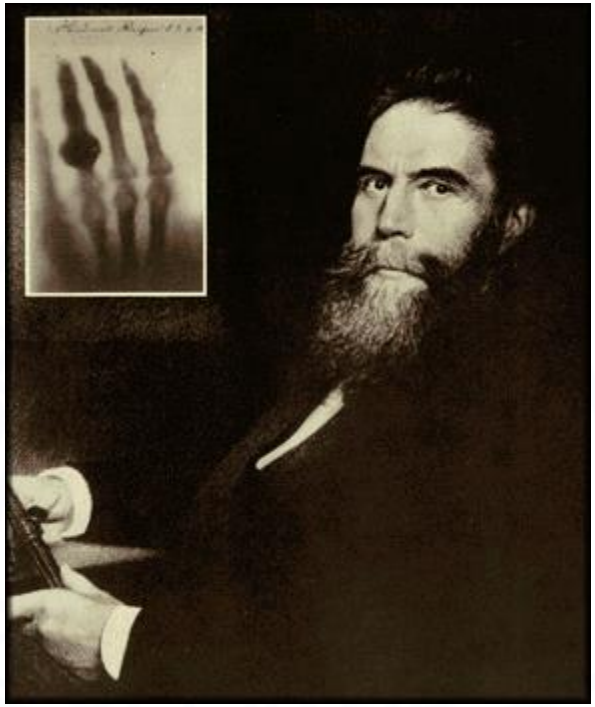
Colorado School of Mines
Analytical X-ray Safety Training

Prepared by
Radiation Safety Officer
Department of Environmental Health and Safety

COLORADOSCHOOLOFMINES

X-RAY HISTORY

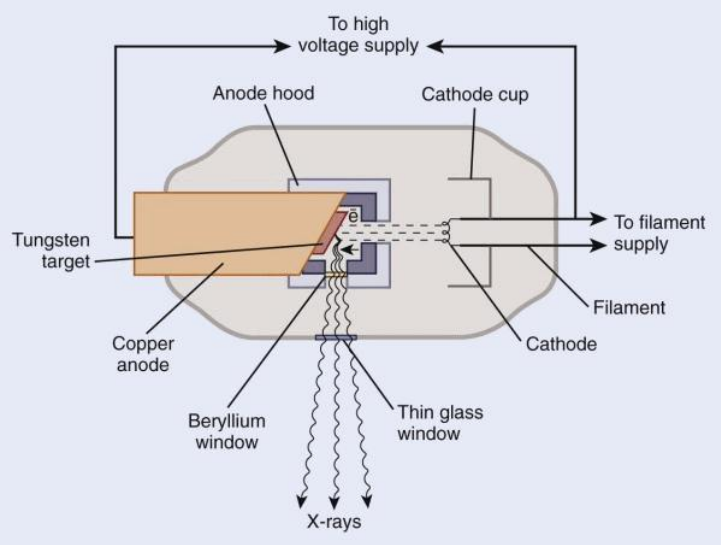
- 1895 Röntgen discovered X-ray
- Shortly after the discoveries, radiation-related biological effects have been observed.
- In 1899 Stënbeck & Sjøgren removed skin cancer; in 1902 first report of X-ray causing skin cancer
- 1906 Law of Bergonié and Tribondeau
  - the radiosensitivity of a tissue is directly proportional to the reproductive activity and inversely proportional to the degree of differentiation



X-RAY HISTORY

"When the X-ray came up, I made the first fluoroscope, using tungstate of calcium…… I started in to make a number of these lamps, but I soon found that the x-ray had affected poisonously my assistant, Mr. Dally, so that his hair came out and his flesh commenced to ulcerate. I then concluded it would not do, and that it would not be a very popular kind of light; so I dropped it." – Thomas Edison

TWO TYPES OF X-RAYS

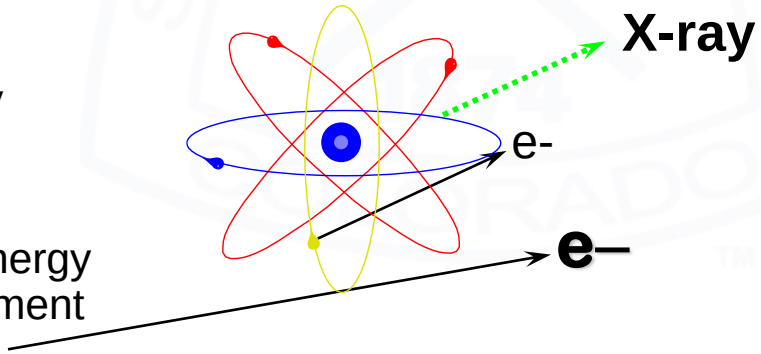


Man-made X-rays

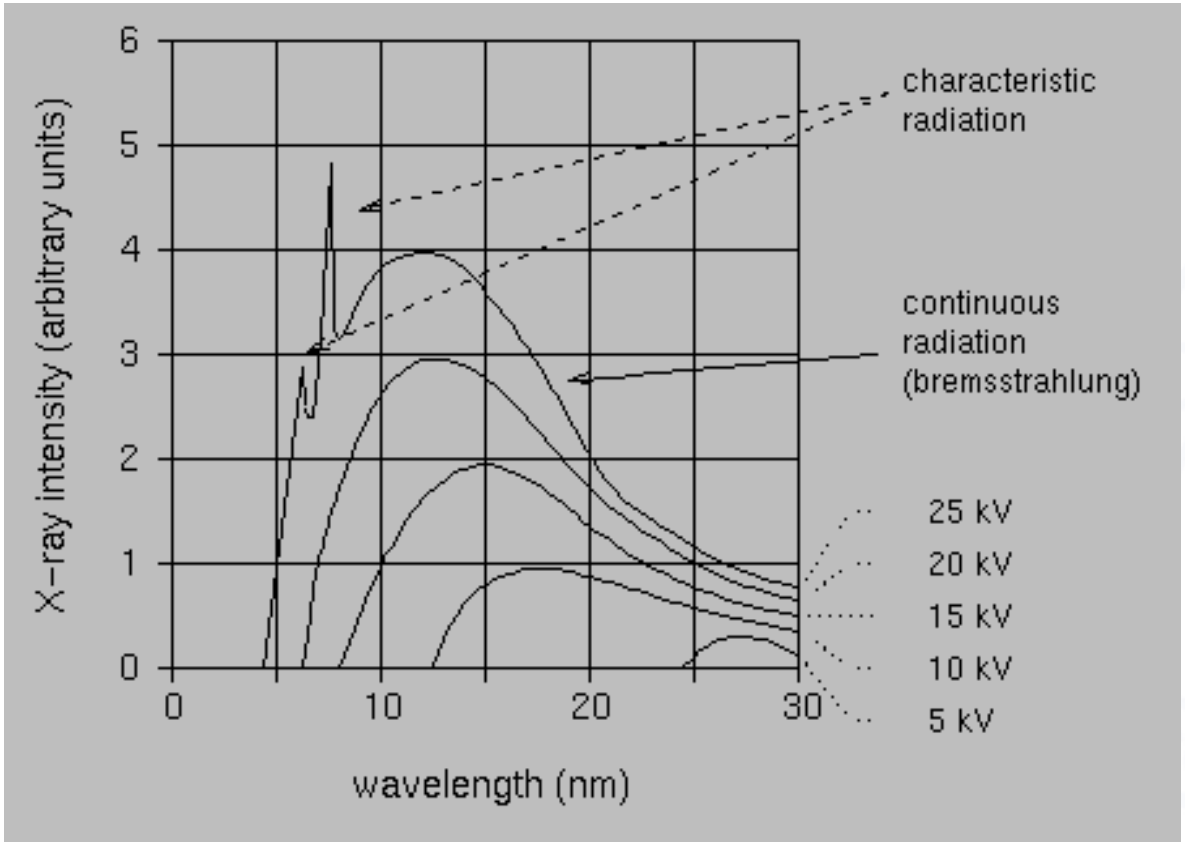
- Electrons are accelerated from the cathode by high voltage, then stopped by high-density target at the anode
- Energy of electrons is converted to X-rays
- Energy of X-rays has a continuous spectrum

Characteristic X-ray

- Electrons jump from higher energy orbitals to lower energy orbitals
- Extra energy is release as X-rays
- This type of X-rays has discrete energy spectrum, characteristic to the element

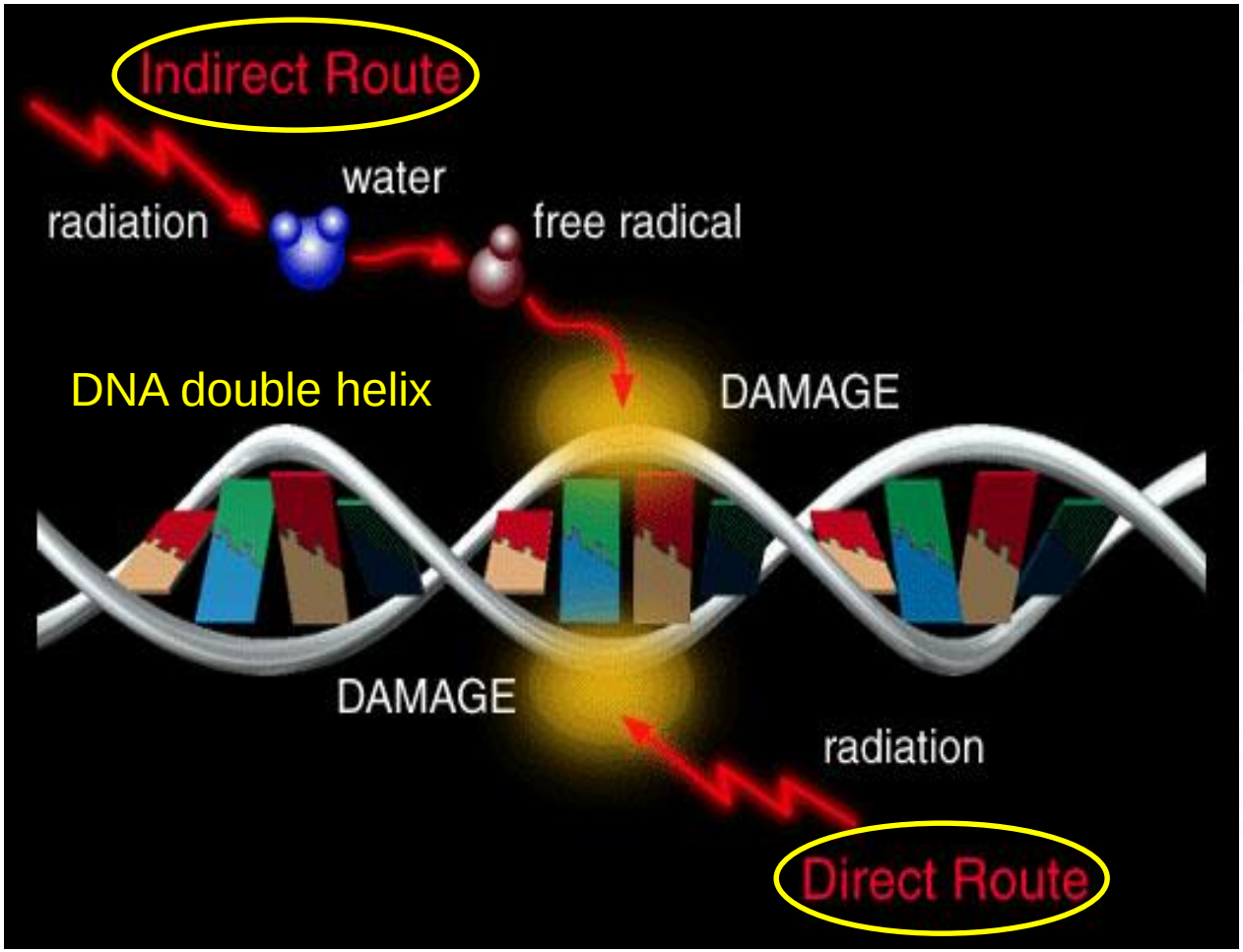


MAN-MADE X-RAY PRODUCTION



- X-rays produced in a spectrum of energy up to a maximum which is determined by the electric potentials
- The distribution of energy is dependent on the electrical potentials and the target materials
- 99% of the input electric energy is heat, < 1% is converted to x-rays
- Characteristic x-rays may also be produced

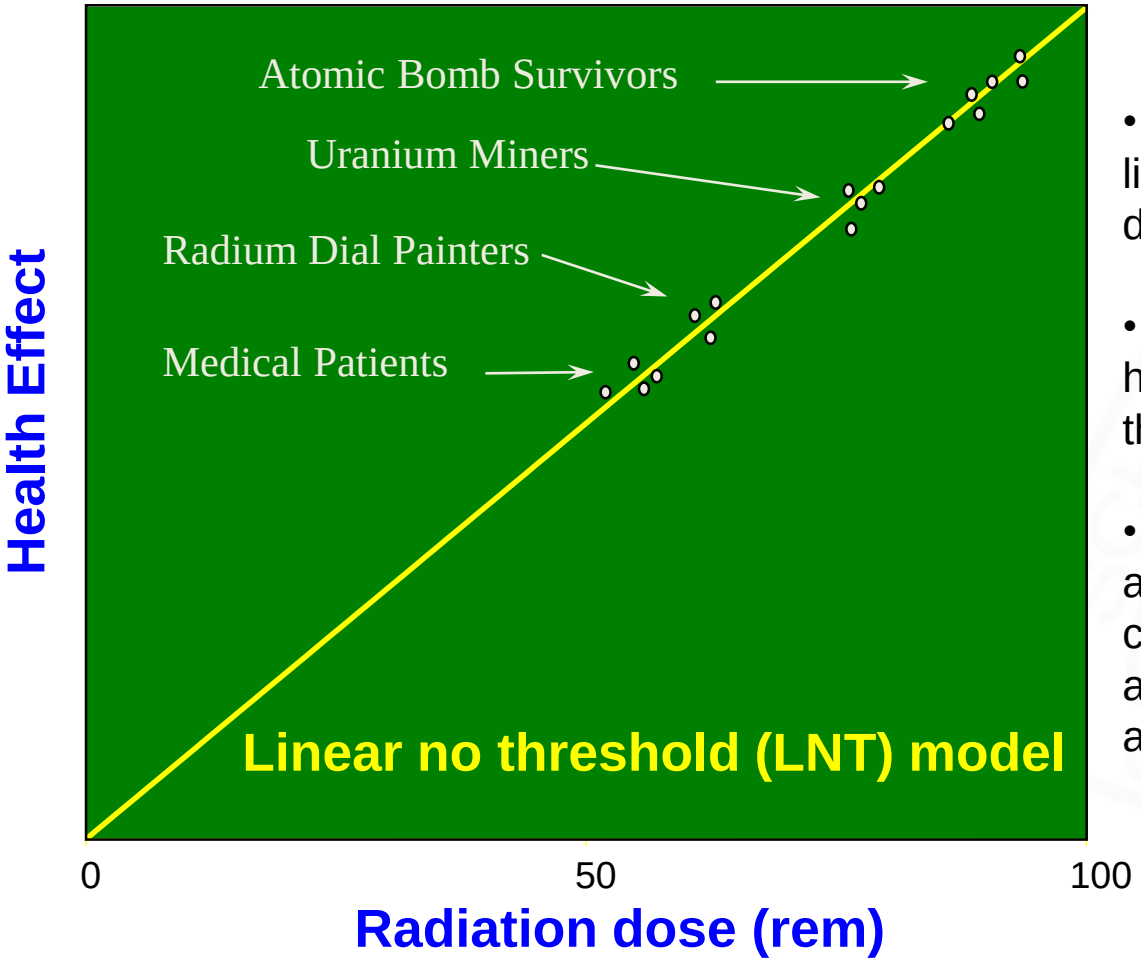
BIOLOGICAL EFFECTS OF RADIATION



- At the molecular level, the energy carried by the incident radiation (X-ray) is transferred to DNA molecules, leading damages in the DNA structure.

- The energy transfer has direct and indirect pathways, in the latter the energy is transferred to water first to produce free radicals and ions. The highly reactive free radicals and ions then diffuses to DNA and causes damages.

BIOLOGICAL EFFECTS OF RADIATION



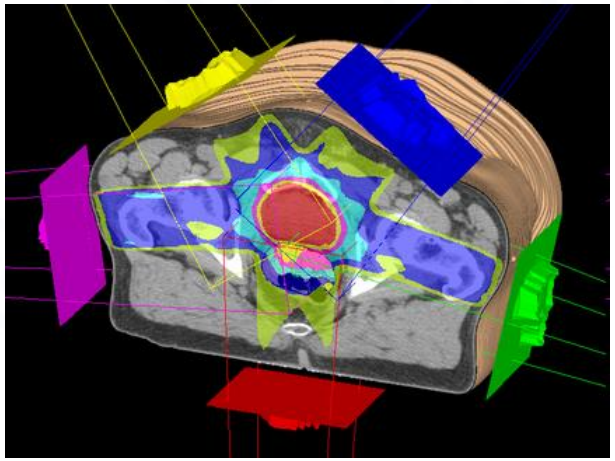
- The health effects of radiation are linearly dependent on the radiation dose (discussed in following slides).
- The model that describes the health effects is called the linear no threshold (LNT) model.
- This model is established based on a number of reliable studies and is commonly accepted by scientific advising bodies and governmental agencies.

ALARA PRINCIPLE

- Because the health effects are proportional to the radiation dose, we want the dose to be As Low As Reasonably Achievable
- ALARA is an approach to control or manage radiation doses as low as social, technical, economic, practical, and public policy considerations permit.

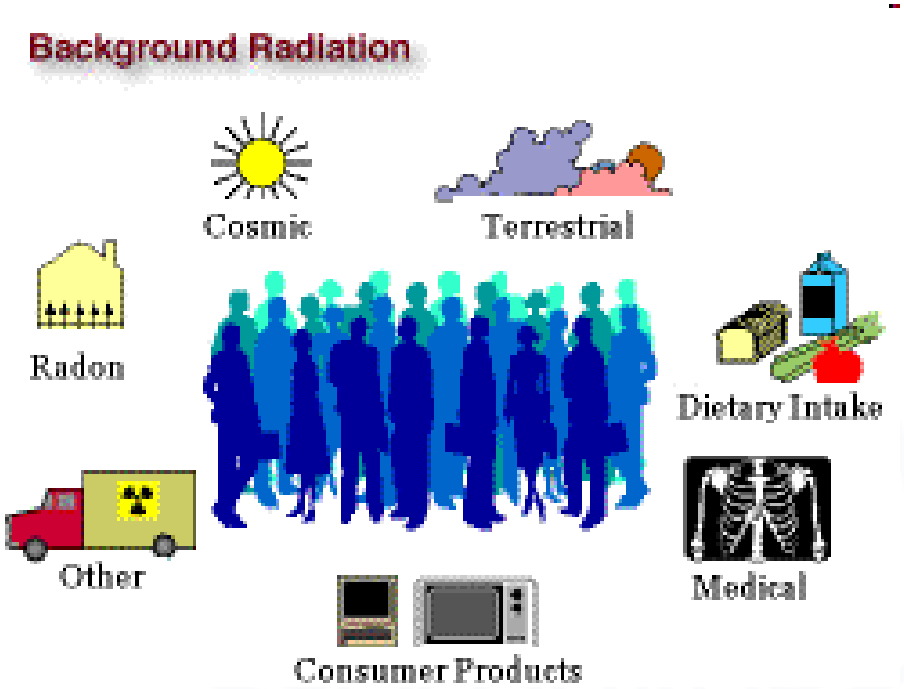
RADIATION DOSE

- Biological effects are proportional to radiation dose. Then what is radiation dose?
- Radiation dose is defined as the amount of energy (carried by α, β, γ or X-ray) absorbed per unit mass of body tissue.
- Units of radiation dose
  - The SI unit of radiation dose is Sievert (Sv)
  - 1 Sv = 1 joule of X-ray radiation energy absorbed in 1 kilogram of body tissue
  - Units of rem and milirem (mrem) are more commonly used
  - 1 Sv = 100 rem = 100,000 mrem

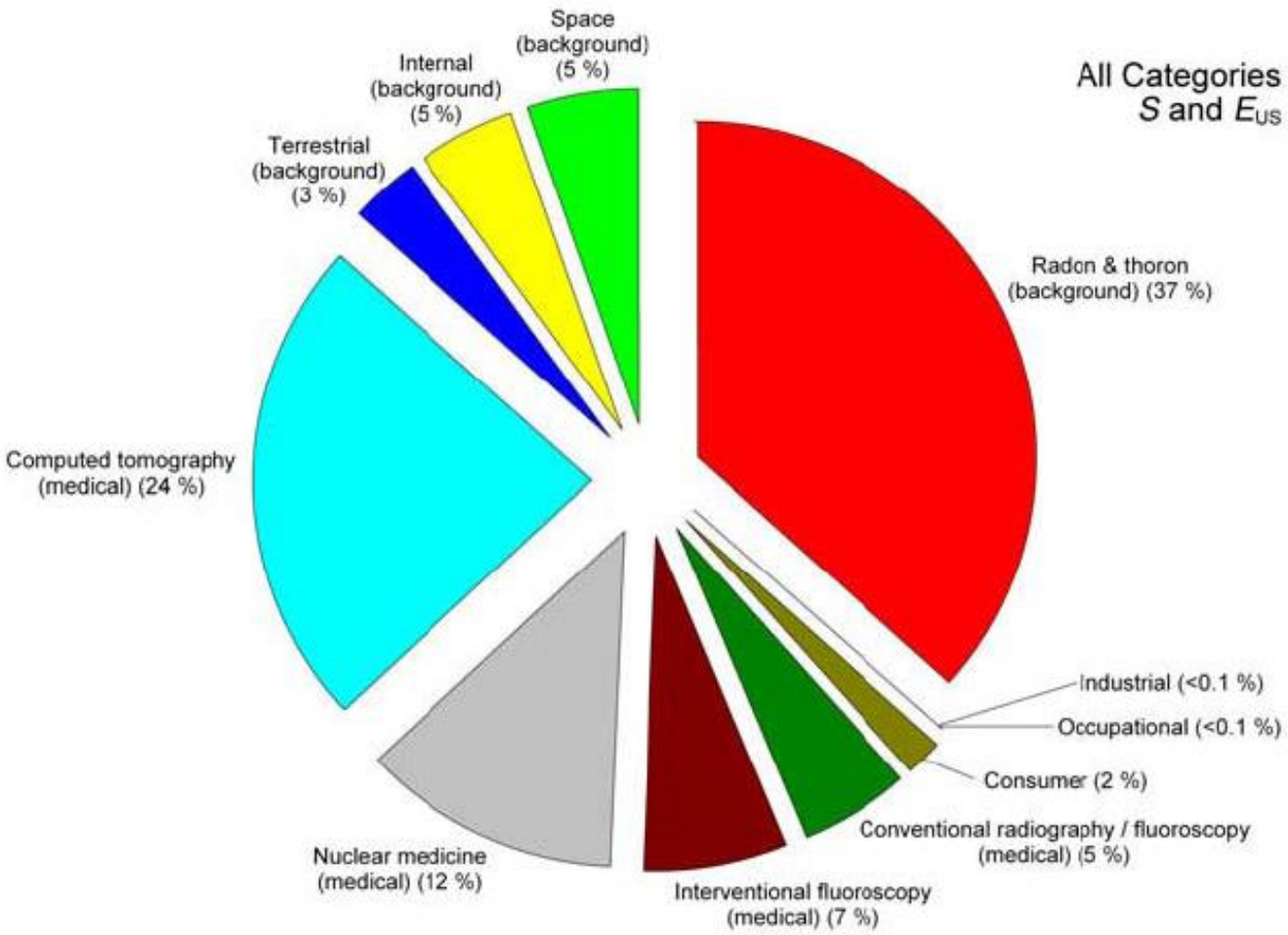


BACKGROUND RADIATION DOSE

- We all live in an environment of radiation.
- The sources of background radiation include cosmic rays, natural radioactive elements in earth, medical treatments, and consumer products.
- On average, each member of general public receives 620 mrem of radiation dose per year from the background – National Council on Radiation Protection and Measurements (NCRP) Report No.160, 2006.



BACKGROUND RADIATION DOSE

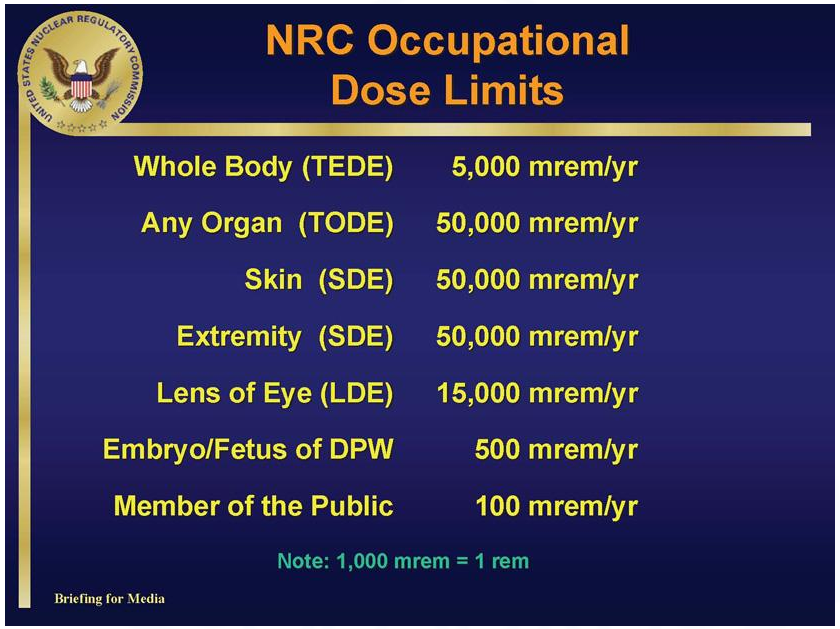


MEDICAL X-RAY DOSE

Type of Exam	Patient Dose Per Exam	Background Equivalent
Pelvic CT	400 - 1200 mrem	1- 2 years
Spine	130-270 mrem	2-6 months
Mammogram	45 mrem	4 weeks
Dental	10 mrem	1 week
Chest	5 - 8 mrem	4 days
DEXA hip or spine	1 - 6 mrem	< 4 days
DEXA wrist, heel	<1 mrem	< 1 day

OCCUPATIONAL DOSE LIMITS

- The governmental agency regulating occupational use of radiation is the US Nuclear Regulatory Commission (NRC).
- NRC Occupational Dose limits:
  - Adult workers: 5,000 mrem/yr whole body; 50,000 mrem/yr to extremity, skin or any organs; 15,000 mrem/yr to lens of the eye
  - Pregnant workers: 500 mrem during the gestation period
  - Minors: 10% of all adult's limits
  - General public: 100 mrem/yr and not to exceed 2 merm in any single hour.



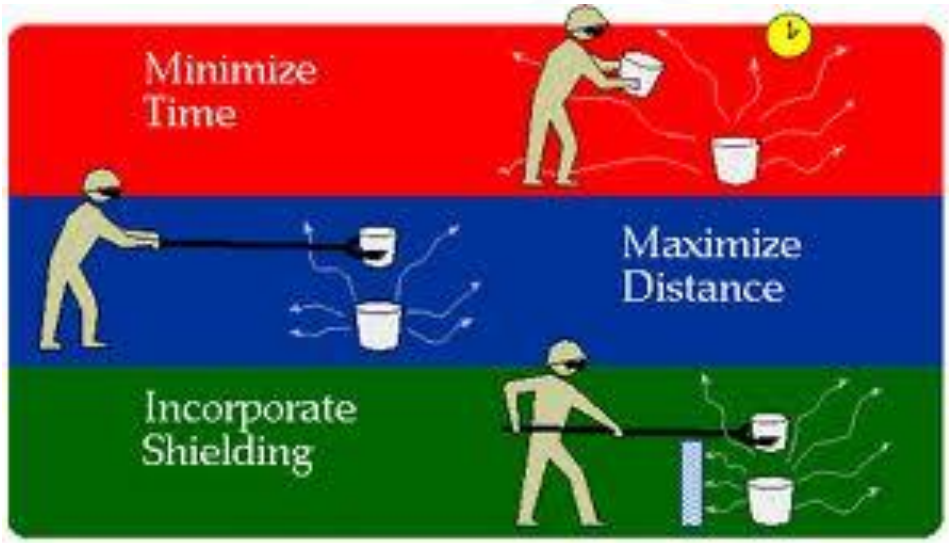
X-ray Safety at Mines

- Colorado's regulating agency is Colorado Department of Public Health and Environment (CDPHE)
- CDPHE registers analytical X-rays and accelarators
- CDPHE inspectors inspect analytical X-rays every two years
- X-ray users receive general X-ray safety training and machine-specific training

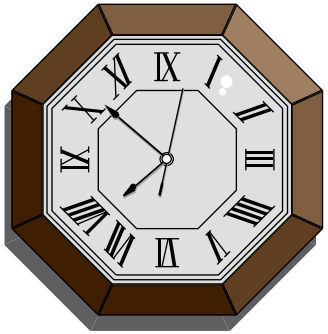
RADIATION PROTECTION PRINCIPLES

- There are three basic principles in radiation protection: time, distance and shielding.

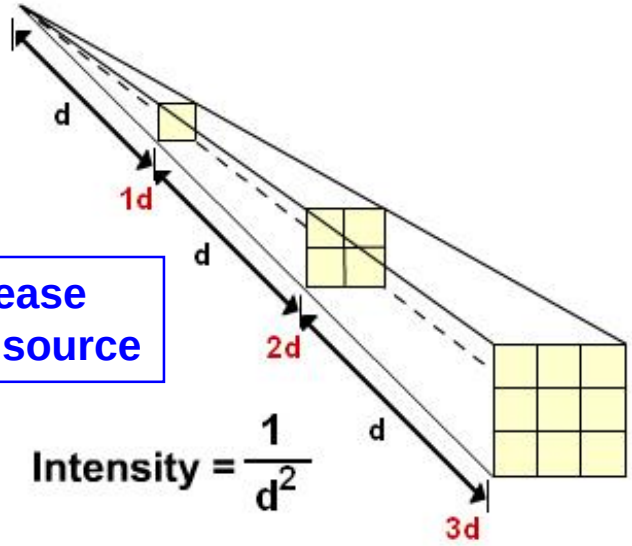
- Use theses principles in addition to proper contamination controls to make dose ALARA



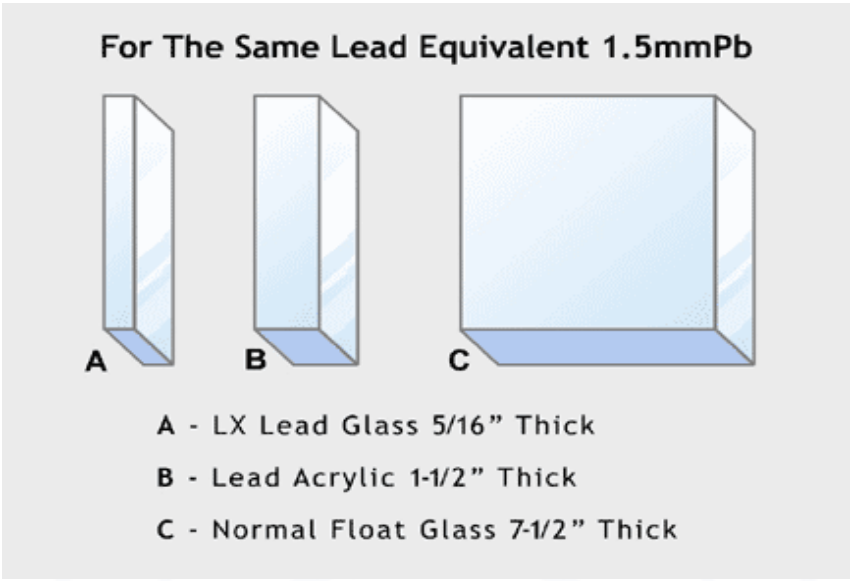
X-RAY PROTECTION



Time: reduce exposure time



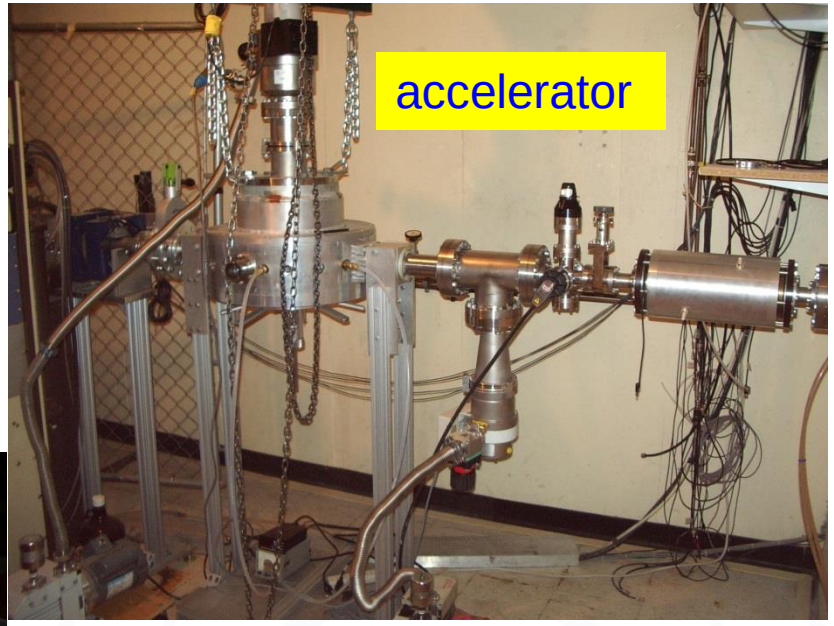
Distance: increase distance from source



Shielding: put something between you and source

X-RAY PRODUCING EQUIPMENT

X-ray

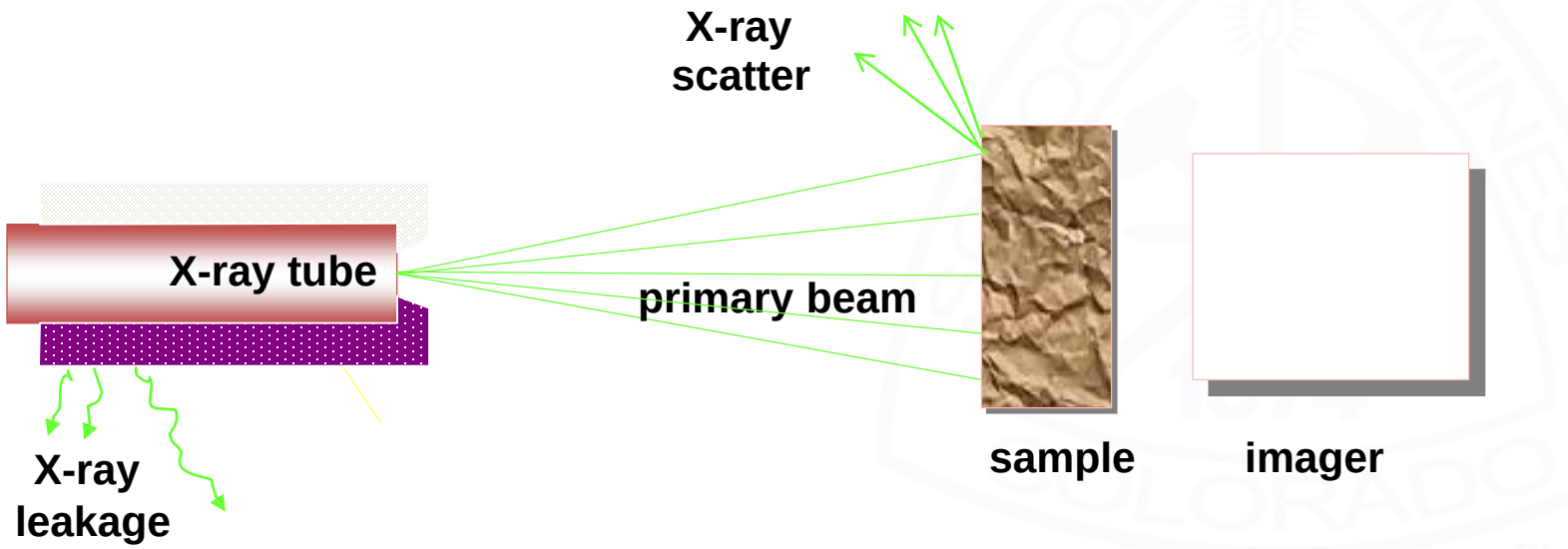


accelerator

hand-held X-ray unit

X-RAY RADIATION HAZARD

- There are three sources of radiation hazard: primary beam, scattered beam, and leakage from the X-ray tube



FACTORS AFFECTING DOSE

- Electric current (in amps) – affecting the number of electrons leaving the cathode and hitting the anode – number of X-rays
- Electric potential (usually in kilovoltage or kVp) – affecting the energy of the electrons and X-rays
- Target materials – how well the materials stop/slow the electrons, affecting the energy of the X-rays – the denser the target, the “harder” the X-ray
- Beam size – affecting how much of X-ray in a unit surface area, controlled by port/shutter size
- Beam direction – exposed in primary, scattered, or leakage X-rays

X-RAY SHIELDING

- Lead and steel shielding surrounding X-ray tube
- Leakage through this shielding may not exceed 100 mR/hr @ 1 meter
- Lead and steel surrounding the whole unit and control console
- Leaded glass and lead lined doors
- Concrete walls surrounding the X-ray room

X-RAY CONTROLS

- Administrative controls
  - rules, regulations, manuals, procedures, accepted work practices
  - safety trainings
  - administrative controls must be followed to be effective
  - registration and inspections
- Engineering controls
  - lead-lined housing and leaded glass
  - interlocks and emergency turn-off
  - warning signs and lights
  - radiation surveys

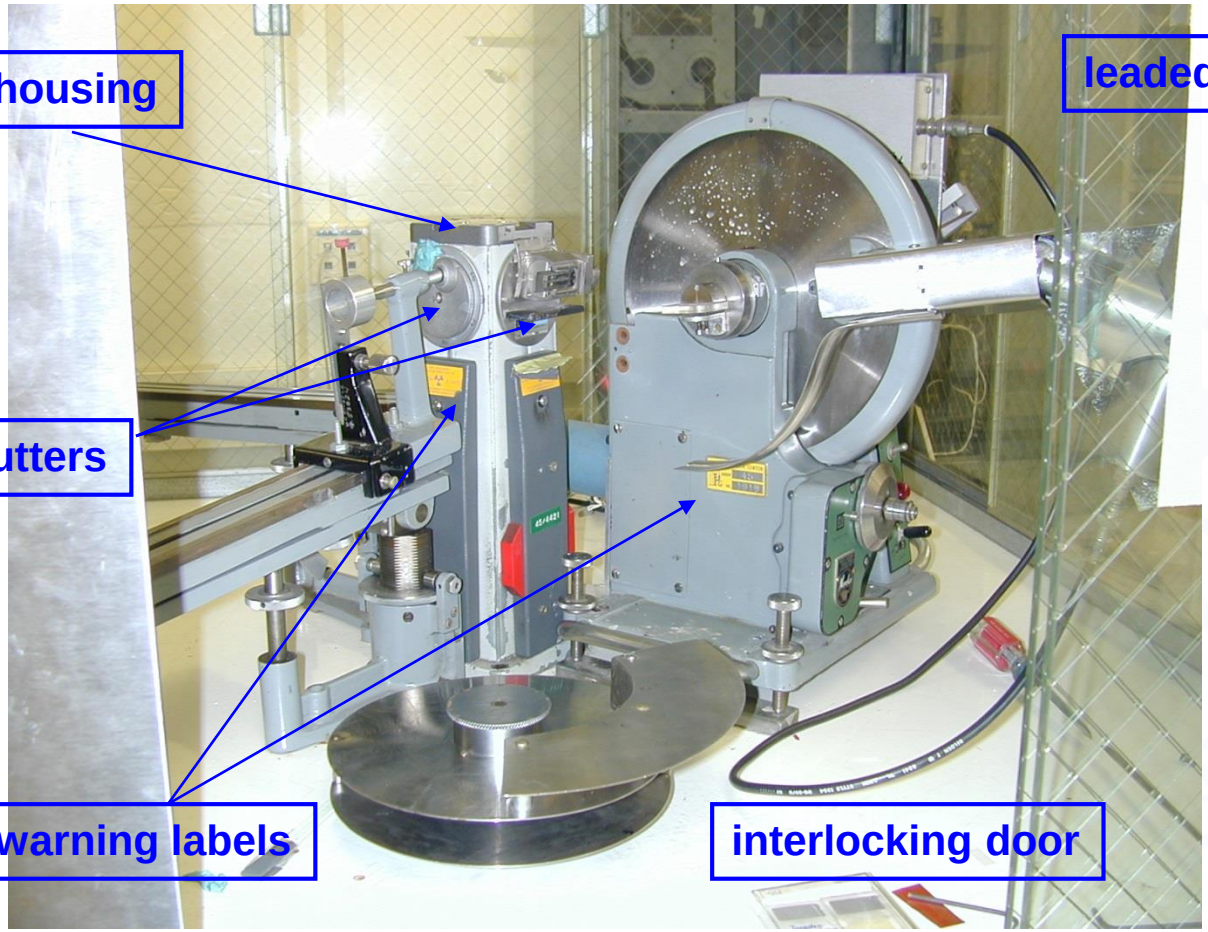
X-RAY SAFETY

- All units shall have an easily identified device located near the radiation source housing and labeled what gives a clear, visible indication of the X-ray generation status (on-off)
- An easily visible warning light shall be illuminated only when the generator is energized, and have fail-safe characteristics
- Unused ports shall be secure in a manner which will prevent accidental opening. Open beam units shall have a shutter over the port which cannot be opened unless a collimator or coupling has been connected.
- Safety interlocks shall not be used to de-activate the X-ray beam except in an emergency or during testing of the interlock system.

WARNING DEVICES

- Warning labels – with the tri-foil radiation warning sign
- Warning lights – may be flashing or color coded – should have a clear indication to the status of X-ray generation
- Audible warning

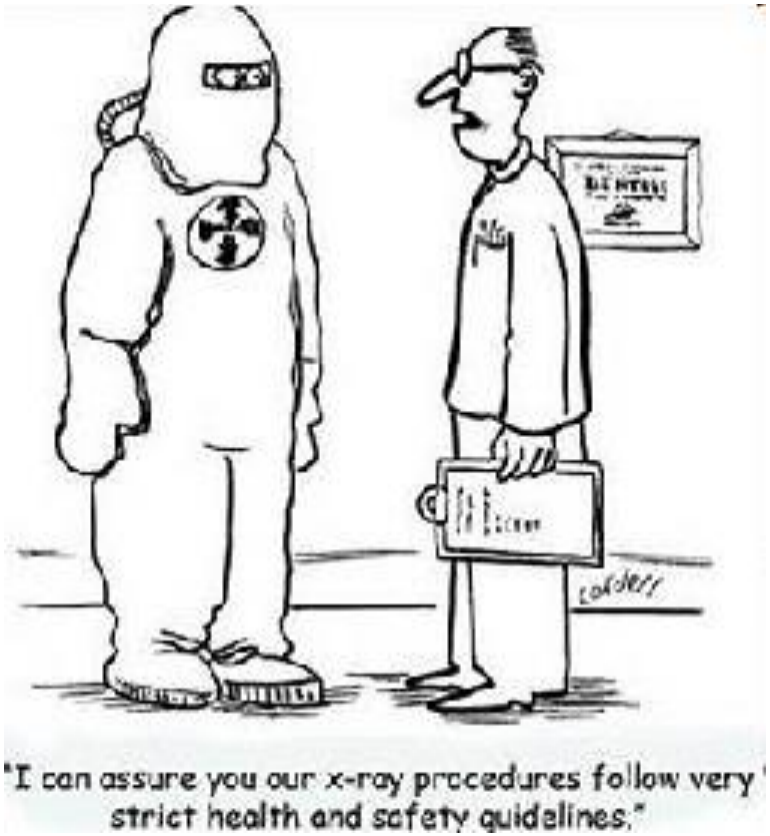
X-RAY SAFETY


X-ray tube housing
leaded glass
ports with shutters
warning labels
interlocking door

SAFETY PROCEDURES

- Only trained personnel shall be permitted to operate an X-ray machine.
- Be familiar with the experiment and operating procedures. DO NOT take short cuts!
- Never expose any part of your body to the primary beam.
- While the beam is on DO NOT attempt to handle, manipulate or adjust any object (sample, sample holder, collimator, etc.)
- Never leave the energized system unattended in an area where access is not controlled.

SAFETY PROCEDURES



- Never remove auxiliary shielding without authorization from the supervisor of the analytical equipment or Radiation Safety Officer.
- Never bypass safety circuits, such as interlocks.
- Only authorized, trained individuals as specified by the supervisor or the RSO may repair, align or make modifications to the X-ray apparatus
- Examine the system carefully and report all unsafe conditions to the supervisor and RSO

UNSAFE CONDITIONS

- Examples of unsafe conditions include:
  - access door/window interlocks do not work
  - warning lights/signals do not work
  - shielding has been damaged
  - viewing window cracked
  - other conditions could compromise shielding

- If an unsafe condition arises while using the X-ray
  - stop work
  - turn off power to x-ray unit
  - notify supervisor and RSO

CAUSES OF ACCIDENTS

- Inadequate training or violation of procedure, e.g., incorrect use of equipment, overriding interlocks
- Poor equipment configuration, e.g., unused beam ports not covered
- Manipulation of equipment when energized, e.g., adjustment of samples or alignment of cameras when x-ray beam is on
- Aligning x-ray beam visually
- Modification of shielding
- Equipment failure, e.g., shutter failure, warning light failure

ACCIDENT DESCRIPTION

- QC inspector & assistant were adjusting a swing arm of the primary beam shutter of an XRD unit. Patient was holding shutter plate in open position by placing right index finger inside the port aperture
- After 40 – 50 sec, felt burning in index finger, but, because the machine was supposedly NOT operating (i.e., shutter open), used another finger to hold it open.
- Experienced burning, looked and saw machine was indeed operating.
- Symptoms of acute localized exposure
  - erythema (skin reddening), swelling, blisters
  - desquamation continued for several weeks

WARNING! Graphic content on next slide

ACCIDENT DESCRIPTION

EMERGENCY

- Fire or other life-threatening situations – CALL 911 immediately
- Stop work, turn off power
- Notify lab supervisors and RSO at ext. 3573; notify relevant authorities when apply – Mines Public Safety ext. 3333
- Follow any lab-specific emergency procedures

REPORTING DUTIES

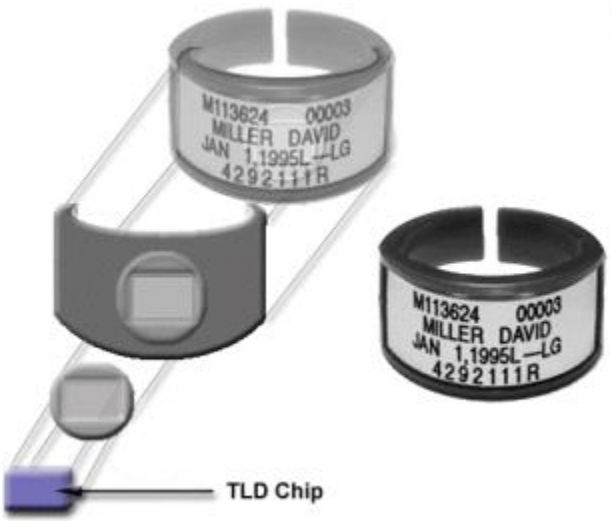
- The X-ray supervisors and operators are required to report to the RSO immediately in the events of
  - installing new units, or relocation of units involving reassembling
  - placing units in disabled/inactive status
  - removing units from Mines' possession by sale, transfer or disposal
  - modification of component that could affect X-ray beam output
  - lost, stolen or damaged
  - suspected exposure

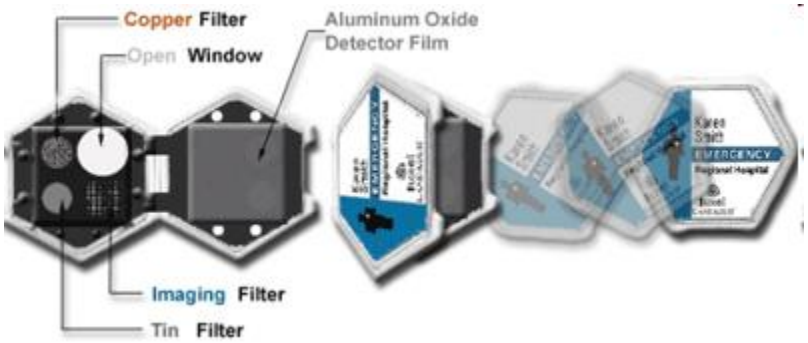
X-RAY INSPECTIONS

- Analytical X-ray machines are inspected biannually and following major repairs and/or system modifications by state-certified inspectors. Hand-held units may be inspected annually as specified by RSO and the inspector.

- X-ray units that are registered and inspected by CDPHE have the Radiation Machine Certification (the “blue sticker”) attached to the machine body. Check the expiration date on it. Report to RSO if it has expired.

DOSIMETERS





- Area dosimeters are attached to cabinet X-ray machines to monitor any X-ray leakage.
- If working in an open-beam configuration, operators of the analytical X-ray equipment will be provided with a body (badge) and/or finger (ring) monitoring device.
- However, it is important to note that the cross-sectional area of the primary radiation beam is usually small and that the monitoring device may not indicate the maximum exposure to the operator – avoid direct contact to the primary beam!

X-RAY USER RESPONSIBILITIES

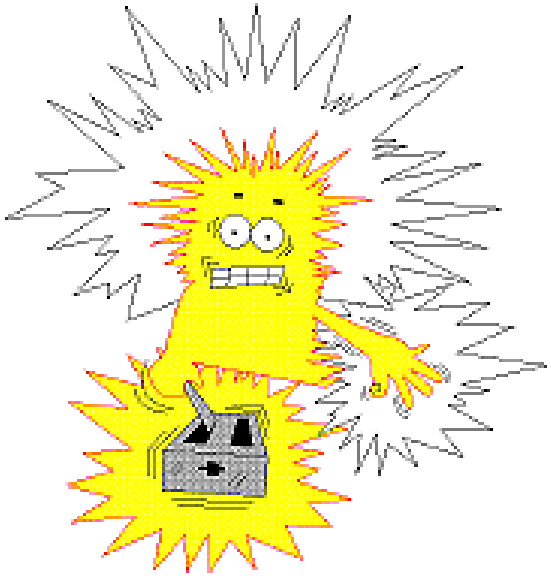
- Obtain safety training and machine-specific training
- Familiarize with safety and operational procedures
- Never expose any part of body in primary X-ray beam
- Check safety interlocks and warning devices
- Report unsafe conditions, suspected excess exposures, and other reportable events
- Exchange dosimeters with EHS in a timely fashion

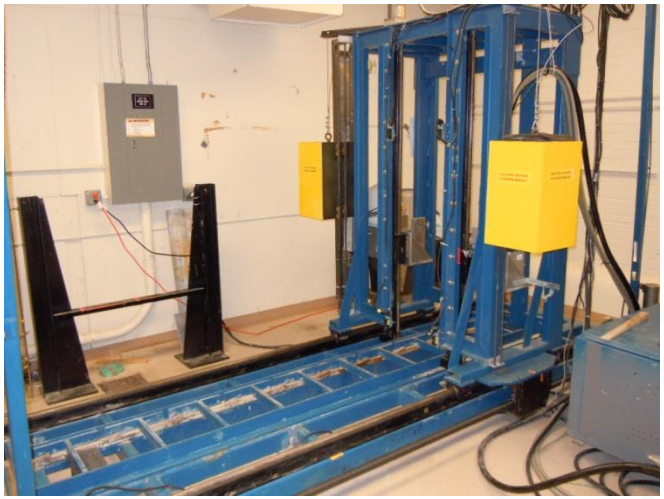
PREGNANT WORKER

- A declared pregnant worker is a woman who has voluntarily informed her employer, in writing, of her pregnancy and estimated date of conception
- A declared pregnancy may be undeclared at any time
- An undeclared pregnant worker may not have her duties restricted because of her pregnancy
- The radiation dose limit for declared pregnant works is 500 mrem/ gestation period
- Private appointment available with RSO

OTHER HAZARDS

- HIGH voltage going from generator to tube
  - Be careful when servicing
  - Watch for frayed cords, electrical arcing





- Moving part hazard – stay clear of the moving part

QUESTIONS?

Radiation Safety Officer
Environmental Health and Safety
Colorado School of Mines

Office: (303) 273-3573
EHS 24 hour Line: (303) 273-3316
McNeil Hall Room 133
1400 Maple Street
Golden, CO 80401

Annual Refresher

- X-ray users are required to refresh this X-ray training every year
- This online training is always available on Canvas
- Use your Canvas login to access this training or contact RSO to have a copy of the training slides sent to you