ES&H Lesson Plan Course # 270

Radiation Generating Device, Radiological Safety

Prepared By:_______________ Date______________

Reviewed By:______________ Date_______________

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ES&H Training course 270
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Course 270 Outline
Radiation Generating Devices (RGD)

I. Definition

Collective term for devices which produce ionizing radiation, typically X-rays, usually incidentally.

This term may also apply to sealed sources and small particle accelerators.

For this training we will not include sealed sources or particle accelerators with energies >10MeV.

II. Regulations, Procedures and policies

A. SLAC Radiological Control Manual, Part 365.

XGR form is used to submit OHP to approve the operation of radiation generating devices.

B. ANSI N43.3

C. 10CFR835 Guideline /C3

III. Devices at SLAC classified as a Radiation Generating Device

Electron Welder, Building 31---60kV (Operates at 50kV)
X-Ray diffraction units at SSRL---60kV
Test Gun facility Building 8--200kV
High Voltage Test Facility, Building 6---200kV
Klystrons, Building 44 test lab, Klystron gallery, (5045)-- 350 kV
RF Test bunker, Bldg 44 Klystron lab 1 MV gap voltage, 150 kW RF power
PEP II 4,8,12, ---90kV, continuous wave
X-Band NLCTA ---500kV
X-Band also at Klystron Lab
ASTA 50 cm section, 30-40 MeV

IV. Classifications of Installations, per ANSI standard

Exempt Shielded
Shielded
Unattended
Open
Analytical Device, Enclosed beam
Analytical Device, Open beam
Particle Accelerators
Electron devices that generate X-Rays Incidentally
Cabinet X-ray Systems

V. X-ray production with electron beams

A. X-rays are similar to gamma radiation in their ability to ionize atoms. It takes 5eV of photon energy to ionize a carbon atom, 33eV to ionize air.
So one X-ray photon of 100keV can ionize thousands of atoms.

B. X rays are generated when electrons (or other charged particles) undergo severe acceleration, like a storage ring at SSRL, (or deceleration). This can happen in any electronic device that operates at several kilo-volt or more (e.g. electron microscopes).

X-rays are produced when charged particles are accelerated by an electrical voltage (potential difference). Whenever a high-voltage, a vacuum and a source of electrons are present in any device, X-rays can be produced.

C. X-rays are produced when a beam of electrons strikes a target. The electrons loose their energy in colliding with electrons in the target causing ionization and excitation. And by deflecting the electron. Heavy nucli are more efficient in producing the x-ray . An electron accelerated across a potential energy may emit an X-ray photon having energies up to its own kinetic energy, equal to the acceleration voltage applied to the tube. Thus a monoenergetic beam of electrons produces a spectrum of X-rays with photon energies up to the value of the beam energy. These X-rays are also called bremsstrahlung. Bremsstrahlung
("braking radiation") arises from the accelerations suffered by the electrons during collision with the atoms.

D. There are intense narrow line emissions that are characteristic of the material of the target. These characteristic lines are important for crystallography but since they amount to only a few percent of the total X-ray output they are of little radiological importance.

E. If energies are high enough to eject electrons from the targets electron shells, outer shell electrons fill the inner shells of the target atoms and discrete energy photons are produced.

F. Properties for production of X-ray

Potential energy and current are the components

1. X-ray output has a continuous energy range that extends up to a value, E_{max} that is measured in electron volts (eV). (1 eV = 1.6 10^{-19} Joules). The photon energy produced by an X-ray device depends on the voltage. A voltage of 10kV will produce up to 10 keV photons. Most of the X-ray photons produced by a given maximum acceleration potential will be approximately one-third of the maximum acceleration potential.

2. The total number of photons produced depends on the current (A). The higher the current, the more X-ray photons are emitted.

3. The total power=V x A

4. Duty Factor is the fraction of operating time during which the device is actually producing radiation. It is the product of the repetition rate (in Hz) and pulse length (seconds). DF=Hz x sec

   30 x 0.0000035=10^{-4}

F. RF Structures

Dark Current-electrons may be removed from the surfaces of matter in a RF field.
A RF structure with current may breakdown causing the beam to be directed into a structure thus producing X-rays

X-rays may be produced in RF structures without an applied current. In general whenever there is high voltage or RF power in a vacuum, x-rays may be produced even though no heated filament or electron source is introduced.

The RF Bunker at Klystron Lab test structures inside a PPS bunker. Uses a Klystron for power. About 1/3 of the power supplied to the bunker is reflected back.

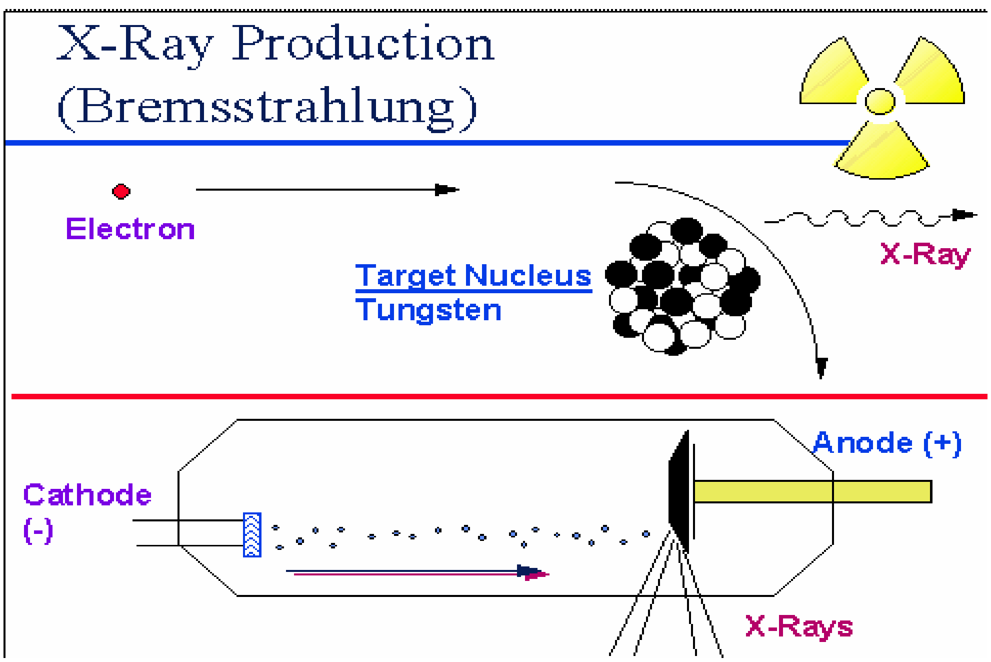
G. The ability to measure X-ray may be limited to the minimum energy of the detector and the devices ability to shield x-rays outside of the devices housing.

Generally we will not begin to measure X-rays until 10's of kV

H. Past radiation dose rates from Klystrons

A radiation survey was performed at the collector of 5045 Klystron without shielding, at ~120kV a thin window instrument began to measure significant x-ray dose. This is the basis for initial surveys.

Past measurements >20 R/h—2001 at the water outlet piping without the horseshoe shielding installed.
With end cap shielding removed-1700 R/hr



VI. X-rays present no activation or contamination hazard until > 10 Mev x-rays are produced such as in an accelerator structure (Rule of thumb). Even then activation may occur but contamination usually is not detected. At SLAC radioactive contamination is measured at surfaces where there is a high flux of x-rays produced.

VII. Personnel categories

RGD Operator-Someone given authority to operate a device and change parameters such as voltage and current on that device. At the Klystron lab these individuals are specified for a device and station. At SSRL these personnel are identified on the X-ray generator Authorization sheet.

Users of a RGD device-Someone who may use the device but does not operate the device

VI. Training Qualifications

A. RGD Operators-RWT I unless the operator does not have the ability to encounter potential X-rays due to interlocks and other securing devices.

B. GERT for Users and operators who will not encounter >0.05mR/h X-rays

C. Device Specific Training-each operator shall receive specific training on their specific device. This training should include hands on demonstration with a device expert
* device specific training is included for some devices in this lesson others may be under a separate lesson plan.

D. Visitors may not enter posted "Radiation Areas"
Visitors may not operate RGD unescorted, They may be with a qualified operator.

VII. Radiation exposure rates, thresholds.

Outside closed type device <0.5 mR/h
Klystrons < 5mR/h at radiation Area ropes,(gallery)
2mR/h in Klystron laboratory
< 100 mR/h at 30 cm
If located outside of a Radiological Controlled Area, <0.05 mR/h

VIII. Shielding

Like gamma rays, X-rays have no definite range - the intensity of radiation transmitted through a material falls exponentially with the thickness of the material.

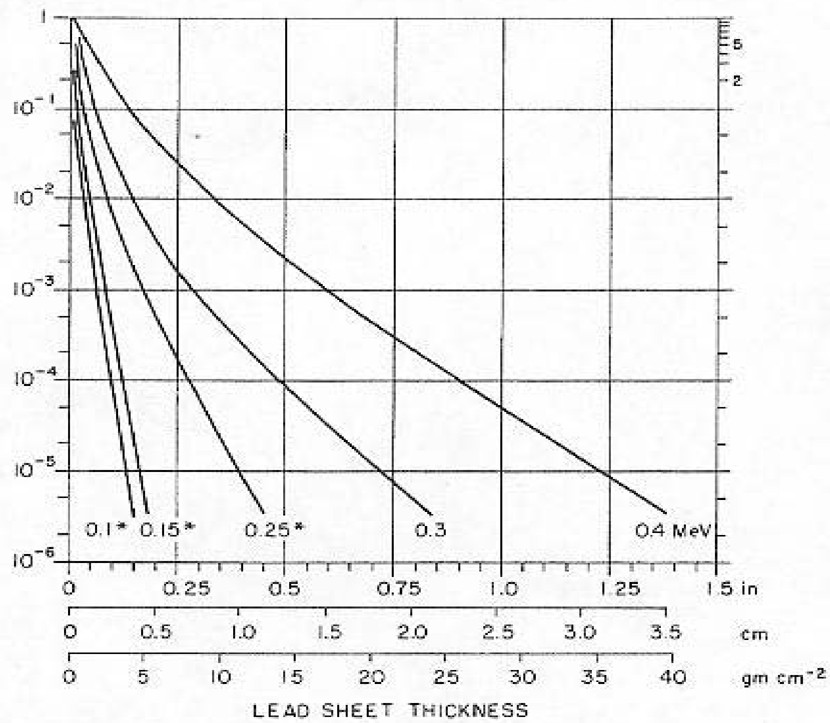
$$I = I_o e^{-ux}$$

where u is the linear attenuation coefficient of the material

Half value thickness of lead for a 100kV = 0.27 mm
500 kV=2.2mm

Shielding reduces the amount (flux) of photons through material, the energy of the photons remains about the same.

E.10 Broad-Beam Transmission Through Lead of X Rays Produced by 0.1- to 0.4-MeV Electrons



Transmission through lead (density 11.3 g cm^{-3}) of x rays produced by 0.1- to 0.4-MeV electrons, under broad-beam conditions. Electron energies designated by an asterisk (*) were accelerated by voltages with pulsed wave form; unmarked electron energies were accelerated by a constant potential generator. Curves represent transmission in dose-equivalent index ratio. (See Appendix E-14 for basis for interpolating between curves.) Curves were derived from NCRP Report No. 34 (NCRP, 1970a).

VIII. Device Specific training

A. Klystron laboratory Klystrons

Users already established detailed procedures for the radiation safety aspects of klystron operation. This lesson plan highlights these procedures. All operators shall review in detail these Klystron Test Lab Procedures.
All Klystron Test Notes (KTN) forms are located in their specific section of the KTN procedure.

1. A Radiation survey Sheet, KTF-012 is used to document radiation surveys on 5045, KTF –013 for Experimental devices and systems.

2. KTN 5, 1 usec processing of 5045
   - Initial survey of the entire shielded klystron at 150kV, 30 pps
     - Important to identify shielding inadequacies.
   - Perimeter only surveys every 25kV intervals
   - Full survey at 350 kV and 180 pps

3. KTN 7, 3.5 usec processing
   - Perimeter survey every 10kV
   - Full survey @ 350kV, 180 pps

4. KTN 15, Final processing
   - Perimeter survey every 10kV
   - Full survey @ 350kV, 180 pps

5. KTN 30, radiation survey procedure
   - a. Instruments
     1. Victoreen 450/450P, Ion Chamber
     2. Bicron mrem, >20 pps rates, plastic scintillator

   - b. KTL exposure rate limits, set by lab policy
     1. <2 mR/h at radiation Area boundaries
     2. < 100 mR/h on contact (limited operation allowed)
     3. <100mR/h @ 30cm

6. KTN 31, radiation Monitoring for R&D systems

   - a. SDR, Shielding design review for planning purposes. KTF-014
     - KRSO and RP review and approval
     - Completed with responsible Engineer / Physicist (REP)

   - b. IRI, Initial Run -Up Instructions for planning of radiation survey plan along with device parameters. KTF-015

Completed with responsible Engineer / Physicist (REP)

7. Practical demonstration
   All operators must complete a full radiation survey of an operating 5045 klystron with either OHP technician or the Klystron Test Lab KSRO.
   This practicle is completed every two years along with RWT training re-qualification.

B. Klystron laboratory, RF Bunker

1. The RF bunker is used to test and process RF cavities. Process to eliminate inner surface contaminants.

2. The design power for the bunker is 150kW however typical use is 100kW. This is about 750 kVolts

3. A radiation survey was taken at about 10kW inside on the gap and 4 R/h was measured?

2. Operation of Bunker is controlled by a BAS. The klystron used to supply power may use an IRI and SDR.

3. Operators perform radiation surveys on the perimeter of the bunker and on the Klystron during operations. Latest BAS has a radiation survey conducted on the outside every 20kW rise in power. Notify Radiation Physics if > 1 mR/h on the outside.

4. Operators should complete training on:
   a. Survey Instruments.
   b. Conducting radiation surveys.
   c. Brief on BAS requirements.
   d. Brief on IRI and SDR, if used.
   d. Operation of the PPS system and interlocks.
   e. Complete Klystron Lab Klystron radiation surveys i.a.w. this lesson Plan.

C. SSRL RGD's

1. X-ray diffraction Unit, Room 140
   a. Controlled by X-ray gen device safety form
   b. Safe Mode Operation
   c. ByPass Mode operation
   d. Interlocks of cabinet certified every 6 months

2. Practical demonstration
   a. By-Pass mode operation, install shield cup
   b. Demonstrate with a qualified operator
   c. Using GM pancake detector for leakage

3. Misc. RGD Devices
   a. Each RGD shall have an X-Ray Generator Authorization Sheet.
   b. Similar to a BAS with pre-running and Running conditions.
   c. Approved by SSRL Safety Officer, OHP Field operations and XRG Manger.
   d. Final Authorization is by the OHP Radiological Controls Manager.
   e. Special Radiological controls and safety items are contained in these documents.

D. NLCTA X-band klystrons and associated rf combiner and transport

1. Review Experimental Authorization procedure similar to an IRI at Klystron Laboratory. Operators shall be responsible for conducting radiation surveys on Klystrons and Rf structures.

2. Radiological Posting

   a. Prior to Klystron operations, the area around shall be posted as a Radiation Area.
   b. ESB and established Radiologically Controlled Area (RCA)

3. Entry qualifications

   a. GERT and RWT may enter a Radiation Area, Visitors should not.

4. Radiation dose rates

   a. The klystrons to arrive at ESB preshielded.
      1. Klystrons < 100 mR/h at 30 cm
      2. RF structures ______

b. Radiation Area Boundary < 5mR/h

c. BSOIC interlocked to Klystrons set at 6 mR/h trip.

d. Radiation sources
1. Side of floor, from Klystron tank.
2. Klystron, gaps in shielding.
3. Rf structures, breakdown areas.

5. Radiation survey frequency
The current radiation survey frequency is contained Experimental Authorization, below is a brief summary of the radiation survey frequency:

a. Klystron, at 200kV and every 50kV increment up to maximum or when any installed shielding is modified.
b. Rf structures when running at 50, 80, 100% power of when changing structure.
c. Following any removal or reinstallation of shielding on Rf structure components
d. Radiation Area boundaries daily.
e. OHP will randomly conduct radiation surveys

6. Radiation survey documentation
a. Full Klystron surveys on Klystron Radiation survey sheet,
b. 8 Pack area, Radiation survey sheet

7. Klystrons for the NLCTA Accelerator
a. Know how to determine operating parameters
Using control system, EPICS

8. Klystrons for the 8-Pack
a. Know how to determine operating parameters
(TBD)

9. Rf transport systems
a. Be able to identify high gradient devices (combiners, splitters, loads, mode converters)
b. Understand shielding for these devices (lead lined plywood, other shielding)

10. Practical demonstration
a. demonstrate survey techniques using an available survey sheet and an appropriate instrument on operating X-band Klystron.
To the NLCTA Safety Officer, or to a supervisor in Operational Health Physics. Forward completed survey sheet to OHP training.

E. Electron welder, Bldg 31

F. Test Gun facility Building 8, and High Voltage Test Facility, Building

IX. Radiation Survey Instruments

These instruments may be discussed if not covered in other training and qualifications such as RWT I

A. Victoreen 450/450P/450B Ion Chamber
- a. Low energy open window->7 keV
- b. Demonstrate Operation
- c. Source Check

B. Bicron millirem, Plastic scintillator > 20 pps
- a. 40 keV
- b. Demonstrate use

C. TBM 15 /3 Pancake GM to search for leakage, Closed devices
- a. > 7keV
- b. Demonstrate Use

D. Radios Digital Dosimeter
- a. Klystron Lab Use
- b. Demonstrate Use and Operation

X. Documentation of training

Completion of training is documented on a Standard training Completion form and submitted to ES&H Training administration.

XI. Device specific photographs and drawings

Attachments

1. Klystron Laboratory Radiation Survey Sheet, 5045
2. Klystron Radiation Survey Sheet, R&D device
3. Radiation Survey Sheet, Building 15
4. Radiation Survey Sheet, 8 pack NLCTA

Initial Klystron Radiation Survey

Radiation Survey Sheet
For the XL4 Klystron Tubes at **NLCTA**

Date: ________________ Operator: ____________________

Time: ________________

Tube#: ________________ Test: __1μsec __3.5μsec __Final

Voltage epy	Pulse Repetition Rate	Pulse Width
kV	60 120 180	1μsec 3.5 μsec

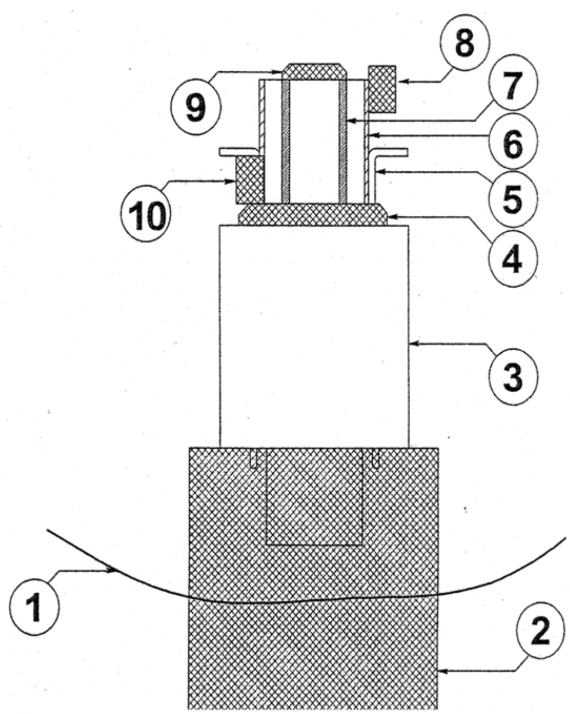
Instrument Type : ___ Bicron mrem ___ Victoreen 450

Serial #: _____________ Calibration Due: _________________

Operator Signature: ______________________________

Survey each area as indicated by number and write the dose rates in the corresponding table below. All dose rates are in mR/hour.
Note: "Additional Shielding" applies to secondary shielding as required.

Survey Point	Contact	30 cm	Additional Shielding Y or N And Type
1. Rope Perimeter			
2 Tank or on floor tiles			
3. Solenoid			
4. Disk-shaped Lead Annulus			
5. Input Waveguide			
6. 0.75" Lead Cylinder			
7. 2.0" Lead Cylinder			
8. Cooling-Water Horseshoe			
9. Lead Cap			
10. Output Waveguide Horseshoe			



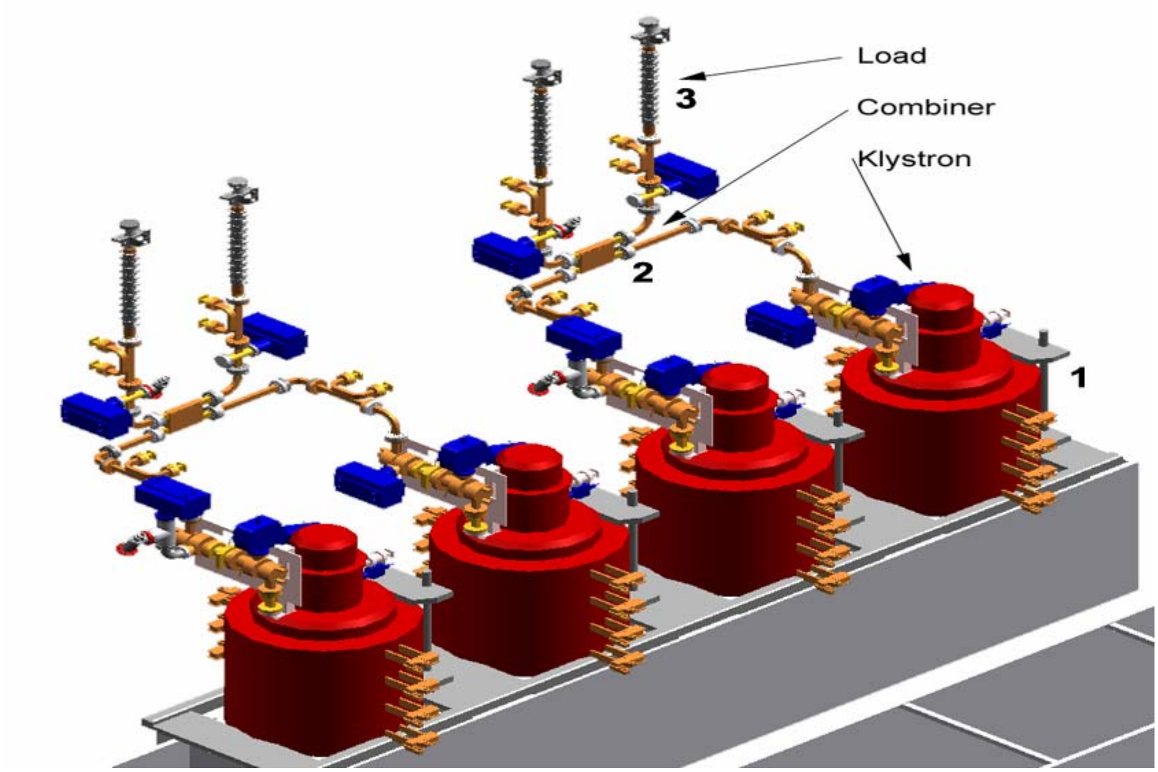
Reviewed by:______________________ Date: ______

8-Pack Radiation Survey Sheet

Pulse length @ Width: ________________
Rate: ________________________________
Meter Type:___________________________
Serial: __________ Cal. due:___________
Operator: ___________________________
Signature: ___________________________
Date: ___________ Time: _____________

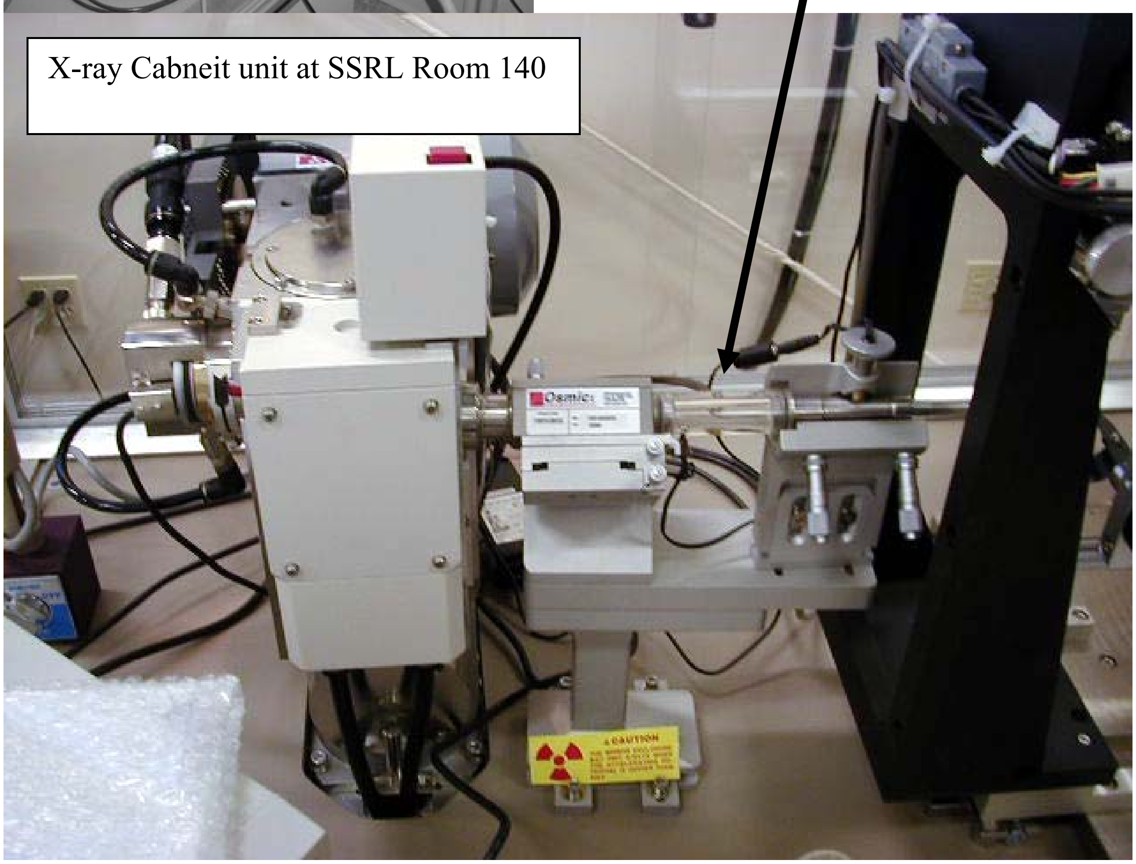
Results:	Contact / 30 cm / 1 meter
1 – Klystron:	
Klystron 5	____ / ____ / ____
Klystron 6	____ / ____ / ____
Klystron 7	____ / ____ / ____
Klystron 8	____ / ____ / ____
2 – Combiner:	
#5 / #6	____ / ____ / ____
#7 / #8	____ / ____ / ____
3 – Loads:	
#5 / #6 Power	____ / ____ / ____
#5 / #6 Extra	____ / ____ / ____
#7 / #8 Power	____ / ____ / ____
#7 / #8 Extra	____ / ____ / ____
Yellow Magenta Ropes	
(If any)	____ / *(n/a)* / *(n/a)*

Note any unusual readings on map below.


Load
3
Combiner
Klystron
2
1

The sliding plexiglass acts as the interlock

The X-ray beam here

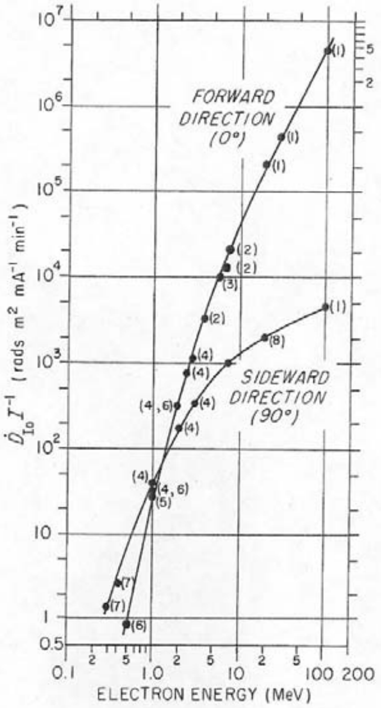


X-ray Cabneit unit at SSRL Room 140

APPENDIX E

X Rays and Gamma Rays

E.1 X-Ray Emission Rates from High-Z Targets



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