University of Pittsburgh

ME/ENGR 2100 Fundamentals of Nuclear Engineering

Radiation Protection:

Radiation Shielding

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Relevant Reading Assignments

- Chapter 9 of "Introduction to Nuclear Engineering," Lamarsh and Baratta, 3rd edition, Prentice-Hall (2001)
- Chapter 3 of "Nuclear Engineering: Theory and Technology of Commercial Nuclear Power," Knief, 2nd edition, American Nuclear Society (1992, reprint by ANS 2008)

Learning Objectives

- Identify the major purposes of reactor shielding and explain secondary radiation.

Radiation Shielding

- Purpose of radiation shielding
  - Protect personnel and/or equipment ("behind" the shield) from radiation exposure
    - Absorb *primary radiation* incident on the shield
    - Reduce primary radiation energy (usually through scattering) to produce *secondary radiation* that is less damaging / easier to absorb.
    - Absorb *secondary radiation* generated within the shield material.

Shielding Effects

- Radiation *Buildup*
  - Absorption/scattering collisions
  - Secondary radiations
- Secondary Radiation
  - Scattered gamma rays
    - Compton scattering
  - Capture gamma rays
    - Neutron capture (n, γ)
  - *Secondary radiation can dominate over primary radiation*

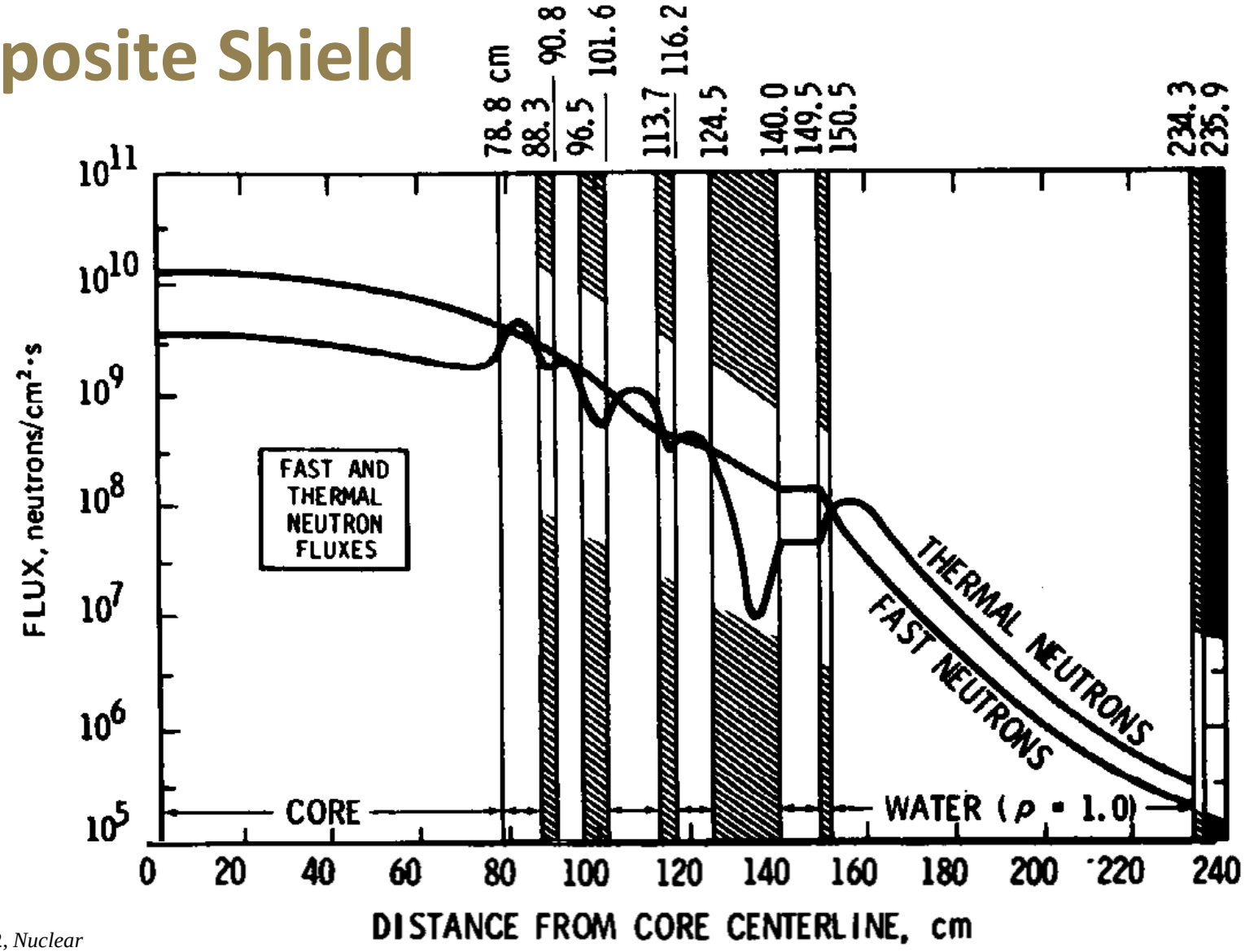
Radiation Shielding

- Alpha / beta radiation
  - Short range, small thickness of any material will work.
  - Requires only simple shielding (Layer of skin / piece of foil).
- Gamma / neutron radiation
  - Extremely penetrating, reaction rates are highly material dependent (preferred shielding materials).
  - Shielding
    - Have to worry about both primary and secondary radiations
    - Usually requires composite shields containing several different materials.

Radiation Shield Types

- Simple
  - Lead — "Hazardous" (toxic), so handle carefully
  - Concrete — General Purpose
  - Water — Research Reactor "Pool"
- Composite (for mixed n, γ radiations)
  - Optimize gamma & neutron attenuation
  - Minimize thickness / weight
- Specialized shields
  - "Lead" Glass for use in shielded "hot cells" that workers must see inside of.

Composite Shield



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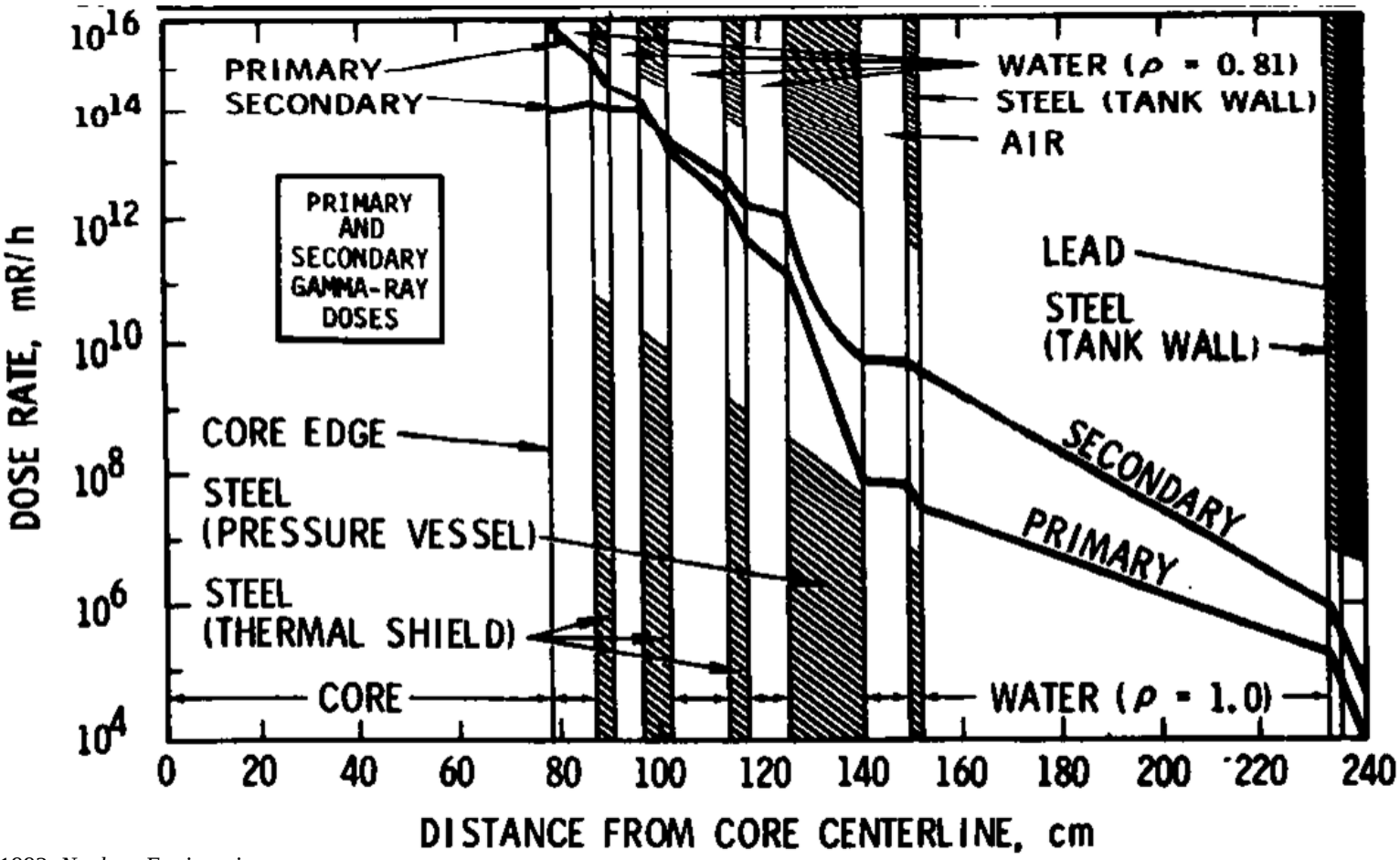
Composite Shield



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Shield Attenuation

- Tenth thickness (also called “tenth-value layer”)
  - Approximate amount (cm or in.) of a specific material required to reduce radiation dose by a factor of 10 (i.e., to $1/10^{th}$)
    - Materials have different values for each type of radiation.
  - Each tenth thickness provides a factor of ten reduction
    - For example: six (6) tenth thicknesses provide 10^6 = 1,000,000 = 1 million reduction factor

Shield Attenuation

$$\frac{I}{I_0} = \left(\frac{1}{2}\right)^{\left[\frac{x}{X_{1/2}}\right]}$$

Half thickness attenuation formula

$$\frac{I}{I_0} = \left(\frac{1}{10}\right)^{\left[\frac{x}{X_{1/10}}\right]}$$

Tenth thickness attenuation formula

I Intensity
x Distance (Thickness of Shield)

$X_{1/10}$ X_{TT} Tenth Thickness [cm]
$X_{1/2}$ X_{HT} Half thickness [cm]

Tenth Thickness Values

TENTH THICKNESSES (X_{TT}) FOR MATERIALS USED FOR RADIATION SHIELDING

Material	Density [g/cm^3]	Tenth Thickness [cm]		
		Fast Neutrons	Gamma	
			1 MeV	Reactor (w/ Buildup)
Water	1.0	23	34	69
Graphite	1.62	21		44
Be	1.85	21		42
BeO	2.3	21		32
Concrete	2.3-4.3	38-14	17-11	34-18
Al	2.7	23	14	30
Iron	7.8	14	5.1	8.5
Lead	11.3	21	2.9	5.8
Glass	2.7-6.2		15-5.6	
Air	0.0011		0.88 km	

Source: Etherington, 1958