rules & Emergency Posting
- FDOH BRC "Notice to Employees" form

C. Personnel Monitoring Requirements

Personnel monitoring (PM) badges provide a legal record of workers' occupational external radiation exposures. Whole body PM badges are assigned to workers using or assisting in the use of radiation sources in accordance with requirements specified in 64E-5.315 and 64E-5.1310, FAC.

- Section 64E-5.315, FAC requires whole body badging of individuals likely to receive annual exposures greater than 500 mrem.
- Section 64E-5.1310, FAC requires whole body badging of individuals working with unsealed sources of any gamma-emitting isotope with gamma ray energy greater than 50 keV or any beta-emitting isotope with maximum beta energy of 300 keV or more. An extremity (ring) badge is required for any individual working with unsealed sources of 1 mCi or more of beta-emitting isotopes with maximum beta energy of 1,000 keV or more in any month or by any individual who receives a dose of 40 mrem or more on a whole body badge.

Work with the following types of radioisotopes does not typically warrant monitoring:

- Pure alpha emitters
- Low energy beta emitters such as H-3, C-14, and S-35
- I-125 "RIA kits" with activity of less than 5 microcuries
- Ni-63 sources in gas chromatographs
- Radioactive materials quantities and concentrations classified as exempt per Florida radiation control regulations

Personnel subject to radiation monitoring must submit a completed Form RC-2 to the RSO. Female workers subject to radiation monitoring must also submit a completed Form RC-15 ("Instructions for Women Working with Radiation").

Whole body PM badges and most finger rings are exchanged each quarter (Jan., April, July and Oct.). If more than 1 mCi P-32 is used in a calendar month, finger rings are exchanged monthly. Instructions for proper use of PM badges are as follows:

- PM badges are individually assigned and cannot be shared. If a replacement badge is used, it must be marked with the name, initials and/or identification number of the individual designated to wear it.
- PM badges should only be worn on site and in restricted areas. Badges cannot be worn during non-occupational radiation exposures (e.g., medical or dental X-rays, etc.).
- Whole body badges are worn on the front of the torso, at or above the waist and below the shoulder. Extremity badges may be worn either on the palmar side of the finger or the wrist.
- Protect badges from moisture, chemicals, intense heat or light. Never leave a badge in close proximity to a source of radiation. When not in use, store badges with the Control badge in a low background radiation area.
- A spare badge may be assigned to a new employee until the badge vendor issues a badge bearing the worker's name for the next monitoring period. Such badges must be imprinted with the worker's name or initials. The dose recorded by the badge will be added to their occupational dose record.
- Workers are responsible for turning in their badges to the RSO at the end of the monitoring period to ensure rapid processing.
- The RSO must be notified immediately if a PM badge is lost or damaged. In such cases, an estimate of the worker's dose for the period covered by the badge must be provided to the badge vendor and kept on file. If a replacement badge is used for the remainder of the monitoring period, the dose recorded on the badge must be added to the estimated dose to obtain the worker's total occupational dose for the monitoring period.
- Monitored workers may request a report of the occupational dose history at any time. Currently, state regulations require the University to issue an annual dose report to all badged workers, and to issue a termination dose report when monitoring has concluded. In the future, such reports may only be issued upon request.
- The RSO reviews dosimetry reports within 30 days of receipt to determine if unnecessary exposures are being received. The RSO will sign or initial, and date each report and will investigate within 30 days the cause of any exposure considered to be excessive. If warranted, the RSO will take corrective actions to prevent recurrence. A report of each investigation and the actions taken, if any, will be documented and maintained for inspection purposes.
- <u>Female workers and declared pregnancies</u>. Prior to working with ionizing radiation, female staff are provided instructions concerning the potential risks involved for pregnant women exposed to radiation and a copy of U.S. NRC Regulatory Guide 8.13 and they sign a Form RC-15 to document receipt of the instructions. Workers that have declared themselves pregnant will be instructed to wear their assigned PM badge at waist level to estimate the embryo/fetus dose. Such workers will sign a Form RC-16 ("Declaration of Pregnancy") that includes the estimated date of conception, and a Form RC-15 ("Instructions for Declared Pregnant Women") to document receipt of instructions on monitoring requirements during pregnancies. The objective is to keep the fetal dose as low as possible, not to exceed 500 mrem from occupational radiation exposures during the pregnancy, and to follow the FDOH BRC recommendation that an embryo/fetus not receive more than 50 mrem in any one month.

  In the event of a declared pregnancy, the badge vendor will be notified to order a fetal badge and request the fetal monitoring reporting option to track exposure of the declared pregnant worker and the embryo/fetus. This reporting option shows the dose to the mother's badge and the fetal badge; each month a summary report shows estimated dose from conception to declaration, rolling exposure history by month for both mother and child, and accumulated fetal totals for the gestation period. Pregnancy monitoring records will be retained with the dose records of the mother.

D. Storage and Labeling of Radioisotopes

- All items that store, use, or are contaminated must be labeled with a radioactive warning label. Use "Radioactive" tape for items that are contaminated. Use a "Caution – Radioactive Material(s)" label for containers, radwaste, refrigerators and freezers.
- All radioactive material and waste containers must be properly labeled to identify the radioisotopes and estimated activity being stored. Use labels or tape that bears the radiation symbol and states "Caution – Radioactive Material(s)".
- The Radiation Safety Office must be notified when potentially contaminated equipment is moved to a new location, disposed of, or otherwise withdrawn from use. Radiation Safety personnel must check these items for contamination prior to transfer or disposition.

E. Contamination Control

There are basic principles which can be applied to the control of radioactive contamination:

- Minimize the amount of activity being handled.
- Make sure there is appropriate containment of radioactive material (normally at least two levels of containment are provided).
- Follow the correct procedures regarding protective clothing, washing, monitoring and decontamination.
- Maintain the lab area in a clean and neat fashion in order to reduce the potential for spills and cross-contamination.

Containment is the most widely employed contamination control technique because it is the least expensive and the most effective. Common containment methods are described below.

Work Area

Work involving radioisotopes in liquid form must be performed on impervious surfaces that are covered with absorbent paper.

Fume Hoods

Fume hoods must be used for work with volatile radioactive materials. The face velocity of the hood averages 100 linear ft/min (lfm) face velocities are adjusted by the hood sash position and the sash position should be marked to indicate where acceptable flow rates exist. The interior of the hood should contain as few items as possible.

Gloves and Protective Clothing

It is impossible to contain completely the radioactive material being used. Open vials, beakers, test tubes, syringes, gels, and the like, allow the radioactive material to be exposed to air and skin. Even though handling devices should be used where practical, there will be situations when contaminated or potentially contaminated items must be handled. Containment is still possible; however, now it is the hands and bodies of the experimenters that are contained. Containment is achieved by wearing gloves, lab coats, and protective eyewear. For non-penetrating and weakly penetrating radiation, these containment devices also provide some shielding.

Surveys & Wipes

Even when an experiment is well designed and carried out by trained personnel, physical measurements must be made to ensure that exposure of the worker is kept as low as reasonably achievable and maintained within regulatory limits. Direct surface contamination monitoring is the simplest and most convenient method. It is carried out to establish the presence of contamination on such surfaces as bench tops, clothing, skin, and so on. Direct measurements allow the contamination level to be calculated and related to the derived working limits of surface contamination. A typical contamination monitor consists of a battery-operated ratemeter equipped with an external probe. All radiation surveys must be performed using an operable and calibrated instrument sensitive enough to detect activities required for adequate contamination control.

Tritium cannot be detected by portable instruments. Surface wipes are taken to detect the presence of removable contamination. Wipes should be initially checked in the lab with a portable probe and then counted with an LSC.

F. Procedures for Safe Use of Radioactive Materials in the Lab

- Licensed sealed and unsealed sources of radiation are only to be handled by trained radiation workers. Apply the principles of time, distance and shielding, and contamination control to keep radiation exposures as low as reasonably achievable (ALARA).
- Security and accountability are priorities; never leave radioactive materials unattended, and properly log all radioactive material use. Labs must be locked when trained workers are not present, or radioactive materials and waste must be secured within the lab by the use of locked storage boxes, refrigerators or other security devices.
- Review pertinent safety practices frequently, especially before using a new radionuclide.
- Wear a lab coat, safety glasses, disposable gloves (double gloves recommended) and if required, a radiation monitoring badge when handling radioactive materials.
- Do not touch equipment, telephones, computer keyboards, refrigerators, face or anything that might get contaminated. Every item that becomes contaminated must be marked "Caution – Radioactive Materials" or "Radioactive".
- Do not wear gloves on both hands when exiting the lab to transfer samples to another location. One hand must be non-gloved to touch door handles or other items that require handling.
- Do not eat, drink, apply cosmetics or store food, drinks or personal effects in restricted areas.
- Use pipette filling devices; never pipette by mouth.
- Avoid punctures, wounds and cuts. Do not work with radioactive materials if there is an open wound in the skin below the wrist.
- Thoroughly wash hands after manipulating isotopes, before eating or smoking, and upon completion of work. Fingernails should be kept short and clean.

- Keep work areas and storage places for radioactive material within the lab to a minimum. Store radioactive material as far as practical from other work areas and behind sufficient shielding to minimize exposures.
- All radioisotope workspaces must be covered with absorbent paper. When working with radioisotopes in liquid or powder form, use of a drip tray lined with absorbent paper is recommended.
- Confine radioactive solutions in covered containers plainly identified and labeled with information regarding radioisotope, date, and the liquid components.
- Radioactive sources or stock solutions in the lab should be shielded in such a manner that the radiation levels in any occupied area will not expose individuals in that area to more than 2 mrem/hr.
- Once used for radioactive materials, equipment cannot be used for other work and cannot be moved to non-radiation areas until demonstrated to be free of contamination.

Radiation survey and wipe procedure

Daily Radioisotope Use and/or Receipt of Radioactive Material

- A survey with a portable radiation survey instrument shall be completed at the end of each day whenever radioactive materials are used. If the survey instrument is not capable of detecting the radioisotope in use then a wipe test for removable contamination shall be performed.

- The type (meter, wipe or both) of survey required depends on radioisotope or combination of radioisotopes being used in lab. All daily surveys must be recorded on your laboratory schematic by the end of the working day.

- If a wipe tested is needed, it shall be conducted using absorbent filter paper or a cotton tip swab. Wipe an approximately 100cm^2 area. Count the swipe or swab in a liquid scintillation counter (set to open window). The results should be reviewed and data taped on the appropriate lab schematic, sign and date the form. If the open window count exceeds three times cpm above background, you should recount the wipe vial. If result is still high, you must decontaminate area and collect another wipe. A background sample should be counted (same LSC) with all of your wipe samples. A background sample is a new/unused filter paper or cotton tip swab placed in same type LSC vial and covered with same type LSC cocktail used for wipe samples.

- A meter reading three times background in any part of your lab area that has no nearby radioactive materials or radioactive waste storage shall be decontaminated. If area cannot be cleaned after two attempts, contact UCF Radiation Safety office staff for assistance.

- Wipe and meter results are recorded on Form RC-14 (Radiation Lab Survey) map for each area requiring monitoring. Form RC-14 documents the lab layout, survey/wipe locations and related information. The forms and LSC printouts are maintained in Radiation Records notebooks.

- Any contamination exceeding the action limits will be highlighted on the lab survey form. Radiation safety staff will provide assistance during any lab or personnel decontamination procedure, as necessary.

Instructions for self-monitoring

- Anyone who enters a restricted area must monitor his or her hands and shoes before departing the lab and at the end of the workday.
- The survey meter's audible switch should be turned on, and "fast" response selected, if provided.
- Maintain a close distance (about one centimeter) between the probe and the surface being surveyed, while avoiding potential probe contamination from contact with the surface. Move the detector slowly so it will have time to respond.
- Check hands first, before handling the probe.
- Check bottom of shoes, moving the probe very slowly.
- If contamination is found, perform decontamination as necessary and re-monitor; if decontamination efforts are unsuccessful, call the EH&S Dept. immediately.
- After the survey, turn the instrument to preserve the batteries.

Instructions for radioisotope experiments

- Monitoring devices (whole body badge, ring badge) must be worn when prescribed.
- Before setting up for the experiment, monitor the work area, floor, surrounding areas and waste containers for contamination. If contaminated, contact the EH&S Dept.
- Prepare your work area. Cover the work bench surface with absorbent paper. When working under conditions that a spill or incident would not be confined to a small area, the work should be done over a spill tray, or other provisions should be made to minimize the extent of a contamination incident.
- Gather all materials necessary for the experiment.
- Routinely monitor the work area and your gloves during the experiment. Change contaminated gloves immediately during the experiment.
- Dispose of radioactive waste in clearly labeled appropriate waste containers. Liquids that are disposed in the sink must be recorded on the effluent monitoring log (Form RC-12). Contact the RSO for more information prior to start-up of sink disposal.
- Never discard radioactive materials into regular waste containers. Do not discard non-radioactive waste materials into radioactive waste containers.
- After completing area survey and wipes, monitor your hands, then wash your hands.
- Notify the RSO of any unsafe conditions.

G. Ordering Radioisotopes

- Only the RSO is authorized to approve orders for radioactive material, to ensure that the requested material and form are authorized by the license and will not exceed possession limits specified in the University's license. Requests for radioactive materials shall not be submitted if such materials and quantities, plus the materials and quantities on hand, exceed those listed on the radiation use authorization as approved by the Radiation Safety Committee.

- Orders **must be made through the departmental purchasing agent** and shipped directly to the radiation safety office.
- After the RSO processes the order, the material will be delivered to the lab.
- When a radioisotope delivery is made, a trained worker must sign for the package.

H. Radioisotope Inventories

Each PI that possesses licensed unsealed radioactive material is required to maintain a current inventory of the radioactive materials in their possession using Form RC-6 Radioisotope Inventory Log.

The following information is documented at the top of the form:

- Tracking number assigned to each shipment of radioisotope
- Date received
- Isotope and Compound
- Activity received

When it is time to remove the material from the vial:

- Place your name in the column
- The amount taken
- The amount remaining

When you are finished with your experiment:

- Perform your wipe tests or meter surveys.
- Record wipe test results under the wipe column; list "BKG" if the result is back-ground; if the results show contamination, write the highest number down, then clean. Record swipe locations and readings on RC-14.
- Record the survey results under the meter column; list "BKG" if your results are background; otherwise, record the reading, and clean. Record survey locations and readings on RC-14.
- Once a material has been completely used up, list the data of final use or disposal on the bottom of the form.

The formula for calculating decay is: $A = A_o \times e^{(-0.693t/T1/2)}$

Where: A = Activity now

A_o = Activity at some previous time

e = Base of natural logarithm

t = Elapsed time

$T_{1/2}$ = Half-life of the radionuclide (must be in same time units as t)

Physical reinventory may be requested at the RSO's discretion.

Sealed sources will be inventoried by the RSO every six months using Form RC-8 Sealed Source Inventory.

I. Transfers of Radioactive Materials to Other Labs or Facilities

Transfers of radioactive materials to labs must be documented on Form RC-7 and in coordination with the RSO. Each lab's inventory must also be updated (Form RC-6 or Form RC-7 as appropriate).

Transfers of radioactive materials to other facilities must be coordinated with the RSO. Such shipments must be properly packaged, labeled and wipe tested, as necessary. The RSO must have a copy of the recipient's license number as proof of authorization to receive the material.

J. Receipt of Packages Containing Radioactive Material

Emergency Actions: If any radioactive material package appears to be damaged or leaking (appears wet), notify the Radiation Safety Officer immediately. Do no move or handle the package. Leave the package area, move and keep personnel 3 feet away from package. Contact RSO!

Only the RSO and trained designees are authorized to check in and open packages containing radioactive materials or other device containing radioactive material. A separate Radioactive Material Transfer form RC-5 is used for each package and/or isotope received.

VIII. Radioactive Waste Management and Disposal

Radioactive waste is to be handled only by authorized, badged workers. Wastes are sorted in the laboratory by isotope type into dry waste, scintillation vials and liquid waste streams. Radiation symbols and marking are defaced prior to putting in the dry waste. Request for waste collection can be made using the online radiation waste form at:
http://www.ehs.ucf.edu/formsUCFonly/radwasteform.htm

At time of pick up, a reading is taken on the material and recording on the electronic waste receipt. The material is placed in a lined drum with absorbent material for transport to the radiation waste storage area.

Short-lived isotopes are put into drums located in the radiation waste shed and held for decay 10 times their half-lives. After decaying, the containers are checked with a GM detector to ensure contents are at background levels. The RSO ensures there are no markings or labels on the waste prior to disposing of it in the regular trash or sink.

Long-lived isotopes are separated by type, put into lined drums located in the radiation waste area and held for pick up by a licensed radioactive waste vendor.

Sanitary Sewer Disposal of Laboratory Waste Containing Radionuclides

Orlando Campus and Research Park Facilities
Small amounts of water-soluble liquid isotope wastes can be discharged in designated sinks in radioactive material containing labs on the Orlando campus and Research Park Facilities. Sanitary effluents from these facilities average 600,000 gallons/day. Monthly discharge calculations are based on microcuries per milliliter of average daily effluent instead of monthly effluent as a safety factor to ensure discharge limits are not exceeded.

Sanitary effluents are processed at the Iron Bridge POTW facility located in Seminole County, FL.

- Workers must assure that the liquid waste does not exceed criteria listed in the following table.
- The RC-12 isotope sink/sewer discharge log must be filled out for each discharge. Keep log in radiation records notebook.
- Liquid waste should be discharged only via designated sinks.
- Discharge liquid waste slowly to with water running from the faucet to dilute it.
- Survey the sink and surrounding work surfaces to confirm that no residual material or contamination remained in the sink or on work surfaces.
- Prior to leaving the area, decontaminate all areas or surfaces, if found to be contaminated.

The Radioactive Waste Discharge Limits table gives the maximum activity each authorized user group is allowed to discharge on a monthly basis along with other criteria for discharges. Because average daily effluents are used in the calculations instead of monthly, maximum discharge quantities listed in 64E-5 Table III for single isotopes and the sum of the ratios of multiple isotopes will not be exceeded.

Lake Nona Facilities
Authorized users at Lake Nona facilities must contact the RSO for discharge limits.

*Monthly discharge calculations are based on microcuries per milliliter of average daily effluent as a safety factor

Radioactive Waste Discharge Limits				
Radio-nuclide	**Class**	**F.A.C. 64E-5 Table III Monthly Concentrations (uCi/mL)**	**UCF Effluent mL/Day***	**UCF Allowable mCi Discharge/ month/ AU**
H-3	Water, DAC Includes skin absorption	1.00E-02	2.27E+09	2.27E+04
C-14	Monoxide, dioxide	0	2.27E+09	0
C-14	Other Compounds	3.00E-04	2.27E+09	6.81E+02
Na-22	All Compounds	6.00E-05	2.27E+09	1.36E+02
P-32	Phosphates of Zn^{2+}, S^{3+}, Mg^{2+}, Fe^{3+}, Bi^{3+}, and lanthanides	0	2.27E+09	0
P-32	Other Compounds	9.00E-05	2.27E+09	2.04E+02
P-33	Phosphates of Zn^{2+}, S^{3+}, Mg^{2+}, Fe^{3+}, Bi^{3+}, and lanthanides	0	2.27E+09	0
P-33	All Compounds	8.00E-04	2.27E +09	1.82E +03
S-35	All Compounds	0	2.27E+09	0
Se-75	Oxides, carbides, hydroxides and elemental Se	0	2.27E+09	0
Se-75	Other compounds	1.00E-03	2.27E+09	2.27E +03

Other Criteria for Individual Discharges

Wastes must be water-soluble per

Waste must not have a flashpoint below 140F

The pH must be adjusted above 2 or below 12.5

The waste must not contain more than 0.2 mg/L of the following heavy metals:

Arsenic Barium Cadmium	Chromium Lead Mercury	Selenium Silver

The waste must not contain more than 0.2 mg/L of the following solvents:

Carbon tetrachloride Chlorobenzene Chloroform 1,4 Dichlorobenzene 1,2 Dichloroethane 1,1 Dichloroethene	Hexachlorobutdiene Tetrachloroethylene Trichloroetheylene Vinyl Chloride	Benzene Cresol (includes o, m, p) 2,4-Dinitrotoluene Methyl Ethyl Ketone Nitrobenzene Pyridine

The **process generating the waste** must not contain more than 10 percent of the following solvents (before any dilutions):

Acetone Benzene n-Butyl Alcohol Carbon Disulfide Carbon Tetrachloride Chlorobenzene Cyclohexanone o-Dichlorobenzene 2-Ethoxyethanol	Ethyl Acetate Ethyl Benzene Ethyl Ether Isobutanol Methanol Methylene Chloride Methyl Ethyl Ketone Methyl Isobutyl Ketone 2-Nitropropane	Pyridine Tetrachloroethylene, Toluene 1,1,1 – Trichloroethane 1,1,2 – Trichloroethane Trichloroethylene Trichlorofluoromethane 1,1,2-trichloro-1,2,2-trifluoroethane

IX. Laboratory Inspection Procedure

The RSO and/or radiation safety staff performs routine (typically quarterly) inspections of radiological labs to assure the safety of personnel, facilities, and property and compliance with regulatory requirements and UCF policies and procedures. Form RC-13 is used document lab inspection findings, including radiation surveys. If problems are found, an electronic memo describing the findings is provided to the PI responsible for the lab. Corrective actions are described and suggested. If corrective actions are not taken, a meeting to discuss the issues will be set up with the PI and the lab personnel. If the PI refuses to comply with the corrective actions, a meeting with management will be held. Management can suspend or revoke the PI’s RAM authorizations and confiscate the lab’s radiation sources if issues remain unresolved.

In addition to quarterly inspections of the labs, the RS office will conduct monthly contamination wipe surveys of all laboratories with radioactive materials or waste in storage and document on RC-14.

X. Radiological Incident & Emergency Procedures

Radiological Emergency Phone Numbers

Radiation Safety Officer (Renee Michel): **(407) 823-3747 (office)**

Work Control Center **(407) 823-5223**

FL DOH Bureau of Radiation Control (24-hr. no.): **(407) 297-2095**

Workers are responsible for promptly reporting any unsafe conditions. If a spill or any other radiological incident occurs, the primary concerns are to minimize personnel exposures and the spread of contamination. Contact the EH&S Dept. immediately for assistance. Spill response supplies, including the items listed below, should be maintained in each lab.

- Decontamination solution
- Trash bags
- Shoe covers
- Contamination wipes
- Disposable towels
- Box of disposable gloves
- Tape
- Marking pen (Sharpie)

A. Minor Vs. Major Spills

The decision to implement a major spill procedure instead of a minor spill procedure depends on many incident-specific variables such as the number of individuals affected, other hazards present, the likelihood of spreading contamination, types of surfaces contaminated, and the dose rate at 1 foot from the spilled material. For some spills of short-lived radionuclides, the best spill procedure may be to restrict access pending decay to background levels.

Estimate the amount of radioactivity spilled. Initiate a major or minor spill procedure based on the following quantities.

B. Minor Spill Procedure

Radioactive spills involving less than (<) 50 µCi of activity and/or a survey meter reading of less than (<) 5mR/hr at a distance of one foot.
NOTIFY: Notify persons in the lab that a spill has occurred.

PREVENT THE SPREAD: Cover the spill with absorbent paper.

CLEAN UP: Use disposable gloves, lab coat, and eye protection. Cover the spill with absorbent material as quickly and as completely as possible to prevent spreading. To localize the contamination, wipe inward toward the center of the spill. Do not wipe back and forth or in a random fashion. Carefully fold absorbent paper and wipe up spill. Insert into a plastic bag and dispose of in the radioactive waste container. Include all other contaminated materials such as disposable gloves.

SURVEY: With a survey meter, check the area around the spill, and your hands and clothing for contamination. A swipe survey must be performed to demonstrate that decontamination results are below the limit three times background cpm (open window). Retain all survey and wipe results in your red book for future reference.

REPORT: Report incident to UCF's Radiation Safety Officer by phone or email. If the RSO cannot be reached by phone and you need spill supplies or other assistance, call the University Work Control Center at 407-823-5323 for additional EH&S office contacts.

C. Major Spill Procedure

Radioactive spills involving MORE than (>) 50 µCi of activity and/or a survey meter reading of MORE than (>) 5mR/hr at a distance of one foot.

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

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.

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.

CLOSE THE ROOM: Leave the room and lock and stay by the door(s) to prevent entry.

CALL FOR HELP: Notify the Radiation Safety Office immediately. In the event the RSO cannot be reached, utilize the "Radiation Emergencies" contact list on lab posting.

PERSONNEL DECONTAMINATION: Contaminated clothing should be removed and stored in a plastic bag for further evaluation by the Radiation Safety Office. If the spill is on the skin, flush thoroughly and then wash with mild soap and lukewarm water.

D. Stolen, Lost, or Missing Radiation Source

- In the event of a stolen, lost or missing radiation source, immediately notify the RSO.
- Conduct a complete search of the area with an appropriate survey meter capable of detecting the radioactive material. The RSO will notify management and appropriate local and state authorities.

E. Incidents or Unusual Events

- Immediately secure the incident area. Keep people away until the situation is assessed and radiation levels are known. Maintain surveillance of the perimeter to prevent unauthorized entries.
- Care for life-threatening injuries first, even if individuals may be contaminated. Perform first aid and remove them from the area only when medically safe to do so. Evaluate the situation to determine if anyone may have been exposed to radiation. Notify emergency personnel and hospital staff about possible radioactive material contamination. Do not allow any potentially contaminated people to leave the scene; have them remain away from the incident area until they can be surveyed for contamination.
- If any equipment is involved, isolate the equipment until it can be surveyed for possible contamination.

- As soon as possible, notify the RSO. Follow directions provided by the RSO. If necessary, the RSO will notify the appropriate local and state authorities.
- Wait for technical assistance prior to approaching the incident scene until the extent of contamination has been determined. Use a survey meter to determine the presence of elevated radiation levels and/or contamination in the area or on personnel. Special precautions and protective clothing/equipment must be used to perform decontamination and disposal of any contaminated materials.

APPENDIX A: Introduction to Radiation Safety

A. Structure of Matter

Matter is the name given to the materials that compose the Universe. It exists in four physical forms: solid, liquid, gas and plasma. All matter consists of a number of simple substances called **elements**.

An element is a substance which cannot be broken down by ordinary chemical processes into simpler substances. The **atom** is the smallest part of an element that can enter into chemical combinations. In nature, elements are usually chemically linked to other elements in the form of **compounds**.

A compound consists of two or more elements chemically linked to definite proportions, e.g. water, H_20, which consists of two atoms of hydrogen and one atom of oxygen.

B. The Atom

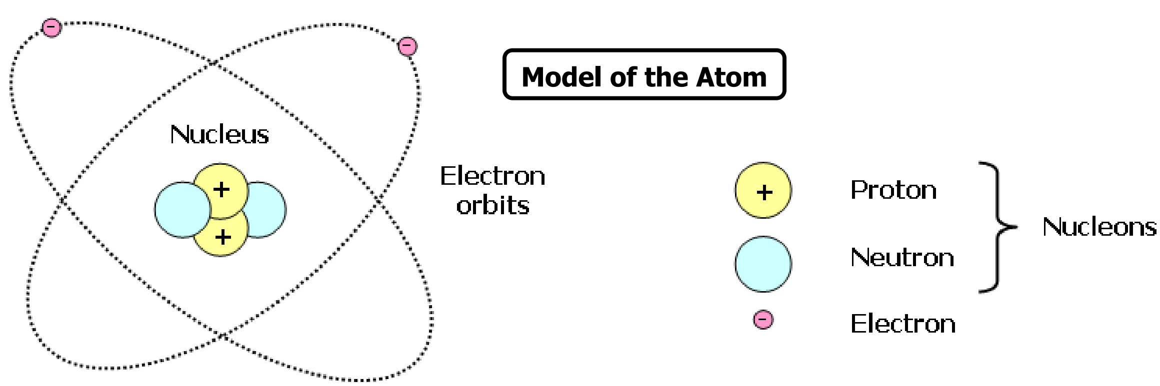
Atoms are composed of even smaller particles. These particles, from which all atoms are constructed, are called protons, neutrons, and electrons.

The **proton** (p) carries a positive electrical charge of a magnitude of one unit on the nuclear scale, and a mass of approximately one atomic mass unit (amu or u).

The **electron** (e^-) has a negative electrical charge of the same magnitude as the proton's positive charge. It has a mass of 1/1840 u, which for most purposes is neglected in considering the mass of the atom.

The **neutron** (N) is often regarded as a close combination of a proton and an electron. It is electrically neutral and neglecting the mass of the electron, has a mass of approximately one atomic mass unit.

The neutrons and protons of an atom form a central core, or **nucleus**, around which the electrons rotate in various orbits. A stable electrical balance is maintained by an equal number of protons and electrons, with the charges "canceling out" one another. An atom remains neutral unless an external force causes a change in the number of electrons. The number of the protons in an atom is called the **atomic number**, represented by the symbol Z. It determines the chemical properties of the atom and so defines the element. The sum of the number of protons plus the number of neutrons is called the **mass number** and is represented by the symbol A. Thus, A = Z + N.



C. Isotopes

Although all the atoms of a particular element contain the same number of protons, they may occur with different numbers of neutrons. This means that an element can have several types of atoms. For example, the element phosphorus (P) has an atomic number of 15 (i.e., each atom contains 15 protons), but it can occur with different numbers of neutrons.

$^{28}_{15}P$ 15 protons and 13 neutrons (Z = 15, A = 28)

$^{30}_{15}P$ 15 protons and 15 neutrons (Z = 15, A = 30)

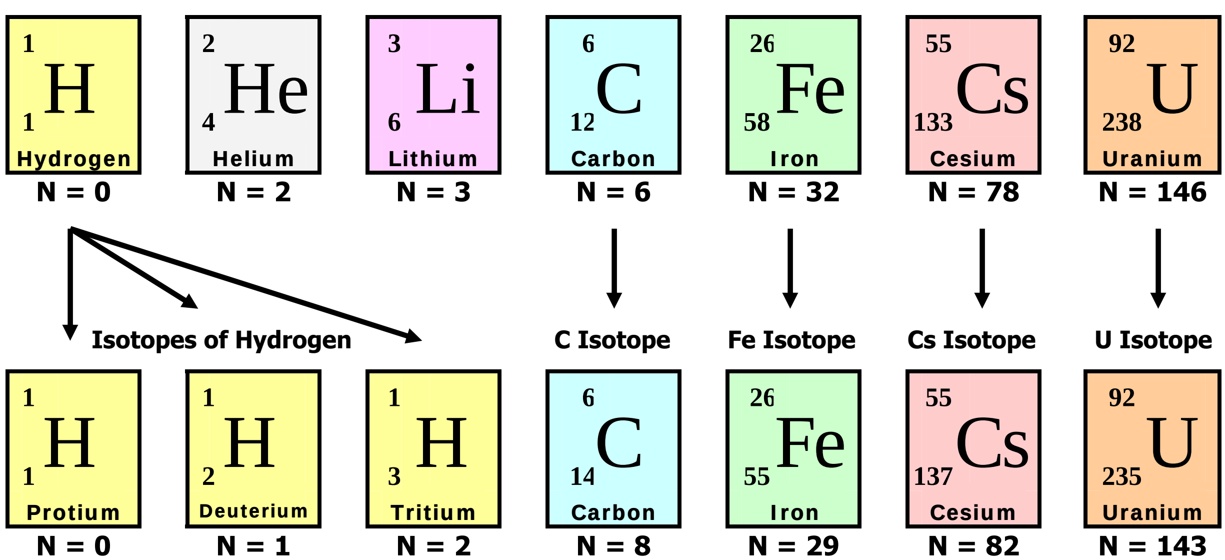
$^{32}_{15}P$ 15 protons and 17 neutrons (Z = 15, A = 32)

These different forms are called **isotopes** of the element. For example, P-28, P-30 and P-32 are all isotopes of phosphorus. Neutrons contribute to the stability of the nucleus. Stable nuclei tend to have equal numbers of neutrons and protons. It is important to note that all the isotopes of a given element are chemically identical, since the chemical properties are determined by the atomic number of the element.

One convention for distinguishing isotopes is to list the element name followed by the atomic mass number; e.g., U-235 (92 protons + 143 neutrons = 235) and U-238 (92 protons + 146 neutrons = 238).

Isotopes are also denoted by the following formula:

$^{A}_{Z}\mathbf{X}$ where: X = chemical symbol
A = atomic mass (no. of protons and neutrons)
Z = atomic number (no. of protons) (often omitted)



Superscript # = Atomic No. (Z) - no. of protons in nucleus Subscript # = Atomic Mass (A) - no. of protons & neutrons

D. Radioactivity

Some isotopes are stable, while others are unstable (**radioactive**). Some atomic configurations are stable while others are unstable. Stable atoms maintain their configuration for indefinitely long periods of time, while the nucleus of unstable atoms tend to disintegrate spontaneously. These unstable atoms are called **radioactive isotopes**, **radioisotopes**, or

radionuclides, and the process of disintegration is known as **radioactivity**. More than 800 radioisotopes have been discovered, with at least one for every element.

When a radioactive nuclide disintegrates, the nucleus undergoes a transformation and energy is liberated. A given radioisotope will always change the same way, and in some cases, particles are ejected from the nucleus. The energy released may be shared by the emitted particles; i.e., the particles are ejected with considerable velocity and possess kinetic energy or energy may be released in the form of electromagnetic waves of very short wavelength.

E. Ionizing Radiation

The mechanism of transfer of energy from radiation to matter is called **ionization**. Ionization occurs when the electrical balance of atoms is disrupted. When an electron has been removed from an atom, the atom becomes positively charged, `since it has lost a unit of negative electrical charge. This positively charged atom is called a positive **ion**. The expelled electron either remains free or may join another atom creating a negative ion. In either case, the pair of particles with opposite charge is referred to as an **ion pair**. About 34 **electron volts*** are required to produce an ion pair. This process of **pair production** is a common and important effect of radiation on matter. Hence, such radiation is referred to as **ionizing**.

*The energy of ionizing radiation is typically given in eV units. One eV is defined as the amount of kinetic energy gained by an electron when it is accelerated through a voltage difference of 1 volt. Abbreviations:
1 keV = 1000 eV
1 MeV = 1 million eV

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Ionizing radiation comprises energetic particles and electromagnetic radiation from both natural and artificial nuclear reactions. Three common types of radiation emitted from radioactive isotopes are alpha, beta and X-ray/gamma radiation. These may be distinguished by their paths in a magnetic field and by their distance of travel in air.

Alpha Radiation

Alpha particles (α) are slow, heavy particles, having a double positive (+2) electrical charge. They consist of two neutrons and two protons and are identical with the nucleus of the helium atom. They are highly energetic particles having energies of 4 MeV or greater. These energies are up to several orders of magnitude greater than other types of radiation associated with radioisotopes used in biological laboratories.

From a radiation safety standpoint, alpha particles are easily stopped by a thin absorber, such as a sheet of paper or the skin epidermis. External to the body, such sources do not present a great hazard. Inside the body, however, alpha emitters are highly significant. Because the alpha particle is double-charged and relatively massive, it undergoes many interactions with surrounding atoms, depositing all its energy in a very small volume, on the order of 3×10^{-9} cm^3 in muscle. An energy deposition of this magnitude within a cell will virtually guarantee cell destruction.

Beta Radiation

Beta particles (β) are unpaired, singly charged electrons possessing kinetic energy. The mass of the beta particle is about 1/8000 of the mass of an alpha particle. Negatively charged (-1) beta particles are identical to orbital electrons except that they have a nuclear origin. They are referred to as negative electrons or negatrons. **Positrons** or positive electrons have the same mass as negatrons but are positively charged (+1). When a positron is emitted from the nucleus, a proton is converted to a neutron. When a negatron is emitted, a neutron is transformed into a proton.

In UCF labs, ß-emitting isotopes (**beta-emitters**) are common and include H-3 (tritium), C-14, P-32, P-33 and S-35. Accelerators and electron microscopes also emit high-energy electrons. The ability of a beta particle to penetrate matter is a function of its energy. A 1 MeV ß particle will travel about 1 m in air, 1 mm in Lucite, and 1-3 mm in skin. Low-energy beta particles (less than 0.2 MeV) are easily absorbed in the outer layer of skin. Beta sources external to the body present a greater threat of penetration when compared to alpha particles. As with alpha radiation, beta sources inside the body, within cells or incorporated into biologically active molecules, may give significant doses that may disable and kill cells.

X-rays and Gamma Radiation

X-rays and gamma radiation (γ) are **electromagnetic radiation** traversing matter. They have neither mass nor charge. They create ionization in material through which they pass by a number of mechanisms that cause excited electrons to be ejected from absorbing or struck atoms. Since X- and gamma rays are without mass or charge, their interactions per unit volume are less than for alpha or beta particles and therefore they are vastly more penetrating than those particles. X-rays and gamma rays have identical physical property characteristics. They differ only in method of production. Gamma rays result from the emission of energy as an excited nucleus drops from one energy level to a lower energy state; X-rays result from transitions within the electron cloud of an atom or are emitted when a charged particle is accelerated.

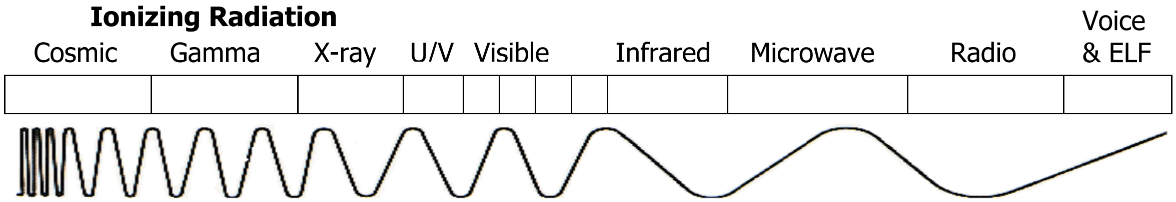
The amount of energy transmitted is related to the wavelength of the radiation. It is found experimentally that $E=1/\lambda$ where E is the energy of the **photon** of electromagnetic radiation and λ is its wavelength. All electromagnetic radiations travel through free space with the same velocity of 3×10^8 m/s (186,000 miles/sec). Their velocity decreases in dense media, but in air, the decrease is negligible.

Whenever a high-energy electron approaches the nucleus of a material of high atomic (Z) number and large nuclear charge, a sudden deceleration of the impinging electron is likely to occur. The electron loses some energy in this process and this energy appears in the form of photon energy. Such photons are highly penetrating, so certain beta sources are difficult to shield unless first placed in containers of lower atomic number where the probability of two types of radiation is greatly reduced.

When the term "radiation" is used in this manual, it refers to ionizing radiation, but a broader definition is any energy that comes from a source and travels through some material or space. Light, heat and sound are all types of radiation. Some forms of radiation, like visible light, microwaves, or radio waves do not have sufficient energy to remove electrons from atoms and are called **non-ionizing radiation**.

The **electromagnetic spectrum (EMS)** encompasses the full range of all possible **electromagnetic radiation (EMR)** – both ionizing and non-ionizing.

Electromagnetic Spectrum



Increase in wavelength = decrease in frequency and energy

The EMS and EMR are named for their two fields (electric and magnetic). Both fields are pure energy, with no mass and no charge. EM radiation travels at the speed of light and can be categorized by its energy and location on the EM spectrum. The EM spectrum extends from frequencies used in the electric power grid (at the long-wavelength end) to gamma and cosmic radiation (at the short-wavelength end), covering wavelengths from thousands of kilometers down to fractions of the size of an atom. Waves in the EM spectrum vary in size from very long radio waves the size of buildings, to very short gamma rays smaller than the size of the nucleus of an atom. While the classifications are generally accurate, there is often some overlap between types of EM energy. For example, some low-energy gamma rays actually have a longer wavelength than some high-energy X-rays.

According to the quantum theory, EM radiation consists of "particles" of energy. Each particle (called a quantum, or more commonly, a **photon**) contains a discrete quantity of EM energy. The energy of a typical visible light photon is ~ 2 eV. Low-energy photons, like radio, tend to behave more like waves, while higher energy photons (e.g., X-rays) behave more like particles. That's why we refer to X-ray energies instead of X-ray waves.

Neutron Radiation

Neutron radiation (n) is often called indirectly ionizing radiation. Neutrons do not ionize atoms in the same way protons, photons, and electrons do (by exciting an electron) because neutrons have a neutral charge.

However, neutron interactions are largely ionizing; for example when neutron absorption results in gamma emission and the gamma subsequently removes an electron from an atom, or a nucleus recoiling from a neutron interaction is ionized and causes more traditional subsequent ionization in other atoms. Because neutrons are uncharged, they are more penetrating than alpha radiation or beta radiation. In some cases they are more penetrating than gamma radiation, which is impeded in materials of high atomic number. In hydrogen, a low energy neutron may not be as penetrating as a high energy gamma.

Neutron sources are made by combining alpha-emitting isotopes like americium-241, polonium-210, plutonium-238 or radium-226 with beryllium. Another neutron source is the transuranium element Californium-252 (Cf-252), which emits neutrons as it undergoes spontaneous fission. Some accelerators also produce neutrons, either by photon-neutron production or by smashing a deuterium (H-2) atom into tritium, producing neutrons.

Neutron activation is a process based on the ability of neutron radiation to induce radioactivity in most substances it encounters (including biological tissues). This occurs through the capture of free neutrons by atomic nuclei, which are transformed into a heavier nuclide (frequently a radionuclide) and enter an excited state. The excited nucleus often decays immediately by emitting particles such as neutrons, protons, or alpha particles, often accompanied by gamma radiation. Neutron capture, even after any immediate decay, often results in the formation of unstable **activation products** with half-lives ranging from fractions of a second to many years. The process is associated with nuclear installations and linear accelerators. As the equipment is continuously bombarded by neutrons, long-lived activation products accumulate until the radioactive equipment must eventually be replaced and disposed of as radioactive waste. Neutron activation has practical applications: **neutron activation analysis** is one of the most sensitive and accurate methods of trace element analysis. Although the activation induces radioactivity in the object, the levels are typically low and the lifetimes may be short, so the effects soon disappear. In this sense, neutron activation is a non-destructive analysis method. Other applications of neutron radiation in biotech labs include scattering and diffraction experiments to access the properties and structure of materials.

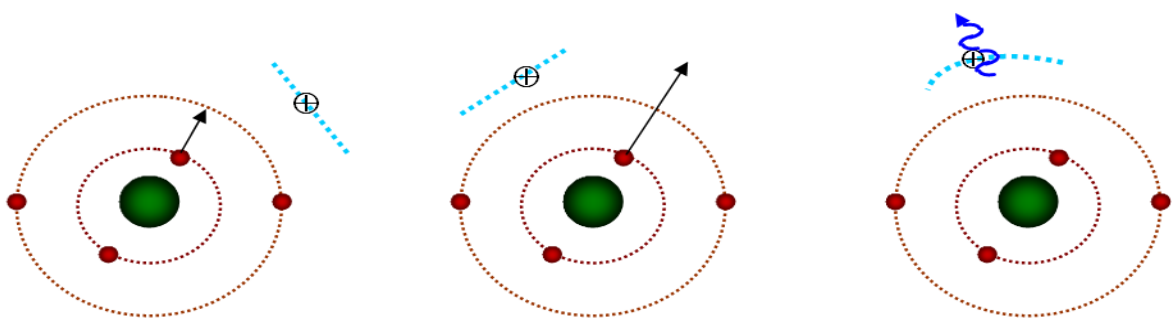
F. Interaction of Radiation with Matter

Charged Particle Interactions

Alpha and beta particles lose energy mainly through interactions with atomic electrons in the absorbing medium. The energy transferred to the electron causes them either to be excited to a higher energy level (**excitation**) or separated entirely from the parent atom (**ionization**). Another important effect is that when charged particles are slowed down very rapidly, they emit energy in the form of X-rays. This is only of practical importance in the case of beta radiation.

This third major mechanism of energy transfer is called **bremsstrahlung**, a German word meaning "braking radiation." As the charged particle interacts with the orbital electrons of the absorber, its path is deflected. This change in direction is a deceleration which causes a photon (in the X-ray energy region) to be emitted. This is the principle of operation of an X-ray machine, in which very energetic electrons impinge on a target (e.g. copper or tungsten) and emit bremsstrahlung. The intensity of the bremsstrahlung is directly proportional to the energy of the charged particle and its atomic number Z, and inversely proportional to the square of the mass of the charged particle. For example, at a given energy, an electron will produce about 4 million times more bremsstrahlung than a proton.

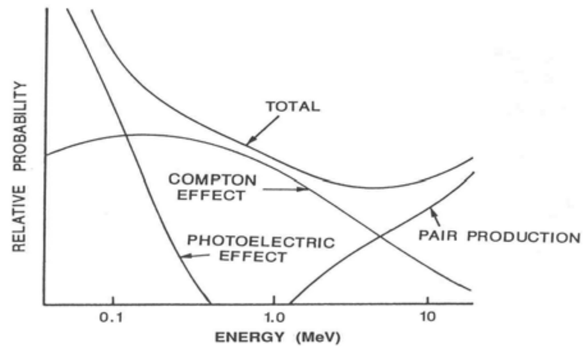
If human tissue is the radiation absorber, ionization and excitation account for about 99% of the energy deposited while bremsstrahlung accounts for the remaining 1%. The three energy loss mechanisms are illustrated below.



Excitation Raises electron to a higher E level | **Ionization** Removes electron | **Bremsstrahlung** Releases EM energy

X and Gamma Radiation

X- and gamma radiation interact with matter through a variety of alternative mechanisms, the three most important of which are the photoelectric effect, Compton scattering and pair production. In the **photoelectric effect**, all the energy of an X- or gamma photon is transferred to an atomic electron which is ejected from its parent atom. The photon is, in this case, completely absorbed. **Compton scattering** occurs when only part of the energy of the photon is transferred to an atomic electron. The photon is therefore scattered with a reduced energy. The process in which a photon of sufficient energy gives up all its energy and forms two particles, an electron and a proton, is called **pair production**.



The three processes: photoelectric effect, Compton effect, and pair production, account for the main photon interactions with matter. Both the photoelectric and Compton effects decrease with increase of gamma energy, while pair production increases.

APPENDIX B: Radiation Units

There are currently two systems of radiation protection units in use: "old" and "new." The old system of units goes by several other names: conventional, customary, English, special, traditional. The new system is the International System of Units (SI); "SI" is an abbreviation for Système International d'Unités, the international metric system. U.S. regulations and technical literature use SI units (which may or may not be followed by the old units). However, U.S. industries and academia have been slow to adopt the new system because the SI units are unfamiliar and their numerical sizes are very different from the old units.

At UCF, four of the old radiation units are generally used: curie (Ci), the unit of activity (quantities of radioactive material); roentgen (R), the unit of exposure in air; rad, the unit of absorbed dose; and rem, the unit of dose equivalent. These units' SI counterparts may also be encountered, such as on radioisotope container and package labels.

A. Activity (Curie and Becquerel)

"Activity" refers to the disintegration rate of a sample of radioactive material. The old unit is the **curie (Ci)**, which is the quantity of a radioisotope which produces 3.7 x 10^{10} disintegrations (decay events) per second (dps). The curie is a very large unit, and amounts much smaller than one Ci are typically used in lab work, so subunits are commonly used:

millicurie (mCi) = 10^{-3} Ci or 3.7 x 10^{7} dps

microcurie (μCi) = 10^{-6} Ci or 3.7 x 10^{4} dps or 2.2 x 10^{6} dps

nanocurie (nCi) = 10^{-9} Ci or 3.7 x 10^{1} dps

Becquerel (Bq) is the SI unit for activity; one Bq equals a quantity of a radioactive material that will have 1 disintegration per second (dps). Thus, 1 Ci = 3.7 x 10^{10} Bq. Because it is a very small unit, multiples are typically used: thousands (kBq), millions (MBq) or billions (GBq).

B. Exposure (Roentgen)

The quantity "exposure" measures the ability of photons (X-rays and gamma rays) to produce ionization in air. It is defined as the sum of the charge of one sign (+ or -) produced by photon irradiation per unit mass of air. The traditional unit of exposure is the **roentgen (R)**. One R equals 2.58 x 10^{-4} Coulombs per kilogram (C/kg) of air. There is no equivalent SI unit; the roentgen was intentionally left out of the SI System to discourage its use. This was done because of its three fundamental limitations as a unit of measurement:

- The roentgen applies only to photons. It can't be used to measure alpha or beta particles, or neutrons.
- The roentgen applies only in air. It can't be used to directly quantify dose in human tissue.
- The roentgen is defined only for photon energies below 3 MeV. This is because to measure exposure, it is necessary to collect all of the charge released by photons in the mass of air. At energies above 3 MeV, it becomes impossible to collect all the ion pairs formed by the secondary electrons because their range in air is too great.

Despite theses limitations, the unit remains in wide use within the U.S., and many radiation detection instruments measure exposure in units of roentgens [also milliroentgens (mR), equal to 1/1000 roentgen, and microroentgens (uR) equal to 1,000,000 roentgen]. Fortunately, for general purposes, measurements taken in roentgens can typically be converted to rem for required records.

C. **Absorbed Dose** (Rad and Gray)

The quantity "absorbed dose" measures the energy deposited by radiation in a given mass. The old unit of absorbed dose is the **rad** (radiation absorbed dose), which equals 100 ergs per gram of energy deposited in any medium. The SI unit is the **gray (Gy)**, which equals 100 rads or 1 Joule per kilogram. The rad and gray can be used to measure all ionizing radiation at all energies and in all media including human tissue. Because the gray is a large unit, absorbed dose is often expressed in terms of hundredths of a gray, or centigrays (cGy).

An exposure of 1 R results in about 87 ergs/gram of energy absorption in air; therefore, 1 R equals 0.87 rad in air. It turns out that 1 R results in about 95 ergs/gram in human tissue, so for all practical purposes, 1 R equals 1 rad in tissue.

A pitfall of the rad is that it does not take into account the differing biological effects of various radiations. Since, for example, alphas are more biologically damaging than betas in human tissue, 1 rad of alphas is considerably more hazardous than 1 rad of betas. This is related to the fact that the linear energy transfer (LET) of alphas is higher than betas by a factor of about 20.

D. **Dose Equivalent** (Rem and Sievert)

To account for the fact that different radiations have differing biological effects for the same amount of energy deposition, the **quality factor (Q)** was defined. Q is a modifying factor by which the absorbed dose can be multiplied to incorporate biological injury. Q is actually a function of LET, but Q values have been set in the regulations. The adjacent table shows Q values for different radiations.

Radiation Quality Factors

Radiation Type	Quality Factor (Q)
alpha	20
beta	1
gamma	1
X-ray	1
neutron	3 - 10

The modified absorbed dose is the product of the absorbed dose and the quality factor, Q. This product is called the **dose equivalent** (or equivalent dose) and is only defined in human tissue. The old unit of dose equivalent is the **rem**. Dose equivalent is often expressed in terms of thousandths of a rem, or millirem (mrem). To determine dose equivalent (rem), you multiply absorbed dose (rad) by a quality factor (Q) that is unique to the incident of radiation:

rem (dose equivalent) = absorbed dose (rad) x Q

The absorbed dose and the dose equivalent will be numerically equal only when Q = 1. With Q = 1 for X-rays and gamma rays, 1 R is approximately equal to 1 rad in human tissue, which is also approximately equal to 1 rem.

Rule of Thumb: For X-rays and gamma rays in human tissue: 1 R = 1 rad = 1 rem

The SI unit for dose equivalent is the **sievert (Sv)**. 1 Sv equals 100 rem or 1 Joule per kilogram. Equivalent dose is often expressed in terms of millionths of a sievert, or microsievert (uSv). To determine equivalent dose in Sv, you multiply absorbed dose in Gy by the quality factor (Q) that is unique to the relevant type of incident radiation.

Dose equivalent is can be further defined as the product of absorbed dose (D), quality factor (QF), dose distribution factor (DF), and other necessary modifying factors. The DF is a factor which accounts for modification of the dose effectiveness in cases in which the radionuclide distribution and the resultant dose are non-uniform. The resulting dose equivalent (in rem) is then equal to the absorbed dose (in rads) multiplied by the appropriate modifying factors: rem = rad x QF x DF x ...

Summary of Radiation Units

Quantity	Old Unit	SI Unit	Conversions
Radioactivity	curie (Ci)	becquerel (Bq)	1 Ci = 3.7×10^{10} Bq
Radiation exposure	roentgen (R)	coulomb per kilogram (C/kg)	1 R = 2.58×10^{-4} C/kg
Absorbed dose	rad	gray (Gy)	1 rad - 0.1 Gy
Dose equivalent	rem	sievert (Sv)	1 rem = 0.1 Sv

E. Effective Dose Equivalent (EDE)

In many instances a person receives a partial body exposure, rather than a whole body exposure. Such a case presents the task of assessing dose not only to the portion of the body that was exposed, but also evaluating what effect the local exposure would have on the body as a whole. For example, a person may receive a significant dose to the thyroid from inhalation of I-131. Although the iodine passed through the respiratory system, the organ most affected is the thyroid, which accumulates approximately 100% of the iodine which enters the body. The dose to the thyroid could be calculated directly, assuming the volume and concentration are known.

The second part of the task is evaluating what effect the uptake has on the body as a whole. The **effective dose equivalent (EDE)** is used in this case. The EDE is an administrative quantity which is used to assess the risk to a worker from both uniform whole body and non-uniform partial body exposures. It makes use of **weighting factors** which take into account the reduced risk of cancer mortality and genetic effects when only some body organs receive a dose. Thus, it goes one step further than the dose equivalent by weighting the dose in rem by the associated risk.

The effective dose equivalent is defined as the sum of the weighted dose equivalents for irradiated tissues or organs, or

$$H_e = \Sigma(W_T \times H_T)$$

where: H_e = effective dose equivalent

w_T = weighting factor for tissue/organ T

H_T = dose equivalent received by tissue or organ T

Weighting Factors

Tissue or Organ	Risk Weighting Factor
Gonads	0.25
Breast	0.15
Lung	0.12
Red bone marrow	0.12
Thyroid	0.03
Bone Surfaces	0.03
Remainder	0.30
Total	1.00

F. Committed Dose Equivalent (CDE)

The **committed dose equivalent (CDE)** applies only to internally deposited radioactivity. It has the symbol H_{50}, and represents the total cumulative dose delivered to the worker for a 50-year time period beginning with the time of intake of radioactive material. If the particular radionuclide has a short half-life or the body eliminates it quickly, the CDE will be approximately equal to the annual internal dose equivalent for the year of intake. If the half-life is long and the body eliminates it slowly, then the CDE will be larger than the annual internal dose equivalent because it includes dose that will be delivered in future years.

G. Dose Rate

The rad and rem are units expressing an amount radiation which may have been received over any period of time. In controlling a radiation hazard, it is usually necessary to know the rate at which the radiation is being received. Thus, if a person works in an area for 2 hours and receives a dose equivalent of 0.4 rem, then the dose equivalent rate is 0.2 rem/hr. Similarly absorbed dose rates are expressed in rad/hr. The relationship between dose, dose rate and time is: Dose = dose rate x time

Ex.: Dose rate = 2 mrem/hr   Time = 1.5 hrs   Dose = 2 mrem/hr x 1.5 hrs = 3 mrem

APPENDIX C: Occupational and Public Dose Limits

The U.S. Nuclear Regulatory Commission (NRC) has established the occupational dose limits listed below, which have been adopted by all federal agencies and state radiation control programs. The federal limits are specified in 10 CFR 20.1201; the equivalent Florida limits are specified in 64E-5.304, FAC. Refer to Appendix B for a description of radiation exposure and dose terminology.

Type of Exposure	Limit (Old & SI Units)	
Whole body (TEDE – total effective dose equivalent; sum of internal and external doses)	5 rem/yr	0.05 Sv/yr
Organ dose (sum of DDE and CDE to any individual organ or tissue)	50 rem/yr	0.5 Sv/yr
Eye dose (LDE – lens dose equivalent)	15 rem/yr	0.15 Sv/yr
Extremity dose (SDE – shallow dose equivalent to skin or extremity)	50 rem/yr	0.5 Sv/yr
Minors	0.50 rem/yr	5.0 mSv/yr
Pregnant woman	0.50 rem/ gestation period	5.0 mSv/gp
Members of the public	100 mrem/yr 2 mrem/hr	1.0 mSv/yr 0.02 mSv/hr

No clinical evidence of harm would be expected in an adult working within these levels for a lifetime. Because the risks of undesirable effects may be greater for young people, persons under 18 years of age are permitted to be exposed to only 10 percent of the adult occupational limits. (This lower limit also applies to members of the general public).

The current exposure limits for people working with radiation have been developed and carefully reviewed by nationally and internationally recognized groups of scientists. It must be remembered, however, that these limits are for adults. Special consideration is appropriate when the person being exposed is, or may be, an expectant mother, because the exposure of an unborn child may also be involved. Types of exposures:

Acute: A large dose/exposure given over a short period of time. Examples: radiation accidents, radiation treatment of patients.

Chronic: A small dose/exposure given over a long period of time. Examples: biotech workers, X-ray technicians.

APPENDIX D: Biological Effects of Ionizing Radiation

Ionizing radiation absorbed by living tissue results in damage. The damage is due primarily to ionization and free radical production within the cells. This results in damage to the cells, and depending on the severity of the damage, the cells may no longer be capable of functioning. Because living cells are primarily water, ionizing radiation absorbed in the cellular water results in the formation of peroxides and other strong oxidizing agents. These oxidizing agents are powerful enough to break down macromolecules such as proteins and DNA. A major factor in radiation injury is the effect produced on the division of cells. Even a small change in the rate of cell division for a few cells can have serious effects.

The two major types of biological effects of radiation are identified as somatic and genetic. **Somatic effects** are those experienced by the irradiated individual and are the most obvious. These effects include damage to body tissues and organs, which impairs their ability to function. The somatic effects are rather long term and are of primary concern in radiation protection.

An increase in the probability of leukemia, a shortening of the expected life span, and initiation of certain types of carcinoma are some of the effects of ionizing radiation. The occupational exposure limits define the amount of radiation, which may be received by an individual within a specified period with no expectation of significant biological effects. The specified period for an average worker is 50 years, or approximately a working lifetime.

The other major effects of ionizing radiation, **genetic effects**, are those effects that may be passed on to future generations. Radiation can change genes and thereby produce mutations that may eventually result in anomalies in the offspring. Because many mutations are recessive, several generations may be necessary before the effects become apparent.

The above information is a brief discussion of a complex topic. UCF staff members are encouraged to learn more, starting with three documents available from the RSO in electronic format:

- "Biological Effects of Ionizing Radiation" (developed for UCF by a radiation safety consultant)
- "Risk From Occupational Radiation Exposure" (adapted from U.S. NRC Reg. Guide 8.29)
- "Instruction Concerning Prenatal Radiation Exposure" (U.S. NRC Reg. Guide 8.13)

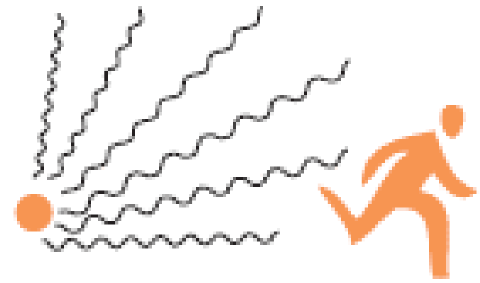
A. External Radiation Hazards

External radiation comes from sources of radiation outside the body. This may be due to beta, X-, or gamma radiation, all of which can penetrate to the sensitive organs of the body. Hazards from external radiation are controlled by applying three principles: time, distance, and shielding. That is to say, protection is provided by:

- Controlling the length of **time** of exposure.
- Controlling the **distance** between the individual and the source of radiation.
- Placing an absorbing material (**shielding**) between the individual and the source of radiation.

Time

The magnitude of a dose is directly related to the duration of the exposure. This is true for all forms of radiation, although for practical applications, only doses from penetrating radiation or skin contamination are easily controlled by reducing the duration of exposure. Much of the radioisotope work in biological research involves the beta emitters H-3, C-14, P-32 and S-35. If sources of these radioisotopes are more than a few centimeters away from the skin, there will be no dose to the body regardless of the time spent working with the material.

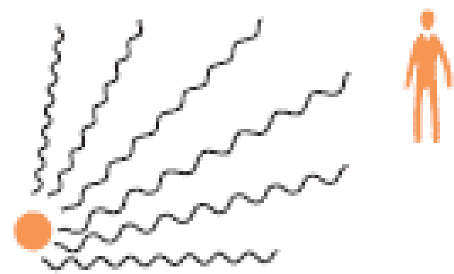


Less time spent near a source equals less exposure

Controlling the duration of exposure for lab workers is often impractical, so other forms of control are necessary.

Distance

The effect of distance on radiation exposure is substantial. Intensity of radiation from a small gamma or X-ray source decreases as the inverse square of the distance. Alpha and beta radiations have fairly definite ranges in air; for short distances the radiation intensity decreases rapidly until at the maximum range the intensity drops to near zero.



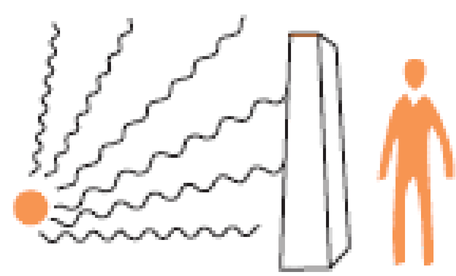
The greater the distance from a source, the less exposure

Exposures can be easily reduced by controlling the distance from the body to the radiation source. For example, using forceps to handle a 5 mCi vial of P-32 will reduce the dose to the hand by a factor of 1,000 compared with the dose received by touching the vial directly with the fingers.

Similar reductions can be obtained for the gamma emitters I-125 and I-131. For low-energy beta emitters such as H-3 and C-14, a distance of 10 cm reduces the dose rate to zero. In addition to using forceps and other mechanical devices and keeping fingers away from radiation sources, sources should be positioned away from personnel. Radioactive solutions are to be stored at the rear of hoods, designated refrigerators, or in areas not frequented by personnel. Desks and study areas are to be located away from radioisotope areas.

Shielding

The absorption of radiation by various materials is a common method for controlling personnel exposures. Alpha and beta radiation have, for the most part, very short ranges in nearly all materials – paper, cardboard, plastic, etc. P-32 is one of a few beta emitters that is rather penetrating, having ranges from 20 ft. in air to 0.61 cm in Lucite. For a high-energy beta emitter such as P-32, 3/8 in. of acrylic is the shielding material of choice.



The more shielding used, the less exposure received

Gamma radiation is absorbed exponentially in absorbing material. The ability of material to stop gamma photons is related to the density and electron density of the material. Lead is a good absorber for gamma emitters such as Cr-51, I-125 and I-131.

Storage of alpha and beta-emitting isotopes in plastic vials prevents external radiation levels and these vials have the advantage of being break-resistant. When high-energy beta or gamma radiation is used, experiments should employ shielded containers and work should be performed behind shielded barriers. Whether shielding is needed and the thickness of the shield, when used, will be determined by the type of radiation, amount in use, and time spent in the work area. When shielding is used, the optimum configuration is that in which the radiation source is close to the shield. The shield area needed increases as the square of the distance from the source for small sources. In fume hoods, the floors and walls as well as the front may require shielding. Similar considerations must be made for lab bench shielding. Radiation passing through a hood floor or lab bench can expose the lower portions of the body. Shielding should be high enough to protect the eyes and the head. If the shield restricts vision, a mirror can be placed at the rear of the work area to allow observation.

Type and Quantity of Radiation Source

In addition to time, distance and shielding, there are two additional ways to minimize radiation exposures. First, the type of radioisotope used may be changed from one that that emits high energy radiation to one that emits lower energy radiation, so that ambient radiation levels in the lab are lowered. Examples of "substitute" radioisotopes are I-125 for I-131, and P-33 for P-32. Second, reducing the quantity/activity of radioisotope used will lower the ambient radiation levels. Another application of the latter approach is to use a lower setting on an X-ray machine. Workers should discuss their options with the RSO to determine if alternative approaches are available that could result in lowering their occupational exposures.

ALARA Philosophy

The University endorses the ALARA philosophy of dose minimization. When working with radioactive material, workers should be always be conscious of the radiation hazard and diligent in their efforts to apply dose reduction methods, so that exposures to themselves and others are kept as low as reasonably achievable (ALARA).

B. Internal Radiation Hazards

Radioactive material, which is inadvertently released is known as **contamination**. Small quantities of radioactive material, which represent an insignificant external hazard can give rise to appreciable dose rates if they come into contact with, or get inside the body. Once the radioactive substance is taken into the body, it will continue to irradiate the body until either the radioactivity has decayed or until the body has excreted the substance. The rate of decay of the radioactivity depends on its **physical half-life**, (the time required for half of the atoms of the radioisotope to decay) which can vary from a small fraction of a second to many thousands of years. The rate of excretion of the substance from the body depends on a number of variables such as the chemical characteristics of the substance, and it may happen in a period of a few days or it may take much longer, perhaps up to many years. Thus when a radioactive substance enters the body it may irradiate it for only a few days or for a much longer period, which may extend to many years in the case of certain nuclides. **Biological half-life** is the time required for a biological system, such as a man or an animal, to eliminate, by natural processes, half the amount of the radioactive material which has entered it. **Effective half-life** is the combined effects of physical and biological half-lives.

There are four ways in which contamination can enter the body:

- Inhalation of airborne contamination.
- Ingestion, that is entry through the mouth.

- Entry through the skin, or through a contaminated wound.
- Absorption on the skin.

When contamination is present in the atmosphere it will be breathed into the lungs and a certain fraction of it will pass into the bloodstream. Another fraction of the inhaled contamination is eliminated from the lungs and swallowed; the remainder is exhaled.

Some radioisotopes distribute themselves fairly uniformly and irradiate the whole body at about the same rate. Many of the common radioisotopes, however, tend to concentrate in particular organs so that an intake of radioactivity may result in different dose rates to the various organs of the body. Examples of such radionuclides are iodine (I-125 or I-131), which concentrate in the thyroid gland, and phosphorus (P-32), which concentrates in the bone. The dose rate to any organ is proportional to the amount of radioactivity in the organ and decreases as the radioactive isotope decays or is excreted.

APPENDIX E: Radiation Detection and Measurement

The fact that the human body is unable to sense ionizing radiation is probably responsible for much of the general apprehension about this type of hazard. Reliance must be place on detection devices which are based on the physical or chemical effects of radiation. These effects include:

- Ionization in gases.
- Ionization and excitation in certain solids.
- Changes in chemical systems.

The basic requirement for an instrument to detect ionizing radiation is the production of a radiation effect as a result of the interaction of the radiation with some material in the detector. The chart below shows some of the radiation effects used in the detection and measurement of radiation for various instruments and detector materials. Descriptions of instrument types commonly employed in the biotech lab environment follow.

Radiation Effect	Type of Instrument	Detector
Electrical	Ionization chamber Geiger-Mueller counter Proportional counter Solid state	Gas (air) Gas Gas Semiconductor
Chemical	Film badge	Photographic emulsion
Light	Scintillation counter Optically stimulated luminescent dosimeter (OSLD)	Crystal, plastic, or liquid scintillator
Thermoluminescence	Thermoluminescent dosimeter (TLD)	Crystal

A. <u>Ionization Chamber</u> (IC)

This is an air-filled chamber with an electrically conductive inner wall and central anode and a relatively low applied voltage. When primary ion pairs are formed in the air volume, from X-ray or gamma radiation interactions in the chamber wall, the central anode collects the electrons and a small current is generated. This in turn is measured by an electrometer circuit and displayed digitally or on an analog meter. These instruments are designed to provide an accurate measure of absorbed dose to air which, through appropriate conversion factors, can be related to dose to tissue. Because most ion chambers are "open air," they have an inherent sensitivity to temperature, humidity and barometric pressure. Common readout units are milliroentgens and roentgen per hour (mR/hr or R/hr).

Ion chambers are used in radiation surveys for direct measurement of exposure or exposure rates that are relatively accurate and independent of photon energies. However, sensitivity drops off for photon energies less than 50 – 100 keV due to attenuation by the ion chamber wall. Thus, these instruments are not recommended for radiation fields less than 1 mR/hr due to questionable accuracy. These instruments perform well in high radiation fields with some designed to read up to 500 R/hr.

B. <u>Geiger-Mueller (G-M) Detector/Counter</u>

A G-M (or GM) tube is a gas-filled device that, when a high voltage is applied, creates an electrical pulse when radiation interacts with the wall or gas in the tube. The pulses are converted to a reading on the meter. If the instrument has a speaker, the pulses also give an audible click. Common readout units are R/hr, mR/hr, rem/hr, mrem/hr, and counts per minute (cpm). G-M probes may be internal or external; the latter are most often used with handheld radiation survey instruments for contamination measurements. Probe designs include side-window, end-window and "pancake" types. When the window is open or exposed, the probe detects both beta and gamma/X-ray radiation; when closed or covered, it detects only gammas and X-rays. Energy-compensated GM tubes may be used for exposure measurements. Some meters used with a GM probe will also accommodate other radiation-detection probes. For example, a zinc sulfide (ZnS) scintillator probe, which is sensitive to just alpha radiation, is often used for field measurements where alpha-emitting radioactive materials need to be measured.

C. **Scintillation Detector**

Scintillation detectors are based on detection of the fluorescent radiation ("scintillations" - usually light) emitted when an electron returns from a radiation-induced excited state. A solid crystal creates a pulse of light when radiation interacts with it. This pulse of light is converted to an electrical signal and then amplified by a photomultiplier tube (PMT), which gives a reading on the instrument meter. The light pulse is proportional to the amount of light and the energy deposited in the crystal by the charged particle or photon. These instruments most often have upper and lower energy discriminator circuits and, when used as single-channel analyzers, can provide information on the gamma energy and identify the radioactive material. If the instrument has a speaker, the pulses also give an audible click, a useful feature when looking for a lost source. Common readout units are μR/hr and/or counts per minute (cpm).

Sodium iodide (NaI) detectors (MicroR meters), or more commonly, thallium-activated sodium iodide [NaI(Tl)] are the most popular, though special plastic or other inert crystal "scintillator" materials are also employed. NaI detectors are excellent for low-range measurements, and are used in hand-held instruments (with internal or external probes) and large stationary radiation monitors. Sodium iodide crystals are preferred to other detector types for three principal reasons:

- They have good resolution of the energies in the 0.3 - 3.0 MeV range.
- They have a high transparency and thus, even weak flashes of light can be detected.
- They are relatively economical.

Because there is less chance that a gamma ray will pass through a large crystal undetected than through a small one, the efficiency of the detector rises with rising crystal volume. NaI detectors, being hygroscopic (they readily absorb moisture), have to be "canned," and this cladding will attenuate low-energy photons, even with low noise electronics. SiLi detectors are generally the instrument of choice for low-energy photons.

Solid state semiconducting detectors, like lithium-drifted germanium crystals, have superior resolving power to that of NaI (50 - 80 times). However, they are expensive and in order to operate effectively, they must be maintained at liquid nitrogen temperatures, thus presenting handling, weight and maintenance cost problems.

A liquid scintillation counter (LSC) is a laboratory instrument used to measure smear/wipe samples for low-energy beta-emitting radioisotopes such tritium and carbon-14. The technique involves dissolving the sample containing the radionuclide in a suitable scintillation solution. The solution normally consists of an aromatic organic solvent containing a fluor (a chemical that absorbs the UV light emitted by the solvent and emits a flash of blue light) together with a detergent to make the whole solution miscible when counting aqueous samples. Two opposing PMTs are used to view the vial containing the sample and liquid scintillator fluid, or cocktail. When the sample emits a radiation (often a low-energy beta) the cocktail itself, being the detector, causes a pulse of light. If both PMTs detect the light in coincidence, the count is tallied. With the use of shielding, cooling of PMTs, energy discrimination, and this coincidence counting approach, very low background counts can be achieved, and thus low minimum detectable activities (MDA). Most modern LSC units have multiple sample capability and automatic data acquisition, reduction, and storage.

D. Proportional Counter

A common lab instrument is the standard proportional counter with sample counting tray and chamber and argon/methane flow through counting gas. Most units employ a very thin (microgram/cm^2) window, while some are windowless. Shielding and identical guard chambers are used to reduce background and, in conjunction with electronic discrimination, these instruments can distinguish between alpha and beta radiation and achieve low MDAs. Similar to LSC units, proportional counters have multiple sample capability and automatic data acquisition, reduction, and storage. Such counters are often used to count smear/wipe or air filter samples. Additionally, large-area gas flow proportional counters with thin (mg/cm^2) mylar windows are used for counting the whole body and extremities of workers for external contamination when exiting a radiological control area.

E. Multichannel Analyzer System

A laboratory MCA with a sodium iodide crystal and PMT, a solid-state germanium detector, or a silicon-type detector can provide a powerful and useful capability for counting liquid or solid matrix samples or other prepared extracted radioactive samples. Most systems are used for gamma counting, while some silicon detectors are used for alpha radiation. MCA systems can also be utilized with well-shielded detectors to count internally deposited radioactive material in organs or tissue for bioassay measurements. An MCA provides the capability to bin and tally counts by energy and thus identify the emitter. Most systems have automatic data acquisition, reduction, and storage capability.

F. Neutron REM Meter, with Proportional Counter

Neutron detection requires specialized instrumentation. A boron trifluoride (BF_3) or helium-3 proportional counter tube is a gas-filled device that, when a high voltage is applied, creates an electrical pulse when a neutron radiation interacts with the gas in the tube. The absorption of a neutron in the nucleus of B-10 or He-3 causes the prompt emission of a helium-4 nucleus or proton respectively. These charged particles can then cause ionization in the gas, which is collected as an electrical pulse, similar to the GM tube. These neutron-measuring proportional counters require large amounts of hydrogenous material (e.g., polyethylene) around them to slow the neutron to thermal energies. Other surrounding filters allow an appropriate number of neutrons to be detected and thus provide a flat-energy response with respect to dose equivalent.

G. Personnel Monitoring Devices - Dosimeters

"Dosimetry" includes personnel monitoring badges and other a devices used to measures the radiation dose accumulated by the wearer. Film badges were the first type of personnel monitoring device to provide a permanent record of occupational doses and were the principal type of dosimeter used by radiation workers before being replaced by TLDs and OSLDs.

Film Badges

Ionizing radiation affects photographic film in the same way, as does visible light. Photographic film consists of an emulsion of crystals (grains) of silver bromide on a transparent plastic base. The absorption of energy in a silver bromide grain, whether from light or ionizing radiation, results in the formation of a small cluster of metallic silver (a latent image). The degree of blackening on the developed film is determined using a densitometer and then related back to the radiation exposure of the film. The advantage of film badges is that, with the aid of special filters, the type and energy of radiation can be deduced. The disadvantages are that they are not very accurate, can't be reused, and are easily damaged.

Thermoluminescent (TLDs)

TLDs contain small crystals capable of storing some of the energy from ionizing radiation. If the crystals are then heated to a specific temperature, they release the stored energy as light. The amount of light released is proportional to the amount of radiation the TLD badge received, which can be measured to determine the badge wearer's dose. TLDs must be protected from extreme environmental conditions, which may affect their ability to accurately record radiation. TLDs are more accurate than film badges (described below) and can be reused. They must be exchanged at least every three months

Optically Stimulated Luminescent Dosimeters (OSLDs)

OSLDs measure radiation through a thin layer of aluminum oxide. A laser light stimulates the aluminum oxide after use, causing it to become luminescent in proportion to the amount of radiation exposure. Like TLDs, OSLDs can be reused, and must be exchanged at least quarterly.

Direct Reading Dosimeters

A pocket dosimeter is pen-sized, conductive-fiber electroscope with an ion chamber for direct detection of gamma and X-radiation. It enables the wearer to directly measure radiation exposure, giving an instant read-out in mR or R, depending on the device's scale. A metal clip is used to attach the dosimeter to an individual's pocket. It is a simple capacitor (a circuit element able to temporarily store an electric charge) equipped with a single movable electrode (electric conductor) consisting of two quartz fibers; one fixed and one moveable, but each bent into a U-shape. The two fibers are fused together at the end of the U, and a microscope is focused on the opposite end of the movable fiber. The dosimeter is charged from a separate source with a high enough voltage (~200 V) to deflect the movable fiber to the zero point on the scale. The presence of radiation produces ionization, neutralizes the charge, and allows the moveable fiber to return toward the fixed fiber, at a distance proportional to the quantity of radiation absorbed. An image of the fiber is projected onto a scale and viewed through a lens at one end.

Electronic dosimeters are the modern replacements for pocket dosimeters, providing improved energy response and additional features, such as measurement, storage and digitally display of deep and shallow doses, preset audible alarms and the ability to detect beta and/or neutron radiation.