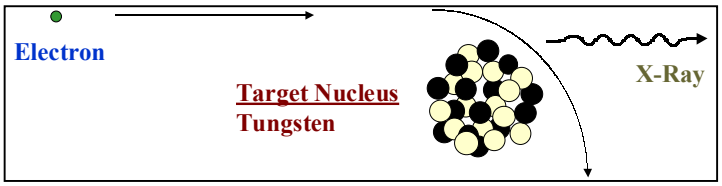
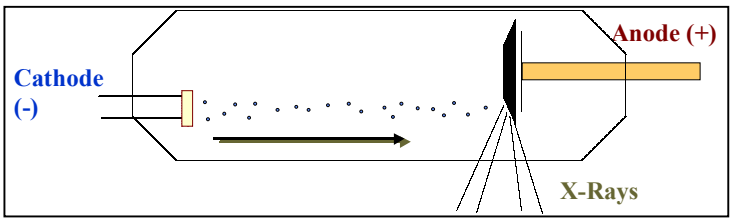
CHAPTER 8 - X-RAYS

Over a century ago in 1895, Roentgen discovered the first example of ionizing radiation, x-rays. The key to Roentgen's discovery was a device called a Crooke's tube. A Cooke's tube is a glass envelope under high vacuum, with a wire element at one end forming the cathode, and a heavy copper target at the other end forming the anode. When a high voltage was applied to the electrodes, electrons formed at the cathode are pulled toward the anode and strike the copper with very high energy. Roentgen discovered that very penetrating radiation was produced from the anode, which he called x-rays.



Whenever electrons of high energy strike a heavy metal target, like tungsten or copper x-rays are produced. When electrons hit this material, some of the electrons will approach the nucleus of the metal atoms where they are deflected because of their opposite charges (electrons are negative and the nucleus is positive, so the electrons are attracted to the nucleus). This deflection causes the energy of the electron to decrease, and this decrease in energy then results in forming an x-ray.



X-ray machines use the same principle as the Crooke's Tube to produce x-rays. The most common x-ray machines use tungsten as their cathode, and have very precise electronics so the amount and energy of the x-ray produced is optimum for their intended purpose.

Analytical X-ray Units

Radiation exposures from x-ray diffraction or fluorescence units can be extremely hazardous. Dose rates in the primary beam can exceed 100,000R/minute. Any part of the body momentarily placed in the beam would receive enough radiation to cause serious radiation burns. X-ray diffraction machines must be operated in accordance with the following basic requirements.

Radiation exposures to individuals must be so controlled that the shallow dose equivalent, eye dose equivalent, and deep dose equivalent limits are not

exceeded. In particular, personnel must not expose any part of their bodies to the primary beam.

Analytical x-ray equipment means x-ray equipment used for x-ray diffraction, fluorescence analysis or spectroscopy.

Analytical x-ray system means a group of local and remote components utilizing x-rays to determine the elemental composition or to examine the microstructure of materials. Local components include those that are struck by x-rays (radiation source housings, port and shutter assemblies, collimators, sample holders, cameras, goniometers, detectors and shielding). Remote components include power supplies, transformers, amplifiers, readout devices and control panels.

Fail-safe characteristics mean a design feature that causes beam port shutters to close, or otherwise prevent emergence of the primary beam, upon failure of a safety or warning device.

Normal operating procedures mean operating procedures for conditions suitable for analytical purposes with shielding and barriers in place. These do not include maintenance but do include routine alignment procedures. Routine and emergency radiation safety considerations are part of these procedures.

Open-beam configuration means an analytical x-ray system in which an individual could accidentally place some part of his/her body in the primary beam during normal operation.

Primary beam means ionizing radiation that passes through an aperture of the source housing by a direct path from the x-ray tube located in the radiation source housing.

A safety device is a device that prevents the entry of any portion of an individual's body into the primary x-ray beam path or which causes the beam to be shut off upon entry into its path.

An individual will be permitted to operate an analytical x-ray unit if he/she has received radiation safety training, demonstrated competence in the safe operation of the machine and radiation survey instruments, and received the approval of the Radiation Safety Committee.

The operator is responsible for all operations including radiation safety. In particular, he/she should keep radiation exposures as low as practical, observe safety precautions and procedures as they apply to each machine operated, and notify the Radiation Safety Office of any known or suspected abnormal radiation exposures.

Each operator must receive instruction and demonstrate competence in:

1. Identification of radiation hazards associated with the use of the equipment;
2. Significance of the various radiation warning and safety devices incorporated into the equipment, or the reasons they have not been installed on certain pieces of equipment and the extra precautions required in such cases;
3. Proper operating procedures for the equipment;
4. Symptoms of an acute localized exposure; and
5. Proper procedures for reporting an actual or suspected exposure.

The Authorized User shall provide the necessary instruction and/or ensure that the instruction has been given to each operator under his/her supervision.

Written operating procedures must be readily available to the operator. The operator should be in immediate attendance at all times when the machine is in operation. When not in operation, the machine must be secured in such a way as to be inoperable to unauthorized persons.

Only properly trained personnel are permitted to install, repair, or make other than routine modifications to the X-ray generating apparatus and tube housing.

Procedures and apparatus utilized in beam alignment should be designed to minimize radiation exposure to the operator. Particular attention should be given to viewing devices to assure that lenses and other transparent components attenuate the radiation beam to minimal levels. When alignment involves working near the open primary X-ray beam, the beam current should be reduced in order to lower exposure rates.

If a fluorescent alignment tool is used, dimming the room light will permit a significant reduction in beam current. The fluorescent alignment tool should be long enough to permit the operator's hand to be kept at a safe distance from the beam. The operator should be familiar with the manufacturer's recommended alignment procedures, and copies of these should be available for reference.

If it is necessary to alter any safety device, (bypass interlocks or remove shielding):

- The Radiation Safety Office must authorize the actions in advance.
- The actions must be performed under the supervision of the registered user.
- The actions must be terminated as soon as possible and safety devices reinstalled.

Any attempt to bypass or alter safety devices should only be undertaken as the last resort to proceed with the research. During the bypass period, a readily discernible sign bearing the words "Safety Device Inoperable" shall be placed on the radiation source housing.

X-ray diffraction machine operators will wear monitoring devices (a film badge, a wrist badge and/or a TLD finger ring) when:

- They are operating; or

- They are near an operating machine.

The film badge should be worn on the torso and the wrist badge or finger ring should be worn on the hand most likely to be exposed.

Users must monitor routinely for stray or scattered radiation in the immediate vicinity of the X-ray machine with an appropriate detector. Leakage radiation from the tube housing must be less than 2 millirem per hour at 5 cm and leakage from the generator cabinet must be less than 0.25 millirem per hour at 5 cm. All safety devices (interlocks, shields, shutters, shields, cabinets, etc.) must also be checked. In addition to routine surveys, a survey must be made after each repair or modification of the apparatus. If any modification is made to the machine, Radiation Safety Officer must be notified. Radiation levels and results of safety device checks must be recorded in the Radiation Survey Log.

The Radiation Safety Office also conducts annual surveys or surveys upon request. Surveys by Radiation Safety Office are supplemental to the required surveys performed by the users.

The high voltage power supply of X-ray machines can be particularly hazardous. Personnel must never tamper with high voltage equipment. Only properly trained personnel are permitted to install, repair, or modify high voltage equipment.

The equipment should incorporate engineered safety features of a fail-safe design to prevent possible exposures:

- For open beam configurations, a safety device to prevent entry of hands and other body parts into the primary beam, or that will shut off the X-rays if the beam path is entered must be provided.
- Unused ports must be secured so that the shutters cannot be opened unless a collimator or coupling is connected.
- Safety interlocks should be employed on tube head ports or shielding.
- The coupling between the X-ray tube and the collimator of the diffractometer, camera, or other accessory must prevent stray X-rays from escaping the coupling.

Visual warnings must be used to indicate the potential for radiation exposure on all devices of open beam configuration:

- Easily visible flashing lights or equally conspicuous signals located near the tube housing that indicate when the X-ray tube is on or off must be provided if the primary beam is controlled in this manner.
- If shutters control the beam, a readily discernible indication of shutter status (open or closed) must be located near each port on the radiation source housing.
- The warning devices should be of a fail-safe design and must be labeled so that their purpose is easily identified.

- A red warning light with the notation "X-RAY ON" or the equivalent, should be located on the control panel, and should light only when the X-ray tube is activated.
- A sign or label bearing the words "CAUTION - RADIATION, THIS EQUIPMENT PRODUCES X-RADIATION WHEN ENERGIZED" or words having similar intent, must be placed near any switch that energizes an X-ray tube.
- A label bearing the radiation symbol and the words "CAUTION - HIGH INTENSITY X-RAY BEAM" must be placed on or adjacent to each X-ray tube housing. It should be located so as to be clearly visible to any person who may be working near the primary radiation beam.
- Each area or room containing analytical X-ray equipment must be posted with a sign bearing the radiation symbol and the words "CAUTION - X-RAY EQUIPMENT".

The user should test all safety devices (e.g., interlocks, shields, shutters, warning lights, etc.) quarterly to insure their proper operation. The tests should be recorded in the Radiation Survey Log.

Diagnostic X-ray

Obtaining optimum diagnostic information from X-ray examinations goes hand in hand with minimizing exposure to both patient and radiological personnel. Doses to X-ray machine operators typically are among the lowest of all radiation workers. The radiation health practices responsible for keeping worker doses low should also help keep doses to patients ALARA. Although technical advances have resulted in systematic dose reductions to patients, poorly operating equipment, a lack of attention to detail, and inadequate operator training can negate these gains.

Annual in-service training in radiation safety is required for all operators of diagnostic X-ray equipment. Licensed practitioners are exempt from the training requirement. Each department should keep a record of all training that operators receive, including the date and content. Operators should sign the training record. The training should include the following:

- Operating and emergency procedures for the machines.
- Use of employee and patient protective devices, including lead aprons, thyroid shields, lead screens, and structural shielding.
- Procedures to minimize patient and employee exposure.
- Use of personnel dosimeters (film badges).
- Film processing procedures.

Each operator is required to use personnel dosimeters (film and/or ring badges) unless control panels are permanently mounted behind fixed barriers and area-monitoring dosimeters are in place. All operators of diagnostic X-ray equipment

are radiation workers and must register with the Radiation Safety Office. In most cases operators wear film badge dosimeters. Operators should:

- Always wear assigned dosimeters during examinations.
- Store them in a safe place away from sources of radiation.
- Never wear another person's dosimeter.

If a lead apron is worn and two dosimeters are used, wear one dosimeter at the collar above the apron and the other dosimeter on the torso underneath the apron. If only one dosimeter is used, wear it exposed at the outside of the apron collar.

The Radiation Safety Office maintains personnel monitoring results as a permanent, legal record of each individual's occupational dose.

Regulations require providing each X-ray machine operator with a written policy statement outlining the institution's radiation safety practices and policies.

X-ray machines shall emit an audible signal when the exposure has ended, and the exposure shall cause automatic resetting of the timer to the initial setting or zero.

A technique chart should be posted at the control panel or exposure switch. The chart should specify parameters for routine exams including the following:

- The patient's anatomical size relative to technique factors used (centimeter measurement of part to be X-rayed, or area of interest, such as incisor, molar, or bitewing).
- The type (film speed) and size of film or film/screen combination.
- Distance between the X-ray tube and the film.
- The appropriate exposure detectors and density setting for each radiographic exam for automatic exposure control (AEC) systems.

The objective of minimizing patient dose while obtaining maximum diagnostic information also is met effectively by maintaining a program that stresses consistency. High-quality radiographs are consistent with reduced doses and fewer retakes. Diagnostic equipment operators should be familiar with daily, weekly, or other periodic quality-assurance procedures. These procedures include routine exposure of control X-ray film, measurement of developer temperature, checking chemical activity of the developer and fixer, and routine cleaning and mechanical inspection.

Automatic film processing shall be monitored to assure the following:

- Temperature of the processing chemicals is appropriate for the type of film being processed at the film transport speed selected. Consult chemical manufacturer recommendations.

- The chemicals used and replenishing rates are appropriate for the film transport speed selected.
- Safelight illumination is adequate for the film speed and darkroom operating procedures used. Consult film manufacturer recommendations.

Manual film processing shall be monitored to assure the following:
- Use of a dedicated darkroom timer with adjustable preset function.
- Use of a dedicated darkroom thermometer.
- Use of a film-processing guide indicating the processing time for various solution temperatures (as recommended by the processing chemical manufacturer).
- Replenishment of processing chemicals at an interval no less than that recommended by the chemical manufacturer.

Each department should maintain records of maintenance, repairs, and modifications performed on each X-ray machine, including the name of the individual who performed the service and the date performed.

The Radiation Safety Office can conduct or arrange for annual inspection of diagnostic equipment for proper operation and compliance with state regulations.

We must post the Rhode Island Department of Health form entitled "Notice to Employees" in a sufficient number of places so operators can see them at any work location. The Radiation Safety Office can provide the form. The Notice to Employees describes where operators may see the following documents:
- Radiological Control regulations.
- The University's Certificate of Registration.
- Any notice of violations and related correspondence.

Electron Microscopes

X-rays are produced by electron microscopes when the primary electron beam or back-scattered electrons strike metal parts of the microscope. The shielding provided by the metal casing of the microscope and leaded glass on the viewing ports is usually adequate to ensure that radiation exposure to personnel is kept to a minimum. However, there are some general principles of radiation safety that you should know about when working with or around electron microscopes.

An electron microscope is exempt from registration if x-ray production is incidental to its use as an imaging device and its dose rate averaged over an area of 10 square centimeters does not exceed 0.5 mrem (5 μSv) per hour at 5 cm from any accessible surface of the unit.

Users shall notify the Radiation Safety Office of each newly acquired electron microscope. The Radiation Safety Office will complete an annual assessment of the dose rates to determine the need for registering the electron microscope.

To complete the assessment, the Radiation Safety Office will provide a dosimeter. The user will place the film badge or TLD dosimeter on or immediately adjacent to the column and exchange it at specified intervals (usually monthly). If the total dose for the calendar year is less than 500 millirems, the electron microscope need not be registered.

New users should be trained in the potential radiation hazards of electron microscopes.

Modern electron microscopes are made to electronic product radiation standards and generally have adequate shielding. Users should ensure that individual units have been manufactured and assembled in accordance with applicable US Food and Drug Administration regulations. Units manufactured before the late 1960's may have significant x-ray leakage. Units manufactured before 1956 may be missing leaded glass windows and shielded intermediate viewing ports

A radiation survey for x-ray leakage should be performed:
- at time of installation;
- any time the microscope is moved, modified, or attachments/accessories are added/removed;
- when any part of the metal casing or viewing windows are removed; and/or
- if the current level is set higher than normal

Radiation surveys should be carried out under "worst case" conditions:
- highest acceleration voltage;
- highest beam current;
- beam at crossover on specimen;
- low magnification; and
- all apertures removed.

A scintillation counter can be used to detect x-ray leakage. However, the energy dependent response of a scintillation counter makes it inappropriate for measuring x-ray leakage. When measurement of x-ray leakage is desired, an appropriately calibrated air ionization chamber should be used.

Move the instrument slowly allowing time for it to respond. During the survey, pay particular attention to the following parts of the microscope:
- gun;
- camera / viewing chamber;
- specimen changer;
- junctions between column sections; and
- attachment joints

The Radiation Safety Office can aid in the selection of appropriate radiation survey equipment or perform radiation surveys of electron microscopes on request.