

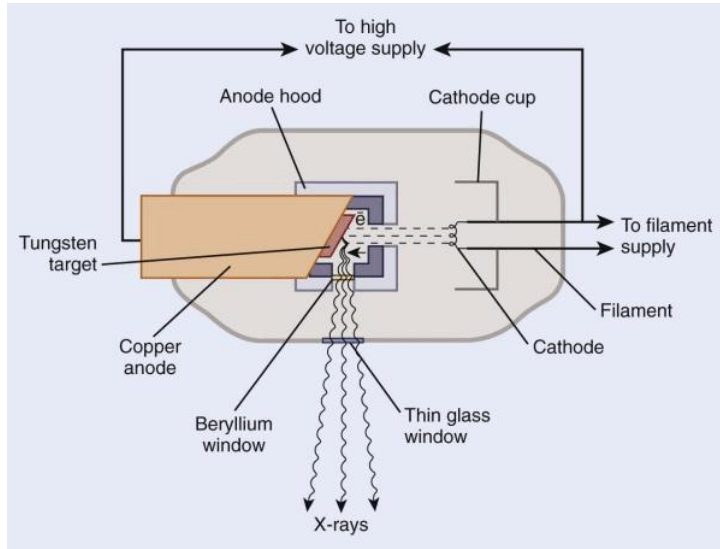
# Analytical X-ray Safety Refresh Training



Radiation Safety Officer  
Department of Environmental Health and Safety



# TWO TYPES OF X-RAYS

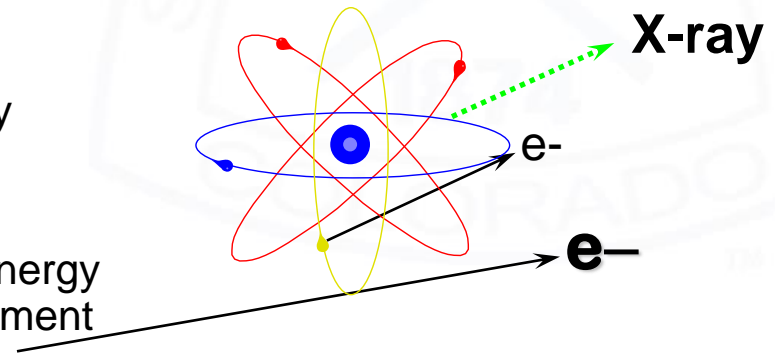


## Man-made X-rays

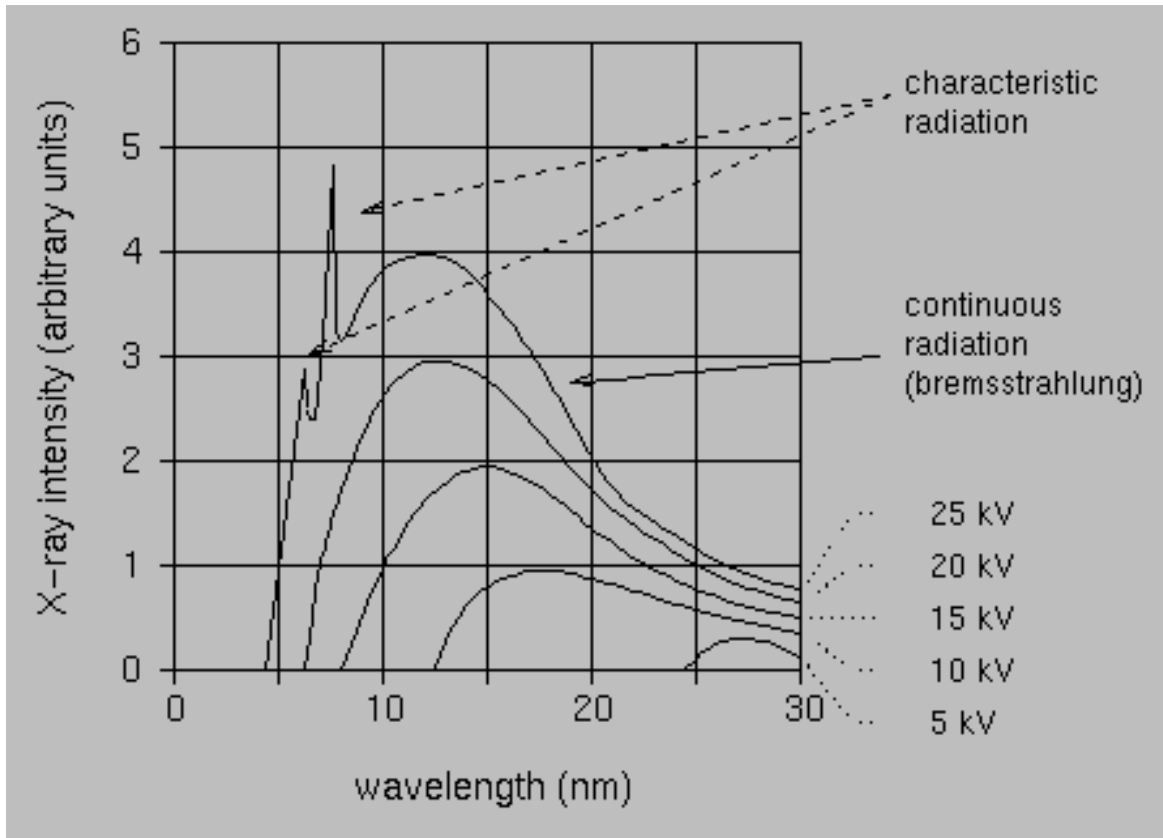
- Electrons are accelerated from the cathode by high voltage, then stopped by high-density target at the anode
- Energy of electrons is converted to X-rays
- Energy of X-rays has a continuous spectrum

## Characteristic X-ray

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



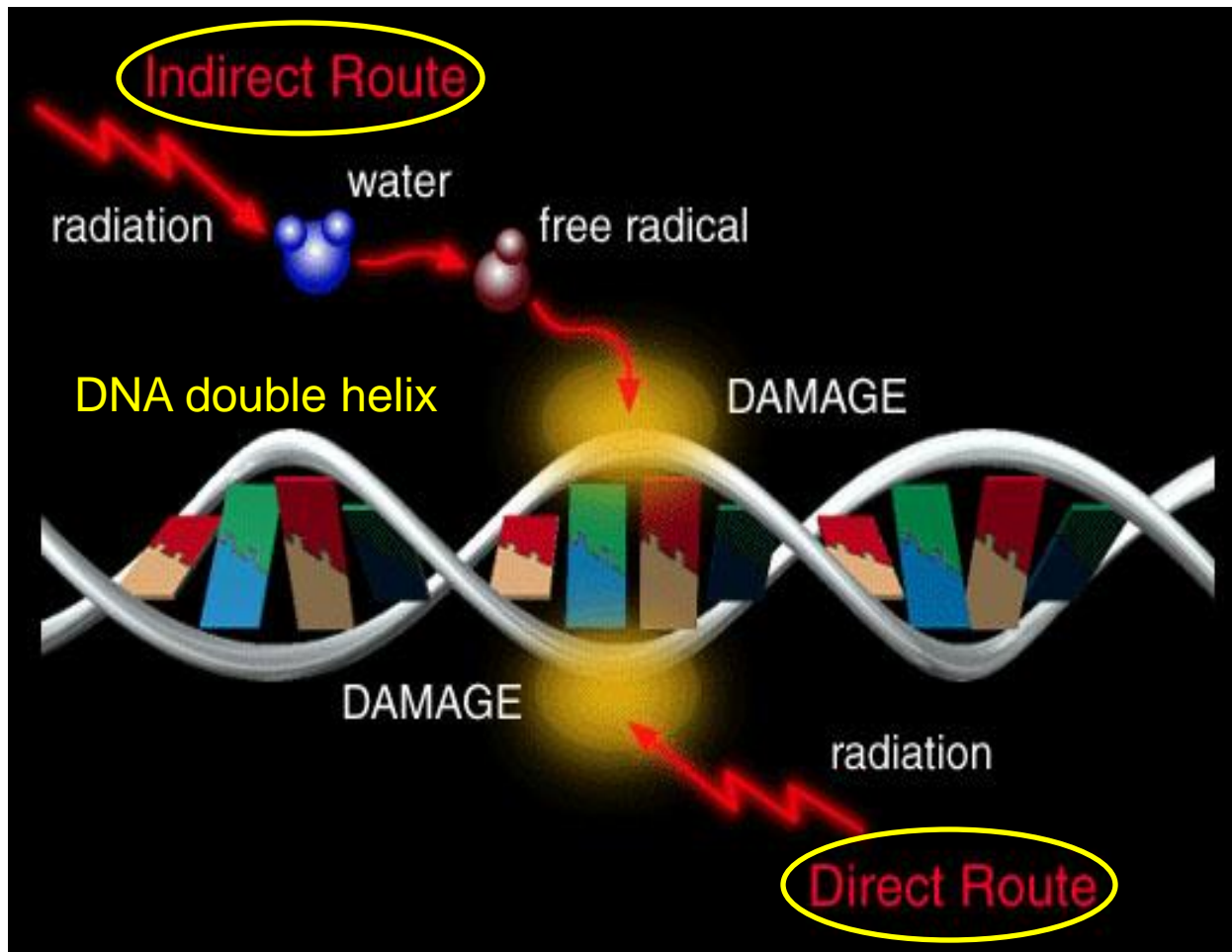
# MAN-MADE X-RAY PRODUCTION



- ▶ 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 electric 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

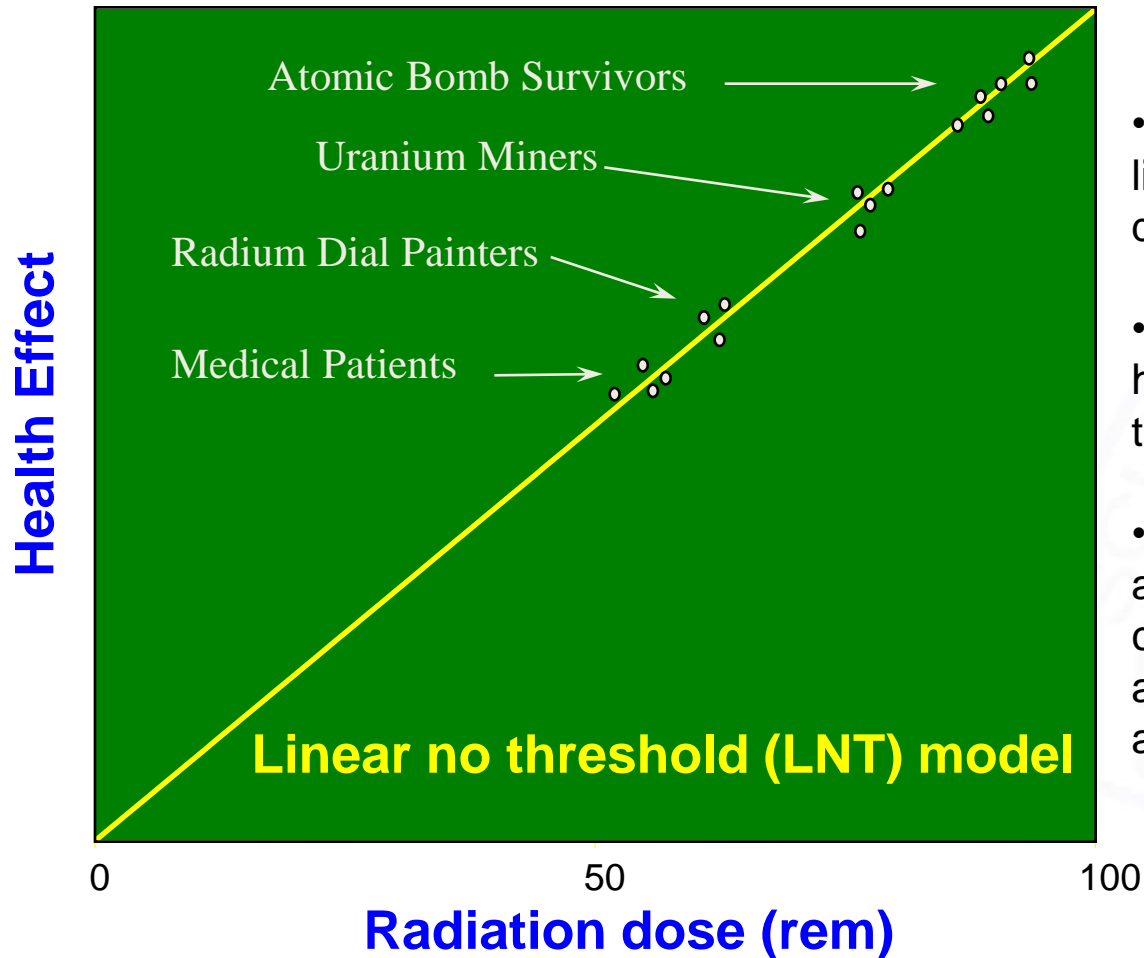


- At the molecular level, the energy carried by the incident radiation (X-ray) is transferred to DNA molecules, leading damages in the DNA structure.

- 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

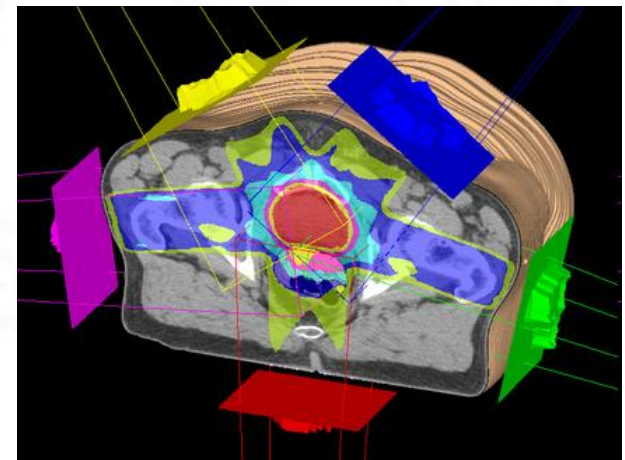
- ▶ Because the health effects are proportional to the radiation dose, we want the dose to be **As Low As Reasonably Achievable**
- ▶ ALARA is an approach to control or manage radiation doses as low as social, technical, economic, practical, and public policy considerations permit.

ALARA



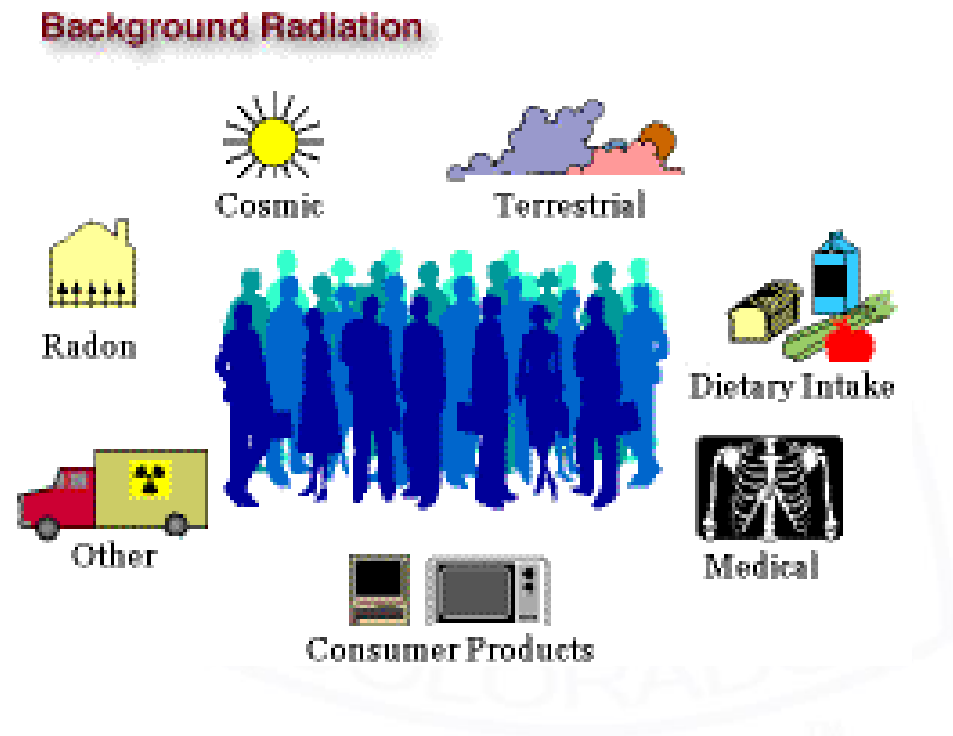
# RADIATION DOSE

- ▶ Biological effects are proportional to radiation dose. Then what is radiation dose?
- ▶ Radiation dose is defined as the amount of energy (carried by  $\alpha$ ,  $\beta$ ,  $\gamma$  or X-rays) 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



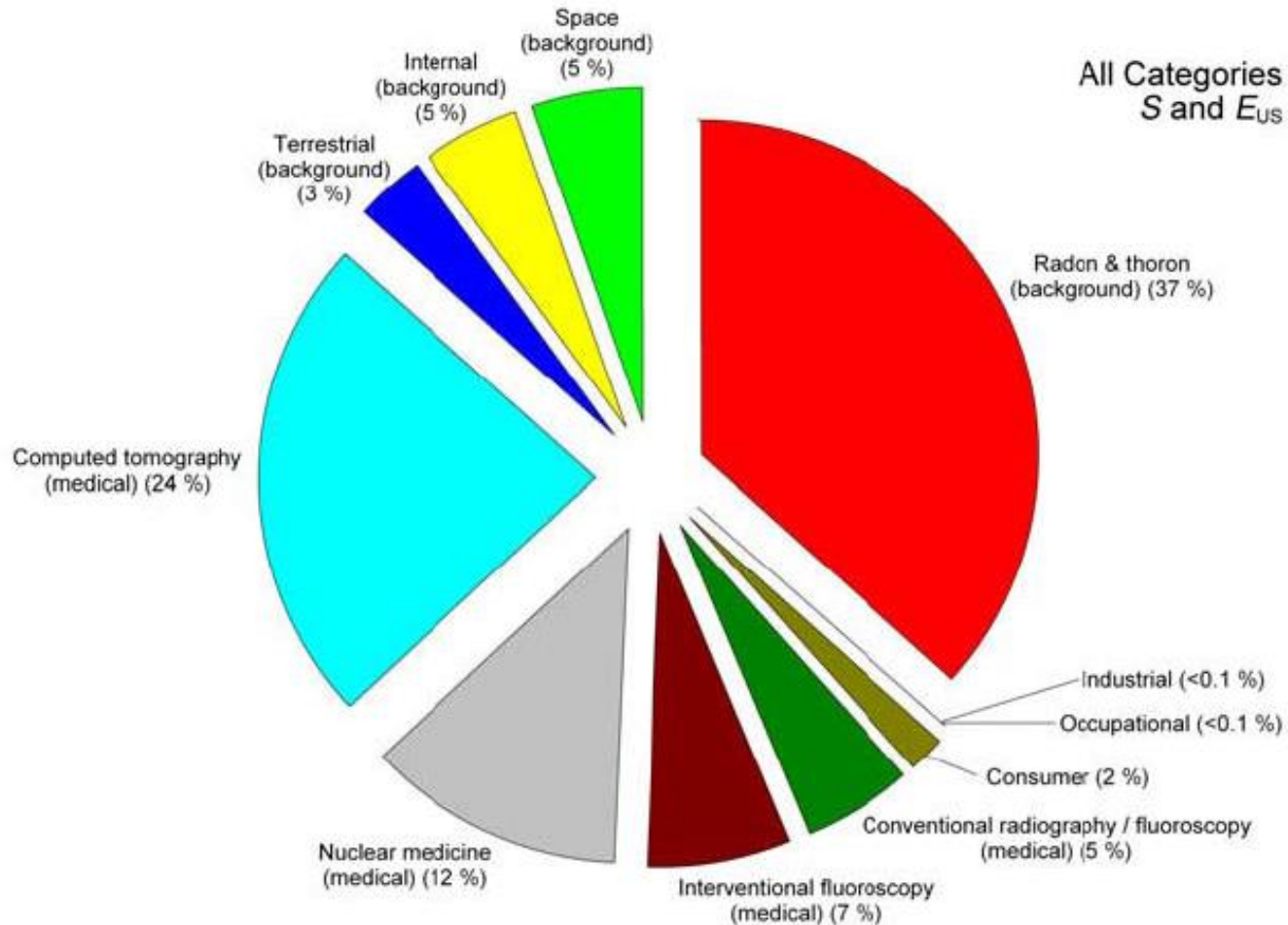
# BACKGROUND RADIATION DOSE

- ▶ 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



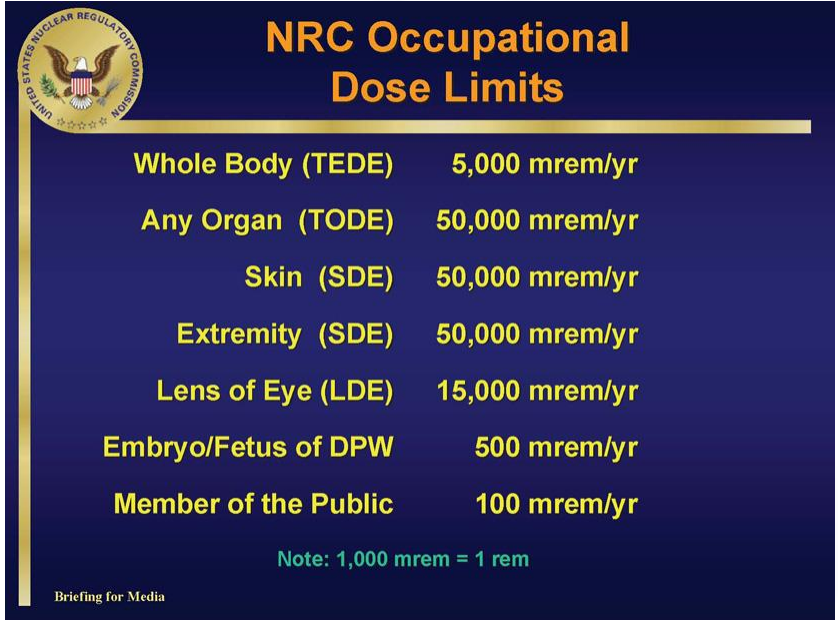
# MEDICAL X-RAY DOSE

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 mrem in any single hour.



The graphic features the NRC logo in the top left corner, which includes an eagle with a shield and the text "UNITED STATES NUCLEAR REGULATORY COMMISSION". The title "NRC Occupational Dose Limits" is displayed in orange text at the top right. A table lists various dose limits in yellow text on a dark blue background. A note at the bottom right states "Note: 1,000 mrem = 1 rem". The text "Briefing for Media" is located at the bottom left of the graphic.

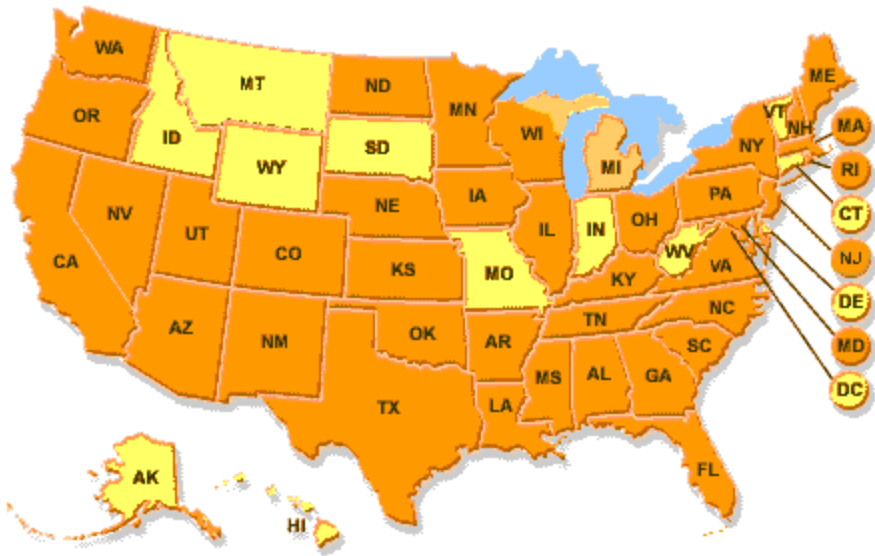
NRC Occupational Dose Limits	
Whole Body (TEDE)	5,000 mrem/yr
Any Organ (TODE)	50,000 mrem/yr
Skin (SDE)	50,000 mrem/yr
Extremity (SDE)	50,000 mrem/yr
Lens of Eye (LDE)	15,000 mrem/yr
Embryo/Fetus of DPW	500 mrem/yr
Member of the Public	100 mrem/yr

Note: 1,000 mrem = 1 rem

Briefing for Media



# AGREEMENT STATES



- ▶ Under the terms of the Atomic Energy Act, the NRC may transfer to approved states the authority to license and regulate occupational use of radiation and uranium, thorium, and certain quantities of special nuclear material.
- ▶ Colorado is one of the “Agreement States”
- ▶ Colorado’s regulating agency is Colorado Department of Public Health and Environment (CDPHE)
  - Rules and regulations pertaining to radiation control 6CCR 1007-1 (google “CDPHE” then go to regulations)



# RADIATION PROTECTION AT CSM



- ▶ CDPHE issues a license to CSM
- ▶ CDPHE registers analytical X-rays and accelerators
- ▶ Environmental Health and Safety Department (EHS) and the Radiation Safety Officer (RSO) manages the radiation protection program at CSM
- ▶ RSO assigns radiation users and provides radiation safety trainings



# ORGANIZATION CHART



→ Agreement



Colorado Department  
of Public Health  
and Environment

→ License



- Independent supervised users (ISU)
- Directly supervised users (DSU)
- Radiation producing equipment operators (RPEO)
- Ancillary personnel (ANP)

- Authorized users (AU)
- Radiation producing equipment supervisors (RPES)

Radiation safety officer

# TYPICAL DOSES AT CSM

## Radiation Dosimetry Report

COLORADO SCHOOL OF MINES  
ATTN: GAYLE ELLIOTT  
1500 ILLINOIS STREET  
GOLDEN CO 80401

## LANDAUER®

Landauer, Inc. 2 Science Road Glenwood, IL 60425-1586  
Telephone: (708)755-7000 Facsimile: (708)755-7016  
Cust Serv: (800)323-8830 Cust Serv Tech: (800)438-3241  
www.landauerinc.com

Electronic Representation



Account	Series	Analytical Work Order	Report Date	Dosimeter Received	Report Time In Work Days
167131	MET	1021410084	08/05/2010	08/02/2010	3

Part #	Name	Material	Radiation Quality	Dose Equivalent (MREM) For Periods Shown Below			Quarterly Accumulated Dose Equivalent (MREM)			Year to Date Dose Equivalent (MREM)			Lifetime Dose Equivalent (MREM)			Records For Year	Inception Date
				Deep DDE	Eye LDE	Shallow SDE	Deep DDE	Eye LDE	Shallow SDE	Deep DDE	Eye LDE	Shallow SDE	Deep DDE	Eye LDE	Shallow SDE		
				04/01/2010 - 06/30/2010	M	M	M	Quarter 2	2010	2010	2010	2010	2010	2010	2	09/2000	
				CONTROL REPORTED GREATER THAN 50 MREM, USE CONTROL SUBTRACTION	M	M	M									09/2000	
				CONTROL REPORTED GREATER THAN 50 MREM, USE CONTROL SUBTRACTION	M	M	M									09/2000	
P				8	8	7	8	8	7	8	8	7	316	312	321	2	10/2001
P				1	1	M	1	1	M	6	6	4	355	352	381	2	10/2001
P				2	2	M	2	2	M	2	2	2	0	0	0	2	10/2000
P				1	1	M	1	1	M	3	3	3	41	41	46	2	10/2008
P				2	3	4	2	3	4	5	6	6	14	15	14	2	10/2008
P				3	3	M	3	3	M	4	4	3	20	20	20	2	10/2008
P				7	7	3	7	7	3	10	10	5	19	19	14	2	04/2009
P				6	6	3	6	6	3	8	8	5	15	15	12	2	07/2008
P				6	6	2	6	6	2	6	6	4	6	6	4	2	07/2009
P				7	8	9	7	8	9	9	10	13	19	20	22	2	07/2009

Quality Control Release: JAS 1 PR 9564 RPT131 N1 5888  
Accredited by the National Institute of Standards and Technology through NVLAP for the scope of accreditation under NVLAP Lab Code 100518-07.  
Page: 1

8	8	7
1	1	M

quarterly dose in mrem

8	8	7
6	6	4

yearly dose in mrem

316	312	321	2	10/2001
355	352	381	2	10/2001

lifetime dose in mrem since 2001  
(remember, annual background dose is 620 mrem)

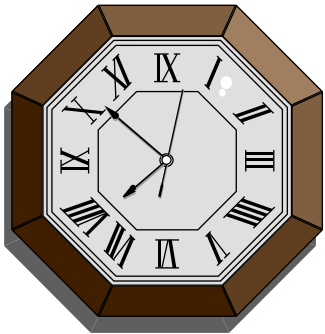
# RADIATION PROTECTION PRINCIPLES

- ▶ There are three basic principles in radiation protection: **time, distance and shielding**.
- ▶ Use these principles in addition to proper contamination controls to make dose **ALARA**



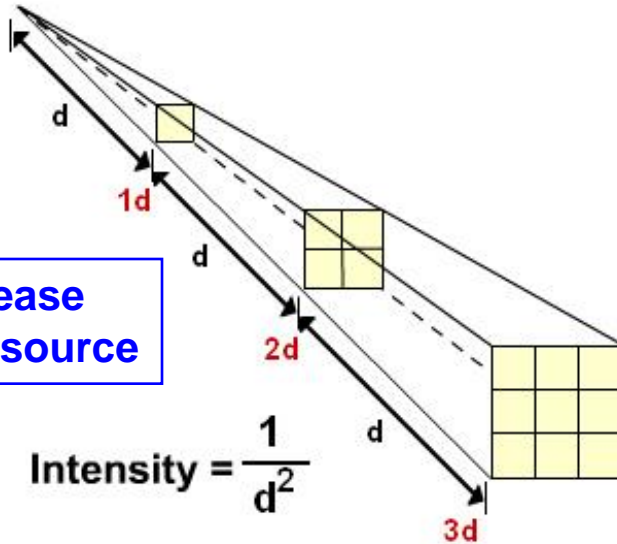


# X-RAY PROTECTION

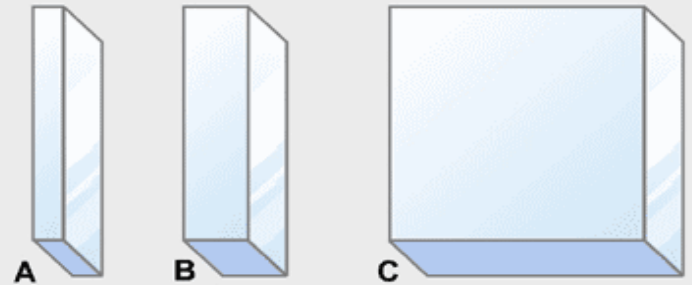


**Time:** reduce exposure time

**Distance:** increase distance from source



For The Same Lead Equivalent 1.5mmPb



A - LX Lead Glass 5/16" Thick

B - Lead Acrylic 1-1/2" Thick

C - Normal Float Glass 7-1/2" Thick

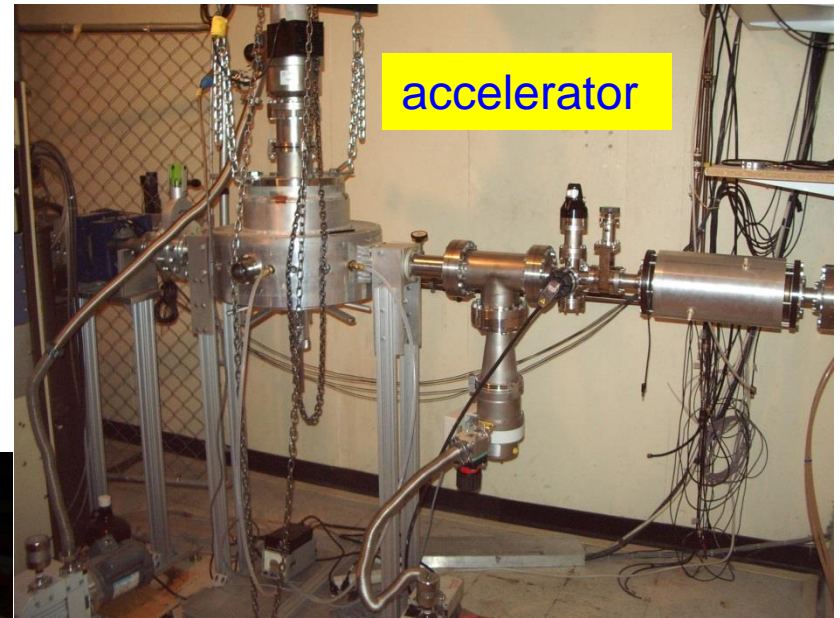
**Shielding:** put something between you and source



# X-RAY PRODUCING EQUIPMENT



X-ray



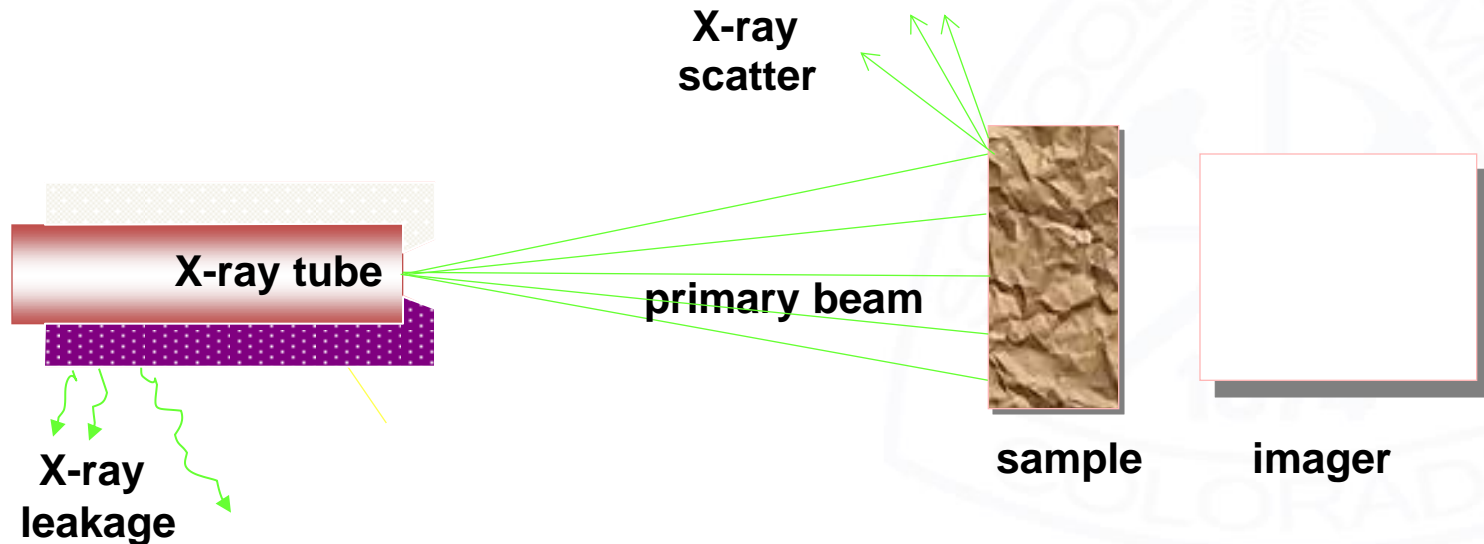
accelerator



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

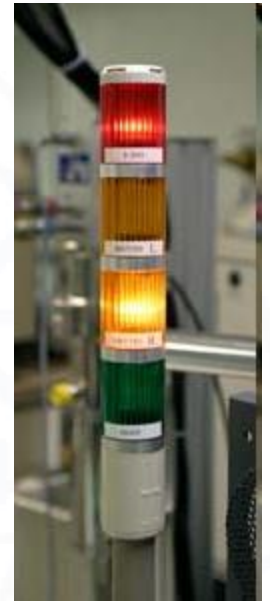


- ▶ All units shall have an easily identified device located near the radiation source housing and labeled what gives a clear, visible indication of the X-ray generation status (on-off)
- ▶ An easily visible warning light shall be illuminated only when the generator is energized, and have fail-safe characteristics
- ▶ 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 deactivate the X-ray beam except in an emergency or during testing of the interlock system.



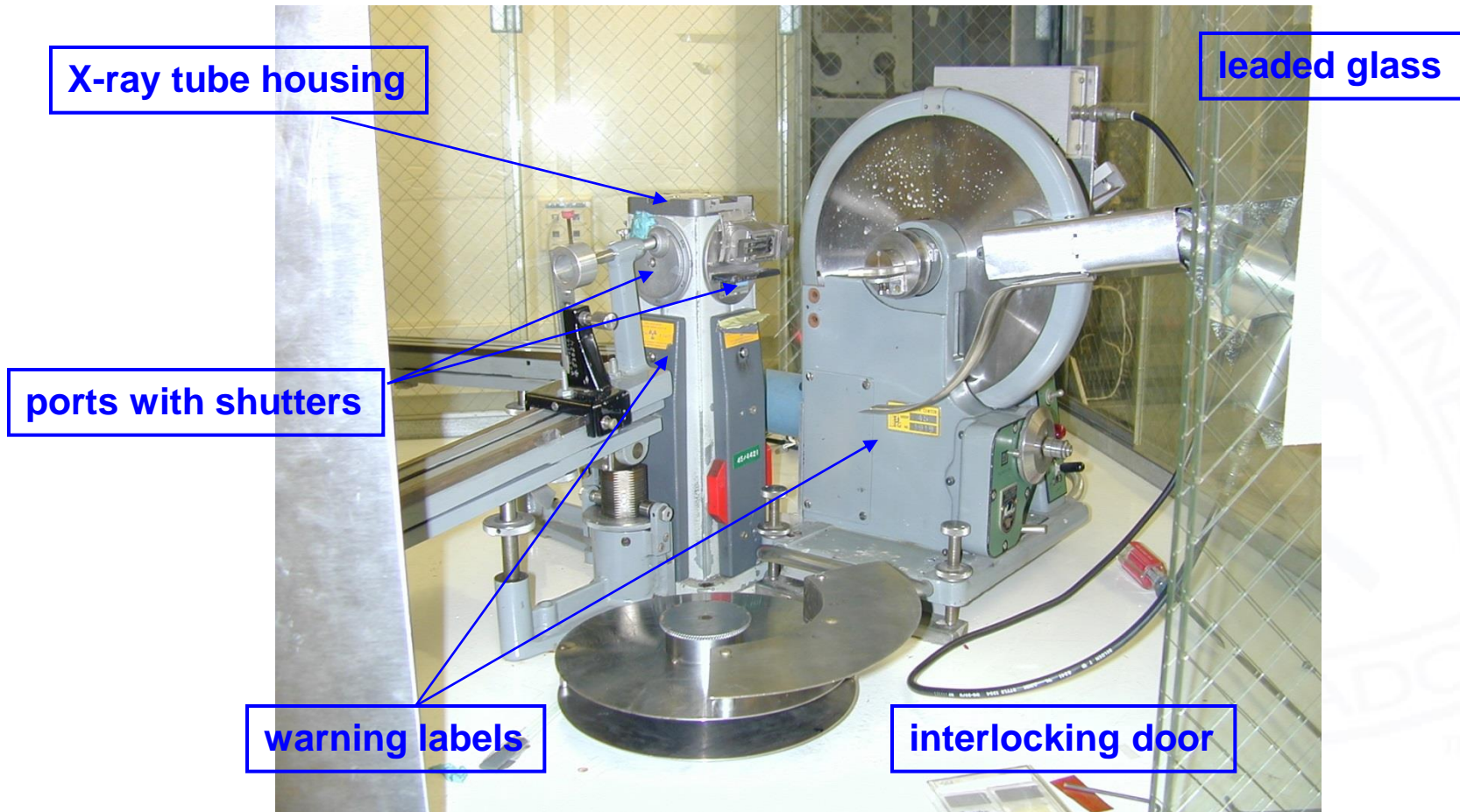
# WARNING DEVICES

- ▶ 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



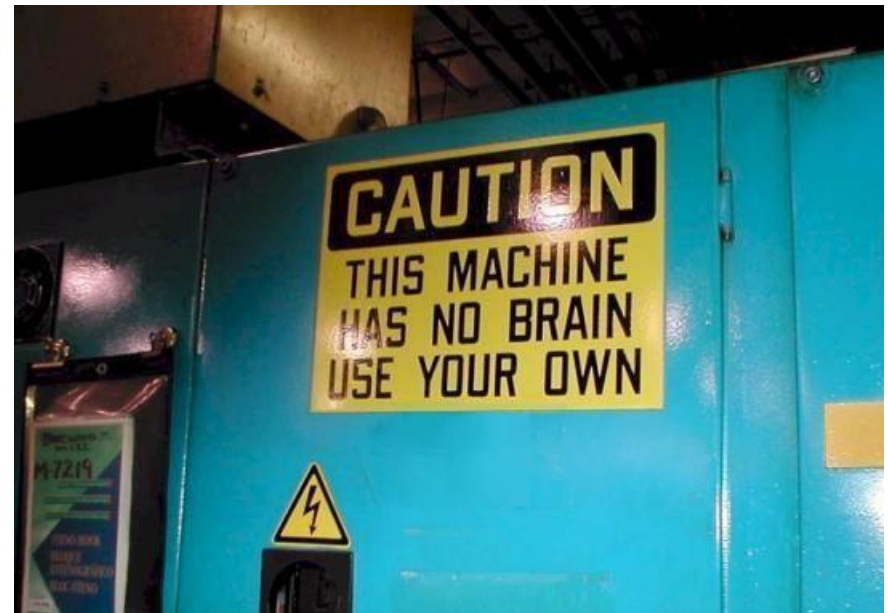


# X-RAY SAFETY

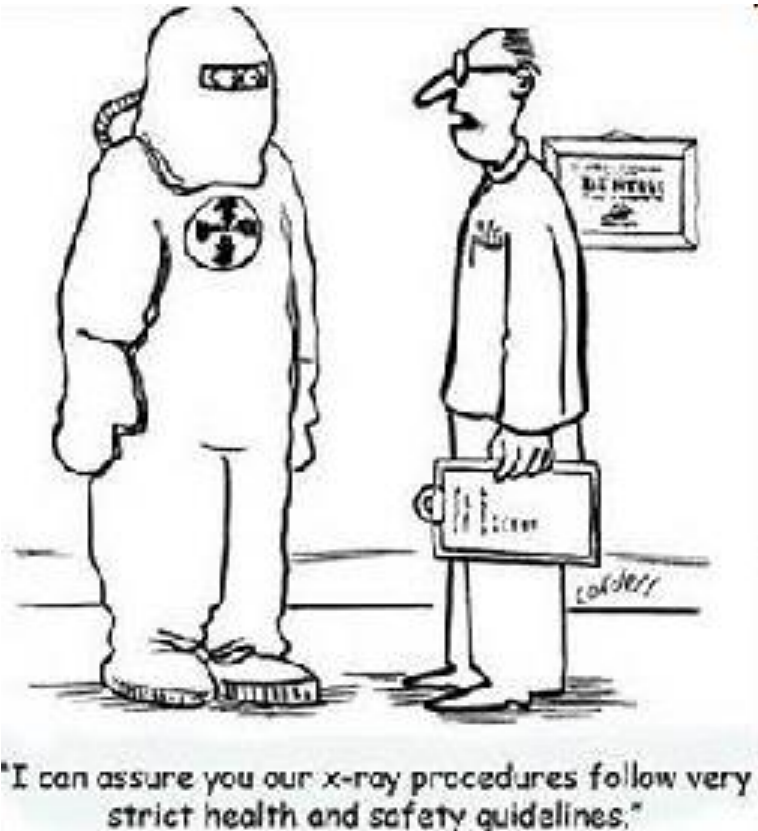


# SAFETY PROCEDURES

- ▶ 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.), except for beam alignment procedures.
- ▶ 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

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*" Just to be on the safe side, let's start with an x-ray of your wallet. "*



# 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 – CSM 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
  - removing units from CSM's possession by sale, transfer or disposal
  - modification of component that could affect X-ray beam output
  - lost, stolen or damaged
  - suspected exposure

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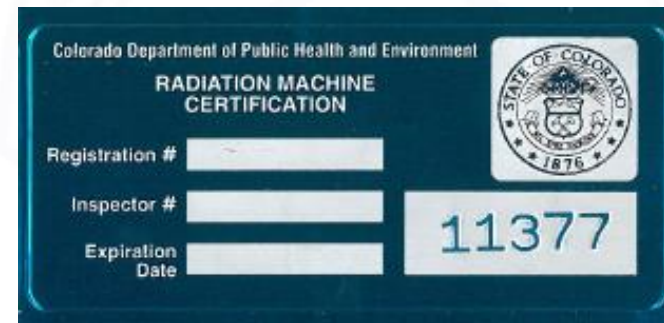
As a "Health and Safety Officer", my duty is to report this office as being a safety hazard!

search ID: cga0161

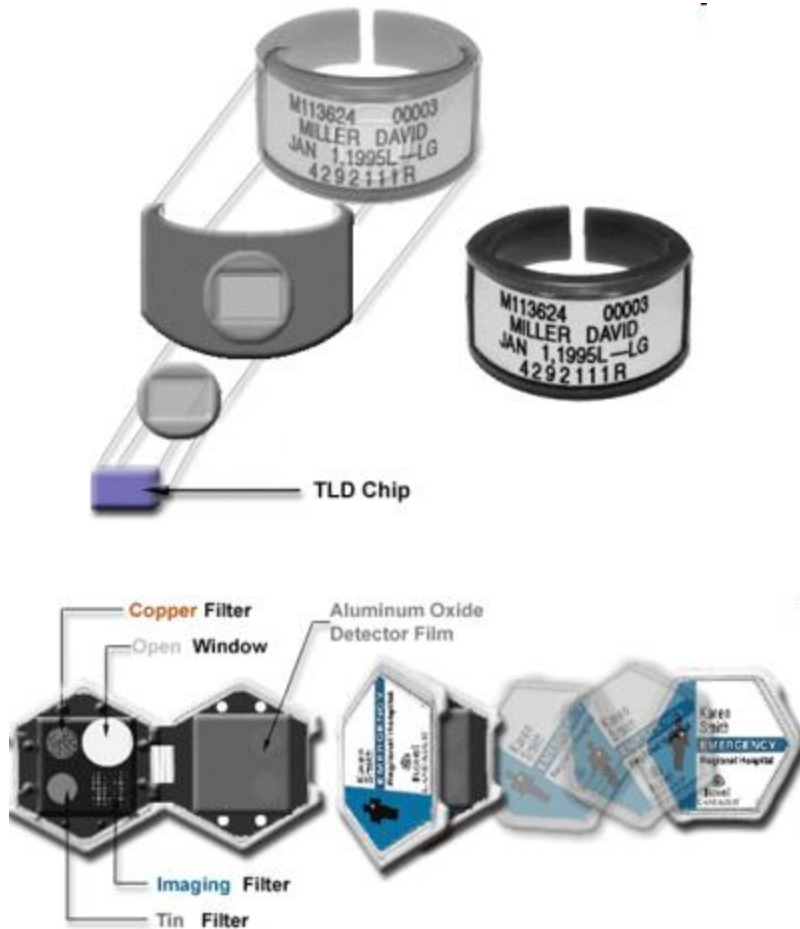


# X-RAY SURVEY AND INSPECTION

- ▶ The Radiation Safety Office (RSO) will perform a survey annually. This survey will include inspection of all safety systems and a radiation exposure survey.
- ▶ Analytical X-ray equipments are inspected biannually and following major repairs and/or system modifications by state-certified inspectors. Hand-held units are inspected annually.
- ▶ X-ray units that is registered and inspected by CDPHE have the Radiation Machine Certification (the “blue sticker”) attached to the machine body.



# DOSIMETERS



- ▶ To measure the amount of radiation received during operations, operators of 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!

# DOSIMETERS

- ▶ Radiation badge dosimeter measures whole body exposure; ring dosimeter measures extremity exposure
- ▶ Distributed quarterly from EHS
- ▶ Dosimeters must be worn when operating X-ray machines. When not in use, keep dosimeters away from light, heat, radiation
- ▶ Do not lose, do not break open. Return to EHS in a timely fashion for reading



# 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

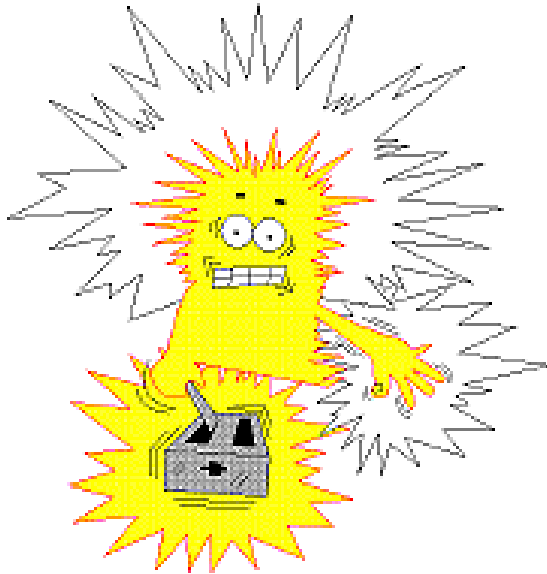


- ▶ A declared pregnant worker is a woman who has voluntarily informed her employer, in writing, of her pregnancy and estimated date of conception
- ▶ A declared pregnancy may be undeclared at any time
- ▶ An undeclared pregnant worker may not have her duties restricted because of her pregnancy
- ▶ The radiation dose limit for declared pregnant workers 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  
Fax: (303)-384-2081  
Facilities Management Building  
1318 Maple Street  
Golden, CO 80401

