Radiation Safety for X-ray Diffractometers

Laboratory Safety Pamplet

Radiation Units

a) **Roentgen (R) :** amount of radiation that produces one unit of ions/cm3. (measure of X-rays) 1mR/hr is considered a low rate. 100mR/hr is considered high.

b) **Radiation Absorbed Dose (rad)** [SI unit : gray (Gy) where IGy = 100 rad]: Energy imparted to matter in volume (V) divided by the mass. 1 rad = 100 ergs/gram (measure of any radiation) 100 rad/sec = 1 Watt/kg

c) **Radiation Equivalent Dose (rem)** [SI unit sievert (Sv) where 1Sv--100 rem]: Product of the absorbed dose and the relative biological effect (RBE) necessary to express on a common scale. rad x (RBE) = rem for X-rays the RBE = 1.0 and for neutrons = 10.0 (measure of radiation effect on humans)

for X-rays :

I rad = 1 rem	1 R
3.6×10^5 R/hr	1 Watt/kg

d) **Maximum Permissible Dose: (DOE: www.tis.eh.doe.gov/docs/rcm/)**

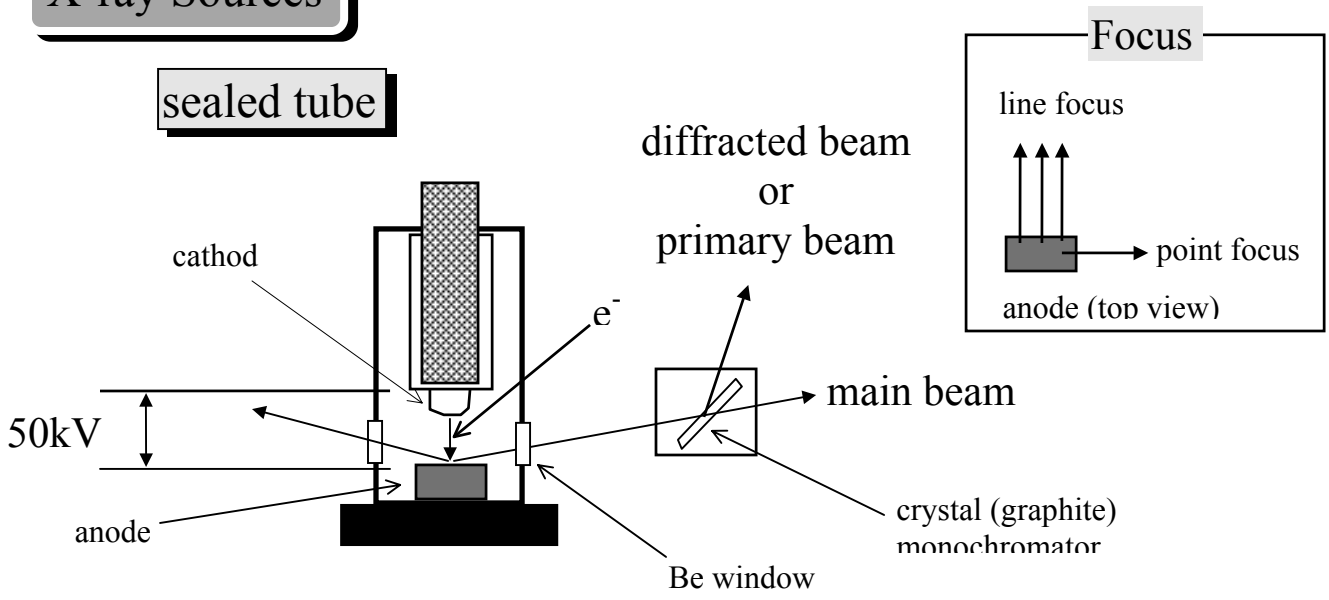
Whole body	5rem/yr. (elbows up; knees up)	2.5mR/hr
eyes	15 rem/yr.	
hands & body	50 rem/yr	
non-occupational	0.1 rem/yr.	
minors	0.1 rem/yr	0.01 mR/hr
pregnant (declared)	0. 5 rem/9-month (must be declared in writing)	

e) **Background Radiation**

Highest (world)	5 rem/yr.	Kerala, India
Highest (U. S.A)	0.2 rem/yr	Leadville, Colorado
Average(world)	0.09 rem/yr	
Lowest(U.S.A)	0.07 rem/yr	Atlantic/Gulf coast

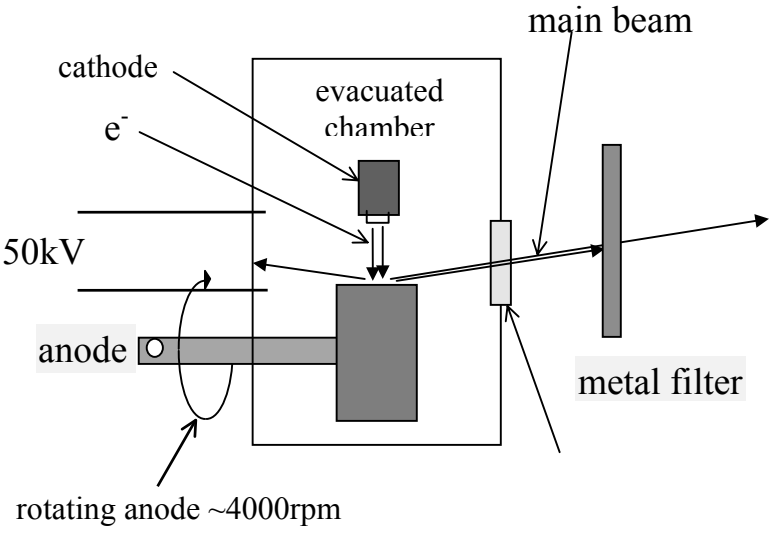
X-ray Sources

sealed tube



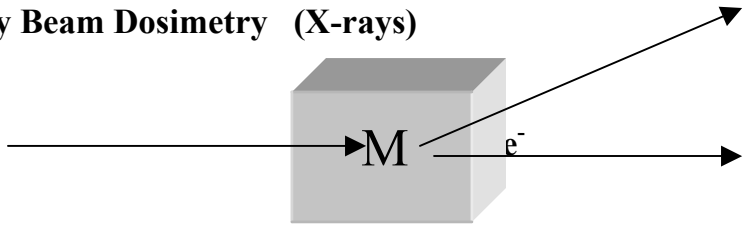
Normal operation 50kV and 30ma the power = 1500 watts

rotating anode

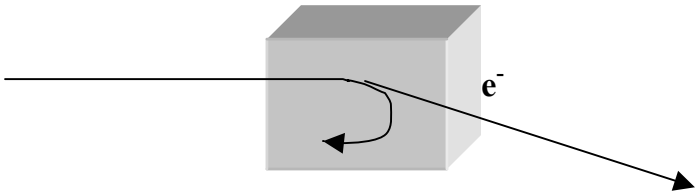


Normal operation 50kV x 180ma the power = 9000 watts

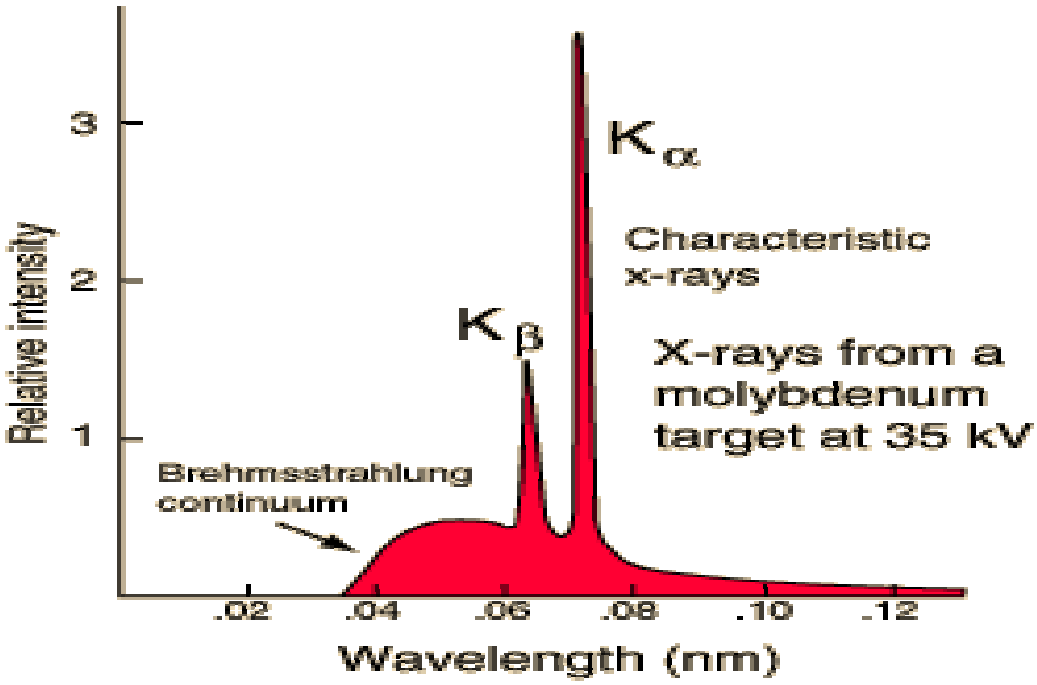
Primary Beam Dosimetry (X-rays)



Characteristic
X-rays
K_{alpha} K_{beta}



White Radiation
"Bremsstrahlung"
or breaking radiation



Energy (KeV) = 12.398 / λ (Å)

Radiation Level

Inverse Rate Law

$R/hr = 2432 * [(kV * mA)/cm^2] * Z$ atomic number of the target

X-rays - **'Soft'** radiation - easily attenuated **but** never attenuated to **zero.**
$1/d^2$ decrease (standard temperature and pressure)

X-ray diffraction -

monochromatic - reduces the radiation level ($\sim 10^5$)

Filtered - reduces the radiation level ($\sim 10^1$)

collimated beams directional
separate user from the source
reduce the primary radiation area

Leakage Dosimetry

Normally very low for X-ray Diffractometers unless collimator and/or monochromator misaligned. (labyrinth design, well fitting joints)

Almost negligible leakage from tube housing.

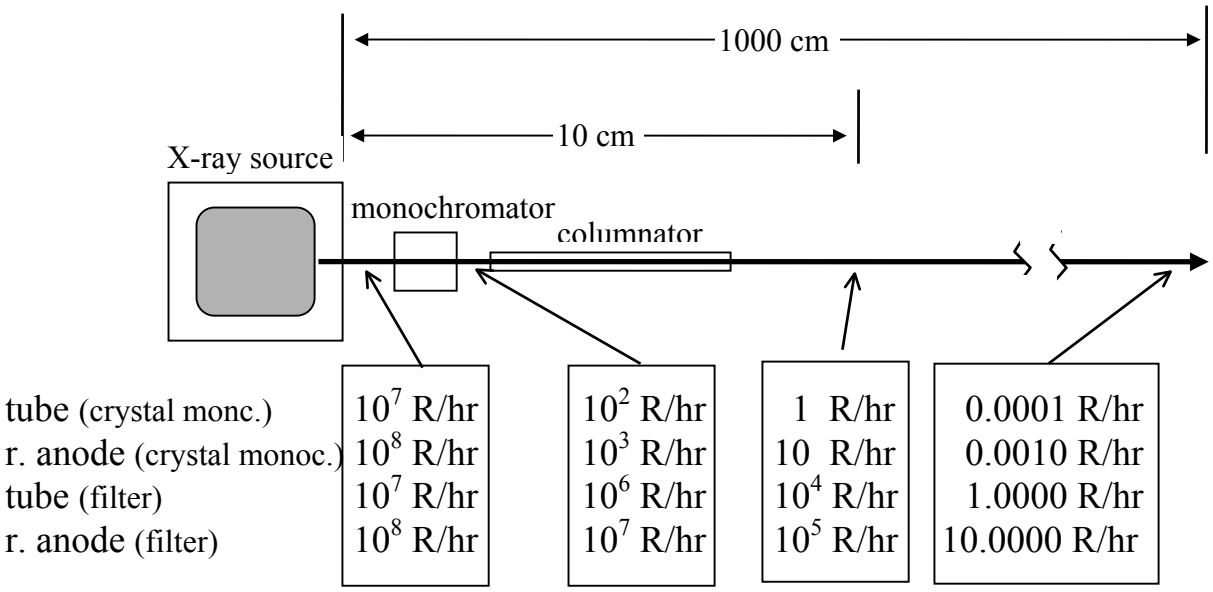
Stray X-ray beam directions tend to be at large angles away from the direction of the primary beam.

Adventitious Radiation.

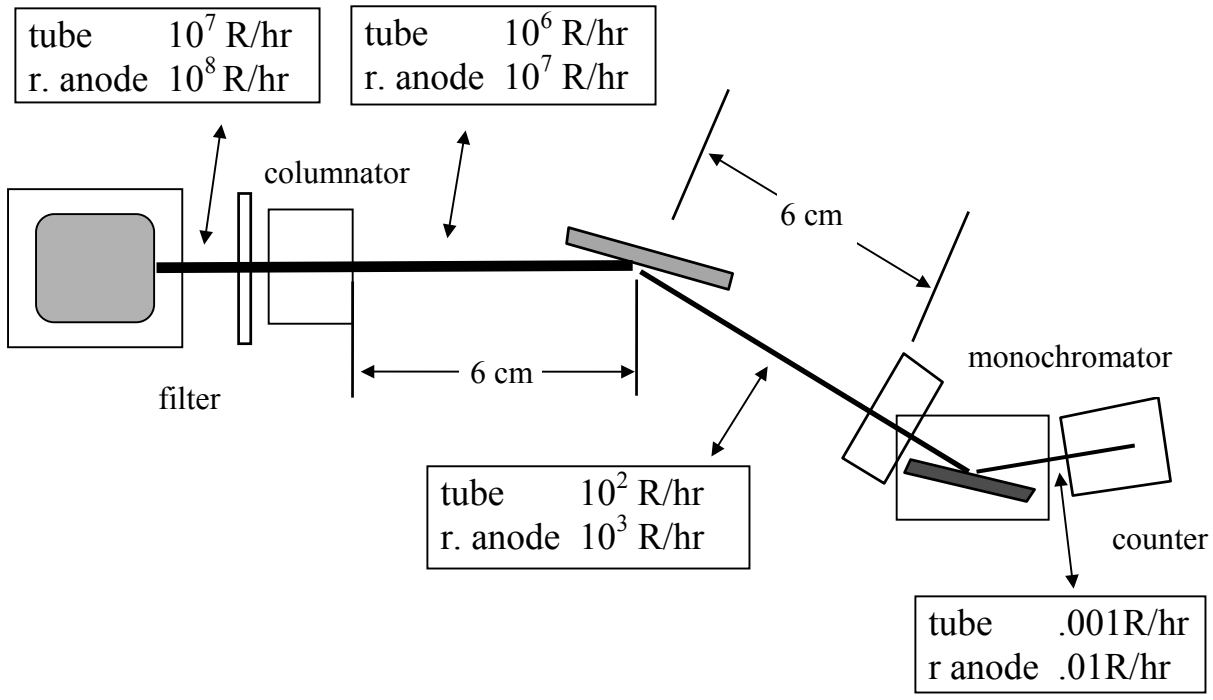
High voltage rectifiers. (a X-ray tube is a rectifier) Troublesome if tube or electronics malfunctions.

Radiation Hazard

single-crystal diffractometer



powder diffractometer



Radiation Measurement

Personal Dosimetry

a) types

-LiF Thremoluminescent dosimetry **TLD** Pocket and extremity badges. (lowest detectable dose 2-3 mrad ; highest 105 rad) -Film badge

-Pocket ion chamber (pencil dosimeters; show immediate response)

- usage

-badges should be worn in such a way as to maximize the possibility of exposure in case of accident. (line of sight)

- advantages

usually first sign that something has gone wrong. extremity dosimetry is the most useful legal aspects

- disadvantages

-directionality of the primary beam and scattered radiation. monitoring devices must sustain a direct hit a 1/ 10000 chance for pocket and 1 /100 chance for extremity badges -nuisance (if too troublesome it won't be used) -expensive

- dosimetry exclusions

-workers who are likely not to exceed the max. yearly limits. - dosimeters will be distributed on a rotating basis.

Radiation Detectors

- ion chamber, proportional counter, Geiger counter
- measure ionization events.
- instantaneous results
- most cost effective

Accidental Exposure

Rate

1 accident per 100 machines per year in 1968 and
1 accident per 200 machines per year in 1974.

for 10 X-ray diffractometers I accident every 10 years. 75% of those

accident

are with **XRD** instruments. **Relative User Risk** (increasing risk)

- routine users are the safest (lowest risk)
- advanced users (a little knowledge is dangerous)
- managers and service personal (highest risk)

Causes for accidents (50 to 75% due to human error).

- haste
- faulty equipment
- overriding safety features
- obscuring safety indicators
- lack of training
- poor lighting, space restrictions or room conditions

Contributing factors for accidents

- multiple users
- lack of safety procedures enforcement
- bad attitude
- multiple applications on the same machine
- multiple machines in close proximity

Exposure of Radiation to Flesh (localized) : Symptoms (10^3 rad)

-fingers, arms, eyes etc.(finger/hand exposure is the highest risk) - depth of exposure of 10-20 keV X-rays 1.3-4.3 mm ($t_{1/2}$) -non-stochastic (skin reaction)

0-1 hr.	tingling
1-7 days	swelling, blistering, pain, erythema, hair loss (epilation), skin loss (desquamation)
7-30 days	ulcers (sores that will not heal), gangrene
30-300 days	loss of digits.
300+ days:	cataracts, skin grafts

As dose increases the time for symptoms to appear decreases

Other doses

500-1000 rad	erythema and epilation
300-500 rad	mild erythema, some epilation
300 rad	lowest visible detection of skin damage
1-300 rad	no visible skin damage
0.1-1 rad	significant dose (over-exposure)

As beam area decreases the dose required to produce skin damage increases.

stochastic (radiation-induced mutation : cell damage : cancer)

- No known threshold dose!
- risk is roughly proportional to the dose^2
- >100 rad is considered significant
- >3000 rad cause cell sterilization - highest risk is between 2500-3000 rad
- known case for exposure above 2000 rad
- most cancers take more than 10 years to manifest symptoms
- for workers exposed to 100rem/life show only a statistical decrease in life expectancy of 1%. (70 days for 70 years life expectancy)
- statistically one day of life loss for each rem of exposure.
- exposure is accumulative (rem/life)

Accident Detection

- X-rays are invisible (no sight, sound or taste)
- X-rays do not generate heat in tissue. (no touch)
  400 rad will raise the skin temperature by only 0. 001° C
- X-rays do not produce detectable amounts Of 03, NO etc. (no smell).
- Personal Dosimetry
- Biological/Health Effects

Post Accident

- Activate the kill switch and throw the breaker
- stop any action that would put you at risk of radiation exposure.
- leave experiment *as is*
- contact supervisor, sub-licensee and the ORS at once ORS **845-1361** or after hours **845-4311**
- return all badges (if any) to the ORS at once for processing.
- make a note in the machine log, describe the accident in detail.
- seal off instrument and stop any action until a reasonable explanation for the exposure is agreed upon.
- post warning signs and/or notify all personal who may come in contact with the instrument.
- undertake a time and motion study. (ORS will also survey) use machine logs, computer time stamps, agendas, notebooks and any other clues to where and when you could have been exposed.
- complete physical. (for the health record)
- provide a written description of the incident to the ORS (as soon as possible).

Control

Administrative

- Administrative is the easiest (keep in mind that any administrative rules at will curtail activity or use of any instrument will be ignored!)
- Operational Safety Procedure (OSP) document that summarizes all safety
  provisions for any given X-ray diffractometer.
  Binder where all safety information is stored including:
    management,
    modifications,
    accident history,
    room diagram,
    explanation of safety features,
    list of users,
    training forms (signed by trainee and instructor),
    emergency response

- X-ray machine log book
  -time/date user name/project any remarks (no matter how trivial).
  -direct written communication between users.
- User Survey (before and after use)
  check the log,
  inspect beam stop and collimator,
  Open and close shutters (attenuator),
  Survey for stray radiation,
  inspect "fail-safes",
  inspect safety lights,
  check the kV and mA gauges.
  Inspect primary beam path, with the GM or hand-held screen,
  for radiation

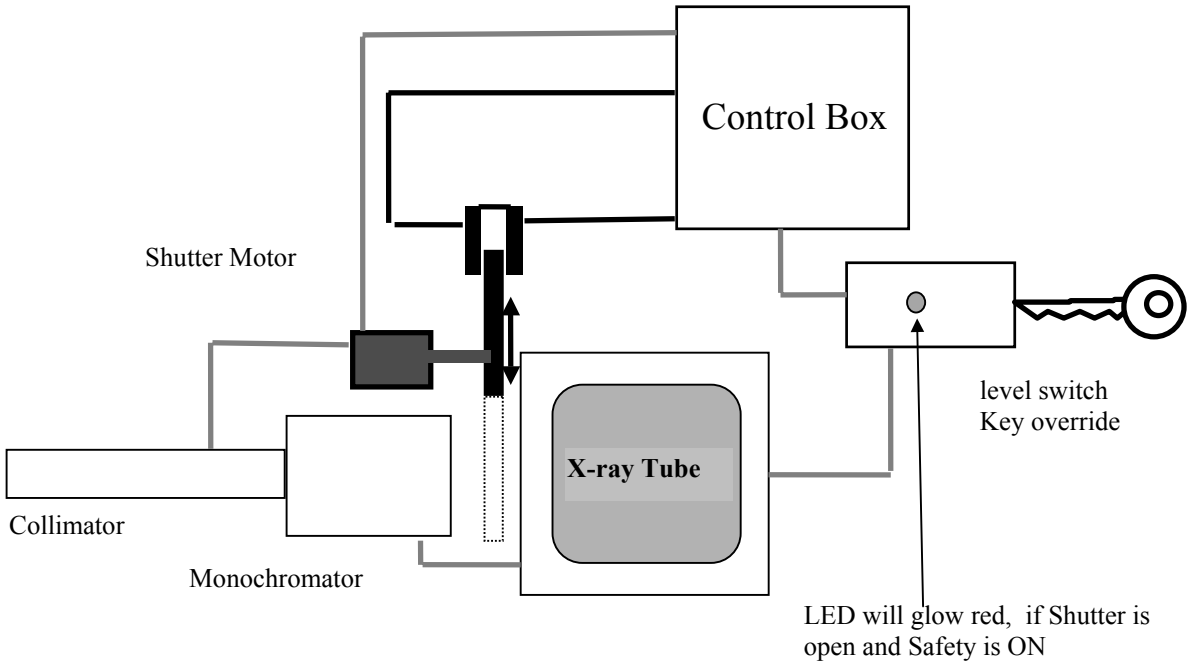
Control

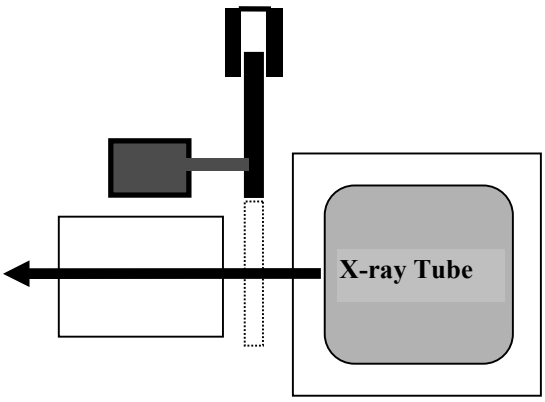
Hardware

- area and beam monitors.
- enclosure hoods, shielding (movable walls or other barriers) lead, brass,, steel, lead-load acrylic, lead-glass, PVC, glass 2mm lead or 7mm of steel will attenuate 107 R/hr (for occupational and non-occupational workers)
- warning lights
- posted signs (in-use do not open, X-rays produced)
- shutter fail-safes and safety interlocks. 'redundancy with diversity'
- restricted areas (key entry, locked doors, floor tape, barriers)
- safety glasses (normal glass is - 5% as effective as lead 3cm of glass will attenuate the most intense X-ray beams)

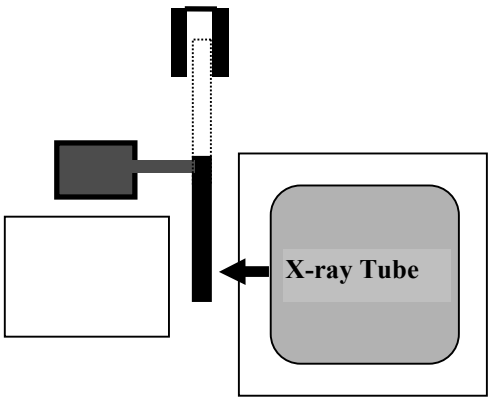
Shutter Safety Interlock

Instrument : Siemens P4 single-crystal X-ray diffractometer
S/N : 1690
Location : Rm 2404 Chemistry





Shutter Open



Shutter Closed

Legal Maters

"Ultra Hazardous Equipment"

"Strict Liability" :	No matter what you do to prevent the accident you are still responsible.
"Use-of-tools"	A situation where a user has used tools to modify the instrument.
"Assumption of Risk" :	Responsibility cannot be delegated, transferred or assumed.

Procedures must be "by the book" any deviation are not legal.

Bibliography

"Procedures Manual for Use of Radioisotopes and Radiation Producing Devices", Office of Radiological Safety, Texas A & M University

"A Guide to the Safe Use of X-ray Diffraction and Spectrometry Equipment", Martin, E., Science Reviews Ltd., Ash Drive, Leeds, LS 17 8RA U.K.

"A Case History of Severe Radiation Bums from 50 kVC X-rays", Steidley, K., Stabile, R. & Santillippo, L. *Health Physics* (1981). 40 399-405.

"Analytical X-ray Hazards: A Continuing Problem" Lubenau, J., Davis, J., McDonald, D. & Gerusky, T. *Health Physics* (1969). 16, 739-746.

"Occupational Hazards in X-ray Analytical Work" Lindel, B. *Health Physics* (1968). 15, 481-486.

"Incidence, Detection and Monitoring of Radiation from X-ray Analytical Instrumentation" Jenkins, R. & Haas, D. *X-ray Spectrom* (1975). 4, 33-39.

"Protection Against Radiation Injury" Cook, J. & Oosterkamp, W. *International Tables for Crystallography* (1962). 333 -338.

"Characteristic X-ray Flux from Sealed Cr, Cu, Mo, Ag, W Tubes" Honkimski, V., Sleight, J. & Suortti, P. *J Appl. Cryst.* (1990). 23, 412-417.