e, X, γ – The Good, the Bad, and the Promising (not necessarily in that order)

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Midwest Medical Device Sterilization Workshop

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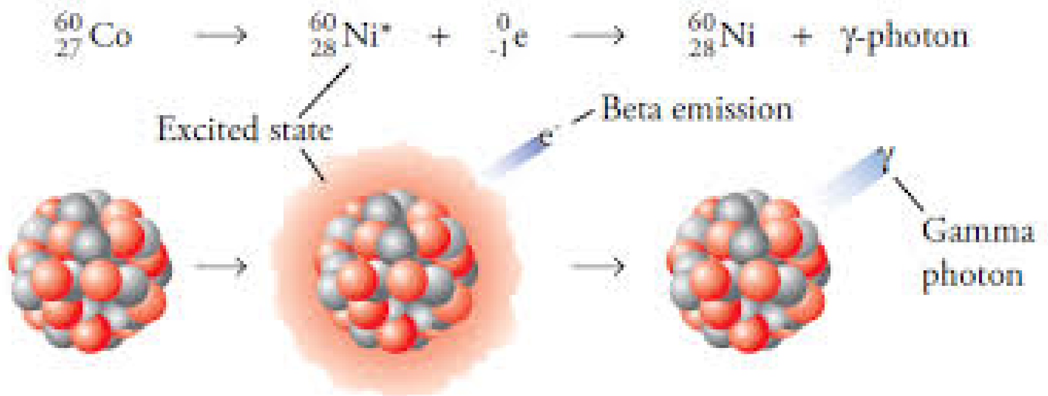
What are we talking about?

- Ionizing Radiation
  - Electrons – directly ionizing radiation
  - Photons – indirectly ionizing radiation
    - X-ray and γ refer to how the photon is produced
    - But once produced, they are just photons

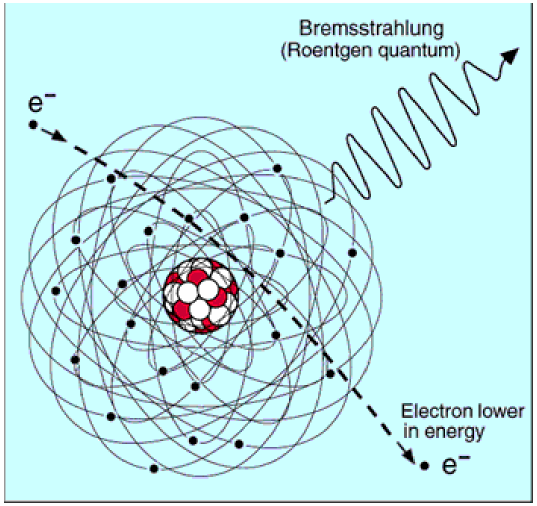
- Ionization → Sterility by disrupting the biologic processes of micro-organisms
  - SAL – 10^{-6}

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



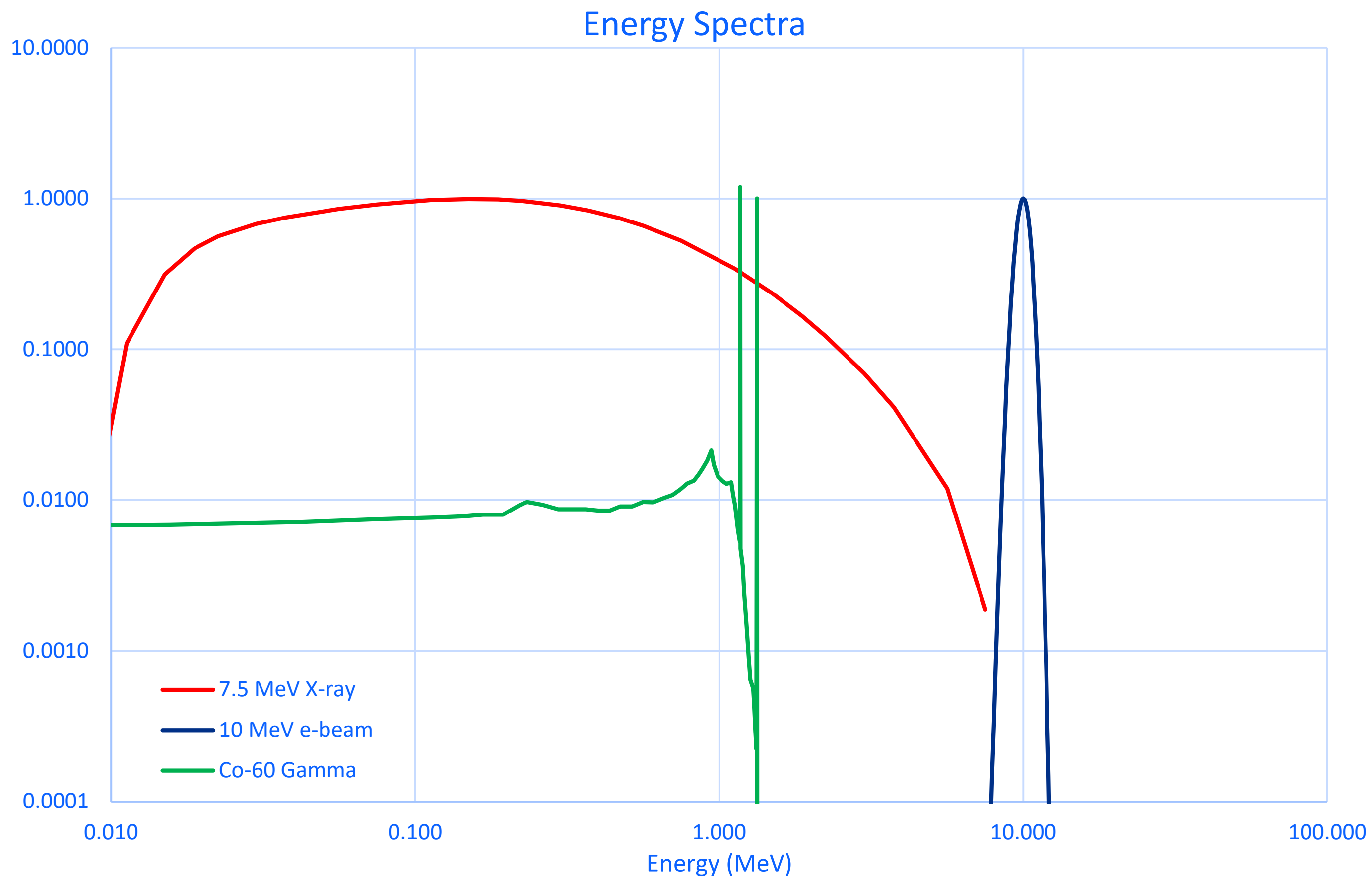
- No difference other than their energy

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

Energy Spectra for each



The broad spectrum of energies for x-rays is the only reason for concern that they may not be exactly equivalent to gamma from Co-60.

Is it reasonable to think there is a difference γ & x ?

Atoms, Radiation, and Radiation Protection

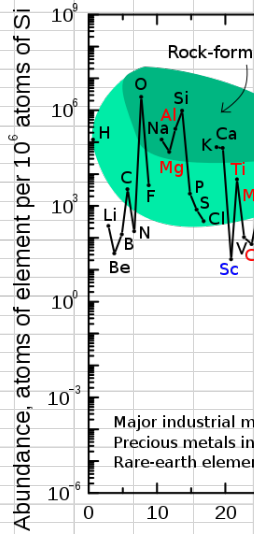
Table 13.3 G Values (Number per 100 eV) for Various Species in Water at 0.28 μs for Electrons at Several Energies

	Electron Energy (eV)							
Species	**100**	**200**	**500**	**750**	**1000**	**5000**	**10,000**	**20,000**
OH	1.17	0.72	0.46	0.39	0.39	0.74	1.05	1.10
H_3O^+	4.97	5.01	4.88	4.97	4.86	5.03	5.19	5.13
e^-_{aq}	1.87	1.44	0.82	0.71	0.62	0.89	1.18	1.13
H	2.52	2.12	1.96	1.91	1.96	1.93	1.90	1.99
H_2	0.74	0.86	0.99	0.95	0.93	0.84	0.81	0.80
H_2O_2	1.84	2.04	2.04	2.00	1.97	1.86	1.81	1.80
Fe^{3+}	17.9	15.5	12.7	12.3	12.6	12.9	13.9	14.1

If it requires ~100 eV to create an ion species, does it matter that the photon is 1.17, 1.33 MeV or 7.5 MeV?

Why 10 MeV for electrons, but 7.5 MeV for x-rays?

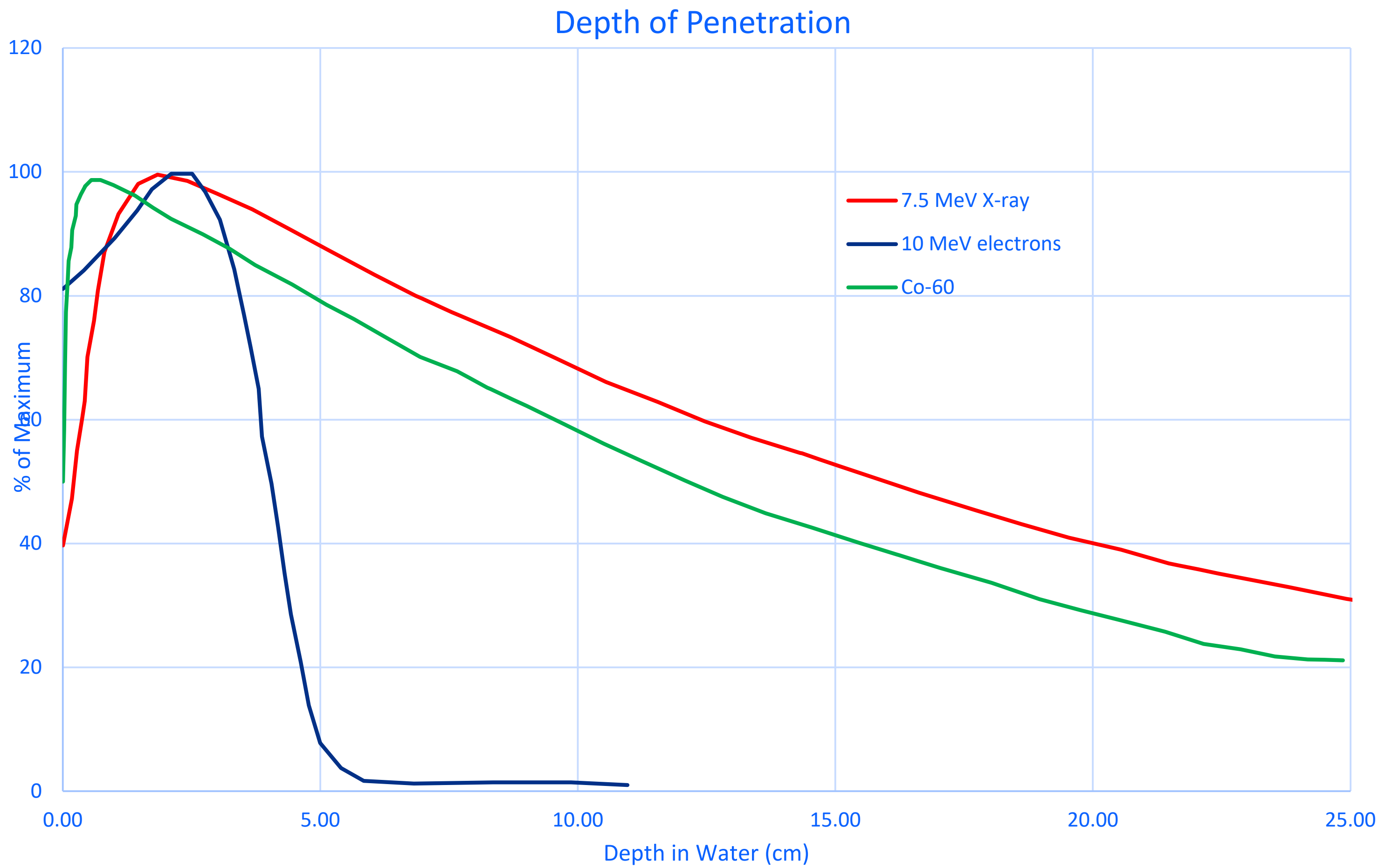
No concern - threshold > 10 MeV	Product Stable ?	Concern ?	Target	Product	Threshold		half life (sec)	energy (MeV)	mode	isotopic abundance	Webelements elemental abundance (ppm)
			H-1							99.985	1500
			H-2	H-1	2.225	(γ,n)				0.015	0.15
			H-2	n	2.225	(γ,p)	660	0.782	beta		
			He-3	?	7.72	(γ,n)				0.00013	
			He-3	H-2	5.49	(γ,p)					
			He-4	He-3	20.58	(γ,n)				99.9999	
			He-4	H-3	19.81	(γ,p)	3.86E+08	1.86E-02	beta		
			Li-6	Li-5	5.66	(γ,n)	1.00E-21			7.42	17
			Li-6	He-5	4.59	(γ,p)	2.00E-21				0.0017
			Li-7	Li-6	7.25	(γ,n)				92.58	
			Li-7	He-6	9.97	(γ,p)	0.82				
			Be-9	Be-8	1.66	(γ,n)	1.00E-14			100	1.9
			Be-9	Li-8	16.87	(γ,p)	0.85				0.00019
			B-10	B-9	8.44	(γ,n)	3.00E-19			18.8	8.7
			B-10	Be-9	6.59	(γ,p)					0.00087
			B-11	B-10	11.46	(γ,n)				81.2	
			B-11	Be-10	11.23	(γ,p)	8.52E+13				
			C-12	C-11	18.72	(γ,n)	1.23E+03			98.89	1800
			C-12	B-11	15.96	(γ,p)					0.18
			C-13	C-12	4.95	(γ,n)				1.11	
			C-13	B-12	17.53	(γ,p)	0.027				
			N-14	N-13	10.55	(γ,n)	6.06E+02			99.63	20
			N-14	C-13	7.55	(γ,p)					0.002
			N-15	N-14	10.83	(γ,n)				0.37	
			N-15	C-14	10.21	(γ,p)	1.81E+11				
			O-16	O-15	15.66	(γ,n)	124			99.76	460000
			O-16	N-15	12.13	(γ,p)					46
			O-17	O-16	4.14	(γ,n)				0.04	
			O-17	N-16	13.78	(γ,p)	7.2				
			O-18	O-17	8.04	(γ,n)				0.2	
			O-18	N-17	15.94	(γ,p)	4.16				
			F-19	F-18	10.43	(γ,n)	6.58E+03			100	540
			F-19	O-18	7.99	(γ,p)					0.054
			Ne-20	Ne-19	16.87	(γ,n)				90.51	
			Ne-20	F-19	12.85	(γ,p)					
			Ne-21	Ne-20	6.76	(γ,n)				0.27	
			Ne-21	F-20	13.01	(γ,p)	11.4				
			Ne-22	Ne-21	10.36	(γ,n)				9.22	
			Ne-22	F-21	15.27	(γ,p)	4.4				
			Na-23	Na-22	12.42	(γ,n)	8.21E+07			100	23000
			Na-23	Ne-22	8.79	(γ,p)					2.3
			Mg-24	Mg-23	16.53	(γ,n)	12.1			78.99	29000
			Mg-24	Na-23	11.69	(γ,p)					2.9
			Mg-25	Mg-24	7.33	(γ,n)				10	
			Mg-25	Na-24	12.06	(γ,p)	5.40E+04				
			Mg-26	Mg-25	11.09	(γ,n)				11.01	
			Mg-26	Na-25	14.14	(γ,p)	60				
			Al-27	Al-26	13.06	(γ,n)	2.21E+13			100	82000
			Al-27	Mg-26	8.27	(γ,p)					8.2
			Si-28	Si-27	17.18	(γ,n)	4.2			92.23	270000
			Si-28	Al-27	11.58	(γ,p)					27
			Si-29	Si-28	8.47	(γ,n)				4.67	
			Si-29	Al-28	12.33	(γ,p)	1.39E+02				
			Si-30	Si-29	10.61	(γ,n)				3.1	
			Si-30	Al-29	13.51	(γ,p)	3.96E+02				
			P-31	P-30	12.31	(γ,n)	1.50E+02			100	1000
			P-31	Si-30	7.3	(γ,p)					0.1
			S-32	S-31	15.04	(γ,n)	2.7			95	420



IAEA-TECDOC-1287
Natural and induced Radioactivity in food

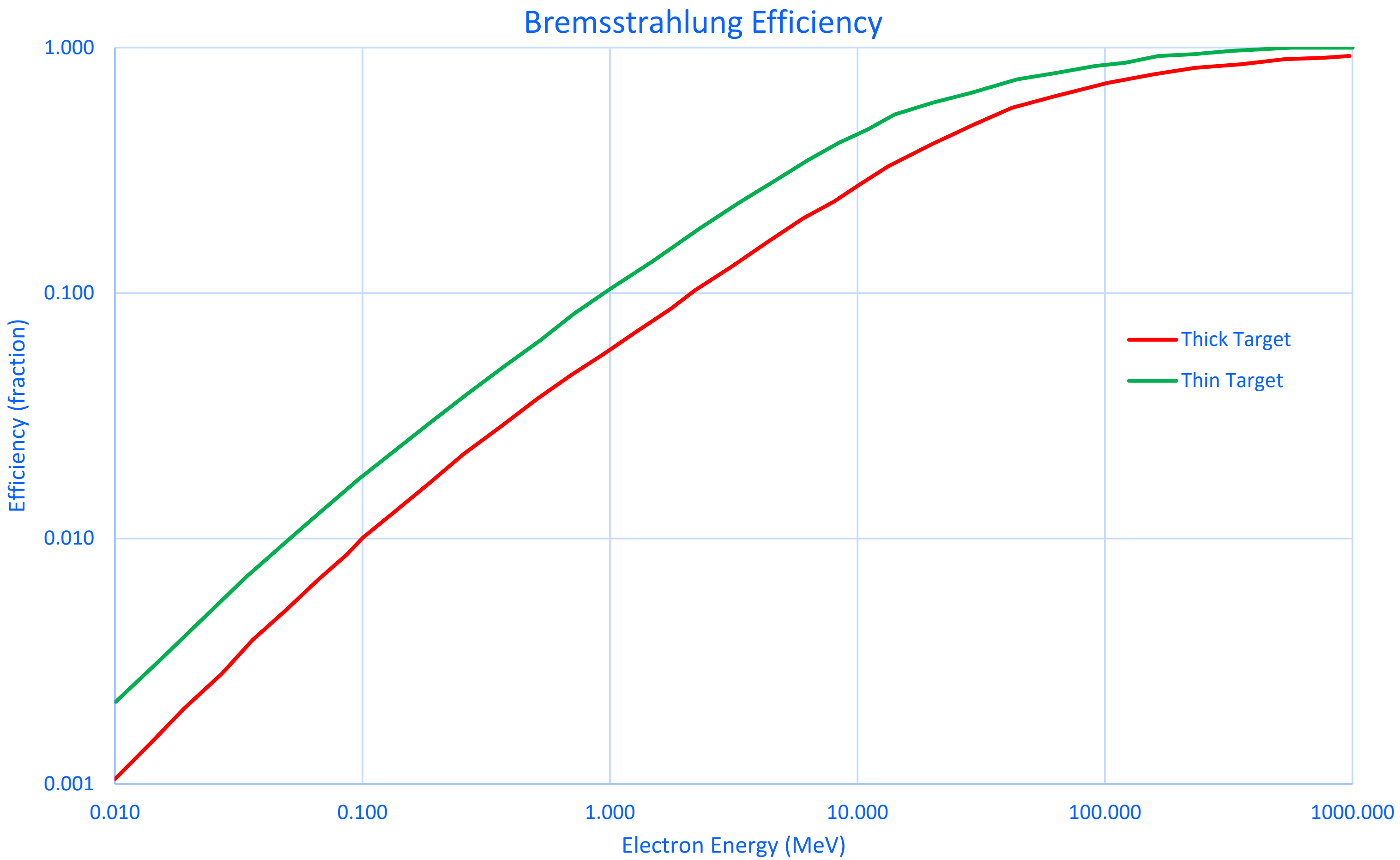
Fermilab

Penetration



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

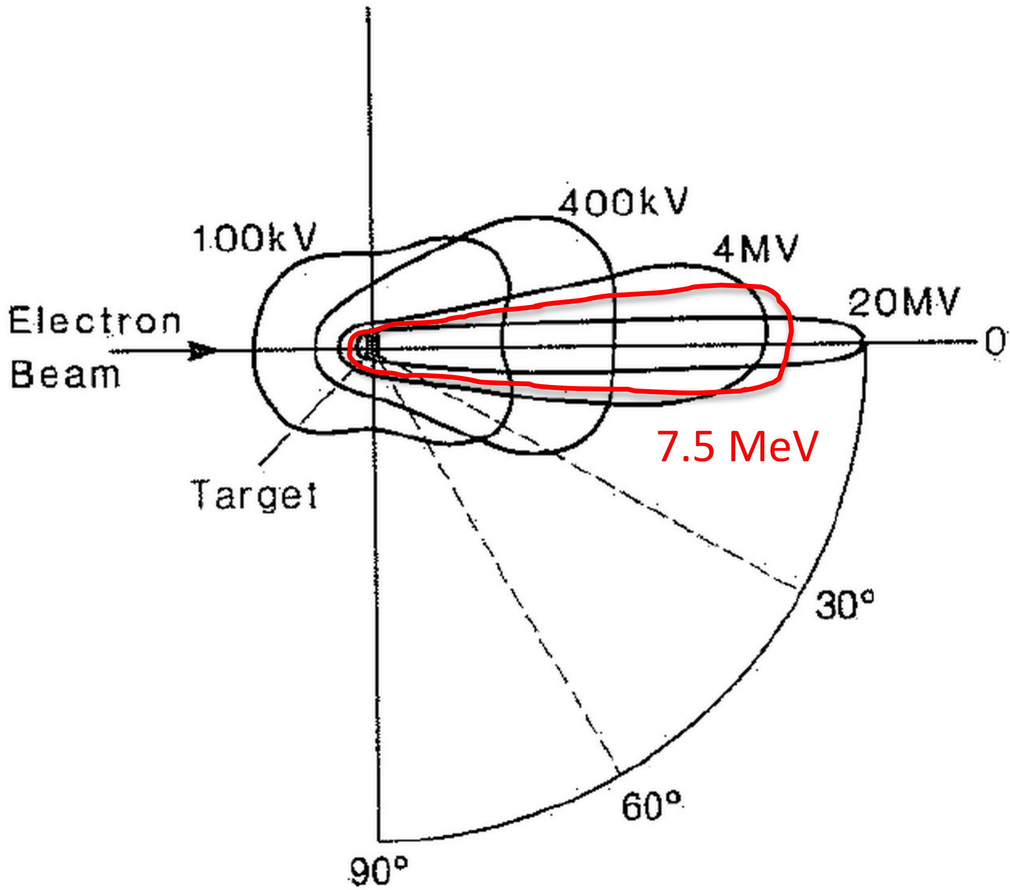
Generating X-rays



“I cannae change the laws of physics.” – Scotty

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)

Power

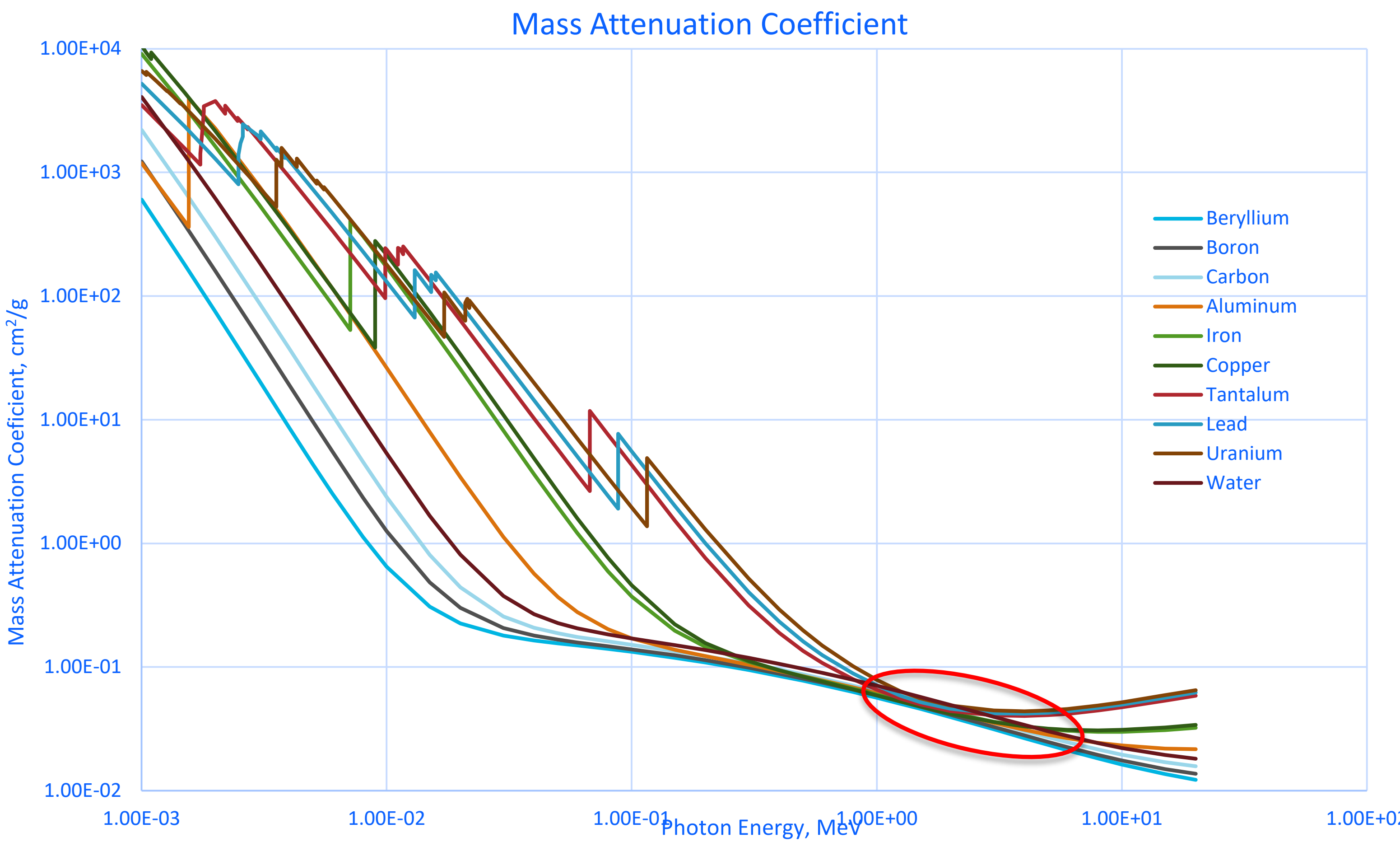
- 1 Mci = $3.7\text{x}10^{16}$ decays/second
  - Total energy released – 2.505 MeV/decay
  - 15 kW
  - Typical irradiation bunker – 30-60 kW of “beam” power
- Electron beam machines can provide this easily
- X-ray must overcome inefficiency of Bremsstrahlung process
  - 200 – 400 kW of electron beam 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)

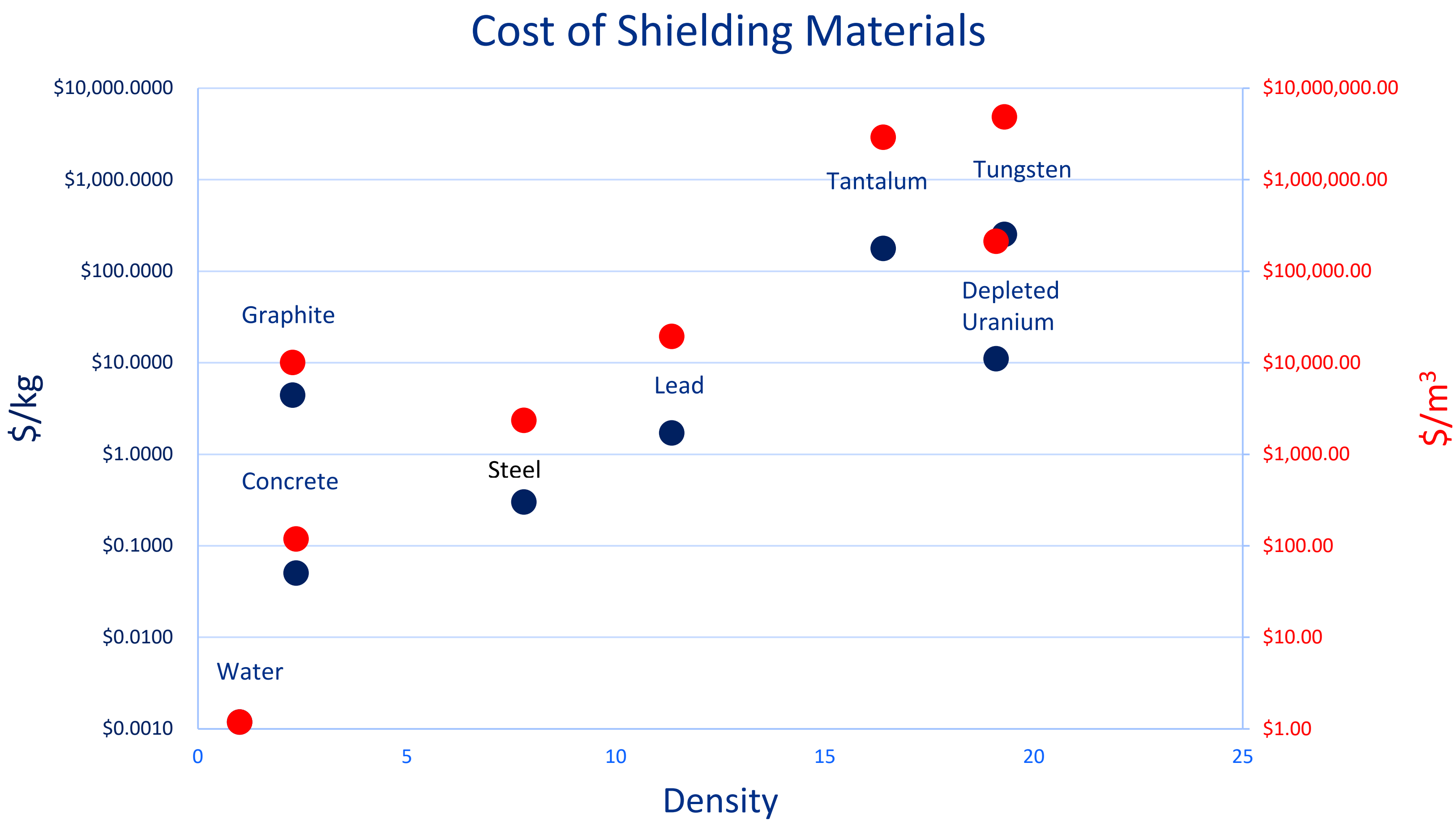
1 MCi gamma ≈ 120 kW X-ray

Why can’t we do something clever with shielding?



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

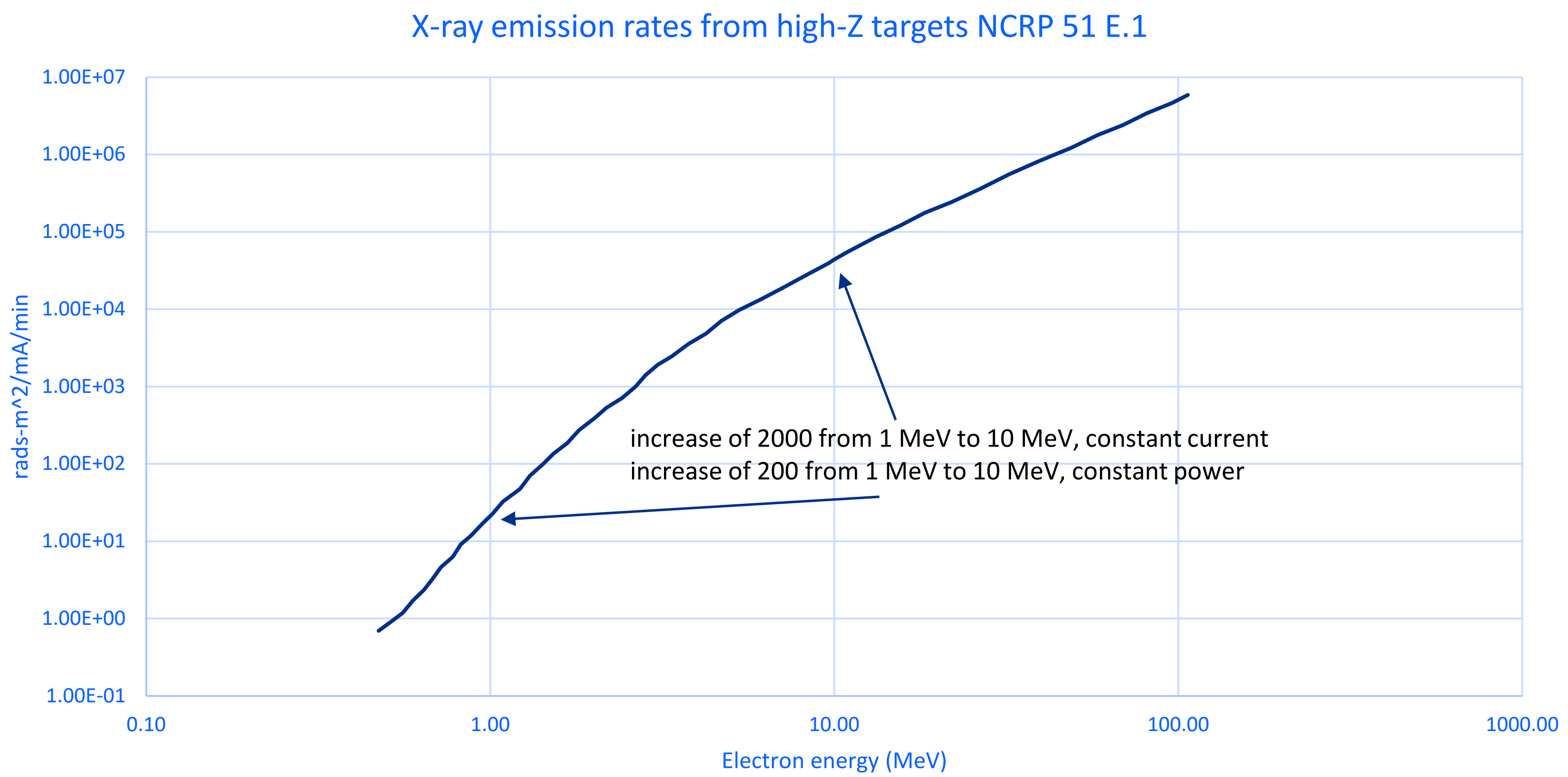
Why is shielding always concrete?



Using denser materials saves volume, but costs more.

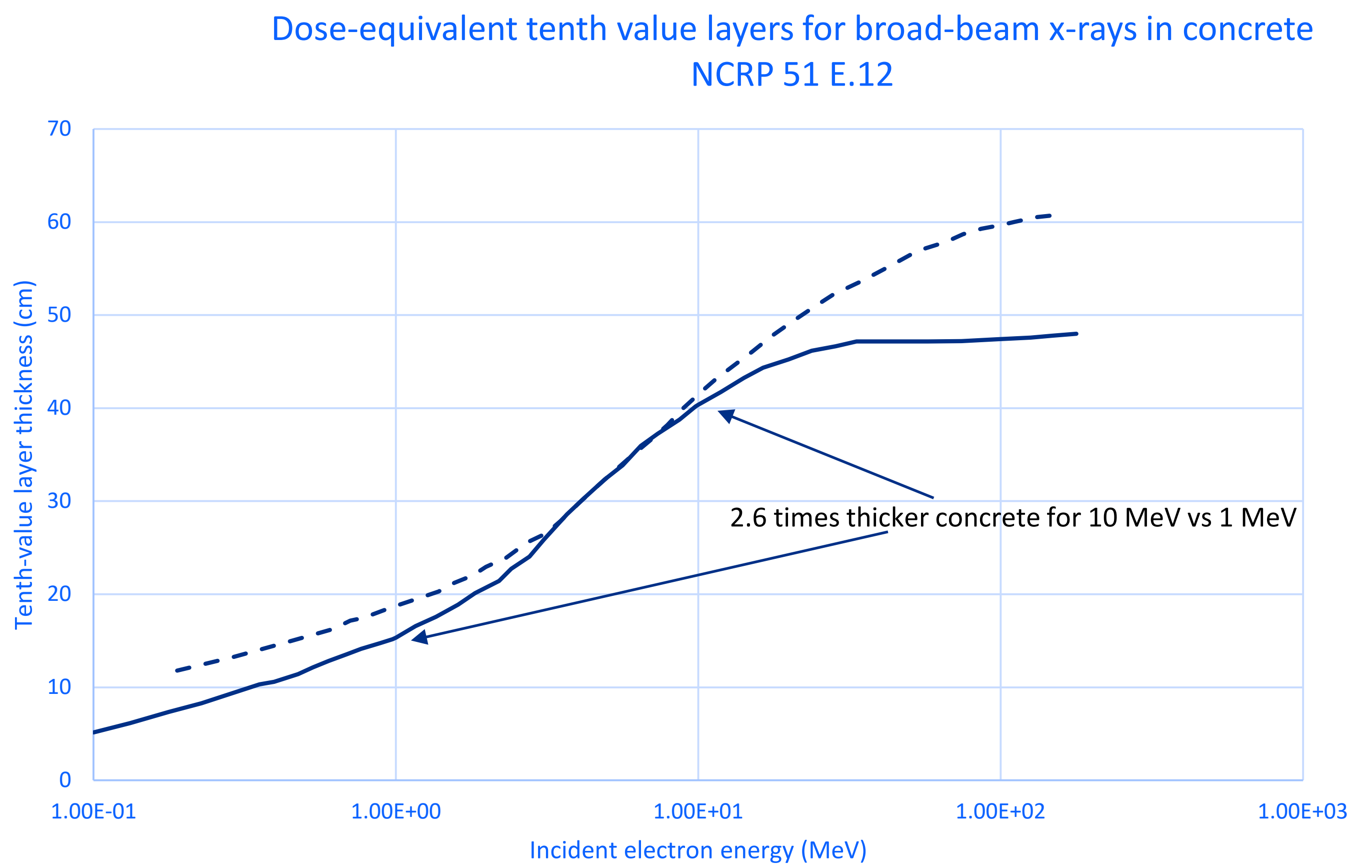
Fermilab

How to maximize throughput



Use the highest energy allowed. Also gives best penetration.

Impact of Energy on Shielding



Higher energy does require more shielding.

Thank you