Radiation Producing Machines
Radiation Safety Training for X-ray Diffraction Units

RADIATION SAFETY GUIDE

IMAGING AND MICROSCOPY FACILITY
University of California, Merced

Training Document (February 2010)

INTRODUCTION

UCM 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 UCM are 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 IMF has been developing information for use in training, with assistance from members of UCM's Environmental Health and Safety department. The present handout constitutes an elementary description of analytical x-ray equipment and of radiation safety, which may fulfill the minimum radiation safety training requirement for analytical x-ray equipment. Each new faculty member, staff employee and student should return the attached form to the Imaging and Microscopy Facility before continuing to the hands on portion of the training.

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. 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 x 105 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 machine includes all types of diffraction and spectrographic x-ray systems. In diffraction techniques, 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 UCM, the common external irradiation possibilities involve the whole body, the hands and the skin. The common limits are given Table 2 and comprise the basic limits at UCM.

TABLE2 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 UCM 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 UCM, 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.

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

XRD 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. Do not attempt to make repairs or remedy malfunctions. Always consult the IMF. 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:** Eye Protection is not required for XRD, safety glasses and corrective eyewear can reduce the dose to the eye considerably but plastic lenses provide hardly any protection,. 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 EH&S and IMF Personal.

    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 IMF or EH&S. Additionally, any questions or uncertainties about safety should be discussed with EH&S. 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.

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

New Installations: The EH&S 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 UCM safety requirements.

Existing Installations: Each machine is inspected periodically by EH&S personnel. The periodic surveys for leakage radiation are 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 IMF for the machine 658-3020.

3. Call the EH&S (228-4234) or Police Department (ext. 911).

ADDITIONAL INFORMATION

http://ehs.ucmerced.edu/research-safety/radiation-safety
http://imf.ucmerced.edu

UNIVERSITY OF CALIFORNIA, MERCED
RADIATION SAFETY DIVISION

TO: Radiation Safety Division
I,__ _____, hereby certify that I have received and read a copy of "Radiation Safety Guide for X-ray Diffraction."
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 UCM Radiation Protection Manual are based on State of California regulations and official UCM policy. I agree to adhere to these requirements as they pertain to my operations.

Signature: _____

Department: _____

Date: _____

To be returned to the EH&S Radiation Safety Division,

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 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: