ESH 705 Analytical X-ray

Welcome to ESH 705 Analytical X-ray training course. This course is designed to provide an understanding of the radiological hazards associated with analytical X-ray devices. It also reviews the policies, procedures and other safeguards established to allow workers to safely use these devices.
You must complete this training, ESH700 or ESH713 and a device-specific orientation before you may use an analytical X-ray device. Retraining is required every 24 months.

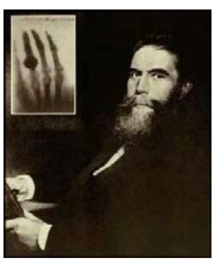
If you have any problems, questions or comments, contact Sitewide/RGD Safety Officer

Learning objectives:

- Identify sources of radiation associated with analytical X-ray devices.
- State the main causes of accidental X-ray exposure.
- List potential health effects of X-ray exposure.
- Define fundamental terminology associated with X-ray generating devices.
- Identify the basic components of an analytical X-ray machine.
- Identify operational safeguard requirements.
- Identify responsibilities of management, Health Physics, custodians and users of analytical X-ray equipment.
- State the correct response to an area radiation alarm.

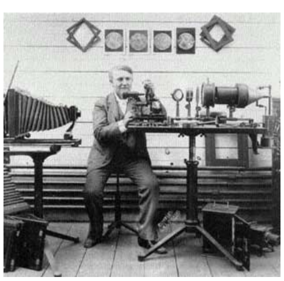
Discovery of X-rays

Wilhelm Roentgen



On November 8, 1895, Wilhelm Roentgen discovered mysterious, penetrating rays emanating from an evacuated cathode ray (electron) tube. He performed a thorough investigation of these so-called X-rays during the next several weeks. In January, 1896, Roentgen mailed his research to fellow scientists. He also included this “X-ray” photograph of his wife’s hand. The photograph was soon published in newspapers throughout the world. Many doctors, dentists, scientists, engineers and others began experiments with X-ray equipment. Within a few months, some researchers reported that X-rayscould cause burns to the skin. Several early researchers had to havefingers amputated.

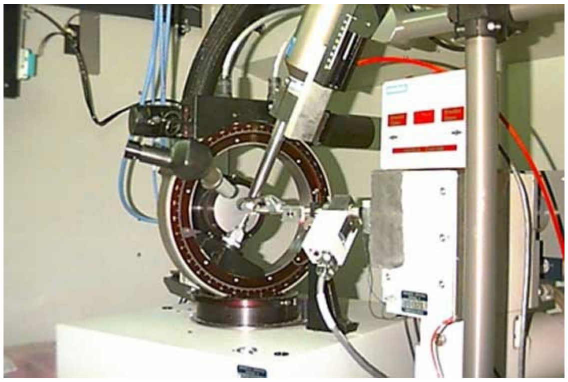
Thomas Edison



One of the more famous investigators of Roentgen’s discovery was Thomas Edison. Edison wanted to develop a commercially viable X-ray system. He assigned this project to an engineer named Clarence Dally in early 1896.
Notice the X-ray tube in this photo. The tube is unshielded and no collimation is used. By today’s standards it is very unsafe. But this was common practice 100 years ago. Mr. Dally used similar equipment and soon developed a degenerative skin disorder which led to carcinoma. His death in 1904 is the first known radiation related death in the US. We should still remember today that X-ray equipment is potentially hazardous.

Analytical X-ray Device

This training program is designed for persons who work with one or more analytical X-ray devices. It is not designed for medical or industrial X-ray device users. An analytical X-ray device can be defined as a device that uses intentionally produced X-rays to evaluate the phase state or elemental composition of materials. This is done by study of the diffracted X-rays or fluorescence of the sample.



The photograph shows an analytical X-ray system used for diffraction studies. Several components are identified. The X-ray tube is housed within a shield. Can you also see the X-RAYS ON warning light?

Analytical X-ray Device Components

Detector – the device which typically measures diffraction patterns or energy spectra produced by interaction of X-rays with the sample

Backstop – the component located behind the sample, which absorbs non-diffracted X-rays; also called a beam trap

Sample – the item inserted into the X-ray beam for study by X-ray diffraction or efflorescence

Goniometer – the mechanism which allows the sample position to be adjusted, relative to the incident X-ray beam.

Tube Housing – a radiation shield which contains the X-ray tube

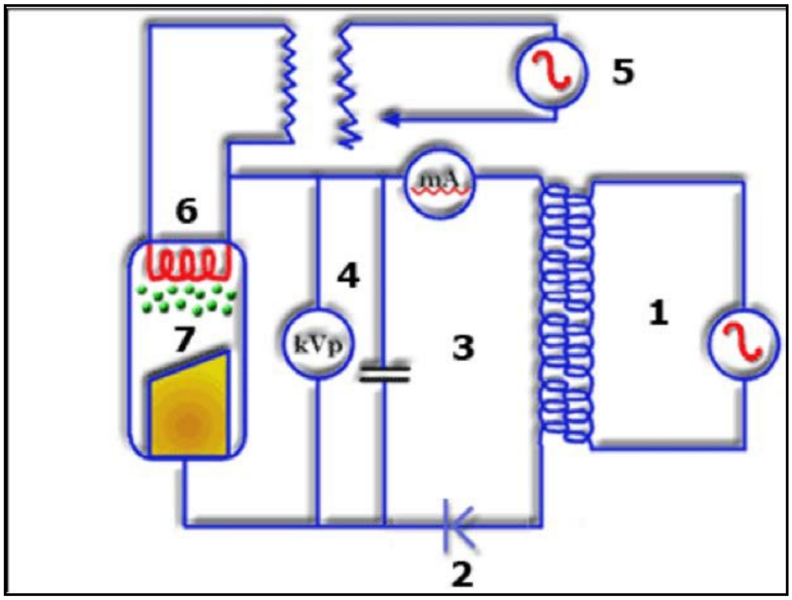
Primary beam – the x radiation emitted directly from the target and passing through the window of the x-ray tube

Monochromator – An instrument that diffracts x-rays from a crystal to produce a beam having a narrow range of wavelengths

Shutter – a safety device made of tungsten, tantalum, or lead that is inserted into the beam path in order to stop all X rays

Collimator – a device that narrows the beam of X-rays

Safety interlock – a device that is intended to prevent the generation of X-rays when access by any part of the human body to the interior of the X-ray system is possible.



Functionality of Analytical X-ray Devices

1. The X-ray generator takes line voltage through a step-up transformer to provide a high voltage.

2. The high voltage is converted from AC to DC by a rectifier.

3. A capacitor helps provide a constant high voltage across the X-ray tube.

4. A voltmeter indicates the high voltage potential across the X-ray tube. The ammeter measures the current (electron flow) across the tube. 5.5.An adjustable filament current or heater circuit regulates electrical current to the cathode and the subsequent X-ray intensity.

5. As the filament heats up, electrons “boil off” via thermionic emission. The cloud of electrons accelerates across the vacuum tube as the electrons are attracted toward the positively charged anode. X-rays are produced as the electrons interact with atoms in the target.

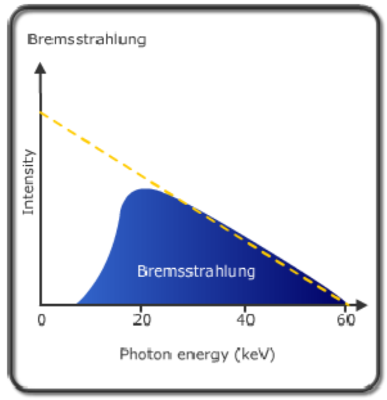
6. The X-rays released from the anode have a range of energies up to the maximum voltage applied across the tube. Filters are commonly inserted at the tube window to filter out X-rays of undesirable energies.

X-ray Spectrum

Let's take a closer look at the energy spectrum of X-rays produced by the X-ray tube. We will also see what happens to the spectrum as these X-rays exit the tube and are filtered before reaching the sample

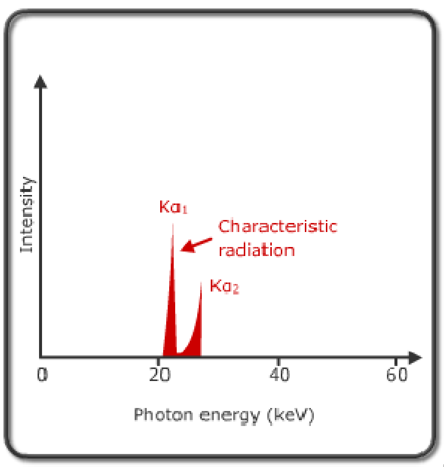
Bremsstrahlung

As accelerated electrons travel through the target material, some are deflected by the electrostatic fields of the target nuclei, because the negatively charged electrons are attracted by the positive charge of the target's protons.



Any change in the electron's speed or direction cause the electron to emit photons, including X-rays. This phenomenon is called Bremsstrahlung, a German word that means "braking radiation". The Bremsstrahlung energy spectrum is very broad.

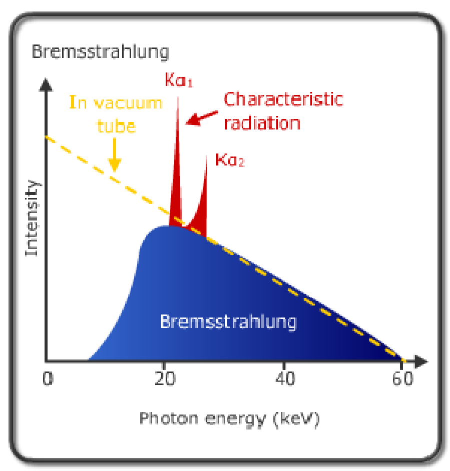
The maximum energy will correspond to the maximum high voltage applied to the X-ray tube. The maximum X-ray intensity occurs at about one-third of the maximum energy. For example, a 60 kV tube voltage will generate mostly 20 keV X-rays.



Characteristic X-rays

Some of the accelerated electrons will ionize target atoms, meaning an electron will transfer energy to a K-, L- or M-shell orbital electron, knocking it out of the atom. Once an orbital shell vacancy is created, an electron from an outer shell will drop into the vacant shell. As it does this, it emits a characteristic X-ray.

For any given target material (e.g. copper, tungsten, molybdenum, etc.), several X-rays having discrete energies are produced. Those most useful for diffraction studies include the K-alpha, K-beta, L-alpha and L-beta X-rays.



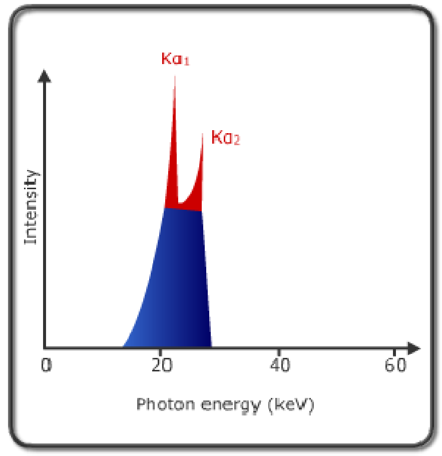
Beam Before Filter/Monochromator

Before reaching the filter/monochromator, the beam consists of both Bremsstrahlung and characteristic X-rays.

Notice that the characteristic X-rays appear as intensity peaks on top of the Bremsstrahlung background spectrum.

Although the X-rays have not yet passed through a filter, the very low energy X-rays are missing. This is because the X-ray tube window acts as a filter.

Beam After Filter/Monochromator



Ideally, diffraction studies would utilize a mono-energetic X-ray beam.

Filters are inserted in the beam path outside the tube in order to reduce the intensity of X-rays above and below the characteristic peaks.

Crystal monochromators may also be used in an attempt to produce a mono-energetic beam.

The final beam consists of both Bremsstrahlung and characteristic X-rays within a narrow energy range.

Regulatory Drivers and Guidance

There are several regulatory drivers which require Argonne to have a safety program for its analytical X-ray devices.

Regulatory Drivers
Code of Federal Regulations – 10CFR835 (Occupational Radiation Protection)
Code of Federal Regulations – 21CFR1020.40 (Performance Standards for Ionizing Radiation Emitting Products)

As a user of an X-ray device you must follow LMS-PROC-109.

There are numerous persons who play a role in the Argonne National Labs analytical X-ray safety program. Review these key players and their responsibilities starting in section 3.2.1 of LMS-Proc-109.

Sources of X-ray Exposure

Most users of the analytical X-ray equipment receive no measurable radiation dose. It is easy to forget that a hazard is present. However, it is possible to receive a significant radiation exposure with grave consequences.

Review the items below for more information on the parts of an analytical X-ray device where exposures are possible. Please pay attention to the exposure units. For our purposes, 1 roentgen (R) = 1 rad = 1 rem.

Open Primary Beam - 50,000-500,000 R/min (NOT millirem, NOT per hour) is the typical exposure rate at an unshielded, open port to the X-ray tube housing.
Collimated Primary Beam - Active ports typically have a collimator attached which reduces beam intensity by a factor of 10. The exposure rate between the collimator & sample ranges from 5,000 - 50,000 R/min (NOT millirem, NOT per hour).

Leakage Radiation - The housing around the tube and other components does not always block all of the X-rays. Leakage radiation is sometimes encountered. The levels at 5 cm from beam barrier could be: 500 - 5000 mR/hr.

Scattered Radiation - Some of the X-rays which strike the sample or the backstop are reflected or scattered. The exposure rate 5 cm from sample may be <10 - 300 mR/hr.

Causes of Radiation Accidents

Unfortunately, people have been injured by analytical and industrial radiation generating devices. Why did these accidents or near misses happen? The common causes of radiation accidents.

Equipment failure – This is frequently the initiating event. The components which most often fail are beam shutters and interlocks.

Inadequate maintenance programs – Any mechanical or electrical device will eventually fail. Periodic testing and a maintenance program should be established to detect and repair components before they fail.

Inadequate radiation surveys – We cannot detect ionizing radiation with our senses. Careful radiation measurements are needed to detect excessive X-ray leakage or other abnormal radiation conditions. Some unnecessary radiation exposures have occurred because personnel did not know how to use survey meters properly.

Failure to conduct radiation surveys – Abnormally elevated radiation levels have occurred without the knowledge of the persons working with X-ray devices, because no routine surveys were ever conducted.

Failure to establish or follow operating procedures – Alignment operations are potentially more hazardous than normal operations. However, any operation may be hazardous if a careful safety analysis review is not done. Established procedures are of no value if they are not followed by the users.

Unqualified (inadequately trained) users – Past accidents often show that the persons involved lacked a good understanding of the hazards and methods of control. Anyone who works with X-ray devices must be trained to have the knowledge and skills required to work safely.

Acute Radiation Dose Effects

An acute (severe) radiation dose may occur during an X-ray device accident. Most accidents involve X-ray exposure of the fingers. These are the most common, observable health effects. Additionally, victims of acute X-ray exposure have an increased risk of future skin cancer. The latency period between exposure and effect is typically 15-20 years.

Dose (rad)	Effect to Skin
300	Temporary Epilation (hair loss) - One of the first signs of accidental acute X-ray exposure is that the hair on the exposed body part will fall out.
600	Erythema (skin reddening) - This occurs promptly (within a few hours) though lesser doses may take days or weeks for symptoms to occur.
1500-2000	Dermal Necrosis (cell death) and Ulceration - This effect takes several days or weeks to become noticeable. It will worsen over a period of months. The skin will appear burned.
100-200	Cataracts to Lens of Eye - While the skin is the most likely body part to be affected, the eye may also be at risk. At this dose, some cells within the lens die. Since there is no blood flow within the lens, these dead cells are not removed or replaced with new cells. They block transmission of light to the retina and the victim's vision will degrade.

Radiation Burns

X-rays penetrate the epidermis and damage the deeper, basal skin layer which produces new skin cells. The damage is not immediately apparent.

Unlike a thermal burn (e.g. fire), the victim does not feel any heat sensation while exposed to the X-ray source. There is no reflex action to pull away from the hazard. If the basal cell epithelium is destroyed, the damaged area will no longer produce new skin cells. If the capillaries are destroyed by the radiation, skin grafts will not survive. This photo shows a man's hand 2 months after receiving an acute radiation dose on the order of several thousand rad. In this case, the victim's fingers were later amputated.

Interlock

Are your interlocks bypassed?

One of the most important safeguards against injury by X-ray generating devices is the interlock safety system. Interlocks are designed to turn off the X-ray generator if an unsafe condition occurs. However, there may be circumstances under which interlocks are temporarily bypassed.

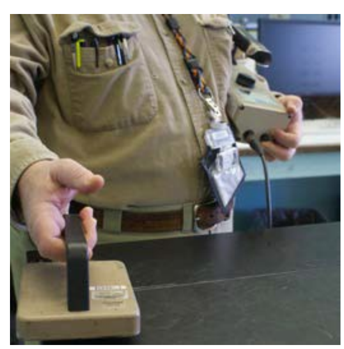
This photo shows the corner of a hutch which contains an X-ray device. The memo is taped to a sliding door which allows users full access to the X-ray device. The black object above the memo is an interlocked sensor switch. It will automatically turn off the X-ray source if the door is opened. During alignment and some other operations, authorized users may bypass the safety system. This means that the X-ray source stays on when the door is open.

Does the equipment you operate allow this type of open beam in operation? If someone bypassed the interlock switch on your equipment, how would you know?

Interlock Bypass Indicator

Before you may operate an analytical X-ray device, the custodian must give you an orientation. You should clearly understand whether or not the machine can operate in open beam mode. If it were in open beam mode, how would you know? Some machines use a special light and/or an alarm sound.
On the device in the photo, the green light on the box near the interlock switch indicates that the switch is functional. If the red light were on, it would mean that the interlock switch is bypassed and X-rays could be persistent while the door was open.
Only the custodian or his/her designee may bypass safety interlocks. This may only be done for short periods of time (2 hours). If you ever wish to bypass interlocks to do open beam operation, you must contact the custodian to do it for you. Persons using the machine may not bypass the interlocks.
If a custodian wishes to operate a device in open beam mode, he or she must have a delegate custodian apply the bypass.

Radiation Survey Instruments



Many X-ray facilities have a portable radiation survey instrument available. If your facility has one, ask the custodian or area Health Physics how to use it.

The purpose of the radiation survey instrument is to perform a qualitative check to find out whether the radiation levels are normal.

Basic Procedure:

- Test the battery by rotating the switch or pressing the button.

- Verify that the instrument label is within the calibration due date.
- Verify that the meter gives a normal reading when the X-ray tube is off.
- Select HIGH scale first.
- If no radiation is detected, turn to a more sensitive scale.

Safeguards

ALL INSTALLATIONS

A list of users/operators shall be posted conspicuously at the entrance to each facility or laboratory containing analytical X-ray equipment.

A warning light of failsafe design labeled with the words “X-RAYS ON” shall be conspicuously located near the X-ray tube housing to indicate when the X-ray tube is activated.
A sign or label indicating:

shall be placed near any switch which directly energizes an X-ray tube.

Incidental radiation from components such as high voltage rectifiers, beam traps, etc. shall not exceed 0.25 mrem/hr in any accessible region 5 cm from the outside surface of the generator cabinet.

Unwanted radiation doses from rectifiers, etc. shall be reduced as low as reasonably achievable.

Normal operating and alignment procedures shall be as recommended by the manufacturer of the X-ray system, or by the facility manager if the source housing and X-ray accessory apparatus are not compatible components by the same manufacturer. Normal operating and alignment procedures shall be in accordance with the Argonne National Labs administrative exposure control limits.

All safety devices (shutters, warning lights) shall be tested every six months to ensure their proper operation. Records of these tests shall be maintained by the facility manager.
Any attempt to alter safety devices shall be approved by the RGD custodian and the Health Physics RGD Safety Officer.

Upgrades of equipment shall follow recommendations of the manufacturer, whenever possible, and shall be reported to the RGD Safety Officer, division ESH coordinator and local Health Physics group.

A radiological label is normally posted that designates the device as a “Radiation Generating Device, Authorized Users Only”. However, for high-dose open-beam X-ray generating equipment, a posting is located outside the room. Labs containing cabinet-style X-ray units and other RGDs are generally not radiation areas since the maximum dose rate outside the unit is less than 5 mrem/hr. There is also a small label near the on-off switch that warns that “this device produces x-rays when energized” (or a similar statement).

Dosimetry requirements are specified in LMS-PROC-109.

Enclosed Beam Only

All X-ray beam paths shall be enclosed such that no body part can be exposed during normal operation.

Inherent shielding of the unit’s chamber walls shall limit the dose rate at 5 cm from surface to 0.25 mrem/hr during normal operation.

The sample chamber shall be interlocked by failsafe methods so no X-ray beam can enter while it is open.

If radiation source housing has more than one port or source, all requirements above must be satisfied for each port in every source housing associated with the system (many X-ray units have 4 ports).

Open Beam Only

A “shutter open” warning indicator of failsafe design must be in place.

Dose rates shall be < 2.5 mrem/hr at 5 cm from the surface of the housing with all shutters closed. (Note: this level is 10 times higher than allowed for an enclosed beam system.)

Each port requires an interlocked beam shutter so the port can only be open when the collimator or coupling is in place. Shutters at unused ports shall be secured.

A guard or interlock which prevents entry of any part of the body into the primary beam path shall be utilized.

Interlocked Guard or Barrier

An open beam system which has areas where a person could insert their hand, finger, etc. must have a barrier or guard in place. The guard must be interlocked to turn off the beam if it is removed.

Backscatter Monitor

A backscatter monitor detects low energy (scattered) X-rays which may occur under an accident scenario. The device sounds an audible alarm if the radiation dose rate exceeds 0.3 mrem/hr. It does not turn off the X-ray source.

Area Monitor Alarm

In the event of an Area Monitor Alarm:

- Move away from the X-ray source
- Warn others as necessary
- Turn off the power to the X-ray generator. (The X-rays will immediately stop being produced, but the alarm may still sound for a minute or so)
- Notify Health Physics and the Custodian.

This concludes ESH705 Analytical X-ray training.

You will now be directed to the learning measurement exercise.

Please click the here to proceed.