Neutron Spectra
Gamma Effects

Phys 150 – W 2025

Lubin

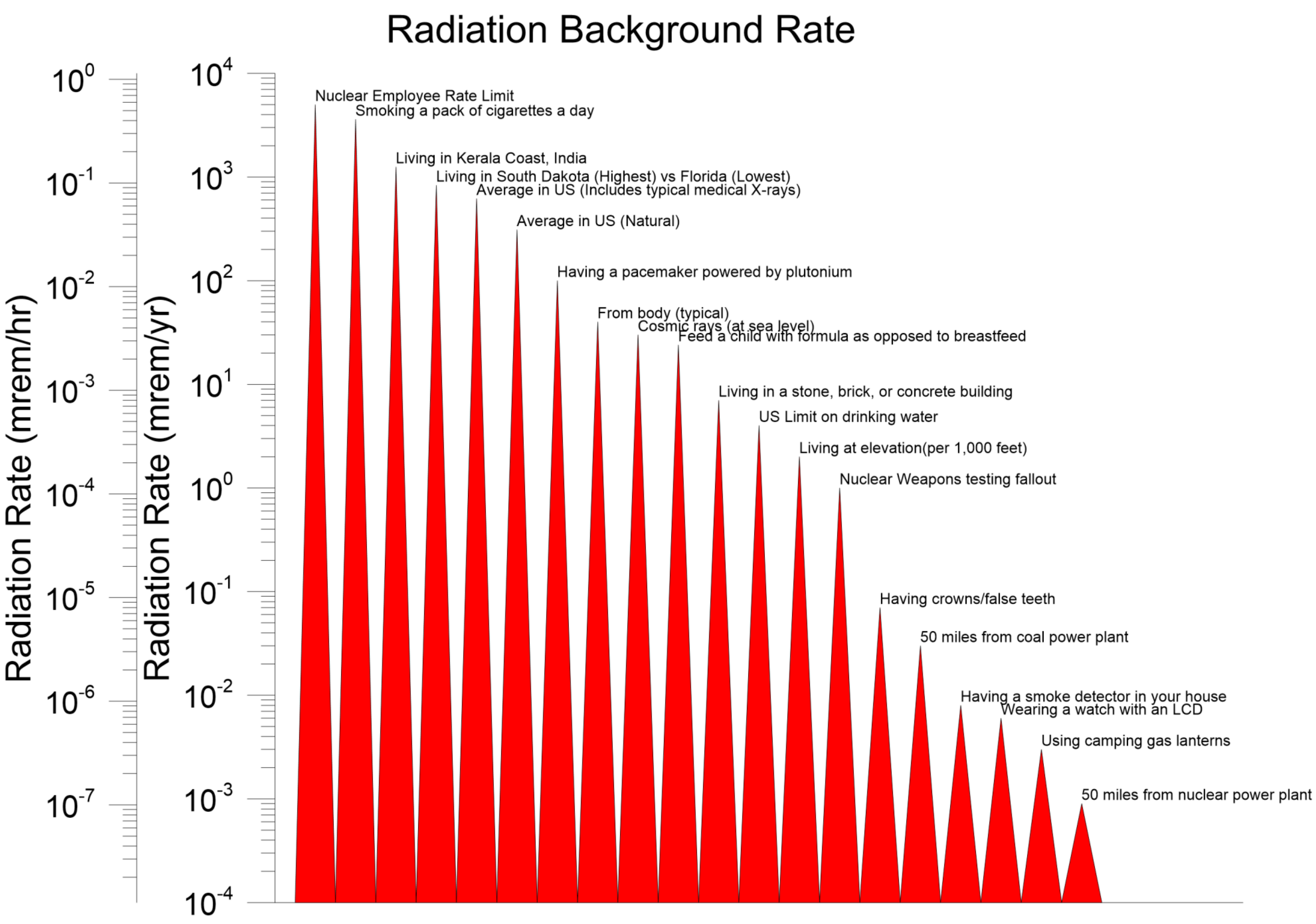
Quality Factor for Neutron in Tissue

REM=QF*RAD

https://www.nrc.gov/reading-rm/doc-collections/cfr/part020/part020-1004.html

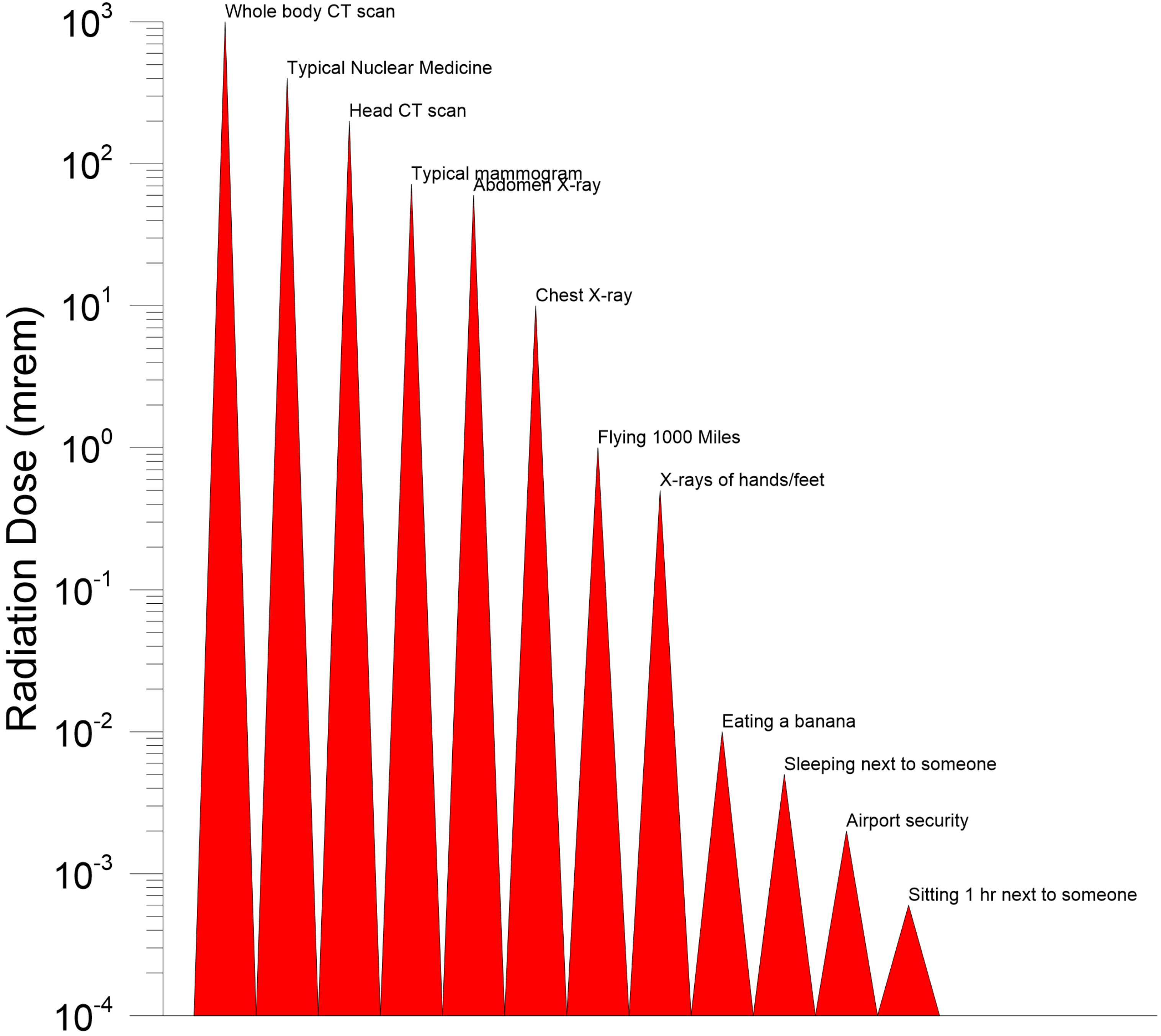
[a] Value of quality factor (Q) at the point where the dose equivalent is maximum in a 30-cm diameter cylinder tissue-equivalent phantom.
[b] Monoenergetic neutrons incident normally on a 30-cm diameter cylinder tissue-equivalent phantom.

	Neutron energy (MeV)	Quality factor[a] (Q)	Fluence per unit dose equivalent[b] (neutrons cm^{-2} rem^{-1})
	2.5×10^{-8}	2	980×10^{6}
	1×10^{-7}	2	980×10^{6}
	1×10^{-6}	2	810×10^{6}
	1×10^{-5}	2	810×10^{6}
	1×10^{-4}	2	840×10^{6}
	1×10^{-3}	2	980×10^{6}
	1×10^{-2}	2.5	1010×10^{6}
	1×10^{-1}	7.5	170×10^{6}
	5×10^{-1}	11	39×10^{6}
	1	11	27×10^{6}
	2.5	9	29×10^{6}
	5	8	23×10^{6}
	7	7	24×10^{6}
	10	6.5	24×10^{6}
	14	7.5	17×10^{6}
	20	8	16×10^{6}
	40	7	14×10^{6}
	60	5.5	16×10^{6}
	1×10^{2}	4	20×10^{6}
	2×10^{2}	3.5	19×10^{6}
	3×10^{2}	3.5	16×10^{6}
	4×10^{2}	3.5	14×10^{6}



Radiation Background Rate
Radiation Rate (mrem/hr)
Radiation Rate (mrem/yr)
10^0
10^-1
10^-2
10^-3
10^-4
10^-5
10^-6
10^-7
10^4
10^3
10^2
10^1
10^0
10^-1
10^-2
10^-3
10^-4
Nuclear Employee Rate Limit
Smoking a pack of cigarettes a day
Living in Kerala Coast, India
Living in South Dakota (Highest) vs Florida (Lowest)
Average in US (Includes typical medical X-rays)
Average in US (Natural)
Having a pacemaker powered by plutonium
From body (typical)
Cosmic rays (at sea level)
Feed a child with formula as opposed to breastfeed
Living in a stone, brick, or concrete building
US Limit on drinking water
Living at elevation(per 1,000 feet)
Nuclear Weapons testing fallout
Having crowns/false teeth
50 miles from coal power plant
Having a smoke detector in your house
Wearing a watch with an LCD
Using camping gas lanterns
50 miles from nuclear power plant

Radiation Background Dose



Little Boy U (Hiroshima) N Spectra
Prompt fission (inside) and Weapon Leakage (outside casing) (Spriggs 2017)

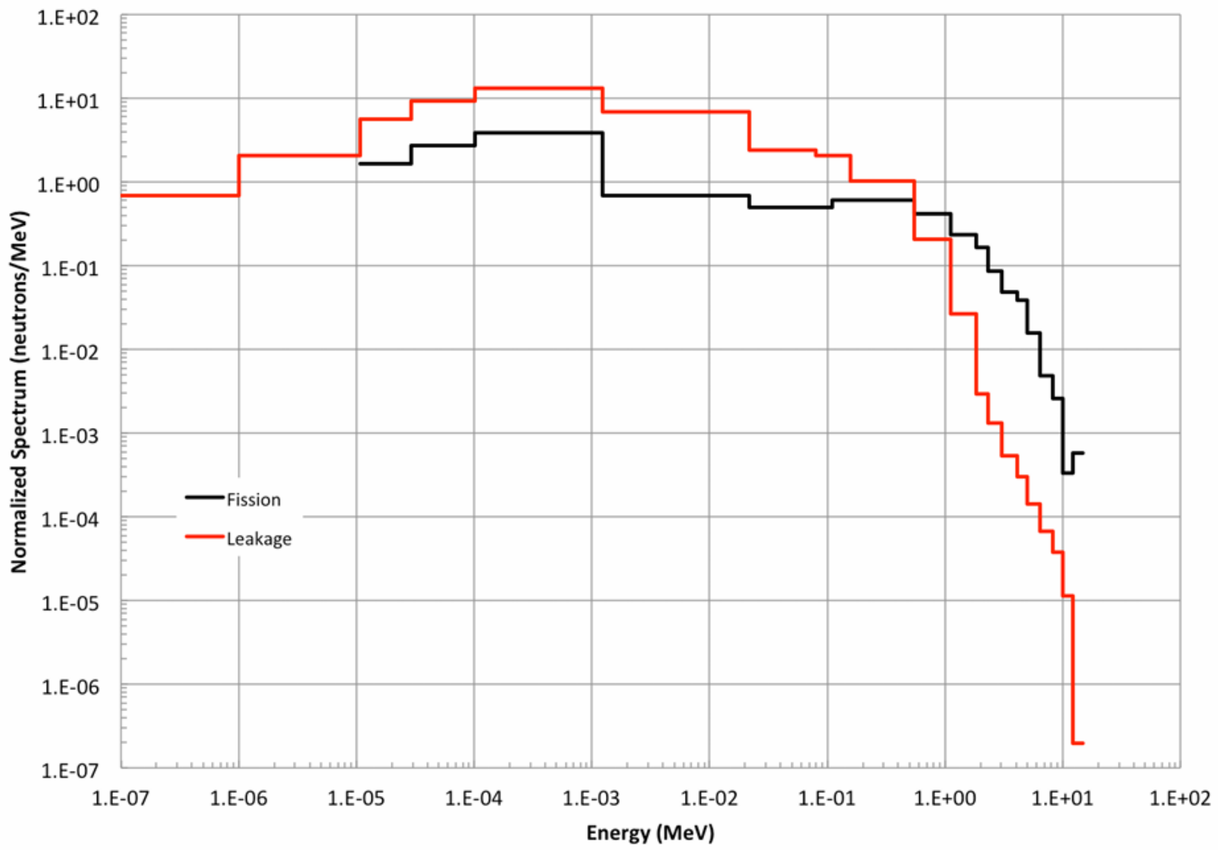


Figure 5. This is a plot of the neutron spectra (normalized to 1 neutron) that was used to estimate the residual radiation source term for the Hiroshima detonation. The average neutron energy of the prompt fission spectrum was 1.46 MeV and the average neutron energy of the leakage spectrum was 0.31 MeV. The prompt fission spectrum was used to estimate the fission-product yield curve, which is used to determine the radionuclides in the fission product source term. The leakage spectrum was used to calculate the air-activation source term and the ground-activation source term.

Fat Man (Pu implosion) and Little Boy (U gun) Weapon Gamma Spectra

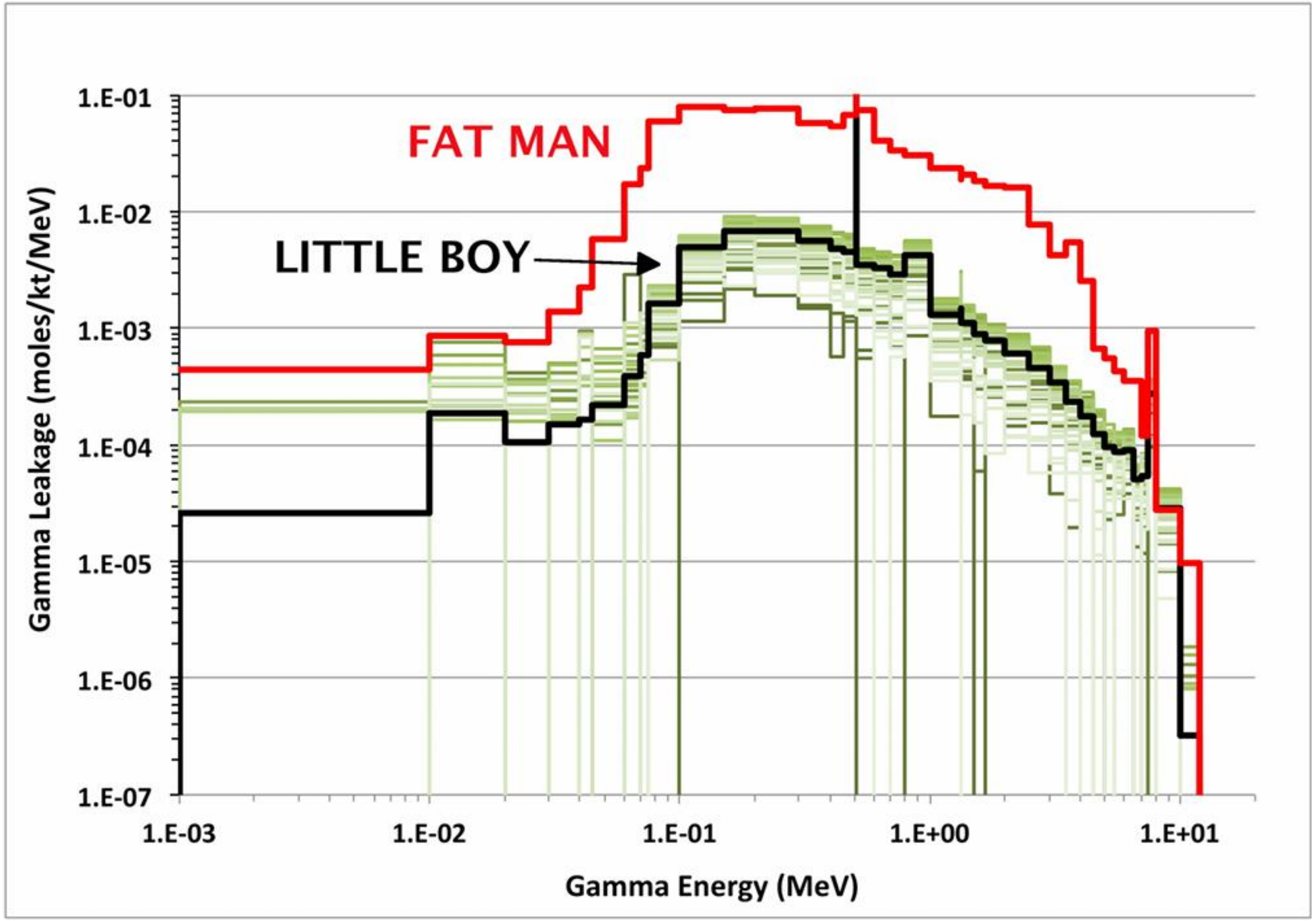


Figure 3: Gamma spectra for Fat Man and Little Boy. The total Little Boy output (sum over all angles) is shown along with the 40 individual segment tallies scaled up to the full sphere. The segment tallies illustrate the two-dimensional variation of the output.

Fat Man (Pu implosion) and Little Boy (U gun) Weapon Neutron Spectra

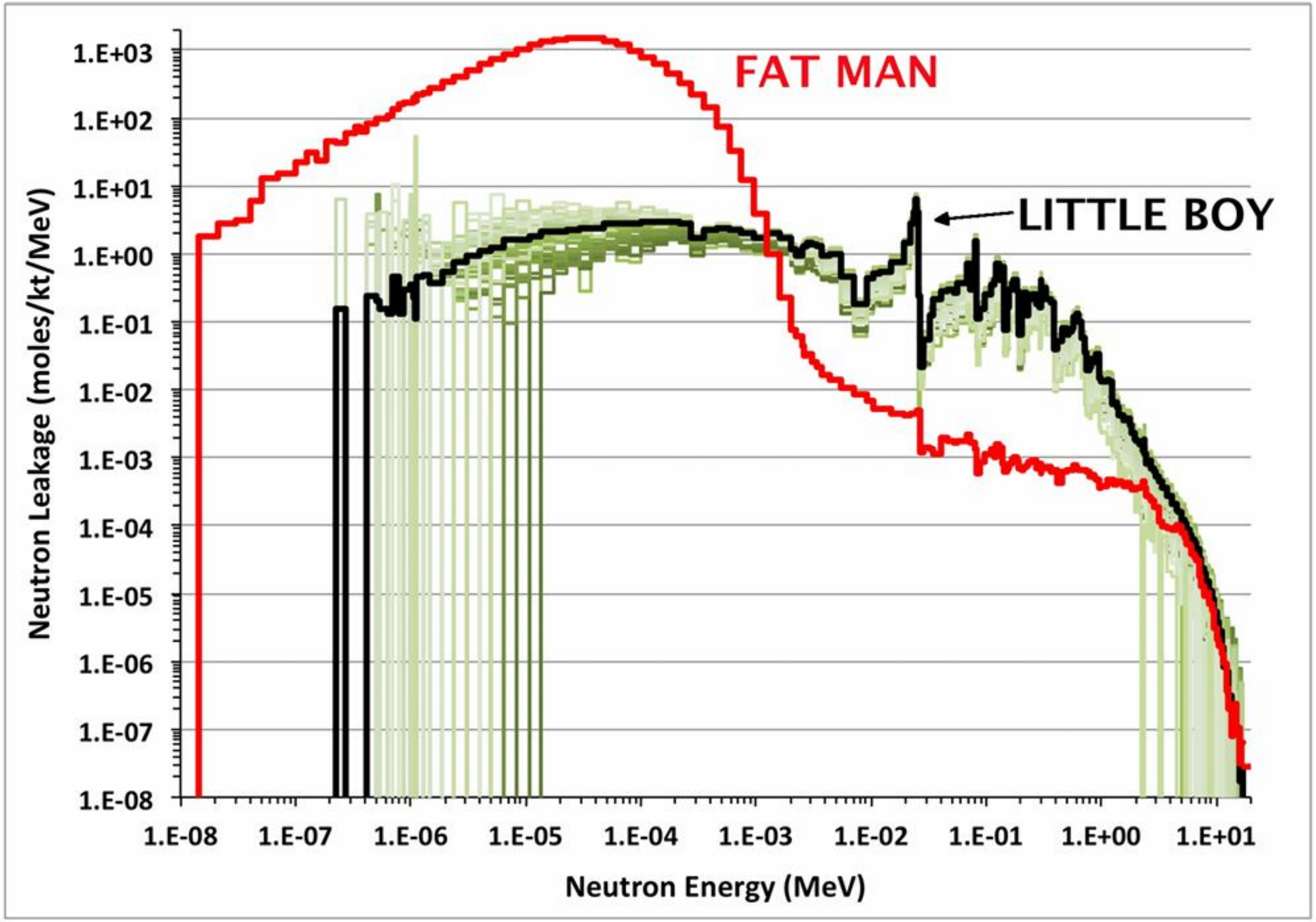


Figure 2: Neutron spectra for Fat Man and Little Boy. The total Little Boy output (sum over all angles) is shown along with the 40 individual segment tallies scaled up to the full sphere. The segment tallies illustrate the two-dimensional variation of the output.

Fat Man (Pu implosion) and Little Boy (U gun) Weapon Gamma vs Angle

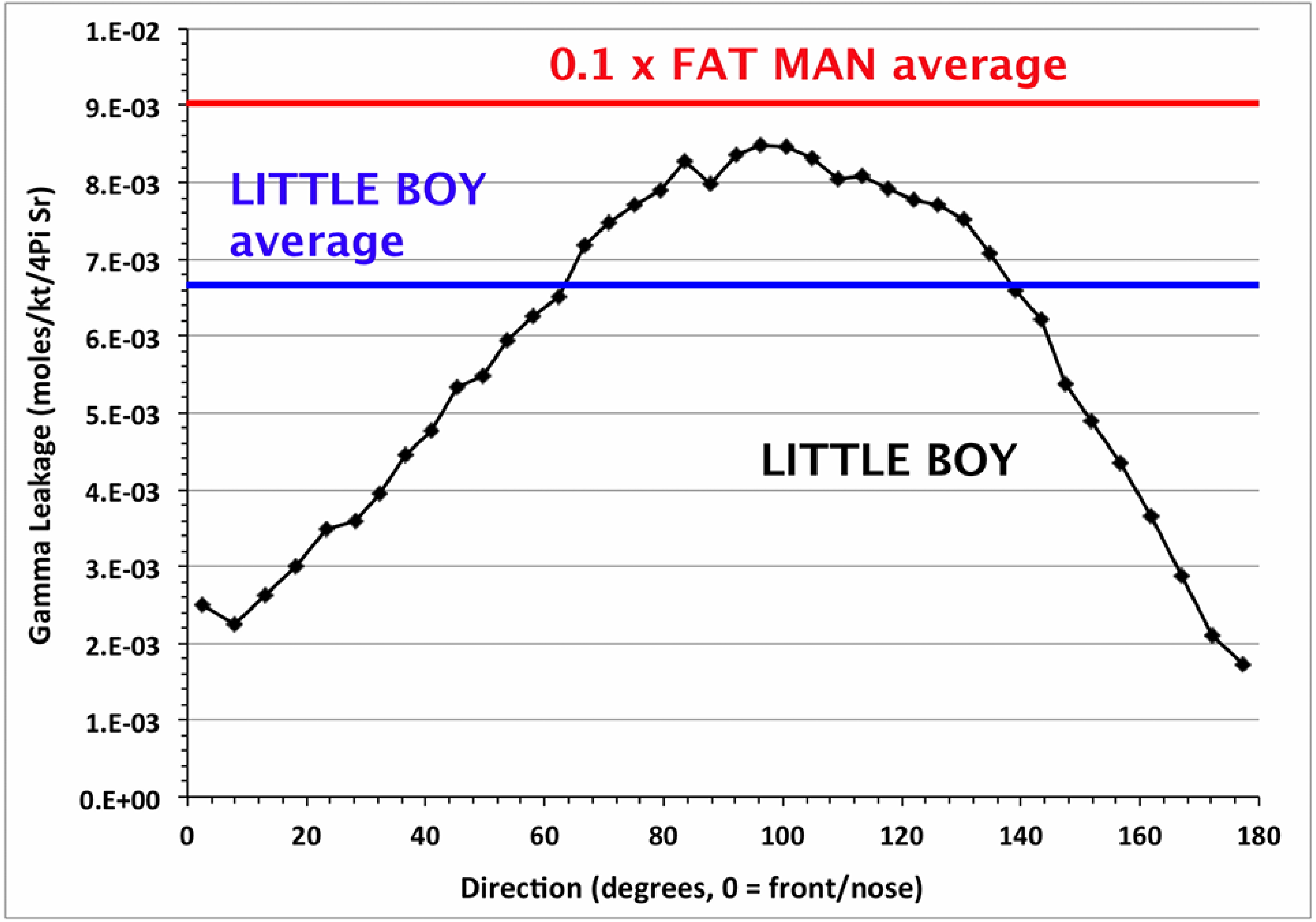


Figure 5: Gamma output variation with angle. Segment tallies have been scaled up to the full sphere. Note that the Fat Man value has been reduced by a factor of 10. As with neutrons, the output is suppressed toward the nose (0°) and tail (180°), though these directions represent a small solid angle and the average is heavily weighted toward the values near the waist (90°).

Thermonuclear N Spectra (per KT yield)

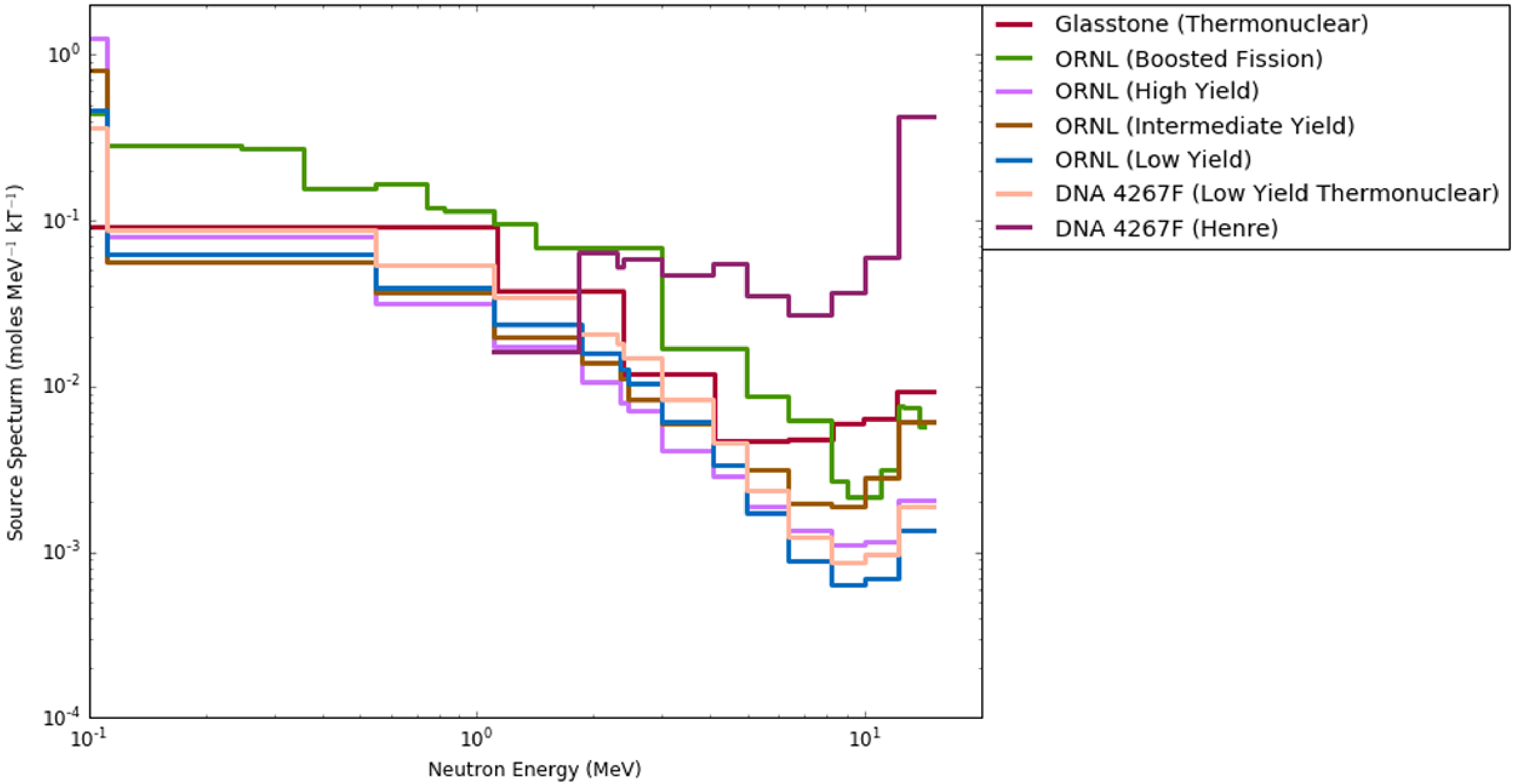


Figure 4. Thermonuclear neutron spectra with energies greater than 0.1 MeV

Gammas from Weapon

- "Instantaneous" Gamma's are produced within the weapon and almost entirely absorbed by the dense nuclear material during the fission and fusion process. Most do not leave the weapon
- Prompt Gamma's peak at about 10-100 ns after detonation
- Delayed Gammas come as the weapon expands into the air/ground/vacuum as the vaporized (plasma) weapon material density rapidly decreases
- In addition to the gammas from the weapon, there is also neutron capture in the air (Nitrogen primarily) that emits a radiative capture (of n) and produces more gammas
- If the detonation is near the ground, the neutrons induced radioactivity in the ground (and air) that can produce gammas.

Time Dependence of Gamma Radiation

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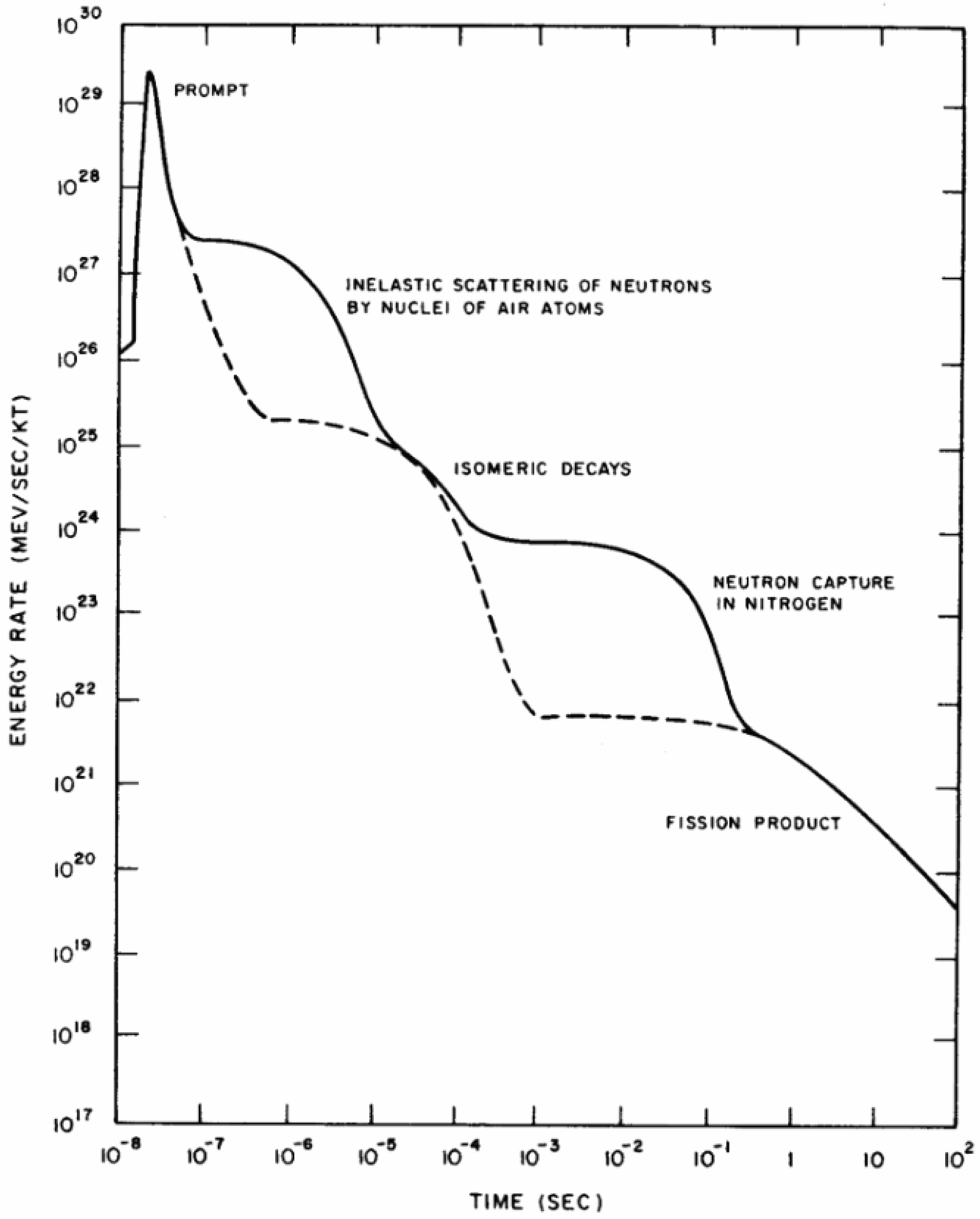


Figure 8.14. Calculated time dependence of the gamma-ray energy output per kiloton energy yield from a hypothetical nuclear explosion. The dashed line refers to an explosion at very high altitude.

Gamma glow from Atmosphere Backscatter

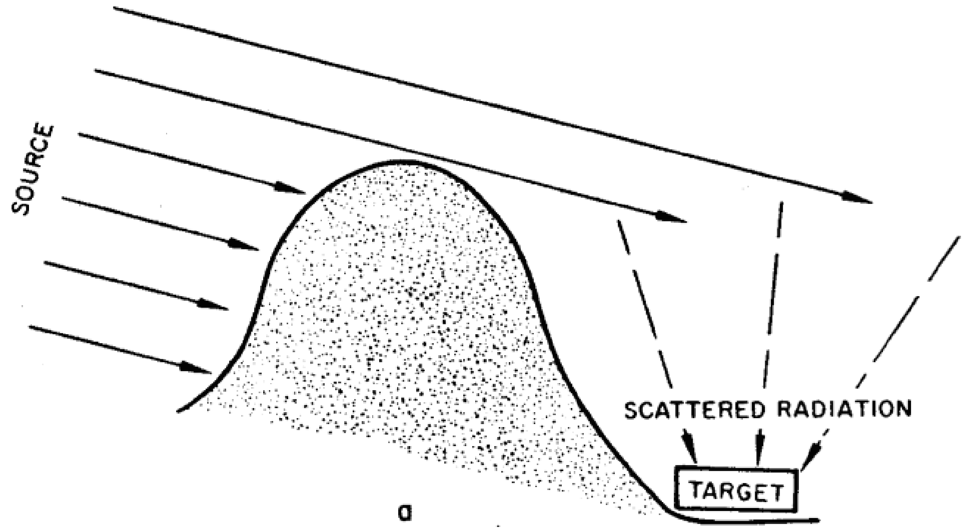
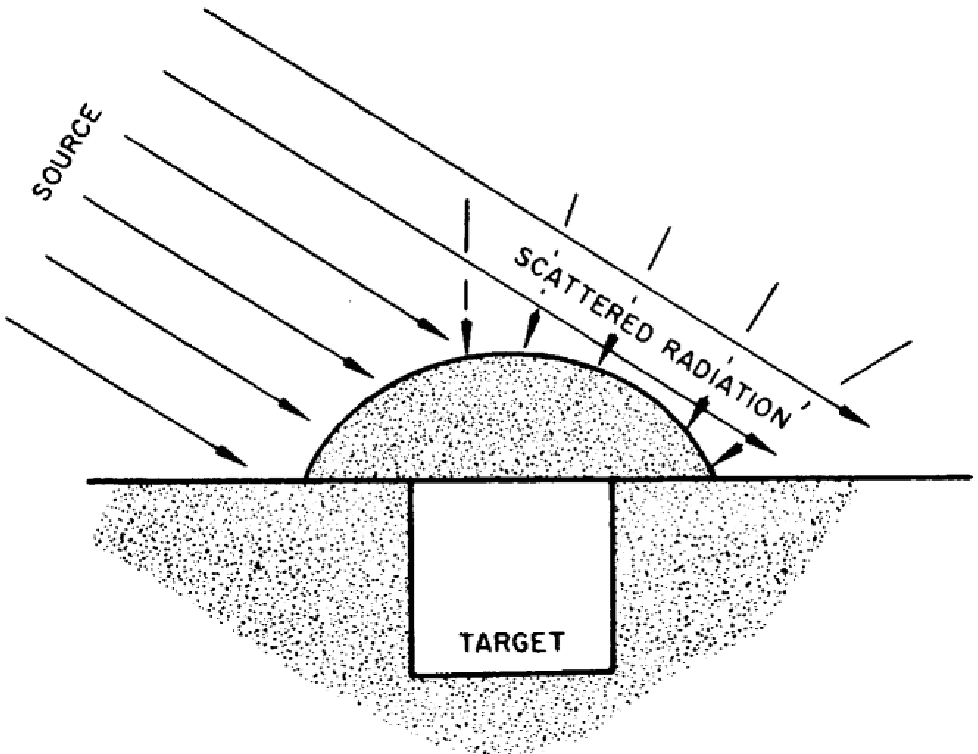


Figure 8.45a. Target exposed to scattered gamma radiation.



Fission Weapon Gamma Dose vs Slant Range

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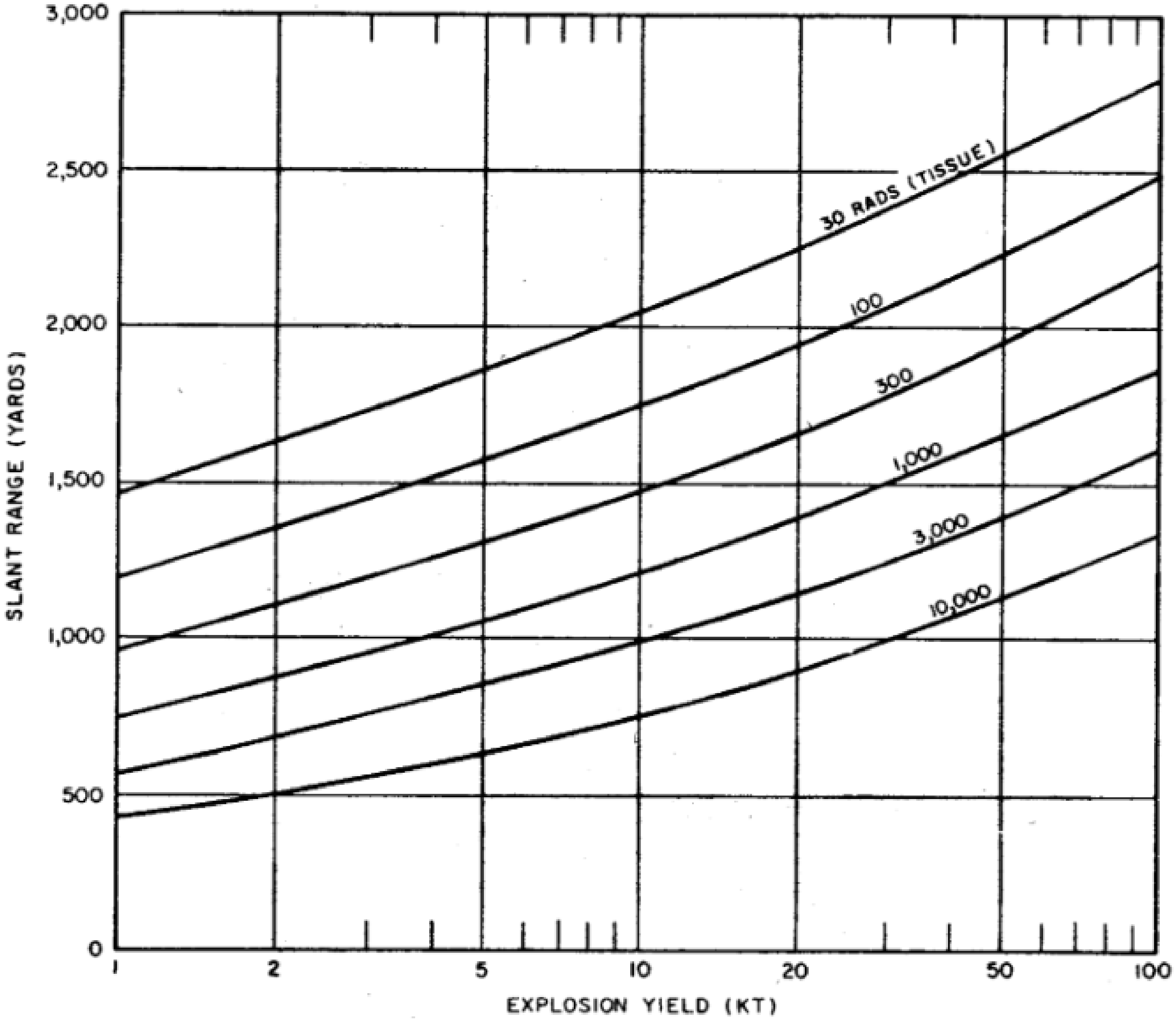

Figure 8.33a. Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst fission weapons based on 0.9 sea-level air density. (Reliability factor from 0.5 to 2 for most fission weapons.)

TN Weapon Gamma Dose vs Slant Range

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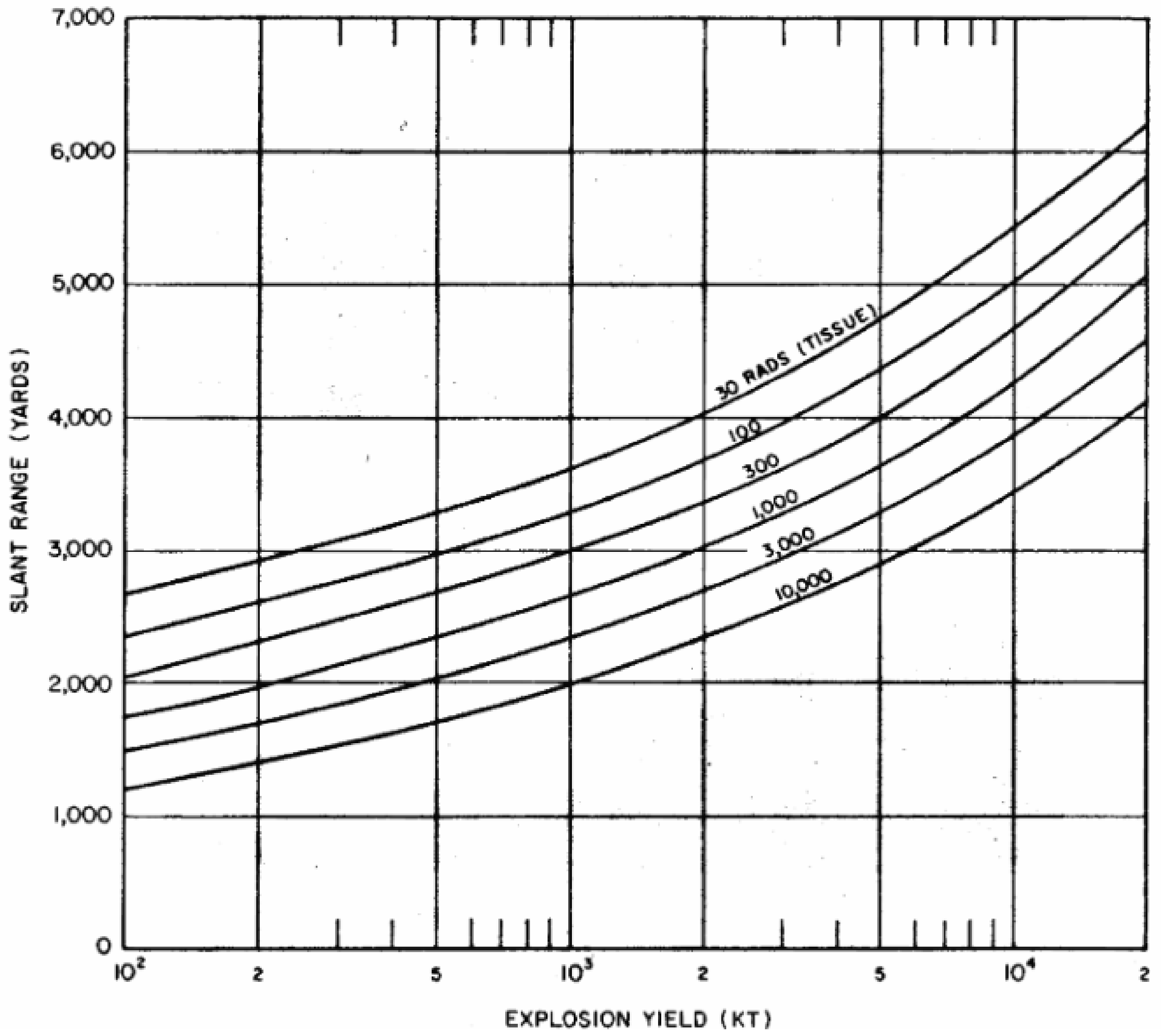

Figure 8.33b. Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons with 50 percent fission yield, based on 0.9 sea-level air density. (Reliability factor from 0.5 to 1.5 for most thermonuclear weapons.)

Shielding Thickness for Fission Products and Nitrogen Capture Gamma

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Table 8.41

APPROXIMATE EFFECTIVE TENTH-VALUE THICKNESSES FOR FISSION PRODUCT AND NITROGEN CAPTURE GAMMA RAYS

Material	Density (lb/cu ft)	Fission Product: Tenth-Value Thickness (inches)	Fission Product: D × T (lb/sq ft)	Nitrogen Capture: Tenth-Value Thickness (inches)	Nitrogen Capture: D × T (lb/sq ft)
Steel (Iron)	490	3.3	135	4.3	176
Concrete	146	11	134	16	194
Earth	100	16	133	24	200
Water	62.4	24	125	39	201
Wood	40	38	127	63	210

Percent of Initial Gamma Dose vs Time 20 KT and 5 MT

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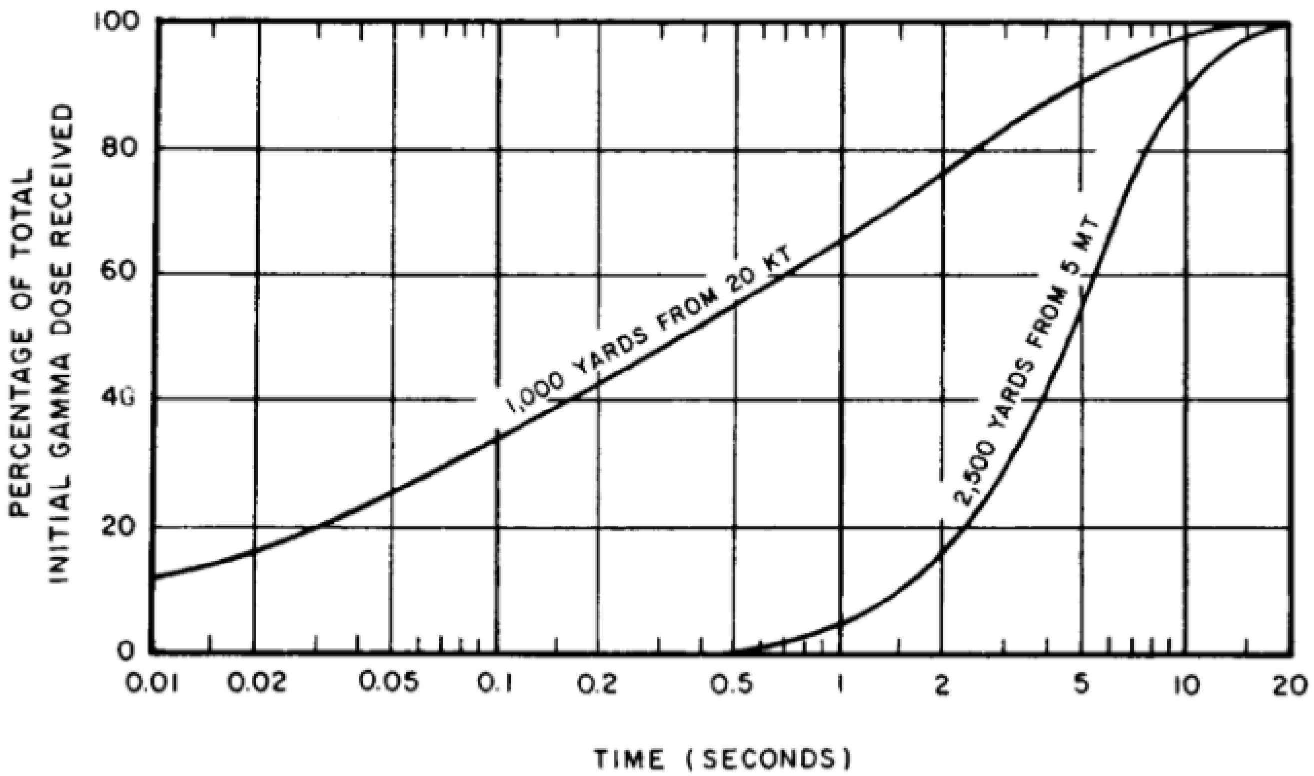

Figure 8.47. Percentage of initial gamma-radiation dose received as a function of time for 20-kiloton and 5-megaton air bursts.

Neutrons from Weapons

- Neutrons carry a relatively small fraction of weapon yield
    - Typ ~1%
- Prompt Neutrons Come within 1 μs after detonation
    - Neutrons come from both fission and fusion process
- Delayed Neutrons come from Fission products
    - Delayed Neutrons are < 1% of total neutrons
    - However the delayed neutron dose is "enhanced" by "hydrodynamic effects" from the blast wave (less air as it is "pushed out of the way"). For distances > ~1km from high yield weapon (MT range) the dose from delayed neutrons can exceed the dose from prompt neutrons
    - Majority of delayed neutrons come within 1 minute
- Due to scattering on weapons materials, casing, air the neutron spectrum (# vs energy) at observer is quite different (softer spectrum) than inside the weapon (at moment of detonation/ creation)
- Neutron from fission are typ ~ 1 Mev while those from fusion are typ ~ 12-14 MeV (peak of spectrum outside weapon)

Fission Weapon Neutron Dose vs Slant Range

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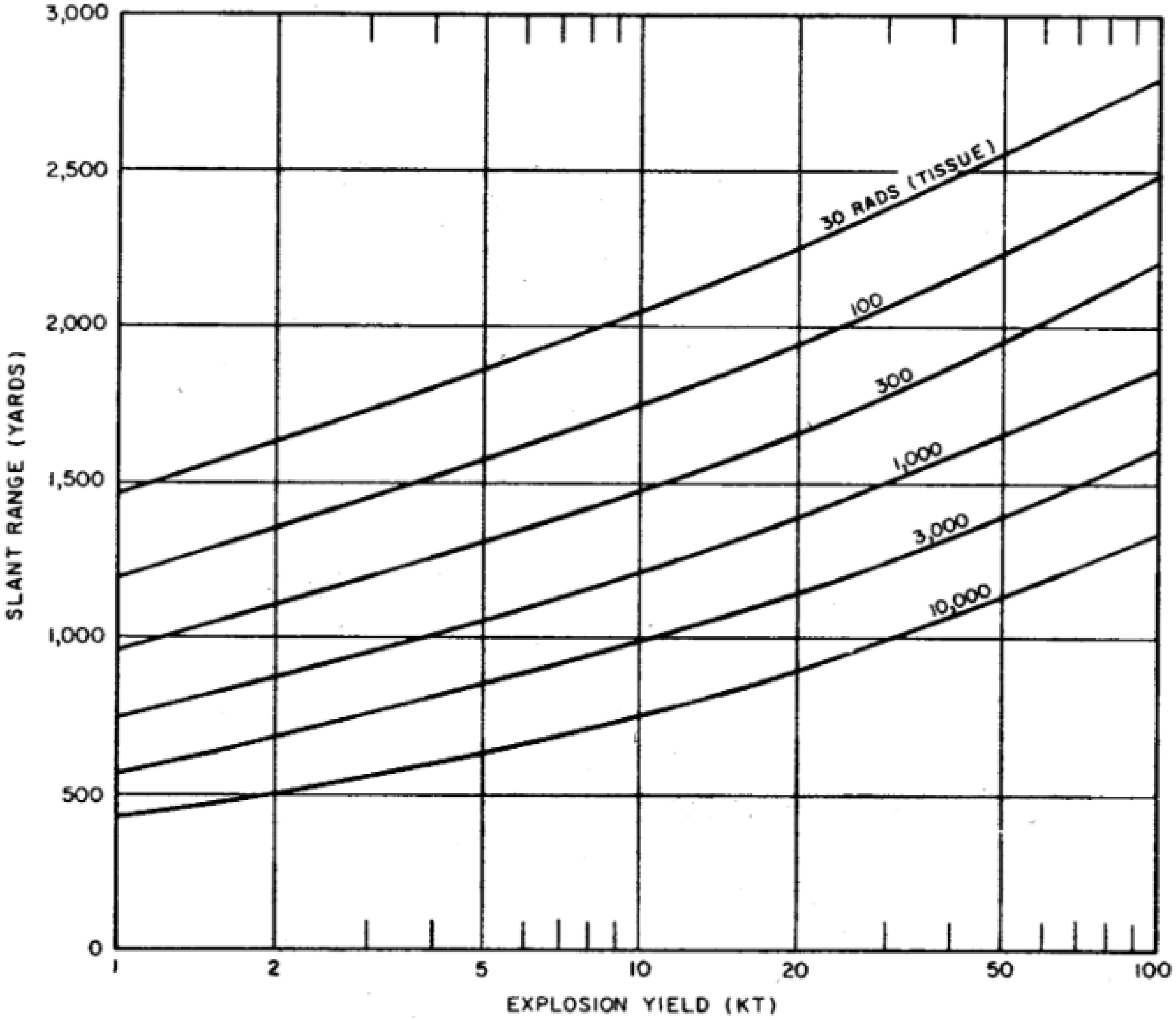

Figure 8.33a. Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst fission weapons based on 0.9 sea-level air density. (Reliability factor from 0.5 to 2 for most fission weapons.)

TN Weapon Neutron Dose vs Slant Range

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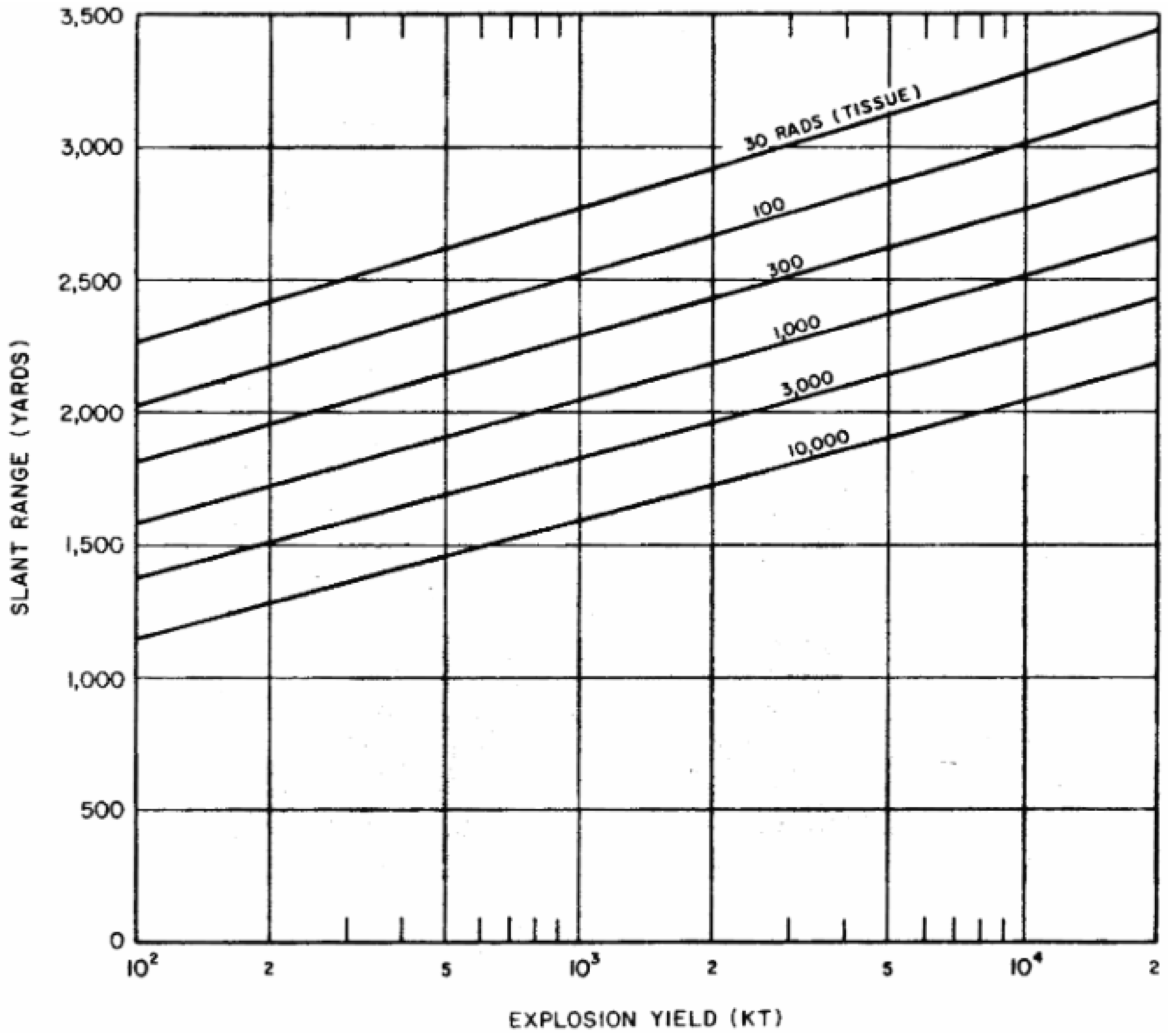

Figure 8.64b. Slant ranges for specified neutron doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons with 50 percent fission yield, based on 0.9 sea-level air density. (Reliability factor from 0.25 to 1.5 for most thermonuclear weapons.)

Shielding Thickness for Gamma and Neutrons

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Table 8.72

DOSE TRANSMISSION FACTORS FOR VARIOUS STRUCTURES

Structure	Initial Gamma Rays	Neutrons
Three feet underground	0.002-0.004	0.002-0.01
Frame House	0.8-1.0	0.3-0.8
Basement	0.1-0.6	0.1-0.8
Multistory building (apartment type):		
Upper stories	0.8-0.9	0.9-1.0
Lower stories	0.3-0.6	0.3-0.8
Concrete blockhouse shelter:		
9-in. walls	0.1-0.2	0.3-0.5
12-in walls	0.05-0.1	0.2-0.4
24-in walls	0.007-0.02	0.1-0.2
Shelter, partly above grade:		
With 2 ft earth cover	0.03-0.07	0.02-0.08
With 3 ft earth cover	0.007-0.02	0.01-0.05

Stable and Unstable Isotopes

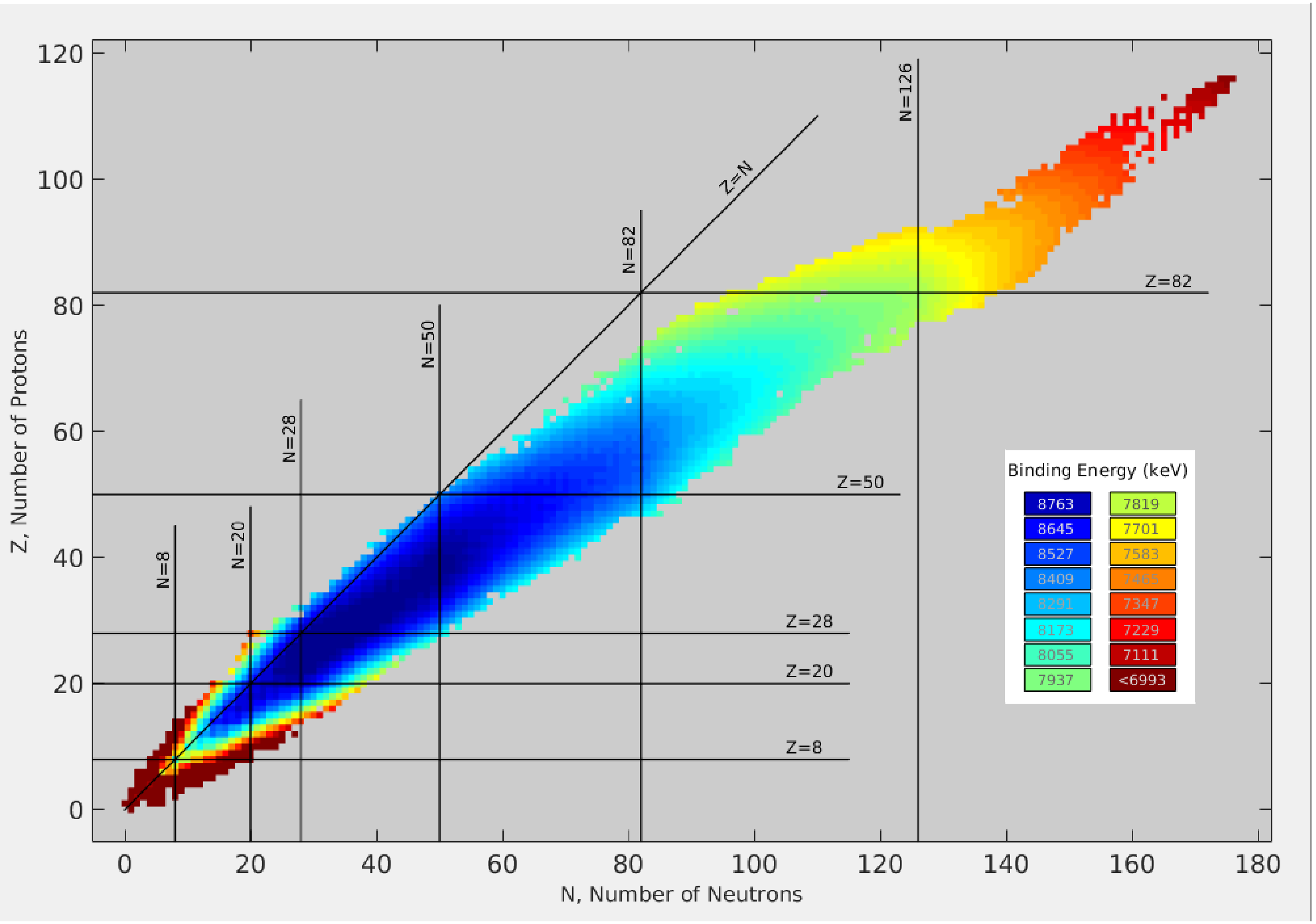


Chart of nuclides (isotopes) by binding energy, depicting the valley of stability. The diagonal line corresponds to equal numbers of neutrons and protons. Dark blue squares represent nuclides with the greatest binding energy, hence they correspond to the most stable nuclides. **The binding energy is greatest along the floor of the valley of stability.**

Stable and Unstable Isotopes

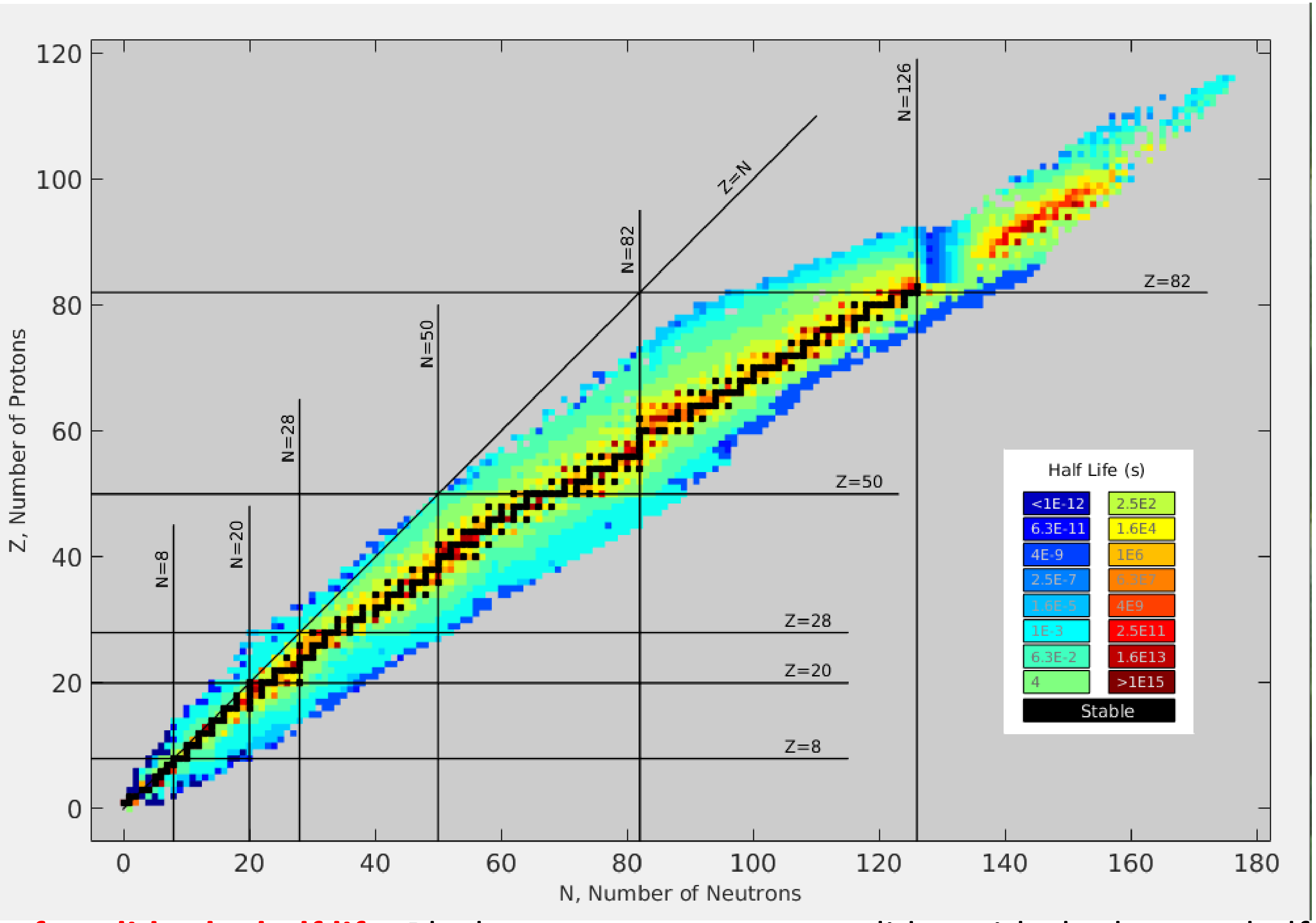


Chart of nuclides by half life. Black squares represent nuclides with the longest half lives hence they correspond to the most stable nuclides. The most stable, long-lived nuclides lie along the floor of the valley of stability. **Nuclides with more than 20 protons must have more neutrons than protons to be stable.**

Stable and Unstable Isotopes

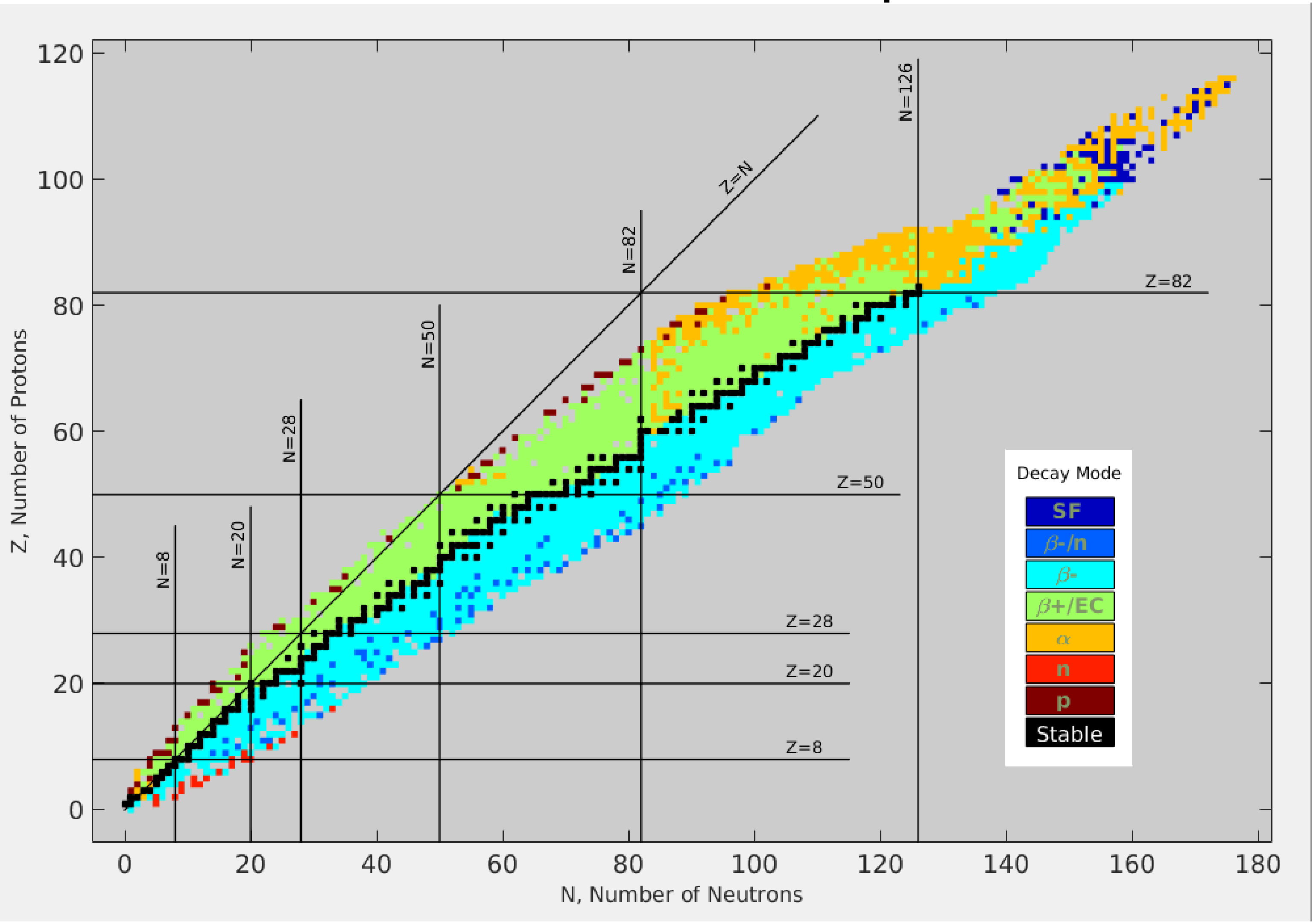
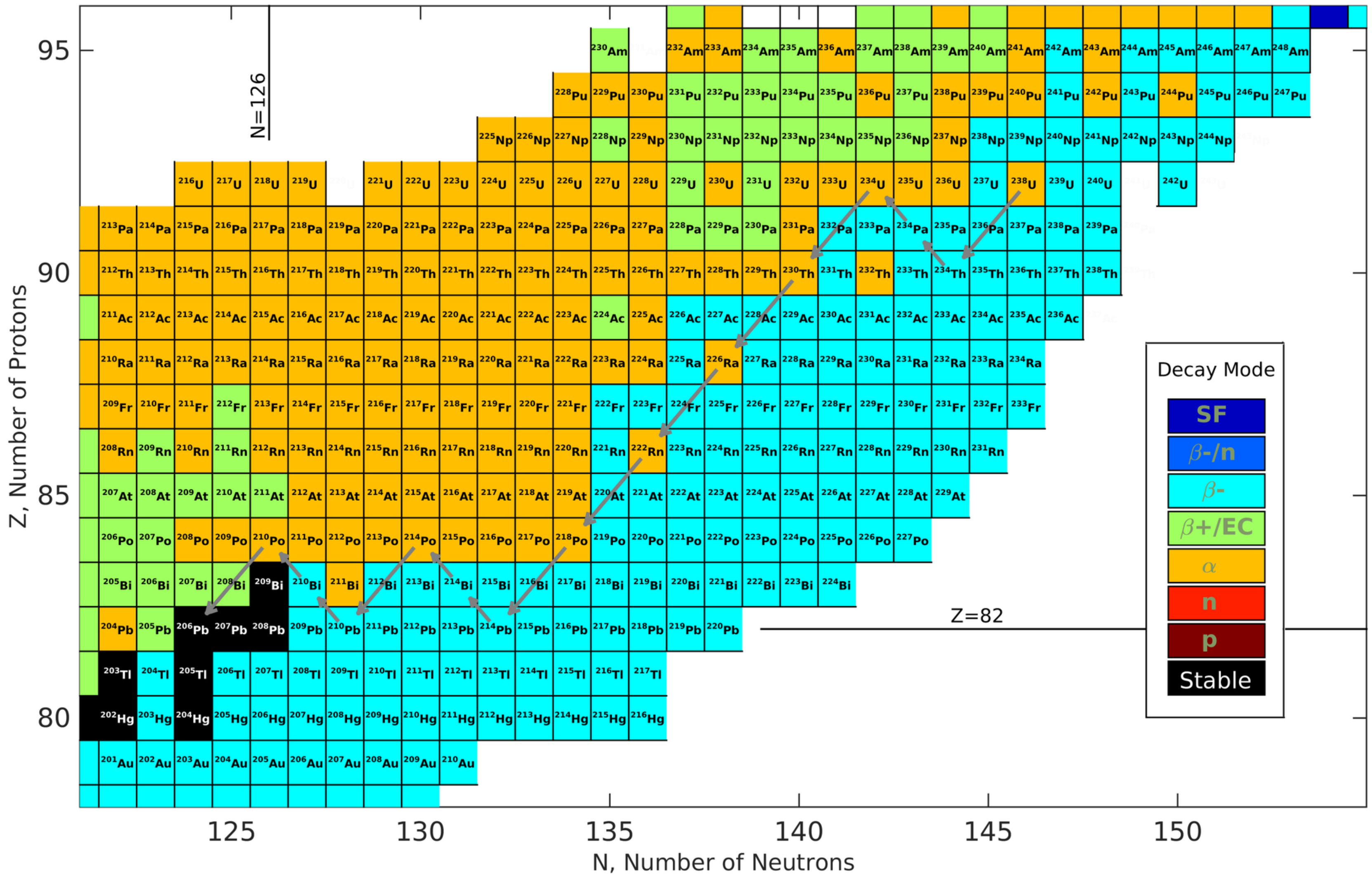


Chart of nuclides by type of decay mode. Black squares are stable nuclides. Nuclides with excessive neutrons or protons are unstable to β− (light blue) or β+ (green) decay, respectively. **At high atomic number, alpha emission (orange) or spontaneous fission (dark blue) become common decay modes.**

Stable and Unstable Isotopes



Example: The uranium-238 series (grey line) is a series of α (N and Z less 2) and β− decays (N less 1, Z plus 1) to nuclides that are successively deeper into the valley of stability. The series terminates at lead-206, a stable nuclide at the bottom of the valley of stability.