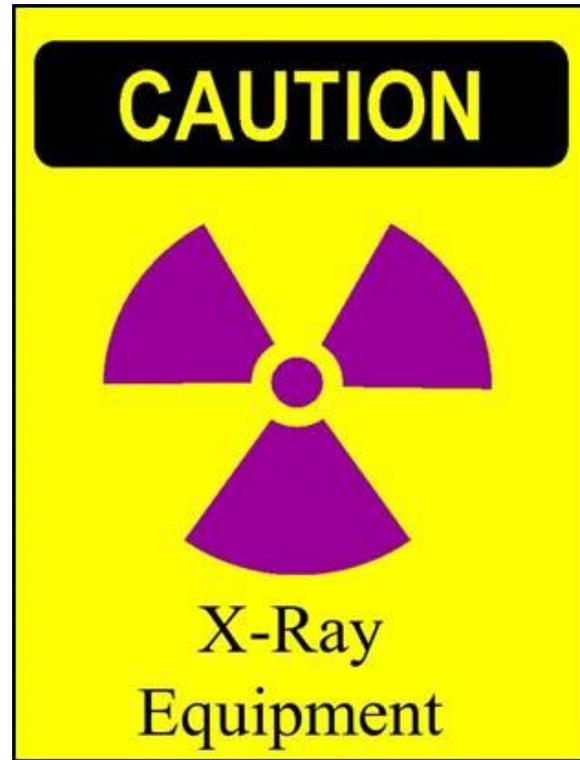


# NMSU Analytical X-Ray Safety



# Examples of Analytical X-Ray Equipment at NMSU



X-Ray Diffraction  
(Rigaku MiniFlex II)



X-Ray Diffraction  
Panalytical Empyrean



X-ray Fluorescence  
(Rigaku ZSX)



X-Ray Fluorescence  
(Innov-X Alpha)



X-Ray Diffraction  
Bruker D8 Advance

# NMSU Radiation Safety Program Overview

## State of New Mexico Radiation Control Bureau (under the New Mexico Environment Department)

- ❖ Primary regulatory agency controlling the use of most radioactive materials and radiation-producing devices in the State of New Mexico.

## NMSU Radiation Safety Committee (URSC)

- ❖ Members include faculty and technical staff that represent different research areas and techniques using radioactive materials or radiation-producing machines.
- ❖ Set NMSU radiation safety policy and established a radiation safety program to ensure that exposure to NMSU users is kept As Low As Reasonably Achievable (ALARA).
- ❖ Review / approve all new applications to use radioactive material or radiation-producing machines.
- ❖ Annually review the overall performance and compliance of the NMSU Radiation Safety Program.

## Radiation Safety Officer (RSO)

- ❖ Oversees the day to day activities of the Radiation Safety Program.
- ❖ Issues approved Authorized Users Use permits; can modify approved permits when by the AU.
- ❖ Official liaison between NMSU and applicable regulatory agencies.
- ❖ Works closely with faculty and researchers who want to work with radioactive material or devices.

## Authorized User (AU) / Permit Holder

- ❖ Is the faculty or researcher who is authorized by the RSC to use, supervise and control use of radioactive material or devices within the scope of their permit.

# Authorized User Responsibilities

Register authorized workers with the RSO.

Ensure lab operations and processes are organized and safe:

- ❖ Ensure workers have received required training (safety and process / equipment operation specific training)
- ❖ Ensure required survey instruments and/or personal dosimetry are available to workers.
- ❖ Ensure lab-specific administrative & engineering controls are in place and working.
- ❖ Provide written SOPs for routine processes and equipment operations.
- ❖ Provide written procedures for doing beam alignments or other non-standard procedures.
- ❖ Develop and train workers to lab emergency response procedures.

Notify the RSO, in advance, when x-ray equipment is acquired, transferred, surpluses or moved from the permitted location.

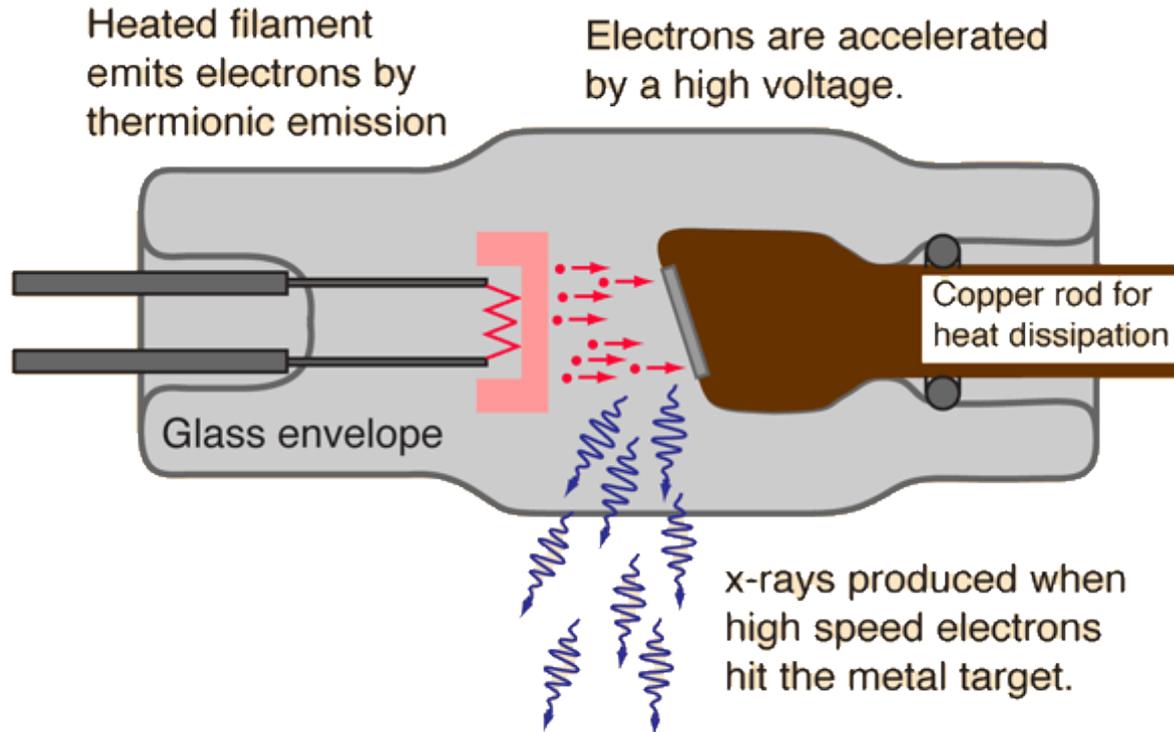
Ensure x-ray leakage and area dose rate surveys are completed as required by the Radiation Safety Program.

- ❖ EH&S Radiation Safety will perform the surveys upon request whenever:
  - New equipment installed.
  - Equipment is moved to a new location.
  - After maintenance requiring disassembly or change in system configuration or components.

# Individual Worker Responsibilities

- ❖ Follow all lab / equipment procedures as directed by the AU.
- ❖ Wear PPE and assigned dosimetry as required by the AU.
- ❖ Do not attempt to defeat or bypass any safety interlocks unless specifically authorized to do so in writing by RSO.
- ❖ Secure the lab or de-energize equipment before leaving the lab.
  - Ensure lab is locked and personnel access is limited if running unattended operations.
- ❖ Keep unauthorized people out of the work area while x-ray is on and notify other workers in the area that equipment is running.
- ❖ Keep your personal x-ray exposure ALARA.
- ❖ Report any problems or anomalies with equipment and/or procedures to the AU or Lab Supervisor before proceeding
- ❖ Notify the AU & RSO of any suspected x-ray exposures

# X-Ray Tube Operation



Fast-moving electrons slam into a metal object and x-rays are produced. The kinetic energy of the electron is transformed into electromagnetic energy of the x-ray.

# Radiation Quantities and Terms

- ❖ **Exposure** is a measure of the strength of a radiation field at some point. It is usually defined as the amount of charge (i.e., sum of all ions of one sign) produced in a unit mass of air when the interacting photons are completely absorbed in that mass. The most commonly used unit of exposure is the "roentgen" (R) which is defined as that amount of X or gamma radiation which produces  $2.58 \times 10^{-4}$  coulombs of charge per kilogram of dry air. In cases where exposure is to be expressed as a rate, the unit would be R/hr or, more commonly, milliroentgen per hour (mR/hr).
- ❖ Whereas exposure is defined for air, the **absorbed dose** is the amount of energy imparted by radiation to a given mass of any material. The special unit of absorbed dose is the "rad" which is defined as a dose of 100 ergs of energy per gram of the matter. The S.I. unit for absorbed dose is the gray where 1 gray equals 100 rads. Absorbed dose may also be expressed as a rate with units of rad/hr, millirad/hr, gray/hr, etc.

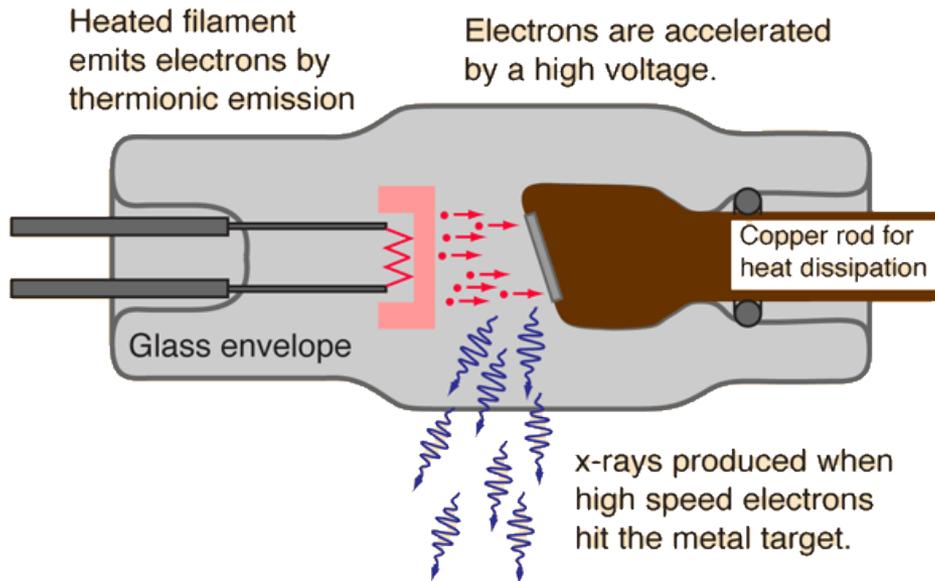
# Radiation Quantities and Terms

- ❖ **Dose Equivalent** Although the biological effects of radiation are dependent upon the absorbed dose, some types of radiation produce greater effects than others for the same absorbed dose. In order to account for these variations when describing human health risk from radiation exposure, the quantity "dose equivalent" is used. This is the absorbed dose multiplied by certain "quality" and "modifying" factors indicative of the relative biological-damage potential of the particular type of radiation. The special unit of dose equivalent is the rem or mrem. The S.I. unit for dose equivalent is the sievert where 1 sievert equals 100 rem. Dose equivalent may likewise be expressed as a rate with units of rem/hr millirem/hr, sieverts/hr, etc. For gamma or x-ray exposures, the numerical value of the rem is essentially equal to that of the rad.
- ❖ **Shielding** is any material, which is placed around or adjacent to a source of penetrating radiation for the purpose of attenuating the exposure rate from the source. For shielding x-rays, materials composed of high atomic number elements such as lead are highly effective.

# Interaction of X-Rays with Matter

- ❖ X-rays transfer their energy to matter through chance encounters with bound electrons or atomic nuclei. These chance encounters result in the ejection of energetic electrons from the atom. Each of the electrons liberated goes on to transfer its energy to matter through thousands of direct ionization events (i.e. events involving collisions between charged particles). Since x-rays and gamma rays transfer energy in this "indirect" manner, they are referred to as "indirectly ionizing radiation".
- ❖ Because the encounters of photons with atoms are by chance, a given x-ray has a finite probability of passing completely through the medium it is traversing. The probability that an x-ray will pass through a medium without interaction depends upon numerous factors including the energy of the x-ray and the medium's composition and thickness.

# Characteristics of X-Rays



**Charge:** No charge, Indirectly ionizing

**Range:** Hundreds of feet

**Shielding:** Very dense materials (lead, concrete, steel, etc)

**Biological Hazard:**

- ❖ Easily penetrate body tissues,
- ❖ Whole body hazard

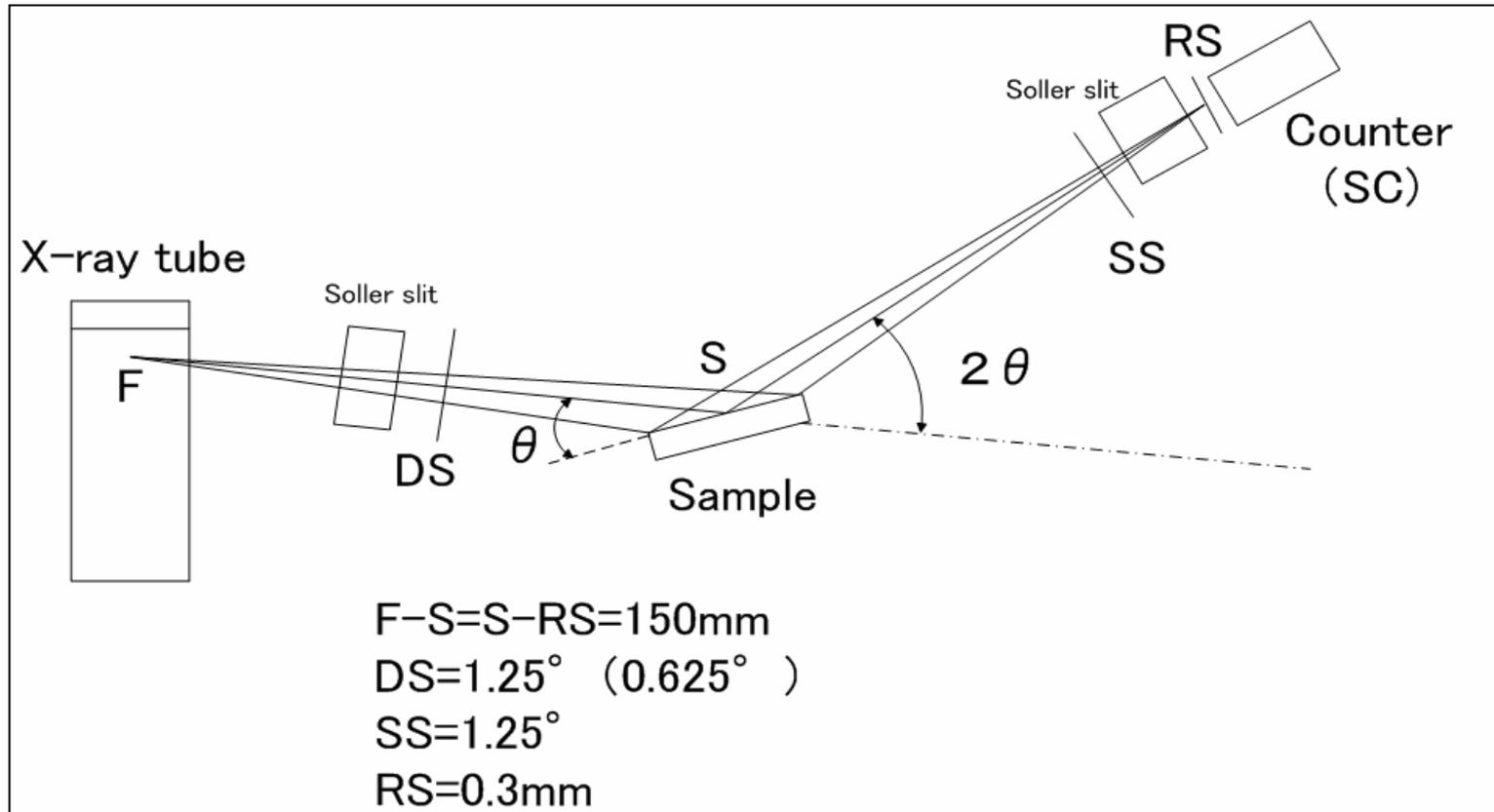
# Operational Modes of Analytical X-ray Systems

- ❖ Analytical x-ray systems generally consist of three basic components: an x-ray source, a specimen support or holder, and a detector. In a given experimental setup, these three components may be enclosed in one integral, commercially available unit or they may be three distinct systems assembled by the user. The way in which the basic components of the x-ray system are assembled depends largely upon the mode of operation. Analytical x-ray systems have two principal modes of operation: **diffraction and fluorescence**.

# X-Ray Diffraction

- ❖ X-ray diffraction is used extensively for analyzing the structure and properties of solid materials. Typical acceleration potentials for devices operating in this mode are from 25-50 kVp. This method may be applied in a number of ways depending upon the thickness and form of the sample and the specific results desired. In a typical configuration of a diffraction system the primary beam from the target of the x-ray tube emerges from the machine through a collimator and strikes the sample, which diffracts it in a characteristic manner. The diffraction pattern is measured with photographic film or a radiation detector.

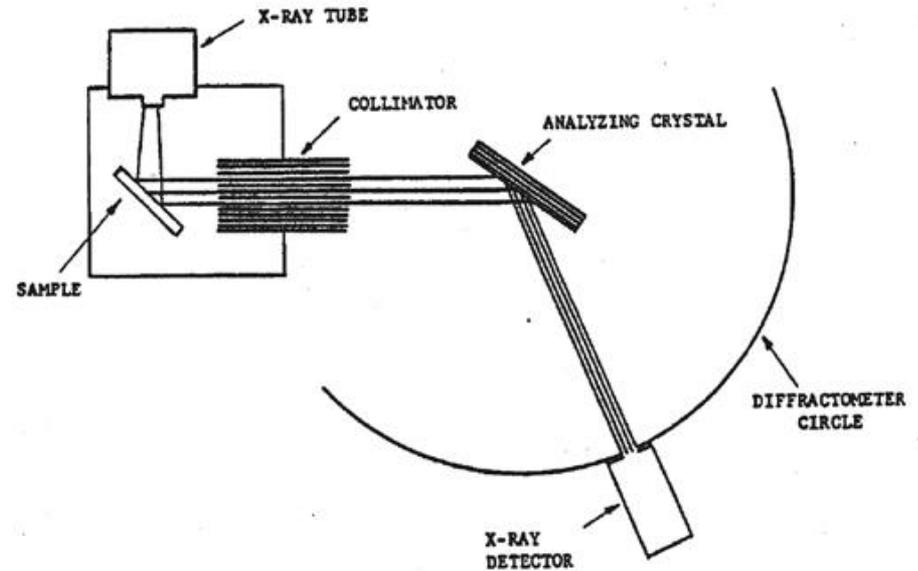
# Example X-Ray Diffraction Optical System



From Rigaku MiniFlex II Hardware Manual

# X-Ray Fluorescence

X-ray fluorescence spectroscopy is an analytical method for determining the elemental composition of a sample. Typical acceleration potentials for devices operating in this mode are in the range of 25-100 kVp. As shown below, the primary radiation beam strikes the sample inside a shielded enclosure, and only scattered radiation and secondary radiation produced in the sample emerges from the machine for analysis.



# Enclosed and Open Systems

- ❖ Many modern analytical x-ray systems are designed with interlocked barriers that enclose all system components in a manner that prevents radiation levels in excess of 0.25 mR/hr at any operator position. Such “enclosed” systems dramatically reduce potential risks to personnel that are inherent in the operation of “open beam” systems. For enclosed systems, standard operating procedures should include references to the various interlocks present in the system and the means for recognizing any failures of these interlocks.

# Radiation Hazards of Analytical X-ray Systems

- ❖ Analytical x-ray systems produce highly intense beams of x-rays that are predominantly low in energy relative to those utilized in medical diagnosis and therapy. Such x-rays are often described as being "soft" because of the ease by which they are absorbed in matter. While this characteristic enables soft x-rays to be readily shielded (generally requiring only a few millimeters of lead), it also makes them particularly hazardous since they are highly absorbed even by soft tissue. For example, 10 KeV x-rays will deposit 50 percent of their energy in the first 0.25 millimeters of tissue.
- ❖ Radiation emitted from an analytical x-ray device consists of the primary beam, diffracted beam, scattered x-rays, and secondary x-rays. The degree to which these various radiation components pose a potential hazard to the equipment operator is determined largely by whether the x-ray system is "enclosed" or "open".

# Primary Beam Radiation Hazards

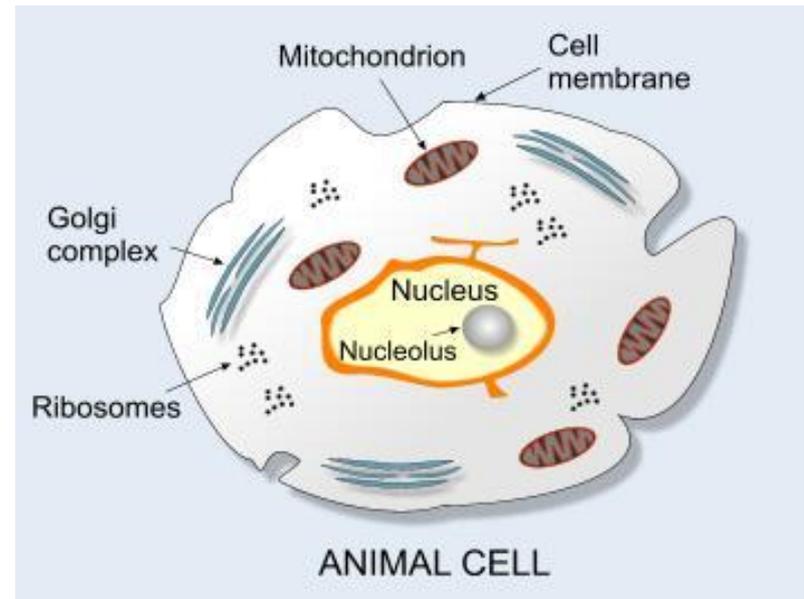
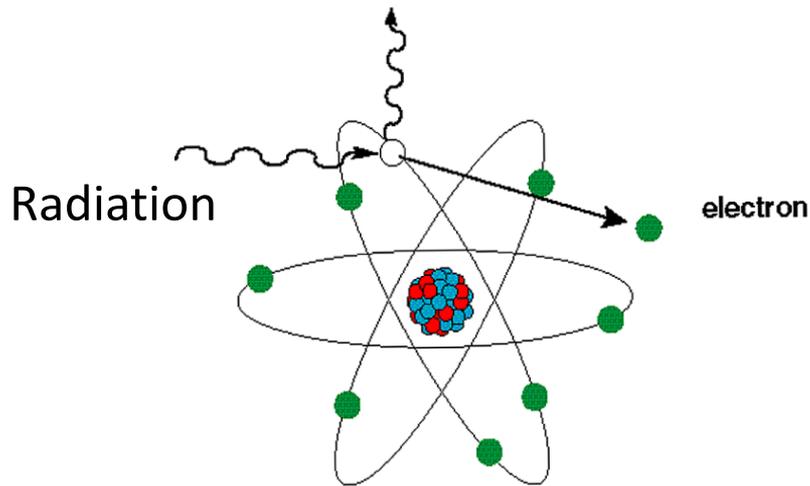
- ❖ The primary beams from analytical x-ray systems are generally well collimated with beam diameters of less than one centimeter. Because of their intensity and their high degree of absorption in tissue, they can produce severe and permanent local injury from exposures of only a fraction of a second. The greatest risk of acute accidental exposure from an analytical system occurs in manipulation of the sample to be irradiated by the direct beam in diffraction studies. Exposure rates on the order of 10,000 R/sec can exist at the tube housing port. At these levels, erythema would be produced from exposures of only 0.03 second and permanent injury could be inflicted in only 0.1 second. The hands, of course, are the part of the body most at risk from such high exposures.
- ❖ Potential exposure to the primary x-ray beam is generally not a major concern for analytical systems operating in the fluorescence mode since these are generally closed systems (i.e., the primary beam is contained within a shielded enclosure). The possibility of leakage of the primary beam through the shield, however, cannot be discounted.

# Diffracted, Scattered & Secondary X-Ray Radiation Hazards

- ❖ For x-ray diffraction systems, the diffracted beam is also small and often well collimated with an intensity of up to 80 R/hr. Prolonged or repeated exposures to a beam of this intensity could result in an individual exceeding the annual dose limit for the particular tissue irradiated.
- ❖ Through interactions with the sample and shielding material, the primary beam in diffraction systems often produces diffuse patterns of scattered and secondary x-rays in the environment around the equipment. Exposure rates of 100 mR/hr near the shielded sample are possible. In contrast, scattered and secondary radiation levels in the vicinity of a fluorescence system (where only secondary radiation emerges from the shielded target-sample assembly) are generally an order of magnitude less.

# Biological Effects of Radiation Exposure

Biological effects begin with the transfer of energy and ionization of atoms within a cell.



# Biological Effects of Radiation Exposure

When ionizing radiation interacts with tissues cells energy is transferred to atoms and molecules can cause damage to cellular structures which regulate vital cell processes (e.g. DNA, RNA, proteins). This damage is caused by

- Breaking of chemical bonds.
- Free radical production.
- Production of new chemical bonds and formation of new, potentially toxic chemical compounds.

Repair mechanisms within the body can repair certain types or amount damage to cells, If the damage is severe enough the cell can die. At low doses (background) the body has mechanisms that can repair damaged cells or replace dead cells without any kind of measurable effect.

At high levels of radiation, many cells are damaged or killed simultaneously. This can produce observable, measurable effects in the body. The effect varies depending on what types of cells are affected.

At extremely high doses, the very large numbers of cells that are affected means that the body cannot be repair or replace quickly enough and entire organ systems and bodily functions begin to fail.

# Cell Sensitivity to Ionizing Radiation

Different types of tissue have varying levels of sensitivity to damage from ionizing radiation. In general cell sensitivity is:

- proportional to the rate of proliferation of the cells
- inversely proportional to the degree of cell differentiation

**Most Sensitive:**

**Blood-forming organs (Bone Marrow)**

**Reproductive organs**

**Skin**

**Bone Surface and teeth**

**Muscle**

**Least sensitive: Nervous system**

# Direct and Indirect Effects

## Direct Effects

Are effects from direct damage to DNA other critical cell organelles. This may kill cell or damage the cell in a way that a cell can't function normally (i.e. affects the cell's ability to divide)

## Indirect Effects

Radiation interacts with water inside the cell membrane causing the formation of secondary products through radiolysis of water.

- Free radicals (H and OH)
- Fragments may recombine to form toxic substance such as hydrogen peroxide ( $H_2O_2$ )

# Acute vs. Chronic Radiation Exposure

**Acute Exposure** = A single large dose delivered over a very short period of time.

**Chronic Exposure** = Small doses delivered over a long period of time.



# Prompt and Delayed Effects

The effects of ionization radiation can be categorized into two groups, Prompt (immediate) effects and delayed effects.

- Prompt effects are seen shortly after exposure to a large dose of radiation delivered over a short period of time (acute exposure):
  - Acute Radiation Sickness
  - Erythema (reddening of the skin)
- Delayed effects may appear months or years after a radiation exposure (acute or chronic exposures):
  - Formation of cataracts in eyes
  - Induction of a cancer

# Prompt Effects

These effects will develop within hours, days or weeks, depending on the size of the dose. The larger the dose, the sooner a given effect will occur.

Dose (Rad)	Effect
< 5	No observable effects.
5 - 50	Can measure slight blood chemistry changes.
50 - 150	Blood chemistry changes, Vomiting (threshold), fatigue.
150 to 1100	Major changes in blood chemistry, blood-forming organs damaged; LD 50/60 at 300-500 Rad (without medical).
1100 - 2000	GI tract effects; death probable within 1 to 2 weeks without immediate intensive medical treatment.
> 2000	Death is almost certain. Above 5000 rad central nervous (brain/muscles) damage, loss of critical body functions.

# Partial Body Exposure

The effects of exposure to radiation can be significantly different when only a portion of the body is irradiated versus a “whole body” exposure.

## **For example:**

500 rem delivered to the skin of an extremity will cause hair loss and skin reddening.

500 rem delivered uniformly to the whole body may cause death

# X-Ray Exposure Signs and Symptoms

The first visual indication of a high x-ray exposure is **erythema or reddening of the skin tissues**.

- Hands and fingers are generally the most at risk when operators perform x-ray beam alignment or system maintenance, repair or modification activities.
- The threshold dose for this effect is approximately 300 rads (3.0 Gray).
- Generally, this effect occurs within a day of the exposure and then disappears.
- The effect may recur 8-14 days later with accompanying pain in the affected tissue.
- After a few days, the skin may return to its normal appearance but remain highly sensitive to future x-ray or ultraviolet radiation exposures.
- **Chronic dermatitis or skin cancer may develop months to years later** as a result of the exposure.

Doses greater than 5000 rads (50 Gray) will likely lead to development of blood flow problems leading to atrophy and ulcerations in the affected tissues. This may eventually require the amputation of fingers or major portions of the hand.



Pictures From: Cutaneous Radiation Injury (CRI): A Factsheet for Physicians, CDC

# Delayed Effects

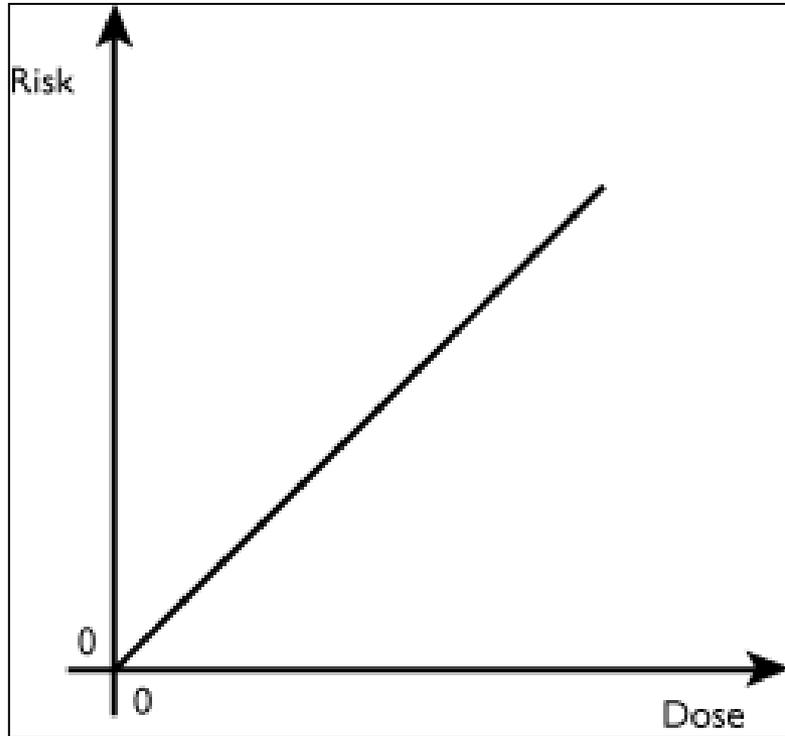
## Cataracts

- Cataracts are induced when the lens of the eye doses exceeding approximately 200-300 rem is delivered to the lens of the eye. Radiation-induced cataracts typically take many months to years to appear.

## Cancer

- Studies of people exposed to high doses of radiation have shown that there is a risk of cancer induction associated with high doses.
- The specific types of cancers associated with radiation exposure include leukemia, multiple myeloma, breast cancer, lung cancer, and skin cancer.
- Radiation-induced cancers may take 10 - 15 years or more to appear.
- There *may* be a risk of cancer at low doses as well.

# Linear No-Threshold Model (LNT)



Some risk is associated with any exposure to ionizing radiation.

# Cancer Risk Estimates

Using the linear no-threshold risk model:

- The average lifetime risk of death from cancer following an acute dose equivalent to all body organs of 0.1 Sv (10 rem) is estimated to be 0.8%.
- This increase in lifetime risk is about 4% of the current baseline risk of death due to cancer in the United States. The current baseline risk of cancer induction in the United States is approximately 25%.

Another way of stating this risk:

- A dose of *10 mrem* creates a risk of death from cancer of approximately *1 in 1,000,000*.

[National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation, 1990]

# Radiation Risk In Perspective

A **1 in 1,000,000** (1 in 1 million) chance of death by participating in some common activities (cause of death is in parentheses):

- Smoking 1.4 cigarettes in a lifetime (lung cancer)
- Eating 40 tablespoons of peanut butter (aflatoxin)
- Whole body exposure to 10 mrem of ionizing radiation (cancer)
- Spending two days in New York City (air pollution)
- Driving 40 miles in a car (accident)
- Flying 2500 miles in a jet (accident)
- Canoeing for 6 minutes (drowning)

(from DOE Radiation Worker Training)

# Genetic Effects

- Studies have not conclusively shown that there are heritable effects from exposure to radiation but indicate that the rate of genetic disorders produced in humans is expected to be extremely low. The best estimate is that the rate of genetic disorders from radiation exposure is on the order of a few disorders per million liveborn per rem of exposure to the parents.



# Prenatal Radiation Exposure

Rapidly proliferating and differentiating cells are the most sensitive for radiation damage. A growing fetus is both rapidly proliferating and differentiating at various stages of the gestation period. Consequently, radiation exposure can produce developmental problems, particularly in the developing brain, when an embryo/fetus is exposed to radiation prenatally.

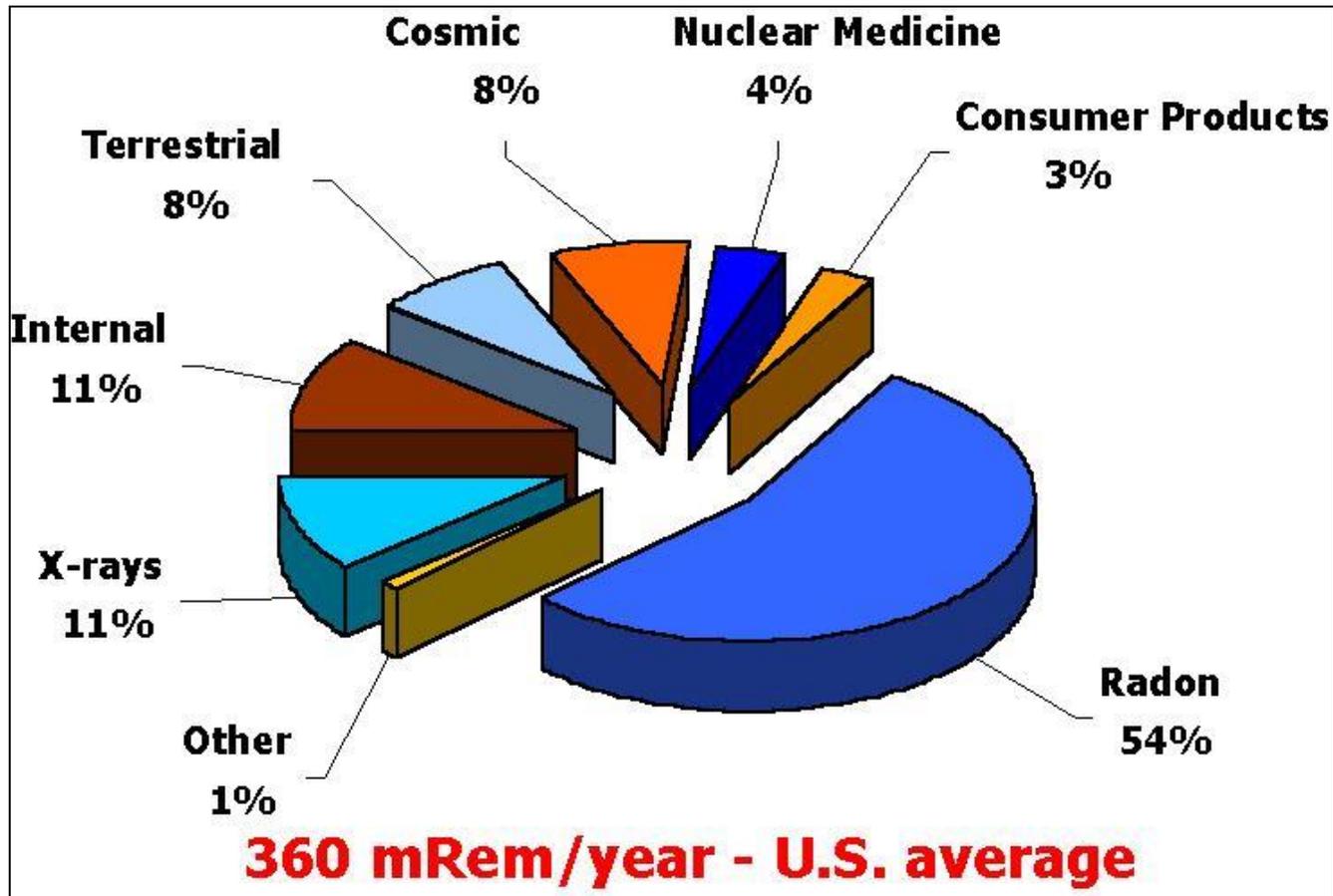
Conditions most commonly associated with prenatal radiation exposure include:

- Low birth weight,
- Microcephaly
- Mental retardation and other neurological problems.

The threshold dose for developmental effects is approximately *10 rem*.



# Sources of Background Ionizing Radiation



Excerpt from NCRP Report 93, Ionizing Radiation of the Population of the United States, 1987

# Radiation Dose Limits for Workers

	State of New Mexico Annual Limits (mrem)	NMSU Administrative Control Annual Limits (mrem)
Whole Body	5000 (50 mSv)	<b>500 (5 mSv)</b>
Extremities	50,000 (500 mSv)	<b>5000 (50 mSv)</b>
Skin & Other Organs	50,000 (500 mSv)	<b>5000 (50 mSv)</b>
Lens of Eye	15,000 (150 mSv)	<b>1500 (15 mSv)</b>
General Public	100 (1 mSv)	<b>100 (1 mSv)</b>
Declared Pregnant Worker	500 (5 mSv) / gestation period	<b>500 (5 mSv) / gestation period</b>

# Worker Exposures to Ionizing Radiation

Any worker exposure greater than a NMSU administrative control limit will be investigated by the RSO who, along with the AU will:

- Evaluate work practices
- Inspect Worksite / laboratory
- Provide or recommend additional training if necessary

These are steps taken to ensure that future exposures to ionizing radiation are maintained As Low As Reasonably Achievable (ALARA).

# NMSU ALARA Policy

All work involving the use of radioactive materials and ionizing radiation must be performed in such a way to keep human and environmental exposures:

## As Low As Reasonably Achievable

It is the responsibility of both individual workers and Authorized Users to maintain worker radiation exposures below regulatory limits whenever possible.

Administrative control limits for worker exposures have been established to ensure worker doses remain below regulatory limits.

# Keeping External Exposures ALARA

You can keep your external exposure to ionizing radiation ALARA using 3 simple concepts:

- **Minimize Time** spent near a source of ionizing radiation.
- **Maximize Distance** between you and a source of ionizing radiation.
- **Use Shielding** appropriate for the type of ionizing radiation you are working with.

# Minimize Time

## Minimizing time exposed to a source of radiation:

- Pre-plan tasks involving the use of the x-ray.
- Perform preparation work away from the x-ray.
- Be familiar with the x-ray machine operations including sample loading procedures before turning on the x-ray beam.
- Don't loiter in the area while the x-ray is on.

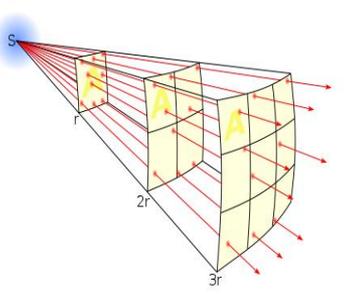
# Maximize Distance

Keep distance between you and the x-ray when the x-ray beam is on.

Away from the machine, dose rate will generally fall off following the inverse square law:

- Double the distance - dose rate falls to  $\frac{1}{4}$
- Triple the distance - dose rate falls to  $\frac{1}{9}$ .

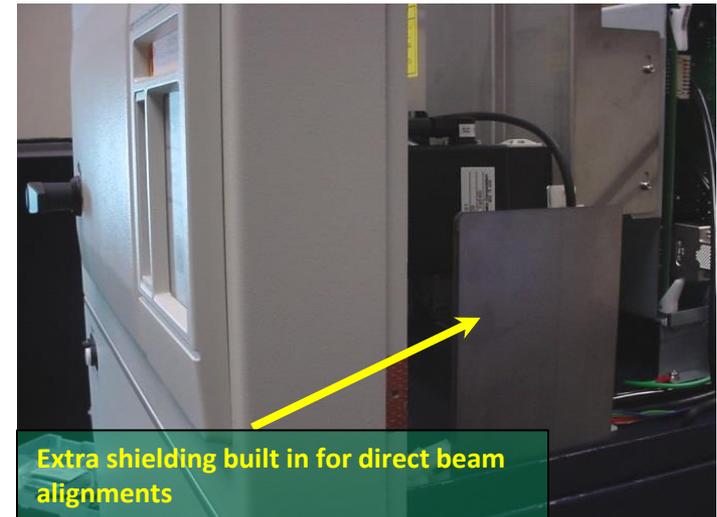
Intensity is inversely proportional to the square of the distance from the source



$$\text{Intensity} \propto \frac{1}{\text{distance}^2}$$

# Use Shielding

- Shielding is built into most commercial analytical x-ray systems.



- Use high-Z materials (i.e. lead, steel) to shield x-rays.
- Amount of shielding needed depends primarily on the energy of the x-rays.

# X-Ray Beam Hazards

**Primary beam:** The primary beam is most hazardous because of the extremely high exposure rates. Exposure rates can be as high as 400,000 rem/minute at the exit port of ordinary diffraction x-ray tubes. Collimated and filtered beams can produce about 5,000 to 50,000 rem/minute. Diffracted beams can be as high as 80 rem/hour.

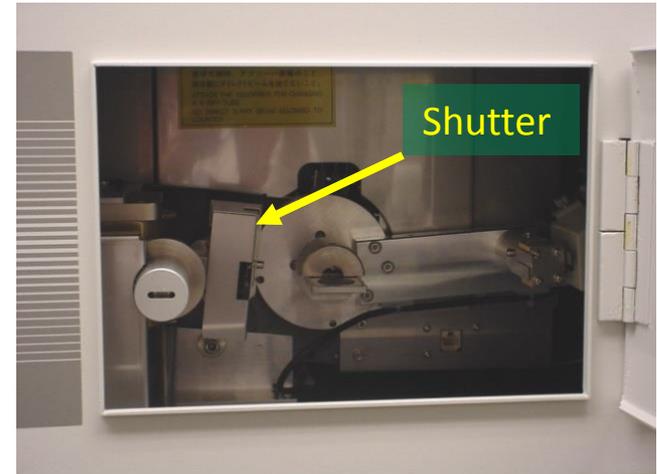
**X-Ray Leakage or Scatter:** The leakage or scatter of the primary beam through apertures in ill fitting or defective equipment can produce very high intensity beams of possibly small and irregular cross section.

**Component X-Ray Penetration:** The hazard resulting from penetration of the useful beam through the tube housing, shutters or diffraction apparatus is minimal in well-designed equipment. Adequate shielding is easily attained at the energies commonly used for x-ray diffraction and fluorescence analyses.

**Diffracted X-rays:** Diffracted beams tend to be small and irregular in shape. They may be directed at almost any angle with respect to the main beam, and occasionally involve exposure rates of the order of 80 rem/hour.

# External Dose Rate Limits for X-Ray Equipment

With the x-ray beam on and the shutter closed, the dose rate @ 5 cm from the closed shutter must be  $< 2.5$  mrem/hr.



With the x-ray beam on, the dose rate at any point @ 5 cm from exterior of the cabinet must be  $< 0.25$  mrem/hr.



Pictures are of a Rigku MiniFlex II XRD

# Commercial System Engineering Controls

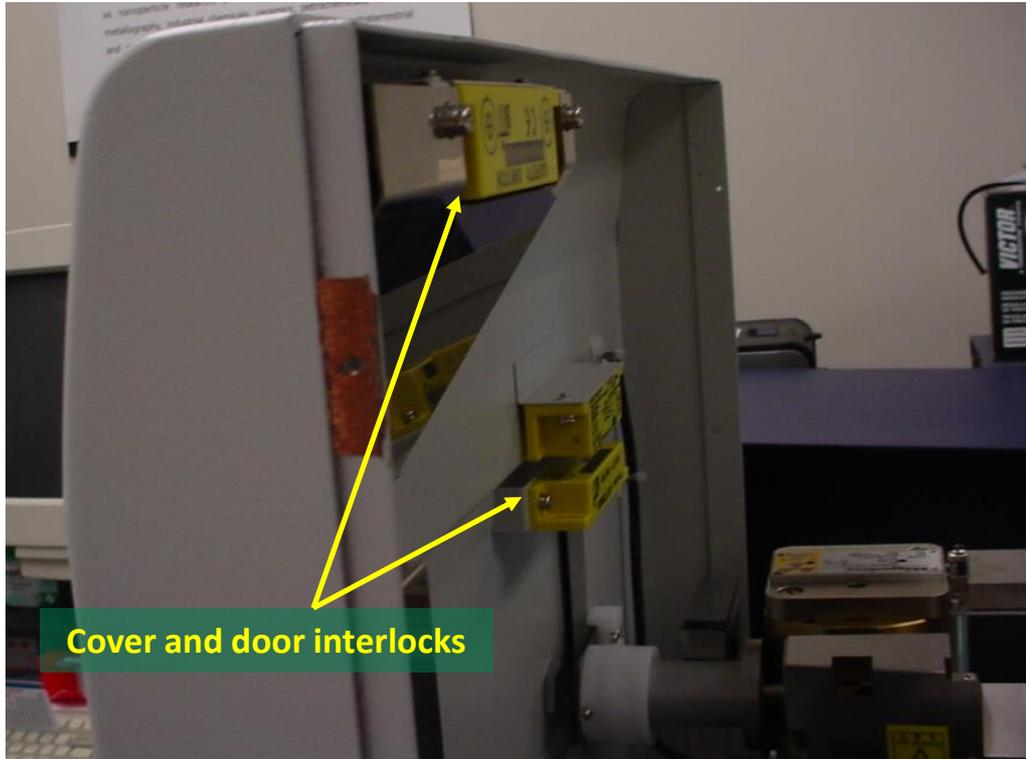
Commercial x-ray systems typically include several built-in safety controls and warning systems.



Shutter automatically closes when door is opened to prevent an accidental exposure.

Pictures are of a Rigku MiniFlex II XRD

# Commercial System Engineering Controls



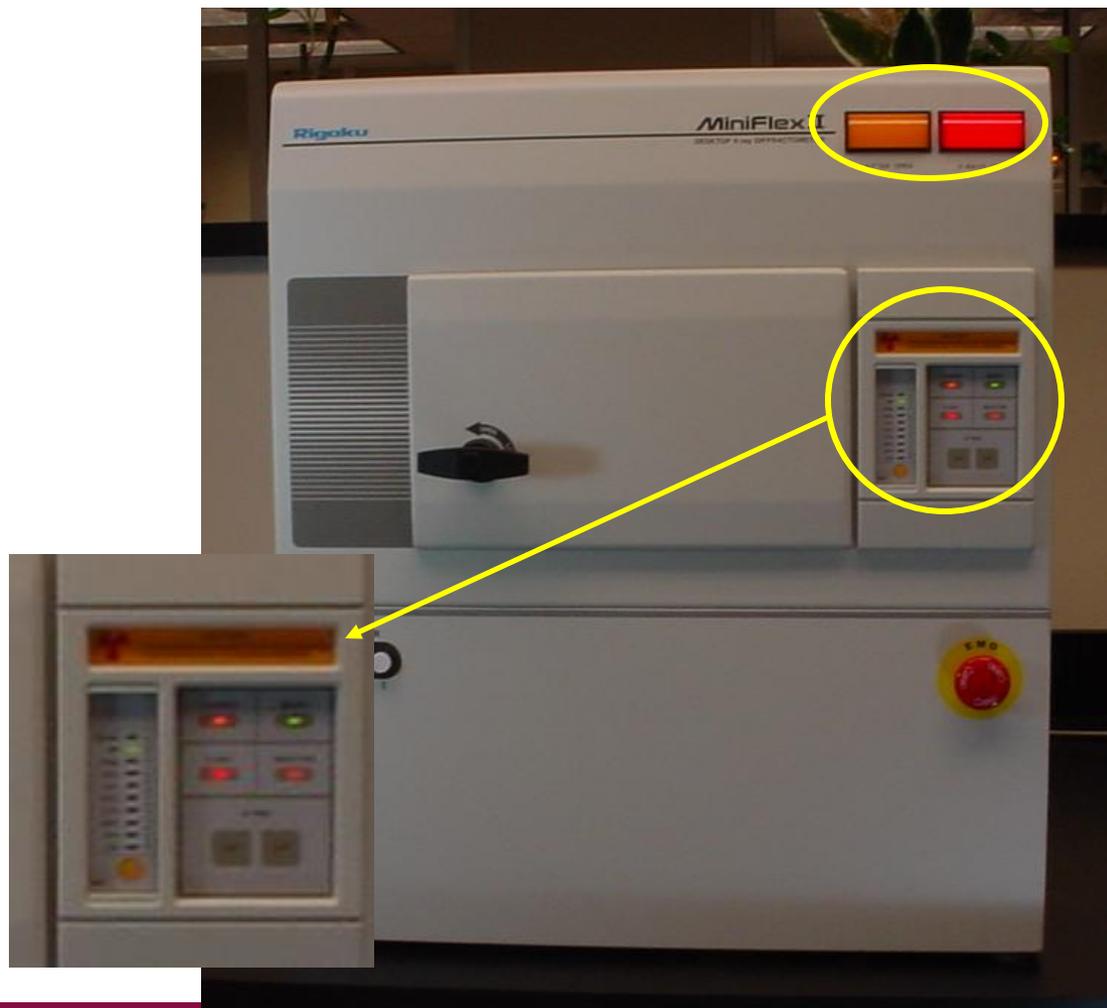
If the sample chamber door is accidentally opened the x-ray shutter automatically closes.

If the outer cover is accidentally removed, the instrument power shuts down completely to prevent accidental exposures.

Pictures are of a Rigku MiniFlex II XRD

# Commercial System Warning and System Status Lights

- X-Ray Beam On Alarm Lamp
- X-Ray Beam On LED
- X-Ray Shutter Open / Closed Status Lamp
- X-Ray Shutter Status LED
- X-Ray Ready Status LED
- Radiation Warning Label
- Power On LED



Pictures are of a Rigaku MiniFlex II XRD

# X-Ray User General X-Ray Safety Guidelines

- 1) Authorized Users and x-ray operators must complete all required safety and operator training prior to using the equipment unsupervised.
- 2) Written Standard Operating Procedures (SOPs) must be available to all operators.
- 3) X-ray equipment must not be operated in any manner other than that specified in the written procedures unless approved in writing by the NMSU RSO.
- 4) Each area or room containing x-ray equipment must be posted with a "CAUTION--X-RAY EQUIPMENT" sign bearing the radiation symbol.
- 5) If assigned by the AU, workers must wear external dosimetry whenever operating or working around x-ray equipment.
- 6) Bypassing built-in equipment interlocks or safety devices is not allowed unless approved in writing by the NMSU RSO.

# X-Ray User General Safety Guidelines

- 7) X-ray devices must not be left unattended in an operational mode unless the equipment / area are secure and the unattended operations are documented in an approved protocol.
- 8) All equipment manufacturer requirements and recommendations for the safe operation of the equipment must be followed. Deviation from the manufacturer requirements or recommendations requires NMSU RSO approval.
- 9) Students and visitors must have the approval from and be supervised by an authorized equipment operator when in area where x-ray equipment is operating.
- 10) Repairs to x-ray equipment must ONLY be performed by properly trained and authorized technical personnel.
- 11) You must notify the NMSU RSO in advance before acquiring an x-ray-generating device.

# X-Ray User General Safety Guidelines

- 12) NMSU Radiation Safety inspects X-ray devices annually.
- 13) All X-ray users must be approved in writing through the AU.
- 14) Notify the NMSU RSO of any major repairs, modifications, disposal, or relocation of x-ray equipment.

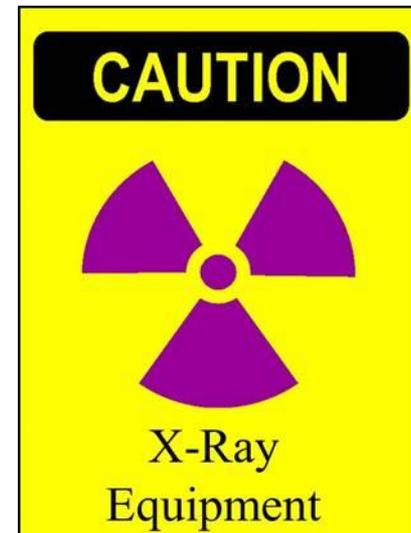
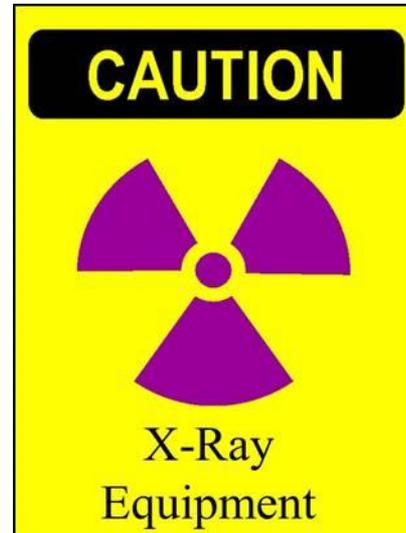
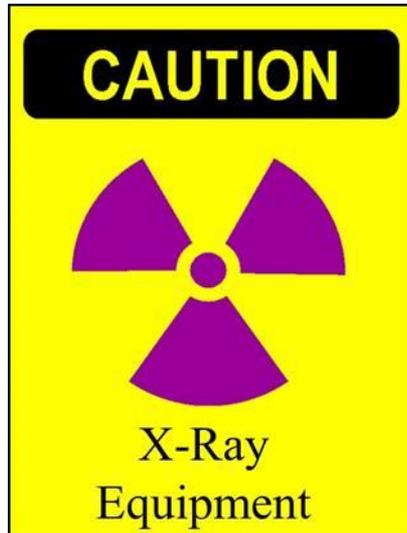
# 4 Common Mistakes

Four common mistakes that can lead to worker exposures:

1. Getting hands / fingers in the primary x-ray beam while changing samples, performing x-ray beam alignment or equipment maintenance / repair activities.
  - Operations and alignment procedures must be written and available to workers
  - Workers must be provided hands-on training.
  - Only trained and qualified workers can make repairs.
2. Improper modification or shifting of shielding built into the x-ray system.
3. Failure to heed warnings on open or unshielded ports.
4. Failure to follow written lab SOPs or manufacturer operating instructions.

# THE END

If you have any questions about this training, analytical x-rays or general radiation safety concerns contact the NMSU RSO at EH&S at 646-3327.



## ALWAYS THINK ALARA