Radiation Safety Manual for Radiation Emitting Equipment

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Radiation Emitting Equipment

1.0 General Working Rules

This manual is designed to control operations conducted at the University of Dayton Research Institute and UD Education Facilities that may result in the potential exposure of personnel, members of the general public and/or the environment to ionizing radiation. The University of Dayton's commitment to the radiation safety is based on the fundamental principle that levels of radioactivity to be used, and exposures to all sources of ionizing radiation, are to be maintained **As Low As Reasonably Achievable (ALARA)**.

The policies and procedures of the this apply to the use of radiation emitting equipment governed by Chapters 3701:1-38 and 3701:1-66 of the Ohio Administrative Code (OAC). All radiation emitting equipment, whether active or in storage, must be registered with the State of Ohio Department of Health. This manual provides general guidance for safety and usage. The provisions in this manual and the operating procedures for each device constitute the Quality Assurance Program required by OAC 3701:1-66-04.

Research utilizes numerous types of radiation equipment including analytical cabinet systems, radiographic equipment and electron microscopes. In this section, the term "registrant" refers to the equipment owner or the person with official responsibility for the equipment. The term "operator" refers to any person actually using the equipment. All operators are radiation workers and shall register with EHS prior to using the equipment. Regulations vary according to the type of X-ray equipment, so the following information-- which includes most of the regulations--is grouped by type. Operators are expected to understand and follow the regulations for the type of equipment used. You may view or obtain a copy of the regulations in EHS.

Each registrant must notify EHS of any change in the status of the equipment, and supply an updated inventory if any changes occur (i.e. equipment rendered inoperable, decommissioned, etc.).

It is the responsibility of the registrant to survey the equipment according to OAC 3701-1-66; 1-38. All survey records must be kept by the registrant and provided to EHS. Surveying of equipment must be performed during initial set up of the equipment, annually thereafter (with exception of electron microscopes), following any change in the initial set up of the system, following any maintenance, or when personnel monitoring equipment show an occupational over-exposure.

The purchase or receipt of radiation emitting equipment shall be coordinated with EHS during the early planning stages to ensure that the facility is adequately shielded and the device can be properly registered. Installed equipment may not be operated, other than for controlled, preliminary, installation tests, until all safety interlocks and warning devices are fully operational, administrative requirements have been met, and acceptance

tests have been performed by EHS or other qualified person approved by the Radiation Safety Committee.

A quarterly inventory of radiation emitting equipment will be performed by EHS. The inventory will include: number, type and location of radiation emitting equipment, date performed and name of individual performing inventory check, and manufacturer/model/serial number of each piece of equipment.

Radiation emitting equipment will be secured against tampering and unauthorized operation. The controls of the device will be inaccessible, locked, disconnected or otherwise disabled, or positively secured when not under the physical supervision of an approved operator. In special circumstances, equipment may be operated while unattended, so long as positive security against unauthorized entrance to radiation areas and the operating controls are maintained. Conditions for unattended operation should be clearly stated in the operating manual. Two requirements for unattended operation are:
1- the entryway must be locked and safeguarded against unauthorized entry;
2- a notice must be posted at the entryway informing departmental and emergency personnel of necessary precautions and actions in case of an emergency (see "Required Postings").

The Research Institute Property Records Office will notify EHS whenever radiation emitting equipment is planned for disposal or permanently disabled so that proper administrative procedures may be followed. Radiation emitting equipment may be disposed by transferring the unit to another facility by sale or donation or scrapping it as waste. EHS will notify ODH of the disposition of the unit and the state registration will be modified. If the unit is transferred to another facility, EHS will inform the new owner of the need to register the device. If the unit is disposed as scrap, the x-ray tube(s) will be de-activated and any hazardous chemicals or materials treated or removed.

1.1 General Precautions when using Radiation Emitting Equipment

- Never expose fingers, hands, or any other body part to the primary beam.
- Never disengage a safety interlock (except as described by an approved protocol) or warning device or operate a unit if one of these systems malfunctions.
- Use time, distance, and shielding to minimize your exposure.
- Properly wear dosimetry, if issued, whenever the equipment may be energized.
- Record usage and maintenance, according to operating procedures.
- Never energize electrical equipment if the floor or equipment is wet or if high voltage wires are exposed.
- Never operate equipment for which you have not been trained.
- Never alter, repair, or perform maintenance on the equipment without authorization and approval from the Registrant.

2.0 Analytical & Radiographic X-Ray

The predominant X-ray-producing equipment used for non-medical purposes is analytical X-ray. It produces intense beams of low-energy X-rays that can cause severe and permanent bodily injury to exposed persons, including reduce cell division, damage genetic material, and produce defects in unborn children. Because of the equipment configuration, most exposures are to the fingers and hands. Exposure of the lens of the eye may occur if visual alignment is performed while the equipment is operating. Despite the low energy of the X-rays, beam intensities up to 40,000 roentgens per minute may be possible. Radiation hazard is not restricted to the primary beam because ill-fitting or defective equipment may produce leakage or scatter radiation. Analytical samples or other material in the beam may give off secondary radiations, and diffracted beams are emitted at almost any angle from the primary beam.

2.1 Dosimetry

Each operator shall obtain and properly use dosimeters as applicable. On most equipment, interlock mechanisms or other design features prevent exposures during routine operation. It is the responsibility of the registrant to report any suspected exposure to EHS. EHS will perform an investigation to determine the cause and extent of exposure, as well as the corrective action taken to prevent during future use.

2.2 Required Training

Registrants or facility supervisors shall provide operators with specific written instructions. Complete instructions shall include notice of radiation hazards and safe work practices. Registrants and supervisors shall provide operators with specific instructions for the equipment they will use. Registrants must document this training, and provide documentation to EHS when requested.

2.3 Required Postings

The registrant shall post the following documents near the controls of each analytical X-ray unit:

- Ohio Department of Health Notice to Employees
- Safe Operating Procedures
- UD's Required Postings and Contract Information Posting

2.4 Required Labels

The registrant shall place a label on analytical X-ray equipment bearing the words (or similar to) "Caution--Radiation--This Equipment Produces Radiation When Energized" with the standard radiation symbol.

2.5 Required Indicators

The registrant shall provide the following indicators that signal whether the beam is on or off and whether safety features are engaged. Such indicators should never be defeated or tampered with.

- A clearly visible indication of the presence of an X-ray beam shall be provided on or immediately adjacent to each tube head.
- A clearly visible indication of the status of each shutter (i.e., open or closed) shall be provided.

2.6 Required Interlocks & Safety Devices

Registrants shall ensure that the following rules for interlocks and safety devices are followed:

- In cases where the primary X-ray beam is not intercepted by the experimental apparatus under all conditions of operation, protective measures such as auxiliary shielding shall be provided to avoid exposure to the primary X-ray beam.
- Whenever possible, an interlocking device shall be provided that prevents the entry of any portion of an individual's body or extremities into the primary beam, or causes the primary beam to shut off upon any entry into its path.
- If for any reason it is necessary to alter safety devices temporarily, such as bypassing interlocks or removing shielding, such action shall be (1) specified in writing; (2) posted near the X-ray tube housing so that other persons will know the current status of the machine; and (3) terminated as soon as possible.
- Unused tube ports shall be closed so that accidental opening is not possible.

2.7 X-Ray Emergency Procedure

Equipment involved in an accidental exposure must be secured against use. It must be inspected by EHS before operation can resume. In case of accidental exposure to the primary beam or scattered radiation, either suspected or actual:

- Turn off power to unit.
- Notify EHS at 229-4503.
- If you are unable to reach EHS, call Public Safety at 911 or 92121

2.8 Symptoms of Injury from Acute Local Exposure to Radiation

Dose Received: 200 - 300 rad

Equivalent thermal burn: first
Symptoms: *Erythema* (redness of the skin). Possible reaction within hours of exposure. Sensations of warmth and itching. Major redness may appear two or three weeks after exposure, with the elapsed time dependent on the dose received. Epilation (hair loss) is possible two to three weeks after exposure.

Dose Received: > 1,000 rad

Equivalent thermal burn: second
Symptoms: *Transepidermal injury*. Wet or dry dermatitis. Wet or dry blisters occurring within one or two weeks of exposure. Blisters usually break open, leaving them vulnerable to infection. Epilation is possible and may be permanent.

Dose Received: > 5,000 rad

Equivalent thermal burn: third
Symptoms: *Severe transepidermal injury*. Resembles intense scalding or chemical burn. Immediate onset of intense pain. Epilation is permanent.

Ocular Effects: >200 rad

Symptoms: Conjunctivitis (inflammation of the eye). At acute, lower doses. Chronic exposures can lead to cataracts.

2.9 Radiation Hazards from X-Ray Units

The primary beam is the most obvious source of possible exposure from an analytical X-ray unit. This beam, however, is usually of low energy and can be attenuated with approximately a millimeter of lead. Beams generated from targets composed of material with higher atomic number (such as Mo versus Cu) yield more penetrating X-rays.

Leakage of the primary beam may be a significant source of unwanted radiation. Shutters and collimators must be properly coupled and unused ports secured to prevent accidental opening. Remember to use an adequate beam stop and to collimate the beam to reduce its cross section.

Other radiation hazards are associated with analytical X-ray units as well. Significant exposure rates are possible from radiation scatter, and shielding against this may be necessary. Also, ancillary equipment may contribute to significant levels of unwanted radiation (e.g., gassy rectifiers in the high-voltage supply may need replacement or shielding).

2.10 Protective Measures from Radiation

Time, Distance & Shielding: Use of the principles of time, distance, and shielding can significantly reduce personal exposure to levels that are **As Low As Reasonably Achievable (ALARA)**.

- Time: Radiation exposure can be decreased by reducing the amount of time people spend working in radiation fields.
- Distance: X ray intensity decreases inversely with the square of the distance ($1/d^2$) when the source is small compared to the distance. For instance, if you double your distance from a radiation source, you reduce your exposure by (1/4) one-fourth. The radiation intensity decreases more slowly for large or planar sources.
- Shielding: Attenuating material placed in the radiation path can effectively reduce external dose. The thickness of shielding needed is determined by the type and energy of radiation, type of shielding material, distance from the source, time spent in the work area, and acceptable level of dose reduction. The adequacy of the shielding is evaluated by the RSO and verified using a survey meter. The exposure rate to the user should be reduced to 1 mrem/hr or less for long procedures. The exposure rate in any unrestricted area must not exceed 2 mrem/hr. Dose to members of the public must be restricted to less than 100 mrem/year. In the interest of ALARA the exposure rate in any unrestricted area should be consistent with background. Information on the attenuating characteristics of shielding materials can be obtained from the RSO.

2.11 Safe Working Practices for X-Ray

Beam Alignment
1. Wear a dosimeter where applicable.
2. Use long handles on fluorescent screens, heavily leaded glass plugs, or electronic alignment where possible.
3. Only authorized persons are permitted to align an analytical X-ray unit. Authorized persons are those individuals who have been specifically trained by the supervisor of the facility.
4. If safety interlocks are being bypassed, post a sign indicating the status of the safety switch.

Sample Changing
1. Monitor the analytical X-ray unit with appropriate radiation detection equipment before changing a sample.
2. Use the shutter to stop X-rays during a sample change. There must be a visible signal (color marking or light) indicating the status of the shutter.
3. Be aware of the operational status of the analytical X-ray unit at all times, especially during sample change.

General Equipment Operation
1. Post a sign if the safety interlock is bypassed.
2. Terminate the safety interlock bypass as soon as possible.
3. Monitor the analytical X-ray unit as often as necessary.
4. Only trained individuals are to operate an analytical X-ray unit. Unauthorized users must not use the equipment at any time, and equipment must be secured by registrant to prevent unauthorized use.
5. Wear a dosimeter when operating an analytical X-ray unit, where applicable.
6. Do not deliberately expose dosimeters.
7. Perform monthly safety checks, where applicable.
8. Replace burned-out light bulbs.
9. If the experimental design does not fit the enclosure, the analytical X-ray unit must comply with standards applicable for an unenclosed unit.
10. Make no assumptions regarding your analytical X-ray unit; units left unattended, especially for a prolonged absence, should be monitored upon return.

3.0 Electron Microscopes

3.1 Required Training

Registrants or facility supervisors shall provide operators with specific written instructions. Complete instructions shall include notice of radiation hazards and safe work practices. Registrants and supervisors shall provide operators with specific instructions for the equipment they will use. Registrants must document this training, and provide documentation to EHS when requested.

3.2 Required Postings

The registrant shall post the following documents near the controls of each electron microscope:

- Ohio Department of Health Notice to Employees
- Safe Operating Procedures
- UD's Required Postings and Contract Information Posting

3.3 Required Labels

The registrant shall place a label on analytical X-ray equipment bearing the words (or similar to) "Caution--Radiation--This Equipment Produces Radiation When Energized" with the standard radiation symbol.

4.0 Inoperable Equipment

Inoperable equipment shall be secured from unauthorized removal or access. It is the responsibility of the registrant to ensure each piece of inoperable equipment is secured at all times. Inoperable equipment that will be removed from UDRI Property Records must go through the decommission process. Please contact EHS in the event a piece of equipment will need to be decommissioned.

5.0 Glossary

Absorbed dose The energy imparted to matter by ionizing radiation per unit mass of irradiated material. The common unit of absorbed dose is the rad, and the SI unit is the Gray.
Absorption The process by which radiation imparts some or all of its energy to material through which it passes.
Activity The number of nuclear transformations occurring in a given quantity of material per unit time.
ALARA As **L**ow **A**s **R**easonably **A**chievable. Philosophy of dose limitation.
Background radiation Radiation from cosmic rays and natural and man-made radionuclides and sources in the environment.
Becquerel The SI unit of activity. One becquerel is equal to one transformation per second. Abbreviated Bq.
Body badge Dosimeter used for the approximate measurement of radiation dose for personnel monitoring purposes.
Ci See Curie
Contamination Deposition of radioactive material in any place where it is not desired, particularly where its presence may be harmful. The harm may merely interfere with an experiment or procedure or may constitute an actual hazard to personnel.
Curie The common unit of activity. One curie (Ci) equals $3.7 \times 10_{10}$ disintegrations per second.
Decay, radioactive Transformation of the nucleus of an unstable atom by the spontaneous emission of charged particles and/or photons.
Declared pregnant woman Any woman who has voluntarily informed her employer, in writing, of her pregnancy.
Deep dose The dose equivalent at a depth of approximately 1 cm in soft tissue.
Dose A general term denoting the quantity of radiation or energy absorbed. For special purposes it must be appropriately qualified, e.g., absorbed dose.
Dose equivalent The absorbed dose multiplied by a modifier to express the radiation dose on a common scale. The special unit of dose equivalent is the rem, and the SI unit of dose equivalent is the sievert (Sv).
Dosimetry Measurement or calculation of the amount of energy absorbed in matter.
Electron volt A unit of energy equivalent to the energy gained by an electron in passing through a potential difference of one volt. Abbreviated eV. Larger units are keV, for thousand electron volts, and MeV, for million electron volts.
Erythema A transient reddening of the skin as a result of exposure to radiation.
EV See Electron volt.
Exposure A measure of the ionization produced in air by X or gamma radiation. The unit of exposure is the roentgen (R).
Extremity A hand, elbow, arm below the elbow, foot, knee, and leg below the knee.
Genetic effect Heritable effect of exposure to ionizing radiation.
Genetically significant dose The dose equivalent to the gonads, weighted for age and sex; used for expressing genetic risk.
GM detector Geiger Mueller detector. A versatile radiation detection device, suitable for detecting alpha, beta, and gamma radiation, that operates on the gas ionization principle.

Gray The SI unit of absorbed dose. One gray (Gy) is equal to one joule per kilogram, or 100 rads.
Half-life, biological The time for the body to eliminate one-half of an administered dose of any substance by the regular processes of elimination. Approximately the same for both stable and radioactive isotopes of the same element.
Half-life, effective Time required for a radioactive element in the body to diminish by 50 percent as a result of the combined action of radioactive decay and biological elimination. Effective halflife = (biological half-life x radioactive half-life)/(biological half-life + radioactive half-life)
Health physics The science devoted to the protection of people and the environment from the harmful effects of radiation.
Intensity The energy per unit time that crosses a unit area at right angles to a beam of radiation.
Ionizing radiation Any electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through matter.
Isotopes Nuclides having the same number of protons in their nuclei (hence the same atomic number) but differing in the number of neutrons (and therefore mass numbers). Chemical properties are virtually identical for all isotopes of a given element.
KeV 1,000 electron volts.
MCi See Millicurie.
Member of the public Anyone other than individuals performing assigned duties for the licensee or registrant that involve exposure to sources of radiation.
MeV Million electron volts.
Microcurie A submultiple of the common unit of activity, the curie. One microcurie is equal to one thousandth of a millicurie, or $3.7x10^4$ transformations per second.
Millicurie A submultiple of the common unit of activity, the curie. One millicurie is equal to one thousandth of a curie, or $3.7x10^7$ transformations per second.
Milliroentgen A submultiple of the special unit of exposure, the roentgen, equal to one thousandth of a roentgen. Abbreviated mR.
MR See milliroentgen.
Occupational dose The dose received by an individual in the course of employment in which the individual's assigned duties for the licensee or registrant involve exposure to sources of radiation. Occupational dose does not include dose received from background radiation, as a medical patient, from voluntary participation in medical research programs, or as a member of the public.
Quality factor A modifying factor by which the absorbed dose in rad (or gray) is multiplied to obtain, for radiation protection purposes, the dose equivalent in rem (or sievert).
R See Roentgen.
Rad The common unit of absorbed dose, equal to 100 ergs of energy deposited in the material of interest.
Radiation The emission and propagation of energy in the form of waves or particles.
Radionuclide A nuclide that spontaneously emits radiation in the form of electromagnetic or particulate radiation.
Registrant Any person who registers an X-ray producing device.

Rem The common unit of dose equivalent. The dose in rem is numerically equivalent to the dose in rad multiplied by an appropriate modifier (such as the quality factor).
Restricted area Any area to which access is limited by the licensee or registrant for purposes of protecting individuals against undue risks from exposure to sources of radiation.
Roentgen The unit of exposure. Equal to 2.58×10^{-4} coulombs per kilogram of air.
Scattering Change in direction of particles or photons as a result of collisions or interactions in matter.
Scintillation A radiation detection process whereby radiation interacting with a crystal emits light in proportion to the energy of the radiation.
Sealed source Any device--containing radioactive material to be used as a source of radiation-- that has been constructed in such a manner as to prevent the escape of any radioactive material.
Shallow dose The dose equivalent at a depth of approximately .007 cm in soft tissue.
Sievert The SI unit of dose equivalent. One sievert is the dose in gray multiplied by a quality factor. Abbreviated Sv. Equal to 100 rem.
uCi See Microcurie.
Whole body For purposes of external exposure, head, trunk (including male gonads), arms above the elbow, or legs above the knee.
X-rays Penetrating electromagnetic radiation having wavelengths shorter than visible light. Identical to gamma rays except for their extranuclear origin.