Radiation and Radiological effects from natural, cosmic and human made backgrounds including nuclear weapons

Gamma and Neutron Radiation for Low Altitude Airburst

Radiation Effects in Humans vs Yield and Slant Range from Detonation

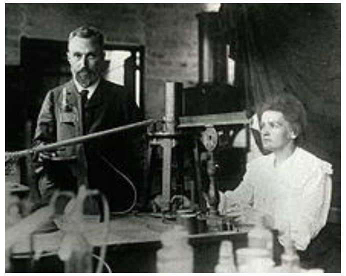
Some from Glasstone and Dolan (Effects of Nuclear Weapons 1977, 2022 – Chap 8)

https://atomicarchive.com/resources/documents/effects/glasstone-dolan/chapter8.html

Radiation Units

- Curies (Cu) = radiation decay rate from 1g $^{226}Ra_{88}$ (Radium)
  - 1Ci = 37 billion decays/s (1 g Ra at Beginning of Life (BOL))
  - Marie Curie – first woman to receive Nobel prize (Physics 1903)
  - First woman to be a professor Univ Paris (1906)
  - Second Nobel Prize (Chemistry 1911)
  - $^{226}Ra_{88} \rightarrow {}^{222}Rn_{86}$ (α)
  - $^{226}Ra_{88}$ (α) $\tau_{1/2}$=1599y → $^{222}Rn_{86}$ (α) $\tau_{1/2}$=3.82 d → $^{218}Po_{84}$
  - Radon is a gas – one of the leading causes of lung cancer
  - Important to have a well ventilated room (esp basement)
- Roentgen (historical unit – X Ray ionization in air)
  - Defined now as 1R = 2.58x10^{-4} Coulomb/kg
- Becquerel (Bq) = 1 decay/s 1 Ci= 37GBq, 1nCi=37Bq (37 decays/s)
- RAD-rad (Radiation Absorbed Dose) = 100 erg/g = 0.01 J/kg
  - (1 erg=10^{-7}J)
- REM-rem (Roentgen Equivalent Man – bio damage)
  - →Typ 50% lethality (50% chance of death) is ~ 500 REM = 5Sv ←
  - 0.055% increase in cancer per REM (5.5%/Sv)
  - Recommended limit is 100 mrem/yr (1 mSv/yr) not including medical x-ray
  - Typ natural background is ~ 300 mrem = 3mSv
  - Recommended limit for nuclear workers is 5rem/yr (50mSv/yr)
  - Ex: Inside US Capitol building ~ 85 mrem/yr (0.85 mSv/yr) due to radiation from Granite
- **Relationship between RAD and REM depends on radiation particle**
  - REM = RAD * QF where QF = quality factor QF ~ 1 beta, x-ray/ gamma, QF ~ 10-20 alpha, QF ~ 1-10 neutrons
- 1 Gray (Gy) = 100 RAD (1 RAD = 0.01 Gy)
- 1 Sievert (Sv) = 100 REM (1 REM = 0.01 Sv=10mSv)
- BED – Banana Equivalent Dose (150 gram banana)
  - Radioactivity Primarily From radioactive Potassium- ^{40}K
  - 0.0117% of natural K is isotope ^{40}K ($\tau_{1/2}$=1.25 Gyr, 31 Bq/g(of total K))
  - Banana has ~ 0.5g of total K → ~ 15 Bq from ^{40}K (**you are radiaoactive**)
  - **0.1μSv, 10 μREM, ~0.4 nCi**
- Human body regulates ^{40}K so you **do not** accumulate it
  - Typ human has 2.5 g/kg of total K or about 175g in 70 kg person (**this is Potassium from all sources you eat**)
  - **Radiation from ^{40}K in person (70 kg) = 175g *31 Bq/g(of total K) ~ 5400 Bq (decay/s) ~150 nCi ~ 400 bananas**
  - Committed effective Dose = net radiological effect from 50 years of exposure
  - US EPA calculates for ^{40}K in our bodies about 5.02 nSv/Bq over 50 years → 5.02 nSv/Bq * 31Bq/g(total K)*0.5 g~ 78 nSv ~ 0.1μSv
    - The above assumes you come to metabolic equilibrium with bananas

1903 Nobel Prize - "in recognition services they of the extraordinary have rendered by their joint researches on the radiation phenomena discovered by Professor Henri Becquerel."



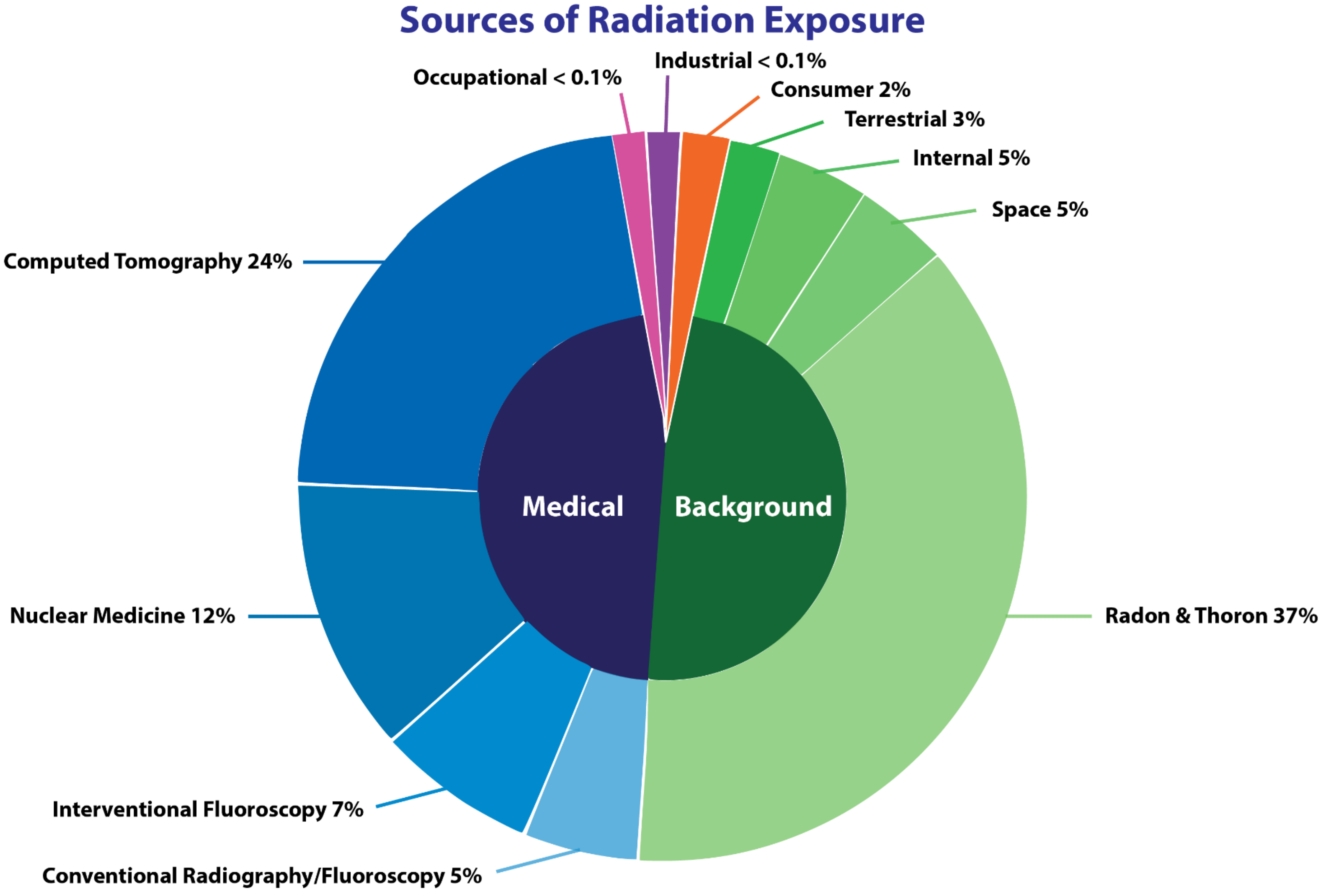
Marie and Pierre Curie - 1904

1911 Nobel Prize - "in recognition of her services to the advancement of chemistry by the **discovery of the elements radium and polonium**, by the isolation of radium and the study of the nature and compounds of this remarkable element."

Ionizing radiation related quantities

Quantity	Unit	Symbol	Derivation	Year	SI equivalent
Activity (*A*)	becquerel	Bq	s^{-1}	1974	SI unit
	curie	Ci	$3.7 \times 10^{10}\ s^{-1}$	1953	3.7×10^{10} Bq
	rutherford	Rd	$10^{6}\ s^{-1}$	1946	1000000 Bq
Exposure (*X*)	coulomb per kilogram	C/kg	$C \cdot kg^{-1}$ of air	1974	SI unit
	röntgen	R	esu / 0.001293 g of air	1928	2.58×10^{-4} C/kg
Absorbed dose (*D*)	Gray **= 100 RAD**	Gy	$J \cdot kg^{-1}$	1974	SI unit
	erg per gram	erg/g	$erg \cdot g^{-1}$	1950	1.0×10^{-4} Gy
	rad	rad	$100\ erg \cdot g^{-1}$	1953	0.010 Gy
Equivalent dose (*H*)	Sievert = **100 REM**	Sv	$J \cdot kg^{-1} \times W_R$	1977	SI unit
	röntgen equivalent man	rem	$100\ erg \cdot g^{-1} \times W_R$	1971	0.010 Sv
Effective dose (*E*)	sievert	Sv	$J \cdot kg^{-1} \times W_R \times W_T$	1977	SI unit
	röntgen equivalent man	rem	$100\ erg \cdot g^{-1} \times W_R \times W_T$	1971	0.010 Sv

Sources of Radiation in your Life

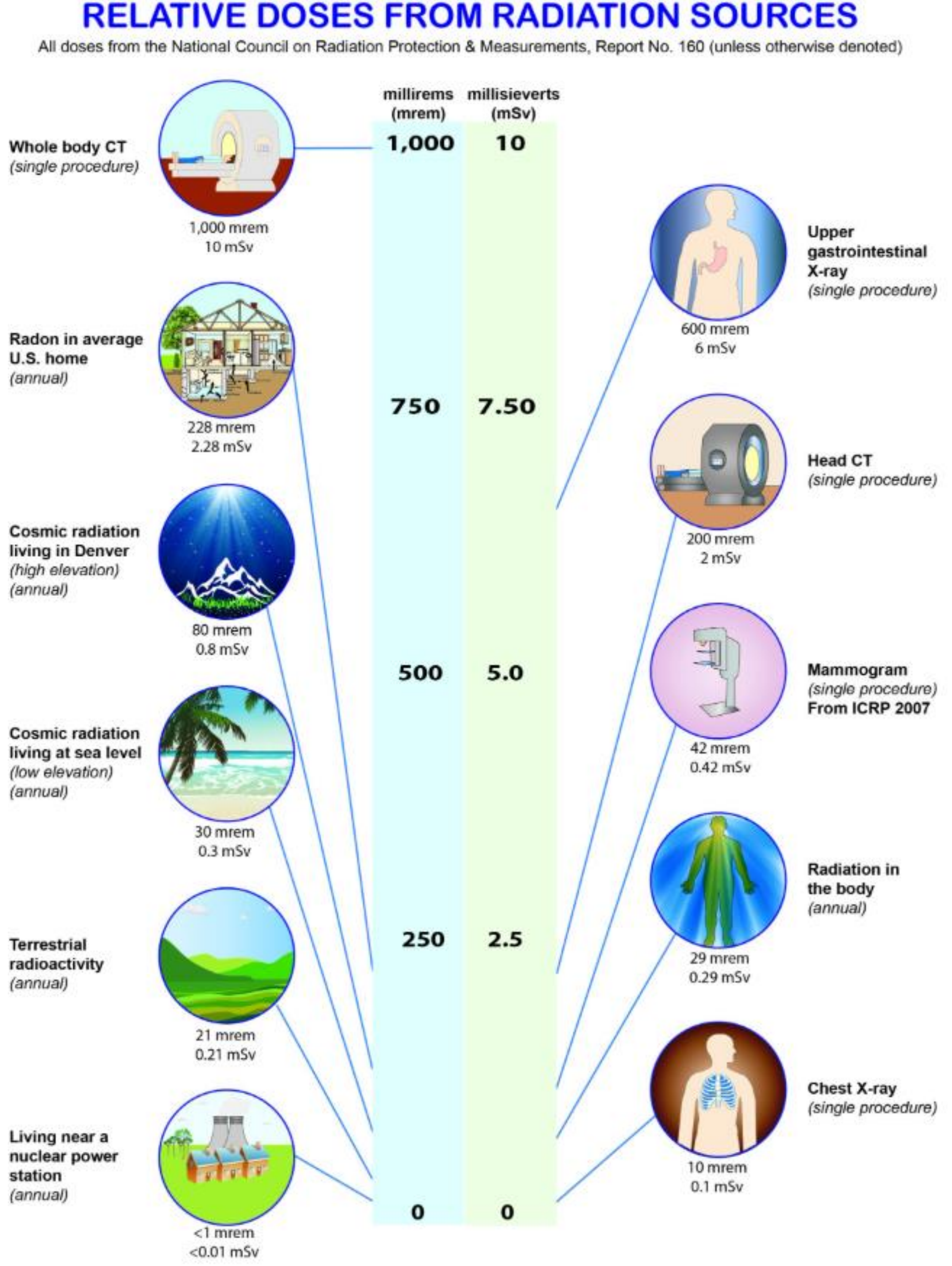


Average Annual Radiation Dose

Sources	Radon & Thoron	Computed Tomography	Nuclear Medicine	Interventional Fluoroscopy	Space	Conventional Radiography/ Fluoroscopy	Internal	Terrestrial	Consumer	Occupational	Industrial
Units mrem (United States) mSv (International)	228 mrem 2.28 mSv	147 mrem 1.47 mSv	77 mrem 0.77 mSv	43 mrem 0.43 mSv	33 mrem 0.33 mSv	33 mrem 0.33mSv	29 mrem 0.29 mSv	21 mrem 0.21 mSv	13 mrem 0.13 mSv	0.5 mrem 0.005 mSv	0.3 mrem 0.003 mSv

(Source: National Council on Radiation Protection & Measurements, Report No. 160)

Relative Doses from Radiation Sources in your Life



Sources:

National Council on Radiation Protection & Measurements (NCRP), Report No. 160

International Commission on Radiological Protection, Publication 103

Natural Uranium variation in drinking water vs Country

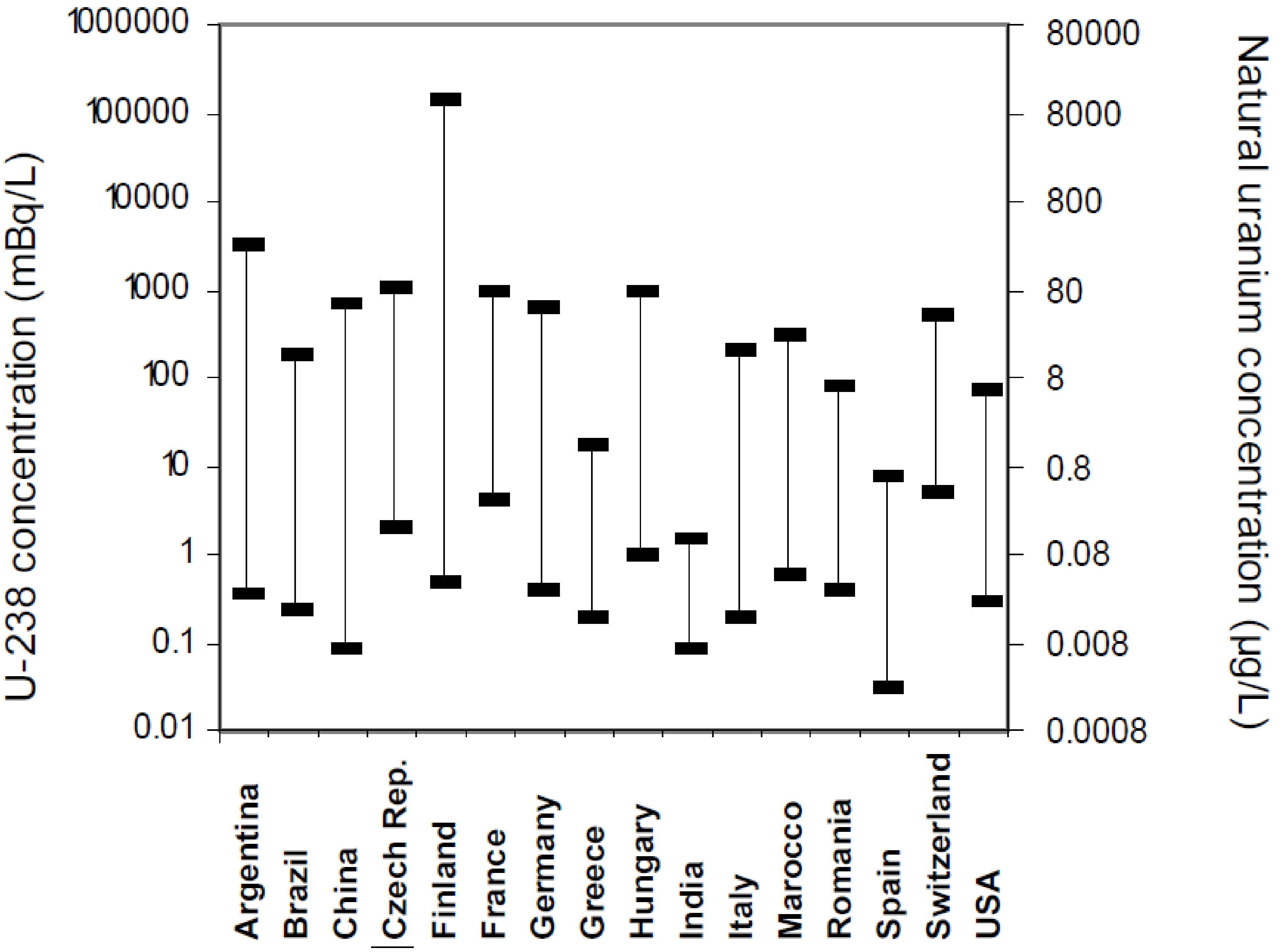


Figure 1. Variability of natural uranium concentrations observed in drinking water

Summary of worldwide annual doses (mSv)

Note Inhalation of Radon is significant Contributor to lung cancer

Source	Average dose (mSv)	Dose range (mSv)	Comment
Natural sources of exposure			
Inhalation (radon)	1.26	0.2 - 10	The dose is much higher in some dwellings.
External terrestrial	0.48	0.3 - 1	The dose is higher in some locations.
Ingestion	0.29	0.2 - 1	
Cosmic radiation	0.39	0.3 - 1	The dose increases with altitude.
Total natural	**2.4**	**0.3 - 1**	**Sizeable population groups receive 10-20 mSv.**
Artificial sources of exposure			
Medical diagnosis (not therapy)	0.6	0 - several tens	The averages for different levels of health care range from 0.03 to 2.0 mSv; averages for some countries are higher than that due to natural sources; individual doses depend on specific examinations
Atmospheric nuclear testing	0.005		Some higher doses around test sites still occur. The average has fallen from a peak of 0.11 mSv in 1963.
Occupational exposure	0.005	~0 - 20	The average dose to all workers is 0.7 mSv. Most of the average dose and most high exposures are due to radon in mines.
Chernobyl accident	0.002		In 1986: ~150 mSv to more than 300,000 recovery workers and > 10 mSv to more than 350,000 other individuals The average in the northern hemisphere has decreased from a maximum of 0.04 mSv in 1986. Thyroid doses were much higher.
Nuclear fuel cycle (public exposure)	0.0002		Doses are up to 0.02 mSv for critical groups at 1 km from some nuclear reactor sites.
Total artificial	**0.6**	**~0 - several tens**	**Individual doses depend primarily on medical treatment, occupational exposure and proximity to test or accident sites**

Radon ($_{86}$Rn) and Radium ($_{88}$Ra)

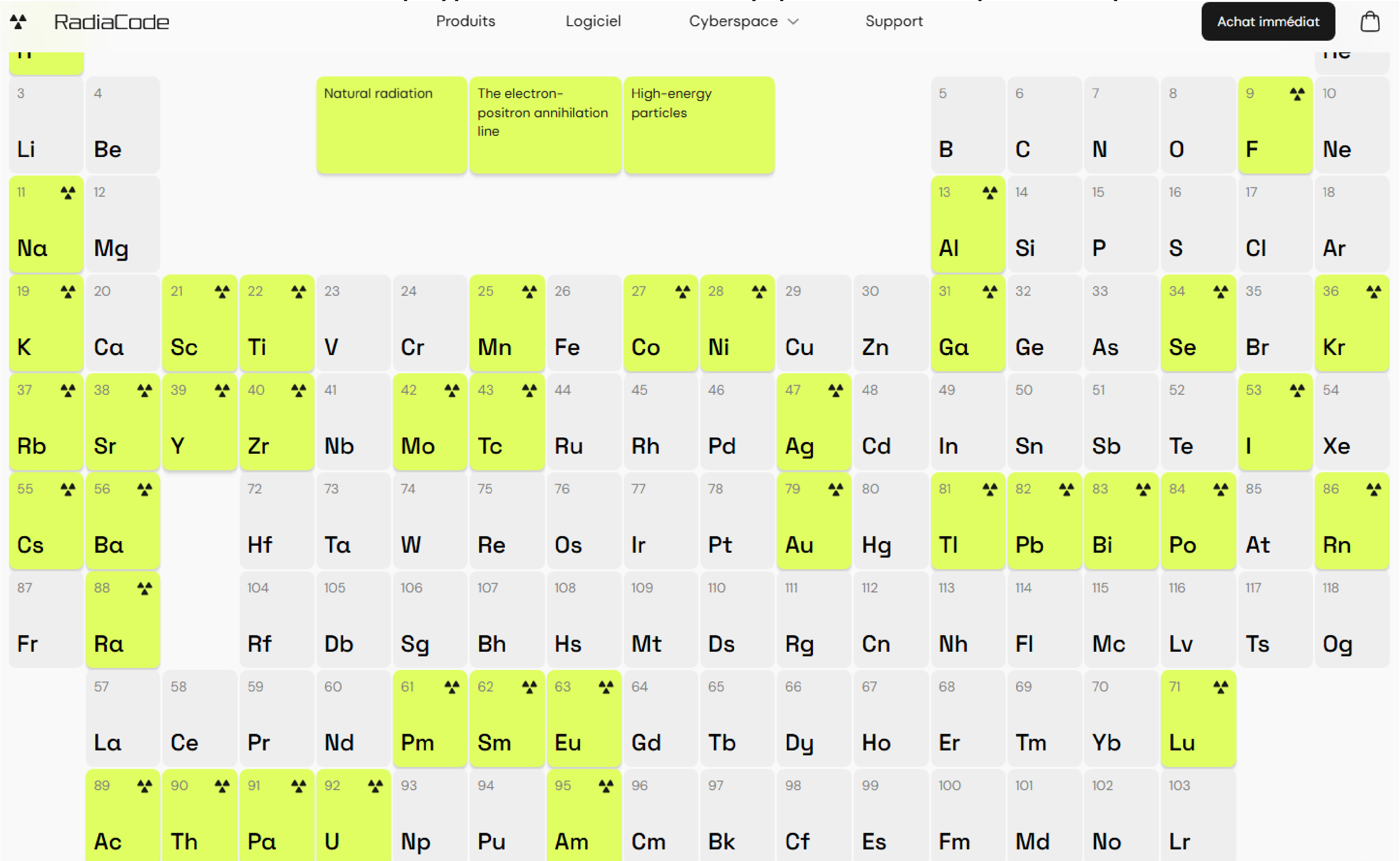
- Radon inhalation is a significant source of radiation exposure
  - Radon is a significant contributor to lung cancer
- ALL isotopes of Radium known are radioactive
- Most stable isotope ($t_{1/2}$ ~ 1600 yrs) of Radium is **$_{88}^{226}$Ra**
- **Primary Radon isotope of concern is $_{86}^{222}$Rn from alpha decay of $_{88}^{226}$Ra**
  - **$_{86}^{222}$Rn** ($t_{1/2}$ ~ 3.8215 d)

Main isotopes[3]			Decay	
Isotope	abun-dance	half-life ($t_{1/2}$)	mode	product
^{223}Ra	trace	11.435 d	α	^{219}Rn
^{224}Ra	trace	3.632 d	α	^{220}Rn
^{225}Ra	trace	14.8 d	$β^-$	^{225}Ac
			α[4]	^{221}Rn
^{226}Ra	trace	1600 y	α	^{222}Rn
^{228}Ra	trace	5.75 y	$β^-$	^{228}Ac

Main isotopes[4]			Decay	
Isotope	abundance	half-life ($t_{1/2}$)	mode	product
^{210}Rn	synth	2.4 h	A 96%	^{206}Po
			$β^+$ 4%	^{210}At
^{211}Rn	synth	14.6 h	$β^+$ 72.6%	^{211}At
			α 27.4%	^{207}Po
^{220}Rn	trace	55.6 s	α	^{216}Po
^{222}Rn	trace	3.8215 d	α	^{218}Po

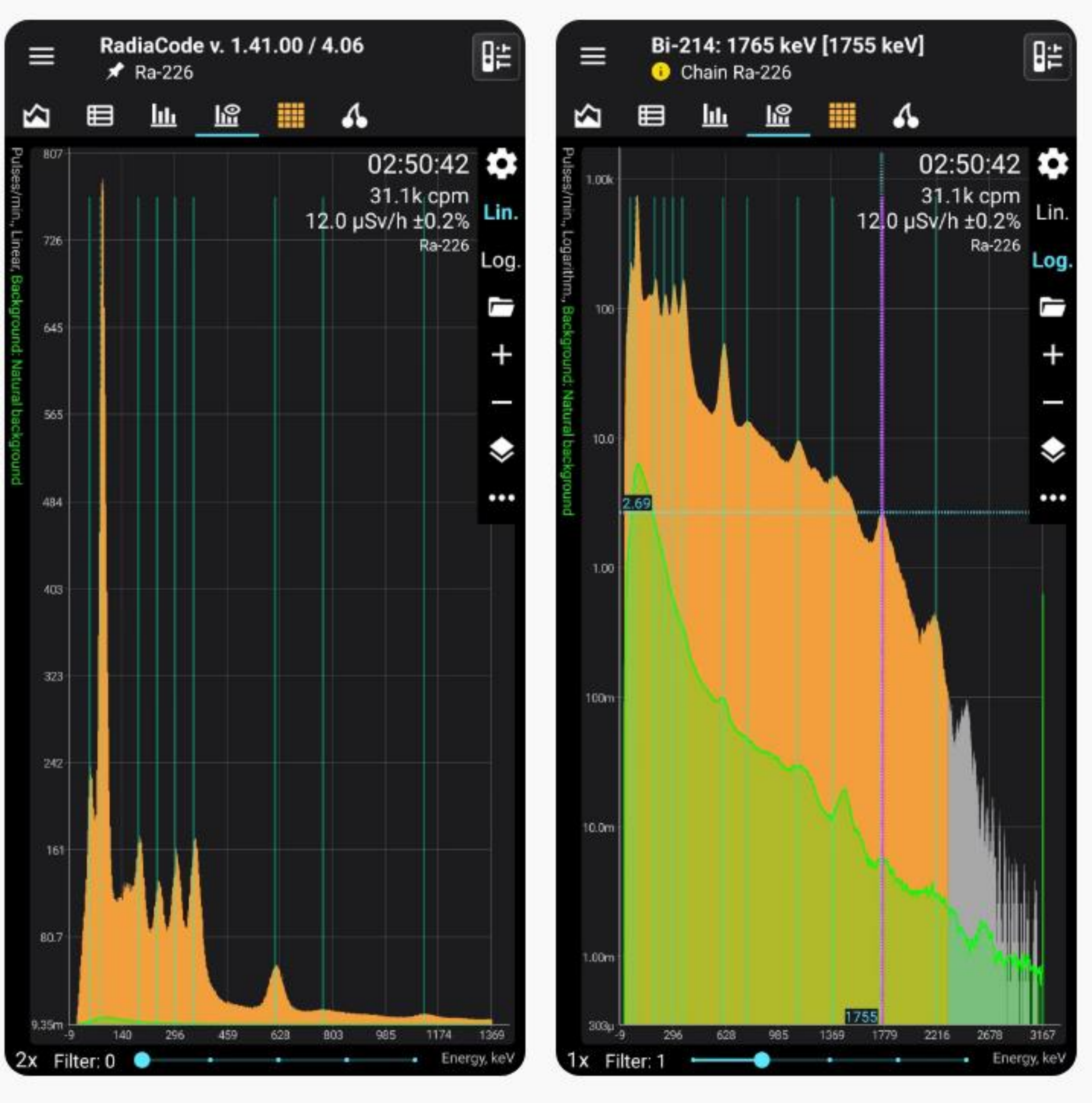
Element and Isotope Library on Radiacode

https://www.radiacode.com/spectrum-isotopes-library



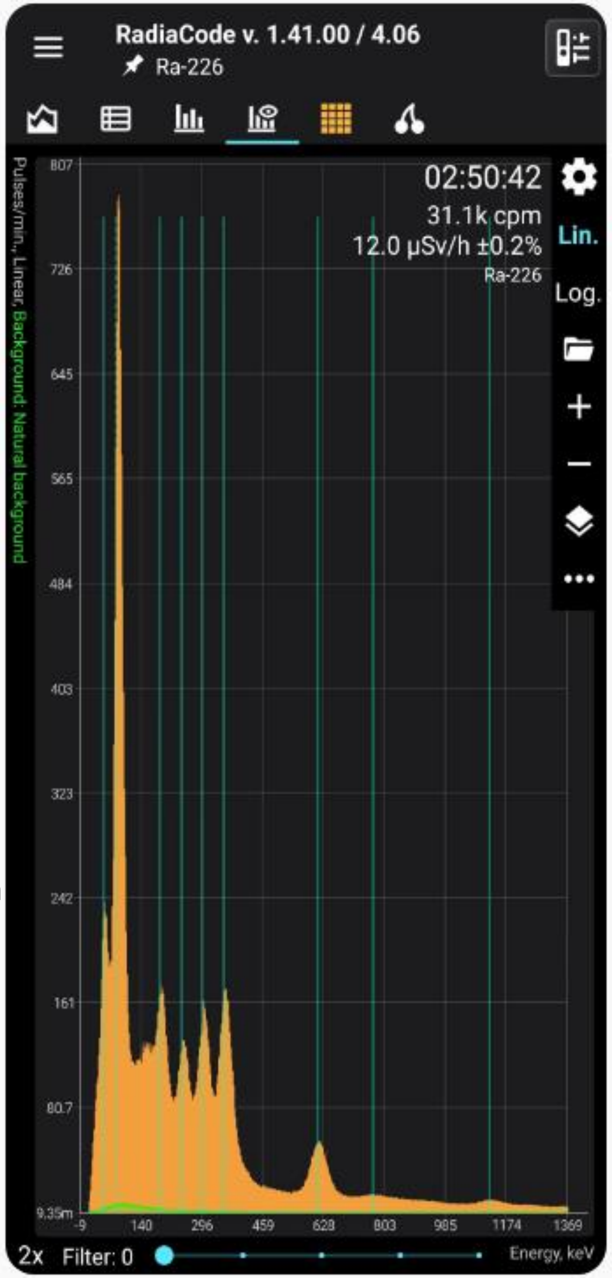
Radium Decay Example

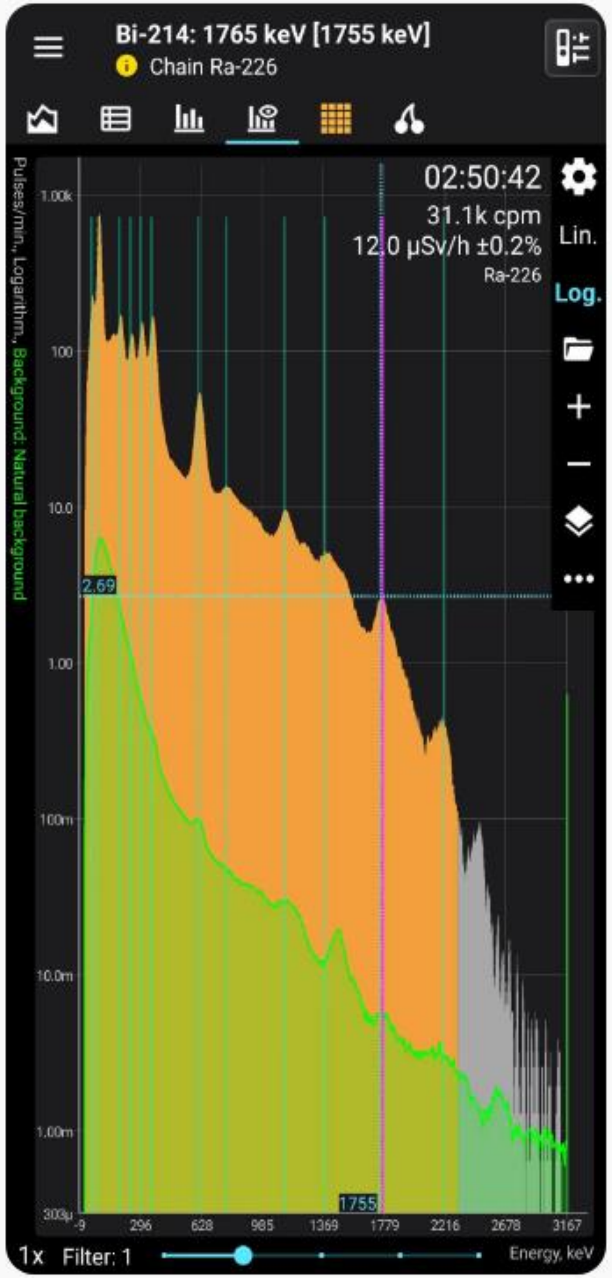
- Ra-226, Radium-226, Natural
- α, β, γ radiation
- **Half-life: 1600 years**
- Lines: 46, 78, 186, 242, 295, 351, 609, 1120, 1760, 2200 KeV
- Radium-226 (Ra-226) is a naturally occurring radioactive isotope of radium, part of the uranium-238 decay series. It has a half-life of approximately 1,600 years and decays by emitting alpha particles, eventually forming radon-222, a radioactive gas. Ra-226 also emits gamma radiation, making it detectable by gamma spectrometry. Due to its radioactivity, Ra-226 is both a radiological hazard and a valuable tool in specific applications.
- Ra-226 was historically used in luminescent paints for watch dials, instrument panels, and other devices, though this practice was discontinued due to health risks. Today, Ra-226 is employed in medicine for cancer treatment, particularly in brachytherapy, where its strong radiation is used to target tumors. Additionally, it is used in calibration sources for radiation detection instruments and in some research applications.
- Ra-226 is found in trace amounts in uranium ores, such as pitchblende, and contributes to natural background radiation. It may also be present in groundwater and soil in areas with high natural uranium content. Due to its long half-life and radioactive properties, Ra-226 is subject to strict regulation and careful handling to minimize environmental and health risks.



Radon Decay Example

- Rn-222, Radon-222, Natural
- α, β radiation
- **Half-life: 3.8 days**
- Main emission lines: Decay chain: Ra-226
- Lines: 47, 78, 242, 295, 351, 609, 1120, 1760, 2200 KeV
- Decay product of uranium thorium or radium. Always present with gamma-emitting decay products. The spectrum is almost identical to that of Radium-226 or natural uranium.
- Radon-222 (Rn-222) is a radioactive isotope of radon with a half-life of approximately 3.8 days. It is part of the uranium-238 decay series, formed as a decay product of radium-226. Rn-222 undergoes alpha decay to produce polonium-218, emitting alpha particles during the process. While Rn-222 itself does not emit significant gamma radiation, its decay products (such as lead-214 and bismuth-214) emit gamma rays at characteristic energies, making radon and its progeny detectable using gamma spectrometry. These gamma emissions are widely used in monitoring radon levels in the environment.
- Historically, radon was used in radon therapy, where patients inhaled radon gas in controlled environments, though this practice has largely been discontinued due to health risks. Modern applications primarily focus on its role as a tracer in geological and environmental studies, such as tracking air and groundwater movement.
- Rn-222 occurs naturally as part of the uranium-238 decay chain. It is found in soil, rocks, and groundwater in areas with high uranium or radium content. It can accumulate in enclosed spaces like basements and buildings, where it is a significant contributor to natural background radiation. High levels of radon in homes and workplaces are considered a health hazard due to its radioactive decay products, which can attach to dust particles and be inhaled. Monitoring and mitigation measures are often implemented in regions with elevated radon levels to minimize health risks.
- https://www.radiacode.com/isotope/bi-214?lang=en, https://www.chemlin.org/isotope/lead-214

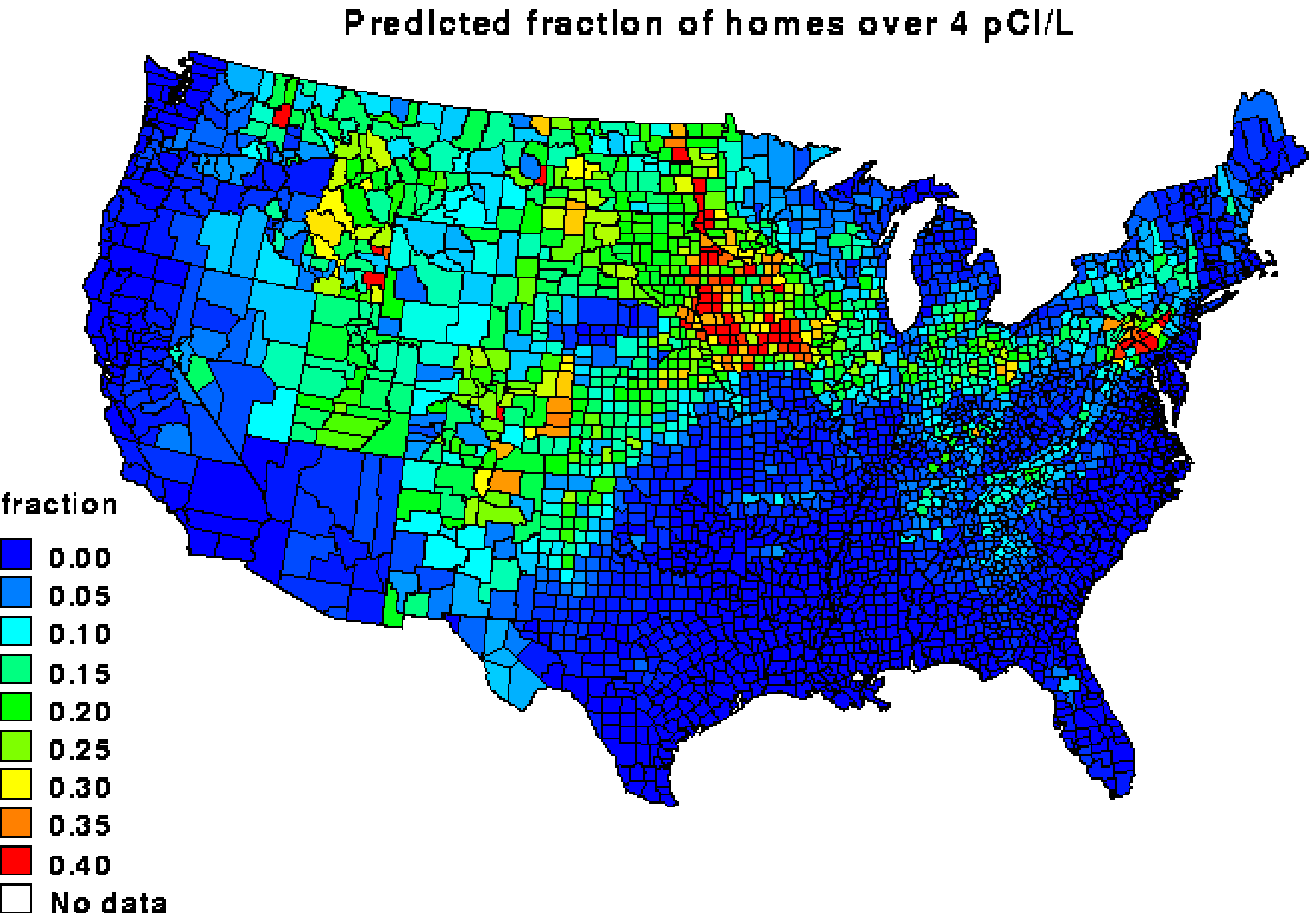


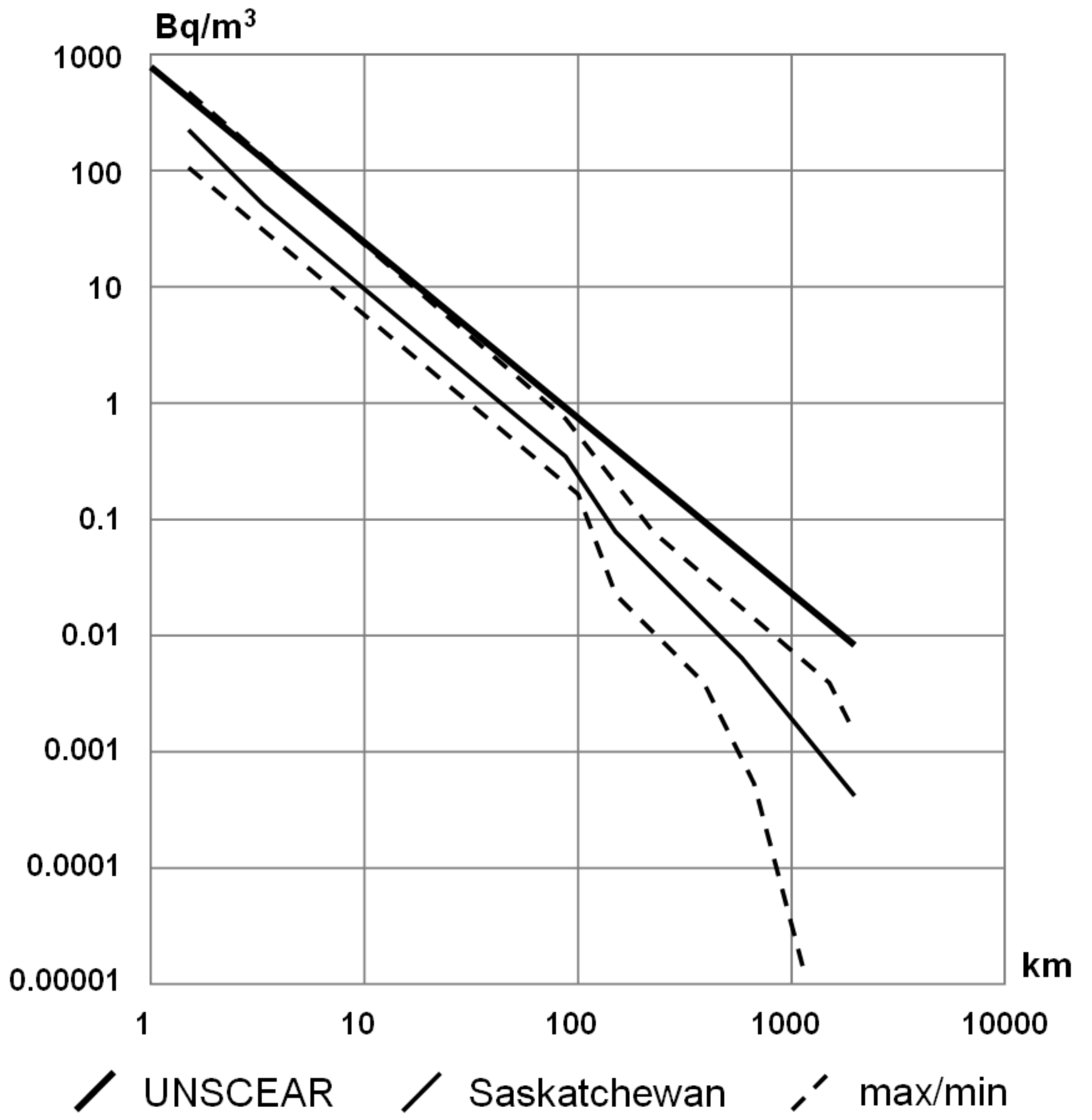


Radon Concentration Implications

Bq/m^3	pCi/L	Occurrence example
1	~0.027	Radon concentration at the shores of large oceans is typically 1 Bq/m^3. Radon trace concentration above oceans or in Antarctica can be lower than 0.1 Bq/m^3, with changes in radon levels being used to track foreign pollutants.
10	0.27	Mean continental concentration in the open air: 10 to 30 Bq/m^3. An EPA survey of 11,000 homes across the USA found an average of 46 Bq/m^3.
100	2.7	Typical indoor domestic exposure. Most countries have adopted a radon concentration of 200–400 Bq/m^3 for indoor air as an Action or Reference Level.
1,000	27	Very high radon concentrations (>1000 Bq/m^3) have been found in houses built on soils with a high uranium content and/or high permeability of the ground. If levels are 20 picocuries radon per liter of air (800 Bq/m^3) or higher, the home owner should consider some type of procedure to decrease indoor radon levels. Allowable concentrations in uranium mines are approximately 1,220 Bq/m^3 (33 pCi/L)
10,000	270	The concentration in the air at the (unventilated) Gastein Healing Gallery averages 43 kBq/m^3 (about 1.2 nCi/L) with maximal value of 160 kBq/m^3 (about 4.3 nCi/L).
100,000	~2700	About 100,000 Bq/m^3 (2.7 nCi/L) was measured in Stanley Watras's basement.
1,000,000	27000	Concentrations reaching 1,000,000 Bq/m^3 can be found in unventilated uranium mines.
$\sim 5.54 \times 10^{19}$	$\sim 1.5 \times 10^{18}$	*Theoretical upper limit:* Radon gas (^{222}Rn) at 100% concentration (1 atmosphere, 0 °C); 1.538×10^5 curies/gram; 5.54×10^{19} Bq/m^3.

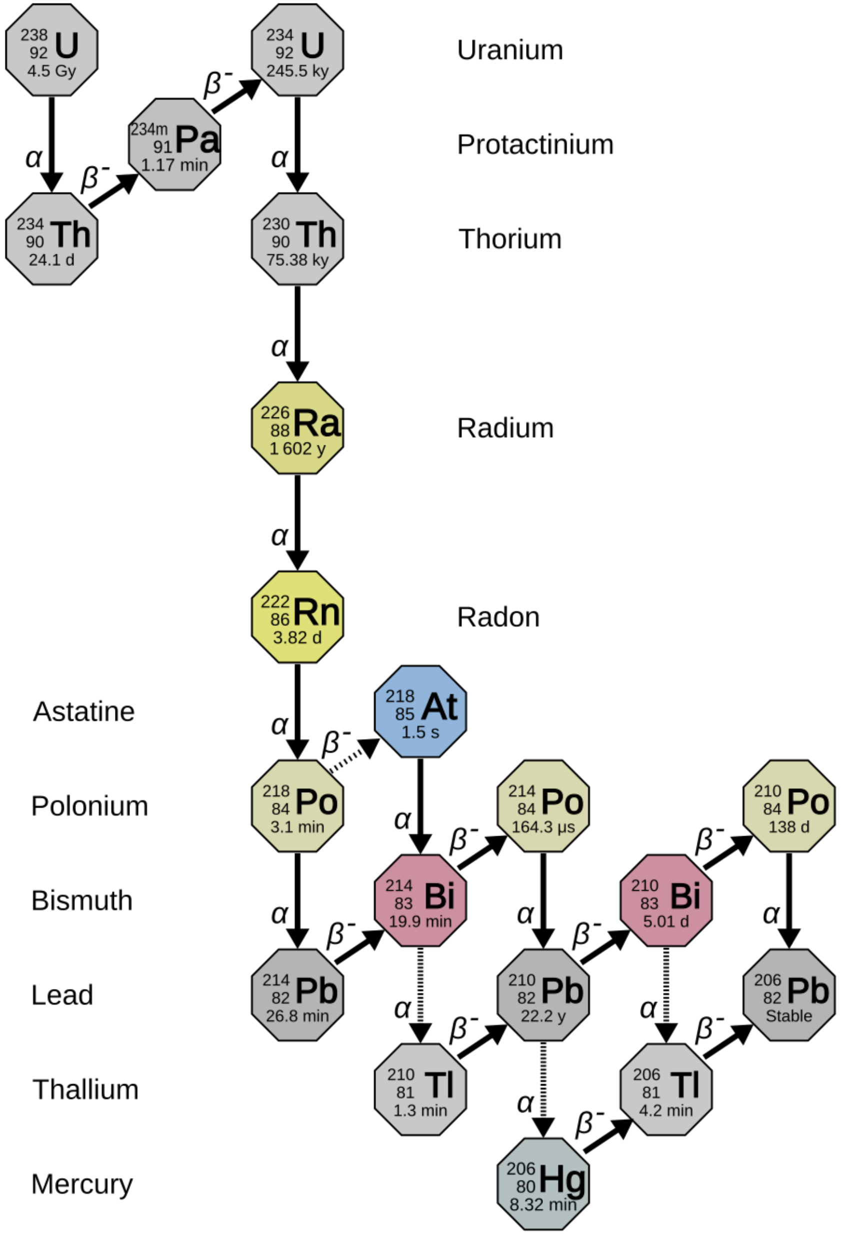
Radon Concentration in US over limit and near to Uranium Mine





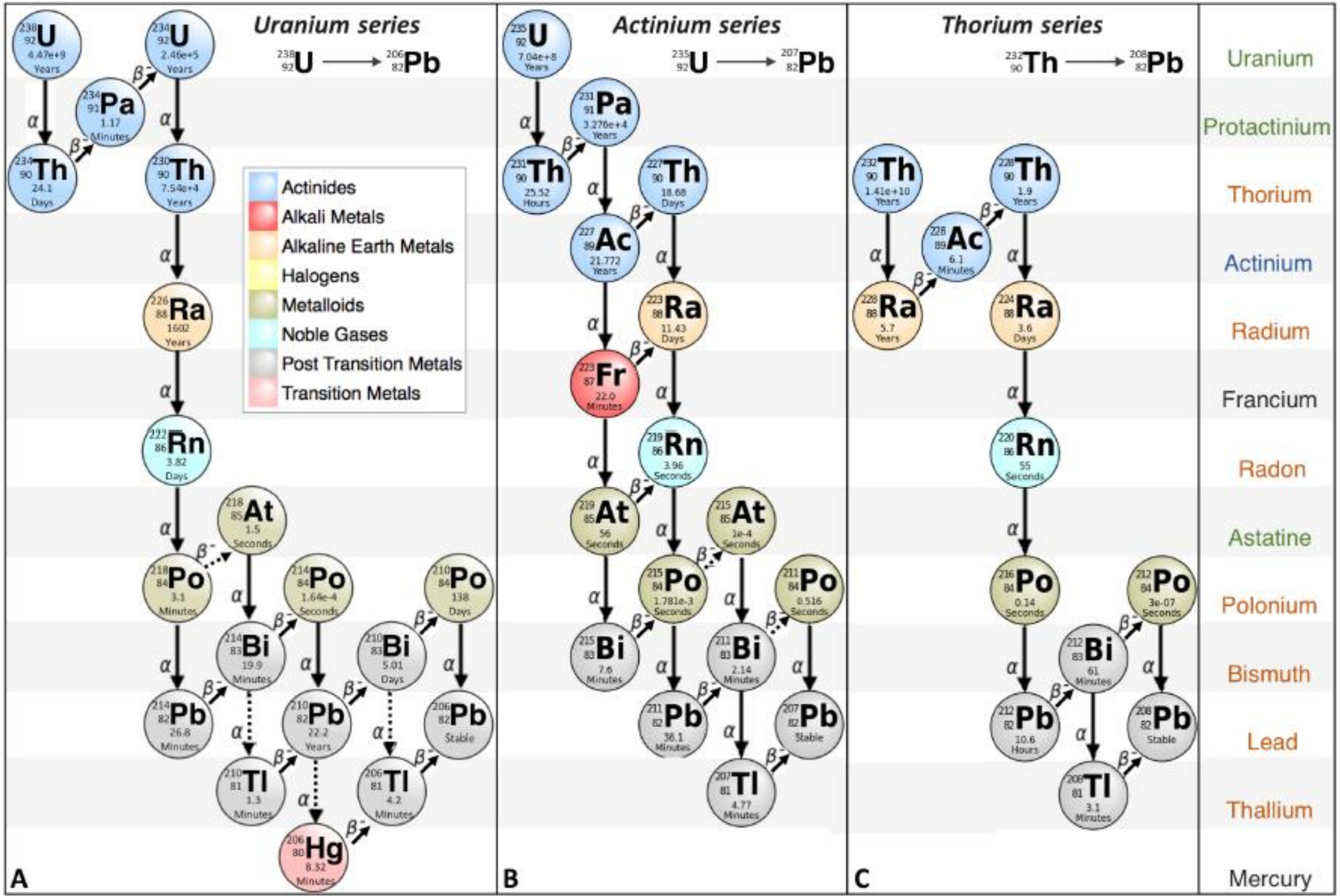
Uranium 238 (99.3% Abundance) Decay Chain

A Common Source of Radium 226



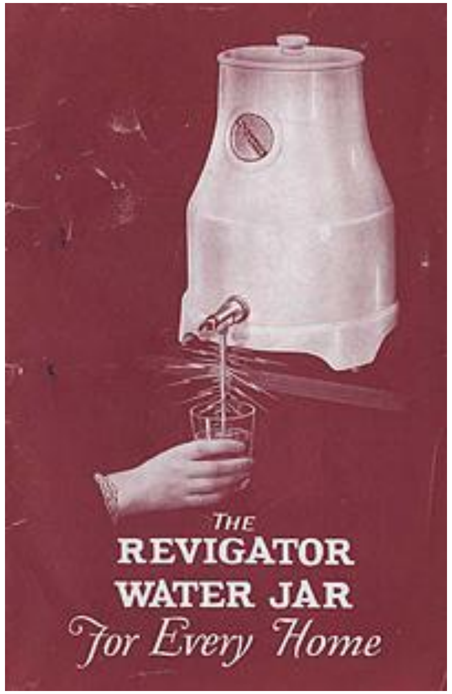
Decay Chain of U 238 ($t_{1/2}$ ~ 4.47 Gyr), 235 (0.70 Gyr) and Thorium 232 (14 Gyr)

Note that Radium and Radon Isotopes are different for each decay chain

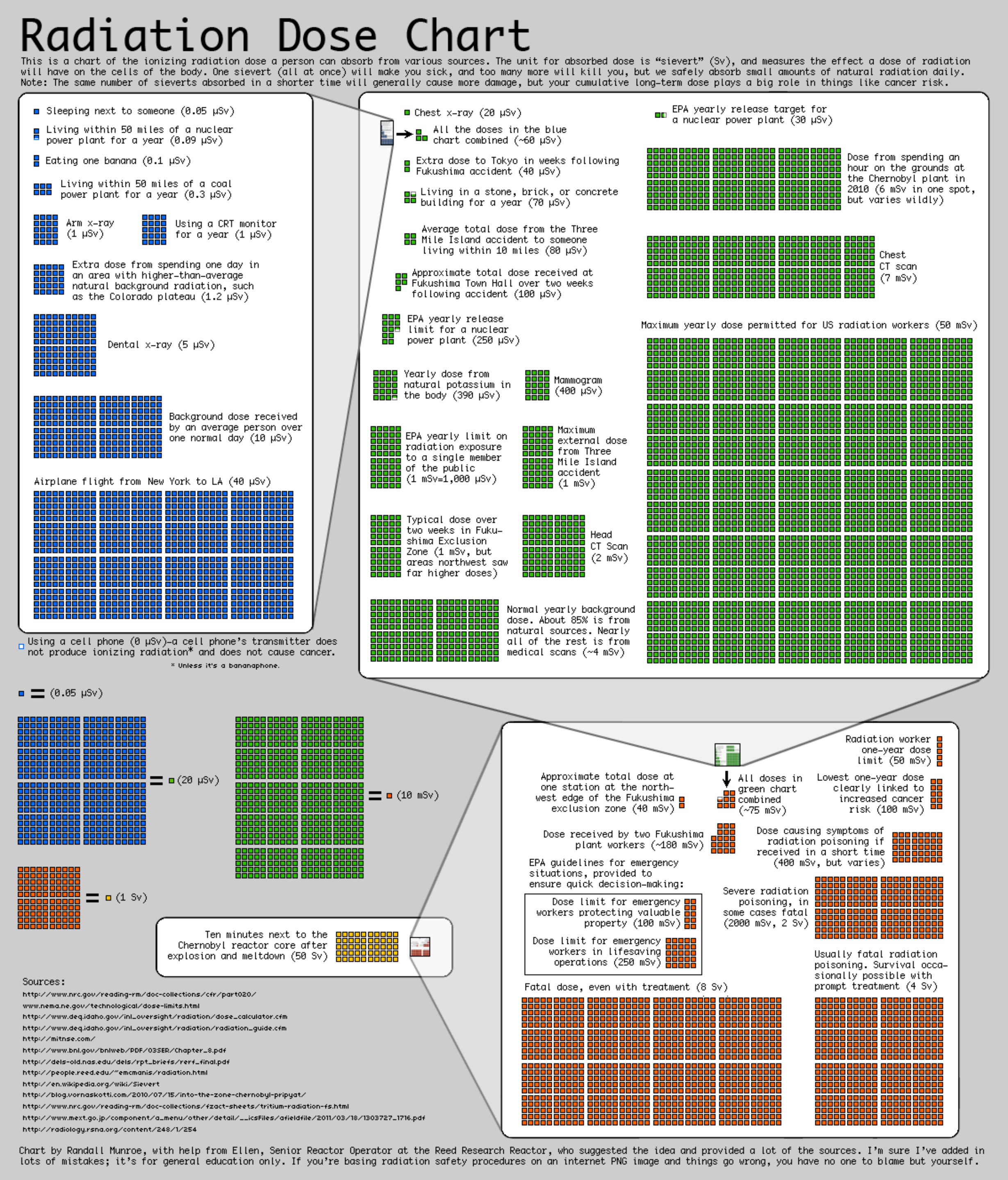


Some people thought Radiation is Good for Health
Revigator

- https://en.wikipedia.org/wiki/Radium_ore_Revigator
- "Fill jar every night. Drink freely … when thirsty and upon arising and retiring, average eight or more glasses daily.“
- marketed as a healthy practice which could “prevent illnesses including arthritis, flatulence, and senility”
- Carnotite $K_2(UO_2)_2(VO_4)_2 \cdot 3H_2O$ (Uranium, Vanadium, Arsenic, Lead)
- Produced Rad
- https://www.nist.gov/news-events/news/2010/01/what-were-they-drinking-researchers-investigate-radioactive-crock-potson infused water to drink
- Epstein, M.S.; et al. (2009). "What Were They Drinking? A Critical Study of the Radium Ore Revigator". *Applied Spectroscopy*. **63** (1406): 1406–1409

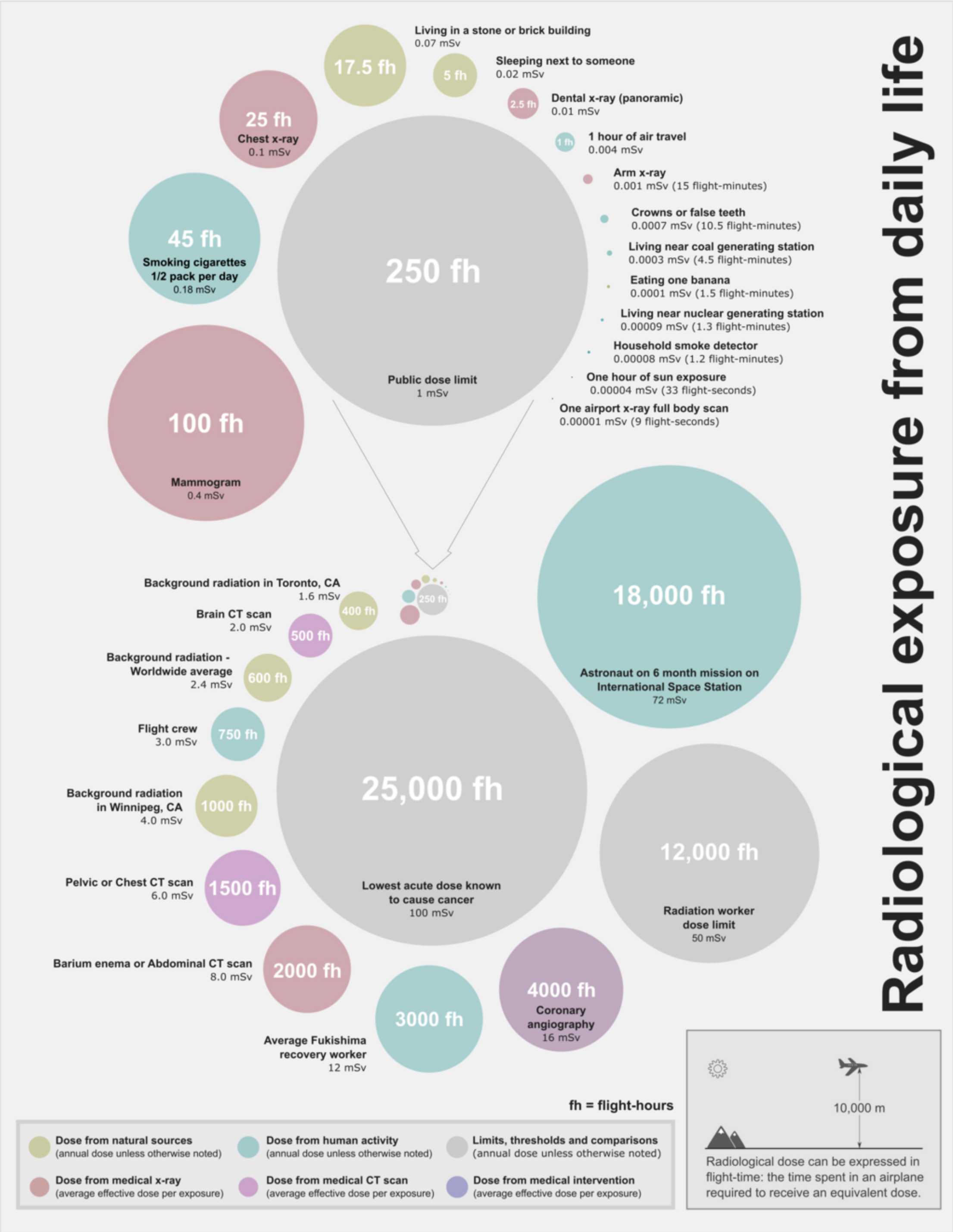


Radiation Doses



Rad Dose relative to Aircraft Flight Hours (fh)

Typical commercial aircraft flies at 10km altitude



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}

REM vs RAD conversion factor (Quality Factor – Q = QF)

https://www.nuclear-power.com/nuclear-engineering/radiation-protection/equivalent-dose/roentgen-equivalent-man-rem-unit/

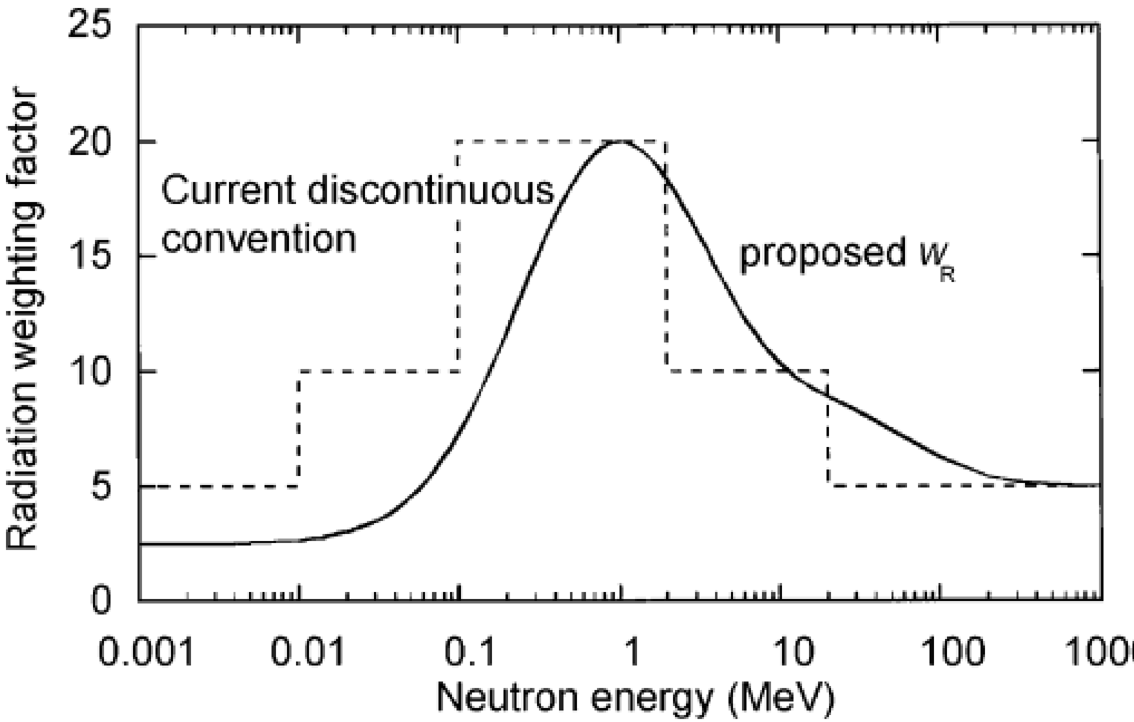
Radiation type and energy range	Radiation weighting factor, w_R
Photons, all energies	1
Electrons and muons, all energies	1
Neutrons, energy <10 keV	5
Neutrons, energy 10–100 keV	10
Neutrons, energy > 100 keV–2 MeV	20
Neutrons, energy > 2–20 MeV	10
Neutrons, energy > 20 MeV	5
Protons, other than recoil protons, energy > 2 MeV	5
Alpha particles, fission fragments, heavy nuclei	20

REM vs RAD conversion factor (Quality Factor – Q = QF) Neutron Energy Fits – Radiation Weighting Factor wR=Q

https://www.nuclear-power.com/nuclear-engineering/radiation-protection/equivalent-dose/roentgen-equivalent-man-rem-unit/

Radiation type and energy range	Radiation weighting factor, wR
Photons, all energies	1
Electrons and muons, all energies	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy nuclei	20
Neutrons	a continuous function of neutron energy (see below)

$$w_R = \begin{cases} 2.5 + 18.2e^{-[\ln(E_n)]^2/6}, & E_n < 1\ \text{MeV} \\ 5.0 + 17.0e^{-[\ln(2E_n)]^2/6}, & 1\ \text{MeV} \leqslant E_n \leqslant 50\ \text{MeV} \\ 2.5 + 3.25e^{-[\ln(0.04E_n)]^2/6}, & E_n > 50\ \text{MeV} \end{cases}$$



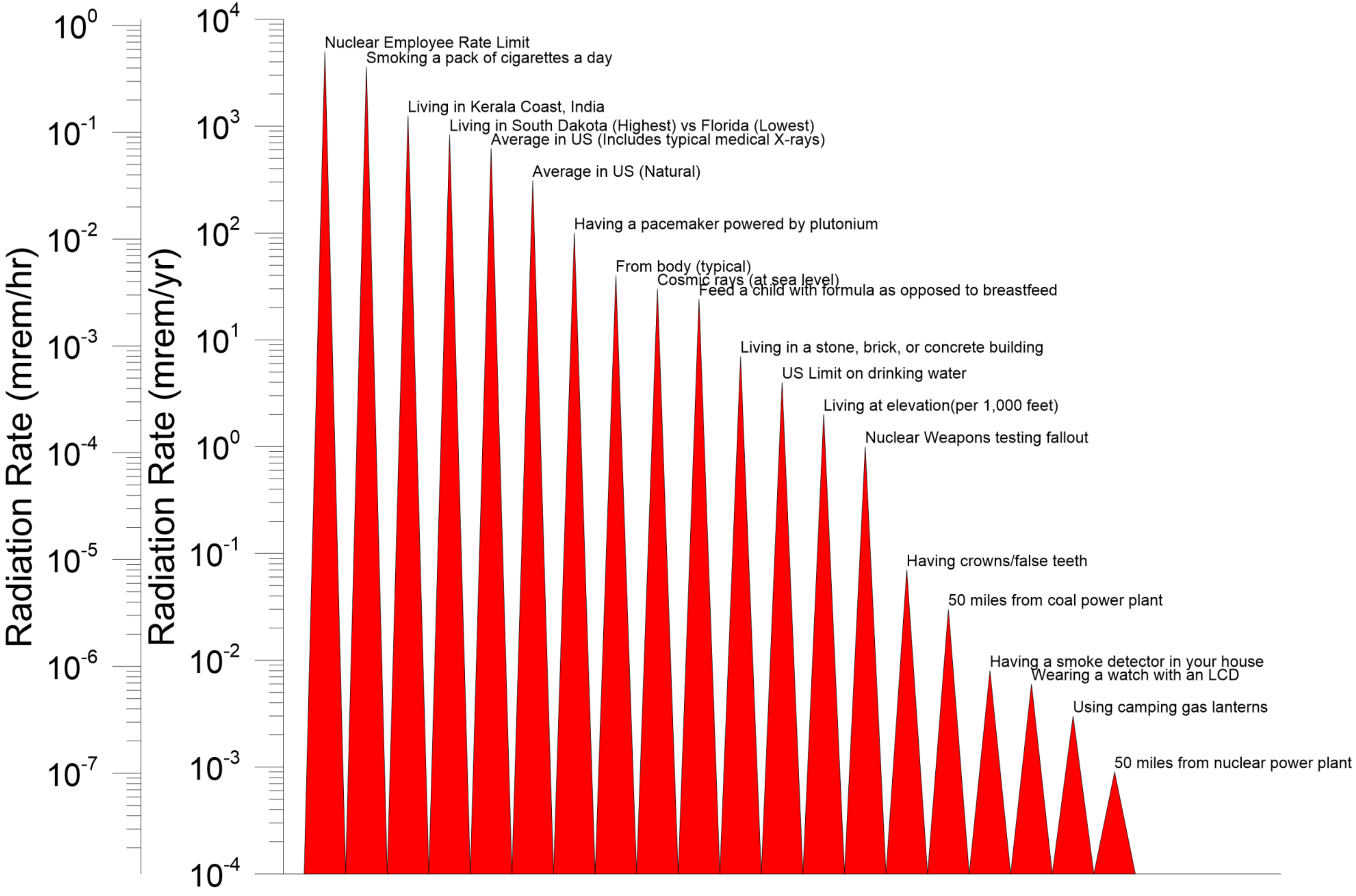
Rad Dose

Acute dose=short time
Chronic dose=long time

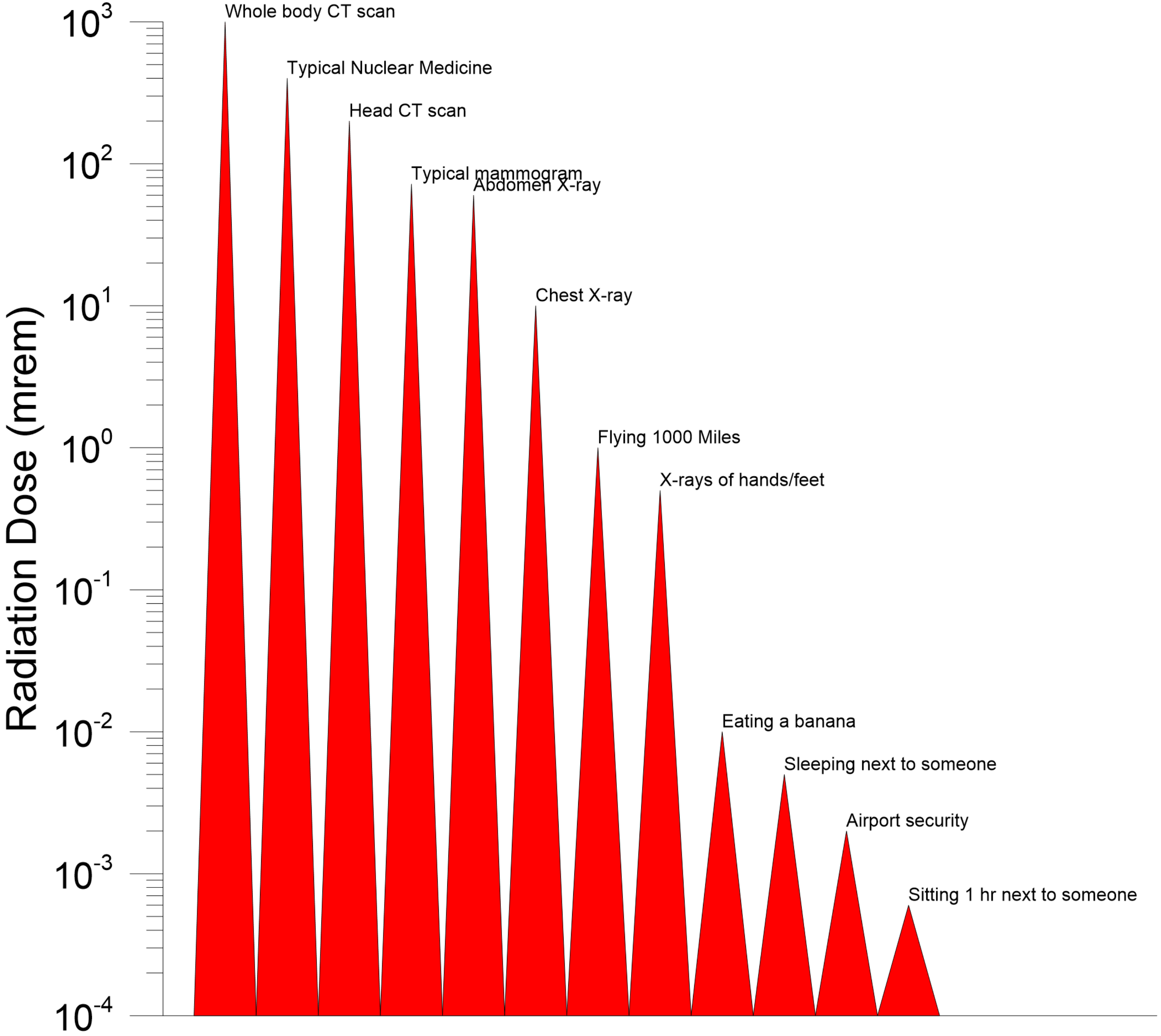
High doses tend to kill cells, while low doses tend to damage or change them. Low doses spread out over long periods don't cause an immediate problem to any body organ. The effects of low radiation doses occur at the cell level, and the results may not be observed for many years.

- **0.005 mrem** – Sleeping next to someone (per night)
- **0.009 mrem** – Living within 30 miles of a nuclear power plant for a year
- **0.01 mrem** – Eating one banana
- **0.03 mrem** – Living within 50 miles of a coal power plant for a year
- **1 mrem** – Average daily dose received from natural background
- **2 mrem** – Chest X-ray
- **4 mrem** – A 5-hour airplane flight
- **60 mrem** – mammogram
- **100 mrem** – Dose limit for individual members of the public, total effective dose per annum
- **365 mrem** – Average yearly dose received from natural background
- **580 mrem** – Chest CT scan
- **1 000 mrem** – Average yearly dose received from a natural background in Ramsar, Iran
- **2 000 mrem** – single full-body CT scan
- **17 500 mrem** – annual dose from natural radiation on a monazite beach near Guarapari, Brazil.
- **500 000 mrem** – Dose that kills a human with a 50% risk within 30 days (LD50/30) if the dose is received over a **very short duration**.

Radiation Background Rate



Radiation Background Dose



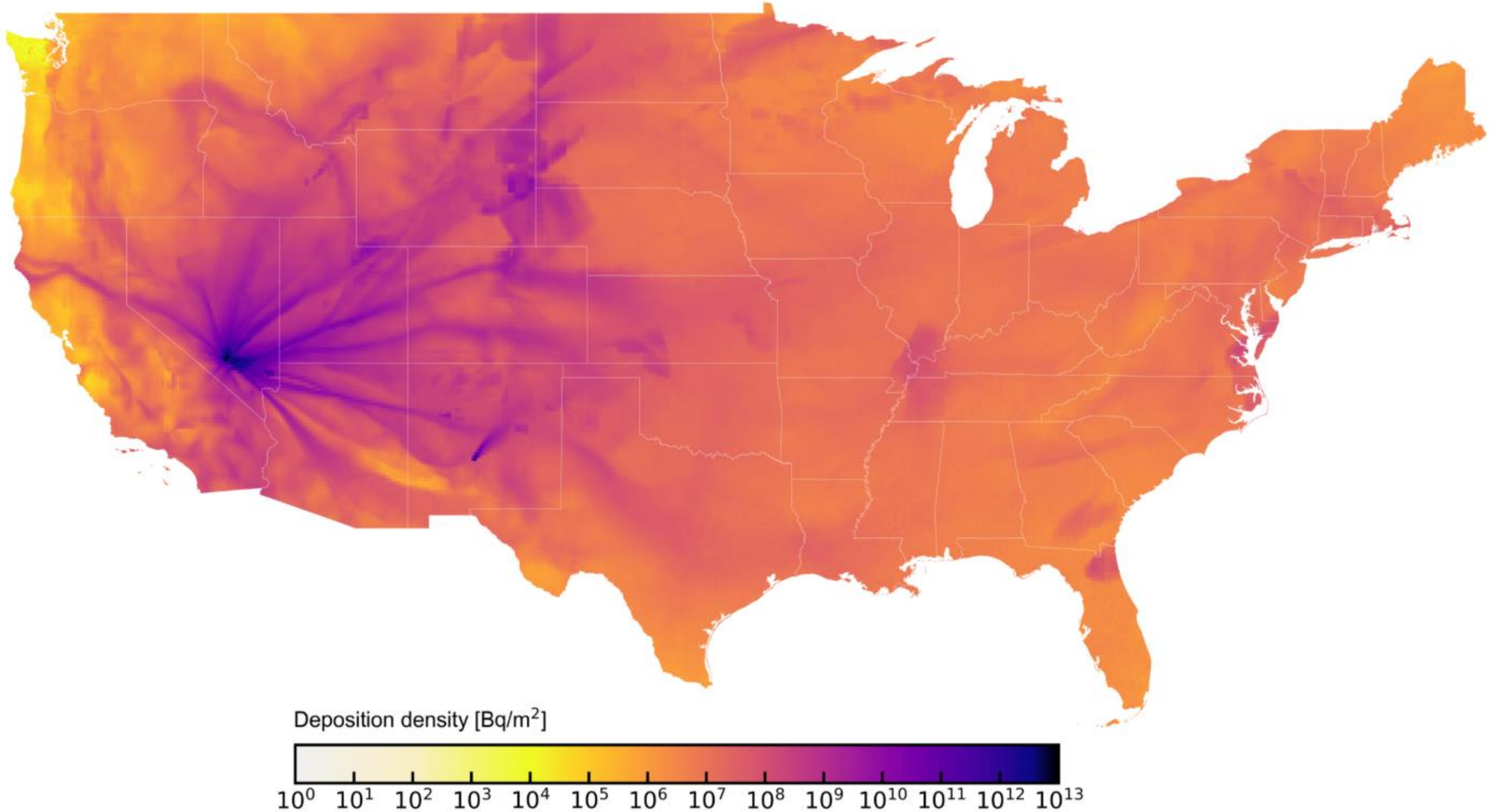
Nuclear Weapons Radiological Effects

For additional Materials See My Nuclear Weapons Class

https://www.deepspace.ucsb.edu/classes/physics-150-nuclear-weapons-physics-and-policy-fall-2025

First Nuclear Detonation – Trinity 6 kg Pu 239 – July 16, 1945 – Alamogordo NM

Map shows Fallout across continental US from Trinity + 93 Nevada Atmospheric Tests (Bq/m²)



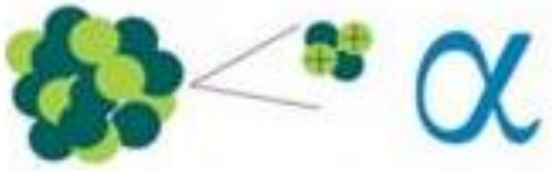
A map depicting composite deposition of radioactive material across the contiguous U.S. from the Trinity test in New Mexico and from 93 atmospheric tests in Nevada.

World wide nuclear fallout from above ground testing

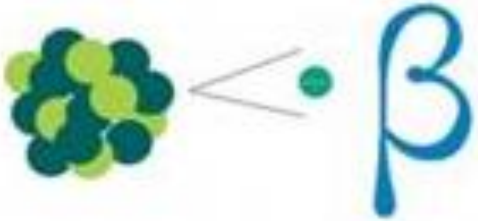
- **Early Spikes (1940s-1960s):** The most dramatic increases in atmospheric radioactivity occurred during the peak of nuclear testing, with significant peaks in the early 1960s from large-yield atmospheric tests.
- **Decay**: Radioactive isotopes decay at different rates (half-lives).
  - **Short-lived:** Iodine-131 (8-day half-life) decays quickly.
  - **Long-lived:** Cesium-137 (30-year half-life) and Strontium-90 remain in the environment and are tracked today.
- **Global Distribution**: Northern Hemisphere tests injected more fallout into the atmosphere, leading to higher concentrations there than in the Southern Hemisphere, with a time lag for mixing.
- **Treaty Impact**: The 1963 Limited Test Ban Treaty significantly reduced new atmospheric fallout, causing day-to-day radiation levels to fall dramatically.
- **Modern Levels**: Current background radiation levels from testing are generally very low, often below detection limits, but long-term monitoring (like EPA's RadNet) continues to track background radiation and specific isotopes.
- **Modern Levels**: Carbon-14 produced from atmospheric ^{14}N neutron capture $^{14}N + n \rightarrow {}^{14}C + p$
- **C-14- 5730 yr half life – C-12 is stable – ratio of C-14 to C-12 used in Carbon dating of dead organisms as organisms (when alive) exchanges Carbon through breathing.**
- **Cosmic ray production - ^{14}C** is also produced by cosmic rays fragmenting nuclei in air (^{14}N)and producing neutrons with same $^{14}N + n \rightarrow {}^{14}C + p$

Alpha - Beta - Gamma Emission

Neutrons are also dangerous but generally reactions are nuclear and not ionizing



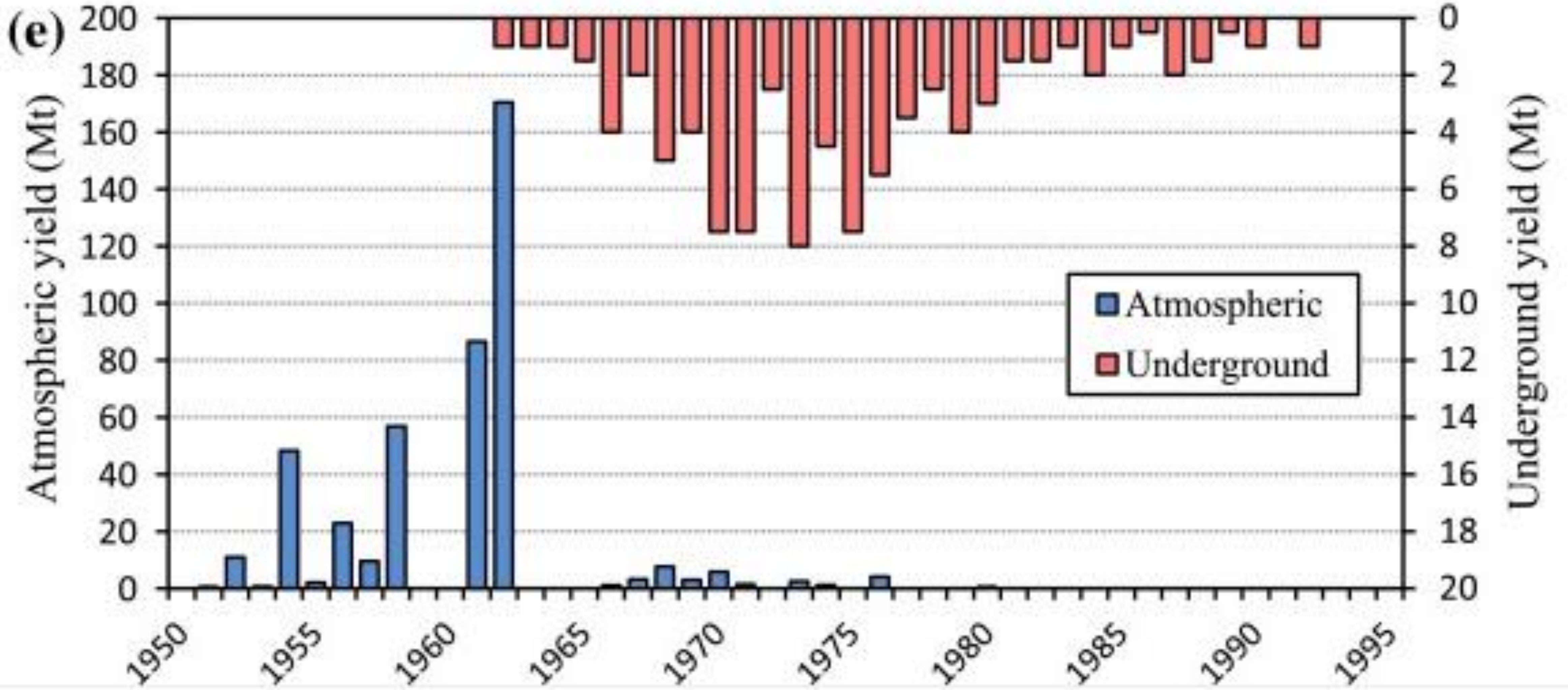
Alpha particles come from the decay of the heaviest radioactive elements, such as uranium, radium and polonium.



Beta-emitters are most hazardous when they are inhaled or swallowed.

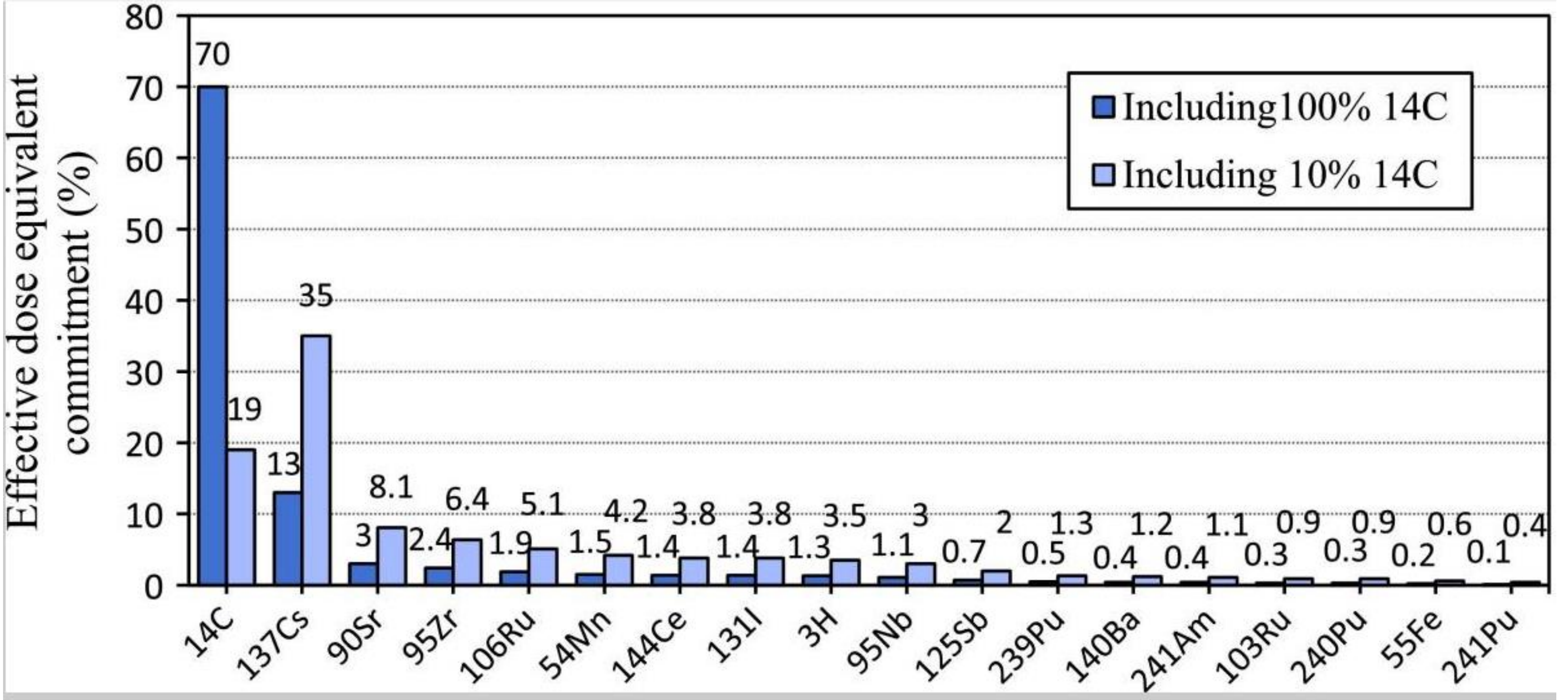
Gamma rays are often emitted along with alpha or beta particles during radioactive decay.

Above and Underground Testing vs Year

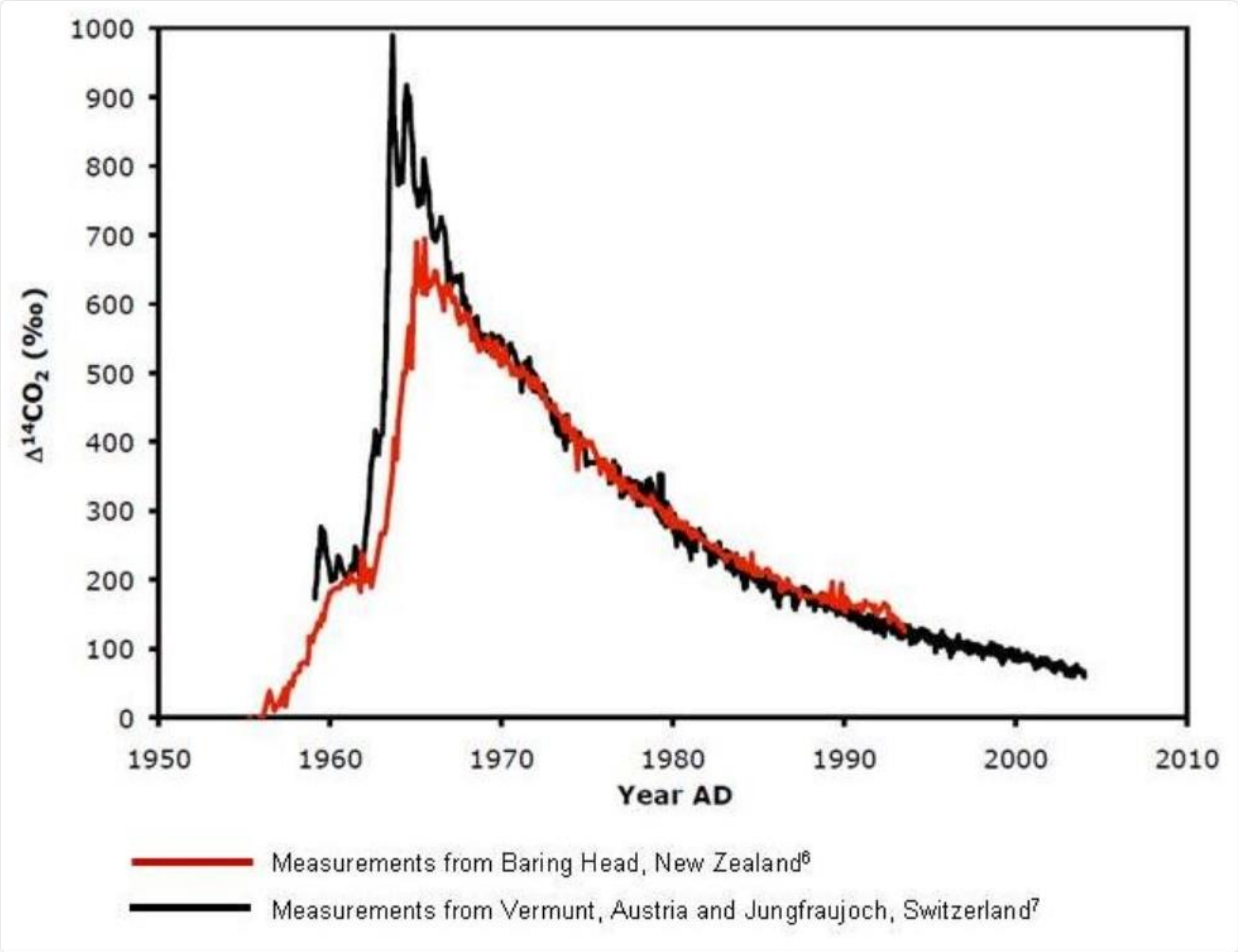


World wide nuclear fallout from above ground testing

10 % of the ^{14}C dose commitment, corresponds to the truncated effective dose commitment in the year 2200 (by which time most of the other radionuclides will have delivered almost their entire dose). ^{14}C only contributes 19 % of the truncated effective dose to the world's population



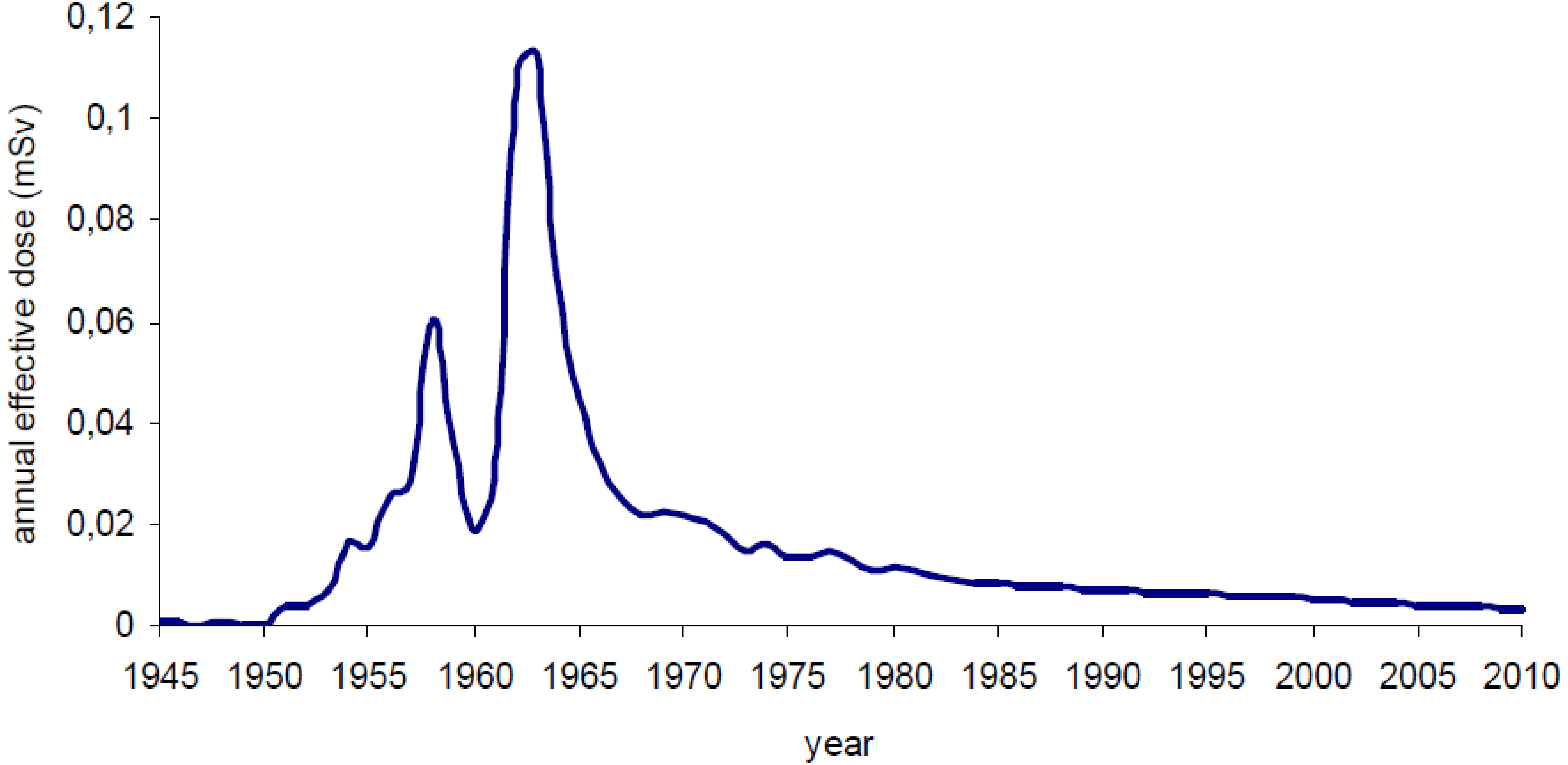
^{14}C in atmosphere from above ground testing



The ^{14}C levels in the Northern and Southern Hemispheres. Nuclear testing resulted in the large "spikes" in the early 1960s.

By the 1980s, most of the "bomb" ^{14}C had been absorbed into the oceans and land biota, leaving slightly elevated levels in the atmosphere. Yet atmospheric ^{14}C levels continue to decrease–now because of CO_2 emissions from fossil fuel burning. Fossil fuels are millions of years old, and have zero ^{14}C

Human radiological annual dose (mSv) from above ground testing - 1945-2010



Radionuclide vs Half-life and Organ Affected via Digestion and via Inhalation

Simon et al 2022

Radionuclide		Half-life	Organs/tissues in adults receiving greatest dose via ingestion	Organs/tissues in adults receiving greatest dose via inhalation
^{89}Sr		50.6 d	Bone surfaces, Colon, active marrow	Bone surfaces, Colon, active marrow, lung
^{90}Sr		28.9 a	Bone surfaces, Colon, active marrow	Colon, bone surfaces, active marrow, lung
	^{90}Y	64.1 h	Stomach wall, colon	Stomach wall, colon, lung
^{91}Sr		9.65 h	Colon	Colon, lung
	^{91}Y	58.5 d	Colon	Colon, lung
^{92}Sr		2.66 h	Stomach wall, colon	Stomach wall, colon, lung
	^{92}Y	3.54 h	Colon	Colon, lung
^{93}Y		10.2 h	Stomach wall, colon	Stomach wall, colon, lung
^{97}Zr		16.7 h	Colon	Colon, lung
	^{97}Nb	72.1 min	Stomach wall, colon	Stomach wall, colon, lung
^{99}Mo		66.0 h	Colon	Colon, lung
	^{99m}Tc	6.0 h	Stomach wall, thyroid	Lung, colon
^{103}Ru		39.2 d	Bladder wall, stomach wall, colon, ovaries, active marrow, uterus	Colon, lung
	^{103m}Rh	56.1 min	Stomach wall, colon	Lung, stomach wall
^{105}Ru		4.4 h	Colon, stomach wall	Lung, colon
	^{105}Rh	35.4 h	Colon	Lung, colon
^{106}Ru		372 d	Stomach wall, colon	Colon, lung
^{132}Te		3.20 d	Bone surfaces, colon, thyroid, ovaries	Bone surfaces, colon, thyroid
	^{132}I	2.30 h	Thyroid	Thyroid
^{131}I		8.03 d	Thyroid	Thyroid
^{133}I		20.8 h	Thyroid	Thyroid
^{135}I		6.58 h	Thyroid	Thyroid
^{137}Cs		30.1 a	All	All
^{140}Ba		12.8 d	Bone surfaces, colon, ovaries	Colon, lung
	^{140}La	1.68 d	Colon	Colon, lung
^{141}La		3.92 h	Stomach wall, colon	Stomach wall, colon, lung
^{142}La		91.1 min	Stomach wall, colon	Stomach wall, colon, lung
^{143}Ce		33.0 h	Colon	Colon, lung
	^{143}Pr	13.6 d	Colon	Colon, lung
^{144}Ce		285 d	Colon	Colon, lung
	^{144}Pr	17.3 min	Stomach wall	Stomach wall, lung
^{145}Pr		5.98 h	Stomach wall, colon	Stomach wall, colon, lung
^{239}Np		2.36 d	Colon	Colon, lung
^{239}Pu		24,100 a	Colon	Lung

Little Boy U (Hiroshima) neutron Spectra outside weapon

Prompt fission (inside) and Weapon Leakage (outside casing) (Spriggs 2017)

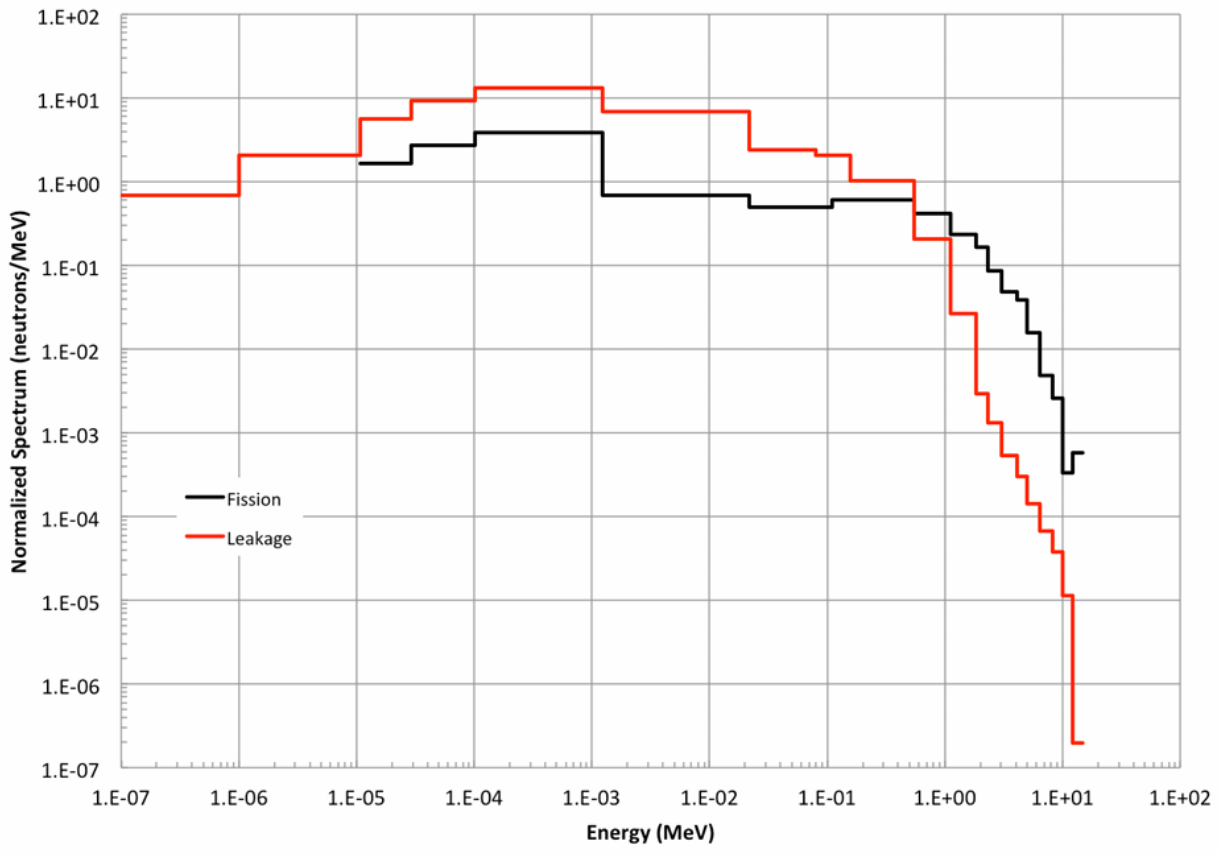


Figure 5. This is a plot of the neutron spectra (normalized to 1 neutron) that was used to estimate the residual radiation source term for the Hiroshima detonation. The average neutron energy of the prompt fission spectrum was 1.46 MeV and the average neutron energy of the leakage spectrum was 0.31 MeV. 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

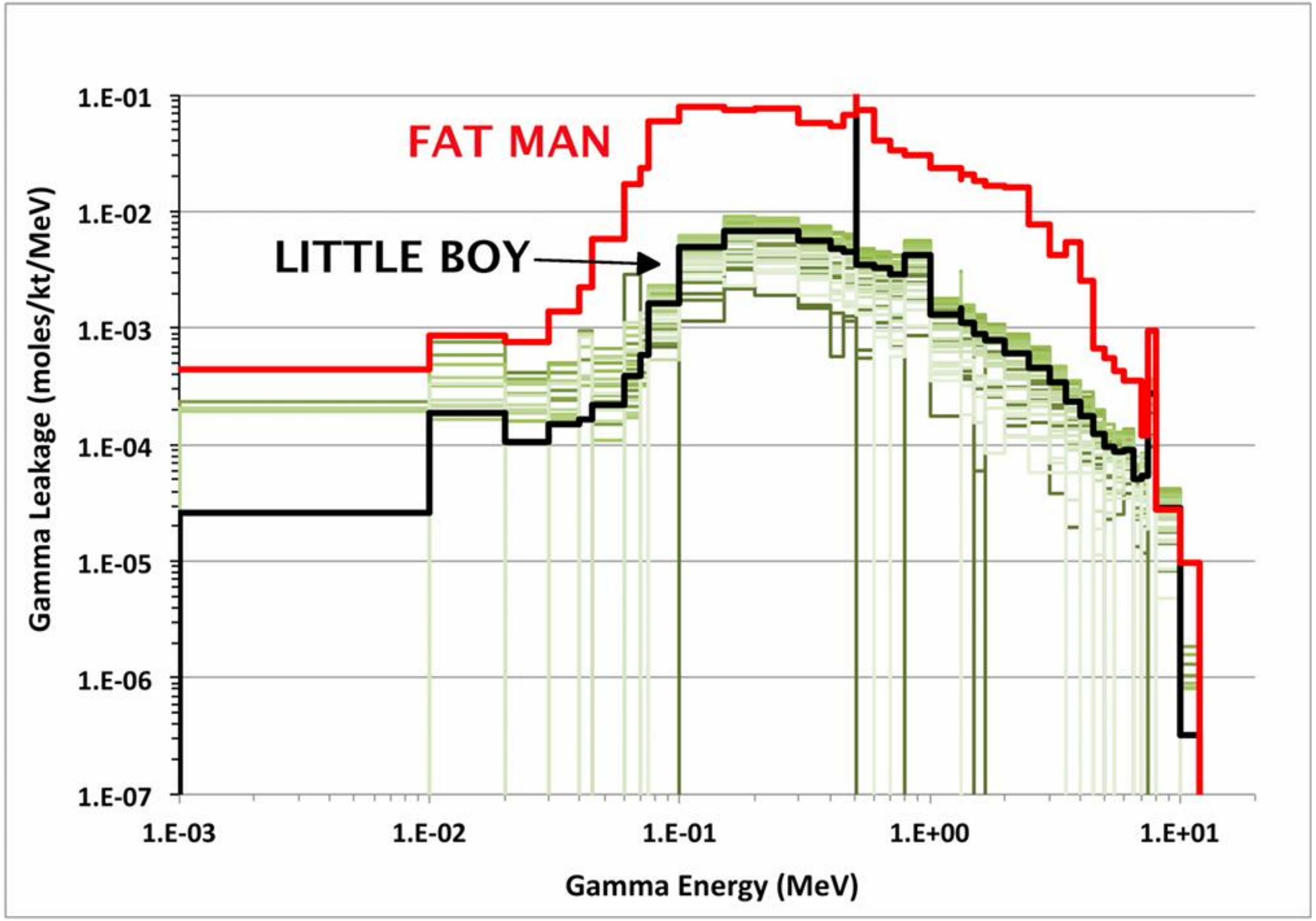


Figure 3: Gamma spectra for Fat Man and Little Boy. The total Little Boy output (sum over all angles) is shown along with the 40 individual segment tallies scaled up to the full sphere. The segment tallies illustrate the two-dimensional variation of the output.

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

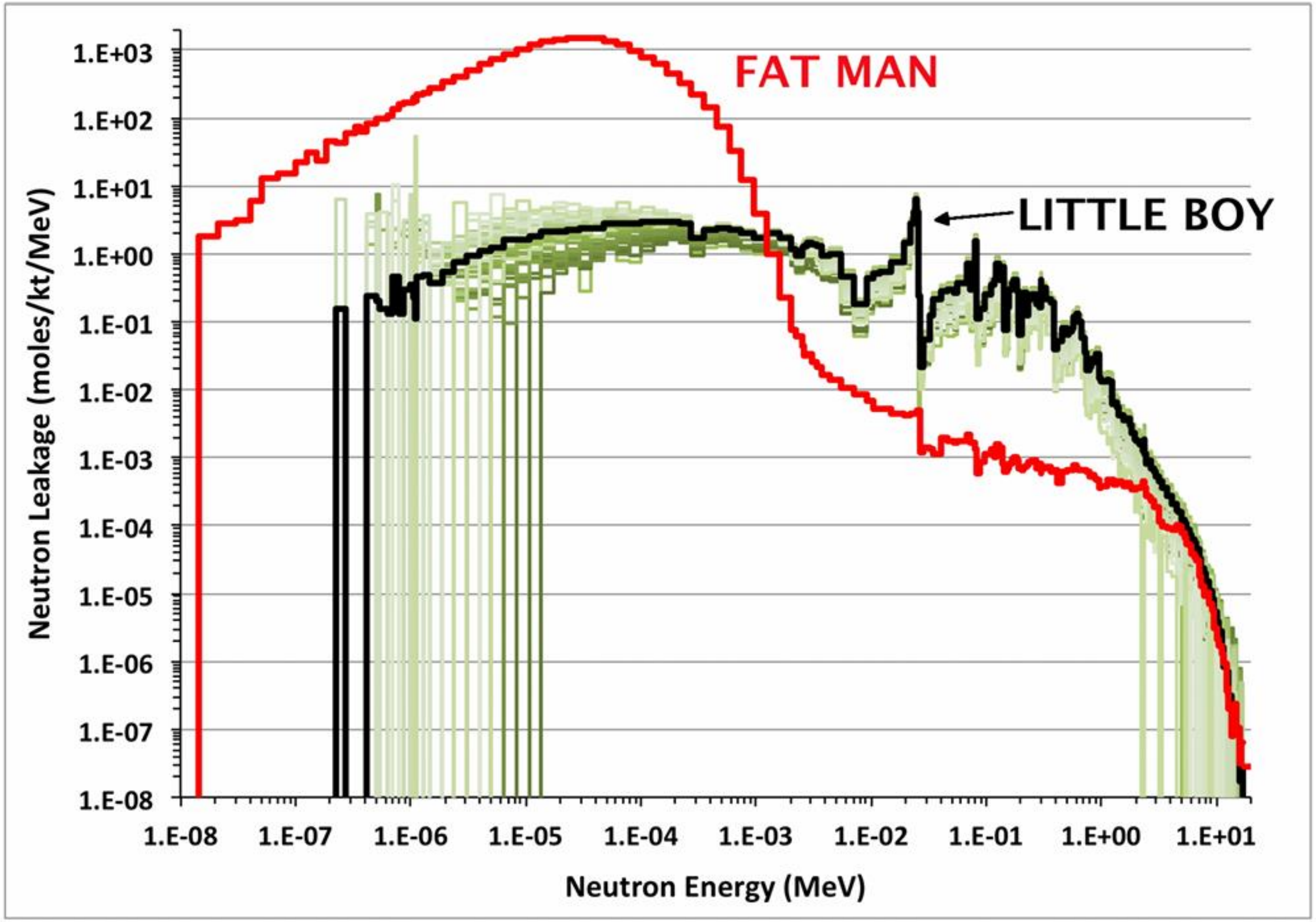


Figure 2: Neutron spectra for Fat Man and Little Boy. The total Little Boy output (sum over all angles) is shown along with the 40 individual segment tallies scaled up to the full sphere. The segment tallies illustrate the two-dimensional variation of the output.

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

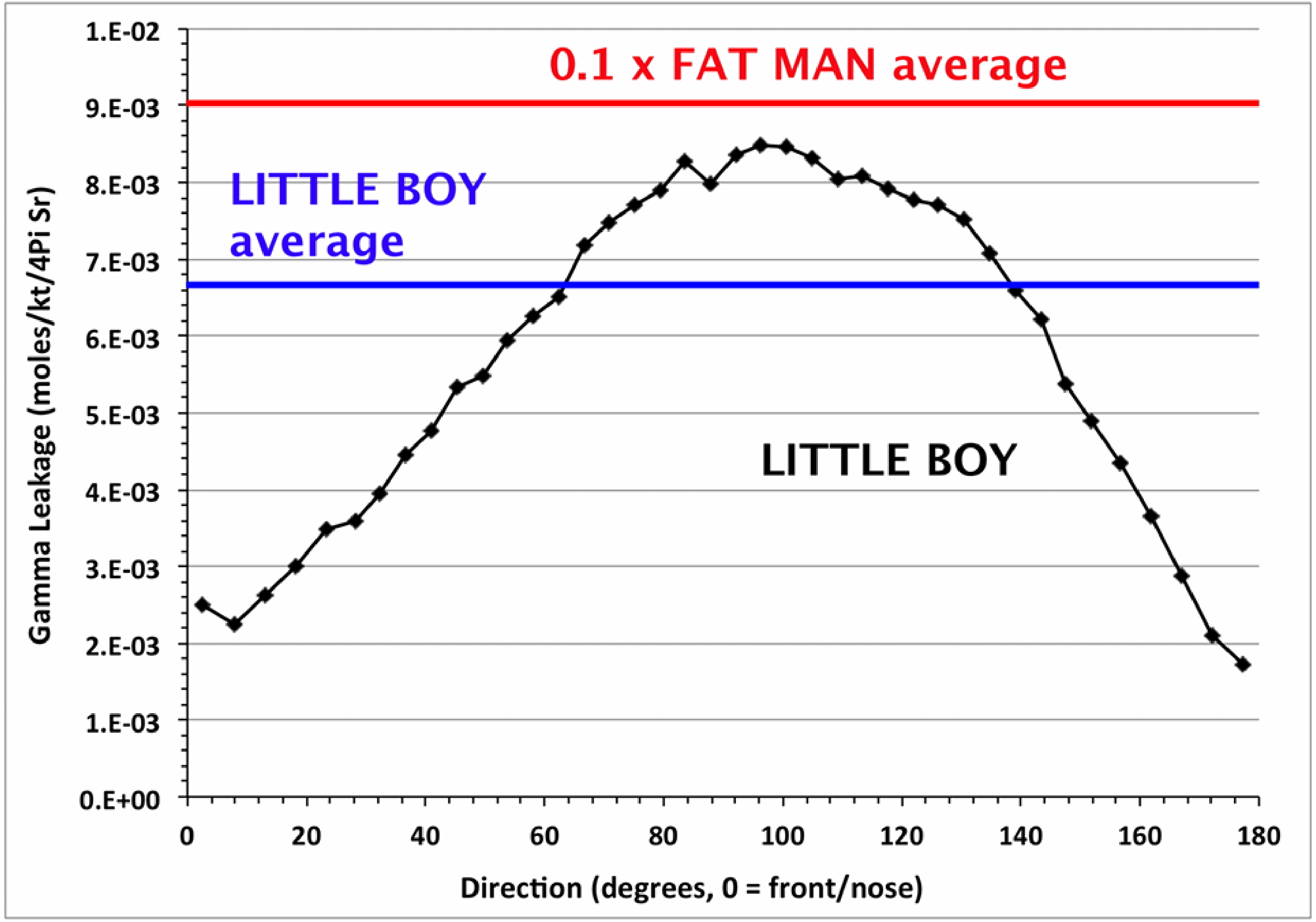


Figure 5: Gamma output variation with angle. Segment tallies have been scaled up to the full sphere. Note that the Fat Man value has been reduced by a factor of 10. As with neutrons, the output is suppressed toward the nose (0°) and tail (180°), though these directions represent a small solid angle and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

Thermonuclear Neutron Spectra (per KT yield) Outside Weapon - DTRA 2017

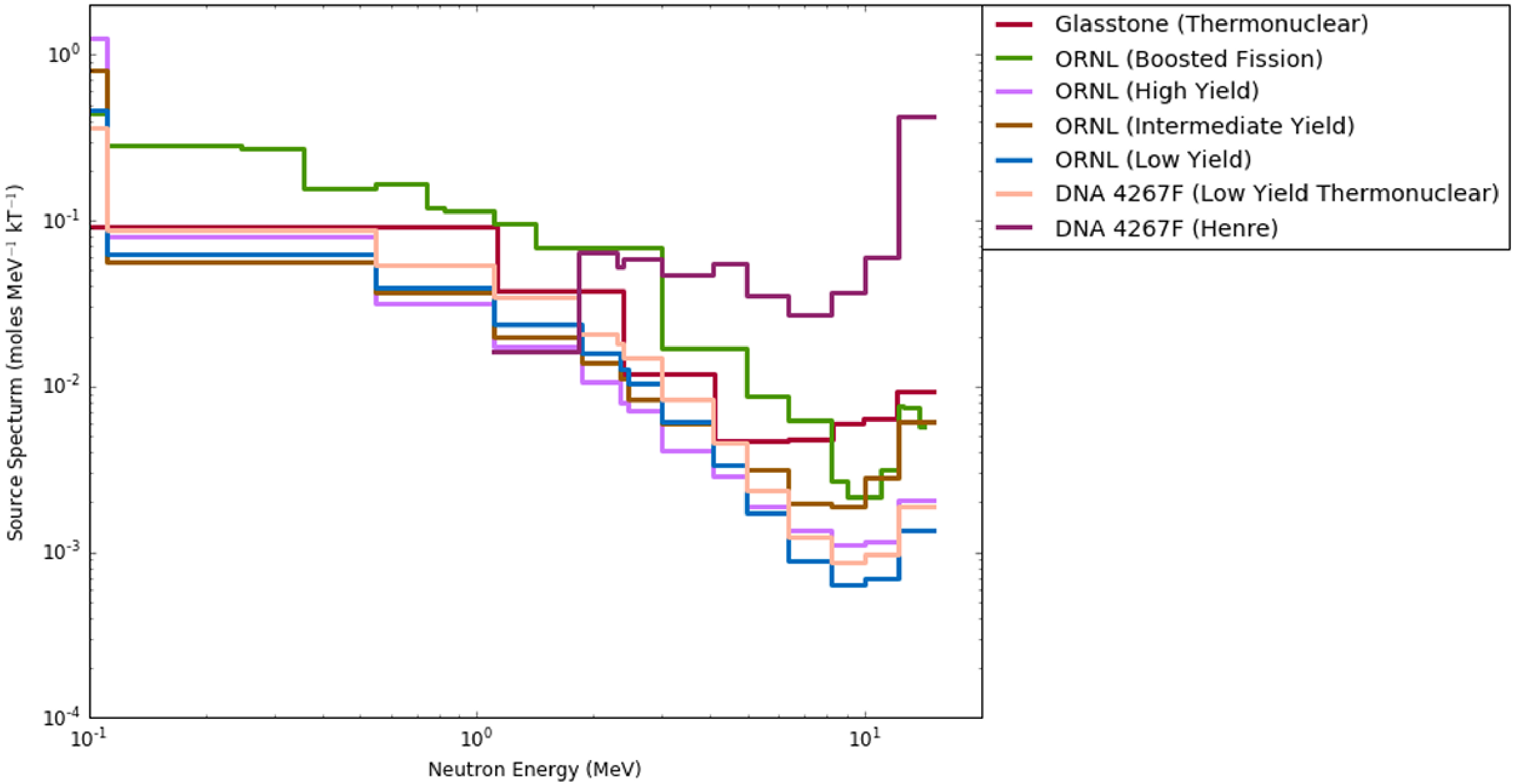


Figure 4. Thermonuclear neutron spectra with energies greater than 0.1 MeV

Thermonuclear Gamma Spectra (per KT yield)
Outside Weapon - DTRA 2017

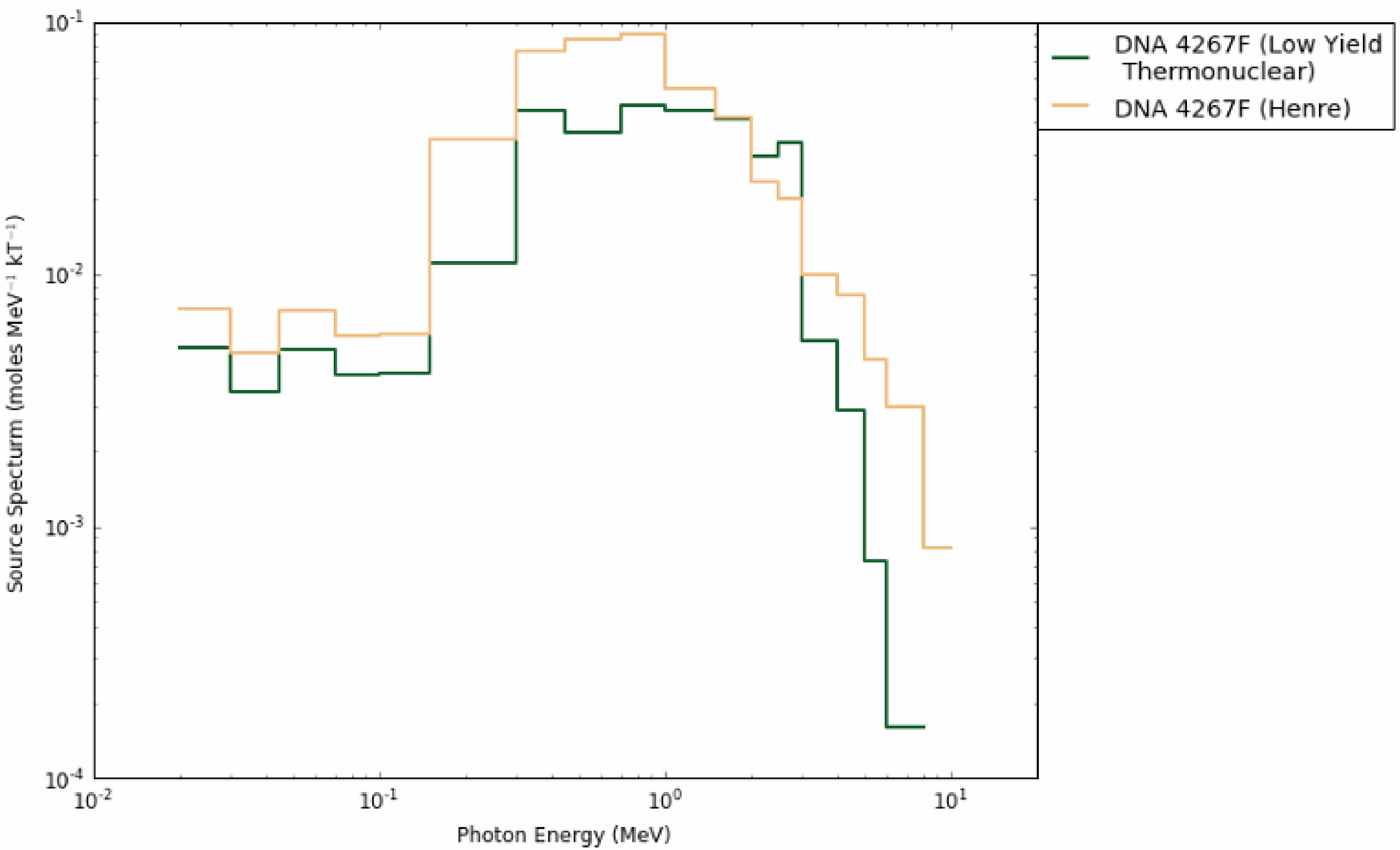


Figure 6. Photon spectra from thermonuclear sources

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

Glasstone and Dolan – Chap 8

Nuclear Isomer is a nuclear metastable state – usually short lived which then decays usually emitting gamma radiation (“isomeric decays”)

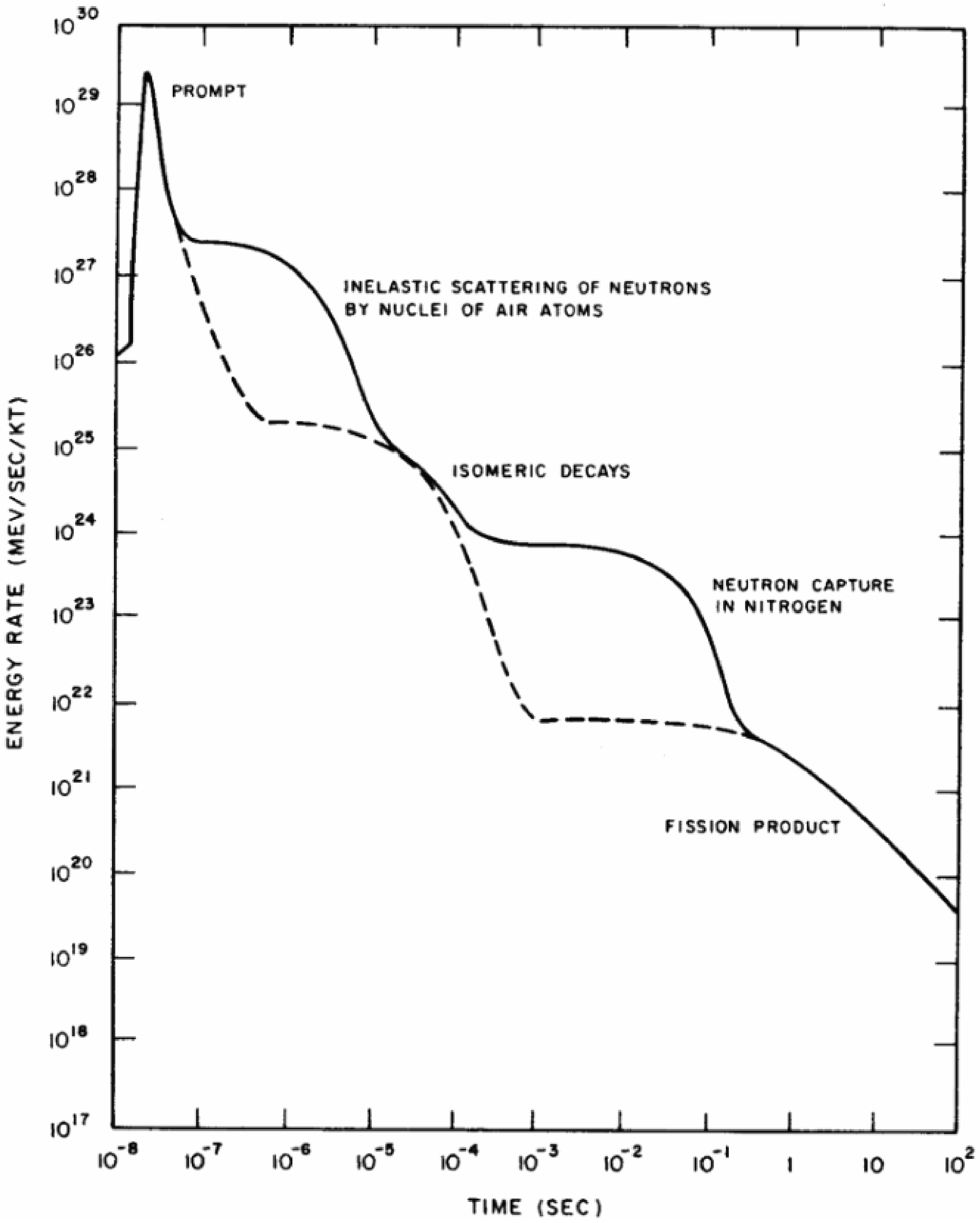


Figure 8.14. Calculated time dependence of the gamma-ray energy output per kiloton energy yield from a hypothetical nuclear explosion. The dashed line refers to an explosion at very high altitude.

Gamma glow from Atmosphere Backscatter

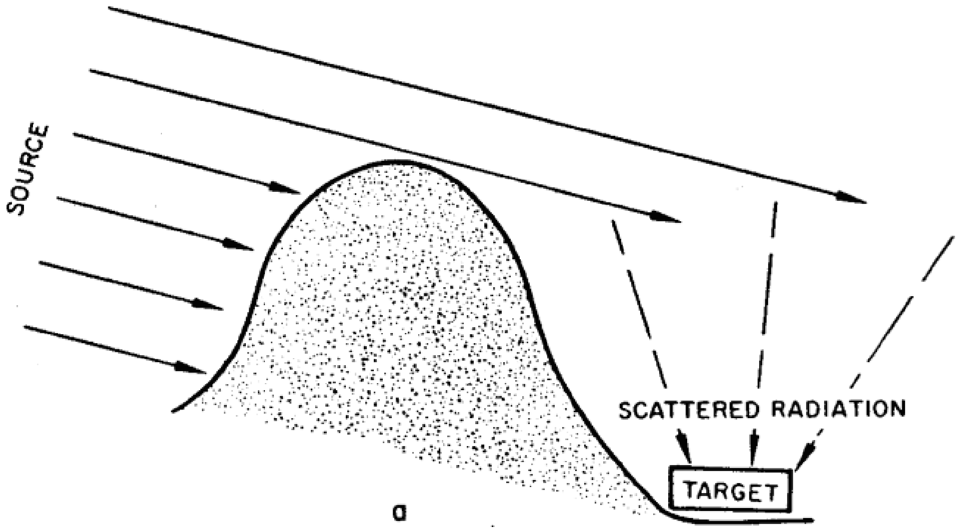
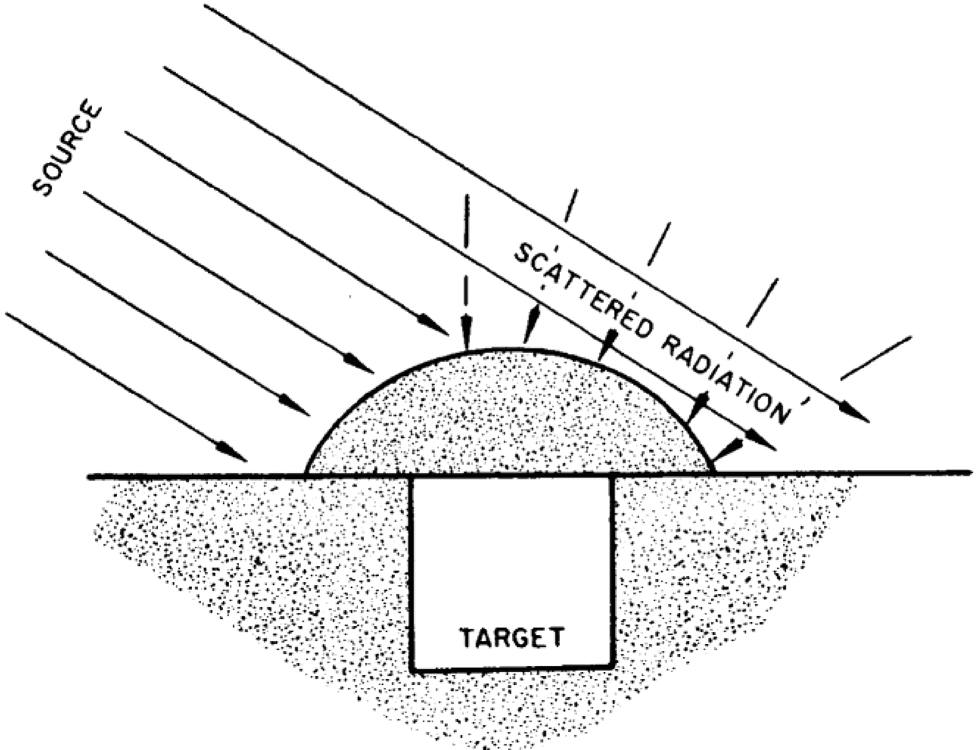


Figure 8.45a. Target exposed to scattered gamma radiation.



Fission Weapon Gamma Dose vs Slant Range Low Alt Airburst

Glasstone and Dolan – Chap 8

Recall 500 REM = 50% lethality

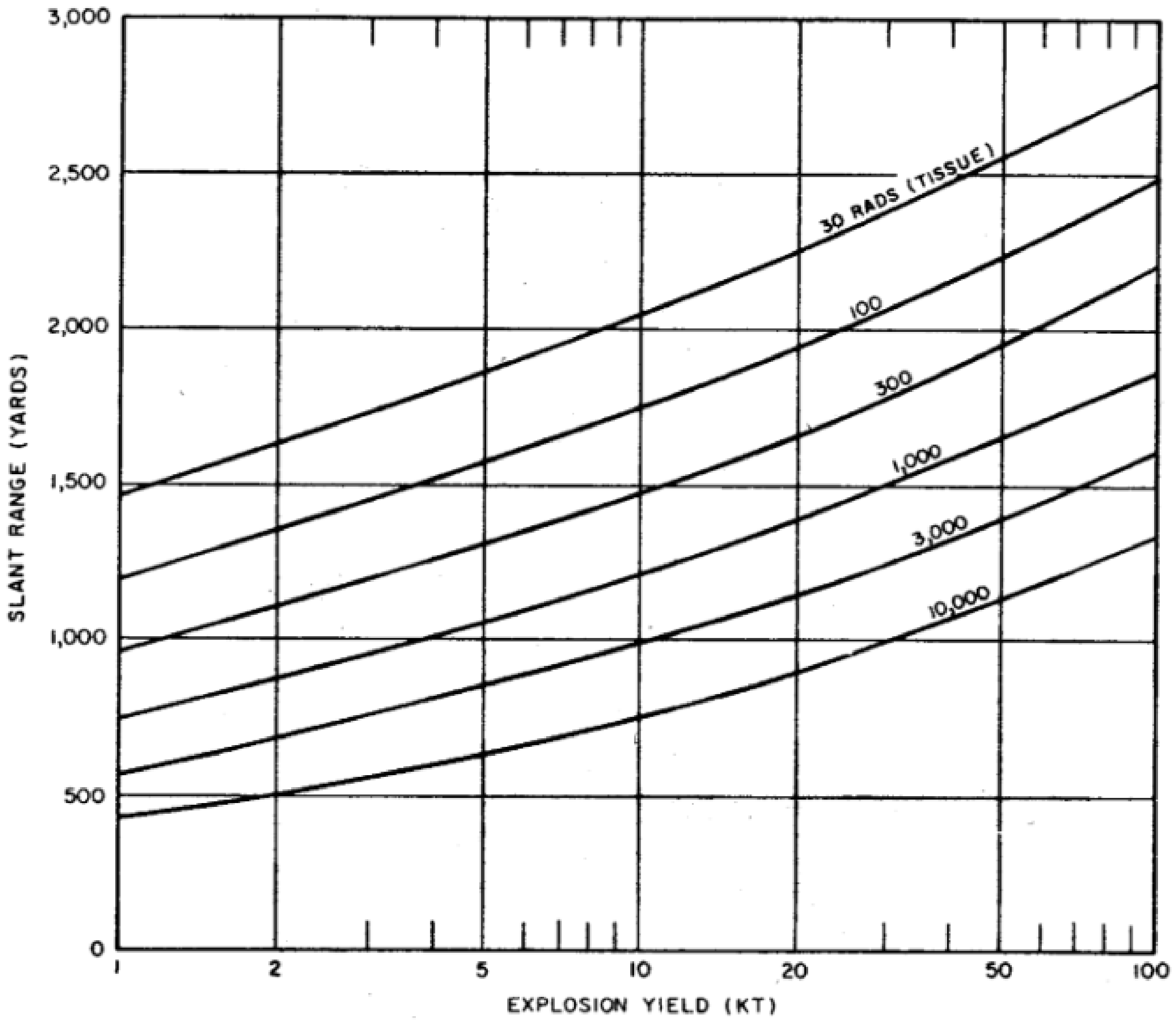


Figure 8.33a. Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst fission weapons based on 0.9 sea-level air density. (Reliability factor from 0.5 to 2 for most fission weapons.)

TN Weapon Gamma Dose vs Slant Range Low Alt Airburst

Glasstone and Dolan – Chap 8

Recall 500 REM = 50% lethality

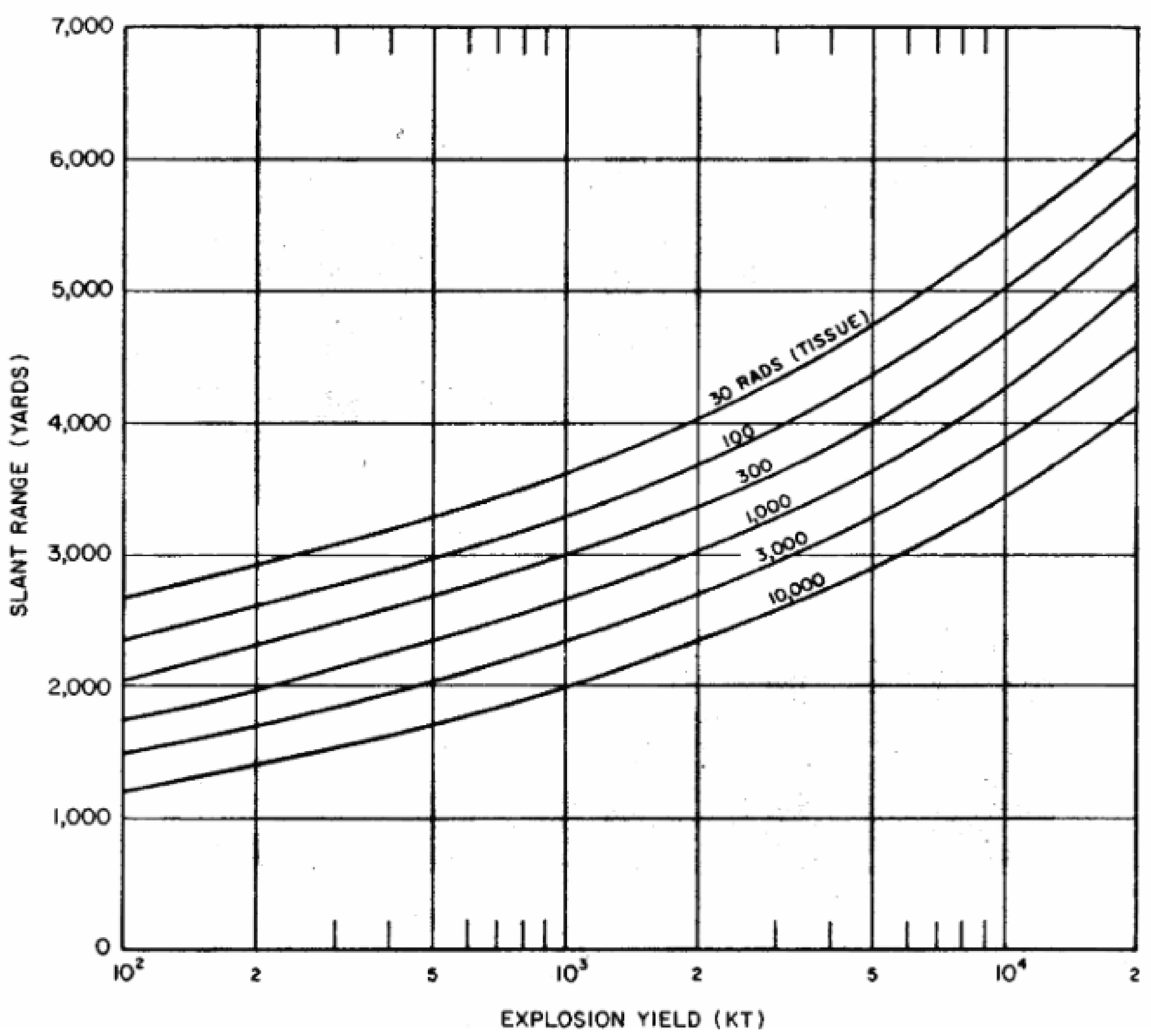


Figure 8.33b. Slant ranges for specified gamma-ray doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons with 50 percent fission yield, based on 0.9 sea-level air density. (Reliability factor from 0.5 to 1.5 for most thermonuclear weapons.)

Shielding Thickness for Fission Products and Nitrogen Neutron Capture Gamma Emission

Glasstone and Dolan – Chap 8

Table 8.41

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

		Fission Product		Nitrogen Capture	
Material	Density (lb/cu ft)	Tenth-Value Thickness (inches)	D × T (lb/sq ft)	Tenth-Value Thickness (inches)	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

Glasstone and Dolan – Chap 8

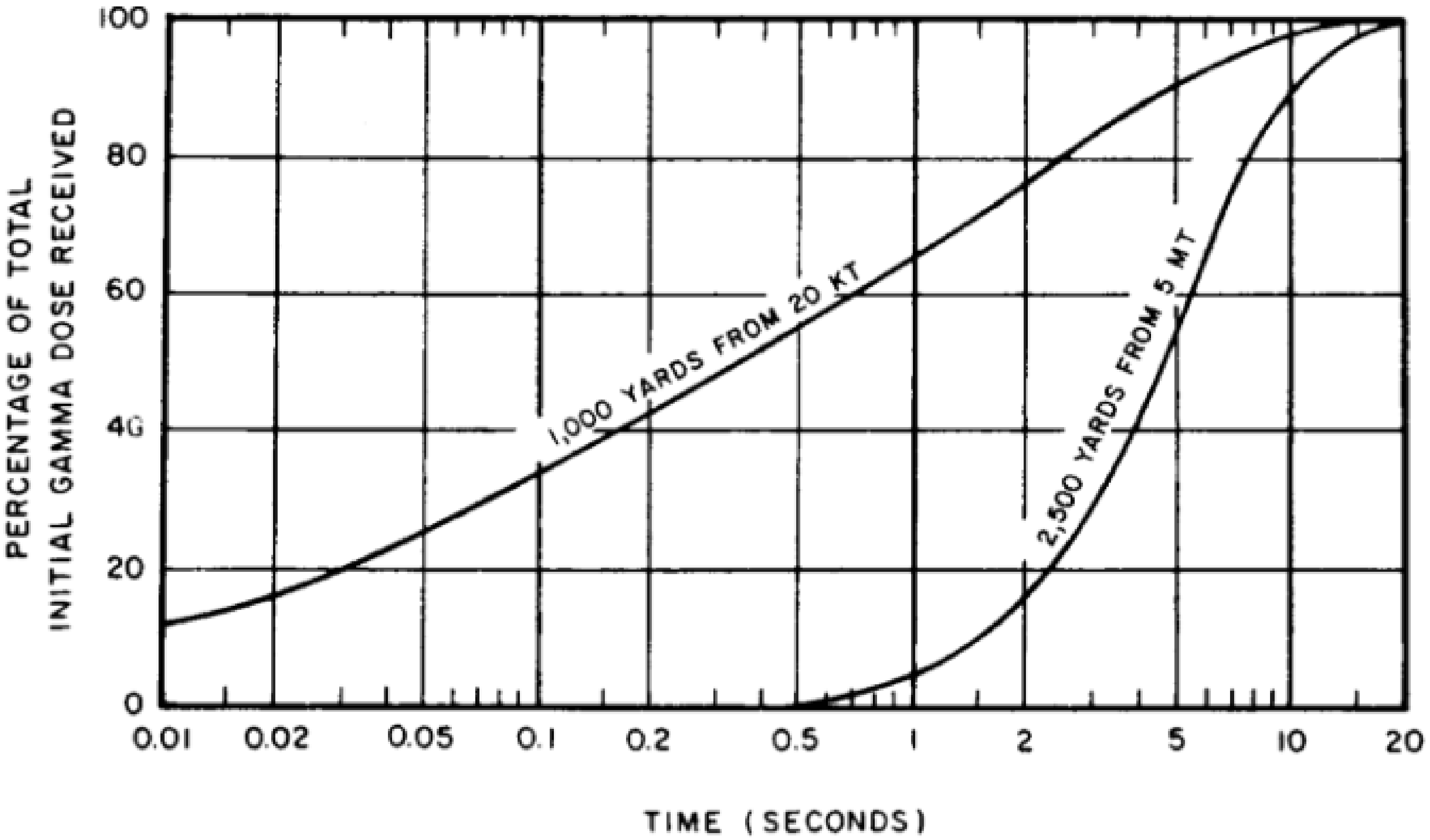


Figure 8.47. Percentage of initial gamma-radiation dose received as a function of time for 20-kiloton and 5-megaton air bursts.

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 Low Alt Airburst

Glasstone and Dolan – Chap 8

Recall 500 REM = 50% lethality

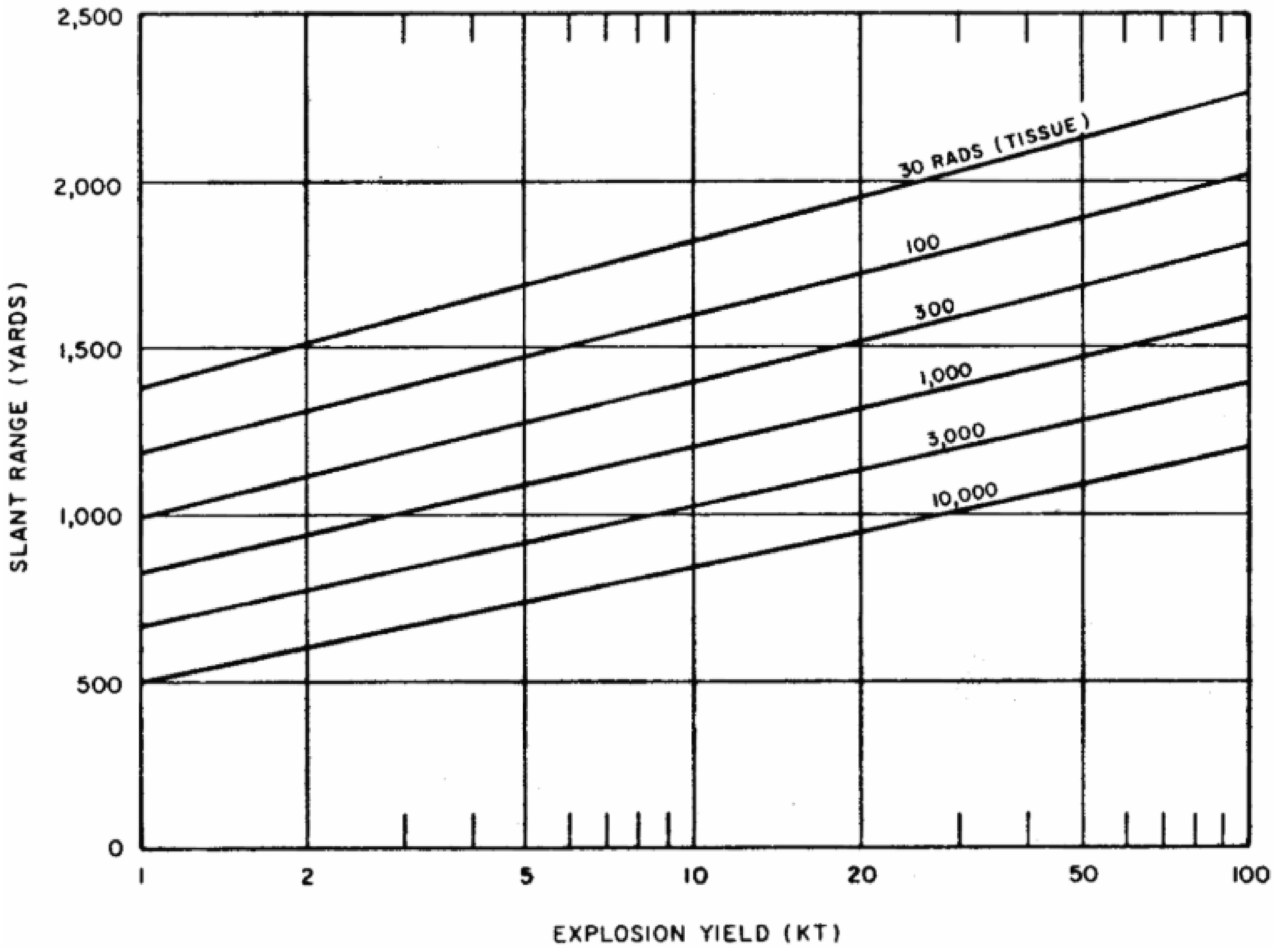


Figure 8.64a. Slant ranges for specified neutron doses for targets near the ground as a function of energy yield of air-burst fission weapons based on 0.9 sea-level air density. (Reliability factor from 0.5 to 2 for most fission weapons.)

TN Weapon Neutron Dose vs Slant Range Low Alt Airburst

Glasstone and Dolan – Chap 8

Recall 500 REM = 50% lethality

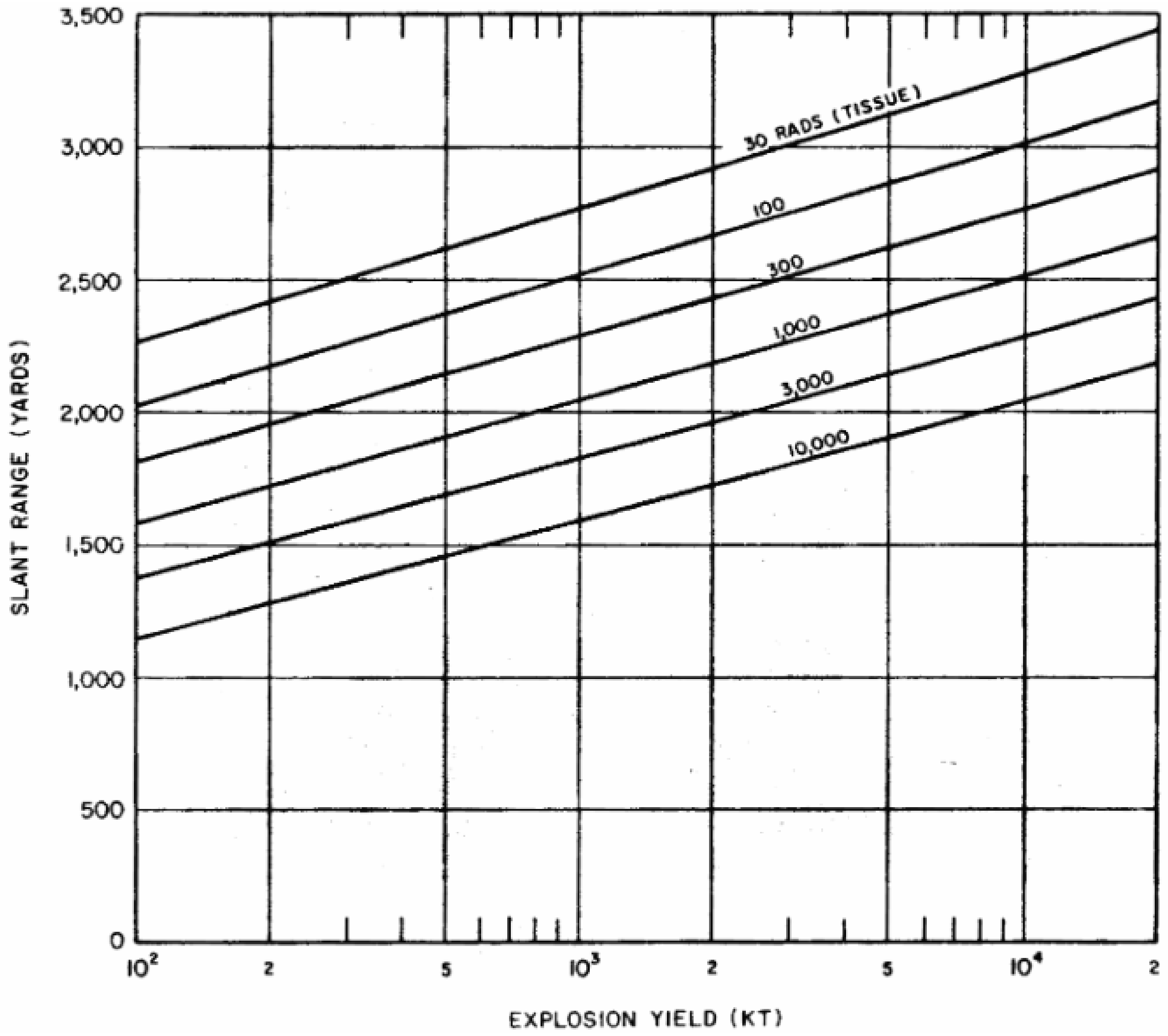


Figure 8.64b. Slant ranges for specified neutron doses for targets near the ground as a function of energy yield of air-burst thermonuclear weapons with 50 percent fission yield, based on 0.9 sea-level air density. (Reliability factor from 0.25 to 1.5 for most thermonuclear weapons.)

Clinical – Medical Response to various Radiation Loads Glasstone and Dolan 1977 – Chapter 12

For consistency, the data in Table 12.108 are the doses (in rems) equivalent to the absorbed doses (in rads) in tissue at the surface of the individual. For gamma rays, these absorbed doses are essentially equal to the exposures in roentgens (§ 8.18). For nuclear weapon radiation, the midline tissue doses for average size adults would be approximately 70 percent of the doses in the table.

Summary of Clinical Effects of Acute Radiation – Table 12.108 GD 1977

Range	0 to 100 rems Subclinical range	100 to 1,00 rems Therapeutic range			Over 1,000 rems Lethal range	
		100 to 200 rems	200 to 600 rems	600 to 1,000 rems	1,000 to 5,000 rems	Over 5,000 rems
		Clinical surveillance	Therapy effective	Therapy promising	Therapy palliative	
Incidence of vomiting	None	100 rems: infrequent 200 rems: common	300 rems: 100%	100%	100%	
Initial Phase Onset Duration	 — —	 3 to 6 hours ≤ 1 day	 ½ to 6 hours 1 to 2 days	 ¼ to ½ hour ≤ 2 days	 5 to 30 minutes ≤ 1 day	Almost immediately[**]
Latent Phase Onset Duration	 — —	 ≤ 1 day ≤ 2 weeks	 1 to 2 days 1 to 4 weeks	 ≤ 2 days 5 to 10 days	 ≤ 1 day[*] 0 to 7 days[*]	Almost immediately[**]
Final Phase Onset Duration	 — —	 10 to 14 days 4 weeks	 1 to 4 weeks 1 to 8 weeks	 5 to 10 days 1 to 4 weeks	 0 to 10 days 2 to 10 days	Almost immediately[**]
Leading organ	Hematopoietic tissue				Gastrointestinal tract	Central nervous system
Characteristic signs	None below 50 rems	Moderate leukopenia	Severe leukopenia; purpura; hemorrhage; infection. Epilation above 300 rems.		Diarrhea; fever; disturbance of electrolyte balance.	Convulsions; tremor; ataxia; lethargy.
Critical period post-exposure	—	—	1 to 6 weeks		2 to 14 days	1 to 48 hours
Therapy	Reassurance	Reassurance; hematologic surveillance.	Blood transfusion; antibiotics.	Consider bone marrow transplantation.	Maintenance of electrolyte balance.	Sedatives
Prognosis	Excellent	Excellent	Guarded	Guarded	Hopeless	
Convalescent period	None	Several weeks	1 to 12 months	Long	—	
Incidence of death	None	None	0 to 90%	90 to 100%	100%	
Death occurs within	—	—	2 to 12 weeks	1 to 6 weeks	2 to 14 days	< 1 day to 2 days
Cause of death	—	—	Hemorrhage; infection		Circulatory collapse	Respiratory failure; brain edema.

Shielding Thickness for Gamma and Neutrons

Glasstone and Dolan – Chap 8

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

Shielding Thickness for Gamma and Neutrons

Glasstone and Dolan – Chap 8

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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

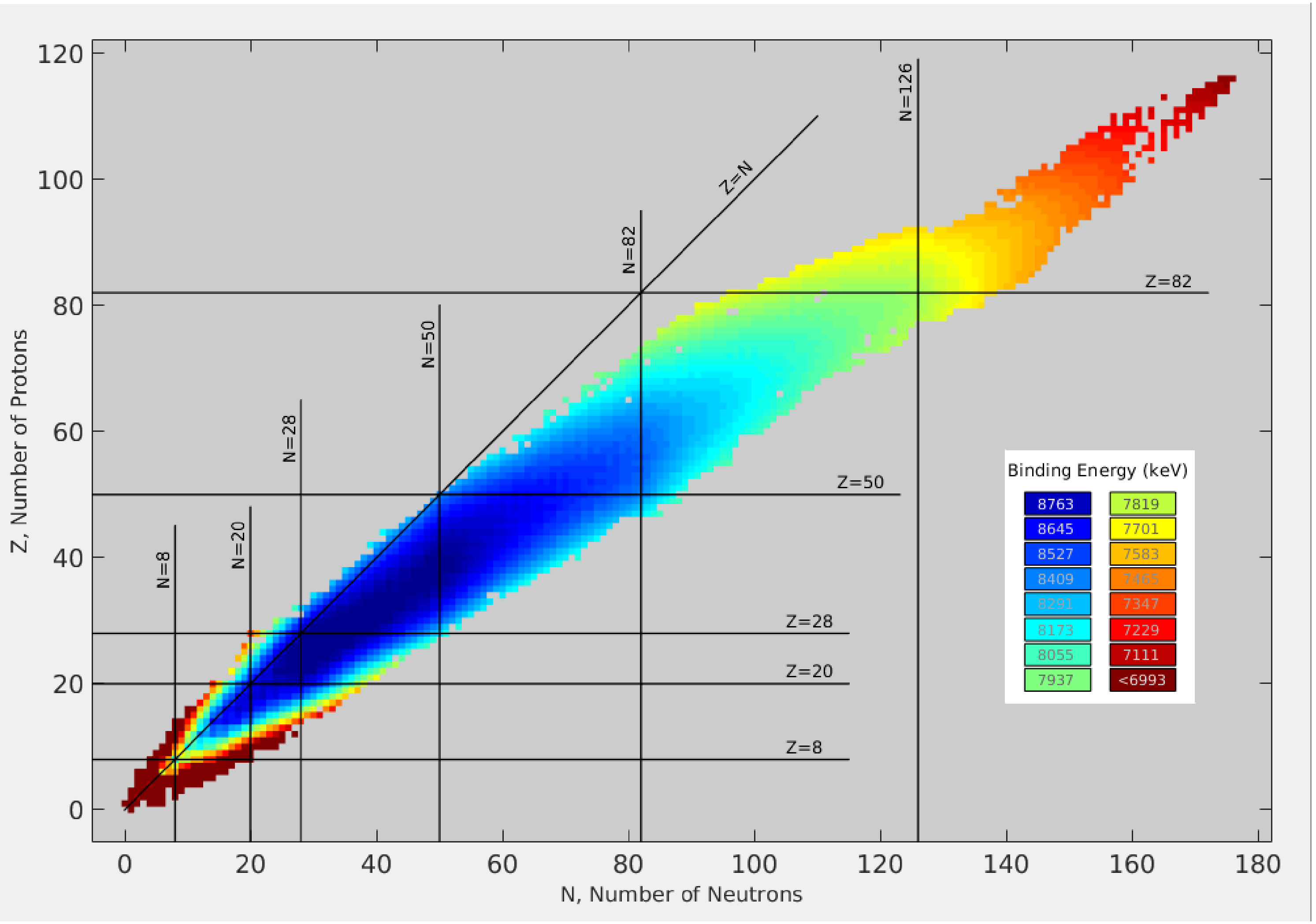


Chart of nuclides (isotopes) by binding energy, depicting the valley of stability. The diagonal line corresponds to equal numbers of neutrons and protons. Dark blue squares represent nuclides with the greatest binding energy, hence they correspond to the most stable nuclides. **The binding energy is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

Stable and Unstable Isotopes

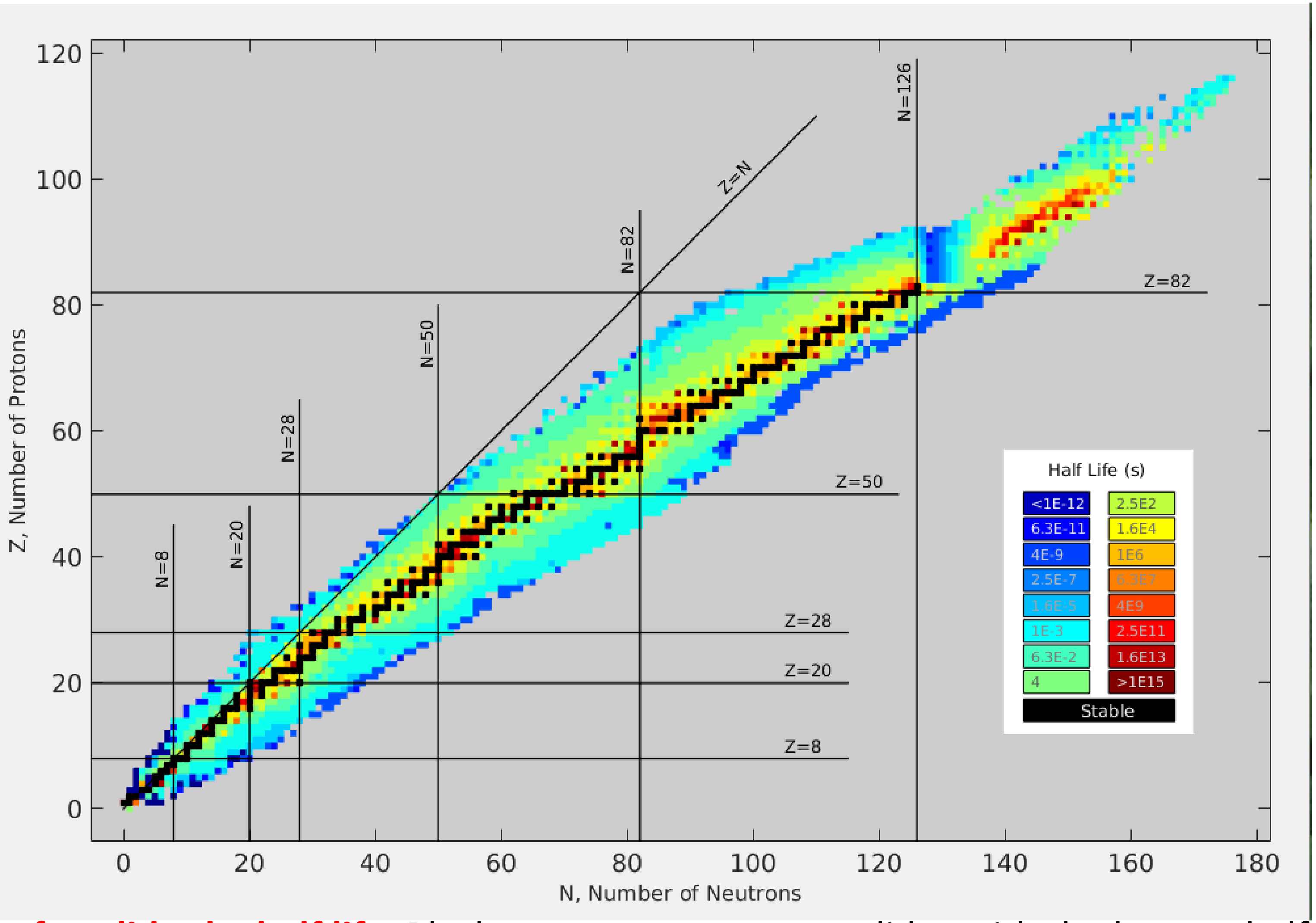


Chart of nuclides by half life. Black squares represent nuclides with the longest half lives hence they correspond to the most stable nuclides. The most stable, long-lived nuclides lie along the floor of the valley of stability. **Nuclides with more than 20 protons must have more neutrons than protons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

Stable and Unstable Isotopes

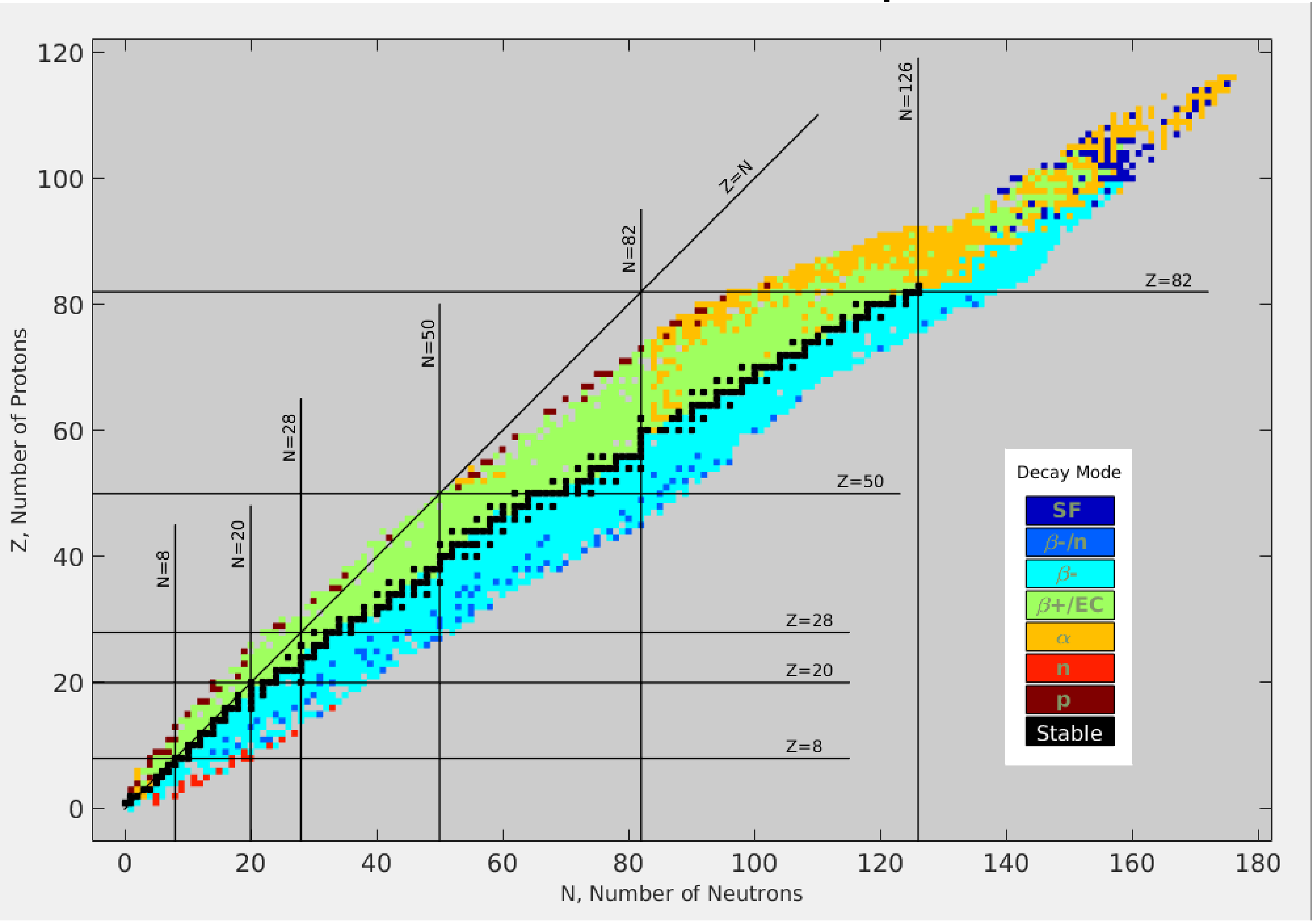
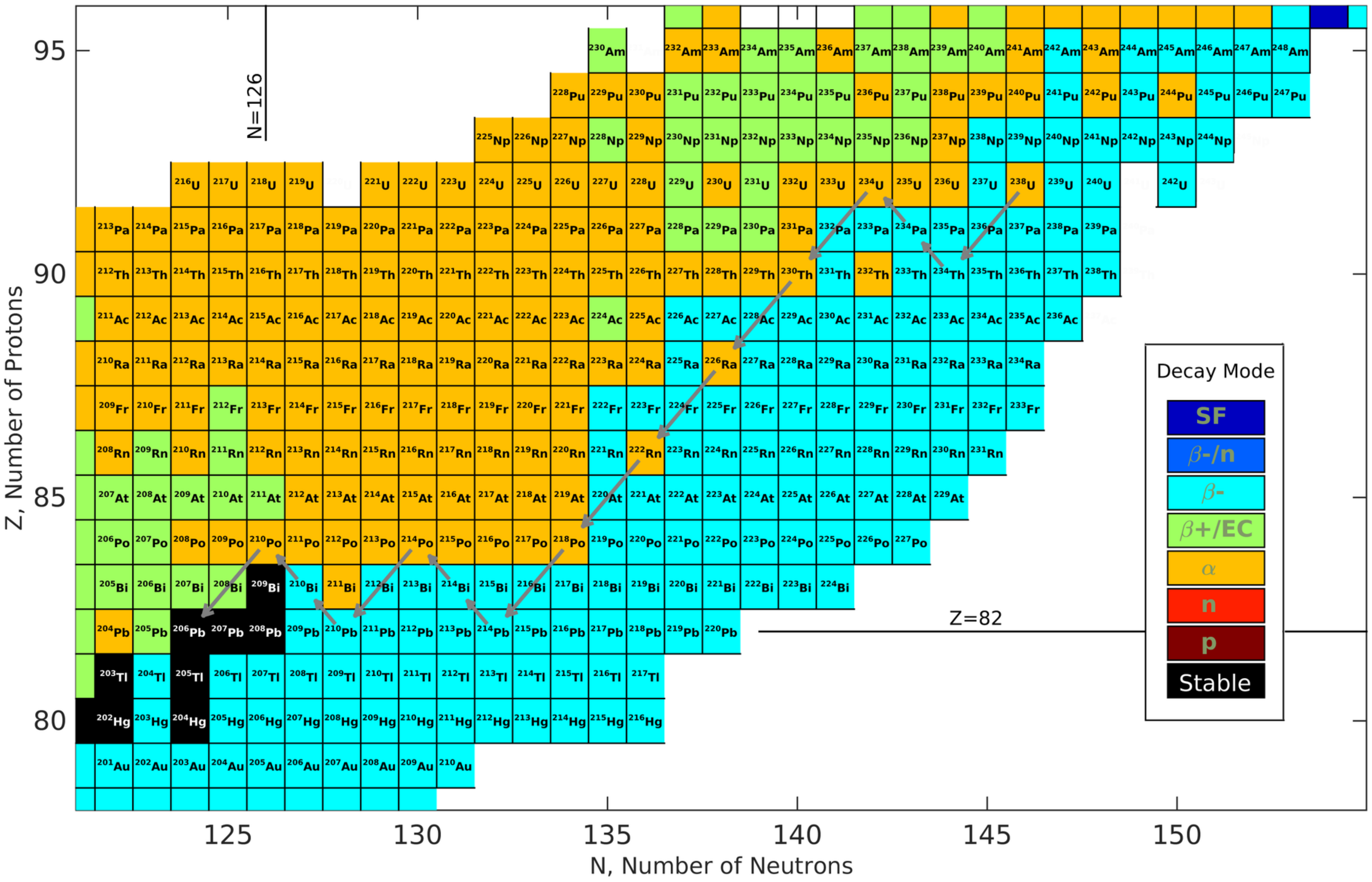


Chart of nuclides by type of decay mode. Black squares are stable nuclides. Nuclides with excessive neutrons or protons are unstable to β− (light blue) or β+ (green) decay, respectively. **At high atomic number, alpha emission (orange) or spontaneous fission (dark blue) become common decay modes.**

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.

Functional Fits to Nuclear Effects

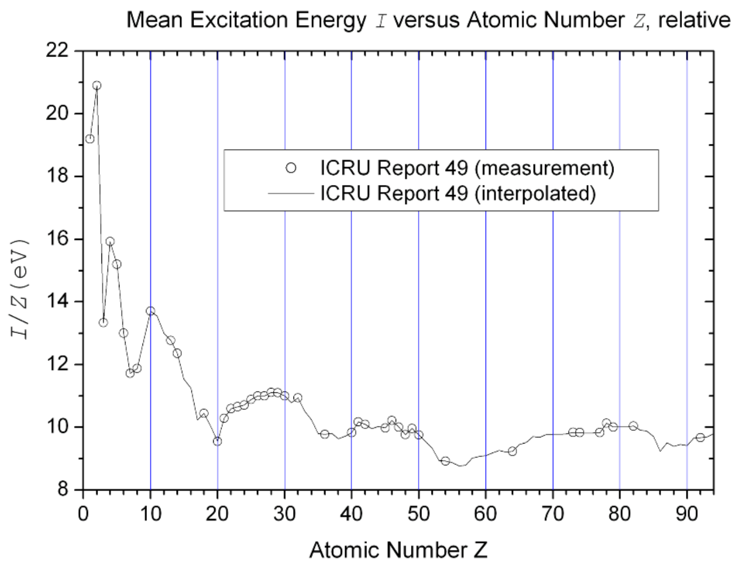
- See Class website for the fits and 1960-1980 “circular slide rule of weapons effects” – a classic!
- PDF file of below is on Phys 150 class website
- **Nuclear Bomb Effects Circular Slide Rule Design and Functional Fits – Fletcher et all 1963 (used in Glasstone and Dolan – Effects of Nuclear Weapons book including 1977 edition)**
- https://apps.dtic.mil/sti/tr/pdf/ADA384998.pdf

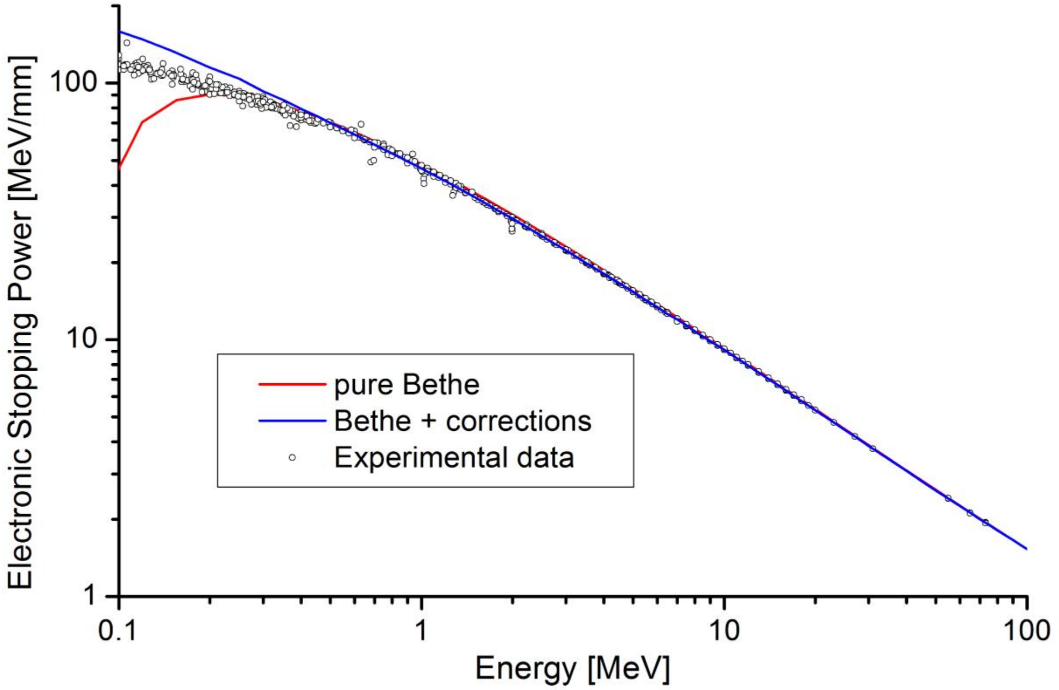
Bethe – Bloch Charged Particle Ionization (dE/dx)

- Non relativistic 1930 (Hans Bethe)
- Relativistic 1932 (Hans Bethe)

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \cdot \frac{nz^2}{\beta^2} \cdot \left(\frac{e^2}{4\pi\varepsilon_0}\right)^2 \cdot \left[\ln\left(\frac{2m_e c^2 \beta^2}{I \cdot (1-\beta^2)}\right) - \beta^2\right]$$

- Note at small β (non rel) dE/dx α z^2/β^2
- Mean Ionization correction 1933 (Felix Bloch)
- I(mean ionization) I(eV) = 10*Z (Left Plot)
- dE/dx of protons in Aluminum (Right plot)





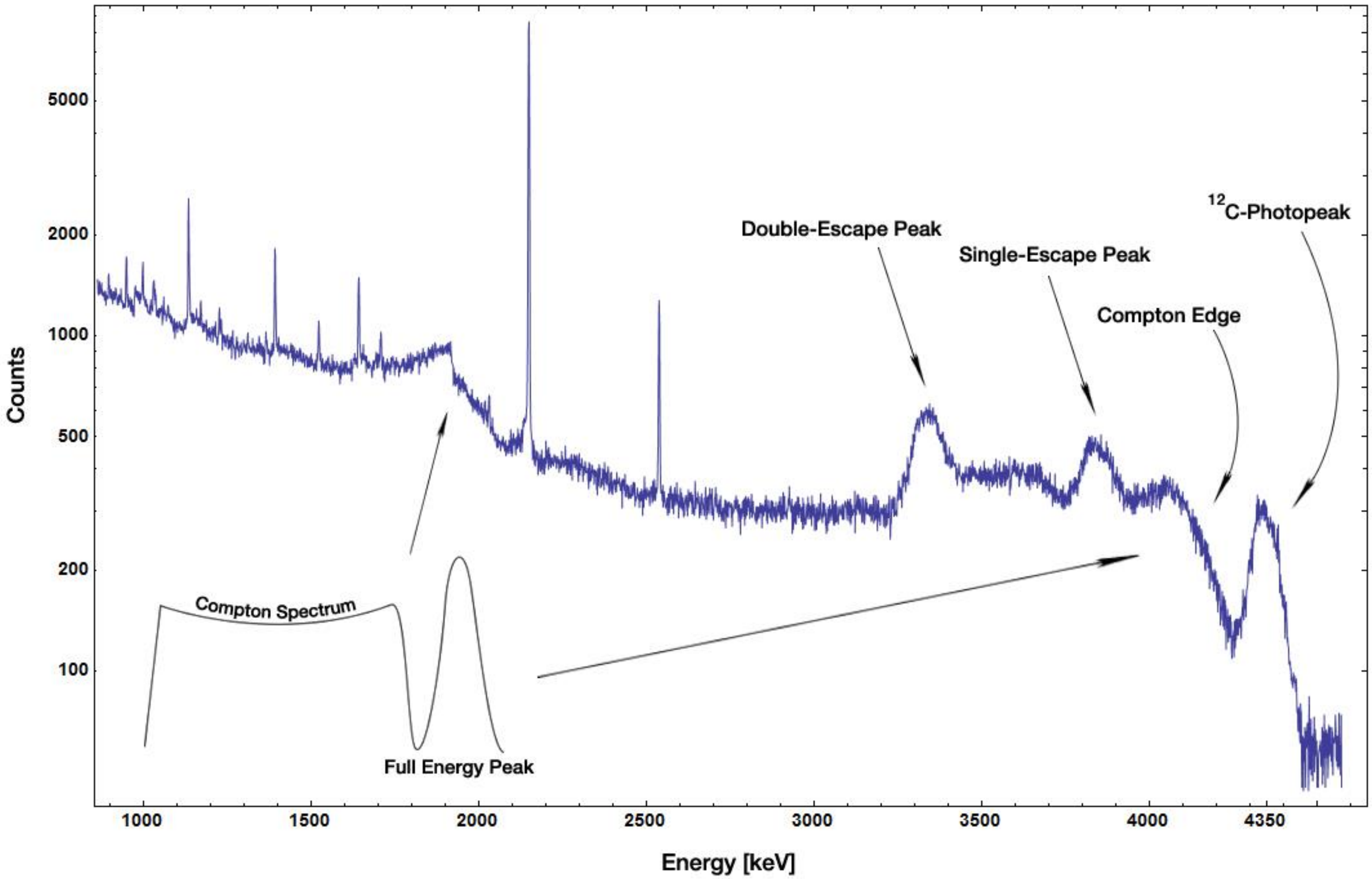
Compton Scattering of Photon and Electron and Edge

- When a photon hits an electron there is momentum and energy transfer
- Formula does not account for the electron binding energy, which can play a non-negligible role for low-energy gamma rays

$$E' = \frac{E}{1 + \frac{E}{m_e c^2}\left[1 - \cos(\vartheta)\right]} \quad where\ E = energy\ incident\ photon,\ m_e = electron\ mass,\ \vartheta = deflection\ angle\ of\ photon$$

- E’ = Compton scattered photon energy
- Note for $\vartheta = 0$ there is no energy transfer
- For $\vartheta = \pi$ (direct backward deflection – maximum energy transfer to electron)
- → $E' = E / 1 + \frac{2E}{m_e c^2}$
- Energy transferred to the electron E^T= E′ – E
- Compton edge (max energy transfer $\vartheta = \pi$) $E_{Compton\,Edge} = E_T(\max) = E\left[1 - \frac{1}{1 + \frac{2E}{m_e c^2}}\right]$

Am-Be Gamma Spectrum – Note Compton Edge

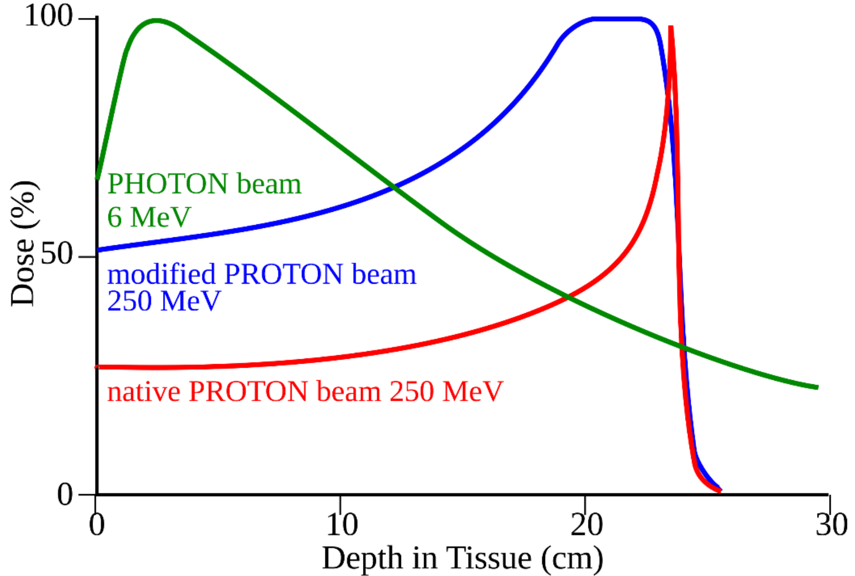


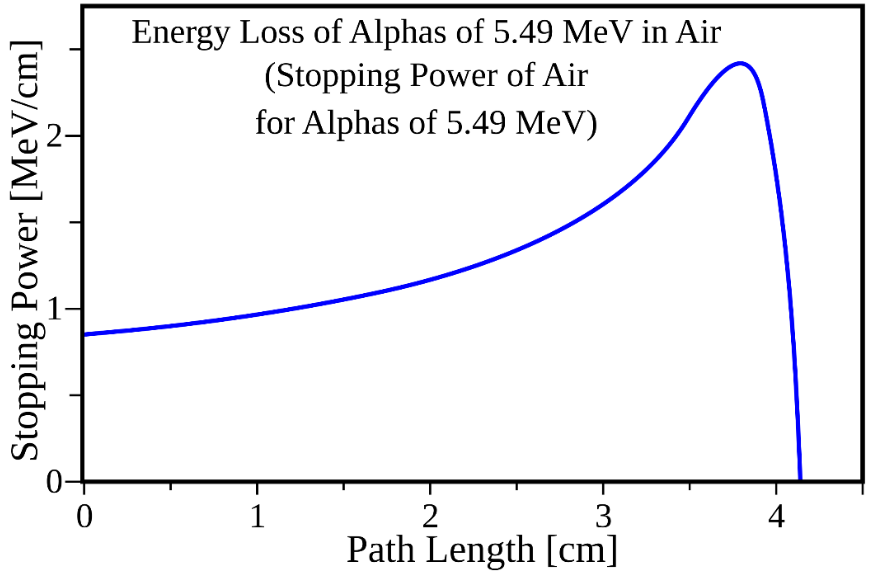
Penetration Depth of Particles into Body

Radiation Type	Typical Energy Range (MeV)	Path Length in Tissue	Key CharacteristicAlpha
Alpha	4-8 (from decay)	**Tens of micrometers** (<0.1 mm)	Short range, high ionization (high LET) – typ does NOT penetrate skin IF external – exhibit a Bragg peak
Proton	1-350 decay and accelerator therapy	**Millimeters to tens of centimeters**	Exhibit a Bragg peak (maximum dose at the end of range)
Electrons/ Positrons	0.5-5 (from decay)	**Millimeters to a few centimeters**	Range is about E/3 cm in water/tissue – no true Bragg peak
Neutrons	0.01-1000	**Centimeters to many meters** (dependent on energy and material)	Indirectly ionizing, highly penetrating, no fixed range
Gamma	0.01-10	**Centimeters to tens of centimeters/meters**	Indirectly ionizing, highly penetrating, no fixed range

Bragg Peak as Particles Traverse Material

- Bragg Peak is large large energy deposition near end of travel (range)
  - Named after William Henry Bragg who discovered this in 1903 using Alphas from Radium
  - Bragg peak is simply very large dE/dx near end of particle penetration into material
  - Particle interacts in material (ionization, inelastic collisions etc) loose energy & slow down
- In the non relativistic limit dE/dx (energy loss per unit length) ~ z^2/β^2
  - See Radiation Interactions in Matter - Robert Bigelow - Chap 5
- As particle looses energy $\beta \rightarrow 0$ so $dE/dx \rightarrow \infty$ hence dE/dx peak (Bragg Peak)





Why Alphas Show a Bragg Peak

- **Heavy & Charged:** Alpha particles (Helium nuclei) are heavy and have a +2 charge, leading to strong electromagnetic interactions with the medium.
- **Slower Speed:** As they slow down, their velocity decreases, increasing the time spent near atoms, which dramatically increases the probability of energy deposition (ionization).
- **Sharp Drop-off:** This effect culminates in a sharp peak (the Bragg peak) right at the end of their range, followed by a rapid drop to zero energy.

Why Electrons Don't Show a Clear Bragg Peak

- **Light & Mobile:** Electrons are much lighter and interact differently, scattering many times as they move.
- **Broad Scattering:** This multiple scattering makes their energy deposition profile less localized and causes significant straggling, spreading the energy loss over a wider area.
- **Broad Peak:** While they do deposit more energy towards the end of their path, it's not a sharp peak like with alphas; the profile is broader and less defined.

Summary

- **Protons/Alphas/Heavy ions:** Distinct, sharp Bragg peak (used in proton therapy).
- **Electrons:** No distinct Bragg peak due to scattering, have a broader energy deposition.

ASTRO - American Society For Radiation Oncology

and additional references

- Excellent in depth review for those interested in radiation biology
  - Medical Physics ABR Exam – see class website for detailed material
- https://www.astro.org/ASTRO/media/ASTRO/AffiliatePages/arro/Yuan%20Lecture%20PDFs/Chapter1.pdf
- Chapters 1,4-13 available
- See also Nuclear Interactions in Matter – incl NUCRAD program - Roberta Bigelow
- https://www.phys.hawaii.edu/~teb/NucRad.pdf
  - See also Nuclear and Particle Physics Simulations: The Consortium of Upper-Level Physics Software: Consortium for Upper Level Physics Software
  - https://www.amazon.com.be/-/en/Roberta-Bigelow/dp/0471548839
- OSHA Radiation Reference (see next slide for additional links)
- https://www.osha.gov/ionizing-radiation/introduction/handout
- See Nuclear and Particle Physics Experiments CAEN Handbook 2018 (PDF)
  - On class website
  - See CAEN company website for modern high speed electronics for particle physics
    - https://www.caen.it/

OSHA Radiation Review

- Attachment 1. Ionizing Radiation Equations
  - https://www.osha.gov/ionizing-radiation/introduction/ionizing-radiation-equations
- Attachment 2. Example Problems
  - https://www.osha.gov/ionizing-radiation/introduction/example-problems
- Attachment 3. Ionization
  - https://www.osha.gov/ionizing-radiation/introduction/ionization
- Attachment 4. EM Interaction
  - https://www.osha.gov/ionizing-radiation/introduction/photoelectric-interaction
- Attachment 5. Radio Active Decay Series
  - https://www.osha.gov/ionizing-radiation/introduction/ionizing-attachment-five
- Attachment 6. Maximum Permissible Dose Equivalent for Occupational Exposure
  - https://www.osha.gov/ionizing-radiation/introduction/ionizing-attachment-six
- Attachment 7. X-Ray Tube
  - https://www.osha.gov/ionizing-radiation/introduction/x-ray-tube
- Attachment 8. Radioactive Isotopes
  - https://www.osha.gov/ionizing-radiation/introduction/radioactive-isotopes
- Attachment 9. Radioactive Cobalt
  - https://www.osha.gov/ionizing-radiation/introduction/radioactive-cobalt
- Attachment 10. Tank Level Detector
  - https://www.osha.gov/ionizing-radiation/introduction/figure-8
- Attachment 11. Principal Isotopes in Sealed Sources
  - https://www.osha.gov/ionizing-radiation/introduction/principal-isotopes
- Attachment 12. Example of Half-Value Layers
  - https://www.osha.gov/ionizing-radiation/introduction/figure-10
- Attachment 13. Shielding Layer Examples
  - https://www.osha.gov/ionizing-radiation/introduction/shielding-layer-examples
- Attachment 14. Gas ionization (Regions of Instrument Response)
  - https://www.osha.gov/ionizing-radiation/introduction/gas-ionization
- Attachment 15. Radiation Detection Instruments
  - https://www.osha.gov/ionizing-radiation/introduction/radiation-detection-instruments

Neutron Detection
Converting Scintillator to Neutron Detector

- To convert a standard scintillator into a neutron detector, you add a neutron-sensitive material (like Boron-10 or Lithium-6) that converts neutrons into charged particles, which then create light in the scintillator, or use advanced techniques like wavelength-shifting fibers to separate neutron detection from light readout, enabling better neutron-gamma discrimination. The key is incorporating a material with a high neutron capture cross-section and processing the resulting light signal to differentiate it from gamma-ray interactions, often using pulse shape analysis.
- https://en.wikipedia.org/wiki/Neutron_detection
- **Next-generation neutron detection using a ^{6}Li glass scintillator composite – Jan 2025**
  - https://www.nature.com/articles/s42005-024-01903-3

More on Detecting Neutrons with a Scintillator Based Detector

Key Components & Techniques:

•**Neutron Converter**: Material like Li6 doped glass or plastic or Boron
•**Scintillator**: Base material (plastic, liquid, or crystal) that collects light
•**Light Collection**: Photomultiplier Tubes (PMTs) or Silicon Photomultipliers (SiPMs) detect light flashes
•**Pulse Shape Discrimination (PSD):** Analyzing the shape and duration of the electrical pulses to **distinguish neutron events (longer pulses) from gamma events (shorter pulses)**
•**Electronics**: Digitizers and computers process these pulses for analysis and visualization
•**IF Neutron flux is much larger than gamma, p, alpha, electron/ positron flux then you do not need the pulse discrimination electronics**
•**See also website paper on possible use of Gallium Nitride for neutron detection**

- **Neutron detection performance of Gallium Nitride (GaN) based semiconductors (used in LED's) – Zhou et al Nature 2019**
- ***Scientific Reports*** **volume 9, Article number: 17551 (2019)**

UCSB Nuclear Physics Engineering Program Reactor

Daily Nexus

Volume 69, No. 86 | Thursday, February 23, 1989 | University of California, Santa Barbara | Two Sections, 20 Pages

Current Book Causes National Controversy

Copies Disappear from Local Stores; Unavailable at B. Dalton, Waldenbooks

By Joel Brand
Reporter

Just as Salman Rushdie's controversial *The Satanic Verses* vanished from bookshelves across the country after Iran's Ayatollah Ruhollah Khomeini issued a "death sentence" for the author, the book has also become very scarce in Santa Barbara bookstores.

The book, released last fall, sat on the shelf for weeks at the Earthling Bookshop in Santa Barbara until it received international attention through Khomeini's death command and soon become a bestseller. "When the Ayatollah threatened Rushdie's life, they sold out within hours," said owner Penny Davies.

Of the six local bookstores contacted, none said it had the book in stock. But most said they would carry it when additional copies became available, which, according to Doug Smoot, senior manager of Santa Barbara Crown Books, could be as soon as the second week of March.

Employees at Santa Barbara Waldenbooks and B. Dalton, whose chains took the book off all their stores' shelves out of concern for their workers, said they were not permitted to talk about the book. None of the employees at the stores contacted said they had received any threats.

Whether Khomeini is genuinely concerned about the heretical aspects of the book or is using it instead only as a political tool has been the topic of debate among experts since the controversy began. "The book appeared very conveniently for Khomeini to unite Iran. I think he is definitely using it for his political purposes," said UCSB Islamic Religion Professor Juan Campo. "If it had been published at a different time, it probably wouldn't have had such an impact."

"Most of the people who are complaining about the book, I think haven't read it," Campo said. He added the book is a work of fiction with historical underpinnings and that Rushdie demonstrates a good understanding of the Islamic history of the prophet Mohammed.

Under Islamic law, a person can be executed for cursing Mohammed, according to Orange County Islamic Society Director Dr. Muzammil Siddiqi. But, he said, "I don't agree that this is the right position, that any man can kill (Rushdie)."

Although Siddiqi himself called the book "blasphemous," he said Iran overreacted to it. If Khomeini had not issued the death order, "it would have died by itself," Siddiqi said. "It is a boring book."

He added that he believes a more reasonable reaction for Khomeini would have been to call for Rushdie's extradition to stand trial as a heretic.

The book addresses conflicts encountered by Muslims arising

(See VERSES, p.4)

The remains of UCSB's nuclear reactor lies dormant, crated away in the depths of Broida Hall.
TONY POLLOCK/Daily Nexus

Reactor Shield Awaits Disposal

Radiation Protection Officer Says Nuclear Reactor Stripped Of Uranium Core in '86

By Tim McDaniel
Staff Writer

In the corner of a room in Broida Hall, among wooden ladders and equipment that would go unnoticed in any metal shop, sits an enormous wooden box with an American flag hanging off one side.

The box houses a lead and steel shield and some waste papers, the remains of UCSB's nuclear reactor, which was disassembled in 1986 and had its radioactive uranium removed from campus, said Frank Gallagher, UCSB Environmental Health and Safety radiation protection officer.

While these remains will eventually be taken from campus, the removal has been slowed by vague federal regulations, Gallagher said. "We're waiting for the federal agencies to get their acts together," he said. Gallagher explained that because the shield contains lead, the use of which is monitored by the Environmental Protection Agency, as well as low level radiation, which is under the jurisdiction of the Nuclear Regulatory Commission, neither agency can take full responsibility for the removal.

Donated to UCSB in 1975 by the University of Nevada at Reno, the reactor was used in Nuclear Engineering 125, an undergraduate spring quarter laboratory course, according to Professor A. Edward Profio, who was in charge of the lab. The reactor was a cylinder eight feet long and eight feet in diameter, he said, and generated only 10 watts of power, about

(See REACTOR, p.4)

Top 10 Food Types and Radioactivity

- **1. Brazil nuts**
  - pCi per kg: 12,000
  - pCi per serving: 240
- **2. Butter beans**
  - pCi per kg: 4,600
  - pCi per serving: 460
- **3. Bananas**
  - pCi per kg: 3,500
  - pCi per serving: 420
- **4. Potatoes**
  - pCi per kg: 3,400
  - pCi per serving: 850
- **5. Carrots**
  - pCi per kg: 3,400
  - pCi per serving: 255
- **6. Red meat**
  - pCi per kg: 3,000
  - pCi per serving: 240
- **7. Avocados**
  - pCi per kg: 2,500
  - pCi per serving: 420
- **8. Beer**
  - pCi per kg: 390
  - pCi per pint: 222
- **9. Water**
  - pCi per kg: 170
  - pCi per pint: 100
- **10. Peanut butter**
  - pCi per kg: 120
  - pCi per serving: 3.6

Radioactivity in Foods, Air, Water

- Air 131I, 134Cs, 137Cs
- Water 3H, 89Sr, 90Sr, 131I, 134Cs, 137Cs
- Milk 89Sr, 90Sr, 131I, 134Cs, 137Cs
- Meat 134Cs, 137Cs
- Other Foods 89Sr, 90Sr, 134Cs, 137Cs
- Vegetation 89Sr, 90Sr, 95Zr, 95Nb, 103Ru, 106Ru, 131I, 134Cs, 137Cs, 141Ce, 144Ce
- Soil 90Sr, 134Cs, 137Cs, 238Pu, 239+240Pu, 241Am, 242Cm

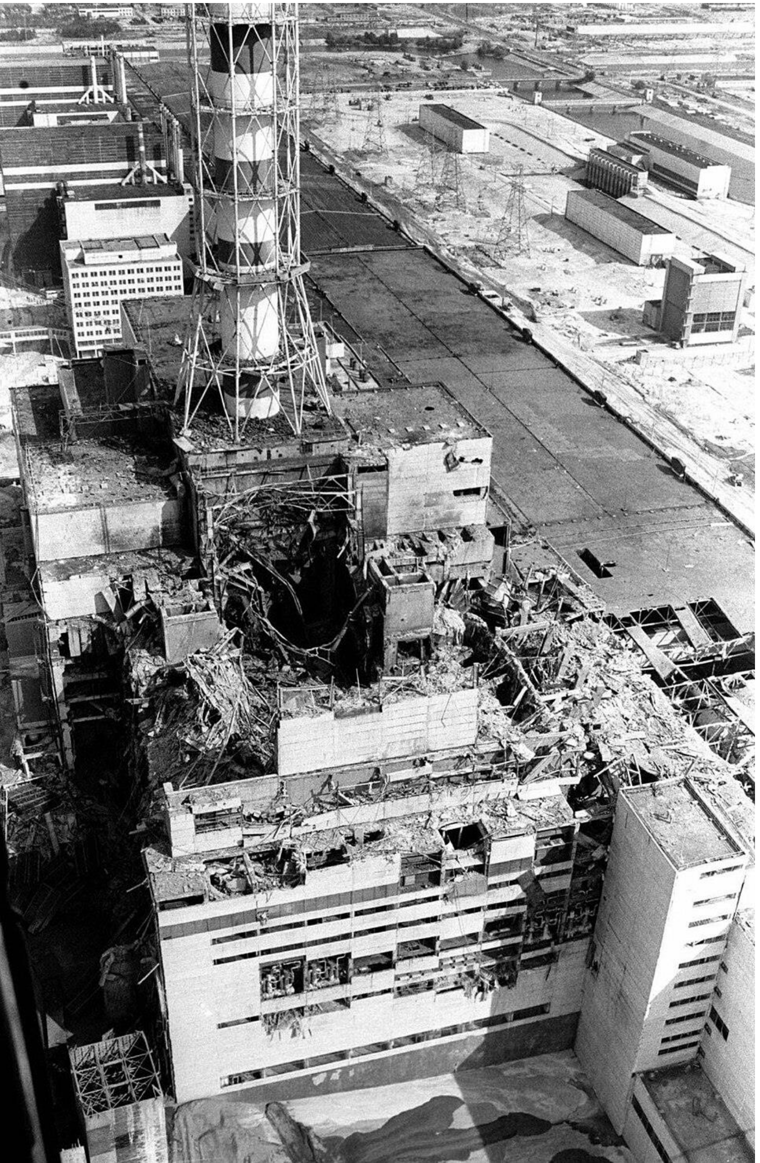
Reactor Accident Radionuclides

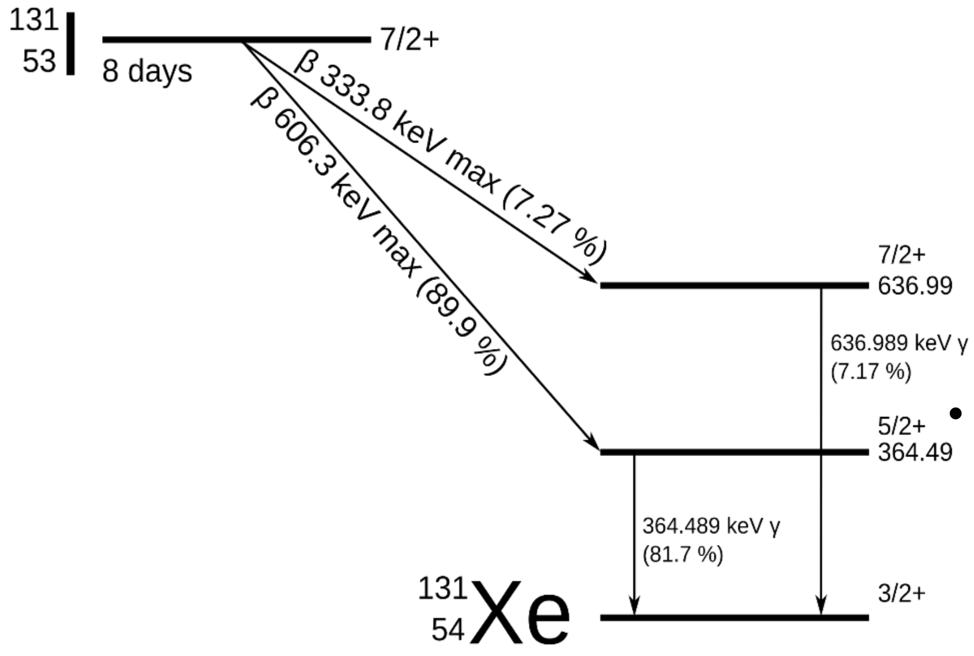
- In the case of a reactor core meltdown such as in Japan, the following nuclides are considered to be of concern:
- Radionuclides with half-lives of 6 hours or greater: 90Y, 91Sr, 93Y, 96Nb*, 97Zr, 99Mo, 105Rh, 109Pd, 111Ag, 113Pd 115Cd, 121Sn, 125Sn, 126Sb, 127Sb, 131I, 132I, 131mTe, 132Te, 133I, 135I, 140La, 142Pr*, 143Ce, 143Pr, 146Ba, 147Nd, 149Pm, 151Pm, 152mEu*, 153Sm, 156Sm, 157Eu, 239Np
- Radionuclides of long term importance: 3H, 89Sr, 90Sr, 91Y, 93mNb, 95Nb, 103Ru, 106Ru, 110mAg, 113mCd, 115mCd, 121mSn, 123Sn, 124Sb, 125Sb, 129I, 134Cs, 137Cs, 141Ce, 144Ce, 147Pm, 160Tb, 238Pu, 239Pu, 240Pu, 241Am, 241Pu, 242Cm, 242Pu, 243Am, 244Cm

Iodine 131 – Relevant to Reactor Accidents

Three Mile Island 1979, Chernobyl 1986, Fukushima 2011 – Image is Chernobyl

Note that Xe-131 is stable





$$^{131}_{53}\mathrm{I} \longrightarrow \beta + \bar{\nu}_e + ^{131}_{54}\mathrm{Xe}^* + 606\,\mathrm{keV}$$

$$^{131}_{54}\mathrm{Xe}^* \longrightarrow ^{131}_{54}\mathrm{Xe} + \gamma + 364\,\mathrm{keV}$$

- ^{131}I decays with a half-life of 8.0249 days[1] emitting beta particles and gamma rays. **Most often (89%), ^{131}I most often expends its 971 keV of decay energy by transforming to stable xenon-131 in two steps, with gamma decay following rapidly (meta-stable state – Xe*) after beta decay.**
- The primary emissions of ^{131}I decay are electrons with a maximal energy of 606 keV **and** gammas of 364 keV.[3] The Beta decay mode also produces an electron antineutrino, which carries off variable amounts of the energy. **The electrons, due to their high mean energy (190 keV, with a typical beta-decay spectrum) have a tissue penetration of 0.6 to 2 mm.**

Iodine 131 – Gamma and Beta

- **All isotopes of Iodine are radioactive with the exception of I-127**
- **I-127 is normally what you have in "normal salt" which your body needs**
  - **In particular it is in your Thyroid**
- **Medical issue with I-131 is that chemically it is the same as I-127 and thus taken up by your body. Since I-131 is radioactive it can cause Thyroid Cancer**
  - **Since I-131 has a short half-life (8 days) it is highly radioactive → thyroid cancer**
  - **If you are near a reactor accident you should take excess I-127 for a few weeks so that your body will not "take up" I-131**
- **Primary Gamma Energy:** 364 keV (kiloelectron volts) is the most prominent gamma ray, with high abundance (around 81%).
- **Other Gammas:** Weaker gamma emissions, such as a ~723 keV line, are also present but less significant.
- **Beta Emission:** I-131 also emits high-energy beta particles (up to 0.606 MeV), which are crucial for its therapeutic effect but cannot be imaged.
- **Spectrum Shape:** When measured with a detector, the spectrum shows a photopeak at 364 keV, along with Compton scattering and potentially escape peaks, depending on the detector.

Iodine 131 Implications in Nuclear Medicine

- **Therapy:** The high energy of its betas and the substantial gamma dose from the 364 keV line make I-131 effective for destroying thyroid tissue (hyperthyroidism, thyroid cancer).
- **Imaging:** The 364 keV gamma is higher than optimal for standard gamma cameras, reducing detection efficiency and image resolution, which is why I-123 (with gamma energies around 159 keV) is preferred for diagnostic imaging.
- **Detection:** Despite imaging limitations, the characteristic 364 keV gamma peak is used to identify I-131 and track its distribution in the body, especially for diagnosing metastatic thyroid cancer.

Iodine 131 Gamma Spectrum

- **Primary Gamma Energy:** 364 keV is the most prominent gamma ray, with high abundance (around 81%).
- **Other Gammas:** Weaker gamma emissions, such as a ~723 keV line, are also present but less significant.
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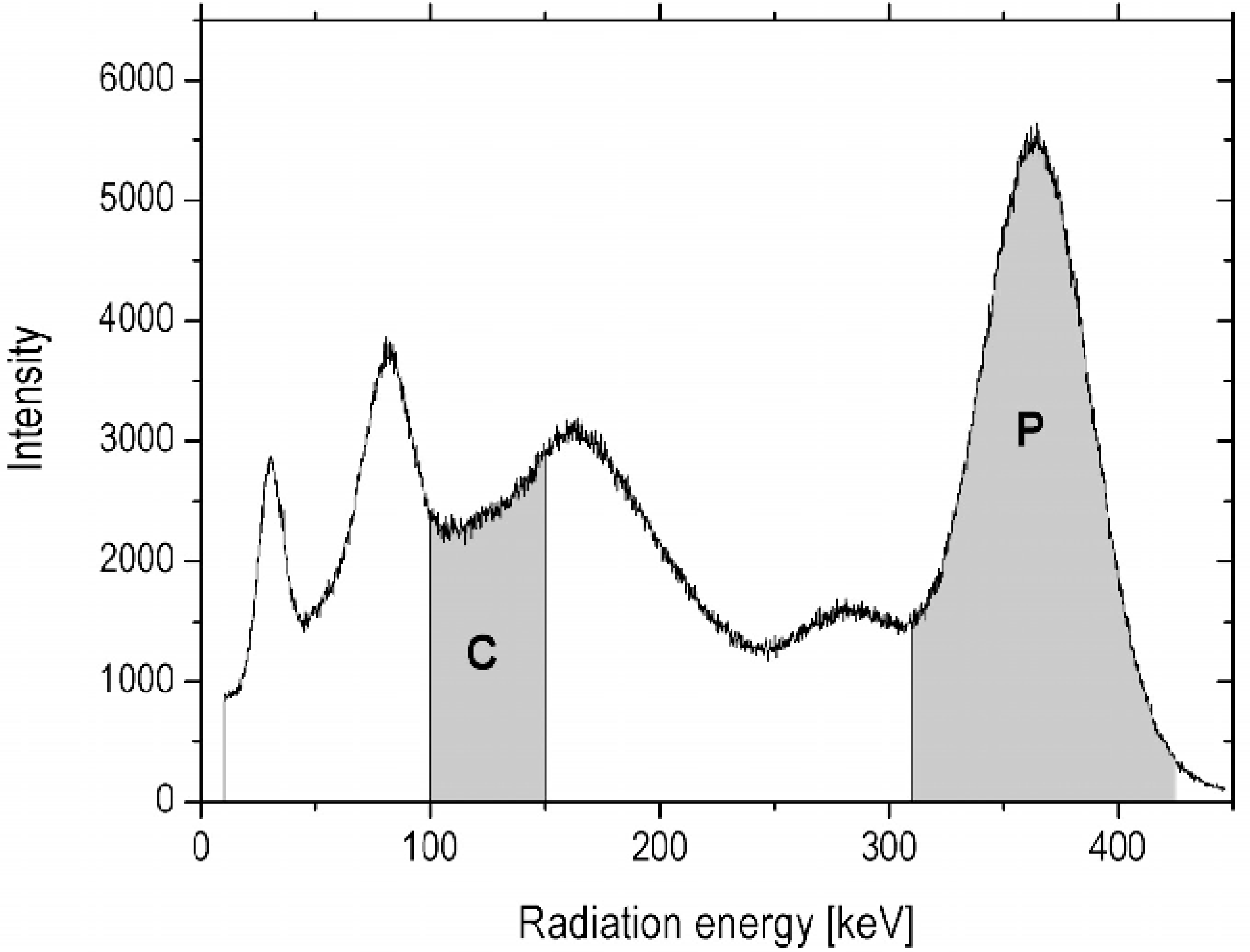
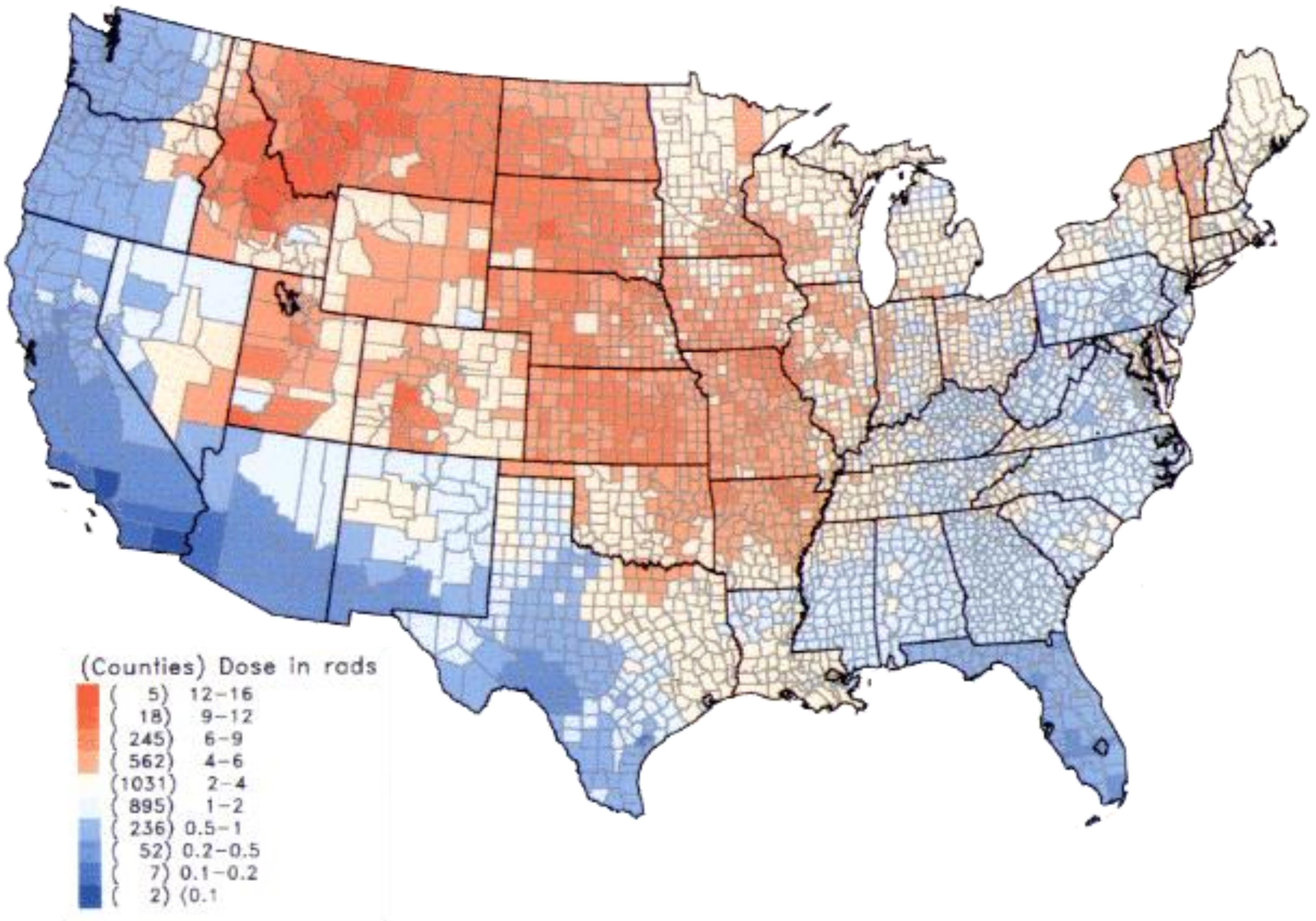


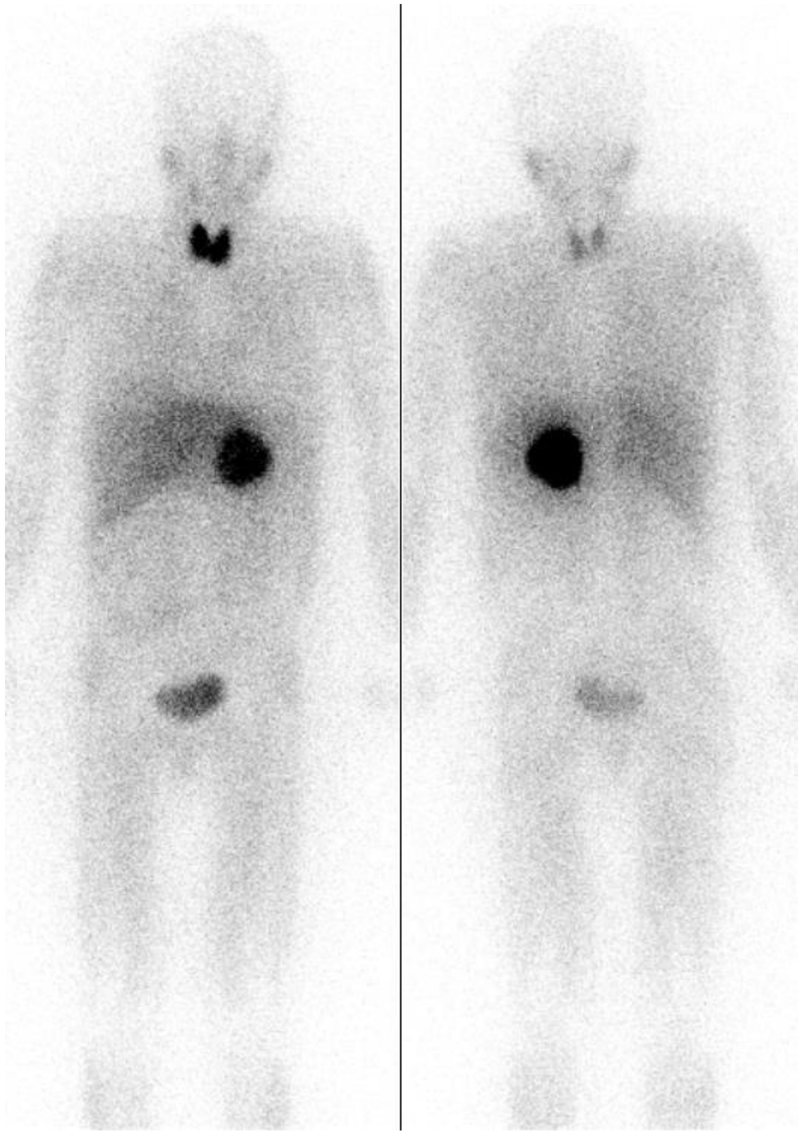
Deaths Caused by Continental US Above Ground Testing
(Nevada Test Site)

- Per capita thyroid doses (rads) in the continental United States resulting from all exposure routes from all atmospheric nuclear tests conducted at the Nevada Test Site from 1951 to 1962.
- CDC concluded ~ 11,000 deaths primarily from Thyroid cancer from I-131



Iodine 131 accumulation in Body
In this case I–131 used for Cancer tumor treatment

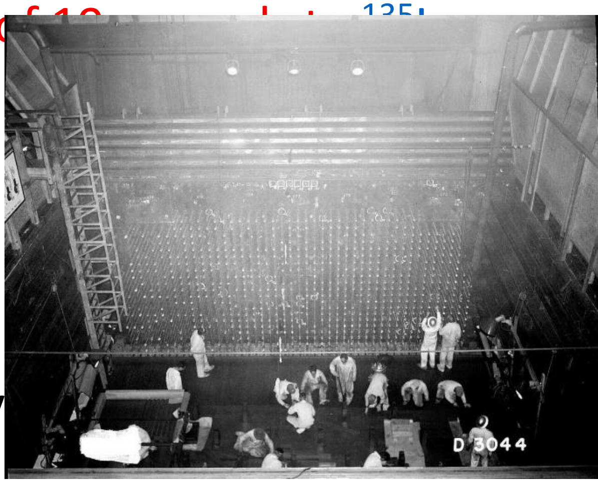
- Tumor in center of chest area
- Thyroid take up seen
- Kidney take up seen in liver, kidneys, bladder
- Salivary gland take up seen in facial area



The Curious Case of ^{135}Xe

"Neutron poisoning" ^{135}Xe in reactors

- Xe-135 is a strong absorber of neutrons
- The **iodine pit**, also called the **iodine hole** or **xenon pit**, is a temporary disabling of a nuclear reactor due to the buildup of short-lived neutron poisons in the reactor core
- The main isotope responsible is ^{135}Xe, mainly produced by beta decay of ^{135}I
  - The half-life of ^{135}I to ^{135}Xe is 6.57 hours
  - Half-life of ^{135}Xe to ^{135}Cs via (beta) electron emission = 9.14 hours
- ^{135}I is a weak absorber of neutrons while ^{135}Xe is the strongest known neutron absorber
  - ^{135}Xe absorption cross section for thermal neutrons of 2.6×10^{6} barns – **ENORMOUS!**
- Common fission product in a reactor is ^{135}Te, which undergoes beta decay with half-life



- The yield of ^{135}Xe for Uranium fission in a reactor is 6.3%
  - about 95% of ^{135}Xe originates from decay of ^{135}I
  - ^{135}Xe acts as a "poison" that can slow or stop the chain reaction after a period of operation
  - ^{135}I and ^{135}Xe in reactor main reason for power fluctuations with change of control rod positions
- ^{135}Xe reactor poisoning played a major role in the Chernobyl disaster
- By neutron capture, ^{135}Xe is transformed ("burned") to ^{136}Xe, which is effectively stable and does not significantly absorb neutrons.
- In the original Manhattan Project Hanford reactor B (250 MW) to produce Pu, the **reactor ran for one day (Sept 16, 1944 went critical) and then shutdown due to ^{135}Xe poisoning.**
- ***Solution was to use extra "fuel rods" to generate enough extra neutrons to burn ^{135}Xe to ^{136}Xe***

Some Isotopes of xenon ($_{54}Xe$) [**more on next slide**]

Main isotopes			Decay	
Isotope	abundance	half-life ($t_{1/2}$)	mode	product
^{124}Xe	0.095%	**1.1×10^{22} y**[2]	εε	^{124}Te
^{125}Xe	synth	16.87 h	β^+	^{125}I
^{126}Xe	0.089%	stable		
^{127}Xe	synth	36.342 d	ε	^{127}I
^{128}Xe	1.91%	stable		
^{129}Xe	26.4%	stable		
^{130}Xe	4.07%	stable		
^{131}Xe	21.2%	stable		
^{132}Xe	26.9%	stable		
^{133}Xe	synth	5.2474 d	β^-	^{133}Cs
^{134}Xe	10.4%	stable		
^{135}Xe	synth	9.14 h	β^-	^{135}Cs
^{136}Xe	8.86%	**2.18×10^{21} y**	$\beta^-\beta^-$	^{136}Ba

Nuclide [n 1]	Z	N	Isotopic mass (Da)	Half-life	Decay mode	Daughter isotope	Spin and parity	Natural (mole fraction)
	Excitation energy							Normal proportion
108Xe [n 9]	54	54	107.95423(41)	72(35) μs	α	^{104}Te	0+	
^{109}Xe	54	55	108.95076(32)#[11]	13(2) ms	α	^{105}Te	(7/2+)	
^{110}Xe	54	56	109.94426(11)	93(3) ms	α (64%)	^{106}Te	0+	
^{110}Xe	54	56	109.94426(11)	93(3) ms	β+ (36%)	^{110}I	0+	
^{111}Xe	54	57	110.941460(64)[11]	740(200) ms	$β^+$ (89.6%)	^{111}I	5/2+#	
^{111}Xe	54	57	110.941460(64)[11]	740(200) ms	α (10.4%)	^{107}Te	5/2+#	
^{112}Xe	54	58	111.9355591(89)	2.7(8) s	$β^+$ (98.8%)	^{112}I	0+	
^{112}Xe	54	58	111.9355591(89)	2.7(8) s	α (1.2%)	^{108}Te	0+	
^{113}Xe	54	59	112.9332217(73)	2.74(8) s	$β^+$ (92.98%)	^{113}I	5/2+#	
^{113}Xe	54	59	112.9332217(73)	2.74(8) s	β+, p (7%)	^{112}Te	5/2+#	
^{113}Xe	54	59	112.9332217(73)	2.74(8) s	α (?%)	^{109}Te	5/2+#	
^{113}Xe	54	59	112.9332217(73)	2.74(8) s	$β^+$, α (~0.007%)	^{109}Sb	5/2+#	
^{113m}Xe	403.6(14) keV			6.9(3) μs	IT	^{113}Xe	(11/2−)	
^{114}Xe	54	60	113.927980(12)	10.0(4) s	$β^+$	^{114}I	0+	
^{115}Xe	54	61	114.926294(13)	18(3) s	$β^+$ (99.66%)	^{115}I	(5/2+)	
^{115}Xe	54	61	114.926294(13)	18(3) s	$β^+$, p (0.34%)	^{114}Te	(5/2+)	
^{116}Xe	54	62	115.921581(14)	59(2) s	$β^+$	^{116}I	0+	
^{117}Xe	54	63	116.920359(11)	61(2) s	$β^+$	^{117}I	5/2+	
^{117}Xe	54	63	116.920359(11)	61(2) s	$β^+$, p (0.0029%)	^{116}Te	5/2+	
^{118}Xe	54	64	117.916179(11)	3.8(9) min	$β^+$	^{118}I	0+	
^{119}Xe	54	65	118.915411(11)	5.8(3) min	$β^+$ (79%)	^{119}I	5/2+	
^{119}Xe	54	65	118.915411(11)	5.8(3) min	EC (21%)	^{119}I	5/2+	
^{120}Xe	54	66	119.911784(13)	46.0(6) min	$β^+$	^{120}I	0+	
^{121}Xe	54	67	120.911453(11)	40.1(20) min	$β^+$	^{121}I	5/2+	
^{122}Xe	54	68	121.908368(12)	20.1(1) h	EC	^{122}I	0+	
^{123}Xe	54	69	122.908482(10)	2.08(2) h	$β^+$	^{123}I	1/2+	
^{123m}Xe	185.18(11) keV			5.49(26) μs	IT	^{123}Xe	7/2−	
124Xe[n 10]	54	70	123.9058852(15)	1.1(2)×1022 y	Double EC	**^{124}Te**	0+	$9.5(5)×10^{-4}$
^{125}Xe	54	71	124.9063876(15)	16.87(8) h	EC / $β^+$	^{125}I	1/2+	
^{125m1}Xe	252.61(14) keV			56.9(9) s	IT	^{125}Xe	9/2−	
^{125m2}Xe	295.89(15) keV			0.14(3) μs	IT	^{125}Xe	7/2+	
^{126}Xe	54	72	125.904297422(6)	Observationally Stable			0+	$8.9(3)×10^{-4}$
^{127}Xe	54	73	126.9051836(44)	36.342(3) d	EC	**^{127}I**	1/2+	
^{127m}Xe	297.10(8) keV			69.2(9) s	IT	^{127}Xe	9/2−	
^{128}Xe	54	74	127.9035307534(56)	Stable			0+	0.01910(13)
^{128m}Xe	2787.2(3) keV			83(2) ns	IT	**^{128}Xe**	8−	
129Xe [n 12]	54	75	128.9047808574(54)	Stable			1/2+	0.26401(138)
^{129m}Xe	236.14(3) keV			8.88(2) d	IT	**^{129}Xe**	11/2−	
^{130}Xe	54	76	129.903509346(10)	Stable			0+	0.04071(22)
131Xe [N 13]	54	77	130.9050841281(55)	Stable			3/2+	0.21232(51)
131mXe [N 13]	163.930(8) keV			11.948(12) d	IT	**^{131}Xe**	11/2−	
132Xe [13]	54	78	131.9041550835(54)	Stable			0+	0.26909(55)
^{132m}Xe	2752.21(17) keV			8.39(11) ms	IT	**^{132}Xe**	(10+)	
^{133}Xe [N 13, 14]	54	79	132.9059107(26)	5.2474(5) d	$β^-$	**^{133}Cs**	3/2+	
133m1Xe [n 13]	233.221(15) keV			2.198(13) d	IT	^{133}Xe	11/2−	
^{133m2}Xe	2147(20)# keV			8.64(13) ms	IT	^{133}Xe	(23/2+)	
134Xe [n 13]	54	80	133.905393030(6)	Observationally Stable			0+	0.10436(35)
^{134m1}Xe	1965.5(5) keV			290(17) ms	IT	**^{134}Xe**	7−	
^{134m2}Xe	3025.2(15) keV			5(1) μs	IT	**^{134}Xe**	(10+)	
^{135}Xe [n 16]	54	81	134.9072314(39)	9.14(2) h	$β^-$	^{135}Cs	3/2+	
135mXe [N 13]	526.551(13) keV			15.29(5) min	IT (99.70%)	^{135}Xe	11/2−	
135mXe [N 13]	526.551(13) keV			15.29(5) min	$β^-$ (0.30%)	^{135}Cs	11/2−	
^{136}Xe [n13, 16]	54	82	135.907214474(7)	**$2.18(5)×10^{21}$ y**	$β^-β^-$	**^{136}Ba**	0+	0.08857(72)
^{136m}Xe	1891.74(7) keV			2.92(3) μs	IT	***^{136}Xe***	6+	
^{137}Xe	54	83	136.91155777(11)	3.818(13) min	$β^-$	^{137}Cs	7/2−	
^{138}Xe	54	84	137.9141463(30)	14.14(7) min	$β^-$	^{138}Cs	0+	
^{139}Xe	54	85	138.9187922(23)	39.68(14) s	$β^-$	^{139}Cs	3/2−	
^{140}Xe	54	86	139.9216458(25)	13.60(10) s	$β^-$	^{140}Cs	0+	
^{141}Xe	54	87	140.9267872(31)	1.73(1) s	$β^-$ (99.96%)	^{141}Cs	5/2−	
^{141}Xe	54	87	140.9267872(31)	1.73(1) s	β−, n (0.044%)	^{140}Cs	5/2−	
^{142}Xe	54	88	141.9299731(29)	1.23(2) s	$β^-$ (99.63%)	^{142}Cs	0+	
^{142}Xe	54	88	141.9299731(29)	1.23(2) s	$β^-$, n (0.37%)	^{141}Cs	0+	
^{143}Xe	54	89	142.9353696(50)	511(6) ms	$β^-$ (99.00%)	^{143}Cs	5/2−	
^{143}Xe	54	89	142.9353696(50)	511(6) ms	$β^-$, n (1.00%)	^{142}Cs	5/2−	
^{144}Xe	54	90	143.9389451(57)	0.388(7) s	$β^-$ (97.0%)	^{144}Cs	0+	
^{144}Xe	54	90	143.9389451(57)	0.388(7) s	$β^-$, n (3.0%)	^{143}Cs	0+	
^{145}Xe	54	91	144.944720(12)	188(4) ms	$β^-$ (95.0%)	^{145}Cs	3/2−#	
^{145}Xe	54	91	144.944720(12)	188(4) ms	$β^-$, n (5.0%)	^{144}Cs	3/2−#	
^{146}Xe	54	92	145.948518(26)	146(6) ms	$β^-$	^{146}Cs	0+	
^{146}Xe	54	92	145.948518(26)	146(6) ms	$β^-$, n (6.9%)	^{145}Cs	0+	
^{147}Xe	54	93	146.95448(22)#	88(14) ms	$β^-$ (>92%)	^{147}Cs	3/2−#	
^{147}Xe	54	93	146.95448(22)#	88(14) ms	$β^-$, n (<8%)	^{146}Cs	3/2−#	
^{148}Xe	54	94	147.95851(32)#	85(15) ms	$β^-$	^{148}Cs	0+	
^{149}Xe	54	95	148.96457(32)#	50# ms [>550 ms]			3/2−#	
^{150}Xe	54	96	149.96888(32)#	40# ms [>550 ns]			0+	

Xenon Isotope Description for Table Above

1 mXe – Excited nuclear isomer.
2 ( ) – Uncertainty (1σ) is given in concise form in parentheses after the corresponding last digits.
3 # – Atomic mass marked #: value and uncertainty derived not from purely experimental data, but at least partly from trends from the Mass Surface (TMS).
4 **Bold half-life – nearly stable, half-life longer than age of universe.**
5 **Modes of decay:**

EC:	**Electron capture**
IT:	**Isomeric transition**
n:	**Neutron emission**

6 Bold symbol as daughter – Daughter product is stable.
7 ( ) spin value – Indicates spin with weak assignment arguments.
8 # – Values marked # are not purely derived from experimental data, but at least partly from trends of neighboring nuclides (TNN).
9 Heaviest known isotope with equal numbers of protons and neutrons
10 Primordial radionuclide
11 Theoretically capable of 2EC decay to 126Te
12 Used in a method of radiodating groundwater and to infer certain events in the Solar System's history
13 Fission product
14 Has medical uses
15 Theoretically capable of β−β− decay to 134Ba with a half-life over 2.8×1022 years[6]
16 Most powerful known neutron absorber, produced in nuclear power plants as a decay product of 135I, itself a decay product of 135Te, a fission product. Normally absorbs neutrons in the high neutron flux environments to become 136Xe; see iodine pit for more information

The isotopic composition refers to that in air.

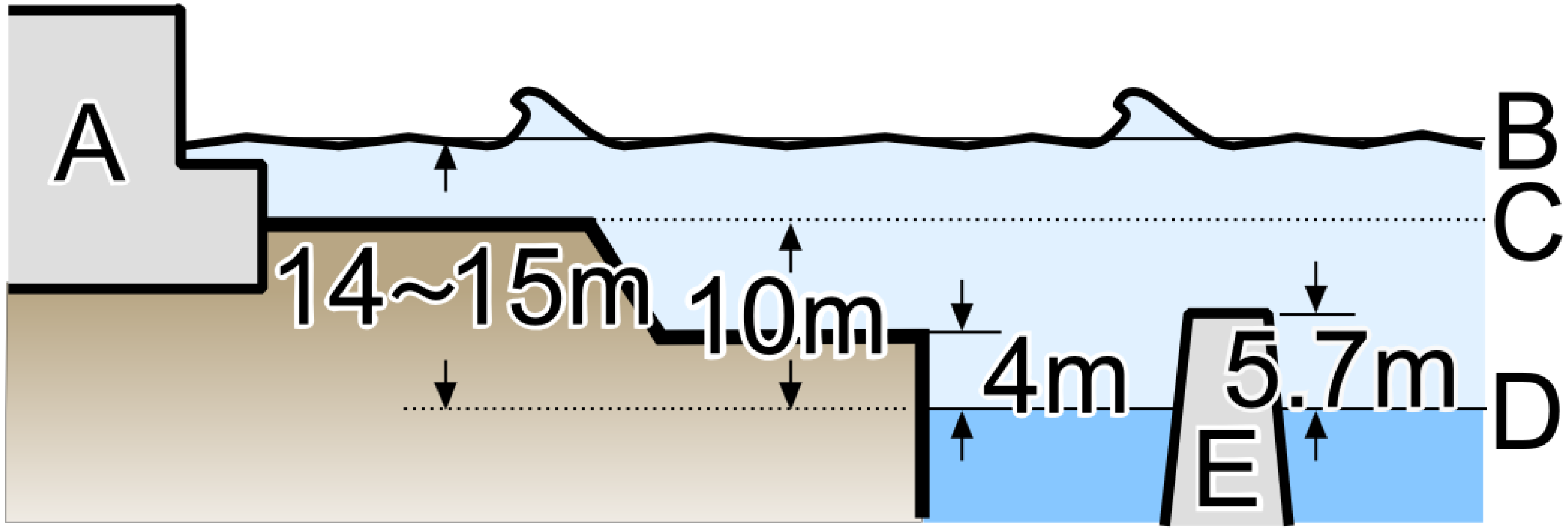
Fukushima Reactor Accident – Six Reactors at Site

Units 1,2 exploded (core melt down), 3 severe damage, 4 light damage - repaired

- March 11, 2011 – Cause was Tsunami wave
- Severe damage from tsunami knocking out backup power for cooling pumps
- Rated a Level 7 (major accident) on the International Nuclear Event Scale
  - https://en.wikipedia.org/wiki/International_Nuclear_and_Radiological_Event_Scale
- Casualties
  - 6 with cancer
  - 16 physical due to Hydrogen explosion in reactor
  - 2 hospitalized radiation burns
  - 164,000 evacuated
- Mag 9.0 Earthquake
  - Tohuka epicenter
  - 50 minutes later tsunami hit
  - 14m (45 ft) wave height
  - Max g force 560 Gal (cm/s^2)
- Right image: Unit 3 after explosion
- Came within 30cm of core melt into ground
  - **"China Syndrome" (movie)**

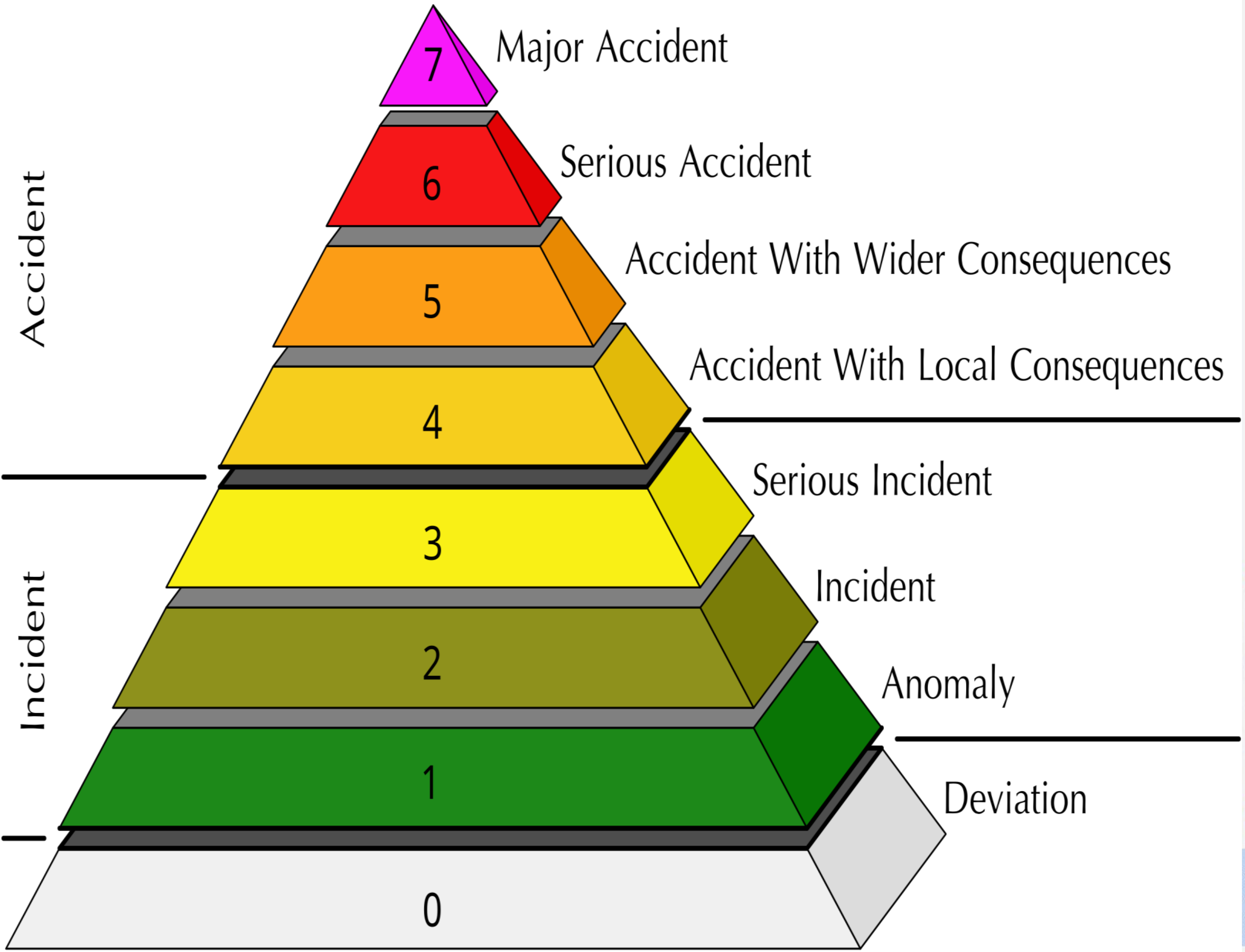
Tsunami Details

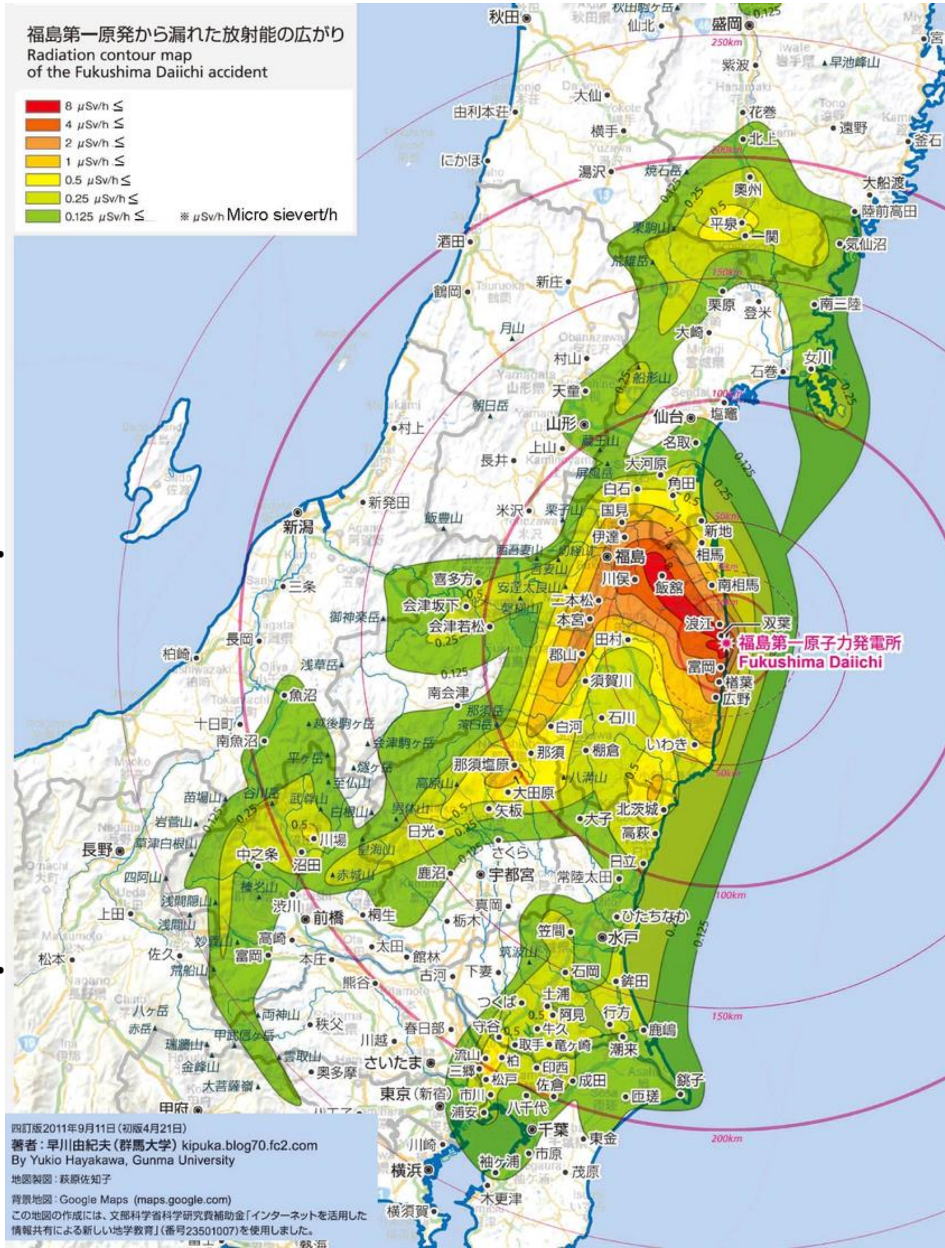
- The height of the tsunami that struck the station approximately 50 minutes after the earthquake
  A: Power station buildings
  B: Peak height of tsunami
  C: Ground level of site
  D: Average sea level
  E: Seawall to block waves
- Hydrogen explosion in units 1,3,4 -



Rated a Level 7 (major accident) on the International Nuclear Event Scale

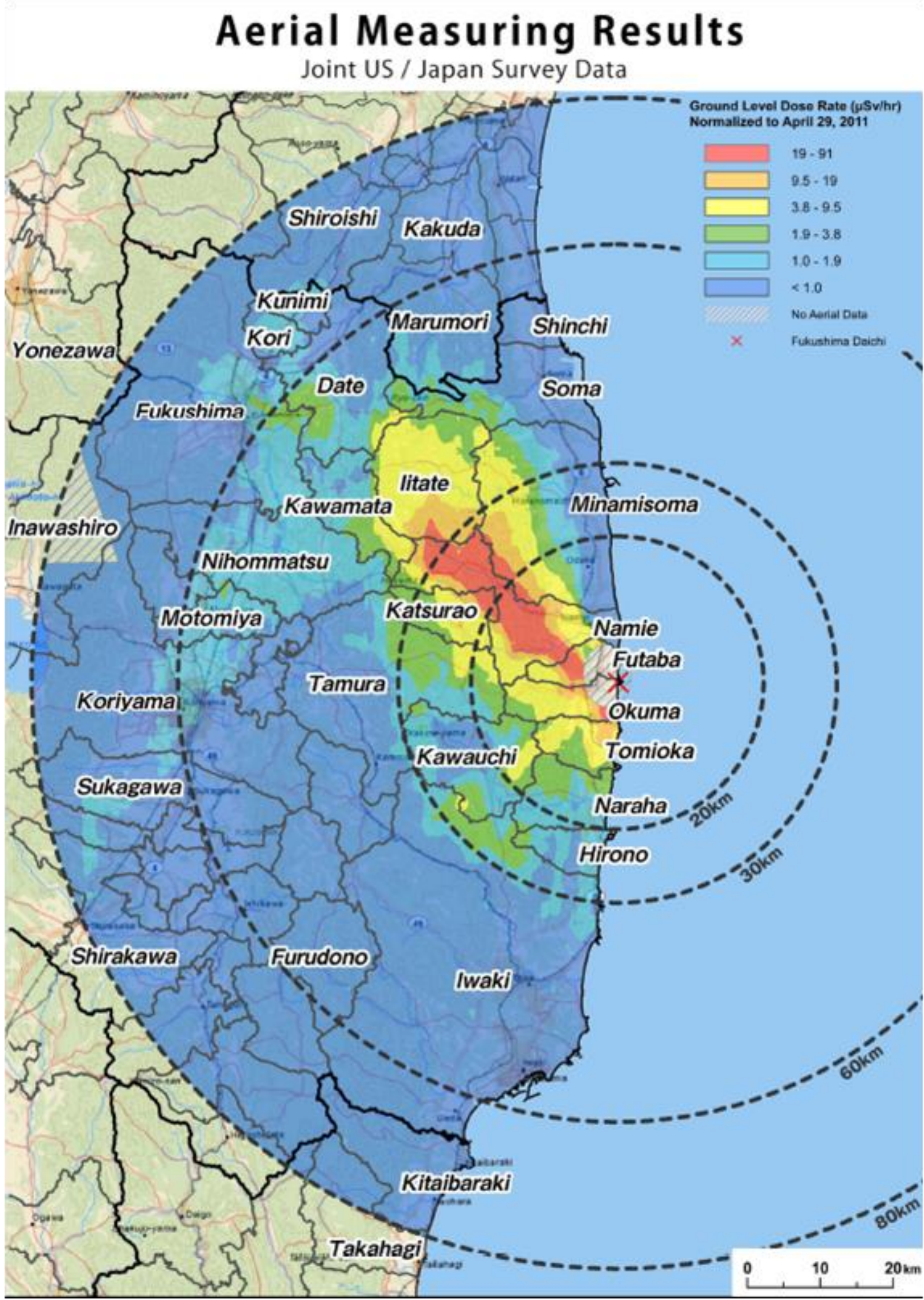
https://en.wikipedia.org/wiki/International_Nuclear_and_Radiological_Event_Scale





Radiation and Radiological Effects from Fukushima

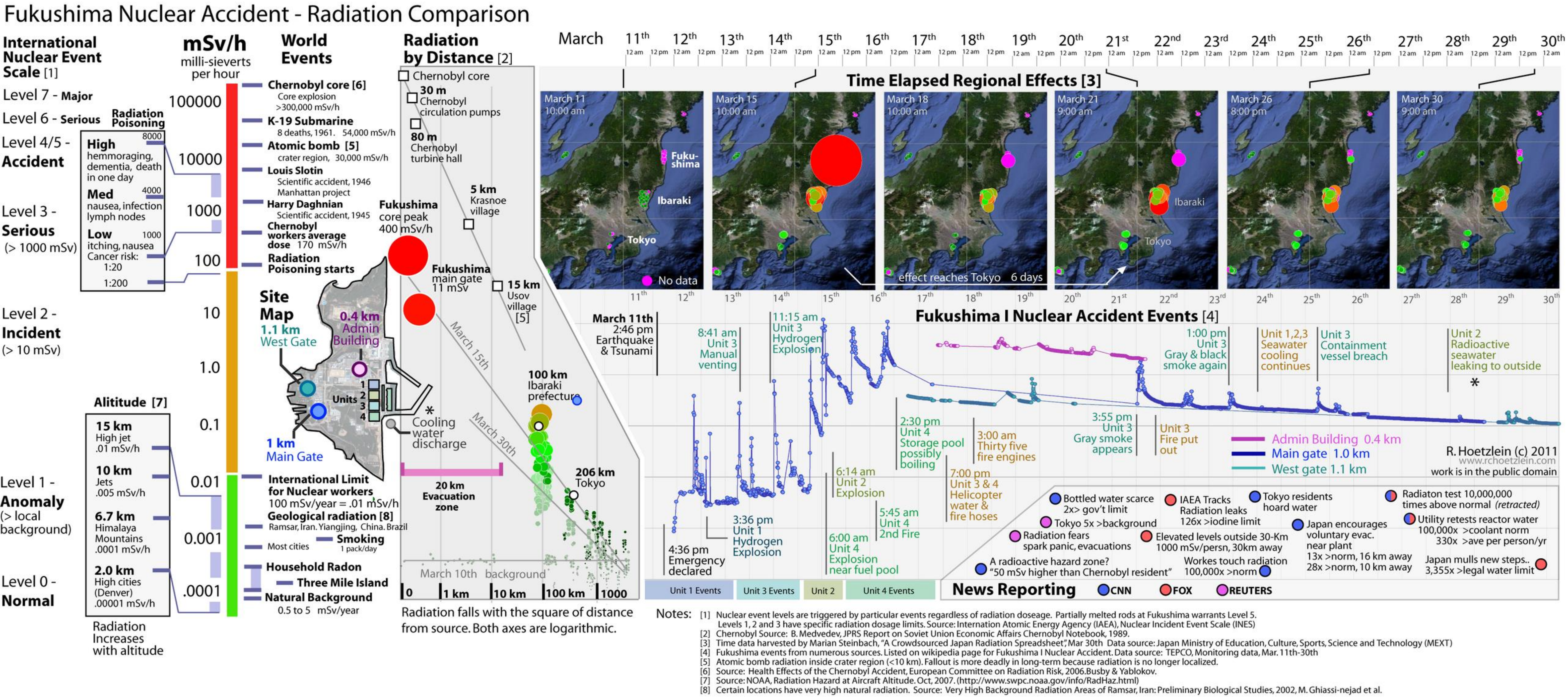
- Contours on right image are in micro Sv/hr
- A June **2012 Stanford University study estimated, using a linear no-threshold model, that the radioactivity release from the Fukushima Daiichi nuclear plant could cause 130 deaths from cancer globally (the lower bound for the estimate being 15 and the upper bound 1100**) and 199 cancer cases in total (the lower bound being 24 and the upper bound 1800)
- December 2012 UNSCEAR statement to the Fukushima Ministerial Conference on Nuclear Safety advised that **"because of the great uncertainties in risk estimates at very low doses, UNSCEAR does not recommend multiplying very low doses by large numbers of individuals to estimate numbers of radiation-induced health effects within a population exposed to incremental doses at levels equivalent to or lower than natural background levels.**



Radiation Release and Isotopes

- An estimated 538.1 petabecquerels (PBq) of iodine-131, caesium-134 and caesium-137 was released.
- 520 PBq was released into the atmosphere between 12 and 31 March 2011
- 18.1 PBq into the ocean from 26 March to 30 September 2011.
- A total of 511 PBq of iodine-131 was released into both the atmosphere and the ocean, 13.5 PBq of caesium-134 and 13.6 PBq of caesium-137.
- In May 2012, TEPCO reported that at least 900 PBq had been released "into the atmosphere in March last year [2011] alone" up from previous estimates of 360–370 PBq total
  - **TEPCO = Tokyo Electric Power Company**
- The primary releases of radioactive nuclides have been iodine and cesium; strontium and plutonium have also been found
- June 2011 report of the International Atomic Energy Agency (IAEA), at that time no confirmed long-term health effects to any person had been reported as a result of radiation exposure from the nuclear accident.
- Japanese government claims that the release of radioactivity is about one-tenth of that from the Chernobyl disaster, and the contaminated area is also about one-tenth that of Chernobyl

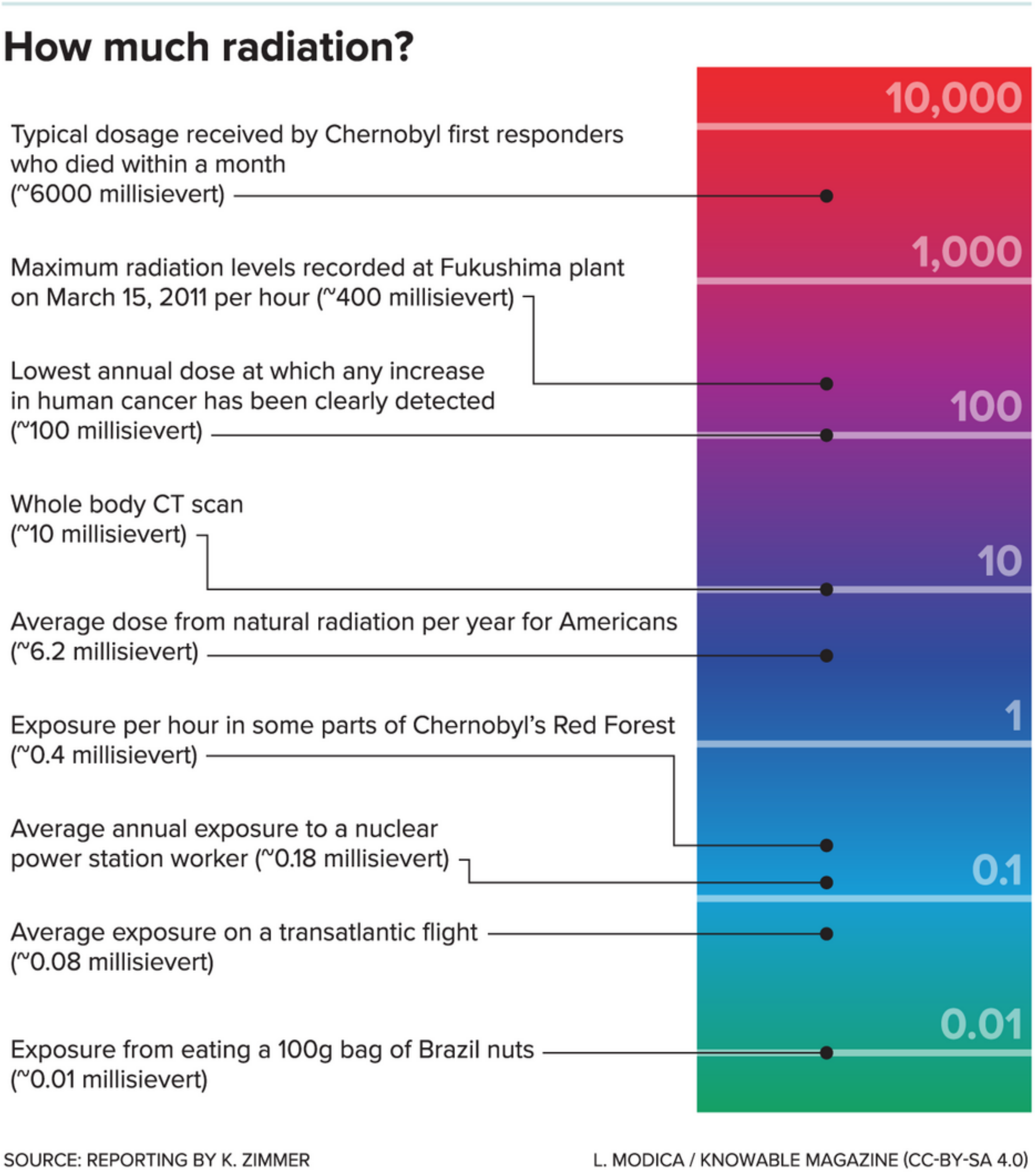
en.wikipedia.org/wiki/Radiation_effects_from_the_Fukushima_nuclear_accident



Radiation Dose Comparison

Note Chernobyl and Fukushim

- Psychological Issues (PTSD)
- At least **10% of participants in studies following the Fukushima disaster developed PTSD**
- Fukushima Prefecture adult participants needing support was **15.8% in 2013, a nearly 6% decrease compared to what was observed in 2011 after the disaster**

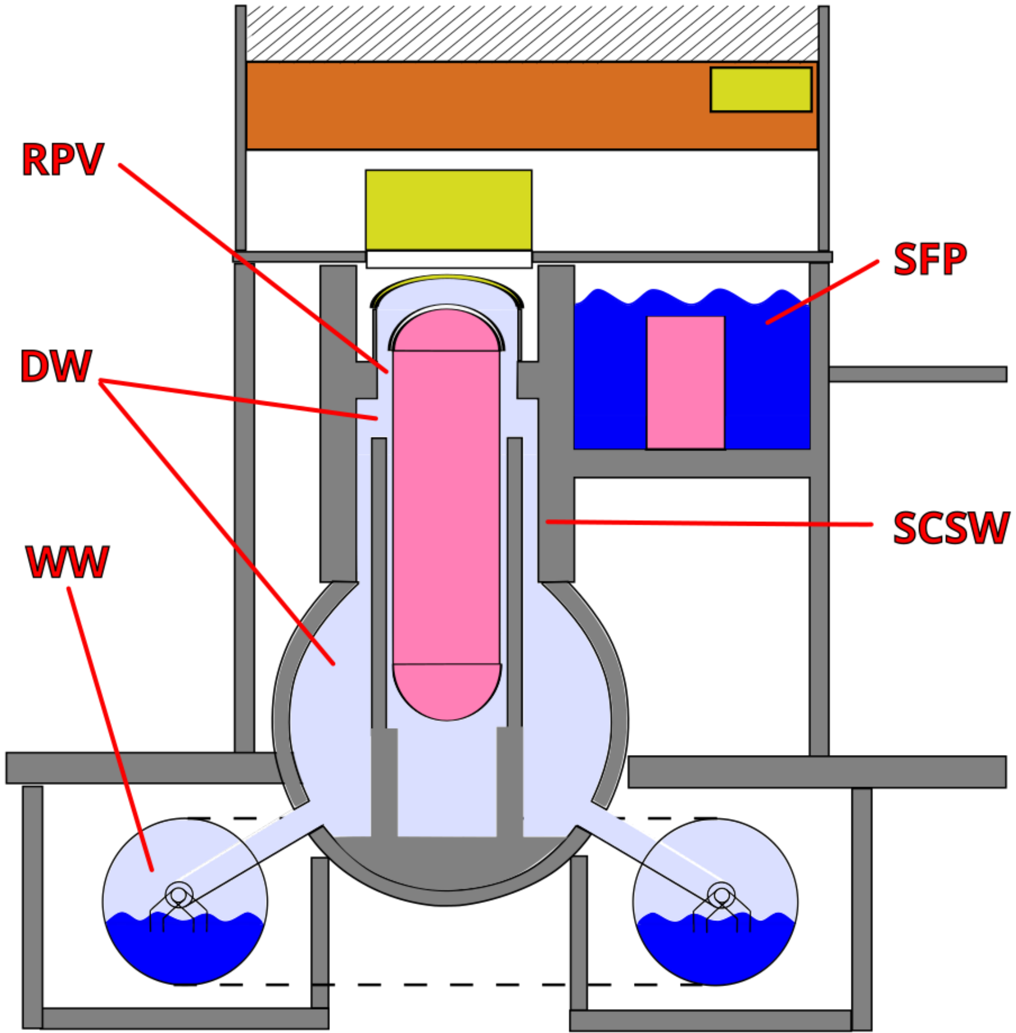


Fukushima Reactors 1-6 Layout

- Right: Aerial view of the station in 1975, showing separation between units 5 and 6, and 1–4. Unit 6, completed in 1979, is seen under construction
- Damaged units 4,3,2,1 from left to right

Fukushima Reactor Design

- **RPV**: reactor pressure vessel
  DW: drywell enclosing reactor pressure vessel
  WW: wetwell – torus-shaped all around the base enclosing steam suppression pool. Excess steam from the drywell enters the wetwell water pool via downcomer pipes.
  SFP: spent fuel pool area
  SCSW: secondary concrete shield wall



Some movies on Fukushima Accident

- **Fukushima Ten years later**
  - https://youtu.be/Lxg38I0P7z4
- Fukushima accident movie
  - https://www.youtube.com/watch?v=sZN3prnIdtA