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 2005)

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 Authorized User (AU) or principal investigator of the machine laboratory should submit an application for Machine Use to the Radiation Safety Division (RSD) to initiate the review and authorization process. The general procedures are presented in the Radiation Safety Journal Chapter 6. Copies of the approved application are provided to the AU and his/her Department and, with any conditions or stipulations, comprise the authorization. One stipulation, that the AU should 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 AU should notify the RSD that some type of training has been provided.

It is also recommended that the AU 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 4×10^5 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 rad range.

SUMMARY OF STANDARDS AND HAZARDS

At UCLA, the common external irradiation possibilities involve the whole body and the hands and the skin. 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 1

TABLE 1

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. The reason for this is 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 that are removed from service or transferred or disposed of 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. Questions regarding any X-ray equipment should be directed to the UCLA RSD 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 N43.2-2001). Guidance regarding shielding of X-ray equipment can be found in the Radiation Safety Journal, Chapter 6.
3. Training and Qualification of Personnel: The AU should assure that personnel authorized to operate radiation-producing machines are trained and qualified. General information on training is contained in Chapter 6 of the Radiation Safety Journal. The AU 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 AU and covers the machine use for specific projects. The APPLICATION FOR MACHINE USE is available from the Radiation Safety Division. Initial radiation safety training is required of all individuals who operate X-ray equipment at UCLA.

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 AU should take the following actions when plans are made to terminate a machine project.

1. Notify the RSD that the project, along with machine use, is to be terminated.
2. Notify the office of any plans to transfer or dispose of the machine from UCLA.
3. Return all dosimeters (whole body, extremity, area, environmental, etc.)

OPERATING AND SAFETY PROCEDURES

1. Important Points to Remember:
   a. The AU has the 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 should be permanently 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 is forbidden….this will result in damage to the exposed tissue.
   g. Only qualified individuals are allowed to repair X-ray equipment. Repair of X-ray equipment must be performed by a manufacturer's service representative, properly trained AU or lab supervisor, etc.
   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 very little 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 the tube head that indicates when x-rays are being produced. (e.g., an assembly consisting of two red bulbs, wired in parallel and labeled "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. For safety reasons, check the MA meter for a positive indication that there is tube current present.
6. Interlock Switches: Interlock switches are 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 – Whole body dosimeters are used to measure radiation dose of the whole body (head, neck, trunk, arms above the elbow, legs above

the knees). Extremity dosimeters are used to measure the dose (usually) to the hands.

b. Environmental/Area Monitoring – Environmental dosimeters are used to measure radiation levels, usually outdoors and for members of the general population, and are shielded for protection against environmental factors. Area dosimeters are used to measure radiation levels, usually in work areas where radiation sources are utilized. Both types of dosimeters can be used to assure that radiation levels are within regulatory limits.

c. Radiation Survey – A radiation survey is performed to determined radiation levels is specific areas and assists the health physicist with determining safety of occupationally exposed staff, if engineering imposed X-ray machine controls are effective, and in positing areas such as radiation area, high radiation area, etc.

8. Radiation Signs and Labels

a. "CAUTION X-RAY" sign should be posted on the entrance to each laboratory containing analytical x-ray machines.

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 may 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.

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: The safety inspection schedule for existing X-ray equipment is contained in the Radiation Safety Journal.

EMERGENCY PROCEDURES

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

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

SAFETY QUALIFICATION
for
ANALYTICAL X-RAY MACHINES

(X-RAY DIFFRACTION AND FLUORESCENCE ANALYSIS UNITS)

Name (Print) Last, First, MI

Department / Division

Date of Birth

Responsible User

Social Security / Passport Number

Employee # / Student ID

Phone Extension

Male☐ Female☐

****

Worker Signature

Date

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 ☐ **PERMANENT** ☐

COMMENTS