

# Radiation Safety for X-ray Diffractometers

Laboratory Safety Pamphlet

## Radiation Units

- a) **Roentgen (R)** : amount of radiation that produces one unit of ions/cm<sup>3</sup>. (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 1Gy = 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 :

$$\begin{array}{ll} 1 \text{ rad} = 1 \text{ rem} & 1 \text{ R} \\ 3.6 \times 10^5 \text{ R/hr} & 1 \text{ Watt/kg} \end{array}$$

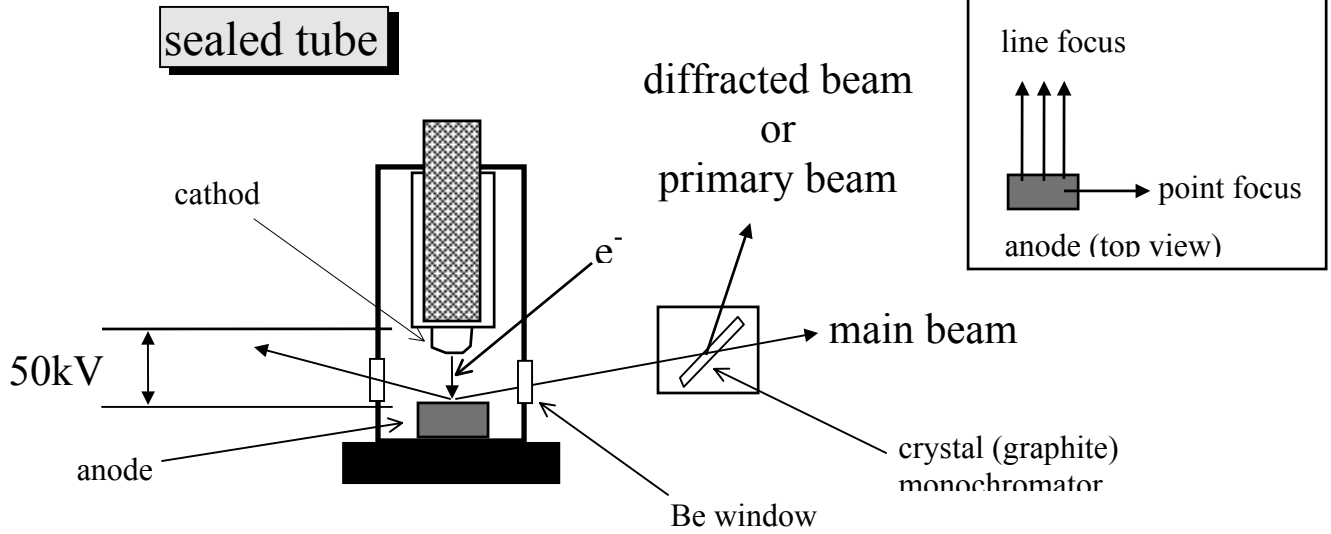
d) **Maximum Permissible Dose: (DOE: [www.tis.eh.doe.gov/docs/rcm/](http://www.tis.eh.doe.gov/docs/rcm/))**

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**

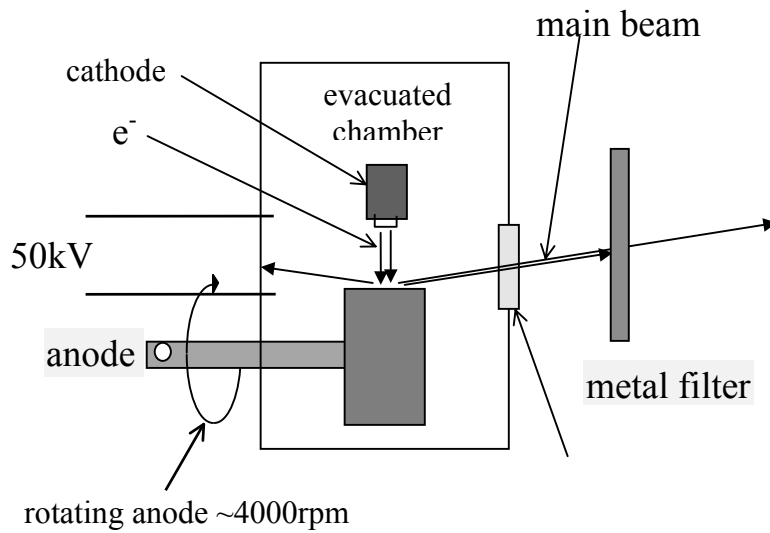
Highest (world)	5 rem/yr.	Kerala, India
Highest (U. S.A)	0.2 rem/yr	Leadville, Colorado
Average(world)	0.09 rem/yr	
Lowest(U.S.A)	0.07 rem/yr	Atlantic/Gulf coast

# X-ray Sources



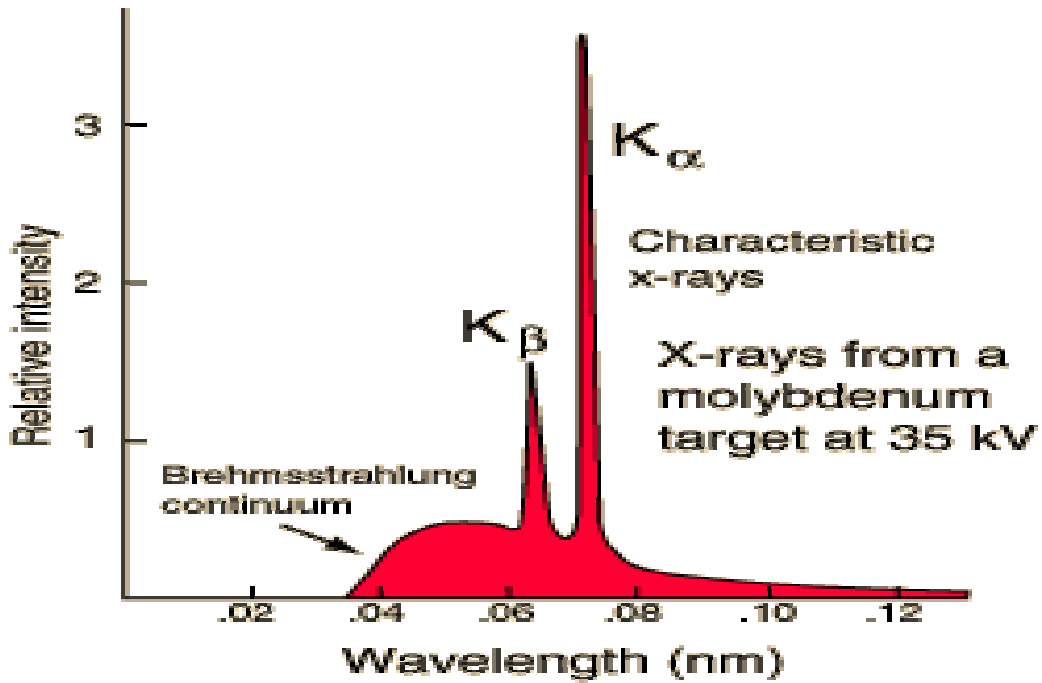
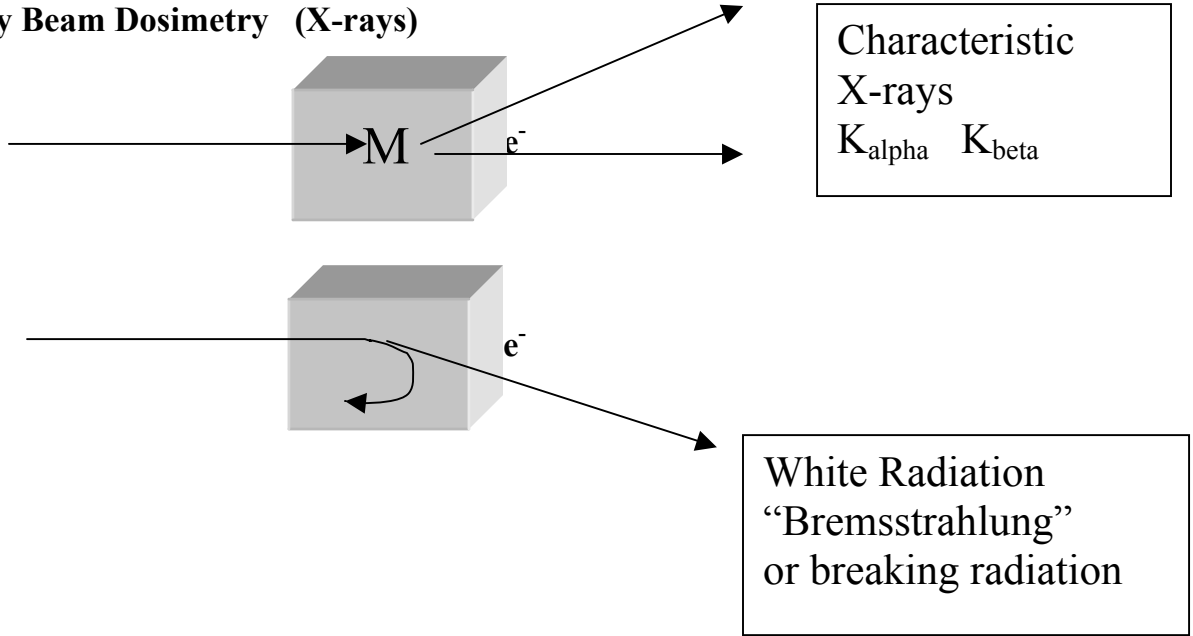
Normal operation 50kV and 30ma the power = 1500 watts

# rotating anode



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

**Primary Beam Dosimetry (X-rays)**



$$\text{Energy (KeV)} = 12.398 / \lambda (\text{\AA})$$

## Radiation Level

Inverse Rate Law

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

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

X-ray diffraction -

(~10 <sup>5</sup> )	monochromatic	- reduces the radiation level
(~10 <sup>1</sup> )	Filtered	- reduces the radiation level
source area	collimated beams	directional separate user from the reduce the primary radiation

## 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.

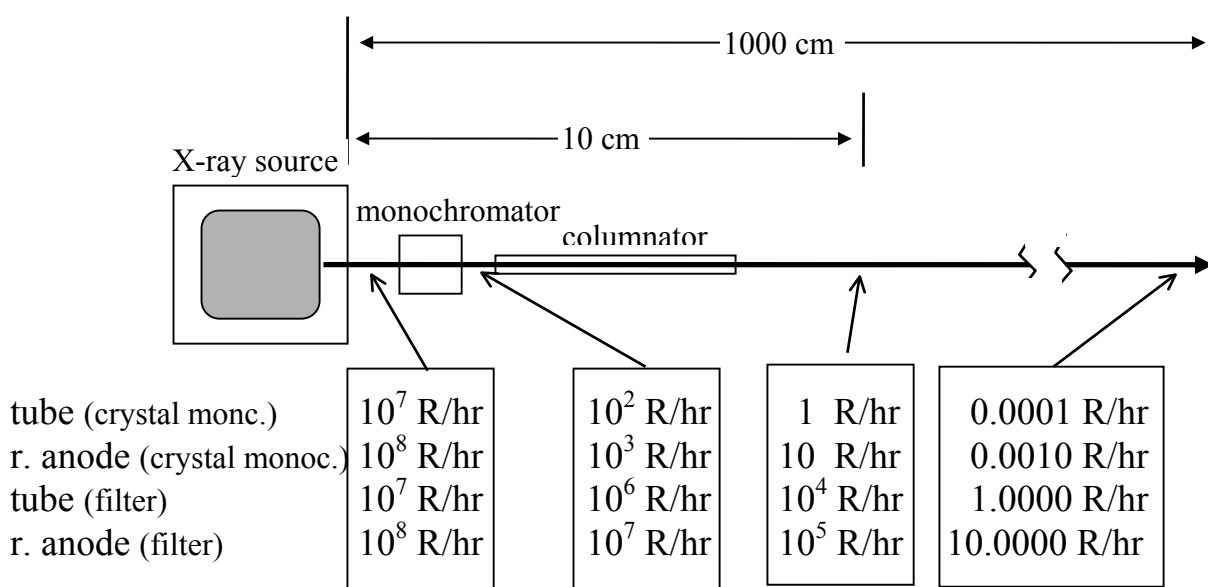
Stray X-ray beam directions tend to be at large angles away from the direction of the primary beam.

## Adventitious Radiation.

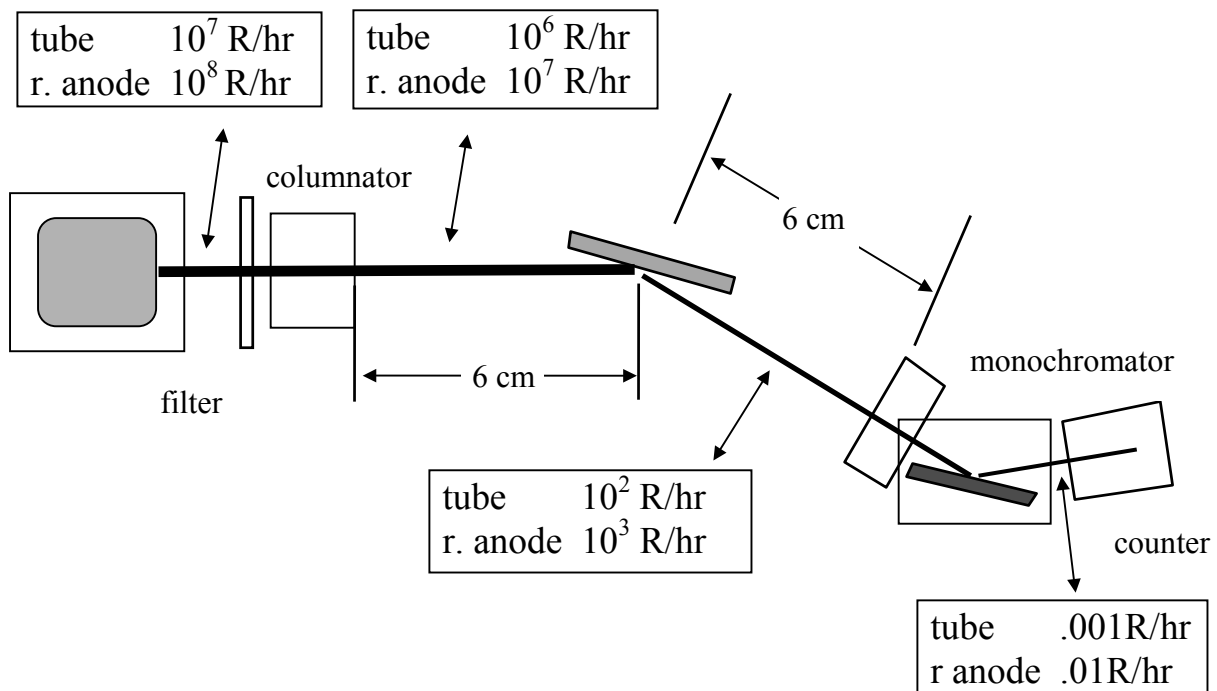
High voltage rectifiers. (a X-ray tube is a rectifier) Troublesome if tube or electronics malfunctions.

# Radiation Hazard

## single-crystal diffractometer



## powder diffractometer



## **Radiation Measurement**

### **Personal Dosimetry**

a) types

- LiF Thermoluminescent 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 1 accident every 10 years. 75% of those accidents

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<sup>2</sup>
- >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 O<sub>3</sub>, 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 personnel 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

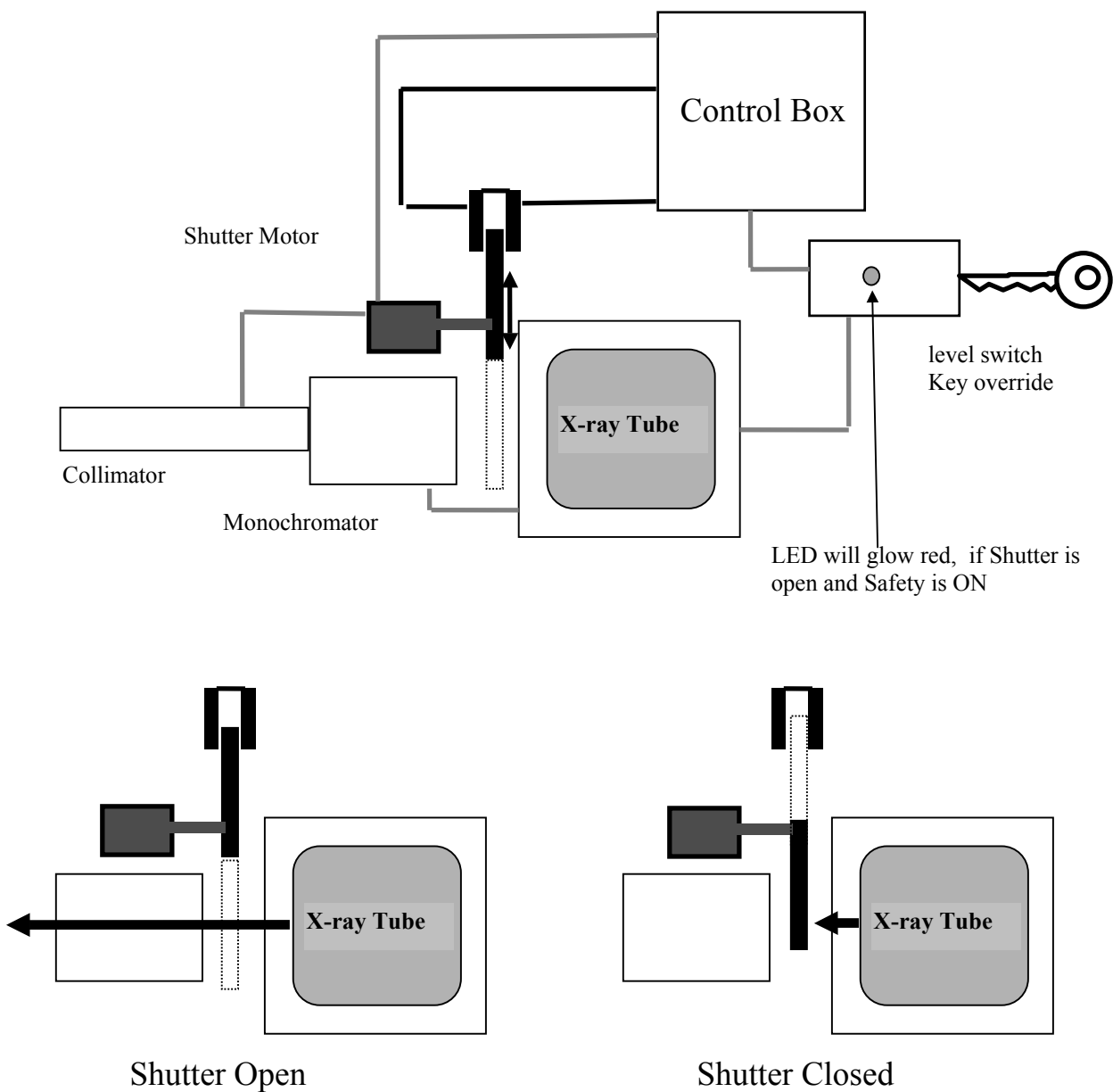
## Control

### 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



## Legal Matters

### "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.

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