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X-Ray Safety Manual



University of Illinois Urbana-Champaign

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1. Introduction

The University of Illinois Urbana-Champaign (Illinois) is committed to protecting the health and safety of its faculty, staff, students, visitors, and environment by appropriately identifying and managing radiological hazards. Additionally, Illinois is committed to minimizing radiation exposures to faculty, staff, students, and visitors that result from the use of ionizing radiation sources in research and teaching to levels that are as low as reasonably achievable.

All radiation-producing machines must be registered with Illinois Emergency Management Agency (IEMA) through the Division of Research Safety (DRS) and must be operated in compliance with state regulations.

This manual is written for personnel working with machines that produce radiation, including X-ray machines, particle accelerators, neutron generators, and similar devices. Equipment that is manufactured for purposes other than the generation of radiation, where the radiation is incidental to operation, e.g., electron microscopes, may be exempted from these requirements (refer to Title 32 of the Illinois Administrative Code, Part 320.40).

This manual is designed to help staff members perform teaching, research, and public service with radiation sources in a safe, legal, and efficient manner. It is a general resource on rules, procedures, and responsibilities for working with radiation. Because of the wide variety of radiation sources, facilities, research methods, and situations, it is impossible to anticipate and address all eventualities within the scope of this manual.

2. Responsibilities for Radiation Safety

Illinois strives to maintain a safe and healthy working and learning environment for faculty, staff, students, and visitors. The cooperation of the entire campus community is needed to realize this goal. This is particularly true of research and teaching that involves radiation sources, where the campus Radiation and Laser Safety Committee (RLSC), DRS and radiation safety officer (RSO), principal investigators (PIs) and department heads, and laboratory workers share the responsibility for creating and maintaining a safe workplace.

2.1 Radiation and Laser Safety Committee Responsibilities

The RLSC advises the Chancellor through the Vice Chancellor for Research and Innovation and DRS on matters related to the campus radiation safety program. The RLSC is composed of academic staff and faculty members representing various areas of research and teaching, and members who represent the campus administration including the campus RSO.

The Chancellor delegates authority to the RLSC to oversee the use of radiation sources throughout the campus. The RLSC has the authority to allow, deny, or revoke authorization for individuals to obtain and use radiation sources at Illinois.

The responsibilities of the RLSC include the following:

1. Review proposals for unusually hazardous uses of radiation sources as deemed by the RSO and establish criteria for equipment and procedures to ensure employee, student, and public safety. This includes the use, fabrication, or modification of radiation producing machines and experimental set-ups.

2. Review cases that involve repeated infractions of the rules and regulations for protection against radiation.
3. Review accidents that may involve exposure or serious economic loss and other cases for which reports to outside regulatory authorities are required.
4. Review public relation problems that involve radiation sources.
5. Review appeals from radiation users and modify rules or the decisions of DRS personnel where necessary, regarding matters and business under the authority delegated to the RLSC in Article II.
6. Meet formally as often as necessary, but at least four times per year, to review the campus radiation safety program with DRS personnel.
7. Recommend the establishment or modification of campus radiation safety policies.
8. Review communications between DRS and government agencies that affect the campus radiation safety program.

2.2 Division of Research Safety Responsibilities

1. Address concerns by members of the campus community and public on aspects of radiation safety.
2. Approve proposals for use and transfer of radiation sources, except proposals involving unfamiliar or extreme hazards that DRS judges as requiring review by the RLSC. Approve proposals for construction of or significant modifications to ionizing radiation producing machines or experimental set-ups utilizing machine produced radiation.
3. Assign personnel monitoring devices (e.g., film badges and dosimeters) when necessary, give instructions in their use, and maintain personnel monitoring records.
4. Check radiation monitoring and survey instruments for proper operation and calibrate as often as necessary.
5. Assist in designing and selecting equipment, shielding, and establishing safe operating procedures for new or existing installations.
6. Report hazardous radiological conditions promptly to the responsible individual and, when necessary, to the immediate supervisor and the RLSC.
7. Enforce all written directives of the RLSC.
8. Stop any operation or deny access of any individual to radiation sources in the interest of safety. Such action must be reported verbally and in writing to the RLSC as soon as possible.
9. Maintain records of federal, state, and local licenses and registrations concerned with radiation sources, and initiate applications for renewals and/or amendments of same.
10. Evaluate radiation incidents to determine whether reporting to regulatory authorities is required and prepare such reports for the approval of the RLSC. Exception: in cases requiring immediate reporting, the campus RSO, with the knowledge and approval of the RLSC Chair when possible, shall submit the report directly to the appropriate authorities and provide copies to the RLSC.
11. Be familiar with the federal, state, and local laws relating to radiation and be aware of changes in such laws as they occur. Inform the RLSC when such changes suggest modifications of policy, and institute necessary changes in the radiation safety program.

2.3 Registrant and Unit Head Responsibilities

In addition to assuming all the responsibilities of an individual radiation user, the Registrant will:

1. Be responsible for ensuring that all personnel, particularly new personnel, who have access to radiation sources under their jurisdiction are properly instructed and that they have the necessary skills to manage radiation safely. The minimum training requirements are outlined in Section 4.
2. Determine safe operating procedures for work under their supervision.
3. Comply with all conditions and requirements listed in the registration.
4. Routinely check protective equipment and instruments to ensure they are working properly and adequately performing their intended functions.
5. Work with DRS to solve radiation safety problems unique to their situation and to correct violations of federal, state, or local rules and regulations.
6. Assist DRS in meeting applicable legal requirements such as record maintenance and report preparation by providing timely and accurate information and assistance.
7. Obtain prior approval of the campus RSO before any individual under age 18 is allowed to work in a radiation laboratory.
8. Notify DRS in advance of any extended absence from campus, or if the Registrant is unable to meet the obligations specified in the X-Ray Safety Manual
9. Ensure that all activities involving radiation sources receive adequate supervision during any extended absence of the Registrant. When a Registrant will be absent from their laboratory for a period of three months or longer, a qualified temporary supervisor must be designated. DRS must be informed in writing of this designation. The temporary supervisor must have the education, training, and administrative authority necessary to ensure compliance with all applicable safety requirements and must be approved by DRS.
10. Ensure that their unit head informs DRS whenever the Registrant will be absent from campus for more than three months, or whenever there are circumstances with regard to the Registrant that might require additional assistance from DRS.

2.4 Worker Responsibilities

Users have the final responsibility for the safe use of the radiation sources to which they have access. Users must:

1. Keep their exposure as low as practical.
2. Wear assigned personnel monitoring devices in an approved manner.
3. Be familiar with and comply with all sections of the X-Ray Safety Manual that apply to their work.
4. Be familiar with the nature of their work area's radiation sources, the extent of their potential risk, and the proper means of safely managing those risks.
5. Assist in maintaining required records.
6. Prevent unauthorized persons from having access to radiation sources in their area.
7. Establish procedures to protect any personnel from entering unsafe radiation areas during operation of radiation-producing machines.

8. Inform their supervisor and DRS of any unexpected problems, incidents, or conditions that could affect safety or compliance.
9. Notify and seek assistance from the Registrant and DRS as soon as possible in the event of an emergency. Immediately inform their supervisor and DRS of any lost, stolen, or missing radiation source.

3. Registering Radiation-Generating Machines

3.1 Submitting a Registration

The use of radiation-generating machines requires an [X-ray Registration](#) with DRS and is only allowed following approval by DRS.

For a new registration, create at least one project/group and enter all radiation-producing machines with their use or storage locations. Provide sufficient detail for reviewers to be able to evaluate risk and safety measures. Once all information is entered, submit each project/group for review.

DRS may inspect proposed use locations to ensure the areas are effectively shielded and safety measures are adequate.

For high hazard applications, DRS may consult with the RLSC. Once all questions and safety concerns have been resolved, DRS will approve the application on behalf of the RLSC Chair. By submitting a registration, the applicant acknowledges their acceptance of the responsibilities associated with the permitted activities.

3.2 Amendments and Deactivation

X-ray registrations must be reviewed annually by the Registrant or their personnel to make sure all information is accurate and updated. Any new radiation-producing machine or changes to existing equipment must be entered online in the X-ray registration system. Any radiation-generating machine must be registered with DRS prior to use. A machine that is no longer in use may be locked out by DRS placing a lockout box on the power plug or marked as inoperative if it is incapable of producing radiation. Doing so will result in a waiver of the annual registration fee for the responsible campus unit.

When a machine has been removed from campus, delete it from the registration and provide the date and route of removal. Once all changes have been made, submit for review. Notify DRS when a registered machine or experimental setup utilizing a registered machine is modified, resulting in a potential change to required shielding or precautions.

When all radiation-producing machines have been removed from a registration and no work with radiation is planned in the future, a registration can be deactivated by marking all projects as complete.

4. Radiation Safety Training Requirements

Regulations require that users of radiation-generating machines are properly trained. All users are required to complete the DRS [X-Ray Safety](#) online training for research use or [X-Ray Safety for Clinical Procedures](#) online training at intervals not to exceed 12 months. In addition, Registrants are responsible for providing specific training on their equipment and procedures. [Risk assessment](#) and [Standard Operating Procedures \(SOPs\)](#) are important tools for developing laboratory-specific training and policies. Training should include:

- Health problems associated with exposure to ionizing radiation
- Unit-specific precautions and procedures to minimize exposure
- Purposes and functions of protective devices and survey meters
- Conditions and requirements in the X-ray registration
- Employee responsibility to promptly report any condition that may lead to or cause a violation of the regulations or cause unnecessary exposure
- Actions to take in the event of an emergency
- Radiation exposure reports that workers may request
- Review of the safety features such as interlocks, warning lights, and markings, including periodic checks and documentation
- Review of documentation of operations log

Regulations require that this knowledge is reinforced by annual X-ray safety training.

Records of this instruction must be maintained by the Registrant for audits by DRS and inspections by state regulators.

5. Using Radiation-Generating Machines

5.1 ALARA (As Low As Reasonably Achievable)

Regulations for working safely with radiation require all exposures to be As Low As Reasonably Achievable (ALARA). Principles and implemented practices must control our individual doses from daily work and our collective doses through our career.

Minimize exposure to radiation by managing these three parameters: **time**, **distance**, and **shielding**.

The exposure risk depends on the type of machine used:

- Cabinet units in which the radiation is completely enclosed and inaccessible to the user and that are sufficiently shielded pose very little risk of exposure.
- Open beam units pose the greatest risk of exposure and require administrative controls and often the use of Personal Protective Equipment (PPE), such as wearable protective shielding.

The following sections discuss the risks and safety measures of the different types of units.

5.2 Analytical X-Ray Machines

Analytical X-ray machines are used to evaluate the elemental or chemical composition or microscopic structure of materials. They include X-ray diffractometers, X-ray photoelectron spectrometers, X-ray fluorescence spectrometers, and similar devices. Regulatory requirements for analytical systems are found in [32 IL Administrative code 380](#).

Most commercially purchased units are cabinet systems in which the beam is completely enclosed. They must be equipped with:

- Interlocks that close the shutter or terminate high voltage to the X-ray tube when an interlock is compromised, e.g., a door is opened. Interlocks must never be overridden or otherwise circumvented.
- Warning devices such as a light or other visible indicator when X-rays are present and whether each shutter is open or closed.

- Warning labels displaying the X-ray symbol at each tube head and the operating switch.

Campus units that build their own systems should include the same safety features as listed above. DRS will review these systems before they are placed into operation. Any unused tube ports must be closed in a manner that prevents accidental opening.

The use of cabinet systems requires:

- Monthly checks of proper function of interlocks and shutters. [Documentation of safety checks](#) must be maintained and made available for inspection.
- A written SOP for each analytical X-ray machine. The SOP must be available at the operator's location. All users must be instructed in the procedure before being allowed to operate any X-ray machine.

Removal of old X-ray tubes may require special handling and disposal as some may contain hazardous components, such as beryllium. Contact DRS for hazardous materials disposal.

5.3 Medical and Veterinary X-Ray Systems

Medical and veterinary X-ray machines include those used for radiography, fluoroscopy, mammography, computed tomography, and therapeutic radiology.

Only persons who are certified or licensed by the State of Illinois may operate medical or veterinary X-ray equipment. Only licensed practitioners or veterinarians may order X-ray exams.

Persons must not be exposed to X-rays for non-medical purposes such as training or demonstrations.

Medical and veterinary equipment must meet performance standards as specified in [IEMA 32 Illinois Administrative Code 360](#). Facilities in which X-ray-producing machines are used may require architectural shielding. New facilities must be evaluated by DRS for their shielding requirements before X-ray-producing machines are used in them.

Written safety and emergency procedures must be available to each person operating a medical or veterinary X-ray machine. These instructions must include restrictions that will ensure safe operation. Guides to assist in selecting operating techniques (e.g., tube potential or kV, tube current and exposure time or mAs, phototimer setting, etc.) based on the patient's anatomical parameters must be available at each operator's position. Workers must receive annual instruction in these procedures. Documentation of training must be maintained.

Whenever possible, patients should be supported and image receptors should be held by mechanical devices. Only individuals required for the exam shall be in the room during the exposure.

The operator should stand at least 6 feet away from the useful beam and the patient during radiographic exposures unless the patient needs to be held. When the patient must be held by a person, this responsibility should be distributed among multiple workers whenever possible to reduce the dose. No person shall be routinely assigned the duty to hold patients. Each such person must remain outside the primary beam and wear appropriate PPE such as lead aprons, thyroid shields, lead gloves, etc.

Fluoroscopy must not be performed as a substitute for radiography. A person who attends to a fluoroscopic exam must wear appropriate PPE (lead apron, thyroid shield, lead gloves, etc.).

DRS will evaluate the need for radiation-monitoring devices (dosimeters). When assigned, monitoring devices must be worn whenever working near radiation sources. Campus units are responsible for providing the names of radiation workers to DRS to request their dosimeters.

5.4 Industrial Radiography

Industrial radiographic systems are used to examine the macroscopic structure of materials. Most such systems are taken to the structure to be examined, which makes shielding technically unfeasible. Due to the high potential for exposure, the State of Illinois has implemented requirements that are found in [32 IL Administrative code 350](#).

Requirements include:

- Only persons who are certified by the State of Illinois may operate industrial radiography equipment.
- All industrial radiography systems must include a locking device to prevent unauthorized or accidental radiation exposure, as well as a visible indication when the radiation source is energized.
- Records must be maintained that indicate each time an industrial radiography device is used. The record must indicate the date, the device used, the radiographer, and location of use.
- Appropriate radiation-monitoring devices (dosimeters) will be assigned by DRS and must be used when performing industrial radiography.
- Operating instructions for each radiography unit must be developed and followed. These instructions must be available at the operator's location.

Radiography systems that are completely contained in a shielded room with no exposure risk to the operators and members of the public may be exempt from the operator certification requirement as determined by IEMA. Such shielded rooms must be equipped with:

- Reliable interlocks that prevent access to the room or prevent an exposure
- Visible and audible alarms that are activated immediately prior to each initiation of an exposure
- Door-locking mechanisms that allow the door to be opened from the inside at all times

This section does not govern industrial radiography using radionuclide radiation sources.

5.5 Particle Accelerators

The term particle accelerator includes any device other than an X-ray machine that emits ionizing radiation as a result of acceleration of charged particles. Devices such as electrostatic particle accelerators (e.g., Cockroft-Walton and Van de Graf devices), cyclotrons, linear accelerators, and some plasma devices are included.

Any facility using an accelerator must develop written operating procedures that specify the conditions under which the device may be safely operated, rules for safe operation, and emergency procedures. Before operating the device, a person must be instructed in these operating procedures in addition to the training as specified in Section 4. These procedures must be available to the operator and maintenance personnel.

Facilities that operate accelerators must maintain a current list of personnel who are authorized to use or maintain the accelerator.

Requirements depend on the type of accelerator and its use. Therapeutic systems must follow [32 IL Administrative code 360](#). Research systems must follow [32 IL Administrative Code 390](#).

Open-beam devices require interlocks and other appropriate safety devices to ensure that personnel are not exposed to high levels of radiation during operations.

In addition, the area surrounding the accelerator and associated components must be surveyed every 3 months to monitor for activation when applicable. A record must be made of the accelerator operating conditions and radiation levels measured at specific control points. The radiation survey instrument used for such surveys must be checked every 3 months and calibrated annually.

All safety and warning devices must be checked monthly. Written records of these checks and maintenance must be maintained for inspection.

6. Surveys

Surveys are used to find leakage of enclosures and stray radiation and to assess the exposure rate to personnel and the public.

6.1 Radiation Detection

Non-quantitative measurements to detect leakage and stray radiation are best done with a survey meter and scintillation probe (usually containing a thin sodium iodine crystal). Geiger-Mueller (GM) counters will respond too but have a very low detection efficiency for X-rays. Ion chambers are useful for evaluating doses of radiation from the operation of a radiation-producing machine.

To perform a survey, first check the operation of the survey instrument by doing the following:

1. Calibration check

Check the calibration label on the instrument and ensure that the instrument is within the calibration period. If the calibration due date has passed, then contact DRS to have the instrument recalibrated, and find another survey instrument to use.

2. Battery check

Turn the switch on the survey meter to "BATTERY," or flip the battery switch to "ON." The needle on the meter face should move to a position within or beyond the indicated area on the meter face scale. Replace the battery if needed before using the survey meter.

3. Speaker check

If there is an audio switch on the survey meter, then turn it to "ON." Set the survey meter to a scale of "X1." The survey meter should chirp or click. If the speaker does not function, then the survey meter can still be used, but the surveyor will need to check the reading on the survey meter face.

4. Background check:

Go to an area with an expected low background rate and note the count rate. The background rate for a GM meter should be less than 100 counts per minute; the background reading for a NaI thin crystal probe should be less than 400 counts per minute. If the background reading exceeds that level, then investigate the area for unknown sources of radiation or detector contamination. Do not use the survey meter if it does not register a background rate.

5. Instrument response check:

Hold the supplied check source (often a thorium lantern mantle) up to the probe window. Note the count rate. The survey meter should respond to the check source, providing positive indication that the instrument is functioning properly.

Once you determined that the meter is functioning properly, hold the probe approximately 1 cm from the surface to be surveyed. If testing an enclosure for leakage, check corners, joints, fasteners and along all sides of the enclosure. Move the probe no faster than 1 cm/second, as fast movements may prevent detection. Include in your survey the place where the operator and other people will be located.

6.2 Assessing Exposure

For assessing exposure, a calibrated dose rate meter is required. Contact DRS if you need to assess exposure.

7. Emergency Procedures

If someone was or believes to have been exposed to the main beam of an X-ray machine, then turn off the beam by closing the shutter or cutting power to the X-ray tube. If an injury was sustained, then seek medical attention. Notify the supervisor and DRS, and provide information on tube parameters such as voltage, current, and exposure time. DRS will use this information to estimate the exposure and perform an investigation. The main purpose of the investigation is to find contributing factors to the accident and to prevent it from happening again.

Exposures exceeding a dose limit (see section 8) must be reported to IEMA.

8. Exposure Limits and Dosimetry

8.1 Occupational Exposure Limits

The annual limit for employees who work with radiation is the lower of:

- The total effective dose equivalent = 5 rem (0.05 Sv); or
- The dose equivalent to any individual organ or tissue (other than the lens of the eye) = 50 rem (0.5 Sv).

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

- Eye dose equivalent = 15 rem (0.15 Sv)
- A shallow dose equivalent = 50 rem (0.5 Sv)

8.2 Non-Occupational Exposure Limits (Members of the Public)

Each user of radioactive materials must conduct operations so that:

- The dose in any unrestricted area from external sources does not exceed 2 millirem (0.02 mSv) per hour.
- The total effective dose equivalent to individual members of the public does not exceed 100 millirem (1 mSv) in any year.

8.3 Declared Pregnant Workers Exposure Limits

The increased sensitivity of rapidly dividing cells makes the human embryo and fetus particularly susceptible to injury from exposure to ionizing radiation. For this reason, regulations require that exposure to the fetus during the gestation period not exceed 500 millirem (5 mSv). More information on this topic can be found under [Recommended reading for pregnant female radiation workers](#).

Any radiation worker who is pregnant or believes that they may be pregnant should contact DRS and review the recommended reading. All inquiries will be confidential. The lower limits apply only after the pregnant worker completes a [Declaration of Pregnancy Form](#). If a written declaration of pregnancy is not submitted, then the worker's dose continues to be controlled under the normal dose limits for radiation workers. A declaration of pregnancy can be withdrawn at any time.

The dose must be approximately uniform throughout the pregnancy. Care must be taken so that no more than 50 millirem (0.5 mSv) is received during any one month during a declared pregnancy. Efforts must be made to avoid substantial variation above the uniform monthly exposure rate to a declared pregnant radiation worker.

If, by the time DRS is informed of the estimated date of conception, the dose to the embryo/fetus has exceeded 450 millirem (4.5 mSv), then the limit for the remainder of the pregnancy will be 50 millirem (0.5 mSv). If DRS has not been notified of the estimated date of conception, then the dose to the fetus must not exceed 50 millirem (0.5 mSv) per month during the remainder of the pregnancy.

For the type of radiation work performed at Illinois, it is rarely necessary to recommend reassignment or changes to job duties to reduce exposure.

8.4 Exposure Limits for Minors

The annual occupational dose exposure limits for minors are 10 percent of the annual occupational dose exposure limits specified for adult workers in Section 8.1.

8.5 Personnel Dosimetry

The use and type of personnel dosimetry is determined by the activities and functions that the individual performs. By regulation, any person who receives or is likely to receive more than 10 percent of the maximum permissible dose or who enters a high radiation area must be provided with and must wear personnel monitoring devices.

DRS evaluates use of dosimetry on a case-by-case basis.

To enroll in dosimetry services, complete a [Dosimetry Request Form](#) and return it to DRS.

Whole-body dosimeters, or badges, monitor exposure to the whole body and should be worn between the neck and the waist, usually on the front of the body.

Finger-ring dosimeters monitor radiation exposure to the hands and fingers. These dosimeters may be worn on any finger and should face the radiation source.

Any person with assigned dosimeters must wear the badges and/or ring dosimeters when working with sources of ionizing radiation.

The dosimeter reading is the legal record of an individual's occupational radiation exposure. Therefore, a dosimeter must be worn only by the individual to whom it is assigned, must not be tampered with or experimentally irradiated, and must not be used to measure radiation exposure received as a medical patient.

When not being worn, dosimeters must be stored in a location where they will not be exposed to radiation.

Dosimeters are collected monthly or quarterly by DRS personnel and sent to a vendor for processing. Dosimeters must be made available for this exchange to occur.

If a dosimeter is lost, then discontinue radiation-related activities and contact DRS. Individuals who have lost a dosimeter must complete the Missing/Damaged Dosimeter Report Form so that an assessment of their radiation exposure can be performed. DRS will arrange for a replacement dosimeter.

8.6 Personnel Exposure Records

DRS maintains exposure records for all monitored personnel. Annual reports of exposure are always available to the worker, and a notice is sent advising each worker to review their exposure report annually.

At the request of a worker, DRS must furnish their exposure report. The report is furnished within 30 days from the time the request is made, within 30 days of termination of employment, or within 30 days after the individual's dose has been determined, whichever is later.

9. Abbreviations and Units of Measure

Abbreviations

ALARA – As Low As Reasonably Achievable

cpm – counts per minute

DRS – Division of Research Safety

GM – Geiger-Mueller

Gy – Gray (unit of absorbed dose)

IEMA – Illinois Emergency Management Agency (formerly Illinois Department of Nuclear Safety (IDNS))

NaI – sodium iodide

PPE – Personal Protective Equipment

R – Roentgen (unit of exposure)

Rad – radiation absorbed dose (unit of absorbed dose)

Rem – Roentgen equivalent man (equivalent absorbed dose)

SOP – Standard Operating Procedure

Sv – Sievert (equivalent absorbed dose)

Units of Measure

1 Gy = 100 rad

1 Sv = 100 rem