



UC IRVINE X-RAY MACHINE SAFETY FACTSHEET

UNIVERSITY OF CALIFORNIA, IRVINE
ENVIRONMENTAL HEALTH & SAFETY
RADIATION SAFETY DIVISION

GENERAL PROCEDURES FOR NON-HUMAN USE X-RAY MACHINES

The following matters relate to the operation of all types of non-human use x-ray producing machines, *except electron microscopes*.

I. RADIATION SAFETY TRAINING

- A. All personnel who will be working with x-ray machines must receive x-ray safety training conducted by EH&S (or its equivalent elsewhere). The training at UCI consists of reading the “Radiation and Electrical Safety Syllabus for New Users of X-ray Machines”, and passing an open-book quiz (<http://www.ehs.uci.edu/programs/radiation/radtrain.html>).
- B. All personnel who will be working with x-ray machines must receive adequate on-the-job training conducted by his/her Responsible Principal Investigator, or by the Responsible Principal Investigator’s assigned representative. This training must be documented in writing by completing an EH&S-provided on-the-job training form, and returning it to EH&S.
- C. Operators of x-ray machines must be instructed on how to report actual and suspected radiation over-exposures to EH&S. Emergency call lists must be available.

II. ADMINISTRATIVE ISSUES & CONTROLS

- A. All x-ray machine operators must be listed on the Responsible Principal Investigator’s RUA (Radiation Use Authorization). Plans for facilities that include x-ray machines must be reviewed by EH&S before the machines are operated, and periodically thereafter to assure that they remain safe and in compliance with applicable safety regulations and guidelines. EH&S must be notified if an x-ray machine is to be acquired, moved, transferred to another investigator, substantially modified, or decommissioned. This notification must be made prior to operation, resuming operation, or disposing of a machine.
- B. An x-ray warning sign (**Caution -- X-rays**) must be posted on each access door leading to a room containing an x-ray machine. Such signs must always be visible, and should contain machine-specific radiation protection instructions when appropriate. *{Not needed for x-ray fluorescence machines.}*
- C. An open-beam x-ray system must **never** be left unattended while it is operating.

- D. **Bypassing engineering safety devices (interlocks, etc.) must be avoided.** If absolutely necessary, they need to be *documented in writing* and a prominent warning sign needs to be posted near the controls to the x-ray machine. Such machines must never be left unattended if personnel entering an area can unwittingly be exposed to radiation. Any such bypasses must be as brief as possible. Persons should contact EH&S if guidance is needed regarding safety issues related to bypassing safety devices.
- E. Operators of x-ray systems should have written standard operating procedures (SOPs) to follow in order to improve safety. These SOPs should include: a) description of the x-ray device; b) normal x-ray parameters (power and current, exposure time, etc.); c) procedures for proper sample preparation, x-ray beam alignment, etc.; d) description of all associated safety hazards (**radiological, electrical, mechanical**); e) description of safety precautions such as interlocks and warning signals; f) procedures for performing tests of interlocks; g) required operator training and dosimetry; g) a safety checklist; and h) emergency/accident information (contact phone numbers, etc.). The SOPs need to be available in a location near the machine.
- F. An x-ray machine use log must be maintained. The following items should be included in use log entries: name of the operator; date; procedure performed; exposure/on-time duration; beam current and beam voltage (*when they vary significantly from run to run*); safety check results (if appropriate) and comments. Information contained in the use log, in conjunction with the machine's maintenance records, can be useful in investigating incidents and in determining the operating status/reliability of the machine.
- G. X-ray machines must be installed in areas isolated from heavily occupied parts of the laboratory. A room solely devoted to the machine is desirable.
- H. When they occur, elevated radiation areas (> 2 mR/h) should be roped off or otherwise restricted to limit access. **Doors must be kept locked during machine operation.**
- I. Personnel not involved in the x-ray experiment must be kept away from the machine during operation. **Visitors are strongly discouraged during operation.**
- J. The lowest effective beam energy and beam size, and the shortest effective beam-on duration, should be used.
- K. Periodic tests of safety devices must be performed and should be documented in the use log. EH&S personnel also perform these tests during visits to the x-ray facility.

III. WARNING SYSTEMS

- A. There must be a visible indicator of the energized beam (usually a red warning light, often indicating “*X-rays On*”). Even when such lights are not illuminated, the beam current meter (also required) must be checked to verify that the beam is not operating before entering the beam area.
- B. When appropriate, there must be warning lights which indicate whether the shutter is open (usually a red light) and closed (often an amber light).
- C. A label indicating “***Caution -- Radiation -- This Equipment Produces Radiation When Energized***” (or an equivalent notification) must be posted near the main switch used to energize an x-ray tube.

IV. RADIATION SHIELDING

- A. The primary x-ray beam must be intercepted by the apparatus. If necessary, additional shielding must be used to reduce radiation exposures from the primary beam and from scattered radiation to **as low as reasonably achievable (ALARA)**.
- B. Significant amounts of radiation must not penetrate to rooms and areas outside of the x-ray laboratory. Shielded walls/ceilings/floors may be needed in some cases.
- C. Enclosed beam systems must have sufficient shielding such that the radiation exposure rate will not exceed 0.5 mR/h at 5 cm from all surfaces of the housing.

V. X-RAY SYSTEM SAFETY MEASURES

- A. Fail-safe interlocks (electric switch cutoffs) must be present on all access doors and safety panels so that x-ray production is not possible when they are open.
- B. When present, unused x-ray tube ports must be secured such that tools are required to open them.
- C. ***X-ray machines must be secured/locked when not in operation. Access to the key must be carefully controlled.*** In cases in which involved/multi-step procedures must be performed to initiate the production of x-rays (such that unauthorized persons would not be capable of activating a machine), it is not necessary to remove the key between uses.
- D. As much of the radiation (including scattered radiation) which can be enclosed should be appropriately enclosed in adequate shielding.

- E. **The safety interlocks must never be used to turn off the machine.** The main switch is for that purpose.
- F. The quantity of scattered radiation should be checked following each beam alignment procedure.

VI. RADIATION MONITORING/DOSIMETRY

- A. Radiation dosimetry (body badges and/or rings [for both hands, when appropriate]) must be worn by all x-ray machine operators and by others who need to be in the immediate vicinity of an open-beam x-ray machine during operation. In cases in which the x-ray beams are completely enclosed and the machines are well-shielded, dosimetry may not be needed. *Personnel using electron microscopes, x-ray fluorescence units, and other low kV/mA machines, will most likely not need to wear dosimetry.*
- B. A thin-window radiation survey meter needs to be available for use if this is specified in the RUA of the Responsible Principal Investigator. ***X-ray machines produce radiation not accurately measured by Geiger-Muller (GM) counters calibrated with high-energy gamma rays (such as those from ¹³⁷Cs).*** GM counters are, however, effective for detection of x-rays because of their excellent sensitivity. However, ***ion chambers*** are the instruments of choice for quantifying x-ray dose since they directly measure the ionization produced in the sensitive volume of the detector. EH&S has several ion chambers which can be used in safety surveys of x-ray machines as appropriate.
- C. In some cases, area radiation monitors (dosimeters and/or real-time monitors) must be used in the vicinity of x-ray machines.

VII. SAFETY TESTS AND SURVEYS

- A. During all tests of radiation fields produced by x-ray machines, normal or dummy samples (*phantoms*, etc.) must be in position so that scattered radiation can be properly quantified under realistic conditions.
- B. Radiation surveys must be made under worst-case conditions (highest beam current used, largest sample size used, etc.) in order to properly characterize the radiation field around a system. Whenever a system is reconfigured, a radiation survey must be performed to ensure the safety of the planned operations.
- C. Radiation readings must be taken at locations representative of the locations at which personnel can potentially be exposed. This may include above the machine, at the sides of the machine, below the main protective beam stop, at access ports, at the operator's station, and in adjacent areas and rooms in some cases.

VIII. ELECTRICAL SAFETY

- A. The x-ray machine chassis/cabinet/enclosure must be properly grounded.
- B. **No jewelry (rings, etc.) should be worn when working with high-voltage machines.** In some cases, rubber-soled shoes should be worn or non-conductive rubber mats should be used to reduce electrocution hazards.
- C. ***Qualified electrical technicians must perform all major electrical repairs.***
- D. Electrical cords should be inspected periodically to look for damage and deteriorated/worn cords should be immediately replaced.
- E. The buddy system should be used when working with high-voltage equipment, especially after-hours and on weekends. **People knowledgeable in CPR should be available during such work.**
- F. A suitable fire extinguisher must be immediately available to fight electrical fires. Fire extinguishers for fighting electrical fires are designated with the letter “C”. Most of the fire extinguishers on campus are “ABC” units and are suitable for this purpose.
- G. Bare feet and moist skin (*even from sweat*) can cause electrical safety hazards.

NON-MEDICAL MACHINE TYPE-SPECIFIC REQUIREMENTS

I. X-RAY DIFFRACTION MACHINES

Open-beam x-ray diffraction machines can be hazardous due to the very high radiation exposure rates (up to several 100,000 R/min) at the x-ray port. Serious injury can occur even after brief exposures to such radiation. In addition, x-ray beams are often quite small and are difficult to locate and measure. Therefore, **extreme caution must be exercised when working with unenclosed x-ray diffraction equipment.**

Fortunately, for the most part, x-ray diffraction machines on campus are modern fully-enclosed units, and x-ray leakage is very low.

The following are requirements for safe use of x-ray diffraction machines:

- A. Machine operators need to follow sufficient written standard operating procedures when appropriate. Written operating procedures, including safety instructions, should be immediately available near the controls to the machine.
- B. Appropriate information must be entered into the use log each time the machine is operated.

- C. Potential radiation exposures must be characterized during a person's initial operation of the machine, and whenever significant modifications are made, using an appropriate survey meter (preferably, an ion chamber). Leakage from the side of the shutter/collimator area is occasionally found, and this radiation is sometimes directed at the machine operator. Wide-beam collimators are especially prone to scatter.
- D. **Appropriate radiation dosimetry must be worn, when appropriate.**
- E. Protective glass eyewear should be worn in rare cases (unenclosed machines). Ordinary glass lenses can attenuate very low-energy x-rays by a factor of 5-10.
- F. A warning light and other safety devices must be operational.
- G. Radiation shielding (lead glass or another appropriate material) must be installed and should be interlocked to prevent exposures to personnel in the event the shielding is removed. Beam stops, designed to block the path of the primary beam, must always be in place and must be located as close to the port as possible.
- H. Lead glass windows on alignment ports should always be checked to make sure that they are in place.
- I. All beam shutter mechanisms must be interlocked to prevent operation if the beam shutter is not properly closed.
- J. The radiation exposure rate must not exceed 0.5 mR/h at 5 cm from any surface of the machine.

II. ELECTRON MICROSCOPES AND X-RAY FLUORESCENCE UNITS

In most cases, electron microscopes and x-ray fluorescence units present very little risk of radiation exposure as long as they are not damaged or improperly modified, and as long as the manufacturer's instructions are followed. Specific requirements include:

- A. Make sure that the units are used in accordance with the manufacturer's instructions.
- B. Immediately cease operation and notify your supervisor or EH&S if the unit is damaged (has a cracked window, etc.), or if operating parameters are not within acceptable limits.
- C. For electron microscopes, the radiation exposure rate must not exceed 0.5 mR/h at 5 cm from the surface.
- D. In general, radiation survey meters are not required when operating these units, although taking periodic measurements is advisable. EH&S can perform these radiation surveys if desired.

III. CABINET RADIOGRAPHY UNITS

These units present minimal risk of significant exposure if their shielding is not modified, if interlocks and warning lights are operating properly, and if the manufacturer's instructions are followed. Some safety considerations related to the use of these units are:

- A. The radiation exposure rate must not exceed 0.5 mR/h at 5 cm from any surface of the unit.
- B. Prominent fail-safe indicators must be used to indicate when x-rays are being produced, and the entry door must be interlocked.
- C. The need for the operators of such machines to be provided with radiation dosimetry will be determined by EH&S on a case-by-case basis.

IV. MEDICAL X-RAY UNITS FOR NON-HUMAN USE

In order to minimize the radiation exposure of personnel operating medical x-ray machines, it is important to comply with the following requirements and safety practices:

- A. A warning light that indicates "***X-Ray On***" must be located near the entrance to the room containing the unit. A sign indicating "***Caution -- X-ray Beam***" (or an equivalent notification) needs to be posted on the x-ray tube housing, and it must be visible to the machine operator.
- B. Machine standard operating instructions, including safety instructions, should be available in a conspicuous location adjacent to the unit.
- C. All personnel working with or in the vicinity of the machine must be wearing radiation dosimetry.
- D. **Only personnel essential to the procedure being performed may be in the room during operation.** All personnel must wear a lead apron (with at least 0.25 mm lead equivalent), or must be situated behind a suitably shielded barrier. If it is necessary for someone's hands to be in the beam, then that person must wear leaded gloves as well. In-beam exposures must be as brief as possible.
- E. Lead apron and gloves must be inspected every 6 months to insure that they are free of defects (leaks, cracks, tears, etc.). These garments must be immediately replaced if found to be defective.
- F. The minimum beam energy/current and exposure time required for a procedure must be used and the beam must be collimated to the film size or area of interest.

- G. When animal studies are performed, no individuals should be regularly employed to hold or support the animals or to perform other in-beam manipulations during exposures. Other methods need to be found to immobilize/restrain the animals or stabilize in-beam items.

V. OTHER X-RAY MACHINES

Radiation-producing devices used in plasma physics research often emit very short pulses (microsecond to nanosecond), often with minutes to days (or more) between pulses. Personnel in the vicinity of these machines can normally stand behind shielding or be evacuated during operation of the machine. *Electrical equipment common to such machines can be very hazardous.*

The Physics Department operates several devices (electron beam generator, ion accelerator, etc.) that generate x-rays secondary to the intended processes. When these machines are to be used, it is essential that all personnel be evacuated to areas outside those in which significant radiation fields will be present. In such cases, safety procedures need to be posted to inform personnel of the risks involved with being improperly situated during machine pulsing. **All hazardous areas need to be locked and searched prior to operating the machine.**

Ion implant machines, some high-power lasers, cathode ray tubes, Van de Graaff accelerators, and projection television units can all produce x-rays. Contact EH&S if there is concern that such equipment is exposing people to hazardous levels of radiation.

EH&S MONITORING

I. BASIC PROCEDURES

- A. **All x-ray machines on campus are monitored by an EH&S Health Physicist at the time of the establishment of a new machine RUA, and during each subsequent RUA renewal meeting (conducted every 2-3 years).** If appropriate, machines may be monitored more frequently (such as annually) by EH&S. All areas in which personnel can conceivably be exposed to x-radiation are monitored with a calibrated survey meter. The monitoring is conducted during a worst-case scenario (phantom present, peak operating parameters {current and voltage used}). **In addition, interlocks, warning lights, use logs, etc., are also checked.**
- B. If a machine is substantially modified, repaired or relocated, the machine is monitored by an EH&S Health Physicist prior to being placed back into service.
- C. If there is any reason to suspect that a machine may be damaged and leaking radiation, the machine needs to be monitored by an EH&S Health Physicist immediately prior to being operated again in studies.

- D. **Each facility/laboratory which contains an x-ray machine is visited annually by an EH&S Radiation Safety staff member for the purpose of checking that the facility or laboratory is in compliance with all of the general and machine type-specific requirements listed above.** If requested, or if deemed necessary by EH&S staff, radiation monitoring can also be conducted during these visits.

II. INSPECTION FEATURES

Among the items to be reviewed during these visits are:

- A. Proper warning signs, labels, and lights.
- B. Emergency call list.
- C. Presence of an appropriate fire extinguisher.
- D. Availability of SOPs, when indicated, including safety issues.
- E. Training of machine operators.
- F. Use of radiation dosimetry, if required.
- G. Completion of a use log.
- H. Availability of an appropriate survey meter, if required.
- I. Other safety features such as lead aprons, etc.
- J. Safe performance of electrical service.

III. INVENTORY PROCEDURES

- A. An inventory of all x-ray machines on campus will be maintained and updated annually.
- B. EH&S will register all x-ray machines in use with the State of California Department of Health Services.