X-ray Safety Fundamentals

(radiation protection training for x-ray radiation-emitting equipment)

University of Dayton
Environmental Health and Safety
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This Training is Intended to:

- Explain what x-rays are
- Explain the hazards of x-ray devices
- Explain the responsibilities for the safe use of x-ray devices
- Help you recognize and respond to unsafe conditions
State of Ohio Regulations

- UD Environmental Health and Safety Office must be notified of all x-ray devices that are brought onto campus (active and inactive)

- UD Environmental Health and Safety Office is required to register each device with the State of Ohio, Ohio Department of Health, Bureau of Radiation Protection (ODH BRP)

- Each x-ray unit/system must have a radiation protection plan which should be revised annually

- The ODH routinely inspects x-ray devices

- The disposal or transfer of any x-ray device must be approved by UD Environmental Health and Safety Office
Program Overview

- It is required that anyone working with or around radiation-generating equipment must be made aware of:
  - The possible hazards of radiation exposure
  - The procedures to be used for the safe handling of radioactive materials
UD Radiation Chain

- Environmental Health and Safety Director
- Radiation Safety Committee
- Radiation Safety Officer
- Authorized Users
- Radiation Workers (auxiliary users)
- Radiation-generating Equipment Users
- Peripheral Workers
- Members of the public (students, staff, visitors, maintenance personnel, janitorial staff, first responders)
Responsibilities

- **UD Environmental Health and Safety (EHS/RM)**
  - Oversees and enforces license requirements
  - Provides radiation safety services including:
    - Radiation monitoring
    - Radioactive waste disposal
    - Assist with authorized users
  - Monitors the purchase/use/transfer/disposal of all radiation-generating equipment on campus
  - Corresponds with the State of Ohio

- **Radiation Safety Committee**
  - Governs the campus radiation safety program
  - Review and approve new users and protocols
Responsibilities

- Radiation-Generating Equipment Users and Workers
  - Responsible for day to day radiation safety in facility
  - Proper use and disposal of equipment
  - Documentation of radiation-generating work
  - Perform surveys and decontamination procedures
  - Supervise auxiliary workers
All X-ray Equipment Users Must

- Contact EHS/RM if you acquire any new radiation-generating x-ray devices
- Annually inspect their x-ray devices
- Operate x-ray devices as specified in the manufacturers operating instructions
- Notify EHS/RM of any repairs, modifications, disposal or relocation of x-ray equipment
- Are required to read safe operating procedures and follow all warnings and precautions
Principles of Radiation
What is Radiation?

- Radiation is energy in the form of waves or particles.
- Radiation with high enough energy to cause ionization is termed **ionizing radiation**.
- Ionizing radiation consists of particles and rays given off by radioactive material, stars, and high-voltage equipment.
- Includes x-rays, gamma-rays, beta particles, alpha particles, and neutrons.
What is Radiation?
What is Radiation?

Radiation Wavelength in Angstrom Units

<table>
<thead>
<tr>
<th>10^8</th>
<th>10^6</th>
<th>10^4</th>
<th>10^2</th>
<th>1</th>
<th>10^2</th>
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<tbody>
<tr>
<td>Radio</td>
<td>Infrared</td>
<td>Visible</td>
<td>Ultra-Violet Light</td>
<td>X-Rays</td>
<td>Cosmic Rays</td>
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Photon Energy in Million Electron Volts (MeV)

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<th>10^{-10}</th>
<th>10^8</th>
<th>10^6</th>
<th>10^4</th>
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<th>10^2</th>
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<tbody>
<tr>
<td>Gamma Rays</td>
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Gamma Rays
Non-ionizing Radiation

- Radiation with enough energy to move atoms (vibrate) in a molecule but do not contain enough energy to interact with material by removing electrons

- Examples:
  - Microwaves
  - Visible Light
  - Infrared Waves
  - Radio Waves
  - Lasers
  - Ultraviolet Light
Ionizing Radiation

- Radiation with sufficient energy to remove electrons from atoms in materials through which the radiation passes (i.e. break chemical bonds in molecules to create charged molecules or ions)
- Ionizing radiation occurs from the addition or removal of electrons from neutral atoms
- Three main types of ionizing radiation:
  - Alpha particles
  - Beta particles
  - Gamma and x-rays
Non-Ionizing vs Ionizing Radiation

- Non-ionizing radiation includes: radio, microwave, infrared, visible light, ultraviolet.
- Ionizing radiation includes: x-ray, gamma rays.

**Non-thermal**
- Induces low currents
- Induces high currents
- Heating

**Thermal**
- Low frequency
- Microwave
- Infrared
- Visible light
- Ultraviolet

**Optical**
- Excites electrons
- Photo-chemical effects

**Broken Bonds**
- Damages DNA

Examples:
- Radio, power line
- AM, FM radio, microwave, oven, heat lamp, tanning booth, medical x-rays
X-ray Radiation
History of X-rays

- X-rays were discovered in 1895 when Wilhelm Conrad Roentgen observed that a screen coated with a barium salt fluoresced when placed near a cathode ray tube.
- Roentgen concluded that a form of penetrating radiation was being emitted by the cathode ray tube and called the unknown rays, X-rays.

Early X-Ray Tube (1899): This tube is a specimen of the first type of gas x-ray tube to incorporate a water-cooled anode. The hollow anode was supplied with water by gravity feed from a supply held in the side bulb. This type of tube was introduced by Mueller about 1899.
What are X-rays?

- A form of electromagnetic radiation which arises as electrons are deflected from their original paths or inner orbital electrons change their orbital levels around the atomic nucleus.
- A form of ionizing radiation (thus have the ability to release electrons from atoms).
- Similar to visible light but contain much higher energy.
- Contain no mass, no charge and travel at the speed of light.
- Are capable of traveling long distances through air and most other materials (low linear energy transfer and high penetrability).
What are X-rays?

- Produced by the acceleration or deceleration of electrons
- Generated on purpose by x-ray tubes
- Used for:
  - Material research
  - Material inspection (non-destructive testing)
  - Medical diagnosis
An x-ray tube requires a:
- Source of electrons (filament)
- Means to accelerate the electrons (voltage) and
- Target to stop the high-speed electrons
X-ray Tube
Principle of X-ray Production

- A filament is heated to emit electrons
- A stream of electrons are accelerated in an electric field toward a target (from the cathode to an anode)
- When the fast-moving electrons slam into the target (the target is usually a high atomic number metal absorber like tungsten or a crystalline structure), the accelerated electrons are slowed down causing the production of bremsstrahlung radiation (“bremsen” is German for brake) or x-rays
- The deceleration of the electron causes the release of energy in the form of x-rays as the kinetic energy of the electron is transformed into electromagnetic energy
Principle of X-ray Production

- The x-ray tube housing contains one or more ports which provide a narrow beam of useful x-rays.
- Only about 1% of electrical energy is converted to x-rays $\rightarrow$ the rest is converted to heat (thus, x-ray units must be cooled).
- The interaction of electrons in the target results in the emission of an x-ray spectrum (The spectrum consists of a continuous bremsstrahlung spectrum along with characteristic x-rays from the particular target material).
Principle of X-ray Production

The x-rays from bombardment of a target with electrons are emitted as a continuous spectrum of different x-ray energies. Depending on the target, the spectrum will also have characteristic photon peaks which result from displacement of electrons in the shell of the target atom. When an electron falls to an inner shell to fill a vacancy, a characteristic x-ray is produced. The energy of this x-ray is characteristic to the element that produced it.
X-ray Interactions

- In passing through matter, energy is transferred from the incident x-ray photon to electrons and nuclei in the target material.
- The amount of energy lost to the electron is dependent on the energy of the incident photon and the type of material through which it travels.
- X-rays require more shielding to reduce their intensity than do beta or alpha particles.
- There are three basic methods in which x-rays interact with matter: photoelectric effect, Compton scattering, and pair production.
X-ray Interactions

Diagram showing the interaction of alpha, beta, and gamma rays with different materials such as paper, plexiglass, and lead, indicating their ionization and distance/penetrability.

- Alpha particles (α): Emit from the nucleus of an atom and travel short distances before energy is dissipated, producing ionization.
- Beta particles (β): Emit from the nucleus of an atom and travel longer distances than alpha particles, causing ionization.
- Gamma rays (γ): Emit from the nucleus and travel long distances, not producing ionization.

Examples of materials:
- Tissue
- Aluminum
- Concrete wall
- Lead
X-ray Tube Output Factors

- Tube voltage (kV) – determines maximum energy and intensity of output (i.e. how penetrating the x-rays are)
  - Mammography ~ 20 - 30 kV
  - Dental ~ 70 - 90 kV
  - Chest ~ 110 - 120 kV

- Tube current (mA) – output proportional to number of electrons (how much radiation is produced)

- Beam time – output proportional to time (how long the machine is on)

- Anode material – higher atomic number (Z), higher output intensity

- Filtering – modification of output by use of filter material

Combination of voltage, current and time determines exposure
X-Ray Effects

The effects of x-ray exposure depends upon:

- Duration (time) - How fast the dose is delivered
- Energy - How much energy was in the x-ray → Low Energy (<50 KeV) = damage only to skin or outer part of body; High Energy = damage to internal organs
  - Voltage determines penetration
  - Current determines dose rate

Total Dose or its magnitude = duration x energy
Sources of Radiation

- X-ray devices produce dose rates inside and outside x-ray machines
  
- Primary beam (coming from x-ray tube, shutter open)
  - Very intense x-ray beam, very small size
  - Localized (a few millimeters at most)
  - Produces tens of grays per minute to tens of grays per second (400,000 R/minute) [Note that Collimated and filtered beams can produce about 5,000 to 50,000 R/minute]
  - Harmful to human tissue
  - Contact with primary beam absolutely forbidden

- Leakage or scatter of primary beam outside detector area
  - Can produce intense x-ray fields
  - Produces up to a few milligray per minute
  - May be caused by defective equipment
  - All directions possible with respect to primary beam
Sources of Radiation

- Leakage of primary beam through shutter or tube housing
  - Usually low level fields
  - Produce up to a few microgray per minute

- Diffracted rays
  - Small size beams...possibly intense
  - Very local
  - Primary direction can vary considerably (all directions possible with respect to primary beam)
  - Produce up to a few gray per minute (1 R/minute)

- Outside machine housing (if enclosed or cabinet system)
  - Less than 0.1 microgray per hour
Sources of Radiation

X-ray diffraction pattern obtained from the protein crystal

diffracted beams

beam of X-rays

protein crystal

beam stop

X-ray source
Common Causes of X-ray Exposure

- Changing samples with beam on or shutter open\textsuperscript{A}
- Visually aligning x-ray beam\textsuperscript{A}
- Modification of shielding\textsuperscript{B}
- Misplacement of shielding after machine service\textsuperscript{B}
- Failure to realize x-rays are emitted from several ports\textsuperscript{C}
- Failure to read and follow manufacturers x-ray operating instructions\textsuperscript{C}

\textsuperscript{A} may only be performed by specialist with permission
\textsuperscript{B} requires mandatory radiation safety check after every modification
\textsuperscript{C} requires safety training and device specific training
Biological Effects of X-Rays

exposure of persons measured in rem or sievert (Sv)

radioactivity measured in curie (Ci) or becquerel (Bq)

absorbed dose measured in rad (erg/gm) or gray (Gy) (J/kg)

x-ray / γ-ray exposure measured in roentgen
Sources of Radiation

- Average person receives 360 mrem per year
  - Natural Sources: 295 mrem (82%)
    - Terrestrial: 228 mrem
    - Human Body: 40 mrem
    - Cosmic: 27 mrem
  - Man-made: 65 mrem (18%)
    - Medical (chest x-ray): 15 mrem
    - Products (tobacco, cosmetics): 10 mrem
    - Other (occupational, nuclear power): 2 mrem

Radiation is all around us in our daily lives.
Biological Effects

- Ionizing radiation absorbed by human tissue can have enough energy to remove electrons from the atoms that make up molecules of the tissue.

- Ionizing radiation can be harmful:
  - Tissue damage in case of very high level exposure
  - Possible enhanced cancer probability in case of low level exposure

- When ionizing radiation interacts with cells, it may or may not induce damage:
  - *Cells are undamaged by the dose*
  - *Cells are damaged, repair the damage and operate normally*
  - *Cells are damaged, repair the damage and operate abnormally*
  - Cells die as a result of the damage

- The amount of radiation damage to cells also depends on the intensity of the radiation to the body.
Biological Effects

Overall biological effects of ionizing radiation can be divided into two categories:

- **Acute or Deterministic Effects** - short term effects (hours to weeks) after high level exposure
- **Chronic or Stochastic Effects** – possible long term effects (months to years) after low level exposure
Acute Exposures

- Large doses received in a short time period
  - Accidents, nuclear war, cancer therapy
- Directly related to radiation exposure
- Minimum exposure needed for effects
- Severity increases with exposure level
- A few seconds in primary beam could cause high exposure
  - Effect varies from skin redness to amputation
  - Effects of radiation exposure appear only after days to weeks
  - No time for cells to repair
- Should be prevented at all cost
  - High radiation dose only possible in case of bad work practice
X-ray Burns

- X-ray versus thermal burns
  - Most nerve endings are near the surface of the skin
  - High energy x-rays penetrate the outer layer of the skin that contains most of the nerve endings
  - One does not feel an x-ray burn until the damage has been done
  - Capable of penetrating to the deeper, basal skin layer, damaging or killing the rapidly dividing germinal cells, that are destined to replace the outer layers
Most radiation overexposures from analytical x-ray equipment are to the extremities.

For x-rays of about 5-30 keV, irradiation of the fingers or hands does not result in significant damage to blood-forming tissue.

At high exposures some general somatic effects to the skin can occur. Very high exposures may necessitate skin grafting or amputation of the affected extremity.
**Chronic Exposures**

- Smaller doses received over long periods
  - Background Radiation Exposure
  - Occupational Radiation Exposure
- Cannot be directly related to ionizing radiation exposure
- No minimum exposure needed for effects
- Probability of effect is related to magnitude of exposure
- Average person in U.S.A. will receive 20 - 30 rem in a lifetime
- Cells have time to repair
- Long Term Effects
  - Increased Risk of Cancer
Biological Risks

- At **high** doses, we **know** radiation causes harm
  - Radium dial painters
  - Early radiologists
  - Populations near Chernobyl
  - Medical treatments
  - Criticality Accidents

- In addition to radiation sickness, increased cancer rates were also evident from high level exposures (atomic bomb survivors)

- However, the **effects of low level radiation are difficult to measure**
Biological Risks

- Health hazards depend on:
  - Total energy deposited (absorbed)
  - Amount of time the energy was deposited
  - Distribution of deposited energy
  - Radiation type
  - Exposed organs
Biological Risks

- Radiation deposits small amounts of energy or "heat" in matter
  - Alters atoms
  - Changes molecules
  - Damage cells and DNA
    - Somatic (body) effects: Damage to genetic material in the cell...may cause cell to become a cancer cell
    - Germline (gametes) Effects: Damage to the hereditary material in a cell nucleus...passed on to offspring (genetic mutations)
  - Causes formation of derivatives – peroxides, free radicals, oxides
  - Can affect cellular enzymes and structures
Biological Risks

- Cells often recover from initial damage, however, repeated exposure may cause damage to be permanent
  - Cell Death
  - Cell Dysfunction - tumors, cancer, cataracts, blood disorders
  - Mitosis (Cell Division) Delayed or Stopped
  - Chromosomal breaks
  - Organ Dysfunction at High Acute Doses

- Rapidly dividing cells are more susceptible to radiation damage - examples of radiosensitive cells are:
  - Blood forming cells
  - The intestinal lining
  - Hair follicles
  - A fetus (A lower dose limit is allowed for the fetus – pregnant employees must voluntarily inform EHS/RM)
Biological Risks

- Ionizing radiation can damage chromosomes in the cell nucleus.

- Damage to DNA can lead to:
  - cell death ........ loss of organ function
  - uncontrolled cell division .......... tumor induction
  - mutations in genetic material .......... genetic effects in offspring

DNA double cleavage

- Deterministic effects
  - cell death
    - sex cell
      - sterility
    - body cell
      - loss of organ functionality
  - body cell
    - tumors
    - leukemia
- Stochastic effects
  - mutation
    - sex cell
    - hereditary effects
Principles of Radiation Protection

- Distinguish between radiation workers and members of the public and take into account the effects of all actions to yourself, co-workers and members of the public

- Prevent high level of radiation exposure at all cost (because of acute effects)

- If low level exposure cannot be avoided, always reduce low level exposure to reasonable levels
  - No unnecessary exposure
  - Only if useful and necessary (if justified)

- Maintain individual exposure limits
ALARA

- Philosophy developed in order to keep doses As Low As is Reasonably Achievable
- The University of Dayton is committed to keeping exposures to radiation ALARA…this means that every reasonable effort shall be made to maintain radiation exposures as far below the dose limits as practical
- Three main ways to keep your doses ALARA:
  - Time of exposure
  - Distance from the radiation source
  - Shielding between the source
Time

- The dose of radiation a worker receives is directly proportional to the amount of time spent in a radiation field.
- Less time spent near source = less radiation received.
- Thus, reducing the time by one-half will reduce the radiation dose received by one-half.
- Operators should always work quickly and spend as little time as possible next to x-ray equipment while it is operating.
Distance

- Radiation exposure decreases rapidly as the distance between the worker and the X-ray device increases.

- The decrease in exposure from a point source, such as an X-ray tube, can be calculated by using the inverse square law.

- This law states that the amount of radiation at a given distance from a point source varies inversely with the square of the distance.

- For example, doubling the distance from an x-ray tube will reduce the dose to one-fourth of its original value.
Distance

- Maintaining a safe distance, therefore, represents one the simplest and most effective methods for reducing radiation exposure to workers

- Using the principle of distance is especially important when working around open beam analytical x-ray equipment
Shielding

- Radiation exposure to personnel can also be reduced by placing an attenuating material between a worker and the x-ray tube.

- Substances such as lead, that are very dense and have a high atomic number, are very practical shielding materials because of the abundance of atoms and electrons that can interact with the x-ray photon:
  - Radiation intensity decreases exponentially with thickness.
  - The energy of the incident x-ray photon is reduced in the shielding material.

- Shielding is often incorporated into the equipment, such as the metal lining surrounding the x-ray tube, or consist of permanent barriers such as concrete and lead walls, leaded glass, and plastic movable screens.
Examples of X-Ray Devices
Types of Devices

- Many different types of machines produce x-rays, either intentionally or inadvertently.
- The most common types of devices are grouped into three main classes:
  - Analytical
    - x-ray diffractometers
    - electron microscopes
    - x-ray fluorescence spectrometer
  - Diagnostic
    - x-rays (Linear Accelerators)
    - nuclear Medicine
    - positron emission tomography (PET)
  - Industrial
    - high activity sealed sources
Open Beam Versus Cabinet Devices

- Depending on the type and set-up of the unit, the hazards and safety requirements may be different

- X-ray devices can be:
  - **open beam systems (aka unenclosed)** – unit provides no safety enclosure that surrounds the beam, thus, there is nothing to prevent extremities or body parts being exposed directly to the beam
  - **cabinet systems (aka enclosed)** – unit where the beam is completely enclosed by walls or doors and contain interlocks to prevent accidental exposures
Analytical X-rays

- Analytical x-ray machines produce intense beams of ionizing radiation that are used in the non-destructive analysis of materials to determine the elemental composition or examine the microstructure of a material.

- Analytical x-ray equipment makes use of very narrow collimated x-ray beams of high intensity:
  - x-rays emitted from an open, uncollimated port form a cone of about 30 degrees and include both characteristic and bremsstrahlung x-rays
  - collimators are used to reduce the beam size to about 1 mm diameter
  - monochromators are used to filter out undesirable wavelengths
Analytical X-rays
Analytical X-rays

- Two main analytical uses:
  - Diffraction (XRD) - X-ray scattering from crystalline materials. “fingerprint” of crystalline atomic structure
    - x-ray scattering from crystalline materials
    - “fingerprint” of crystalline atomic structure
    - identification of known material
    - characterization of unknown materials
  - Fluorescence (XRF) – method for determining the elemental composition of a substance
    - material disposed to x-rays emits characteristic fluorescent x-rays
    - secondary x-rays characteristic for element
    - x-ray can be measured in two ways: wavelength dispersive mode (diffraction of waves) or energy dispersive mode (energy absorption in detector)
    - an X-ray fluorescence (XRF) spectrometer is an x-ray instrument used for routine, relatively non-destructive chemical analyses of rocks, minerals, sediments and fluids.
Examples of Analytical Devices

- Open Beam Unit
  - X-ray beam is not contained within any protective containment (open beam)
  - Used for the analysis of samples
Examples of Analytical Devices

- **Cabinet Unit**
  - Equipment in which the x-ray tube, detector and sample are all contained in housing that provides shielding to the user and others in lab (totally enclosed)
  - While running, the access doors are interlocked and will automatically shut-off when opened
  - Viewing areas are made possible by using leaded glass or Plexiglas
Hazards of Analytical X-ray Equipment

- In the case of cabinet units the beam is totally enclosed within an interlocked housing and there is no hazard to workers outside the housing.
- However, in the case of open beam units, the primary beam and scattered radiation from outside the beam path or from the impact with the target creates an exposure hazard.

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A Most analytical equipment is not used in an open beam configuration (usually a combination of filters, cameras, beam enclosures and shielding are used and reduce the radiation fields around the equipment significantly), however, open beam systems require more caution when working around since they pose a much greater exposure risk – the following 5 slides refer only to open beam analytical systems.
Hazards of Open Beam Analytical X-ray Equipment

- **The primary beam**
  - The primary beam is most hazardous because of the extremely high exposure rates
  - Exposure of the eyes or the skin of the body to the primary x-ray beam may result in severe radiation burns in a matter of seconds
  - *Localized radiation burns produced by the high intensity primary x-ray beam is the principal hazard associated with the use of analytical x-ray equipment.*

- **Leakage or scatter of the primary beam**
  - The leakage of the primary beam through cracks or apertures in ill fitting or defective equipment can produce very high intensity beams of possibly small and irregular cross section
  - Radiation is scattered when the primary beam strikes surfaces of collimators, samples, beam stops or shielding, however, the intensity of the scattered radiation is a couple of orders of magnitude less than that of the primary beam
  - Leaked and scattered radiation can result in significant exposures if not adequately accounted for
Hazards of Open Beam Analytical X-ray Equipment (con’t)

- **Penetration of the primary beam through the tube housing, shutters or diffraction apparatus**
  - Radiation produced as a result of the primary beam penetrating through shutters or the x-ray tube housing
  - This type of radiation is slight (especially in well designed equipment) but can result in significant exposures if not adequately shielded

- **Diffracted rays**
  - Radiation beams resulting from the interaction of the primary beam with the target
  - Beams tend to be small and irregular in shape but can be directed at almost any angle
  - Generally low, high exposure rates for short periods can be significant if the area surrounding the target material is not adequately shielded
### Hazards of Open Beam Analytical X-ray Equipment (con’t)

<table>
<thead>
<tr>
<th>Source</th>
<th>Exposure Rate</th>
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<tbody>
<tr>
<td>Primary beam at an open, unshielded port</td>
<td>50,000-500,000 R/min</td>
</tr>
<tr>
<td>Primary beam between collimator/slitr assemblies and sample</td>
<td>5,000-50,000 R/min</td>
</tr>
<tr>
<td>Leakage of primary beam at 5 cm</td>
<td>0.5-5 R/hr</td>
</tr>
<tr>
<td>Primary beam at one meter</td>
<td>~10,000 R/hr</td>
</tr>
<tr>
<td>Scatter at 5 cm</td>
<td>&lt; 10 - 300 mR/hr</td>
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</tbody>
</table>
Main Causes of Exposure Using Open Beam Analytical X-ray Equipment

- Putting fingers in X-ray beam to change sample
- Aligning X-ray beam visually
- Modification of shielding
- Failure to realize X-rays are emitted from several ports
- Failure to read & follow manufacturers X-ray operating instructions

Any of these actions could cause an unnecessary exposure and a potential negative effect
Result of Exposure Using Open Beam Analytical X-ray Equipment

- X-rays produced by diffraction machines are absorbed in the first few millimeters of tissue and generally do not contribute to the internal organs of the body.

- The main tissues at risk include the skin and the lens of the eye:
  - Skin Burns - the principal hazard associated with use of analytical x-ray equipment is localized skin burns following exposure to the primary beam.
  - Eye Damage - doses capable of causing skin burns are capable of producing serious permanent damage to the eye. Overexposure of the eye can lead to the development of lens opacities and cataracts.

- The most common effect of direct exposure is reddening of the skin (erythema).

- Higher doses may produce significant cellular damage resulting in pigment changes and chronic radiation dermatitis.
Diagnostic X-rays

- Diagnostic X-ray is an examination using electromagnetic energy beams to produce images onto film or computer.

- Two main types of diagnostic X-ray devices:
  - Radiograph – a picture with film or image is sent direct to computer screen.
  - Fluoroscopic – a real time “moving” inspection on inside functions.
Examples of Diagnostic X-ray Equipment

Radiographic Table

- X-ray tube stored in a collimated lead housing. The X-ray beam is pointed down to the table. The table is where the patient is placed and contains a slot for an X-ray film.

- Mobile shield for operator designed to protect the operator from scattered x-rays.

- Control panel where the operator can select x-ray ON (exposure) time in fraction of minutes, the energy of X-ray (in kVp) and current applied (higher current = more X-rays).
Examples of Diagnostic X-ray Equipment

Fluoroscopic

- In fluoroscopy, a medical device called a fluoroscope (sometimes termed a C-arm because of the shape of the device) takes an x-ray of a patient and displays it on a viewing screen.
- Surgeons often use this device to locate structures within the body.
- It is one of the oldest forms of diagnostic radiology used to examine the inner body.
- When this “C-arm” x-ray device is used the operator and support staff wear a lead apron, safety glasses and whole body dosimeter badge.
Hazards of Diagnostic X-ray Equipment

- There are two basic sources of potential x-ray exposure to operators using x-ray diagnostic equipment:
  - leakage radiation transmitted through the equipment housing and shielding that surrounds the source assembly
  - backscatter radiation from the patient and nearby structures

- Leakage and backscatter radiation to the operator can be reduced by:
  - shielding the x-ray unit housing
  - providing external shielding or a means to increase distance between the operator and the unit
    - scattered x-radiation to the critical organs may be significantly reduced by wearing lead equivalent aprons
    - surround the exposed area with radiation protection devices, such as lead shields or limit the size of the x-ray beam
  - monitoring typical exposures near and around the unit
  - identifying necessary safety precaution
Industrial X-rays

- X-rays used for non-destructive testing
  - non-destructive testing (NDT) by means of an x-ray beam inspects the integrity of industrial products or processes without damaging the items under observation
  - It is a method of inspecting materials for hidden flaws by using the ability of short x-rays and gamma rays to penetrate various materials

- Has applications in a wide range of industries
  - used primarily to examine structural components such as beams or pipes in order to find defects in castings, structures, and welds
  - also, used to identify foreign material in food products and inspect luggage at airports
Examples of Industrial X-rays

Industrial radiography

- Use of high activity sealed sources to examine structural components such as beams or pipes
- Both hold luggage and carry-on hand luggage are normally examined by x-ray machines using x-ray radiography
- Non-intrusive freight cargo scanning
Hazards of Industrial X-ray Equipment

- Use of high activity sources with external exposure risks
- Inadvertently walking up on an exposed source resulting in overexposure or radiation burns
- Industrial radiographers are in many locations required by governing authorities to use certain types of safety equipment and to work in pairs. Safety equipment generally consists of four basic items:
  - a radiation survey meter (such as a Geiger/Mueller counter)
  - an alarming dosimeter or rate meter
  - a gas-charged dosimeter
  - and a film badge or thermoluminescent dosimeter (TLD)
Working Safely With X-Rays

CAUTION

X-RAY DEVICE IN POSSIBLE USE
Overall

- Working with modern x-ray machines are very safe provided:
  - operation and safety instructions are followed
  - special jobs, like visual alignment, are reserved to specialists
  - devices are regularly checked for leakage

- The electromagnetic radiation from x-rays is **only** emitted when the unit is energized and the shutter opened → there is **no** radiation hazard when the x-ray unit is off

- In normal circumstances radiation exposure is extremely low … well below natural background levels

- In case of severe breach of safety rules exposure can be very high especially to hands and fingers and can result in physical damage

- In case of any questions regarding the safe operation of x-ray machines consult EHS/RM
Safety Measures

- Room access restrictions
- Warning Labels
- Engineering Controls
- Radiation monitoring equipment
- Periodic radiation safety checks
- Personnel training
General Regulations

- General rules for radiological areas
  - access restricted to classified personnel
  - warning signs outside area

- Area with closed x-ray machines
  - not classified as a radiological area
  - no access restrictions
  - no personal dosimetry needed
  - additional measures in case of use of open machines

- Machine specific radiation protection
  - warning signs on x-ray machine
  - operation of machines only with proper instruction and authorization
  - special jobs only by specialists with permission
  - interlock override key must be kept in a safe place by local expert
  - regular safety inspection
Warning Labels

- Use visual warnings to indicate:
  - each area or room containing x-ray equipment
  - the presence of an x-ray device (warning sign on machine or machine exclosure)
Use visual warnings to indicate:

- the potential for radiation exposure on all devices, especially of open beam configuration
  - place a label bearing the radiation symbol and the words “Caution Radiation, This Equipment Produces X-radiation When Energized” near any switch which energizes an x-ray tube
  - place a label bearing the radiation symbol and words “Caution High Intensity X-ray Beam” on or adjacent to each x-ray tube housing (ensure the label is clearly visible to any person who may be working near the primary radiation beam)
Warning Labels (con’t)

- Use visual warnings to indicate:
  - When a beam is energized or turned on (yellow or red lamp)
    - provide easily visible lights located near the tube housing that indicate when the x-ray tube is on or off
    - if the beam is controlled by shutters, locate a readily discernible indication of shutter status (open or closed)
  - use a fail-safe design for warning devices and label them so that their purpose is easily identified
Engineering Controls

- Interlocks
  - In order to prevent access to the high radiation levels of the primary beam, equipment should be equipped with an interlocked enclosure where removal of the enclosure cover shuts off the power or blocks the beam thereby preventing injury to fingers.
  - Employ safety interlocks on tube head ports or shielding in order to prevent stray X-rays from escaping.
  - For open beam configurations, provide a safety device to prevent entry of hands and other body parts into the primary beam (especially when dealing with open beam units) and secure unused ports so that the shutters cannot be opened.
  - Interlocks or other safety devices must never be bypassed.

- Warning Lights
  - Always know the beam status whenever working with x-ray units.
Engineering Controls (con’t)

- **Shielding**
  - Prevents direct exposure to x-ray primary beam and diffracted beams
  - Shielding made of plastic, glass, or metal should be used to reduce the level of scattered radiation in occupied areas
  - Necessary shielding depends on voltage and current

- **Emergency shut-off switches**
  - Machine shuts down or shutter closes when safety is broken

- **Regular Testing**
  - Test all safety devices (e.g., interlocks, shields, shutters, warning lights, etc.) to insure their proper operation
Monitoring Equipment

- In contrast to heat, light, food, and noise, people are not able to see, feel, taste, smell, or hear ionizing radiation → thus, we are dependent on instruments to indicate the presence of ionizing radiation.

- Radiation exposure rates, materials and contamination can be directly measured by using the appropriate instrument such as GM detectors and personal dosimetry.
Personal Monitoring

- Thermoluminescent dosimeters (TLDs) are used to measure exposures of workers to radiation
- Whole Body Badge and/or Ring Badge
- Required for:
  - Anyone likely to receive at least 10% of the dose limit
  - Minors or declared pregnant women
  - Anyone working with gamma emitters
  - Anyone working with certain types of radiation generating equipment
Personal Monitoring (con’t)

- Most analytical X-ray devices **do not require** users to be issued personal monitoring devices
  - open beam systems beams employ narrow radiation beams that are not easily detected by whole body monitoring badges whereas cabinet systems contain safety interlocks that block and prevent the beam from accidental exposure

- Diagnostic and industrial devices and x-ray equipment users who utilize units other than the cabinet unit generally **do require** personal dosimetry monitoring devices

- If provided, dosimetry badges (whole body or ring) should be worn by the operator during x-ray equipment use and stored in an appropriate location in the laboratory when not in use

- X-ray users should address any radiation safety concerns to EHS/RM
Unsafe Conditions

- Examples of unsafe conditions include:
  - access door interlocks do not work
  - shielding has been damaged
  - viewing window is cracked

- If an unsafe condition arises with an x-ray device:
  1. Immediately STOP all work
  2. Turn power OFF to X-ray (remember that an x-ray requires power to produce radiation)
  3. Notify your Principal Investigator and EHS/RM
Emergency Contact Numbers

- During Business Hours (8:30am – 4:30pm) contact Environmental Health and Safety at 229-4503 (x94503)

- After Hours contact UD Public Safety at 229-2121 (x92121) or 911

- Immediate emergencies contact 911*

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* Note that calling 911 from a campus phone directs the call to UD public safety while calling 911 from a cell phone directs the call to Dayton Police
Additional Resources

- Click on the links below to view additional safety videos:
  - Radiation Safety for X-ray Generating Devices
  - X-ray Diffraction Hazards (Howard Hughes Medical Institute Video; click play to start video)