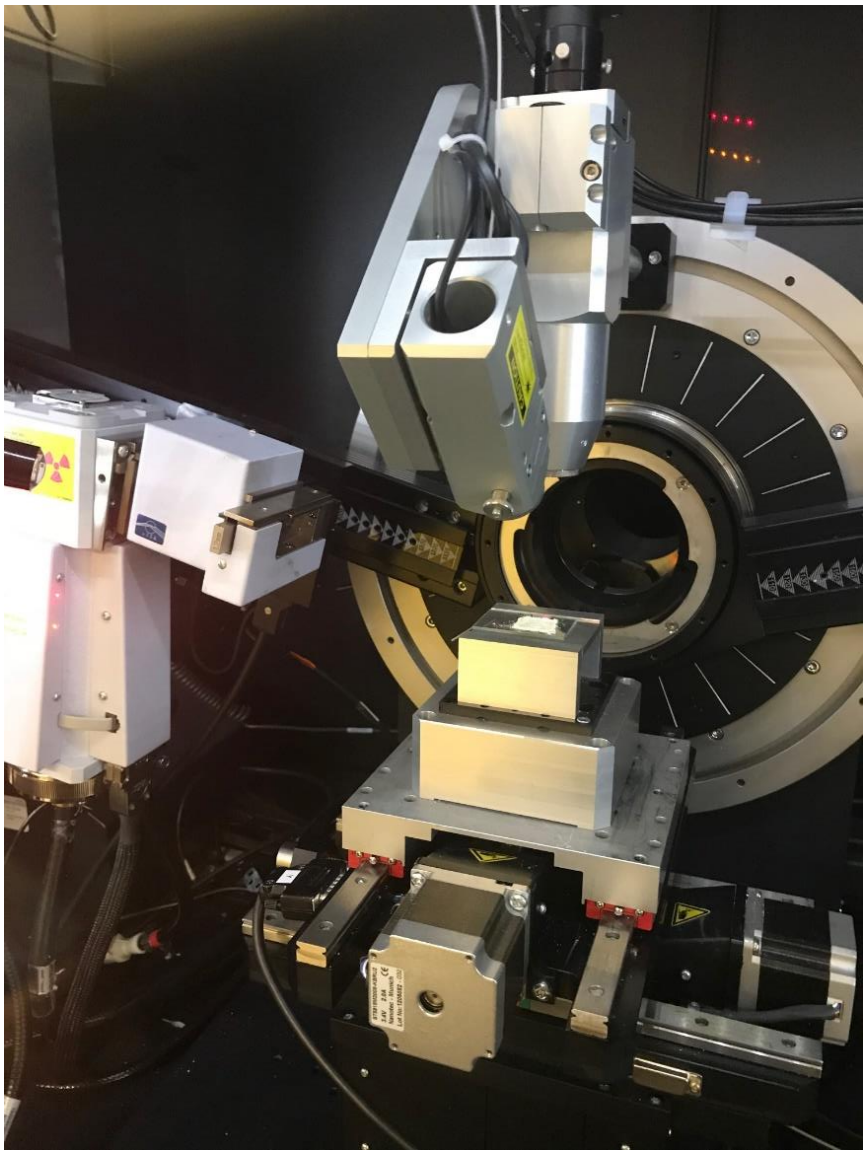

Revision Date
9-16-2020

THE SAFE USE OF ANALYTICAL X-RAY PRODUCING EQUIPMENT

University of Delaware
Department of Environmental Health and Safety
www.udel.edu/ehs
302-831-8475 work hours/ 831-2222 after hours

The most current version of this manual can be found at the EHS web site- www.udel.edu/ehs

Contents

Administration of the UD Radiation Safety Program

The State of Delaware Office of Radiation Control (ORC) regulates the use of all x-ray producing devices in Delaware. The University of Delaware (UD) must register all of its x-ray producing devices with the ORC and provide their locations. X-ray Registrations must be renewed every three years. As new devices are acquired and old devices are disposed, UD must submit amendment requests to the ORC. Renewing and amending the X-ray Registrations with the ORC is a responsibility of the UD Radiation Safety Officer. The X-ray Registration for each x-ray facility is posted where x-ray operators can examine it.

The UD Vice President for Research, Scholarship and Innovation (VP) is the UD adminstrator responsible for the safe and compliant use of x-ray producing equipment. The VP has appointed a Radiation Safety Officer (RSO) and the members of a UD Radiation Safety Committee (RSC) to develop, update, and manage a radiation safety program to ensure safe and compliant use. All the activities of the RSO and RSC are directly reported to the VP.

Faculty and others that wish to supervise a project involving the use of x-ray producing devices must submit details of the project to the RSC for review. The RSC determines what procedures must be followed by UD staff to ensure compliance with the State of Delaware X-ray Regulations. The RSC is composed of 1) members with technical knowledge in the safe use of x-ray equipment and radioactive materials, 2) the Radiation Safety Officer, and 3) members that represent the administration.

The Radiation Safety Officer (RSO) is the person who manages the radiation safety program as defined in the State of Delaware X-ray Regulations and as directed by the RSC. The RSO must have adequate credentials to protect x-ray equipment operators and enforce compliance with safety requirements. The RSO is empowered with the authority to require the immediate termination of any unsafe activity. The Radiation Safety Technician assists the RSO with management of the program.

The State of Delaware Office of Radiation Control conducts on-site inspections of UD's use of x-ray producing equipment at approximately four year intervals. An inspector will typically spend two to three days on campus confirming the number and location of x-ray equipment, testing the safety features of the equipment, conducting x-ray survey measurements and interviewing operators of x-ray devices. Citations and fines can be issued for failure to comply with State of Delaware requirements. Operators are obligated to cooperate with inspectors when they visit.

The presence of a positive safety culture is an important component of the UD radiation safety program. UD leadership has committed resources and other support to the radiation safety program. X-ray device operators are encouraged to share ideas for improvement. Radiation safety staff work with operators in a collegial manner when deficiencies are identified.

Obtaining Authorization to Possess and Use X-ray Producing Equipment

Faculty members and others that wish to supervise a project involving the use of x-ray producing equipment must first obtain authorization from the Radiation Safety Committee. Below are the steps to follow.

1. The applicant meets with the Radiation Safety Officer (RSO) to complete an *Application For Analytical X-Ray Equipment Utilization* (RSO phone 302-831-8475) The application form can be found at the UD Environmental Health and Safety (EHS) website in the *Forms* section (www.udel.edu/ehs). The application requires that the applicant identifies all those that will operate x-ray equipment, the room(s) where equipment is located, make/model of each x-ray device including maximum kV and mA, and any portable radiation detecting equipment that will be used to check for x-ray leakage from the equipment. The applicant includes with the application a completed *Statement of Training and Experience* form (also found on the EHS web site) and a written operating procedure or Operator's Manual for each requested device.

2. At this meeting, the RSO will indoctrinate the applicant in the workings of the UD radiation safety program including the responsibilites of an X-ray Supervisor.

3. The applicant provides the RSO with a tour of the proposed x-ray equipment use location(s).

4. The RSO reviews the application and attachments for completeness and forwards the documents on to a member of the Radiation Safety Committee (RSC). The RSC member may contact the applicant to schedule a meeting to review the application and may suggest that changes be made in the proposed use of the equipment.

5. Once the RSC member completes the review, he/she informs the RSO that *conditional approval* should be granted. The RSO will inform the applicant and schedule a time to meet to-

   - Post the room entrance with a *Caution X-rays* warning sign,
   - Post State-required documents inside room,
   - Ensure there is a system (such as a logbook) to document dates of use, operator name, etc.
   - Confirm that the x-ray equipment has the required manufacturer warning labels attached,
   - Conduct the first annual x-ray safety survey which includes testing that the various x-ray safety systems of the device(s) are operating as designed,
   - Conduct an x-ray leakage test to confirm x-rays present outside the device(s), if any, are within limits defined in the State x-ray regulations.

   Properly trained operators may then proceed to use the equipment. The length of time it may take the applicant to get to this point is typically two weeks from the time the applicant provides the RSO with a complete application.

6. *Final approval* of the application is discussed and decided by the entire Radiation Safety Committee at its next quarterly committee meeting. The RSO will inform the applicant of the Committee's decision and, if the decision is favorable, an *X-Ray Equipment Utilization Permit* is issued.

Should amendments to the Permit be required (e.g. to acquire additional x-ray devices, dispose of devices, move equipment to a different work location, etc.), the X-ray Supervisor submits an amendment request to the RSO who will then assist with the permit amendment process.

All workers that will operate x-ray producing equipment under an X-ray Permit must first complete x-ray safety training (see manual section *Authorization to Operate X-ray Producing Equipment*).

Regulatory Requirements for Using Analytical Xray Producing Equipment

There are federal and state regulations on the manufacturing and use of analytical x-ray producing equipment to protect operators and others that may work near such equipment. The UD Radiation Safety Officer conducts testing and on-site surveys to ensure that UD x-ray producing equipment and work practices comply.

- Each area or room containing an x-ray producing device where an individual may receive 2 millirem in any one hour shall be conspicuously posted with a sign bearing the radiation symbol and the words "CAUTION - X-RAY EQUIPMENT, or words having a similar intent.
- Each x-ray registrant shall conspicuously post the certificate of registration and Agency Form X- Notice to Workers.
- The x-ray system shall have a key-actuated control to insure that x-ray generation is not possible with the key removed.
- The x-ray system shall have a control to initiate and terminate the generation of x-rays other than by functioning of a safety interlock or the main power control.
- There shall be permanently affixed or inscribed on the x-ray system at the location of any controls which can be used to initiate x-ray generation, a clearly legible and visible label bearing the statement: Caution: X-Rays Produced When Energized.
- Manufacturers shall provide for purchasers of x-ray systems, manuals and instructions which shall include technical and safety information.
- Each door of a x-ray system shall have a minimum of two safety interlocks. One, but not both of the required interlocks shall be such that door opening results in physical disconnection of the energy supply circuit to the high-voltage generator, and such disconnection shall not be dependent upon any moving part other than the door.
- The x-ray system shall have an easily visible warning device light labeled with the words "X-RAY ON," or words having a similar intent, which is located a) near any switch that energizes an x-ray tube or b) in a conspicuous location near the radiation source housing and radiation beam and visible from all instrument access areas. The light shall be illuminated only when the tube is energized and shall be of a fail-safe design.
- Radiation emitted from the x-ray system shall not exceed an exposure of 0.5 milliroentgen in one hour at any point five centimeters outside the external surface.
- The x-ray tube housing of an x-ray system shall be so constructed that, with all shutters closed, the leakage radiation measured at a distance of 5 centimeters from the x-ray tube housing surface does not exceed 2.5 milliRem (mRem) per hour.
- The radiation dose to individual members of the public from the registered x-ray operation shall not exceed 100 millirem in a year.
- Tests of all safety devices, such as interlocks, shutters, warning lights, and required emergency shut-off switches shall be conducted at intervals not to exceed 12 months on all operable x-ray systems.
- No individual shall be permitted to operate or maintain x-ray devices without appropriate instruction and training. Operators shall have easy access to written operating procedures.
- The registrant's senior management shall designate an individual responsible for radiation safety, or a Radiation Safety Officer (RSO).

If a device is distributed as an x-ray component (such as, the x-ray source on an x-ray photoelectron spectrometer), not all the above requirements may apply.

Authorization to Operate X-ray Producing Equipment

Obtaining authorization to use x-ray equipment is a three step process- 1) obtain permission from the X-ray Permit Supervisor, 2) complete x-ray safety training, and 3) obtain instruction in the correct and safe use of the x-ray device.

STEP 1
X-ray equipment may only be operated by a worker under the authorization of a *X-Ray Equipment Utilization Permit* held by a X-ray Permit Supervisor. Workers must contact the supervisor and obtain permisson to use the x-ray device.

STEP 2
X-ray safety training requirements are dictated by the x-ray device that a worker plans to operate. The chart below describes the training requirements. The Radiation Safety Officer should be contacted if it is not evident what training a worker needs to complete. Workers who have completed x-ray safety training at another university or work location are not exempt from completing UD training.

Any XRD X-ray Diffraction Device (various locations on campus) X-ray Digital Imaging Device (Dr. Arce Lab)	Complete online X-ray Safety Training at www.delaware.bioraft.com.* Then contact the Radiation Safety Officer to schedule a brief meeting to obtain a radiation dosimeter (badge) and instruction in how to survey for x-ray leakage.
ANY X-ray Device that is located in the Advanced Material Characterization Lab AMCL (Room 151 Harker ISE Lab)	Complete online X-ray Safety Training at www.delaware.bioraft.com.* Then contact the Radiation Safety Officer to schedule a brief meeting to obtain a radiation dosimeter (badge) and instruction in how to survey for x-ray leakage.
Orthoscan Mini C-arm Unit (Dr. Elliott Lab) RAD Scan X-ray Irradiator (Life Science Research Facility) Any hand-held X-ray Device Hologic DXA Bone Densitometer (STAR Campus)	Contact the Radiation Safety Officer to schedule a meeting to receive device specific x-ray safety training and to obtain a radiation dosimeter (badge).
All Other X-ray Producing Devices not listed above (microCT, XRF, XPS, aerosol neutralizer, sedigraph, etc.)	Complete online X-ray Safety Training at www.delaware.bioraft.com.* Then contact the Radiation Safety Officer if there are any questions.

STEP 3
Once safety training is complete, the worker must obtain hands-on instruction in the safe use of the device. This instruction may be provided directly by the X-ray Permit Supervisor or by a properly qualified designee of the X-ray Permit Supervisor. This instruction typically involves the worker first observing an experienced operator, followed by the worker conducting experiments themselves with the experienced operator providing direct supervision. It is the responsibility of the X-ray Permit Supervisor to decide when a new operator is qualified to use an x-ray producing device without direct supervision.

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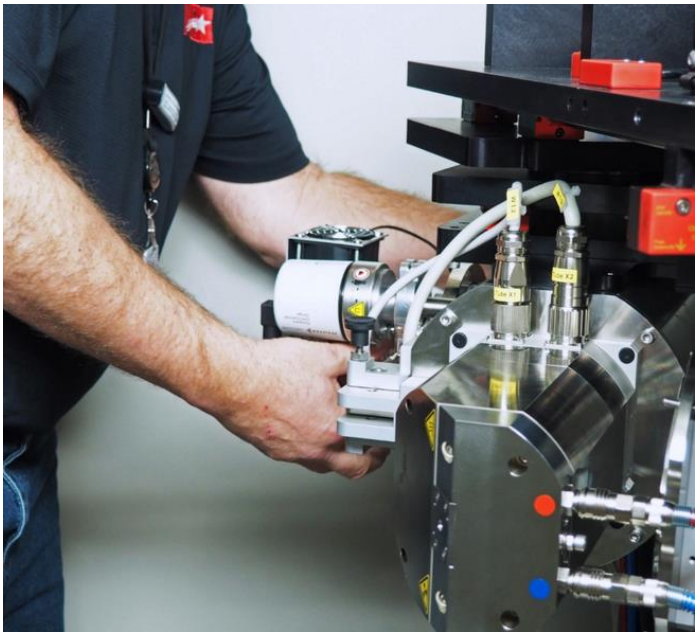
* Workers who do not have a UD email address should contact the Radiation Safety Officer (dehsafety@udel.edu) to obtain "visitor" status so they can access the BioRAFT training system.

Acquistion, Transfer, and Disposal of X-ray Producing Equipment

UD personnel who plan to purchase, or accept a donation of, x-ray producing equipment are strongly encouraged to first discuss the acquistion with the UD Radiation Safety Officer (RSO). Equipment must comply with safety requirements of both federal and state regulations as well as be approved for use on campus by the UD Radiation Safety Committee. The RSO can advise whether the equipment will comply/be approved or whether additional funds may be required to modify the proposed use location, add missing/inoperative safety controls, install shielding, acquire radiation monitoring devices, etc. Fire Code requlations require that electrical equipment have an Underwriters Lab (UL) listing or be safety certified by another National Regulatory Testing Laboratory (NRTL).

Prior to the use of newly acquired x-ray producing equipment, the owner must obtain (or amend) an X-ray Permit (see section- *Obtaining Authorization to Possess and Use X-ray Producing Equipment*). In some cases, installation of x-ray producing equipment must be performed by an entity approved and listed as an "Installer" by the State of Delaware.



The RSO must register newly acquired x-ray producing equipment with the State of Delaware Office of Radiation Control once the the UD Radiation Safety Committee has approved the X-ray Permit. The State may charge an annual fee for possession and use of the equipment.

The X-ray Permit Supervisor must contact the Radiation Safety Officer prior to transferring an x-ray producing device to another on-campus or off-campus location or prior to disposing of the device to trash/metal recycling.

Transfering to a new on-campus location requires an amendment to the X-ray Supervisor's X-ray Permit or, in the case of a new campus owner, the submission of an X-ray Permit Application (see section- *Obtaining Authorization to Possess and Use X-ray Producing Equipment*).

Transferring/selling to a non-UD person or disposing to trash/recyling requires the X-ray Permit Supervisor to submit the webform, *Equipment Activity*, to UD Procurement Services for authorization. The Supervisor must also inform the RSO who must contact the State of Delaware to inform them that UD no longer possesses the device and to provide the name and address of the new owner.

Prior to any x-ray device disposal, the X-ray Permit Supervisor must inform the RSO who will ensure it is safe for disposal. This may involve discharging of capacitors, removal/disposal of hazardous components (oils, beryllium windows, cooling fluids, etc.), defacing or removal of radiation warning labels, and rendering the device inoperable.

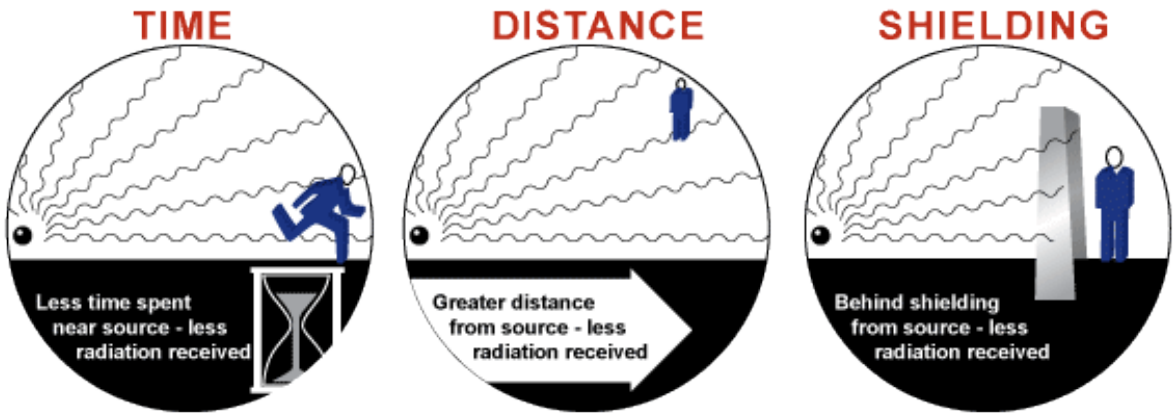
Radiation Protection

Specific information regarding the nature of x-rays, radiation health effects, and methods of radiation protection are provided within the online training course that all x-ray operators must complete. The course can be accessed at any time, for either initial training or for review, by logging into the BioRAFT training system (www.delaware.bioraft.com).

Modern x-ray equipment is manufactured in a manner that utilizes engineering controls to prevent injury, such as access panel interlocks that will shut down the x-rays if the panel is opened by the operator when the x-ray beam is exposed. Provided the operator uses the equipment properly and for its designated purpose, injury is unlikey. Operators, however, should be mindful of a few important radiation protection practices.

- Remember that EXPOSURE or DOSE equals RATE times TIME and falls-off with distance. When working near a source of radiation, exercise one, or more, of the following measures to reduce or eliminate radiation exposure. Reduce the TIME in a radiation field, maximize the DISTANCE between the radiation source and yourself, and interpose SHIELDING between yourself and the radiation source.

  In most cases at UD, the x-ray machine manufacturer has constructed the x-ray enclosure of sufficient shielding that time and distance measures are not needed. Exceptions on campus are: Orthoscan Mini C-arm Unit (Dr. Elliott Lab), RAD Scan X-ray Irradiator (Life Science Research Facility), hand-held X-ray Devices, Hologic DXA Bone Densitometer (STAR Campus).



- Do not operate an x-ray producing device without first completing x-ray safety training followed by training in use of the device from an experienced operator of the device. See section- *Authorization to Operate X-ray Producing Equipment*.

- Do not deviate from the written procedure for using the x-ray device. Ask the X-ray Supervisor or an experienced operator if there are questions.

- Do not defeat any of the safety interlocks or other safety components of the x-ray device.

- Immediately report to your X-ray Supervisor any problem with the operation of the x-ray device, especially if you suspect a problem with a safety interlock or other safety feature. Also, report if you suspect that you may have been over-exposed to x-rays.

Monitoring for External Radiation Exposure and Dosimeters

UD is obligated to maintain the radiation dose to x-ray operators below the occupational radiation dose limits defined in the State of Delaware Radiation Regulations. The regulations also require that individuals must be monitored for radiation dose when it is likely that they will exceed 10% of the annual dose limit. This monitoring is usually accomplished by providing a radiation dosimeter (badge) to each operator that is worn when they operate x-ray equipment and records their dose over time.

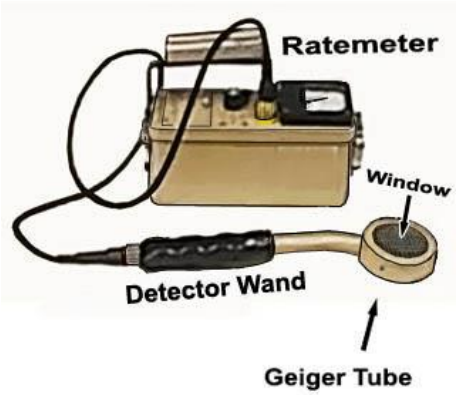
Because many years of past dosimeter readings have shown that the dose to x-ray operators at UD are not likely to exceed 10% of the annual radiation dose limit, UD is not required by the Delaware regulation to issue dosimeters to x-ray operators. UD has chosen, however, to require the wearing of dosimeters by many x-ray operator types as a conservative measure. The chart below shows the x-ray operator groups that are issued individual dosimeters and are required to wear them when working with x-ray devices. The radiation dose to x-ray operators that are not issued an individual dosimeter is determined by posting "area dosimeters" in the vicinity of the x-ray equipment that they operate.

Individual Dosimeters are issued to these x-ray operators and must be worn whenever using x-ray equipment. >>>>>>>>>>>>>>>>>>>> These are primarily workers operating equipment that - 1. is more likely to cause an acute injury if a person is exposed to the direct x-ray beam, 2. emits unenclosed x-rays, by design, that may expose the operator, or 3. is known to "leak" low levels of x-rays out of its x-ray enclosure.	Any XRD X-ray Diffraction Device (various locations on campus) X-ray Digital Imaging Device (Dr. Arce Lab) Orthoscan Mini C-arm Unit (Dr. Elliott Lab) RAD Scan X-ray Irradiator (Life Science Research Facility) Any hand-held X-ray Device Hologic DXA Bone Densitometer (STAR Campus) **ANY** X-ray Device that is located in the Advanced Material Characterization Lab AMCL (Room 151 Harker ISE Lab)
Individual Dosimeters are <u>not</u> issued to these x-ray operators. Dose is measured using area dosimeters. >>>>>>>>>>>>>>>>>>>> These are primarily workers operating equipment- 1. that is unlikely to cause an acute injury with exposure to the x-ray beam, 2. where the x-rays are embedded within the machine and only accessible using special tools.	All Other X-ray Producing Devices not listed above, such as- microCT X-ray fluorescence (XRF) X-ray Photoelectron Spectrometer (XPS) aerosol neutralizer sedigraph

Rules for Use of Dosimeters

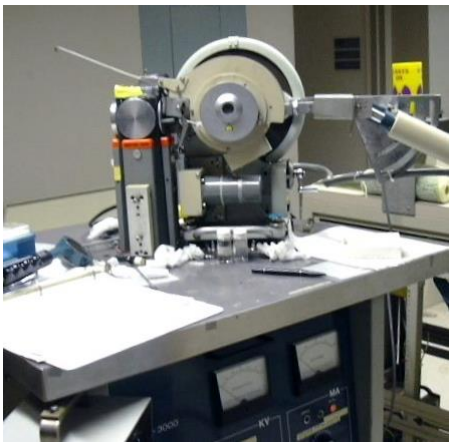
1. If issued to them, operators must wear the dosimeter on their torso with the name facing outward while operating x-ray producing equipment. The Radiation Safety Officer (RSO) should be contacted if the dosimeter is lost or damaged so a replacement can be issued.
2. Dosimeters may only be worn by the person whose name appears on the front of the badge.
3. No one may intentionally expose any dosimeter to radiation as a prank, "experiment", or for any other reason.
4. When not in use, operators must store their dosimeter in the assigned storage location in their x-ray facility. New dosimeters are issued to operators at the beginning of each calendar quarter.
5. The RSO will contact an operator if there is any measureable radiation dose recorded by the dosimeter. Usually, there is none. Operators may request a written report of their radiation exposure history at any time.

Portable Radiation Survey Meters and Leakage Surveys



Portable Geiger-Mueller (GM) radiation survey meters are used to detect the presence of a radiation field surrounding radiation sources and to estimate the dose rate at the measurement location. They are also used to detect x-rays "leaking" out from an x-ray enclosure into the operator's workspace.

Portable radiation survey meters are required to be available to operators in all x-ray facilities with X-ray Diffraction (XRD) units. The UD Radiation Safety Committee may require other x-ray facilities to have a meter. A meter is generally required if the x-ray unit operates at a high power (e.g. 1200W or more). The maximum power is typically listed on the X-ray source tube and can be found in the manufacturer's instructions and the Operating Manual. A meter may also be required if operators are capable of inadvertently making adjustments to a unit's shielding or enclosure that may result in x-rays escaping their confinememt (i.e. "leaking"). X-ray Permit Supervisors should consult with the Radiation Safety Officer prior to purchasing a survey meter for their facility.

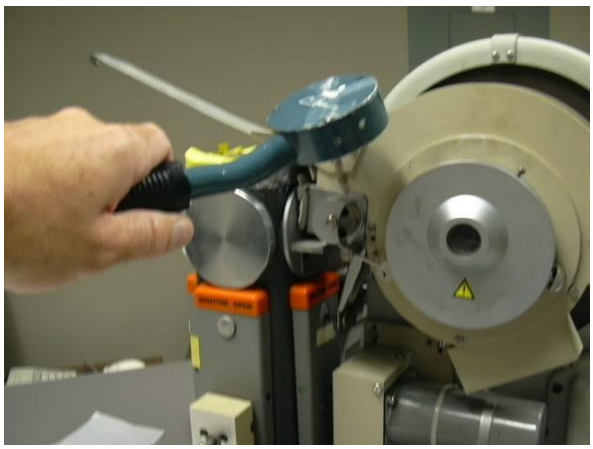


For XRDs without a full cabinet enclosure (like the one pictured to the right), operators are <u>required</u> to conduct an x-ray leakage survey at potential leakage locations <u>every time</u> they run a sample and to record their finding in an XRD usage logbook. The x-ray beam and scattered x-rays pass through a series of components and there is a possibility of leakage from each component-to-component fitting. If leakage is found, the operator must immediately terminate power to the x-ray tube and inform their X-ray Permit Supervisor.

For XRDs with a full cabinet enclosure, operators are advised to conduct x-ray leakage surveys on a periodic basis. There is no requirement to record the result of their survey. Enclosure cabinets have been found to be effective and reliable at confining x-rays.

Instructions for using a Portable Survey Meter—

1. Depending on the model of meter you have, confirm that the batteries are satisfactory by either turning the ratemeter knob to the "battery check" setting or by pushing the "battery check" button on the ratemeter. If the needle on the face of the ratemeter does not go past the "battery OK" marking, replace the batteries.
2. Turn the ratemeter knob to the lowest setting, usually x0.1 or x1, and confirm that the speaker switch (sometimes labeled "AUD") is ON. At this point, you should hear the meter clicking. The meter is detecting "background" radiation which is always present.
3. If the meter has a radiation check source attached to the meter case, hold the meter probe near the source to confirm the meter clicking rate increases indicating that the meter is detecting radiation as expected.
4. To check for the presence of x-ray leakage, approach the area of interest with the tube "window" pointed towards the area. If the clicking rate increases, a radiation field (leakage) is present. To obtain a meter reading, multiply the needle reading on the meter face by the value on the knob setting (e.g. 400 CPM on the x10 scale equals 4000 CPM).



Response to X-ray Related Incidents

The Radiation Safety Officer (or another qualified emergency responder) may be reached-
1) directly during regular working hours at 302-831-8475 or
2) through the Department of Public Safety, 24 hours a day, at 302-831-2222.

The risk of a radiation injury from working with UD x-ray producing instruments is very low. All instruments are modern, have fully functioning safety interlock systems, are well maintained, and are routinely tested for safety by the Radiation Safety Officer. Officials from the State of Delaware Office of Radiation Control inspect UD equipment on a regular basis.

An acute radiation injury has never occurred at UD. Dosimeters worn by operators typically record no radiation dose above that received from normal living (i.e. background radiation). No operator has ever exceeded the annual occupational radiation dose limits.

Operators should always be aware, however, that the interlock systems are present to prevent very real potential injuries and should NEVER be defeated. For example, placing a finger/hand in the primary, focused x-ray beam of an X-ray Diffraction (XRD) Unit will cause a serious burn-like injury within seconds.

High voltage within the x-ray generator component is also a real hazard. The voltage applied to some x-ray tubes may exceed 40,000 volts. Operators must never attempt a repair by opening the x-ray instrument service panels.

Respose to Incidents

1. If you know, or suspect, that any safety feature of an x-ray producing instrument is faulty, turn the instrument OFF, post the instrument with a sign stating “out of service, do not use”, and immediately inform the X-ray Permit Supervisor.

2. If you believe you have sustained a radiation injury, immediately inform the X-ray Permit Supervisor and/or the Radiation Safety Officer (RSO) who will assist you with arranging a medical evaluation. At night or on the weekend, the RSO may be reached by contacting Public Safety at 302-831-2222. Be aware that the onset of pain and redness from a radiation injury to the skin may not be evident until several hours after exposure to x-rays.

3. X-ray producing instruments are not prone to generating fires, however, if this happens-
   - Inform others around you and leave the area immediately closing the door behind you
   - Only fight the fire with a fire extinguisher if you are trained in its use and the fire is very small
   - Exit the building as soon as possible pulling the fire alarm on your way out
   - Remain on the scene outside the building and report to the command post established by emergency responders (a green flashing light is often used to identify the post).

4. If you see someone that needs emergency medical assistance anywhere on campus, call 911 from a land line or from a cell phone. If using a cell phone, calling UD Public Safety at this number will usually get a quicker emergency response: 302-831-2222.