Electron and X-ray Sterilization of Medical Devices

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FDA Medical Device Advisory Meeting

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Electrons and X-rays

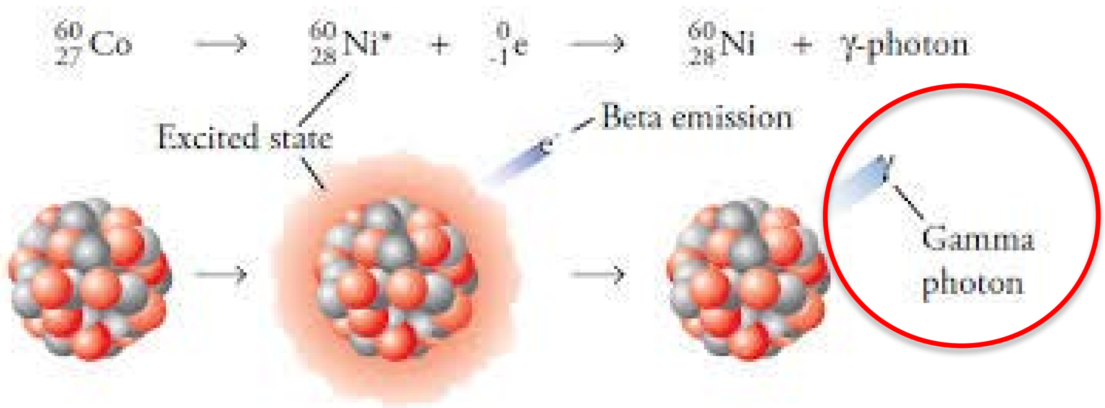
- Overview of x-ray and e-beam; how is it different from gamma?
- Typical or representative devices sterilized with these modalities and material compatibility with this modality
- Description of the industrial infrastructure needed for e-beam and x-ray?
- What is the potential of accelerator technology in this area?
- Can x-ray/e-beam be an alternative to ethylene oxide sterilization?

What are we talking about?

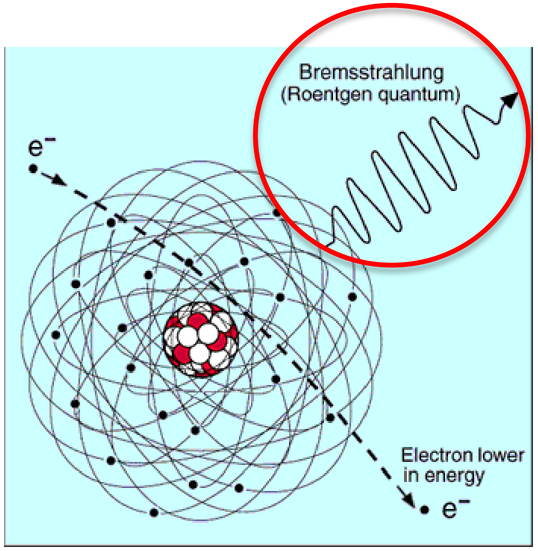
- Ionizing Radiation
  - Electrons – directly ionizing radiation
    - Electrons do ~99.5% of the killing
  - Photons – indirectly ionizing radiation
    - X-ray and γ refer to how the photon is produced
    - But once produced, they are just photons
    - Photons have the penetration power, but electrons do the work
      - Compton Scattering

Photons – X-ray vs γ

- γ rays originate from the nucleus of an atom



- X-rays originate from transitions in the electrons from an atom or Bremsstrahlung



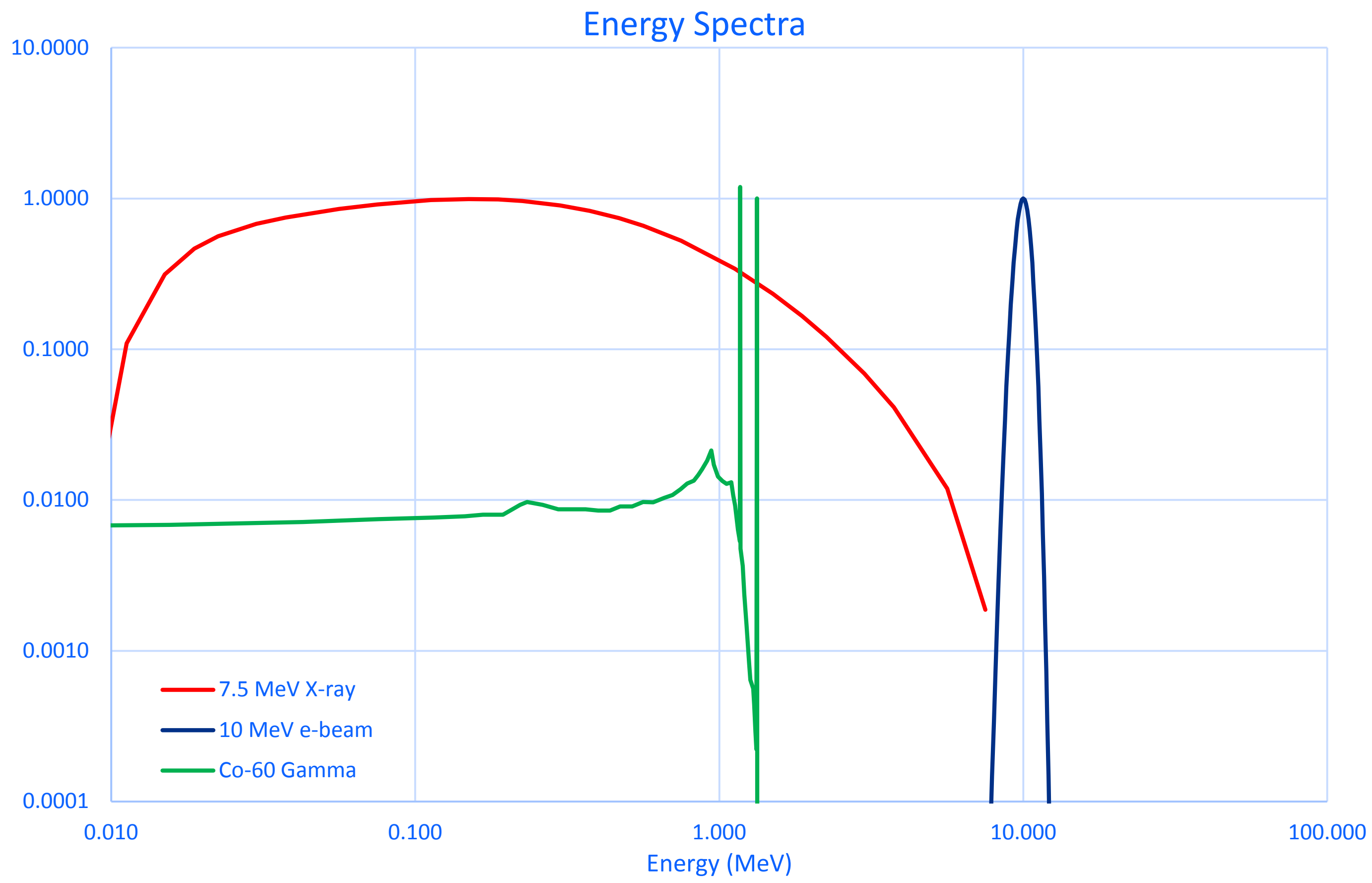
- Both are electro-magnetic energy

Photons – X-ray vs γ

- Caveat
  - γ rays are more monoenergetic
  - X-rays (Bremsstrahlung) have a spectra of energies

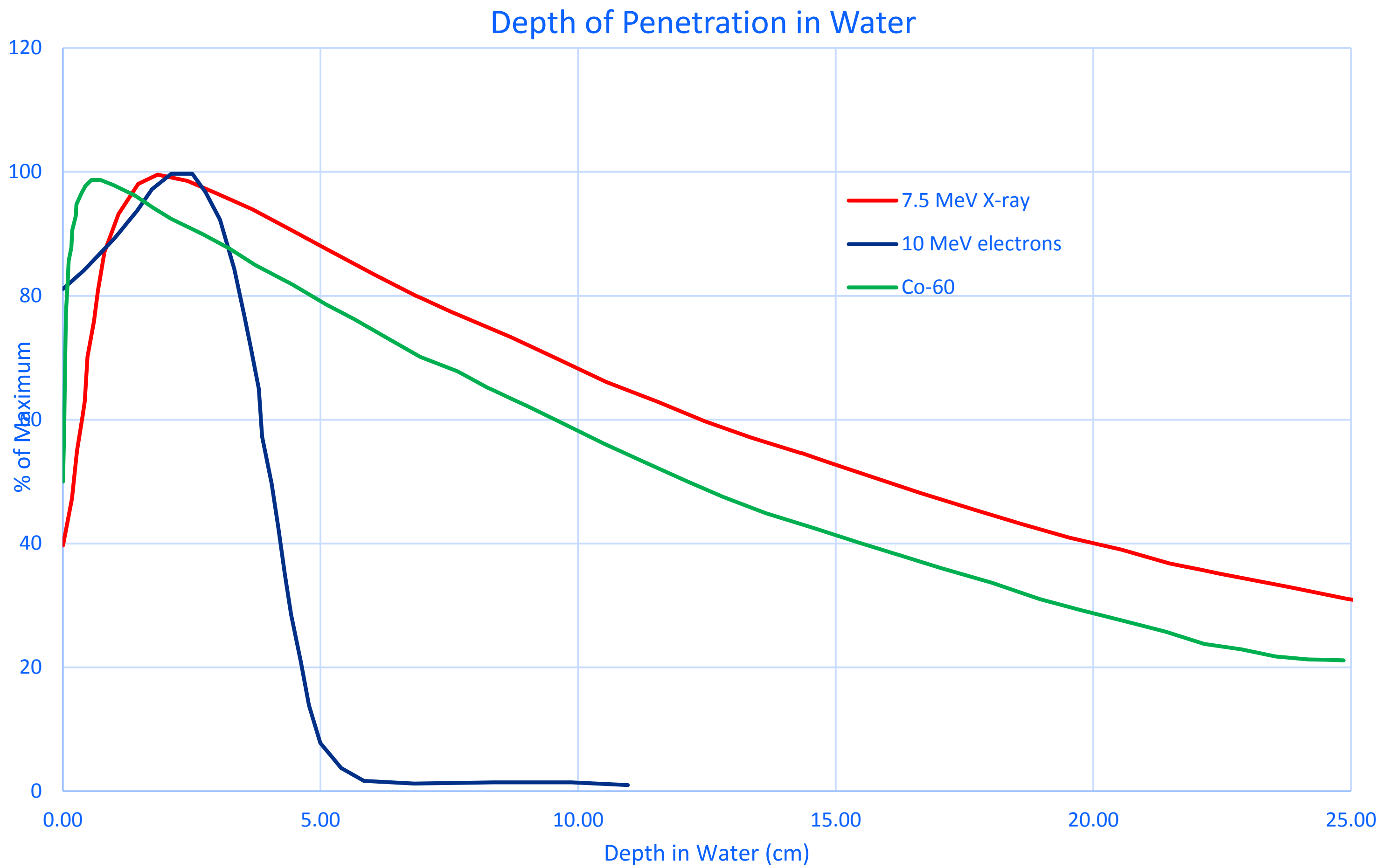
- Fundamentally, a photon is a photon
- (and an electron is an electron)

Energy Spectra for each



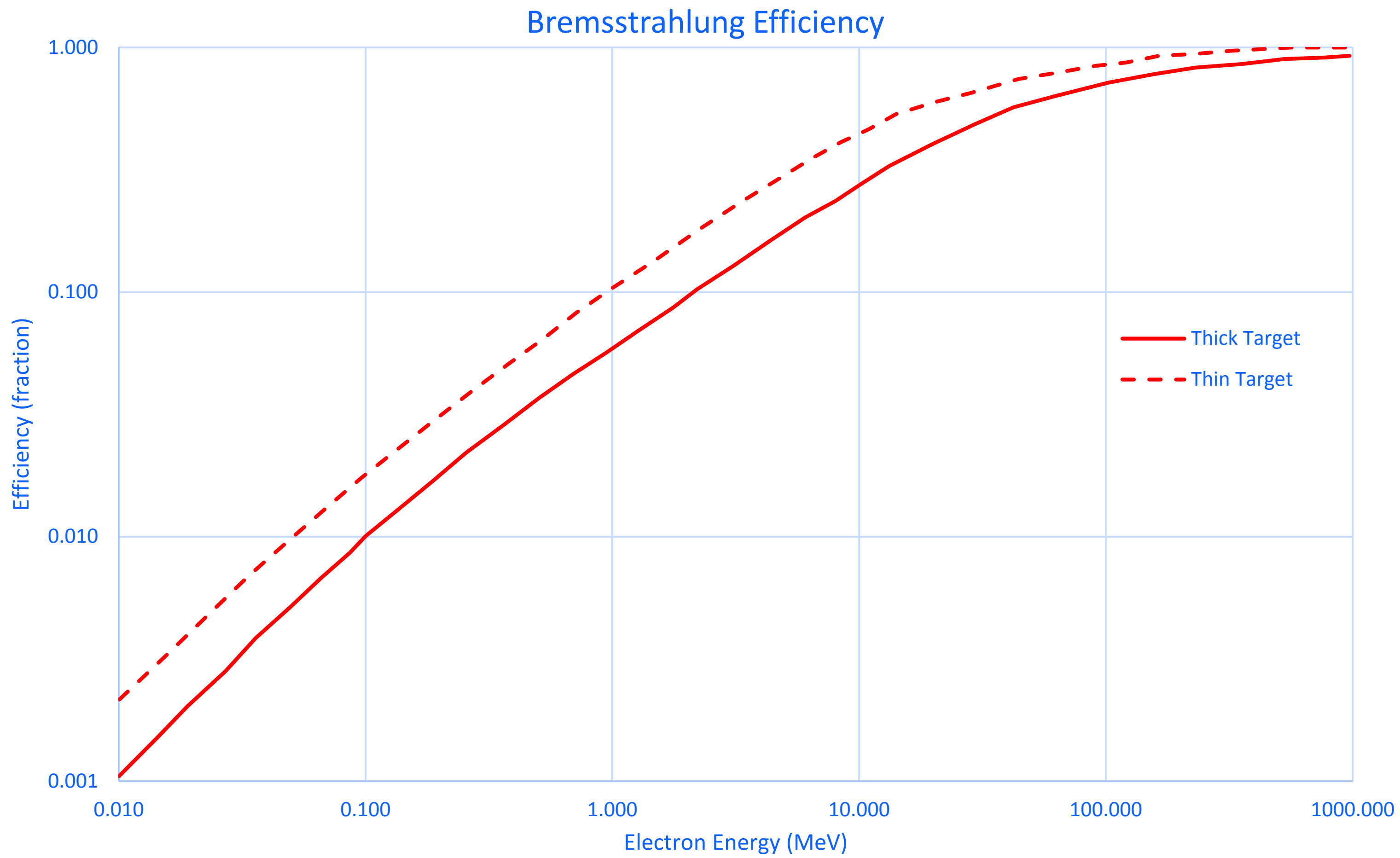
Remember – the electrons are the active ingredient!

Penetration



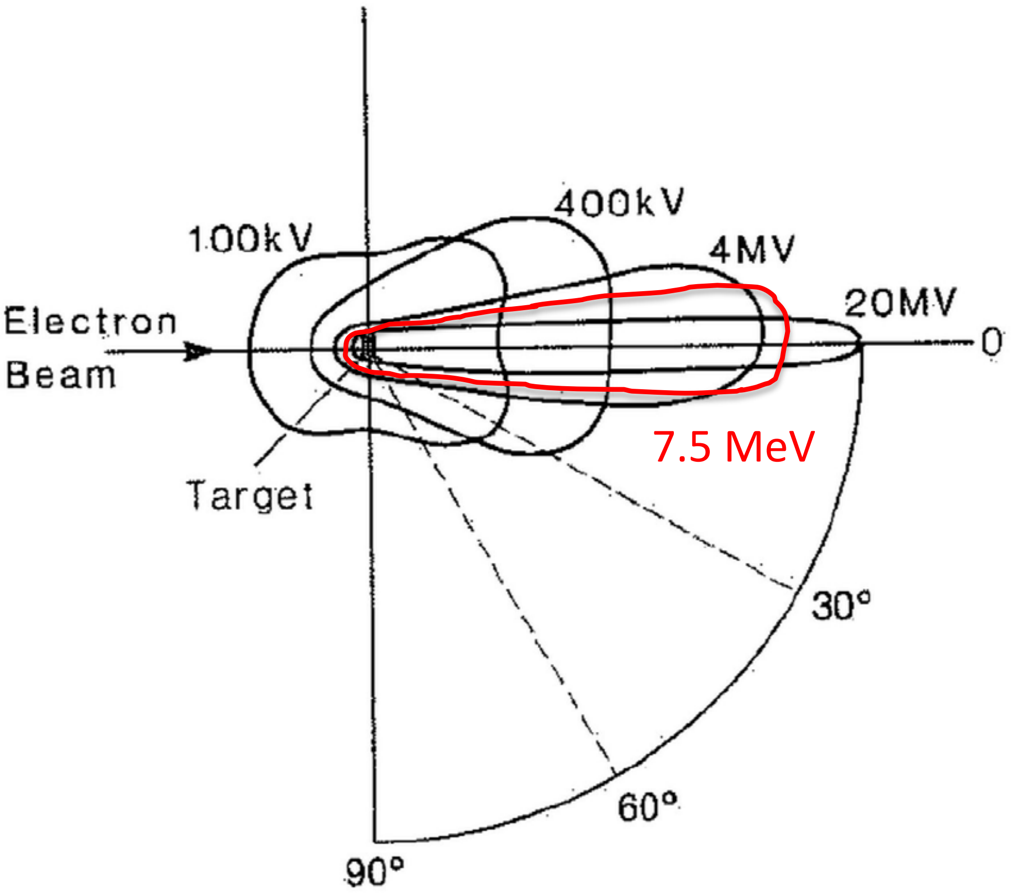
The penetration characteristics of x-ray can be exploited to give better DUR.

Generating X-rays



Generating x-rays will always incur a significant inefficiency. Overcoming this requires high-power electron beams.

Generating X-rays



Much more directed than gammas from a cobalt array. Better utilization.
(Only ~ 30 % of gamma rays are utilized)

What can be sterilized with E-beam and X-ray?

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- Typical or representative devices sterilized with these modalities and material compatibility with this modality
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Transitioning from Cobalt-60 to E-beam or X-ray for Sterilization – a Model for Collaboration

Presented at Fermilab on September 19, 2019

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U.S. DEPARTMENT OF ENERGY

Project Goals

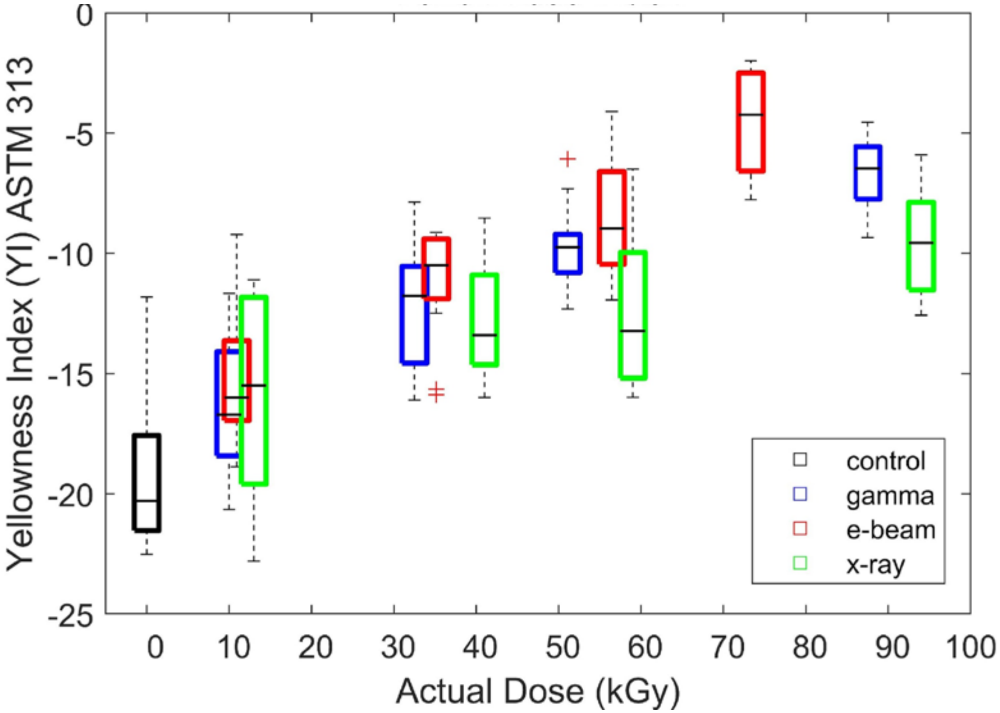
- **Identify specific polymers/elastomers** used in medical products that present the greatest data gaps for radiation effects and would be of greatest industry impact if transitioned to e-beam or X-ray
- **Measure any physical effects** that these materials exhibit when they are given sterilization-level radiation doses from e-beam or X-ray
- Determine **whether these effects would preclude the use of E-beam or X-ray** for associated medical products
- **Execute an industry and public outreach** component that will identify and fill knowledge and education gaps that impede the transition to E-beam and X-ray sterilization
- **Encourage increased use of E-beam and X-ray** for sterilization of single-use medical products

Five Selected Medical Products

- **#1**: Becton-Dickinson *Vacutainer*™ tube.
  - Ultrahigh production volumes for the blood collection market at >5B products/year.
- **#2**: Becton-Dickinson *Vacutainer*™ “Push Button” blood collection set.
  - Significant production volume for the blood collection market at ~260M products/year using multiple polymer families.
- These BD products involve over 6 separate polymers.
- All test measurements recently completed for these BD products.

Data Results – BD Product Coloration

- The data indicate that Yellowness Index changed as much as 20 units for some polymers for the 0-90 kGy dose spread in the study; however, there was little to no discernible trend in the yellowness index between Cobalt-60, E-beam and X-ray samples.



Yellowness Index vs. dose for all 3 irradiation modalities.

Infrastructure

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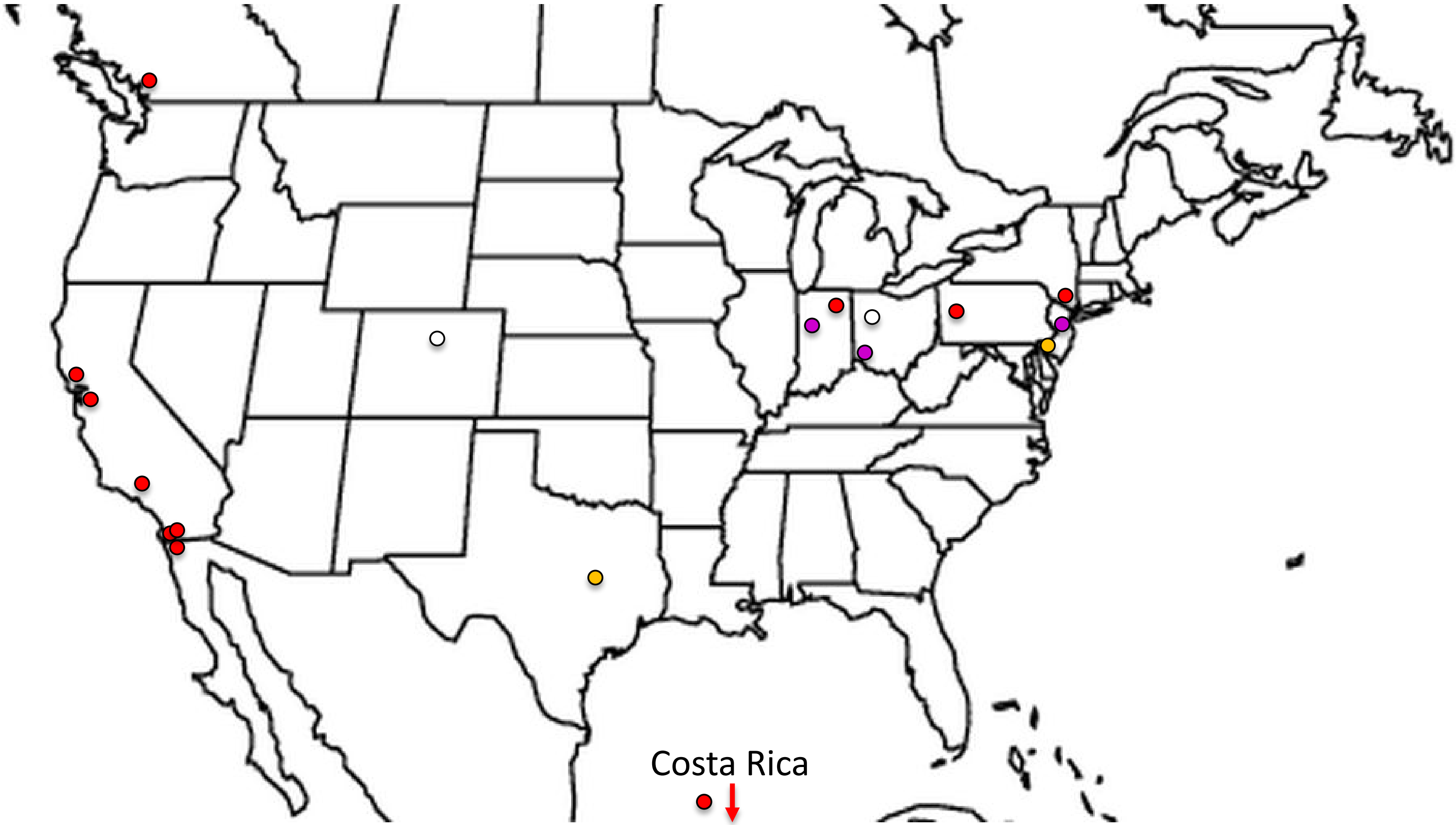
Required Infrastructure

- Reliable electrical power
- Material handling systems are very similar
- Dosimetry, process control, etc. very similar
- Accelerator manufacturers report that on-site technical staff requirements are not significantly higher than gamma facilities
  - Technical skills required similar to well qualified auto mechanic
- Similar or slightly thicker shielding
  - But volume of irradiation room can be much less
  - Less total concrete?
- Less attractive target

Contract Electron Beam Facilities



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Future potential

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Fermilab

Power

- 1 Mci = $3.7x10^{16}$ decays/second
  - Total energy released – 2.505 MeV/decay
  - 15 kW
  - Typical irradiation bunker – 30-60 kW of “beam” power
- Electron beam machines can provide this easily
- X-ray must overcome inefficiency of Bremsstrahlung process
  - 200 – 400 kW of electron beam power
  - Then must include efficiency of electron beam production

Capacity comparisons

- Gamma
  - ~10 kGy/hr
  - 3.4 m^3/h/MCi @ 25 kGy
- Electron Beam
  - ~20 MGy/hr
- X-ray
  - ~60 kGy/hr
  - 2.8 m^3/h/100 kW @ 25 kGy (including target losses)

1 MCi gamma ≈ 120 kW electron beam power to provide equivalent X-ray dose

Potential Accelerator Technology

- Linacs 10 – 50 kW
  - New machines being designed to > 100 kW
- Cyclotrons and Rhodotrons 50 - 350 kW
- Superconducting Linacs in development
  - 250 kW +
  - Direct equivalency to panoramic gamma irradiators

Alternitive to EO?

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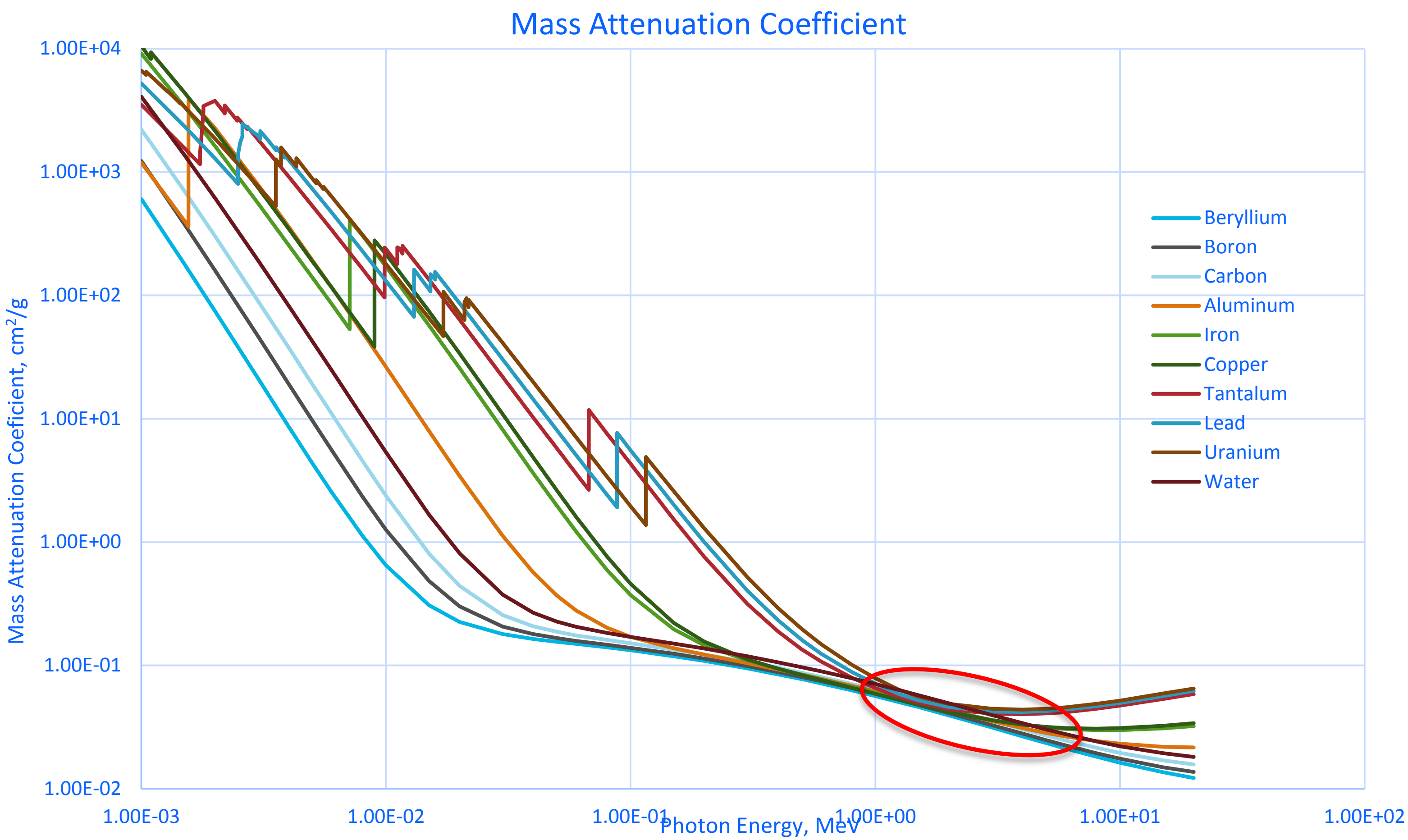
E-beam and X-ray as an alternative to EO

- Very similar to gamma as an alternative to EO
- Difference
  - Irradiation times are shorter with E-beam and X-ray
  - Less time for oxidative processes to occur

- Device manufacturers decide on sterilization modality
  - Education
  - Early planning in device design process can facilitate the use of alternative modalities
  - More “difficult” for established devices

Thank you

Why can't we do something clever with shielding?



All materials have the same stopping power (scaled by density) between 1 and 10 MeV.

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