DEPARTMENT OF ENVIRONMENT, HEALTH & SAFETY

RADIATION SAFETY DIVISION

University of California, Los Angeles

RADIATION SAFETY GUIDANCE

# Radiation Producing Machines - Radiation Safety Training for X-ray Diffraction and Fluorescence Analysis Units

Training Document RSO-05 (April 2002)

## INTRODUCTION

UCLA policy requires that all employees receive radiation safety training, if they are routinely involved in the use of radioactive materials or radiation-producing machines. The type and degree of training depends on the anticipated hazards, and the individual's relevant work experience and/or previous training. Note that the term training here refers to familiarity and working knowledge with the safe use of radiation and accepted practices in radiation safety, and the equipment and procedures employed, as distinguished from education and research experience.

All machines at UCLA must be registered with the State of California Department of Health Services, in accordance with the appropriate parts of the California Code of Regulations, 17 CCR. The acquisition, installation and use of machines requires the authorization of the Radiation Safety Division and, for non-medical machines, the Radiation Safety Committee.

The Responsible User (RU) or principal investigator of the machine laboratory should submit an application for Machine Use (Form MACHAPP-5/95) to the Radiation Safety Division (RSD) to initiate the review and authorization process. The general procedures are presented in the Radiation Protection Manual, Chapter VII. Copies of the approved application are provided to the RU and his/her Department and, with any conditions or stipulations, comprise the authorization. One stipulation, that the RU should undertake or assure, is the training of any students, staff members or faculty is covered in his/her authorization.

The RSD has been developing information for use in training, with assistance from members of UCLA's Radiation Safety Committee. The present handout constitutes an elementary description of analytical x-ray equipment and of radiation safety, that may fulfill the minimum radiation safety training requirement for analytical x-ray equipment. Under the authorization, the RU should notify the RSD that some type of training has been provided. Whether or not this handout is used, each new faculty member and each staff employee and student should return the attached form to this office!

It is also recommended that the RU designate a person to handle day-to-day radiation safety problems, preventive maintenance inspections, and interactions with the RSD, and so advise this office.

**RADIATION SOURCES**

These analytical x-ray machines produce very intense, low-energy, primary beams of photons. The typical tube voltage is 20 to 50 kVp for diffraction units and 25 to 100 kVp for those used in fluorescence analysis. The upper limit of photon energy may exceed 50 keV. The intensity below about 5 keV is low and these x-rays are readily attenuated. The continuum can be assumed to extend from 5 to 100 keV with an intensity maximum in the range 20 to 30 keV, depending on the accelerating potential.

Superimposed on this continuum are the lines of the spectrum characteristic of the anode. These constitute less than half of the output in the case of tubes used for diffraction, and the energies range up to 17.5 keV.

In order to measure the dose from both the continuum and the characteristic spectrum, a survey meter should have energy absorption characteristics similar to air throughout the energy range 5 to 100 keV. The primary beam is hazardous, as the exposure rate near the beam port ranges up to $4 \times 10^5$ R/min. In such a beam, depending on the tube current, serious injury can occur from a very brief exposure. Experience has shown that about one serious exposure (to hands or fingers of the individual involved) occurs per 100 machines in a year in the United States. This accident frequency of up to $10^{-2}$ per year is very high, and requires continual reliance on physical barriers, operating procedures, adequate radiation monitoring, and knowledgeable users. A serious burn can result from a finger exposure to the x-ray beam of 1 second or less.

The term analytical x-ray machines includes all types of diffraction and spectrographic x-ray systems. In diffraction techniques, a serious personnel exposure problem may be encountered, because once a diffraction setup is calibrated, one should not change the operating parameters by turning off the machine for sample changes. Units should be equipped with a mechanism located at the output part of the x-ray tube housing so that the primary beam can be removed from the sample chamber without turning off the machine.

Moderate-to-serious radiation exposure, therefore, can result from the following sources[1]:

1. Primary beam.
2. Leakage or scatter of the primary beam through voids in ill-fitting or defective equipment.
3. Penetration of primary photons through the tube housing and nearby structures.
4. Secondary photons from samples or other irradiated material.
5. Diffracted photons.
6. X-rays from rectifiers in the high voltage supply.

The first four sources are the most hazardous, and sources #5 and 6 can be fairly easily shielded, though periodic shield integrity testing is important.

The usual source of serious radiation injury is from the insertion of the fingers into the primary beam, leakage of primary beam photons due to inadvertent or accidental removal of pieces of the system, or improper installation of accessories. Serious injury has resulted from 1-2 second exposures and reconstructed accidents indicate that the doses received were in the few thousand rads range.

**SUMMARY OF STANDARDS AND HAZARDS**

At UCLA, the common external irradiation possibilities involve the whole body, the hands and the skin (see Radiation Protection Manual, Chapter III). The common limits are given Table 2 and comprise the basic limits at UCLA.

[1] Lubenau, Joel O. et al, Analytical X-Ray Hazards: A Continuing Problem, Health Physics 16, 739-746 (1969).

TABLE 2

Dose Limits for Radiation Workers*

| Category of Exposure | Dose |
|---|---|
| Combined Whole Body | 5 rem/y |
| Skin of Whole Body | 50 rem/y |
| Extremities: Hands | 50 rem/y |
| Eyes | 15 rem/y |
| Radiation worker under 18 year of age | 10% of above limits |
| Pregnant Women** | 0.5 rem over gestation period |

*U.S. NRC (10 CFR 20) and California (17 CCR) standards.

**Prenatal radiation exposure should not exceed 50 mrem per month.

However, these limits are not easily applicable to radiation exposure situations involving these analytical machines. This is because radiation survey instruments and even the small personnel radiation monitoring devices can easily "miss" the narrow radiation beams produced by analytical x-ray equipment.

Notwithstanding the legal dose limits for occupational radiation exposure and the measurement difficulties, the Radiation Safety Program at UCLA is strongly committed to the maintenance of personnel exposures to ALARA levels, i.e., As Low As Reasonably Achievable. This program is effective only when experiments and other uses are carefully planned, machines are well shielded and workers are alert and knowledgeable. Unlike most other radiation sources at UCLA, the second control above (radiation survey instruments) does not necessarily apply; this means that uses must be especially carefully planned and workers must be extra alert.

**MACHINE USER AUTHORIZATION**

1. Registration of Machines: Radiation-producing machines must be registered with the State of California Department of Health Services within 30 days of their acquisition and re-registered every two years. Units which are removed from

service or transferred to users outside of UCLA jurisdiction must be reported to the State within 30 days. The RSD performs these registration functions for machines used on campus and at certain other specified locations. Information for registration and/or status changes is to be supplied by the Responsible User and must include machine type, date of receipt or transfer, and the name and address of the user or the recipient (in case of a machine transfer).

Newly developed radiation-producing machines or experimental devices may fall under regulatory control of the State of California, a federal regulatory agency, or UCLA. Any machine with an accelerating potential of 30 kilovolts or higher may be subject to control. Questions about them should be directed to the Radiation Safety Division before installation and use.

2. Shielding and Access Control: Shielding and access control for radiation-producing machines depends on the type of machine. Electron microscope and cabinet x-ray units have integral shielding and require no additional shielding. A door interlock is required for cabinet x-ray units so that x-ray generation is terminated when the cabinet is opened. X-ray diffraction units may require local, external shielding, as well as beam interlocks to control access during operation. Some medical x-ray equipment may require a facility with permanently installed shielding and automatic access control. Certain shielding requirements have been established by the State of California and other regulatory agencies. General technical guidance is contained in publications by the National Council on Radiation Protection and Measurements (NCRP Report 49) and the American National Standards Institute (ANSI N43.2, 1977).

   a. If permanent or built-in shielding is required (as is usually the case for medical-use machines) plans must be submitted to the Radiation Safety Division for review and approval prior to the installation of the shield or use of the facility.

   b. If a machine is changed or upgraded, work load has increased, or occupancy factors of adjacent areas have changed, the existing shielding of a room may not be adequate. In such cases, the RSD must be contacted, so the shielding can be re-evaluated.

c. Shielding for x-ray diffraction, x-ray fluorescence, and x-ray cabinet units shall be such that no radiation levels in excess of 0.6 millirem per hour are present in any work area adjacent to such a unit.

3. Training and Qualification of Personnel: The RU should assure that personnel authorized to operate radiation-producing machines are trained and qualified. General information on training is contained in Chapter XIII of the Radiation Protection Manual. The RU should assure that machine operators are cognizant of accepted radiation protection practices as an aid in controlling the radiation exposure of the operators as well as other personnel whose duties require their occasional presence near the machines during operation, e.g., technical, custodial and facility personnel.

4. Authorization for Machine Use: The use of radiation-producing machines is controlled by means of the APPLICATION FOR MACHINE USE. The Application is initiated by the RU and covers the machine use for specific projects. The authorization is valid for two years. The four-page APPLICATION FOR MACHINE USE with instructions is available from the Radiation Safety Division (see attached Application form). A summary of the training and experience of the Responsible User and laboratory supervisors in the use of radiation-producing machines should also be submitted, unless such information is already on file. Training and Experience forms are available from the RSD.

5. Tests and Inspections: After the authorization, periodic surveillance and tests are required to assure continued safety operation within the established parameters of the project.

**TERMINATION OF USE OF RADIATION-PRODUCING MACHINES**

It is important that the RSD be kept aware of plans for significant changes in any project involving radiation, so the RU should take the following actions when plans are made to terminate a machine project.

1. Notify the RSD that the project. i.e., the machine use, is to be terminated.
2. Notify the office of any plans to transfer the machine from UCLA, so that the Department of Health Services can be advised that machine registration is no longer needed.

3. Return all monitoring devices (film badges, hand or wrist monitoring devices) assigned to personnel listed on the machine authorization to the RadiationSafety Division.
4. Arrange with the Radiation Safety Division for de-registration, if the machine is to be transferred from UCLA, and the facility is to be assigned a different use. In may cases, detailed radiation measurements will be unnecessary. However, for positive ion machines and some electron accelerators, a decommissioning survey is necessary to assure that radioactive machine parts and room structures are disposed of safely.

**OPERATING AND SAFETY PROCEDURES**

**The shielding, safety equipment and safety procedures prescribed for x-ray diffraction equipment are applicable for only up to 75 kV peak x-rays.**

1. Important Points to Remember:
   a. The Applicant has a basic responsibility for providing a safe working environment by insuring that equipment is operationally safe and that users understand safety and operating procedures.
   b. The equipment operator is responsible for his own safety and the safety of others when using an analytical x-ray machine. ***Never bypass interlocks***!
   c. All unused x-ray ports must be closed.
   d. Prior to opening a shutter, the operator must check both the warning lights and the meters on the console. ***Never trust a warning light unless it is on***!
   e. An energized x-ray machine may be left unattended only when the room is locked.
   f. Exposure of any part of the body to the collimated beam for even a few seconds may result in damage to the exposed tissue.
   g. A person not knowledgeable about x-ray equipment should not attempt to make repairs or remedy malfunctions. Always consult the Applicant or his designated representative first. Repairs to the high voltage section must not be made unless the primary leads are disconnected from the

high voltage transformer, and a signed and dated notice posted near the x-ray "ON" switch. Turning off a circuit breaker is not considered a disconnect.

h. Bare feet are not permitted in the laboratory or around electrical equipment. Even slightly moist skin is an excellent electrical conductor, and contact with faulty ungrounded equipment may result in severe injury or death.

i. Do not attempt to align x-ray cameras without first consulting an experienced person. Alignment procedures require special training and knowledge to reduce safety hazards. ***Special care is required when one power supply is connected to more than one x-ray tube***.

2. Eye Protection: Plastic lenses provide hardly any protection, whereas safety glasses and corrective eyewear can reduce the dose to the eye considerably. The calculated linear absorption coefficient ( ) for 15 keV x-rays is approximately 12.85 $cm^{-1}$ for optical glass and 1.24 $cm^{-1}$ for plastic lenses. Thus 1mm thick glass lenses will attenuate these x-rays by nearly one order of magnitude while plastic lenses of the same thickness attenuate by only a small fraction.

3. Use of Fluorescence Screen: It is unsafe to inspect an x-ray beam with the use of a fluorescent screen without special precautionary measures. The screen must be expected to absorb only a small fraction of the incident radiation, and to emit fluorescent and other secondary radiations. A fluorescent screen should only be viewed through highly absorbing glass, preferably through 0.25-inch thick lead glass.

4. Effective Shielding: Care must be taken to insure that unused ports are blocked with material of sufficient density to attenuate the primary beam to acceptable levels. It is especially important to avoid cracks and small gaps in the shielding materials. Shielding material must be large enough to contain the entire primary beam.

5. Tube Status Indicators: There must be a visual indication located on or near tube head which indicates when x-rays are being produced. (e.g., an assembly consisting of two red bulbs, wired in parallel and labelled "X-RAYS ON"). If one of the lights is burned out, the operator must either replace it before leaving the room, or leave a note on the light assembly that the bulb is burned out. A single

bulb may be used only if it is wired so that failure of the bulb will cause x-ray production to stop. It is important to remember that an unlighted warning bulb does not necessarily mean that x-rays are not being produced. It is wise to always check the milliammeter.

6. Interlock Switches: Interlock switches are to be used to prevent inadvertent access to the beam. Removal of a camera or movable shielding should cause x-ray production to stop. Interlock switches must not be electrically or manually bypassed to permit uncontrolled x-ray production. Switches must be checked periodically to insure that they are functioning properly.
7. Radiation Monitoring: Several types of radiation monitoring are required:
   a. Personnel Monitoring - Each user of analytical x-ray equipment is required to wear a dosimeter. It must be recognized that the dosimeter indicates only the level of radiation dose intercepted by the dosimeter, or the level of scattered radiation in the room.
   b. Facility/Area Monitoring - At least one "Station Badge" is to be placed in each x-ray room. The badge is placed at a selected site to indicate the general level of radiation in the room. The badge must not be moved without the knowledge of the Responsible User.
   c. Radiation Survey - After each major change in experimental set up, the operator must visually inspect each x-ray port and survey the machine for scattered or leakage radiation. Exposure reading above background external to the primary or secondary shields must be reported to the Responsible User or his designee. Additionally, any questions or uncertainties about safety should be discussed with the Radiation Safety Division. It must be remembered that most radiation survey meters, both Geiger-Mueller and ionization chamber type, do not respond accurately at the x-ray energies used for analytical work. Correction factors of 3x to 10x are sometimes required. Radiation survey meters are useful to indicate the presence of unwanted radiation and to trace the origin of leaks.
8. Radiation Signs and Labels
   a. "CAUTION X-RAY" sign must be posted on the entrance to each laboratory containing analytical x-ray machines. Each sign will also contain the

names and telephone numbers of at least two individuals to be called in case of emergency.

b. "CAUTION-RADIATION - THIS EQUIPMENT PRODUCES RADIATION WHEN ENERGIZED" label must be placed near the energizing switch.

c. "CAUTION-HIGH-INTENSITY X-RAY BEAM" label will be placed in the area immediately adjacent to each tube head not provided with an interlock. The sign should be clearly visible to any person operating, aligning, or adjusting the unit, or handling or changing a sample.

d. Signs and labels are available from the Radiation Safety Division and bear the conventional "propeller" radiation symbol and caution colors of magenta and yellow.

**SAFETY INSPECTIONS**

1. New Installations: The Radiation Safety Division must be notified of each new x-ray installation before it is operational, and a radiation safety survey performed to insure that it meets State of California and UCLA safety requirements.
2. Existing Installations: Each machine is inspected periodically by Radiation Safety Division personnel. The periodic surveys for leakage radiation should be made by an authorized operator and records should be maintained.

**EMERGENCY PROCEDURES**

In the event of an accident or unusual incident involving an analytical x-ray machine, proceed as follows:

1. Turn off the machine and record all important parameters (kV-peak, mA, nature and duration of the possible exposure, and distance from the x-ray source)
2. Call the Responsible User for the machine.
3. Call the Radiation Safety Office (5-5689, 5-7147) or Police Department (ext. 911).

UNIVERSITY OF CALIFORNIA, LOS ANGELES
RADIATION SAFETY DIVISION
501 WESTWOOD PLAZA, 4TH FLOOR, Mailcode 160508

TO: Radiation Safety Division

I,_____, hereby certify that I have received and read a copy of "Radiation Safety Guidance for X-ray Diffraction and Fluorescence Analysis Machines."

As an individual using or having the responsibility for use of ionizing radiation, I understand that the various requirements and procedures as set forth in the UCLA Radiation Protection Manual are based on State of California regulations and official UCLA policy. I agree to adhere to these requirements as they pertain to my operations.

Signature: _____

Department: _____

Date: _____

To be returned to the Radiation Safety Division, 501 Westwood Plaza, 4th Floor with the Safety Qualification For Analytical X-Ray Machines form.
Fax # 5-7076...ATTN – Charles Myers

**QUIZ on SAFETY PROCEDURES**
**for the USE of X-RAY DIFFRACTION EQUIPMENT**

Name of prospective user: _____ Date: _____

*Please answer each question in the space provided below it. For most questions, only a few words are needed.*

1. What is the effect of x-rays on tissue?

2. Is it safe or permissible for any user to attempt to remedy a malfunction in the x-ray equipment? What steps should your take in case of a malfunction?

3. Is it safe to attempt to take a radiograph of your hand or and other part of your body with the x-rays used in diffraction studies? Yes No Why or why not?

4. What are the limitations of a film badge?

5. To what extent is an x-ray warning light useful?

6. Can you use a laboratory survey meter to make quantitative measurements of radiation levels from an analytical x-ray machine?

7. What is the difference in eye protection between glass lenses and plastic lenses with regard to x-ray attenuation?

8. Is it safe to visually inspect or align an x-ray beam with the use of a fluorescent screen?
   Yes No
   Why or why not? Name a precautionary measure that may be used.

9. Is it always safe to open an x-ray shutter if the warning light is off?

10. Does an x-ray burn reveal itself immediately after exposure?

11. Describe the only condition under which you would trust a safety light.

12. How are eyes affected by exposure to x-rays?

13. What should you do in case of a suspected over-exposure to x-rays?

14. How do you make reasonably sure that an x-ray tube is de-energized before you open the shutter?

15. What safety measures should be made before pushing the "X-RAY ON" button?

16. What is the safest precaution to take before attempting to remedy a malfunction in any component on the high voltage side (x-ray tube, high voltage cable, etc.)? Is it sufficient to turn off the circuit breaker? Please explain.

_____

_____

17. How do you monitor your working space to x-rays?

    a. For suspected stray radiation:

    _____

    _____

    b. For chronic (long-term) exposure:

    _____

    _____

18. What is the risk associated with being barefooted in a laboratory with electrical equipment?

    _____

    _____

19. Why should you never try to align an x-ray camera without first consulting an authorized person experienced in the procedure?

    _____

    _____

20. Before transferring possession, allowing new users, disposing of, performing maintenance on, or acquiring a new x-ray diffraction machine, does the Radiation Safety Office need to be notified?

    _____

    _____

21. What is the maximum radiation dose permitted?

    _____

    _____

    a. Whole body: _____

    b. Extremities: _____

c. Eyes: _____

**SAFETY QUALIFICATION**
***for***
**ANALYTICAL X-RAY MACHINES**

**(X-RAY DIFFRACTION AND FLUORESCENCE ANALYSIS UNITS)**

Name (Print) Last, First, MI | Department / Division | Extension

Date of Birth Male G Female G | Responsible User

Social Security / Passport Number

Employee / Student ID | Effective Date of Hire

Have you previously worked with ionizing radiation outside of UCLA? Yes G No G

**********

Please list any courses you have taken pertaining to the safe use of x-ray machines.

Have you read RSO-05 and completed the back page of certification? Yes G No G

Worker Signature | Date

Radiation Safety Officer / Health Physicist

**FOR RADIATION SAFETY OFFICE USE ONLY**

**AUTHORIZATION NUMBER** | **SERIES CODE** | **PARTICIPANT NUMBER**

**SPARE NUMBER ISSUED** | **COMPUTER** | **ICN**

**DOSIMETER FOR THE NEXT WEAR PERIOD: SPARE G PERMANENT G**

**COMMENTS**