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# X-Ray Safety Manual

## 2022

**Division of Research Safety**

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# Contents

# 1. Introduction

The University of Illinois at 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 Radiation and Laser Safety Committee 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, including lasers.
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, including lasers.
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 and laser safety policies.
8. Review communications between DRS and government agencies that affect the campus radiation safety program and the campus radioactive materials license.

## 2.2 Division of Research Safety Responsibilities

1. Provide advice and assistance to everyone concerned on all aspects of radiation safety.
2. Approve proposals for procurement, 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 facilities and in formulating or modifying operating procedures for new or existing installations or buildings.
6. Calculate the levels of radiation intensity, time limits of personnel exposure, and minimum working distance around accelerators, reactors, X-ray machines, and other intense radiation sources.
7. Report hazardous radiological conditions promptly to the responsible individual and, when necessary, to the immediate supervisor and the RLSC.
8. Schedule routine medical examinations in accordance with established policy; help to establish criteria and make arrangements for such examinations as may be required in emergency situations.
9. Enforce all written directives of the RLSC.
10. 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.
11. Grant exemptions to the rules (or impose more stringent restrictions) in emergency situations when, in the judgment of DRS, such action is necessary to reduce risk of serious injury or economic loss. Such actions must be reported verbally and in writing to the RLSC as soon as possible.

12. Maintain files of federal, state, and local licenses and registrations concerned with radiation sources, and initiate applications for renewals and/or amendments of same.
13. Determine whether a radiation incident requires a report to any governing body and prepare such reports for the approval of the RLSC. **Exception:** If an immediate report is required, then the campus radiation safety officer will (with knowledge and approval of the RLSC Chair if possible) file such a report with the appropriate authorities and will provide copies to the RLSC.
14. 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 Permit Holder and Unit Head Responsibilities

In addition to assuming all the responsibilities of an individual radiation user, the Permit Holder 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 and disposition to manage radiation safely. The minimum training requirements are outlined in Section 4.
2. Determine the types of radiation sources, equipment, facilities, and procedures needed for their work and work under their supervision.
3. Comply with all radiation permit requirements.
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 complying with existing laws and license requirements (e.g., maintenance of records, preparation of reports) by providing necessary 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. Inform DRS when an extended departure from campus is planned, or if there is any reason the obligations in the X-Ray Safety Manual cannot be met.
9. When away from campus for an extended period, ensure that work involving radiation sources receive adequate supervision. A Permit Holder that will be absent from their laboratory for a period of three months or longer must designate a temporary supervisor and inform DRS in writing of this designation. The education, training, and administrative authority of the person designated as temporary supervisor must be sufficient to ensure that all safety requirements will be met and must be acceptable to DRS.
10. Unit heads must inform DRS whenever any Permit Holder in their unit will be absent from campus for more than three months or whenever there are circumstances with regard to the Permit Holder that might require additional assistance from DRS (e.g., temporary disability).

## 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. Protect service personnel, and allow no maintenance or repairs of area facilities or equipment unless approved by the area supervisor and/or DRS.
8. Notify their supervisor and DRS of unexpected difficulties.
9. Be prepared to handle accidents or injuries.
10. Notify and seek the assistance of their Permit Holder and DRS as soon as possible in emergencies.
11. Take no action that would interfere with the responsibilities of their supervisor.
12. Notify their supervisor immediately of any lost, stolen, or missing radiation source.

# 3. Registering Radiation-Generating Machines

## 3.1 Permit Application

The use of radiation-generating machines is allowed only pursuant to a permit issued by DRS.

Complete a Radiation Permit Application and submit it to DRS. Provide information on each radiation-generating machine you plan to use.

DRS reviews the application and prepares the permit specifying locations and conditions for use of radiation-generating machines and obtains approval of the campus RSO and the RLSC Chair. By agreeing to the permit conditions, the applicant acknowledges their acceptance of the responsibilities associated with the permitted activities. The approved permit must be made available to all persons using radiation sources under its provisions.

Before operations under the permit commence, DRS personnel may inspect the authorized locations to ensure the areas are effectively shielded and properly posted.

## 3.2 Amendments and Deactivation

Permits can be amended to include new locations or radiation-producing machines at any time by notifying DRS of the desired change in writing. All radiation-generating machines must be registered with DRS before their use. Notify DRS when registered machines or experimental set-ups utilizing registered machines are modified resulting in a potential change to required shielding or precautions. Additionally, notify DRS when machines become inoperable or are no longer used. Campus units are responsible for providing all required information and informing DRS when these changes occur. Campus units are also responsible for paying the annual registration fees for their registered machines.

A permit is deactivated when no radiation-generating machines are in use. It can be reactivated quickly by contacting DRS.

# 4. Radiation Safety Training Requirements

Regulations require that users of radiation-generating machines be properly trained. All users are required to complete the DRS online training Analytical X-Ray Safety at intervals not to exceed 12 months. In addition, Permit Holders 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
- Lab-specific precautions and procedures to minimize exposure
- Purposes and functions of protective devices and survey meters
- The permit conditions and requirements
- Employee responsibility to promptly report any condition that may lead to or cause a violation of the regulations or cause an unnecessary exposure
- Actions to take in the event of an emergency
- Radiation exposure reports that workers may request
- Review the safety features including interlocks, warning lights, and markings. Describe procedures for completing periodic checks of interlocks and warning systems, including documentation.
- Review documentation of operations log.

Regulations require that this knowledge be reinforced by annual x-ray safety training.

Records of this instruction must be maintained by the Permit Holder for audit by DRS personnel or for inspection by state regulatory personnel.

# 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 practices implemented 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 by sufficiently shielded walls pose very little risk of exposure.
- Open beam units pose the greatest risk of exposure and require administrative controls and often the use of 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 systems 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. 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 if 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 who build their own systems should include the same safety features as listed above. A review by DRS will occur before these systems 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 such tests must be maintained and made available for inspection.
- A written Standard Operating Procedure for each analytical x-ray machine. The SOP must be available at the operator's location and all users must be instructed in the procedure before being allowed to operate any x-ray machine.

Additional information: 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 material 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 x-ray equipment. Only 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 should 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. If patients must be held by a person, this responsibility should be distributed among multiple workers to reduce the dose. No individual shall be assigned the duty to hold patients routinely. Such persons must remain outside the primary beam and wear appropriate Personal Protective Equipment (PPE) such as lead aprons, thyroid shields, lead gloves, etc.

Fluoroscopy must not be performed as a substitute for radiography. Personnel who attend to fluoroscopic exams must wear appropriate PPE (lead aprons, thyroid shields, lead gloves, etc.).

DRS will evaluate the need for radiation monitoring devices (dosimeters). If assigned, monitoring devices must be worn whenever working around 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 the requirements listed below.

Requirements for Industrial Radiography:

- 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 and 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 are included, but it may also encompass plasma devices.

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.

Interlocks and other appropriate safety devices must be used to ensure that personnel are not exposed to high levels of radiation during operations. A record must be maintained of each instance when an interlock or other safety device is circumvented (e.g., for testing purposes), including the date and reason the interlock or safety device was bypassed.

Facilities that operate accelerators must maintain a current list of personnel who are authorized to use or maintain the accelerator. Units will inform DRS of any changes to this list. The name of the operator in charge must be displayed at the control console whenever the accelerator is operating.

The area surrounding the accelerator and associated components must be surveyed every 3 months to monitor for activation. 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 shall 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, check the operation of the survey instrument first 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 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 also 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, turn off the beam by closing the shutter or cutting power to the x-ray tube. If an injury was sustained, seek medical attention. Notify your 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:

a. The total effective dose equivalent = 5 rem (0.05 Sv); or
b. 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:

a. Eye dose equivalent = 15 rem (0.15 Sv)
b. 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:

1. The dose in any unrestricted area from external sources does not exceed 2 millirem (0.02 mSv) per hour.
2. 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 only apply if the pregnant individual 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 the pregnant worker informs DRS 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 the U of I, 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 normally face the palm side of the hand. Finger rings must be worn under gloves to prevent them from becoming contaminated.

Every 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 provide information to DRS personnel so that an assessment of their radiation exposure can be performed. DRS will order 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 wearer, and a notice is sent advising them 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, Units of Measure, and Detection Efficiency

**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
R – Roentgen (unit of exposure)
Rad – radiation absorbed dose (unit of absorbed dose)
Rem – Roentgen equivalent man (equivalent absorbed dose)
Sv – Sievert (equivalent absorbed dose)

**Units of Measure**

1 Gy = 100 rad
1 Sv = 100 rem