2254 - X-Ray Source

Bi-weekly Project Lab Meeting
2022-10-26


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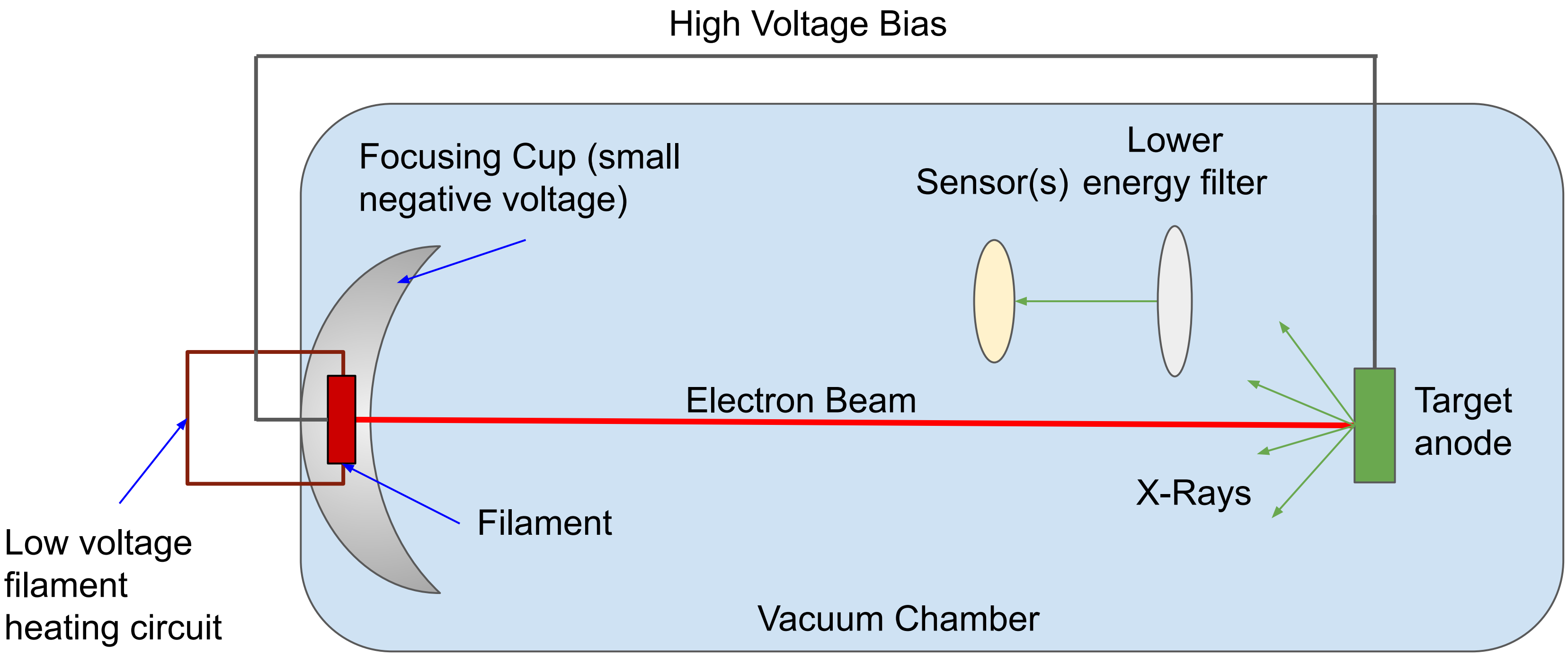
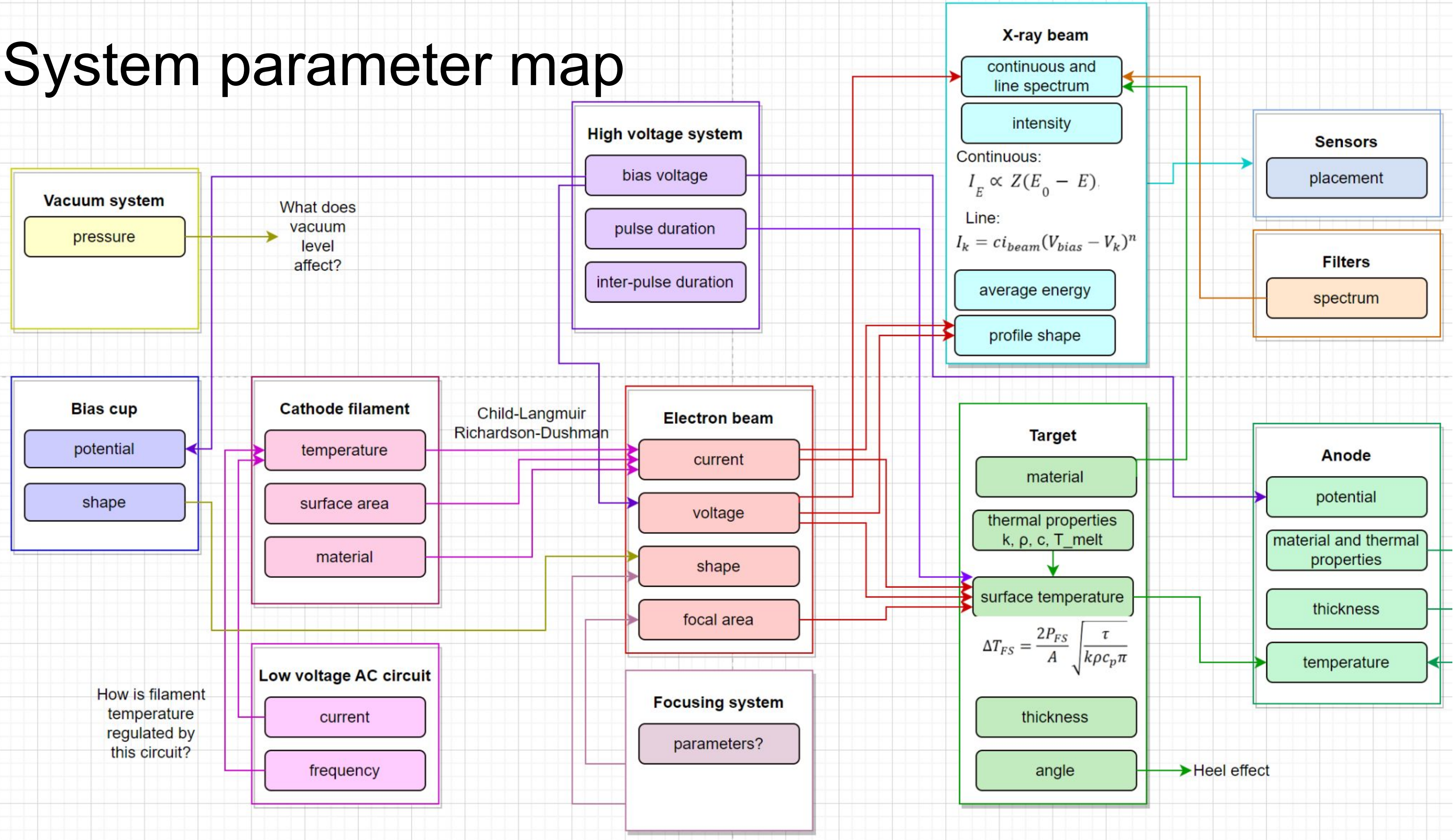
Agenda

1. Review of research and visuals
2. Important clarifications needed
    a. Akbar
    b. Meeting with faculty members

X-ray source system overview (updated for next meeting)



System parameter map



Cathode

3 Main areas of concern:

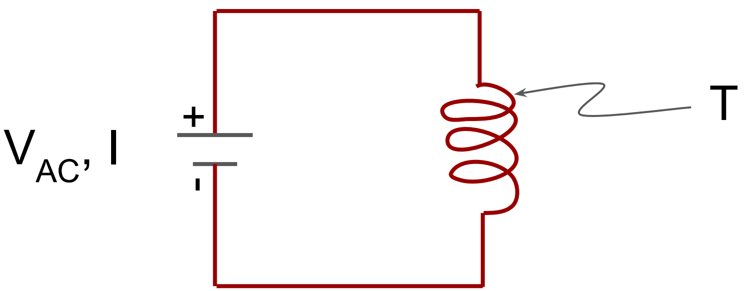
1. Cathode Heating
2. Electron Emission via Thermionic emission (Richardson-Dushman equation)
3. Electron Removal via space charge electrode flow (Child-Langmuir equation)

Plan:

Illustrate equations, parameters, relationships

Create sheets illustrating these relationships

Cathode - Heating

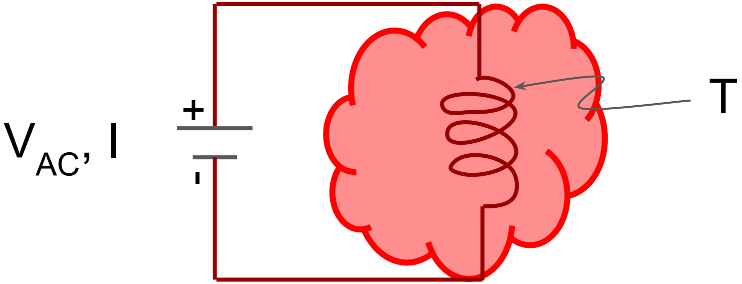


Equation(s) governing:

Trying to control:

Key parameter relationships:

Cathode - Electron Emission



Trying to control:
I, emitted current

Key parameter relationships:
$I \propto A$
$I \propto J \propto T^2 \cdot e^{-1/T}$
A_G and T are material properties

Equation(s) governing:

$$J = A_G T^2 e^{\frac{-W}{kT}}$$

J = emitted current density $\left[\frac{A}{m^2}\right]$

A = material constant $\left[\frac{A}{(m \cdot K)^2}\right]$

W = work function of material $[eV]$

k = Boltzmann constant, $8.62 \cdot 10^{-5} \left[\frac{eV}{K}\right]$

T = Temperature $[K]$

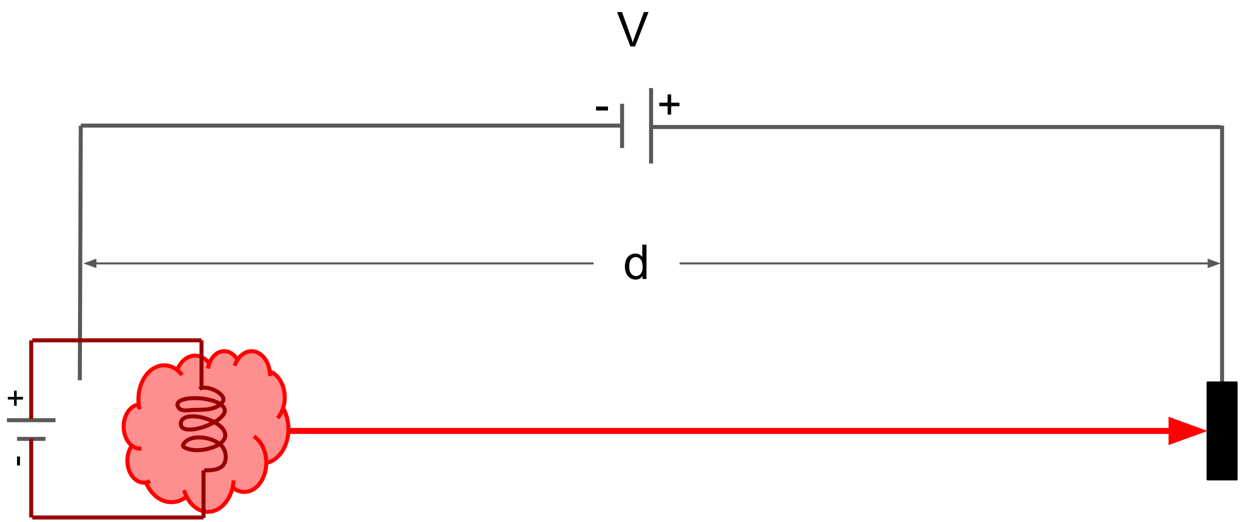
$$I = J \cdot A$$

I = emitted current $[A]$

J = emitted current density $\left[\frac{A}{m^2}\right]$

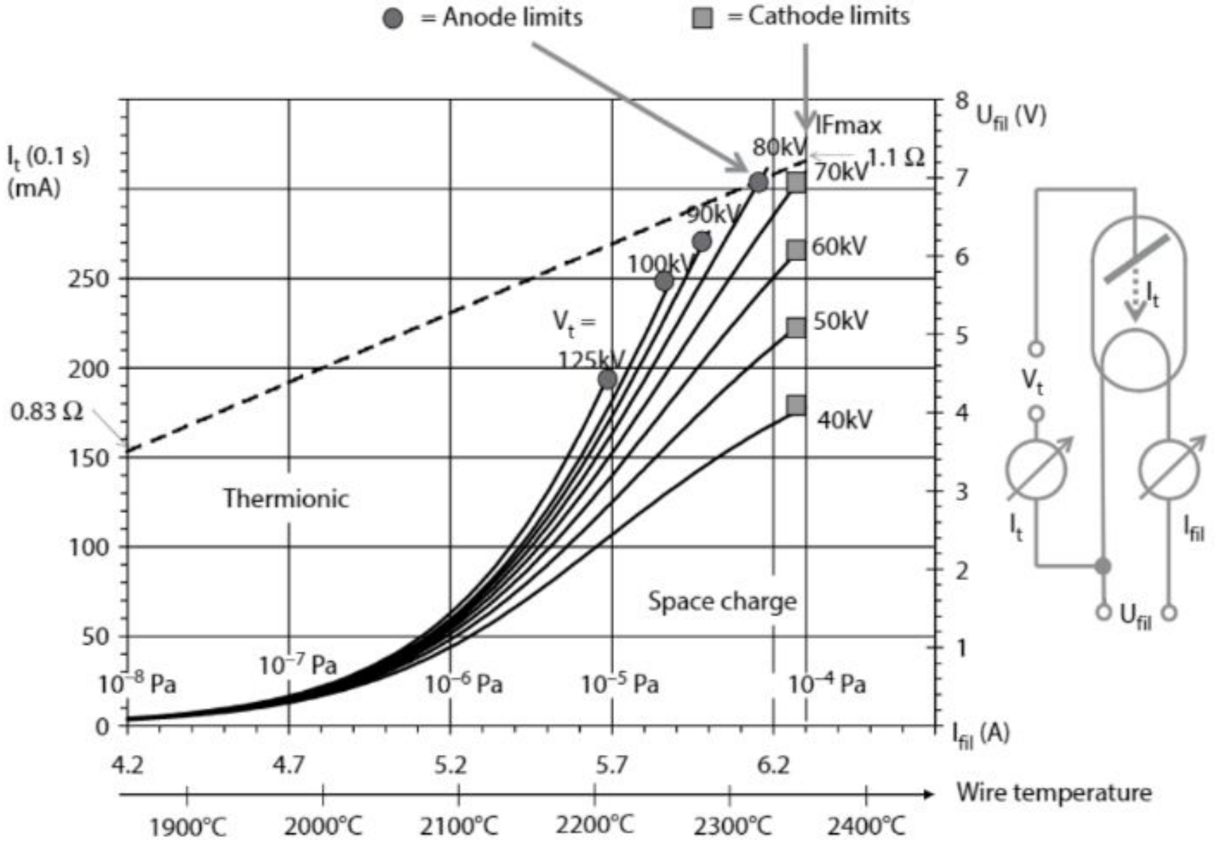
A = external filament area $\left[m^2\right]$

Cathode - Electron Removal



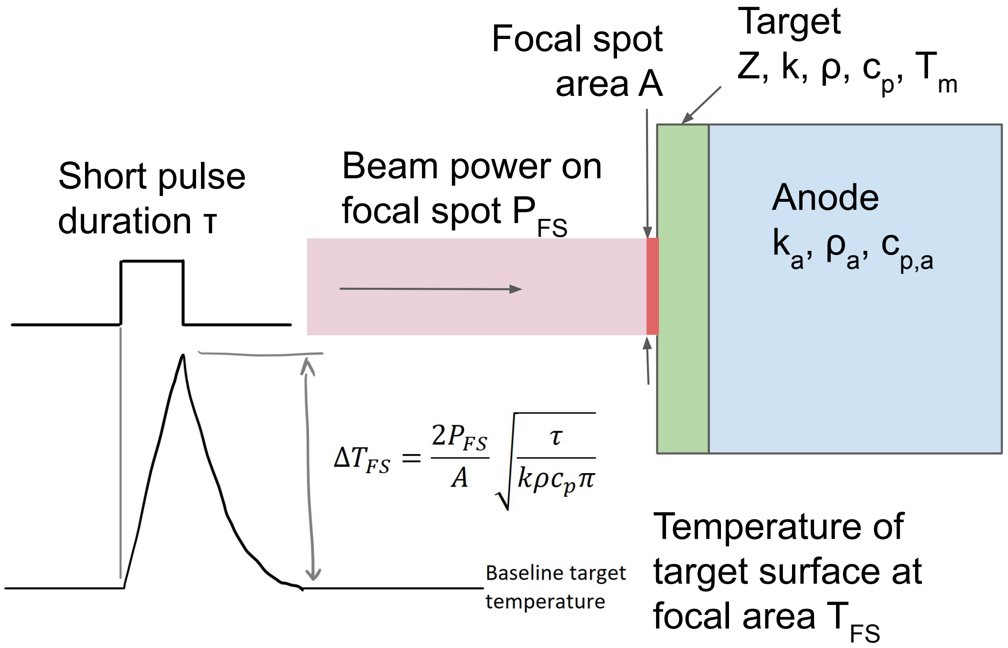
$$J_{C-L} = \frac{4}{9}\varepsilon_0\left(\frac{2q}{m}\right)^{1/2}\frac{V^{3/2}}{d^2}$$

Tube Current Relationship

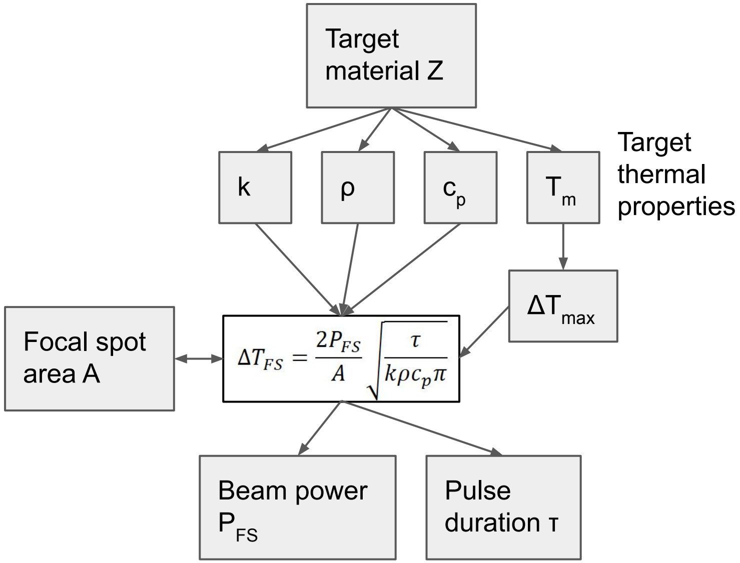


X-Ray Tube Physics and Technology, Rolf Behling

Simplified target heating

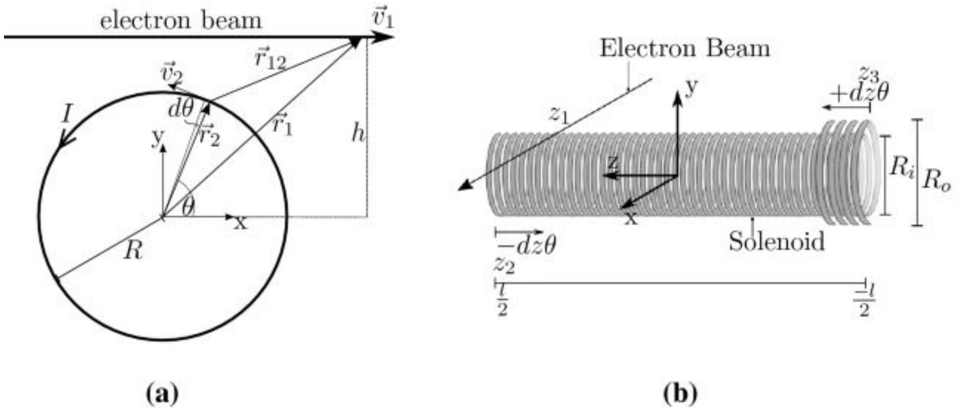


Parameter determination order



Electron Beam Focusing

- Simplest implementation: Solenoid winding around beam path
  - Considerations: behaviour of conducting wire under influence of large external field (bias voltage)
- Higher level methods:
  - Electrostatic lensing
    - Conductive rings, programmed to take small negative charge when electron beam pulse is traversing it
  - More elaborate field configuration
    - Mainly theoretical, evaluate based on necessity

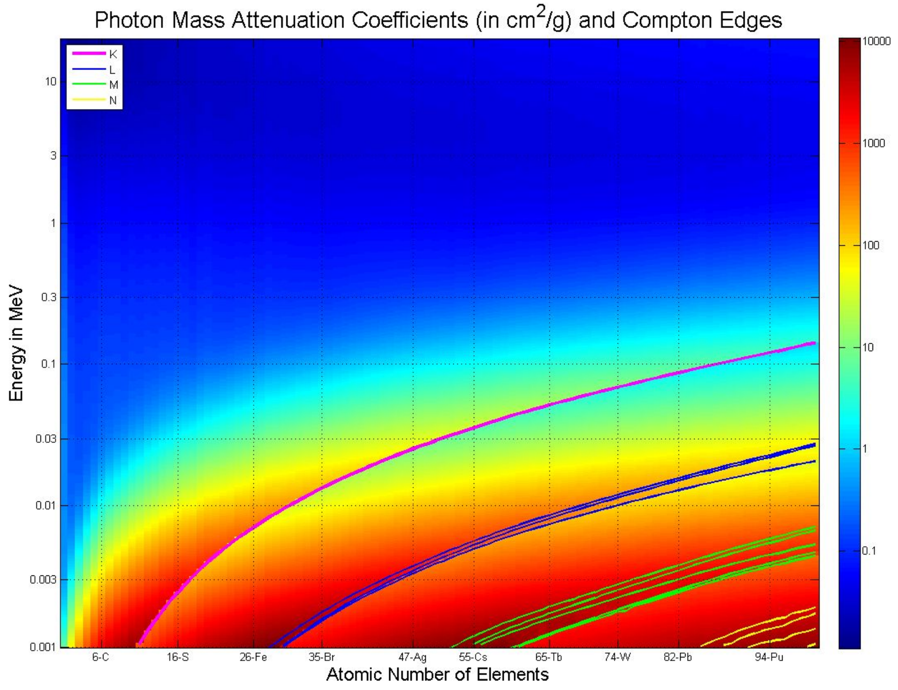


[Accurately predicting electron beam deflections in fringing fields of a solenoid, Nature]

Safety

- NIST database of attenuations values (link)
- Target natural background radiation rate (2 and 4 mSv per year) (safety code 32)
- Conversion from power + voltage to sieverts still unclear
- **Solution: adequate air gap + thin metal shielding**

$$I(x) = I_0 e^{-Ax} = I_0 e^{-(\mu\rho)x}$$



Mass Attenuation Coefficient (source)

Breakdown voltage

Breakdown voltage is a function of vacuum quality.

- At 1bar the anode (non-grounded) will arc through air to ground
- Breakdown voltage should increase as vacuum increases until it reaches a safe level.
- Looking for publications with a fit of breakdown voltage as a function of pressure.

Vacuum quality determines Mean Free Path

Better vacuum means less loss

- Both the electron beam and X-Rays have a mean free path before interacting, as a function of pressure.
- Assuming interactions are losses we can find loss coefficients as a function of pressure.
- Looking for publications with mean free path of electrons and X-Rays as a function of vacuum.

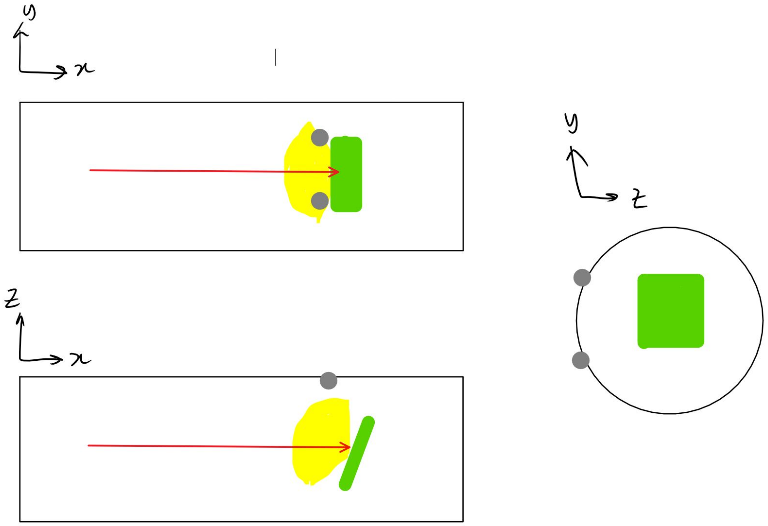
Vacuum Chamber Actuation

Options for target swapping

- Welded bellows
- Ferrofluid seal (dynamic o-ring)
- Magnetic lock (magnet under table trick)

Sensor placements

- Original requirement from Akbar: 2 sensors activated simultaneously
- Symmetry:
    - spatial symmetry of x-ray profile
    - VS
    - temporal symmetry, i.e. repeatability
- Other considerations:
    - Heel effect and how it affects spatial symmetry



X-ray profile

- Team to meet with Dr. Nancy Ford (X-ray physicist at UBC Dentistry) Friday
- Potential questions:
  a. How does directionality vary with e-beam energy? Does power matter?
  b. Do characteristic x-rays have preferential directions?
  c. How does the target thickness affect directionality?
  d. How does x-ray intensity change over target material usage?

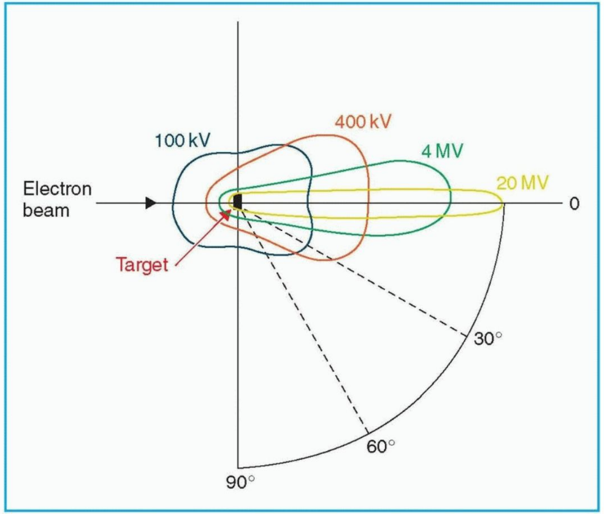


Figure 3.9. Schematic illustration of spatial distribution of x-rays around a thin target.

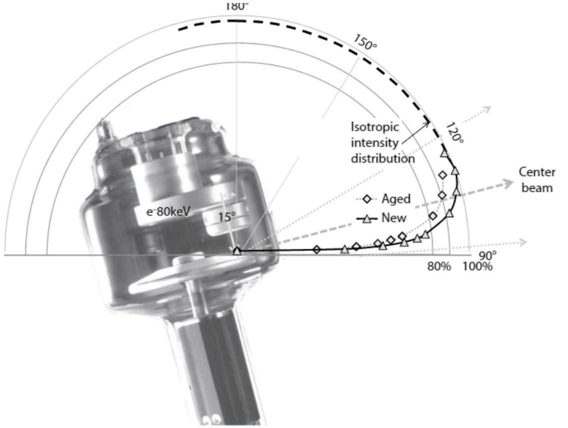


FIGURE 2.4 Polar diagram of the X-ray intensity distribution for a Philips SRO 2550 rotating anode tube. Electrons impinge at an angle of 15° on a targ which has the same anode angle. Triangles: new tube, as processed; tilted squares: aged tube. Beam filtration: 2.5 mm aluminum equivalent plus 20 m aluminum emulating patient filtering. An extrapolated isotropic distribution is overlaid with the measured data for comparison.

Limiting Factors for Proposal

- Beam Current / Power / Intensity specs
- Xray profile (further details)
    - Time of exposure
    - Radiation profile
- Equipment availability
    - HV power supply
    - Vacuum
    - ~budget for remaining components

Current Schedule and Next Steps

Akbar on vacation till Nov 18th, proposal pushback?

In meantime

- Meeting with Dr. Ford Friday
- Building understanding of parameters, how to choose them, how they affect each other
- Building visuals of above
- Working towards below goals

GOALS:

1. Understand how each component is designed, connected
2. Given clarifications from Akbar, be able to adjust our equations, sims, etc to know how our system should be designed