Lecture 10
Nuclear Weapons Effects

Primary reference – we have posted on bCourses

The Effects of Nuclear Weapons

Compiled and edited by
Samuel Glasstone *and* Philip J. Dolan

Third Edition

Prepared and published by the
UNITED STATES DEPARTMENT OF DEFENSE
and the
ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION

1977

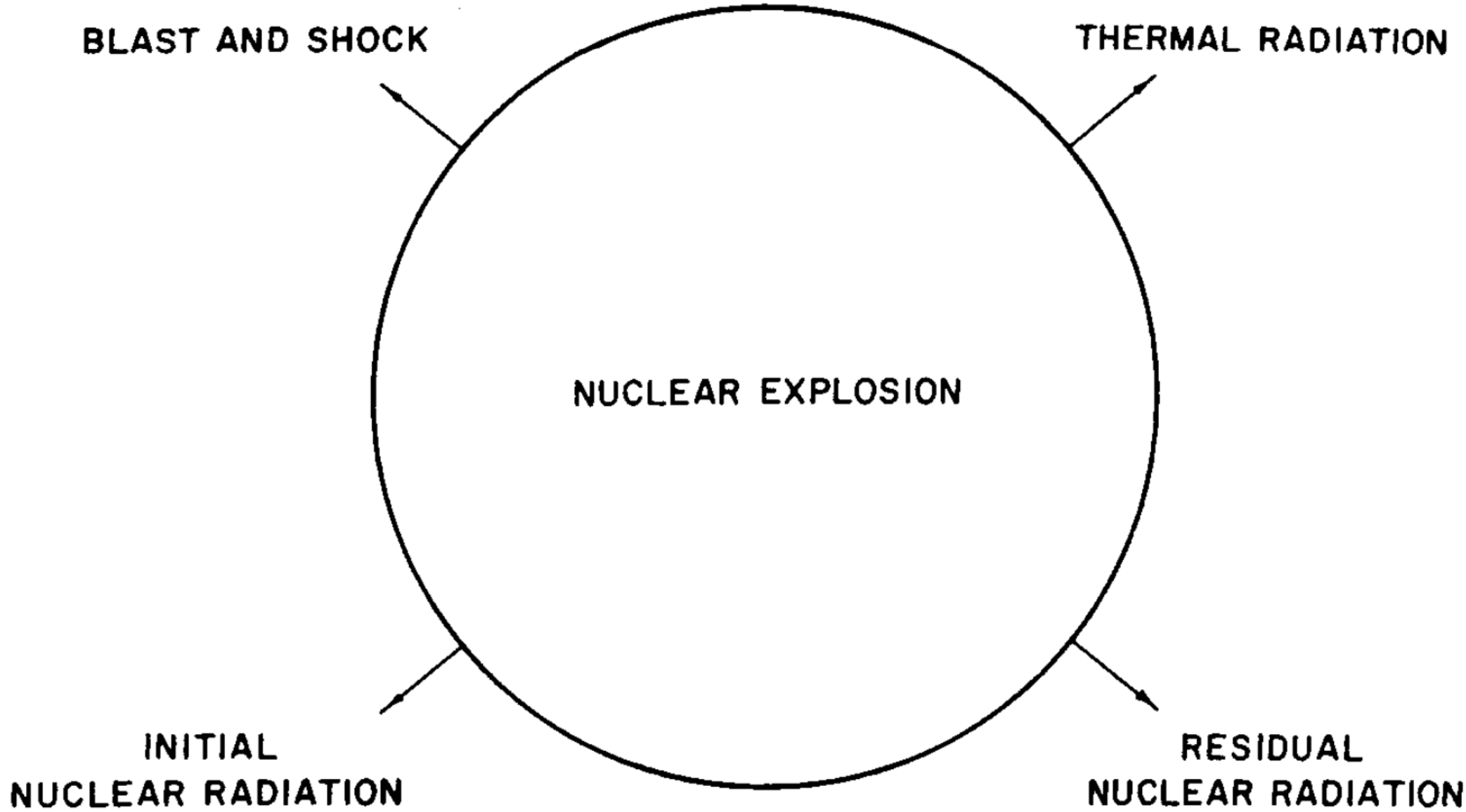
For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

I have also cribbed from a talk by Alexander Glaser (Princeton, 2007), but whose primary reference was also Glasstone & Dolan, to be safe

Effects in context of 2 weapons

- 20 kT Trinity bomb (fission)
  - https://www.youtube.com/watch?v=7dfK9G7UDok
- 15 MT bomb (fission-fusion)
  - https://www.youtube.com/watch?v=R5_9Gi7w19Y

General categorization of physical effects



Nuclear Weapon Tests

	USA	Russia	U.K.	France	China	Total
Atmo-spheric	1945-63	1949-62	1952-58	1960-74	1964-80	528
	215	219	21	50	23	
Under-ground	1951-92	1961-90	1962-91	1961-96	1969-96	1517
	815	496	24	160	22	
Total	1030	715	45	210	45	2045

India (1974, 1998): 1 + 5 Pakistan (1998): ca. 6 North Korea (2006): 1

Burst Types

- Air burst
- High-altitude burst (above 100,000 ft)
- Underwater burst
- Underground burst
- Surface burst

In the following: primary focus on (medium-altitude) air bursts
(fireball above surface, weak coupling into ground)

Effects of a Nuclear Explosion

Typical distribution of energy released

- Thermal radiation (including light) (35%)
- Blast (pressure shock wave) (50%)
- Nuclear radiation (prompt and delayed) (15%)

Effects of a Nuclear Explosion

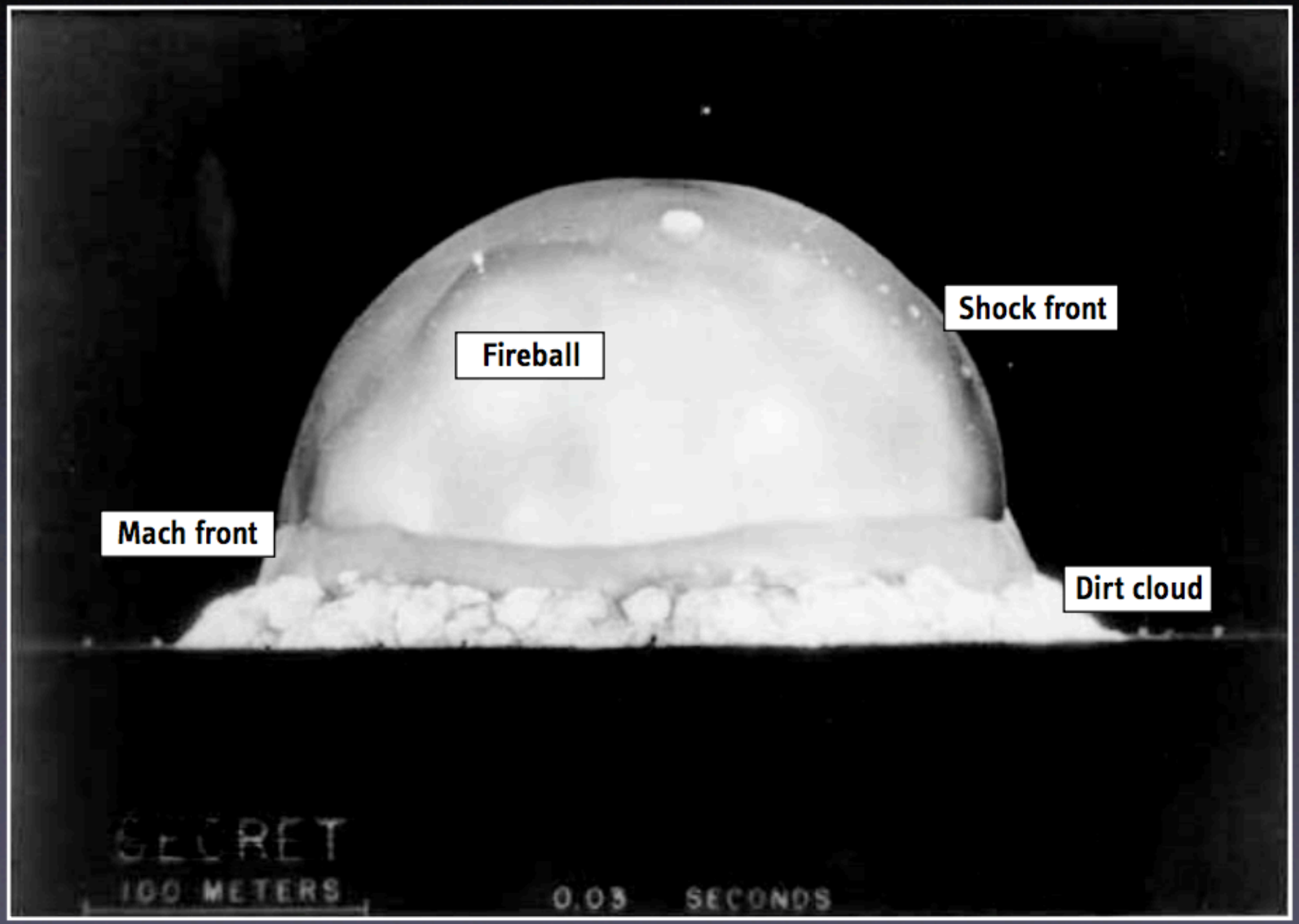
Sequence of events, Part I

FIREBALL
starts to form in less than a millionth of a second after explosion several tens of million of degrees: transformation of all matter into gas/plasma thermal radiation as x-rays, absorbed by the surrounding atmosphere
for 1 Mt explosion : 440 ft in one millisecond, 5,700 ft in 10 seconds after one minute: cooled, no longer visible radiation
Formation of the fireball triggers the destructive effects of the nuclear explosion

For comparison, the Trinity fireball was ~ ¼ mile diameter

Trinity Test

July 16, 1945



Effects of a Nuclear Explosion

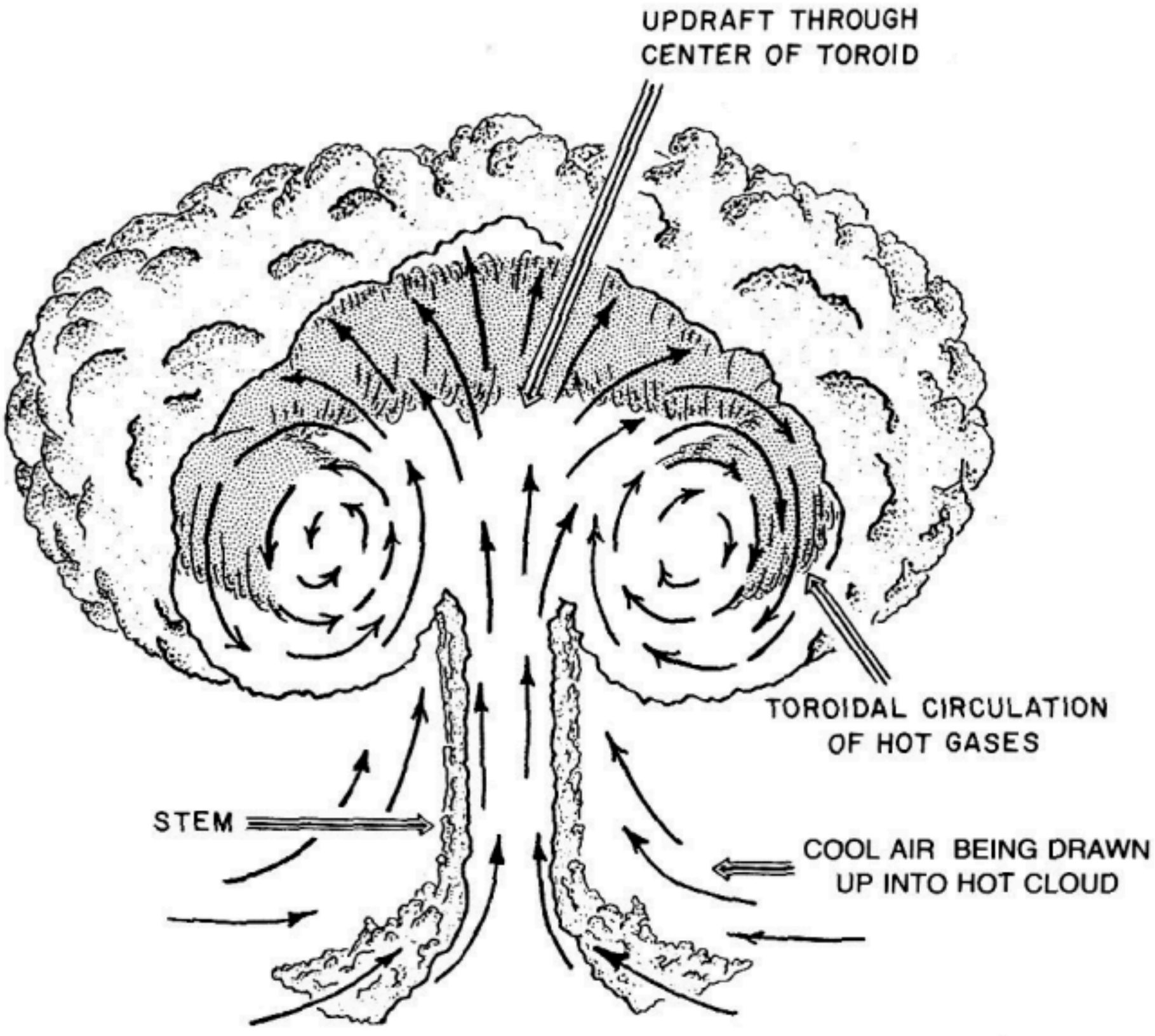
Sequence of events, Part II

RADIOACTIVE CLOUD

During expansion of the fireball, vaporized matter condenses to a cloud containing solid particles of weapon debris

Fireball becomes doughnut-shaped, violent internal circulatory motion
Air is entrained from the bottom
"mushroom" cloud if dirt and debris sucked up from earth's surface

(Source term for radioactive fallout)


UPDRAFT THROUGH
CENTER OF TOROID
TOROIDAL CIRCULATION
OF HOT GASES
STEM
COOL AIR BEING DRAWN
UP INTO HOT CLOUD

Effects of a Nuclear Explosion

Sequence of events, Part III

AIR BLAST / SHOCK WAVE

Pressure wave develops immediately after explosion
and moves outward from the fireball

After 10 seconds of 1 Mt explosion:
diameter of fireball: 5,700 ft, distance of shock front: 3 miles
Wave is reflected from surface, both waves merge to create “Mach wave”

THERMAL RADIATION

Reemitted radiation from the fireball (secondary thermal radiation)

Duration: about 10 seconds for 1 Mt explosion (99% of total thermal energy)

Effects of a Nuclear Explosion

Sequence of events, Part IV

INITIAL (PROMPT/DIRECT) NUCLEAR RADIATION

Defined as radiation releases within the first minute
mostly neutrons and gammas (directly from the explosion or from fission products)

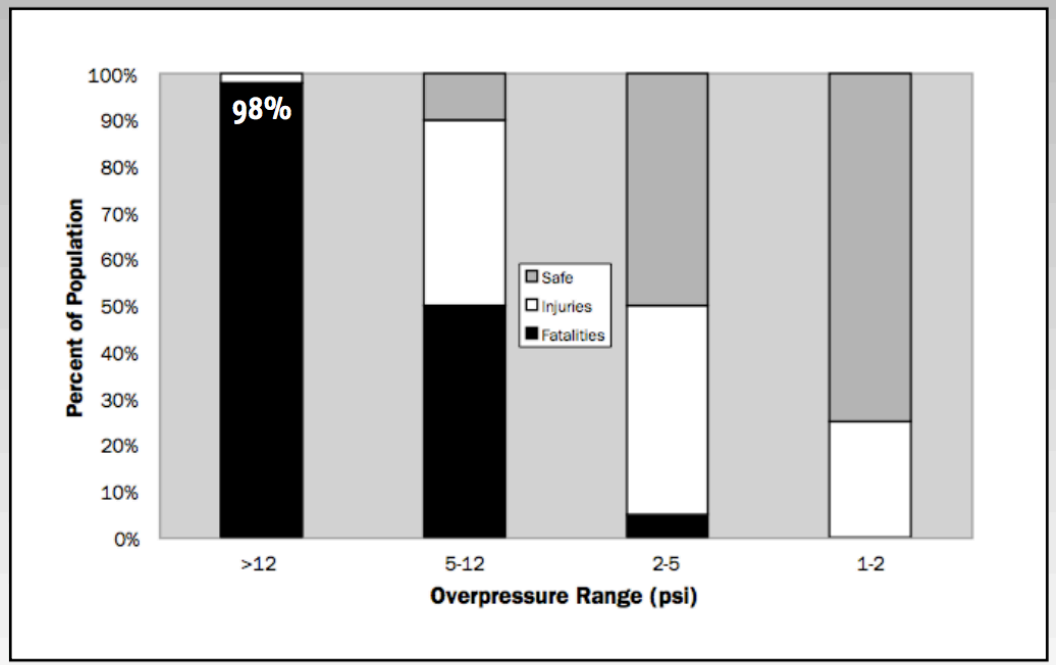
DELAYED NUCLEAR RADIATION / FALLOUT

Origin: material lifted into the fireball right after the explosion
Mixed with radioactive residues of weapon (activated debris, fission products, ...)
Early and delayed fallout: Depending on height of burst, weather conditions, etc.

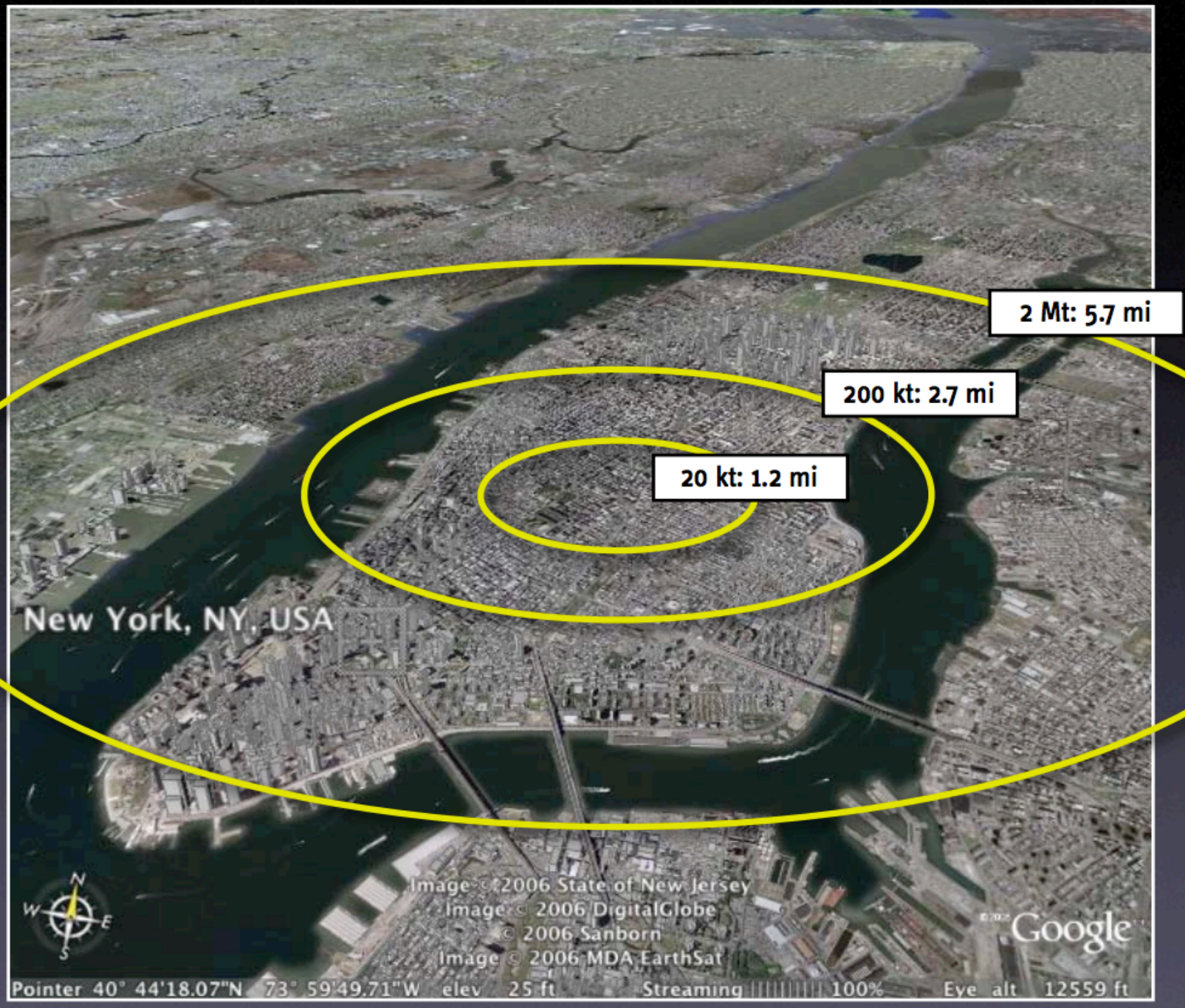
Damage	Overpressure
Light housing destroyed	5 psi
Brick housing/commercial buildings destroyed	10 psi
Reinforced concrete structures destroyed	20 psi
Nuclear weapon storage bunkers	100-500 psi
Command bunkers	100-1000 psi
Missile silos	500-10000 psi
Deep underground command facilities	1000-10000 psi

Percentages of Population Killed

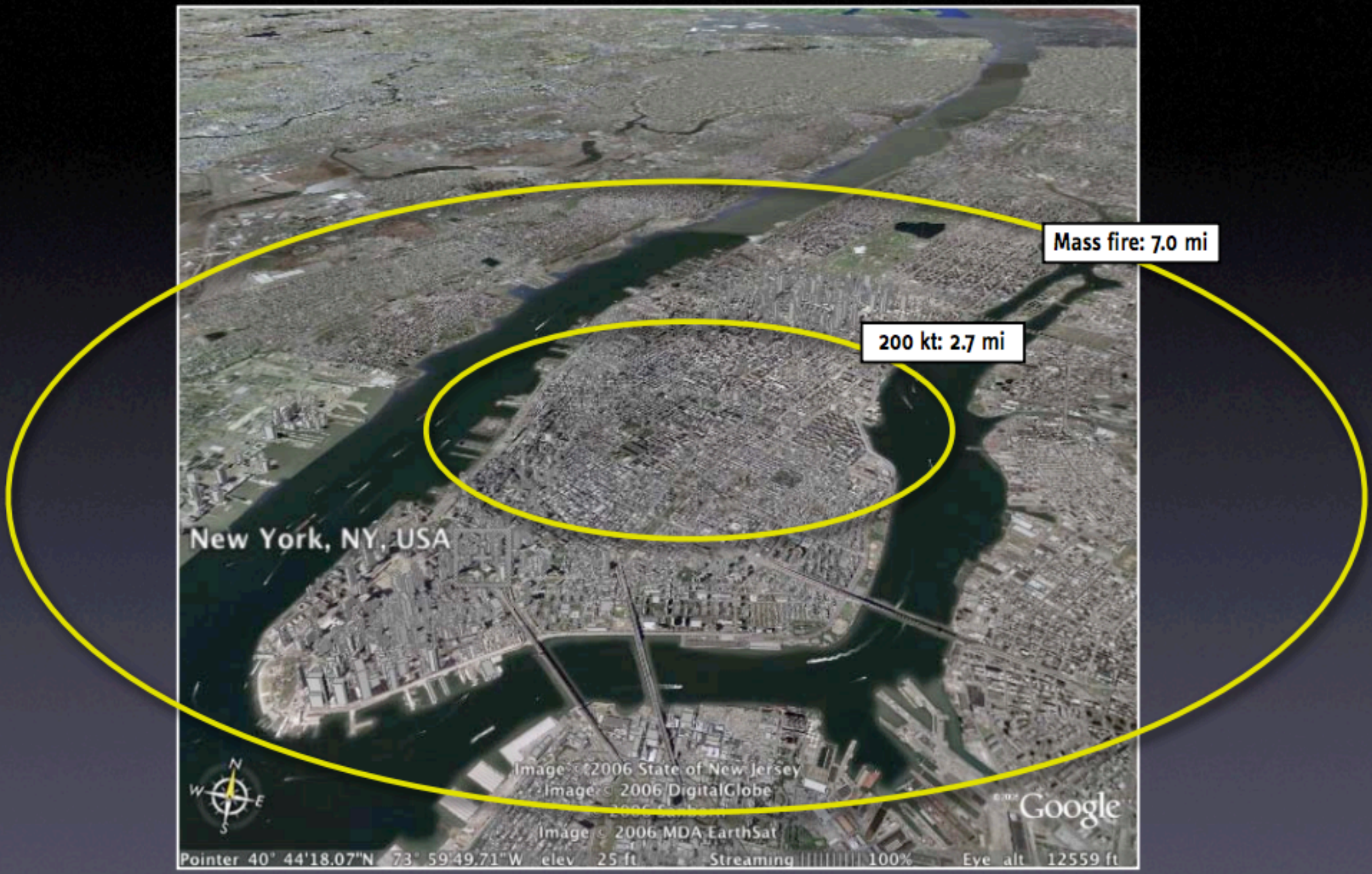
(as a function of peak overpressure)



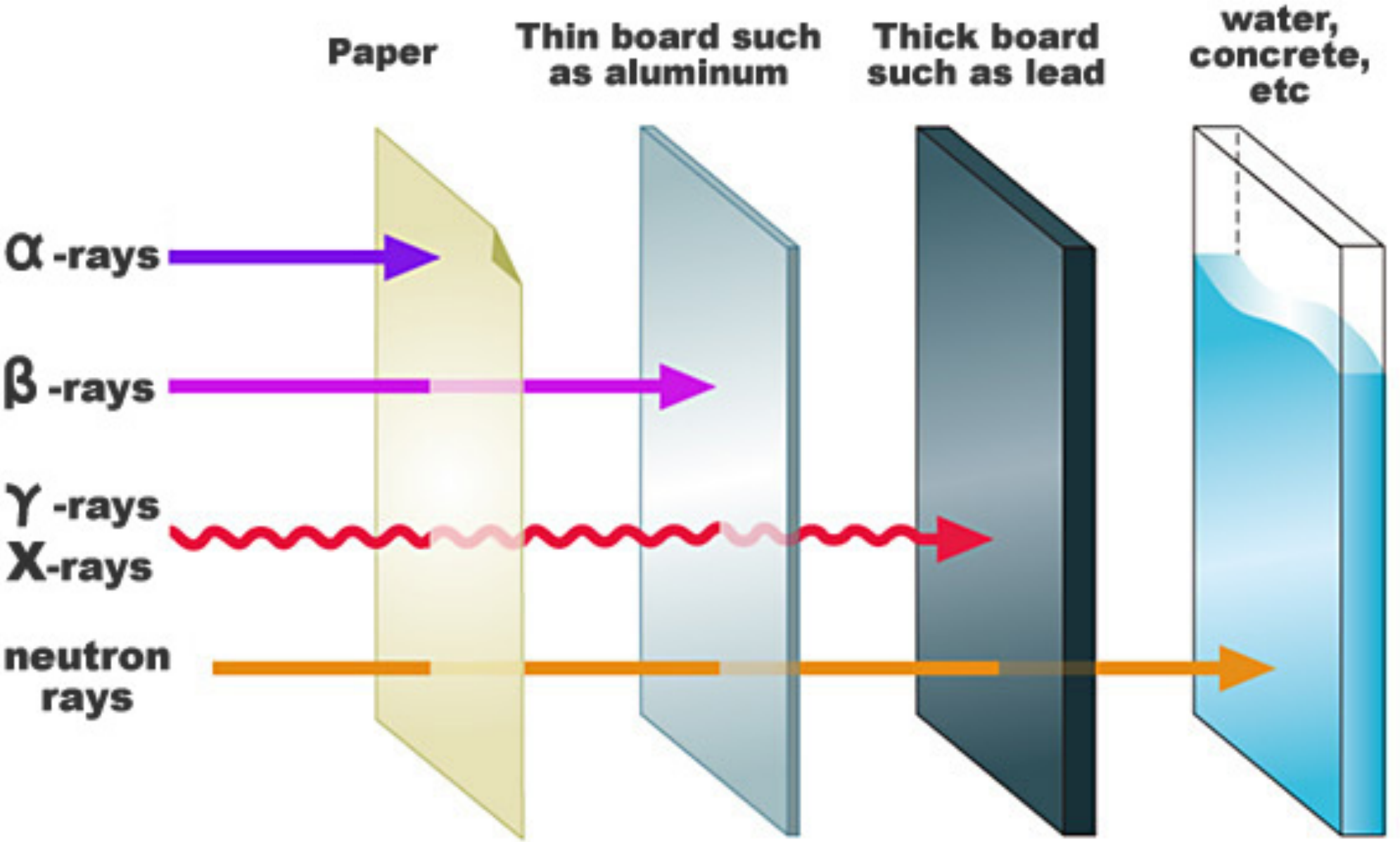
Source: NRDC, The U.S. Nuclear War Plan: A Time for Change, 2001
Original source: OTA, The Effects of Nuclear War, 1979



Height of burst selected to maximize area over which 15 psi or more occurs


Mass fire: 7.0 mi
200 kt: 2.7 mi
New York, NY, USA
Image © 2006 State of New Jersey
Image © 2006 DigitalGlobe
Image © 2006 MDA EarthSat
Google
Pointer 40° 44'18.07"N 73° 59'49.71"W elev 25 ft
Streaming 100%
Eye alt 12559 ft

Penetrating power of radiation



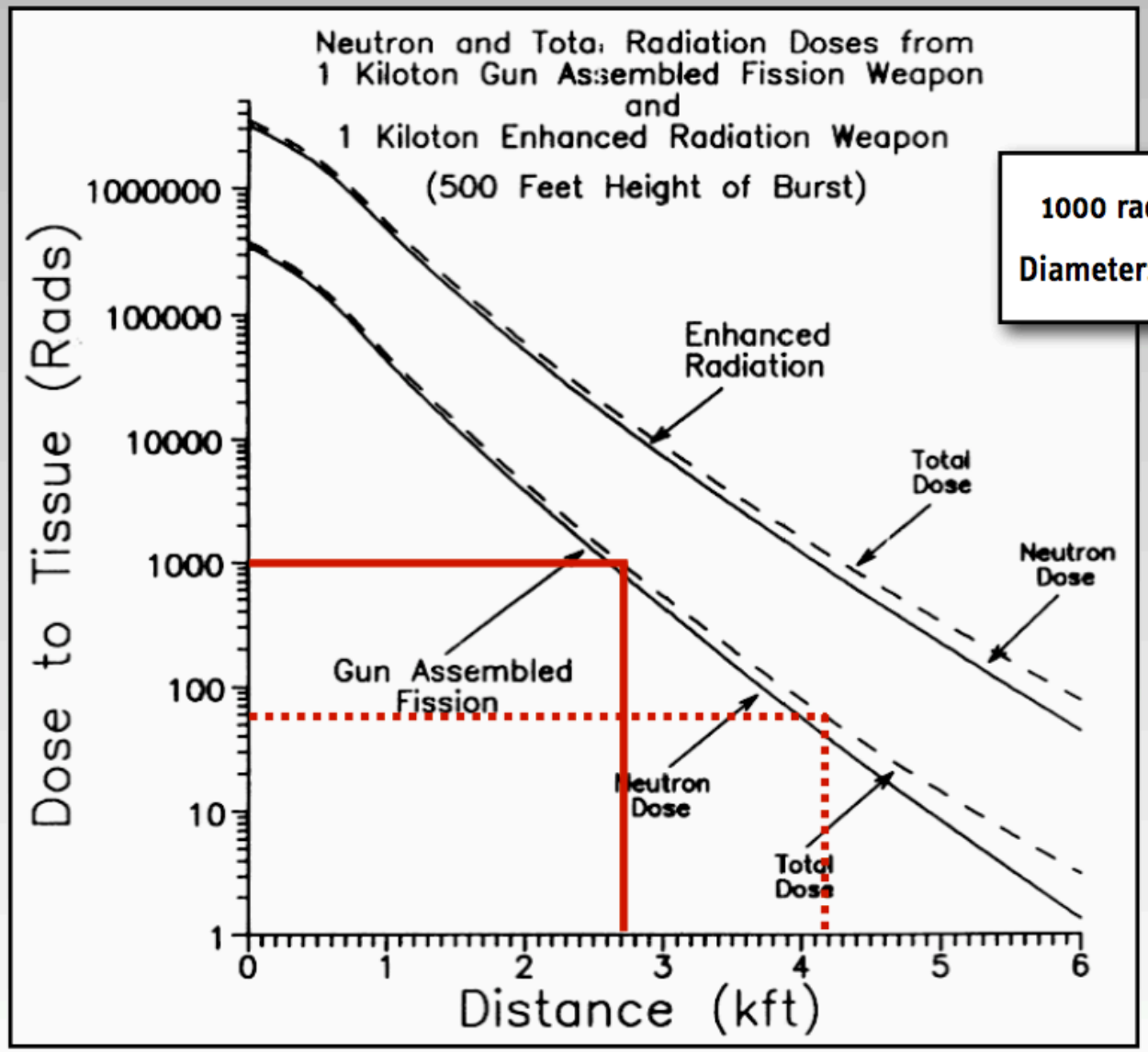
Units of radiation, both dose and biological effects

- Energy deposition per kilogram of any material
  - Old: *Rad* = 0.01 Joule/kilogram
  - New: *Gray (Gy)* = 100 Rads = 1 J/kg
- Relative biological damage due to the radiation
  - Old: *Rem* = Q • Rad
  - New: *Sievert (Sv)* = Q • Gray

Q = *Quality Factor*
= 1 for x, γ, β
= 10 for α
= 20 for neutrons

Initial Radiation

(Dose absorbed in the first minute after explosion)



1000 rads for 20 kt explosion

Diameter: 2 x 4100 ft (ca. 1.5 mi)

LD50 (Lethal Dose for 50% of exposed population) = 500 rem

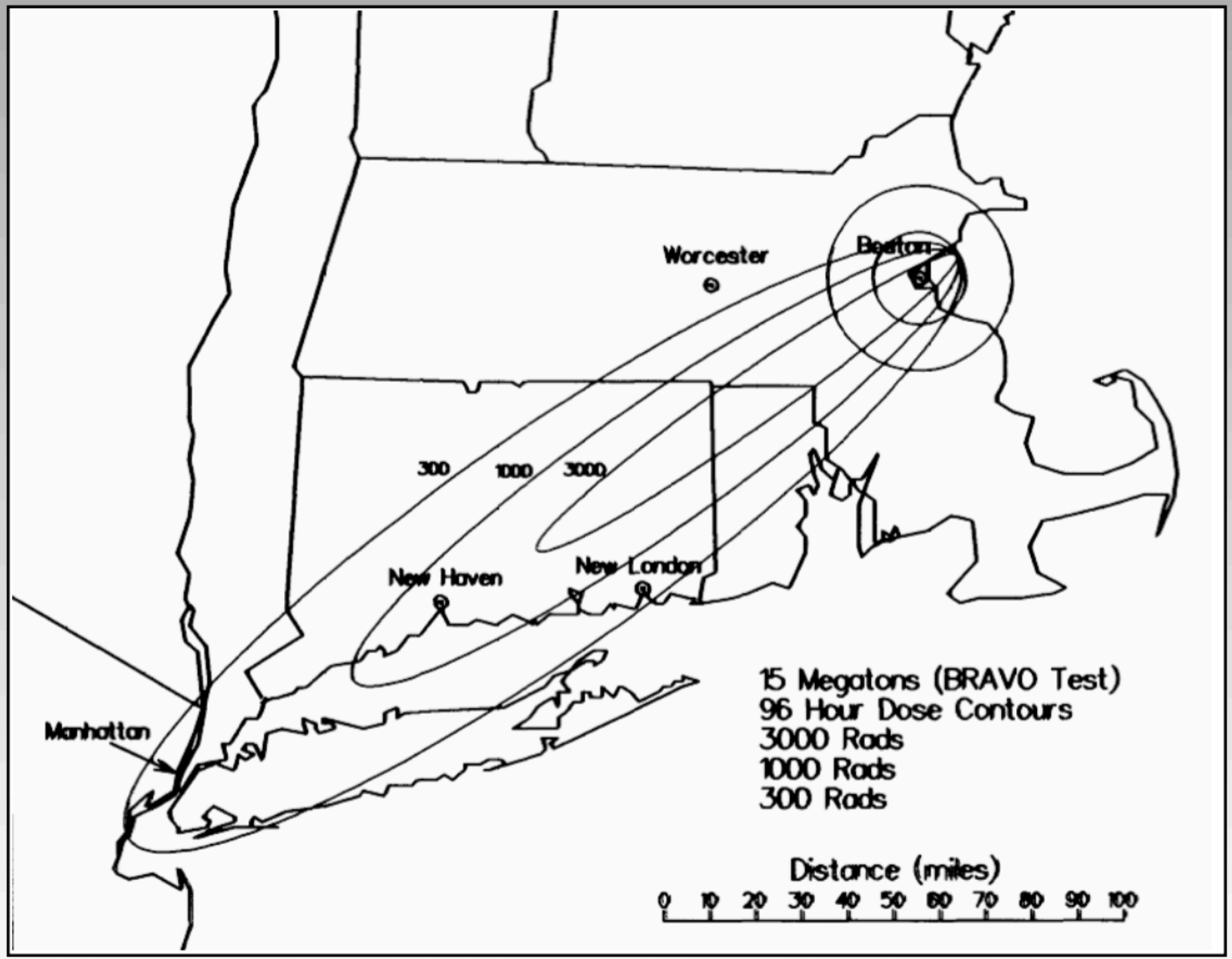
Exposure (rem)	Health Effect	Time to Onset (without treatment)
5-10	changes in blood chemistry	
50	nausea	hours
55	fatigue	
70	vomiting	
75	hair loss	2-3 weeks
90	diarrhea	
100	hemorrhage	
400	possible death	within 2 months
1,000	destruction of intestinal lining	
	internal bleeding	
	and death	1-2 weeks
2,000	damage to central nervous system	
	loss of consciousness;	minutes
	and death	hours to days

Effects of Acute Whole Body Exposure to Radiation

		1-2 Sv	2-5 Sv	5-10 Sv	10-50 Sv	> 50 Sv
Initial Symptoms	Incidence	0-50%	50-90%	100%	100%	100%
	Latency	> 3 hrs	1-2 hrs	0.5-1 hr	0.5 hr	Minutes
Lethality		0-10%	0-90%	0-90%	90-100%	100%
Death occurs within		Months	Weeks	Weeks	2 weeks	1-48 hrs
Leading system		Blood forming (bone marrow)			Intestinal	Nervous

Source: United Nations Scientific Committee on the Effects of Atomic Radiation: Sources, Effects, and Risks of Ionizing Radiation. 1988 Report to the General Assembly, United Nations, New York, 1988. Annex G, Early effects in man of high doses of radiation, in particular, Table 13. Similar information is listed in Glasstone, Table 12.108.

100 rad = 1 Gy



Source: Ted Postol, lecture notes

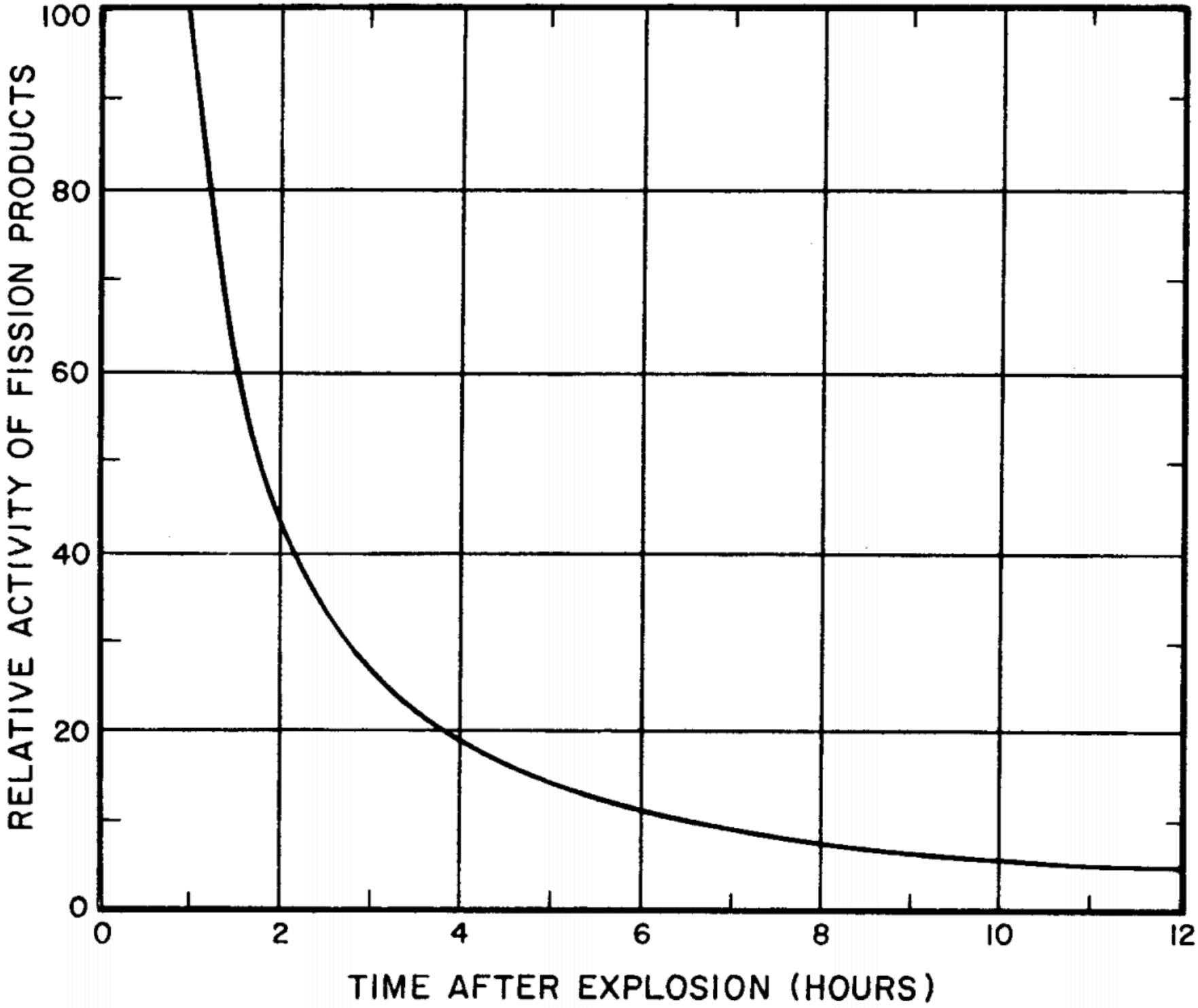
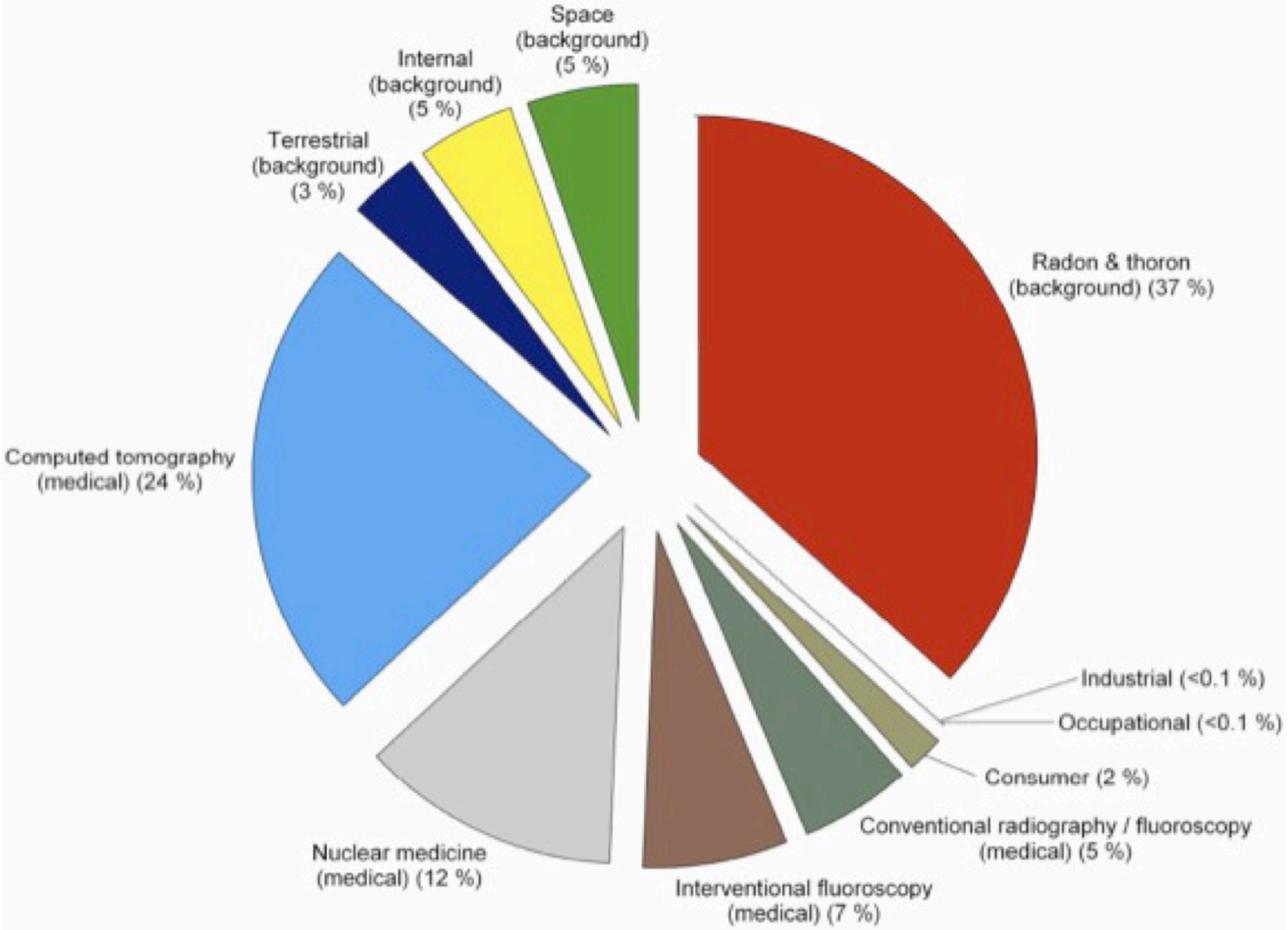


Figure 1.64. Rate of Decay of fission products after a nuclear explosion (activity is taken as 100 at 1 hour after the detonation).



From NCRP Report No. 160, "Ionizing Radiation Exposure of the Population of the United States" (2009)

Electromagnetic Pulse (EMP) – Starfish Prime (July 9, 1962)