Effects of Nuclear Weapons

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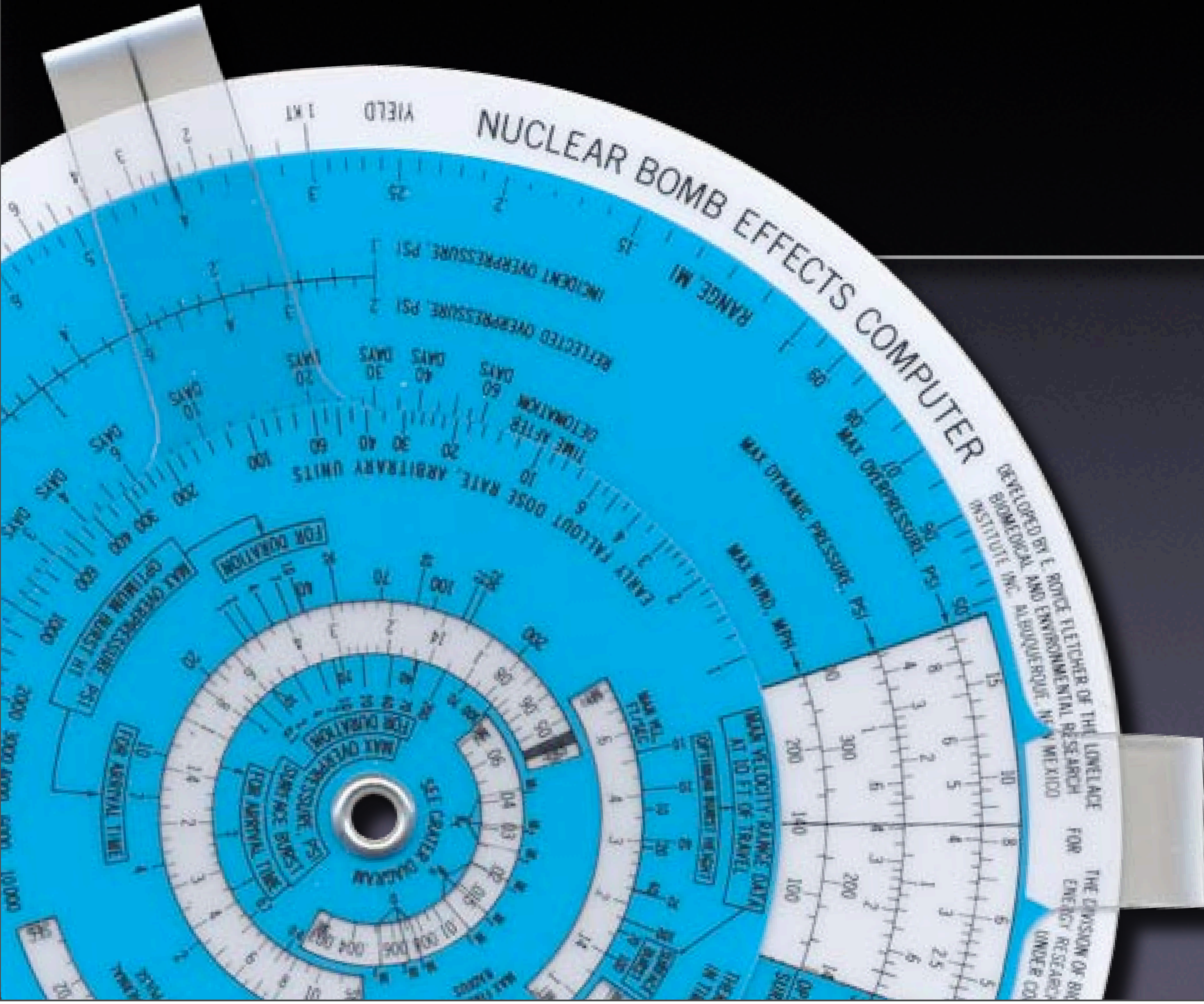
February 12, 2007



S. Glasstone and P. J. Dolan
The Effects of Nuclear Weapons, Third Edition
U.S. Government Printing Office
Washington, D.C., 1977

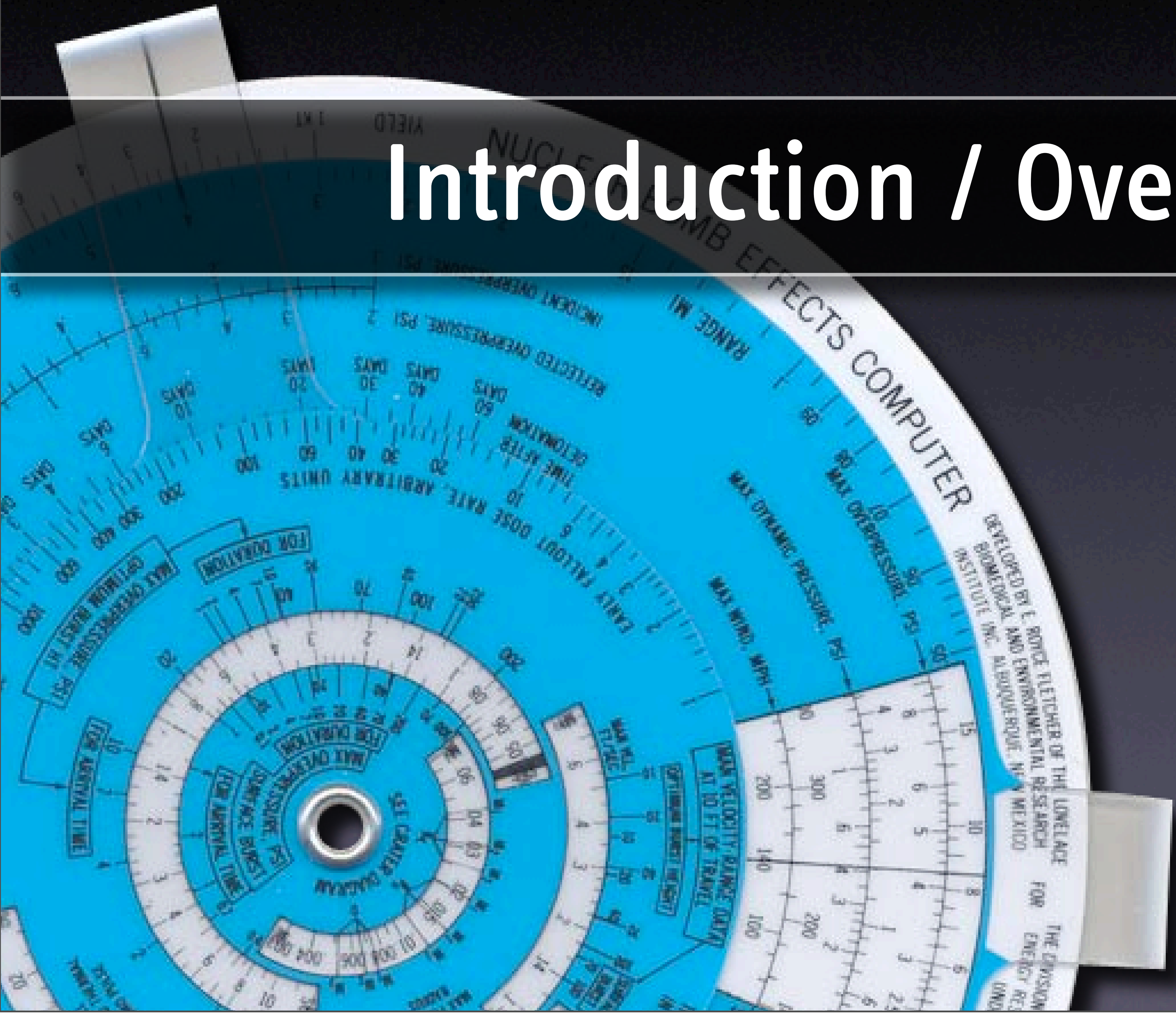
Nuclear Weapon Tests

	USA	Russia	U.K.	France	China	Total
Atmospheric	1945-63	1949-62	1952-58	1960-74	1964-80	528
	215	219	21	50	23	
Underground	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


Paul W. Tibbets
Col. USAF
Pilot: The Enola Gay

Introduction / Overview



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

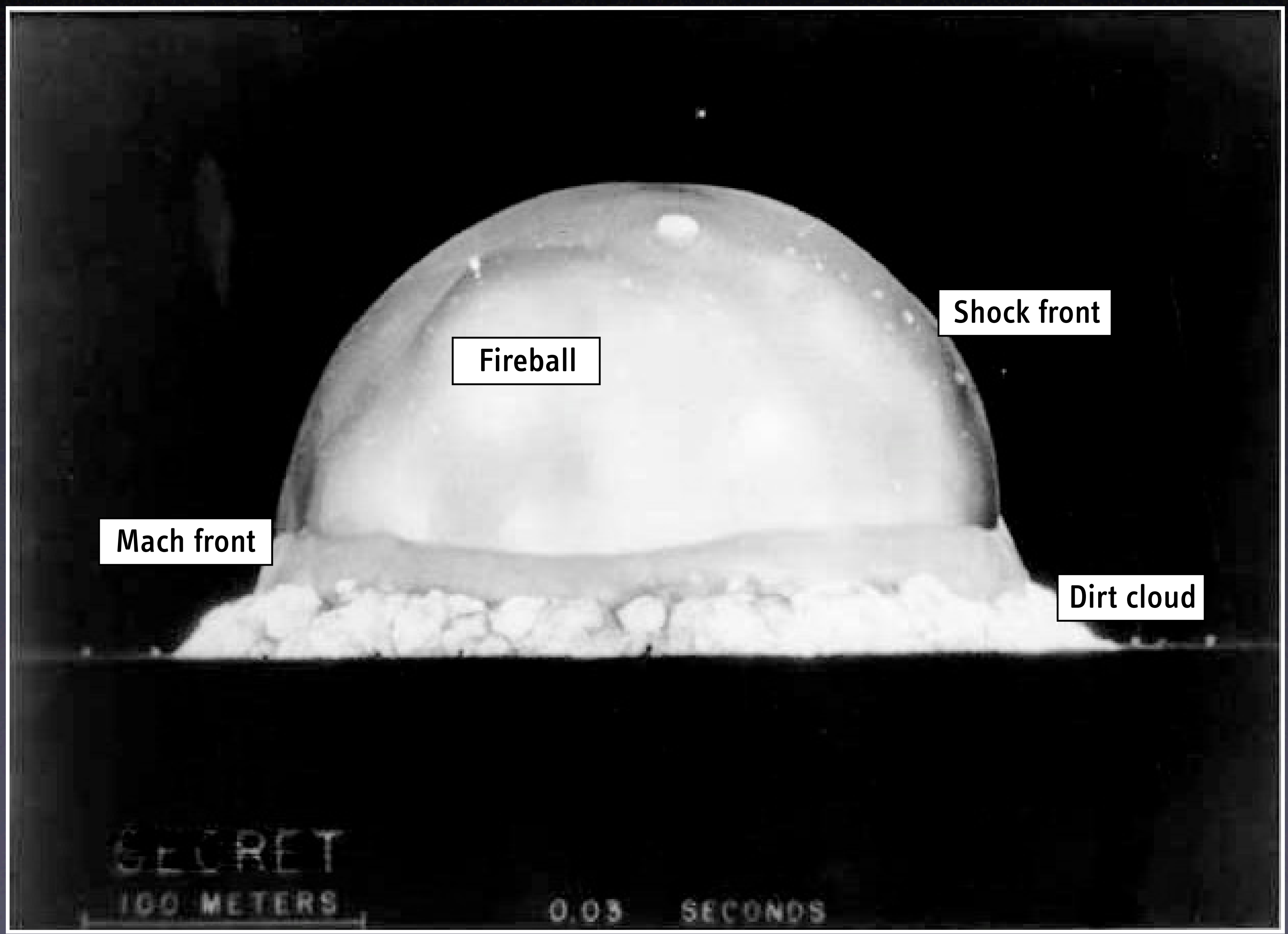
starts to form in less than a millionth of a second after explosion
several tens of million of degrees: transformation of all matter into gas/plasma
thermal radiation as x-rays, absorbed by the surrounding atmosphere

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

Trinity Test

July 16, 1945



Effects of a Nuclear Explosion

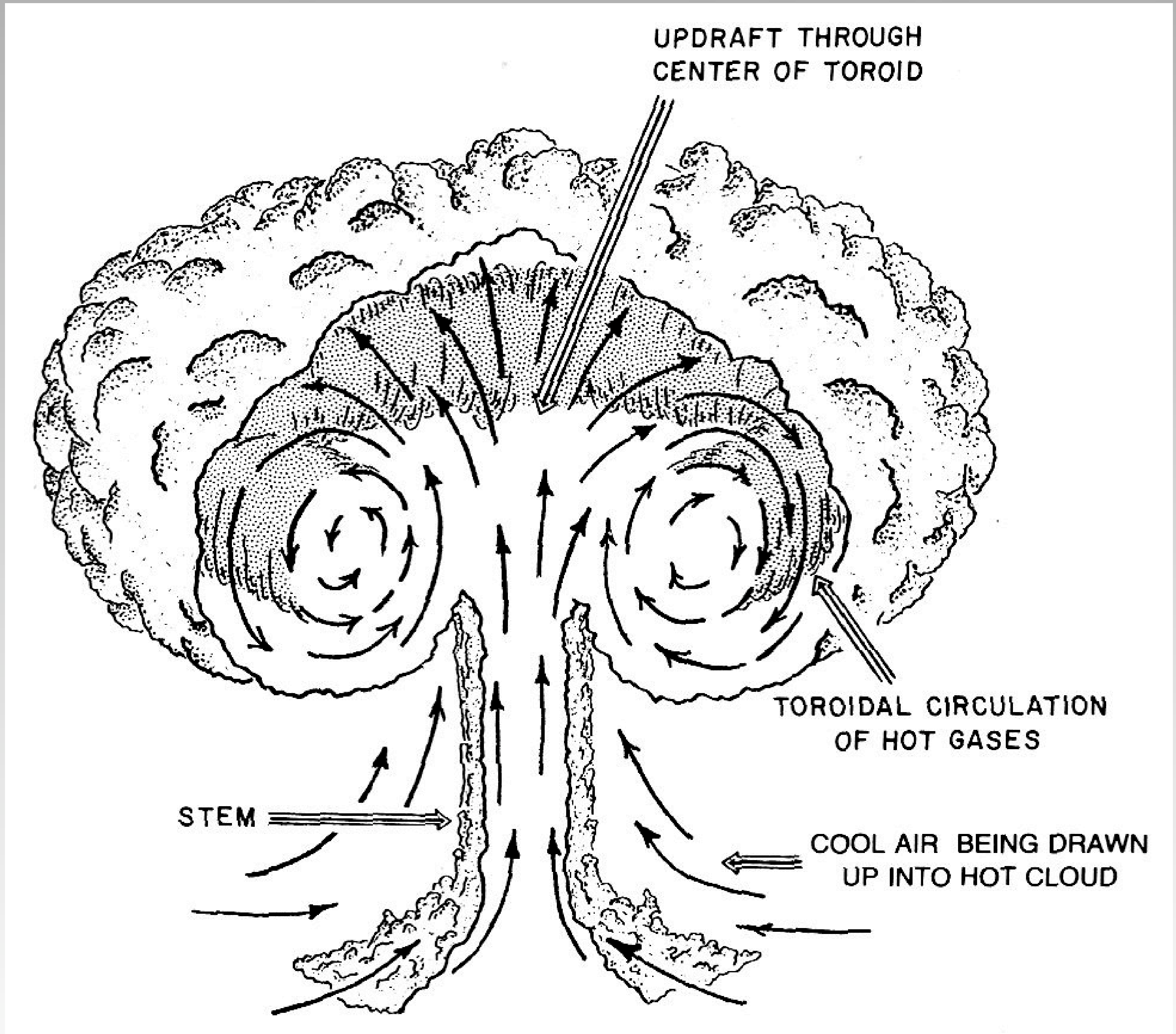
Sequence of events, Part II

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)



Cutaway showing artist's conception of toroidal circulation within the radioactive cloud
Source: Glasstone, Figure 2.07a

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)

Heat and Shock Waves

(Film footage: Federal Civil Defense Administration, ca. 1955)

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)

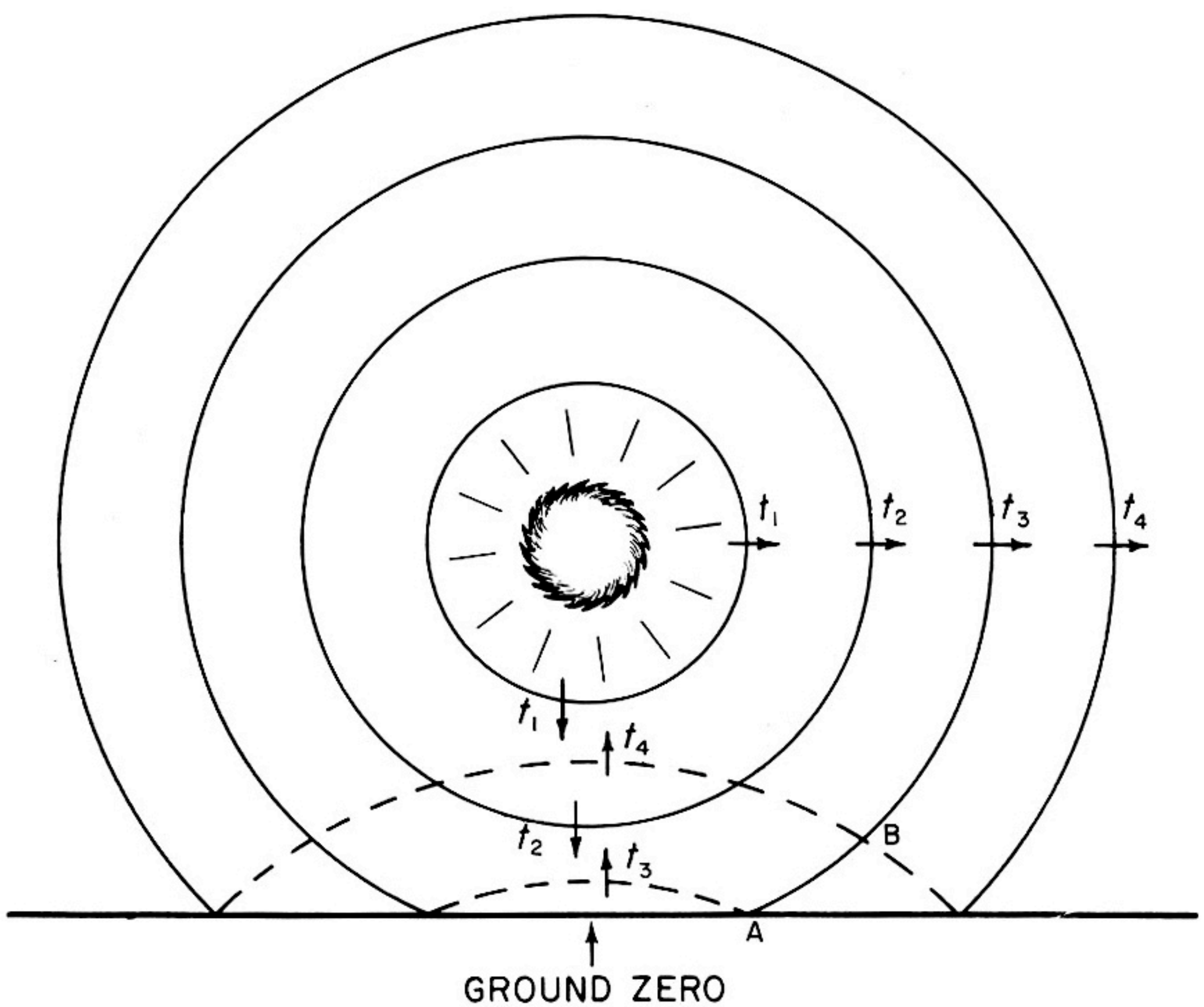
DELAYED NUCLEAR RADIATION / FALLOUT

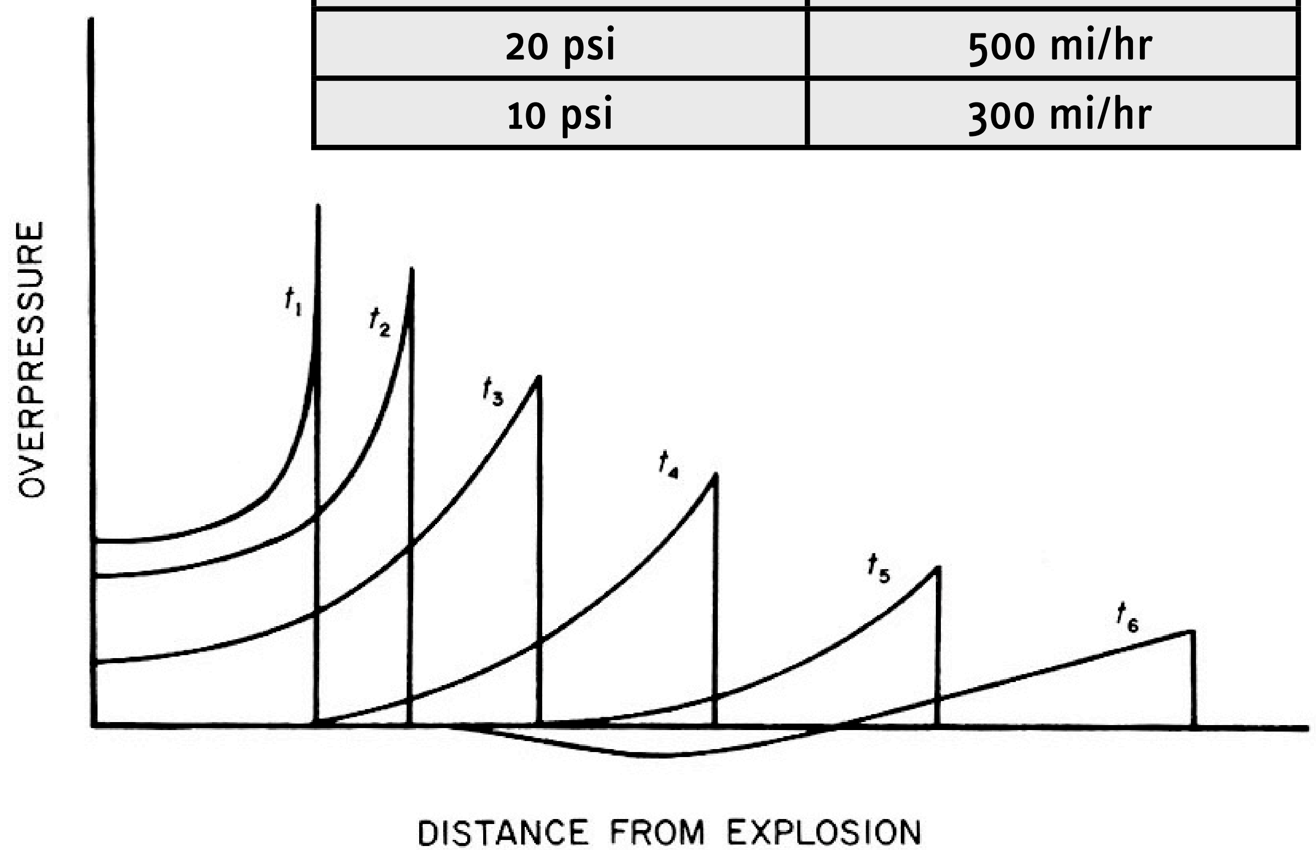
Origin: material lifted into the fireball right after the explosion
Mixed with radioactive residues of weapon (activated debris, fission products, ...)
Early and delayed fallout: Depending on height of burst, weather conditions, etc.

Air Blast


NUCLEAR BOMB EFFECTS COMPUTER
RANGE, MI
MAX OVERPRESSURE, PSI
MAX DYNAMIC PRESSURE, PSI
MAX WIND, MPH
YIELD

Shock Wave and Winds Velocities





Peak overpressure	Max. wind velocity
100 psi	1400 mi/hr
50 psi	900 mi/hr
20 psi	500 mi/hr
10 psi	300 mi/hr

Source: Glasstone, Figures 3.21 and 3.04, Table 3.07

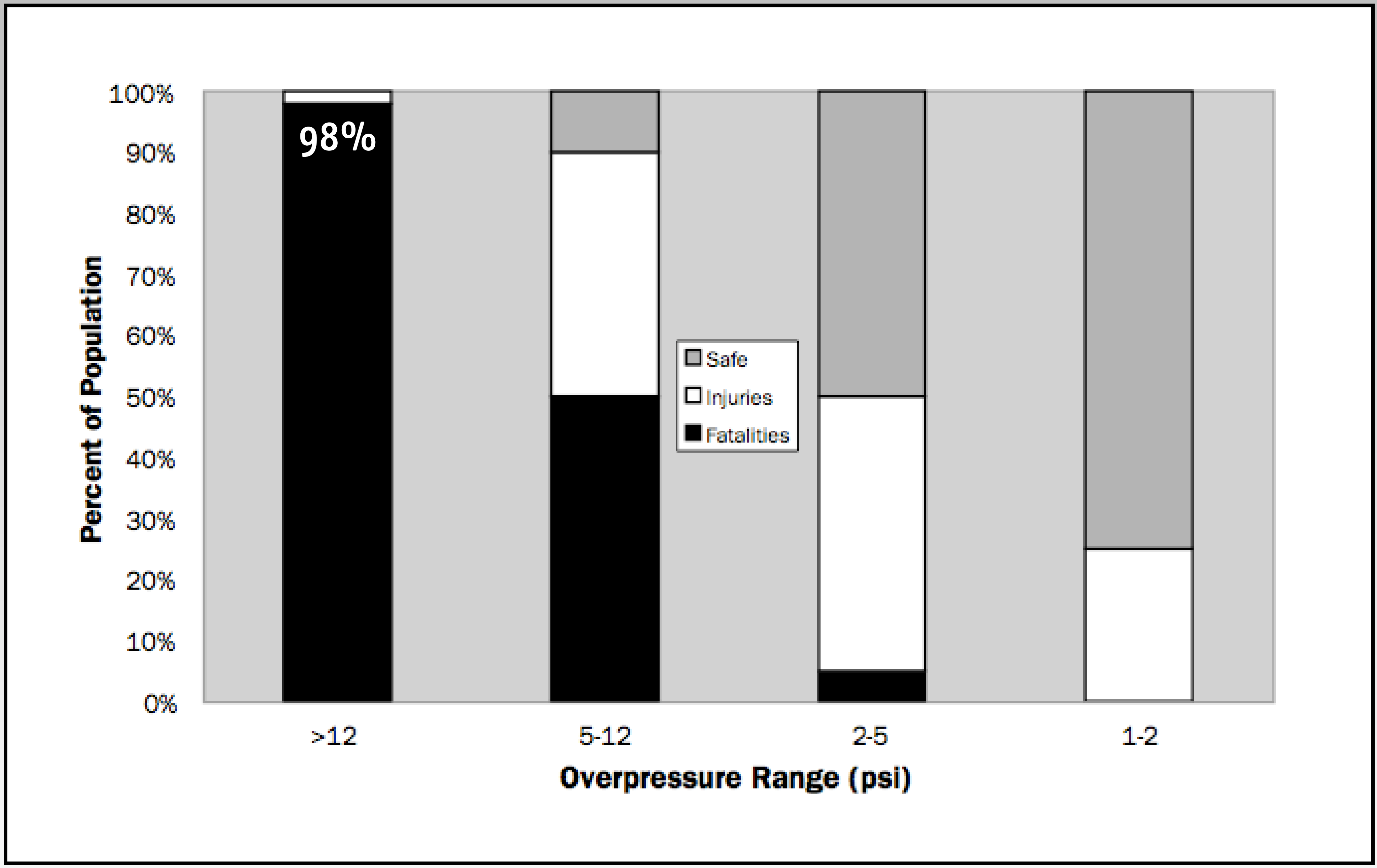
Damage Characteristics for Specific Overpressures

Representative data, e.g. from Physical Vulnerability Handbook

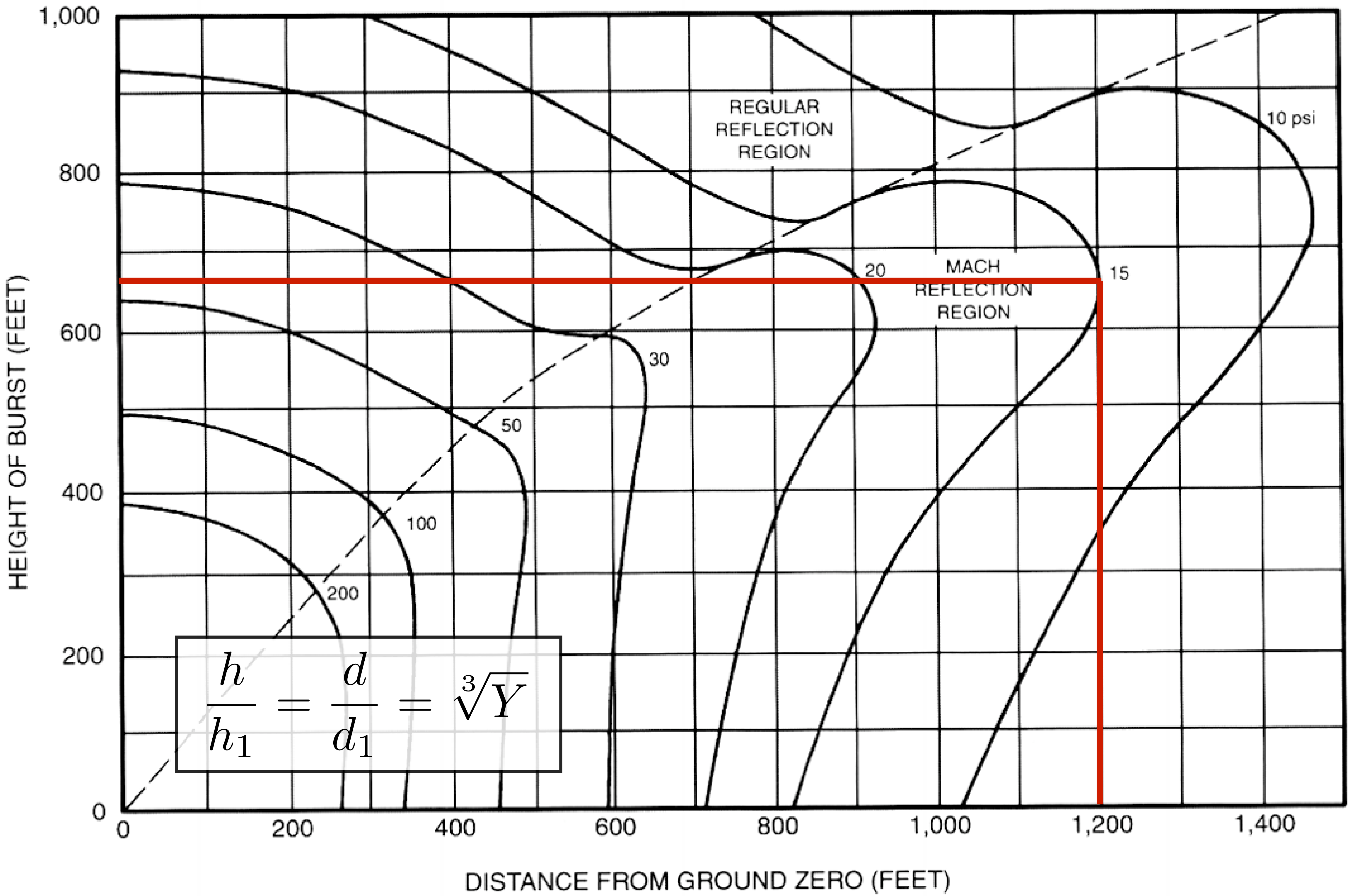
Damage	Overpressure
Light housing destroyed	5 psi
Brick housing/commercial buildings destroyed	10 psi
Reinforced concrete structures destroyed	20 psi
Nuclear weapon storage bunkers	100-500 psi
Command bunkers	100-1000 psi
Missile silos	500-10000 psi
Deep underground command facilities	1000-10000 psi

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



Peak overpressures on the ground for a 1-kiloton burst (intermediate-pressure range)
Source: Glasstone, Figure 3.73b

Analysis of Attacks on Hiroshima and Nagasaki

$$h = \sqrt[3]{Y} \times h_1$$

	Calculated value of the Height of Burst (HOB) for 15 psi	Real value
Hiroshima	$h = \sqrt[3]{15} \times 670 \text{ ft} \approx 1650 \text{ ft}$	1640 ft
Nagasaki	$h = \sqrt[3]{22} \times 670 \text{ ft} \approx 1880 \text{ ft}$	1900 ft

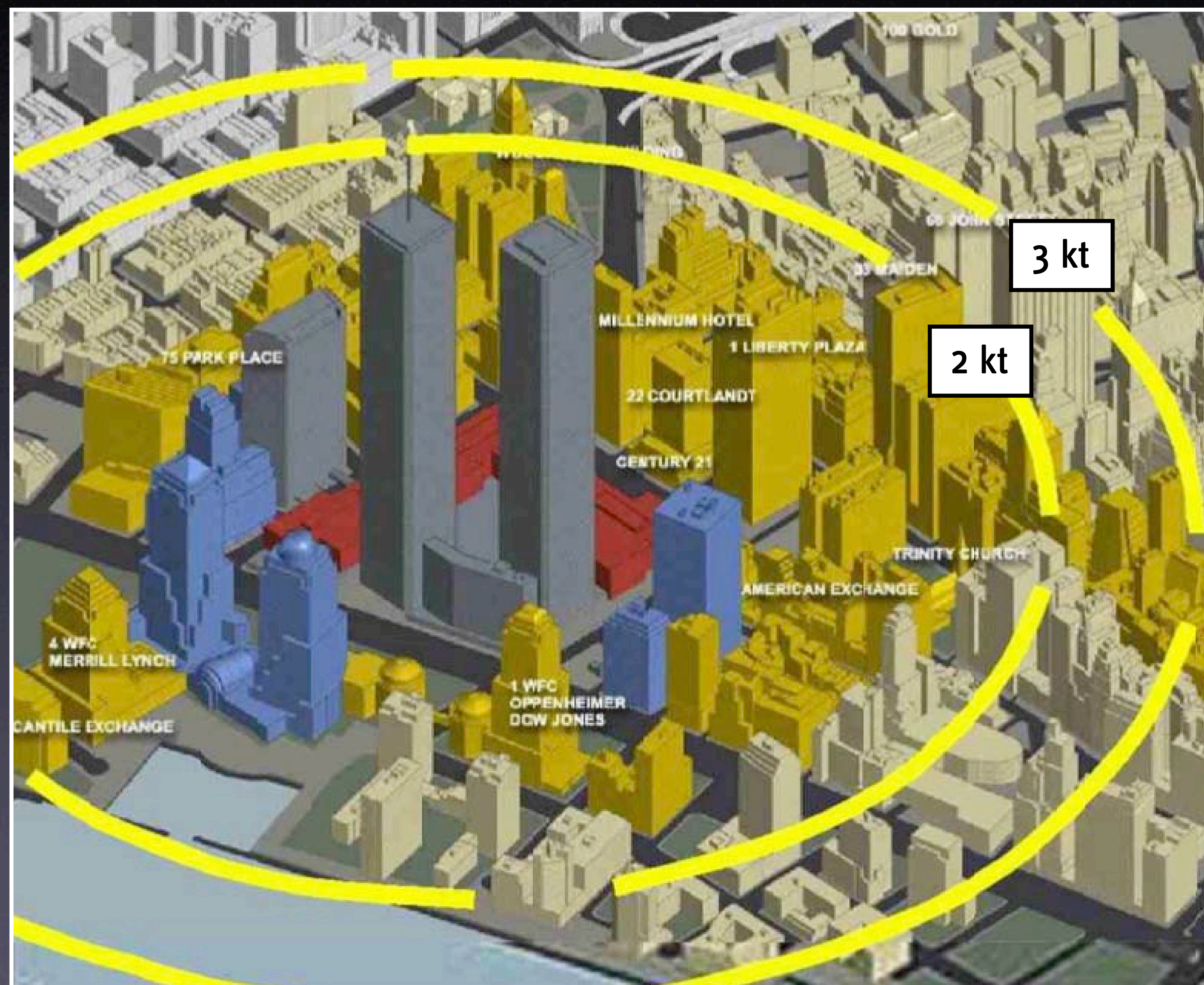
Height of Burst at Hiroshima and Nagasaki chosen to maximize area over which 15 psi or more occurs (1.1-1.3 miles in diameter)

(2.5x times more area destroyed compared to surface burst)

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

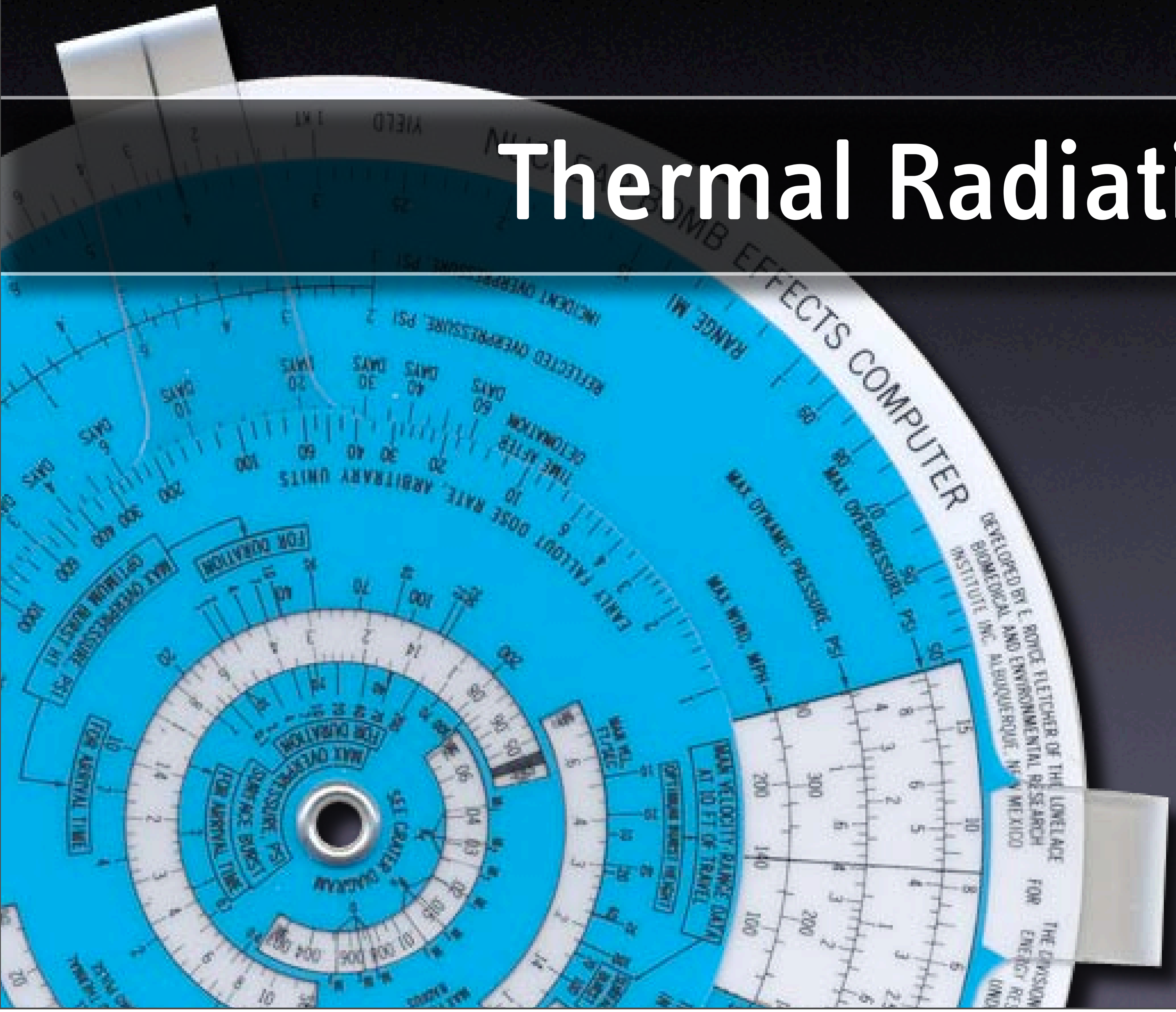
Impact of Fizzle-Yield Explosion

(Area of complete destruction)



Source: Ted Postol, MIT

Thermal Radiation



Thermal Fluence and its Effects

$$Q\left(\mathrm{cal/cm^2}\right) \approx \frac{3.07\, Y(\mathrm{kt})\, f\, \tau}{R(\mathrm{miles})^2}$$

Glasstone, Equation 7.96.4

Thermal partition f: about 0.35; Transmittance to target on the ground: Figure 7.98

Type of material	Effect	Q(min)
Human skin	Second degree burns	6 cal/cm²
Human skin	Third degree burns	10 cal/cm²
Fine or course grass	Ignites	8-9 cal/cm²
Deciduous leaves		6 cal/cm²
Paper		4-10 cal/cm²
Cotton shirt (khaki colored)		21 cal/cm²

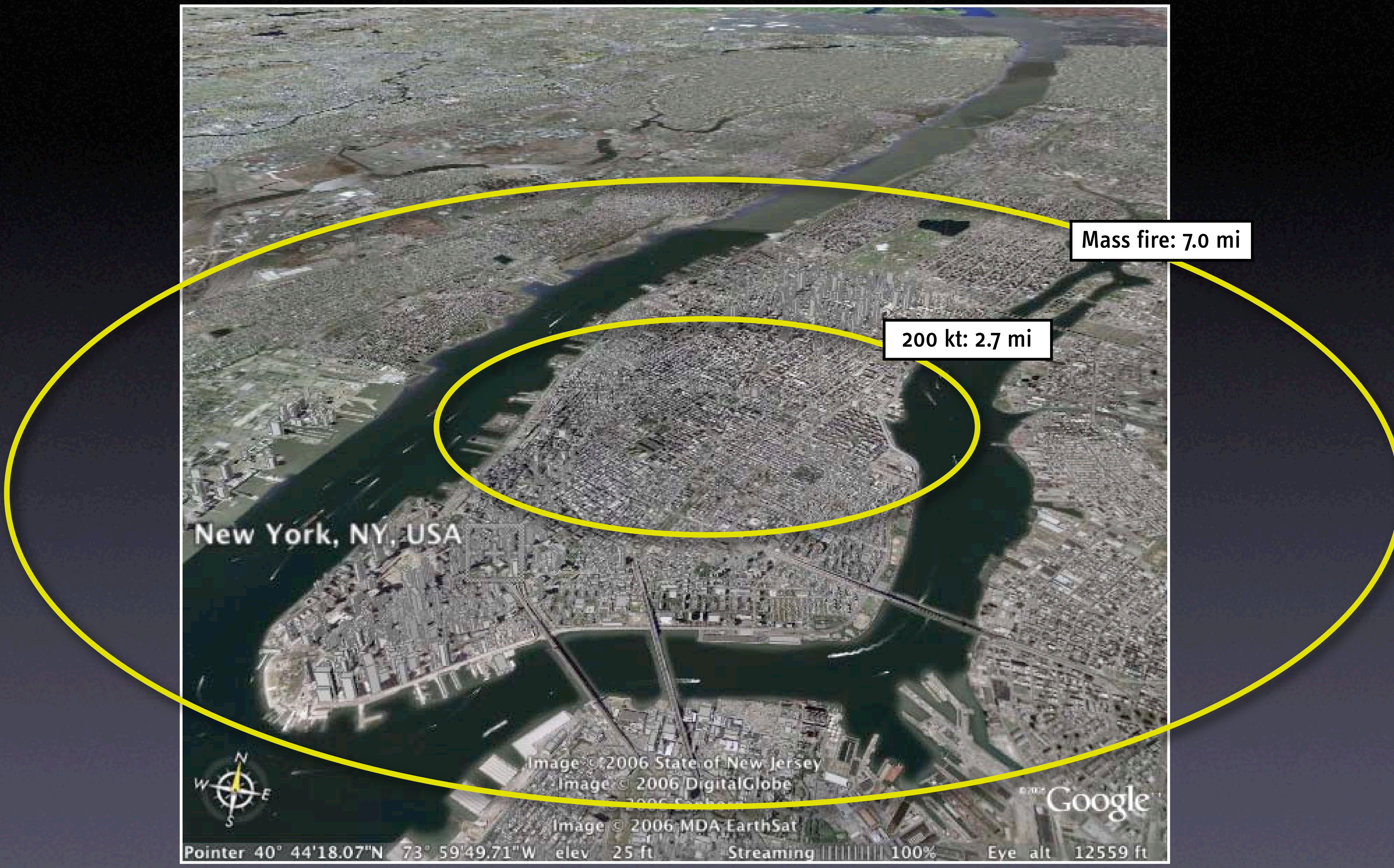
Glasstone, Tables 7.35 and 7.40

Mass Fires

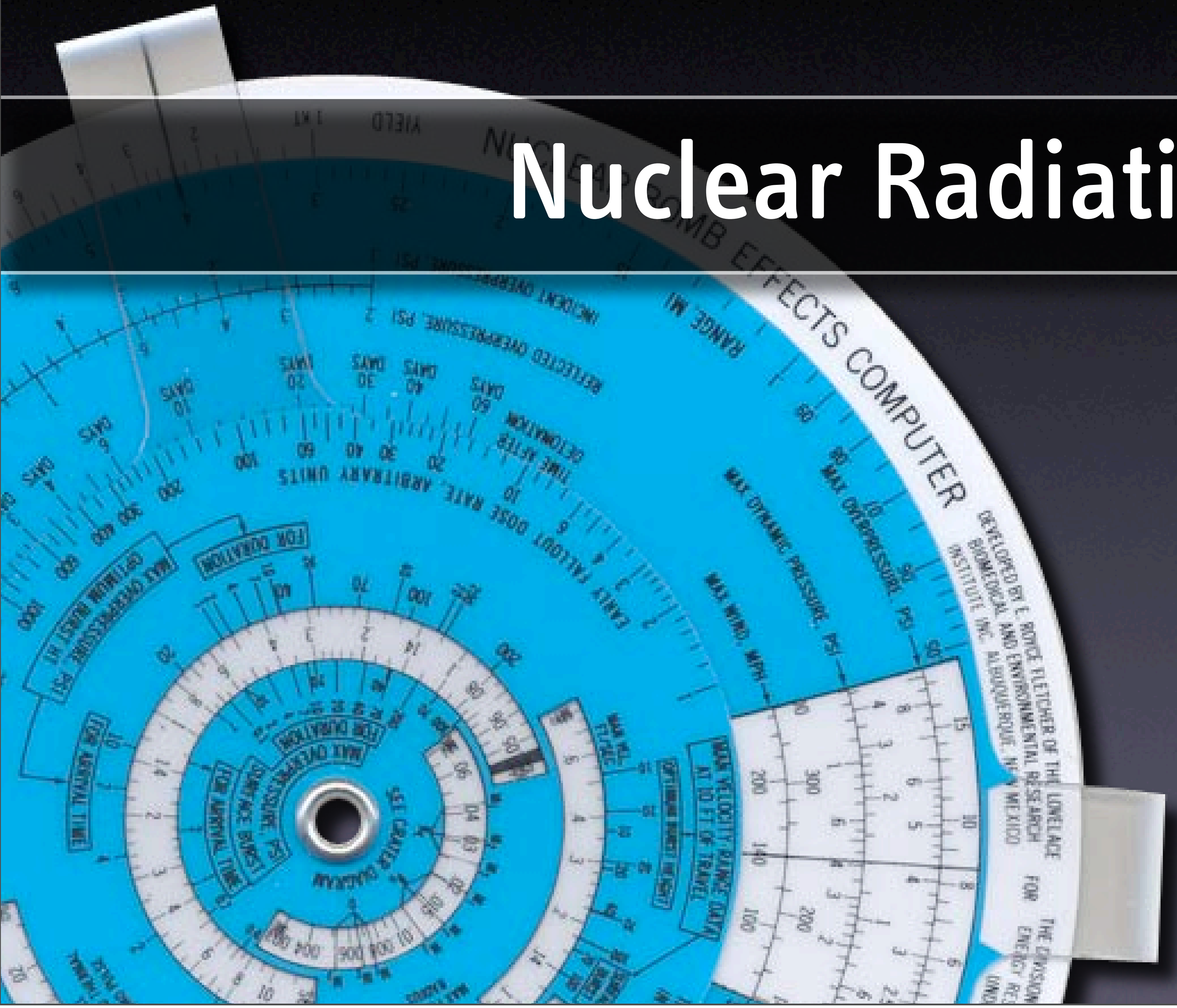
Initial fires (started by the thermal radiation) combine and form “super fire”
Minimum thermal fluence required: about 10 cal/cm^2

High velocity winds directed towards center of fire, “chimney effect”

Firestorm developed in Hiroshima about 20 minutes after explosion
Death caused by heat or suffocation


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

Nuclear Radiation



Effects of Acute Whole Body Exposure to Radiation

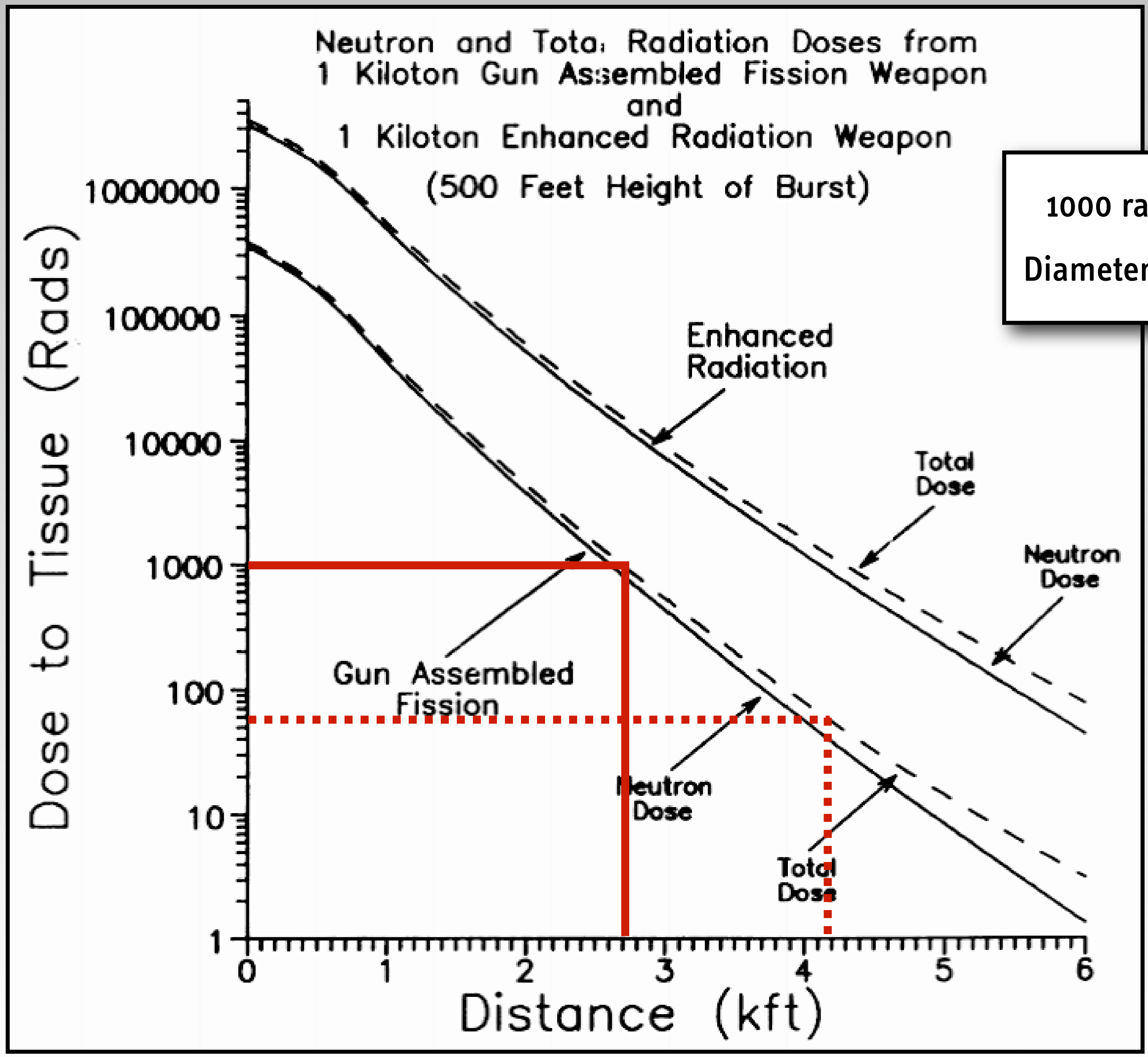
		1-2 Sv	2-5 Sv	5-10 Sv	10-50 Sv	> 50 Sv
Initial Symptoms	Incidence	0-50%	50-90%	100%	100%	100%
	Latency	> 3 hrs	1-2 hrs	0.5-1 hr	0.5 hr	Minutes
Lethality		0-10%	0-90%	0-90%	90-100%	100%
Death occurs within		Months	Weeks	Weeks	2 weeks	1-48 hrs
Leading system		Blood forming (bone marrow)			Intestinal	Nervous

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

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)

Fallout

Early fallout fraction for surface burst: 40-70% within one day

Fallout pattern is difficult to predict
Strongly depends on terrain and meteorological conditions

Fission products and other radioactive debris condense onto solid and molten soil minerals (Particle size: 0.001-1 mm)

Methodology to Predict Fallout

(cf. Glasstone Figure 9.26, Figure 9.93, and Table 9.93)

Table 9.93

SCALING RELATIONSHIPS FOR UNIT-TIME REFERENCE DOSE-RATE CONTOURS FOR A CONTACT SURFACE BURST WITH A YIELD OF *W* KILOTONS AND A 15 MPH WIND

Reference dose rate (rads/hr)	Downwind distance (statute miles)	Maximum wi (statute miles
3,000	0.95 $W^{0.45}$	0.0076 $W^{0.8}$
1,000	1.8 $W^{0.45}$	0.036 $W^{0.7}$
300	4.5 $W^{0.45}$	0.13 $W^{0.6}$
100	8.9 $W^{0.45}$	0.38 $W^{0.6}$
30	16 $W^{0.45}$	0.76 $W^{0.5}$
10	24 $W^{0.45}$	1.4 $W^{0.5}$
3	30 $W^{0.45}$	2.2 $W^{0.5}$

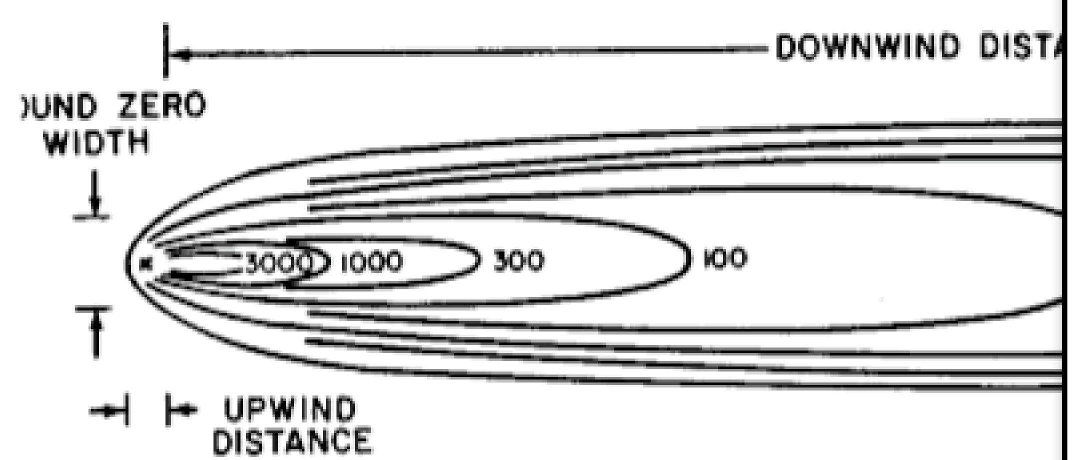


Figure 9.93. Illustration of idealized unit-time dose-rate pattern for early fallout from a surface burst. (The contour dimensions are indicated for a dose rate of 1 rad/hr.)

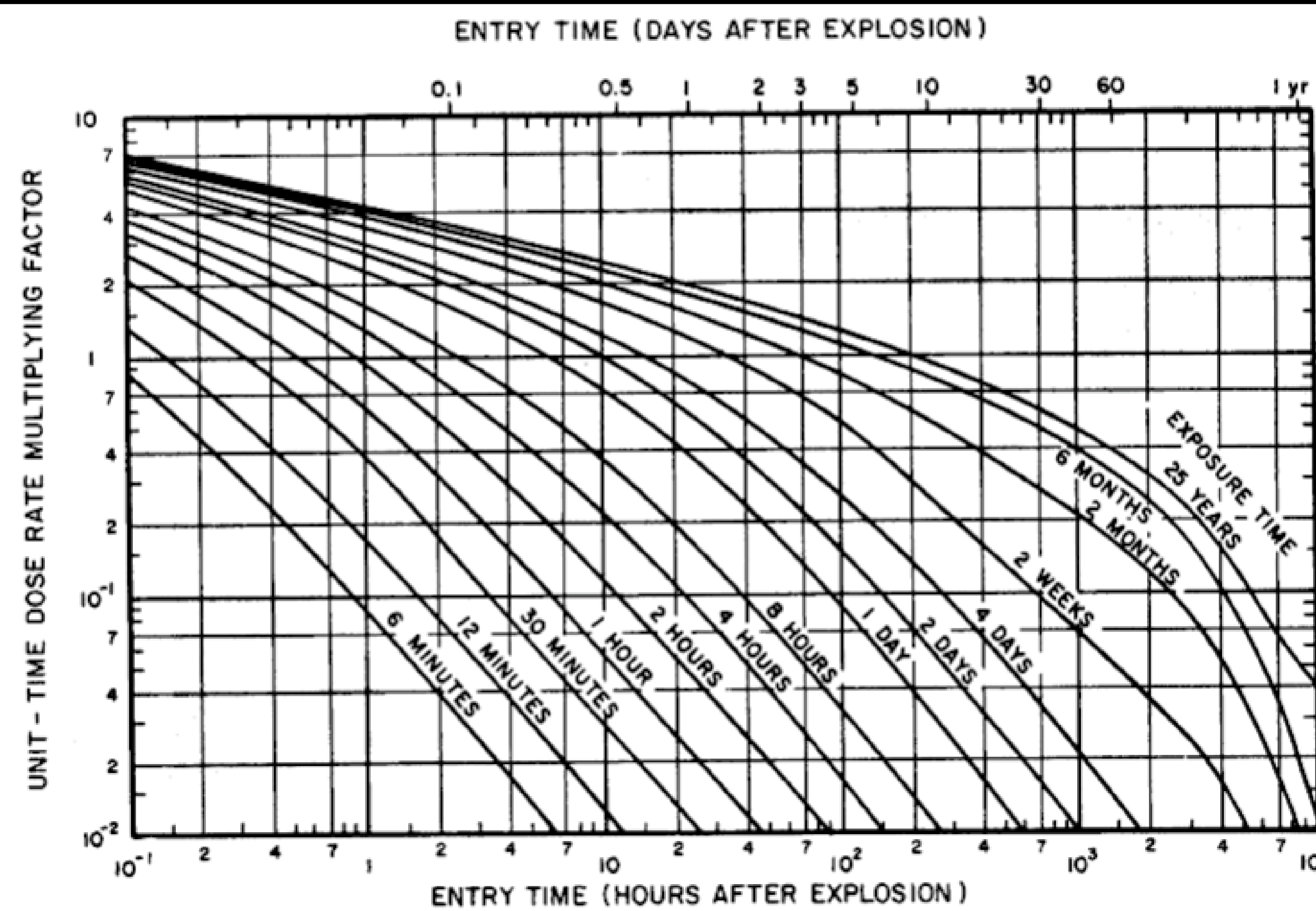
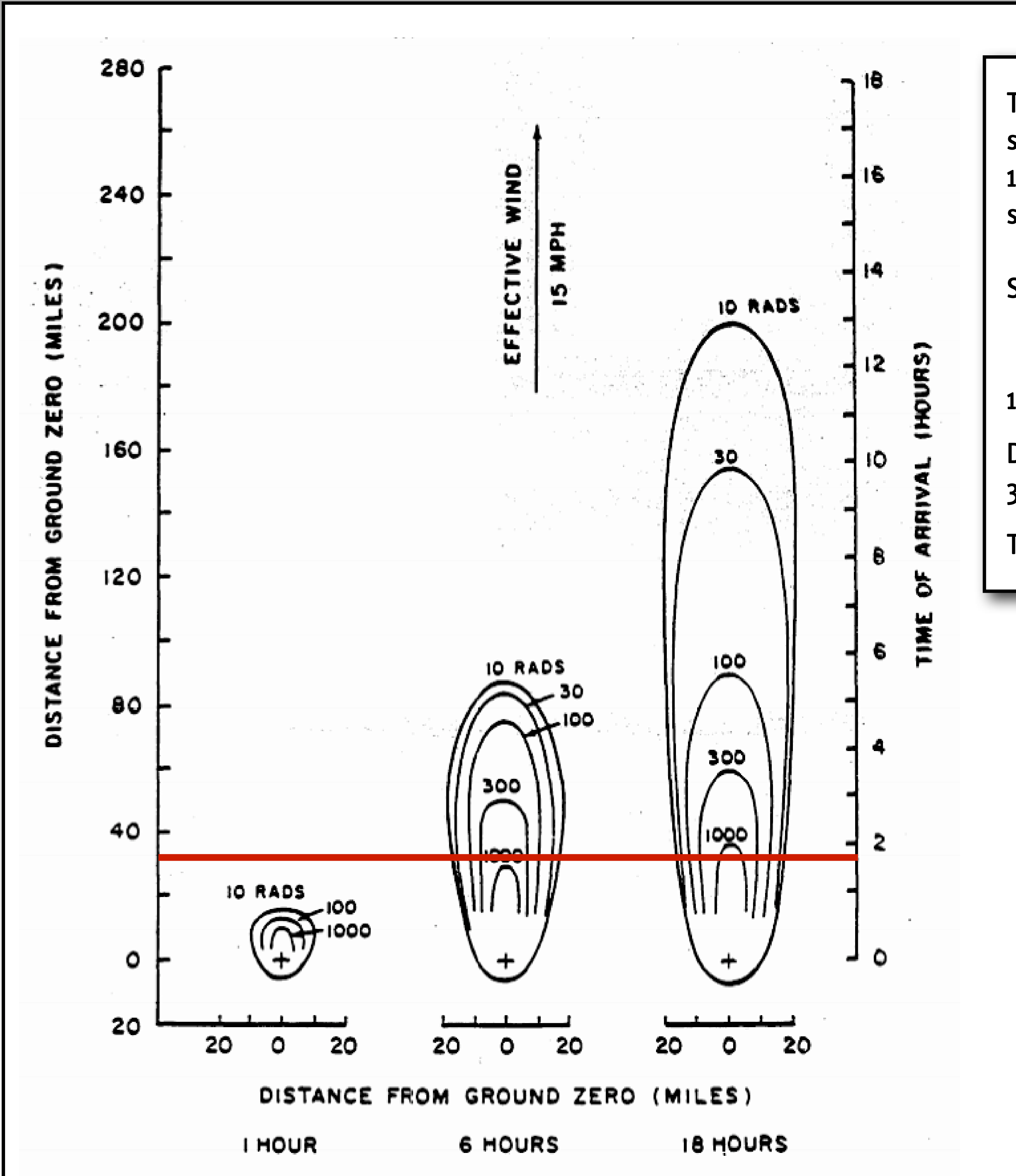


Figure 9.26. Curves for calculating accumulated radiation dose from early fallout based on unit-time reference dose rate.



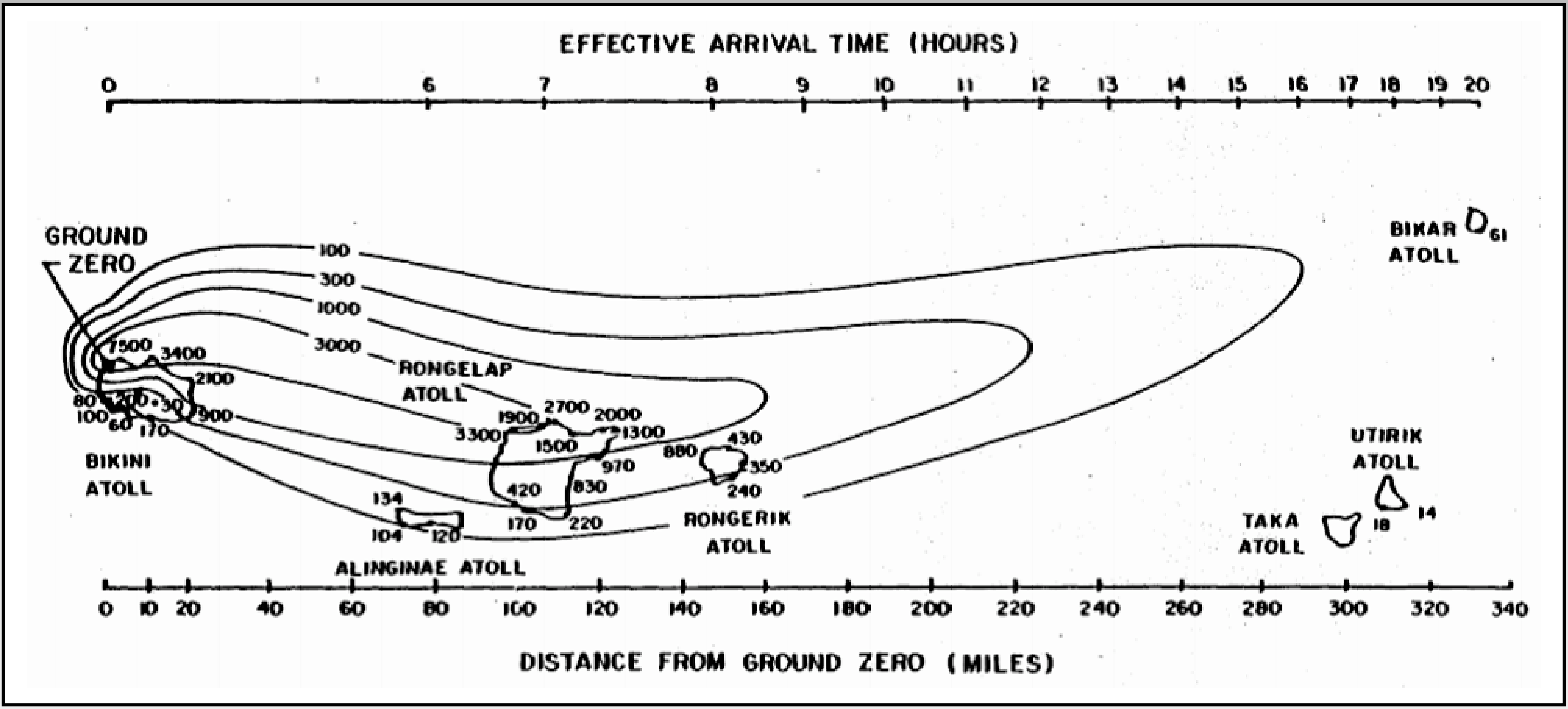
Total-dose contours from early fallout after a surface burst with a total yield of 2 megatons and 1-megaton fission yield (15 mph effective wind speed).

Source: Glasstone, Figure 9.86b

1000 rads (10 Gy):

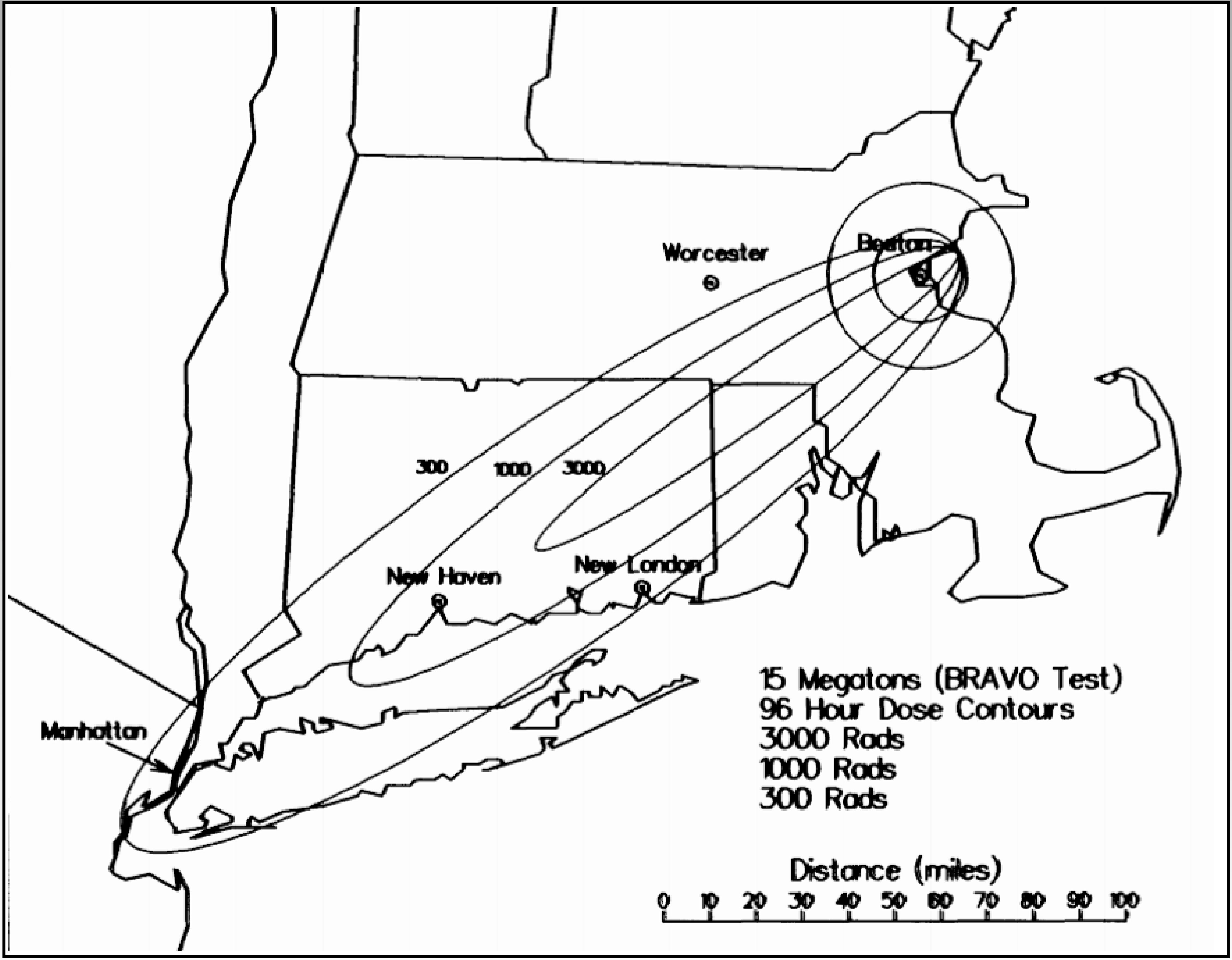
Dose to (unprotected) humans at a distance of 30 miles from explosion (in the direction of wind)

Total area: about 200 square miles



Estimated local (integrated) dose contours in rads at 96 hours after the BRAVO (15 Mt) test explosion

Source: Glasstone, Figure 9.105



Source: Ted Postol, lecture notes

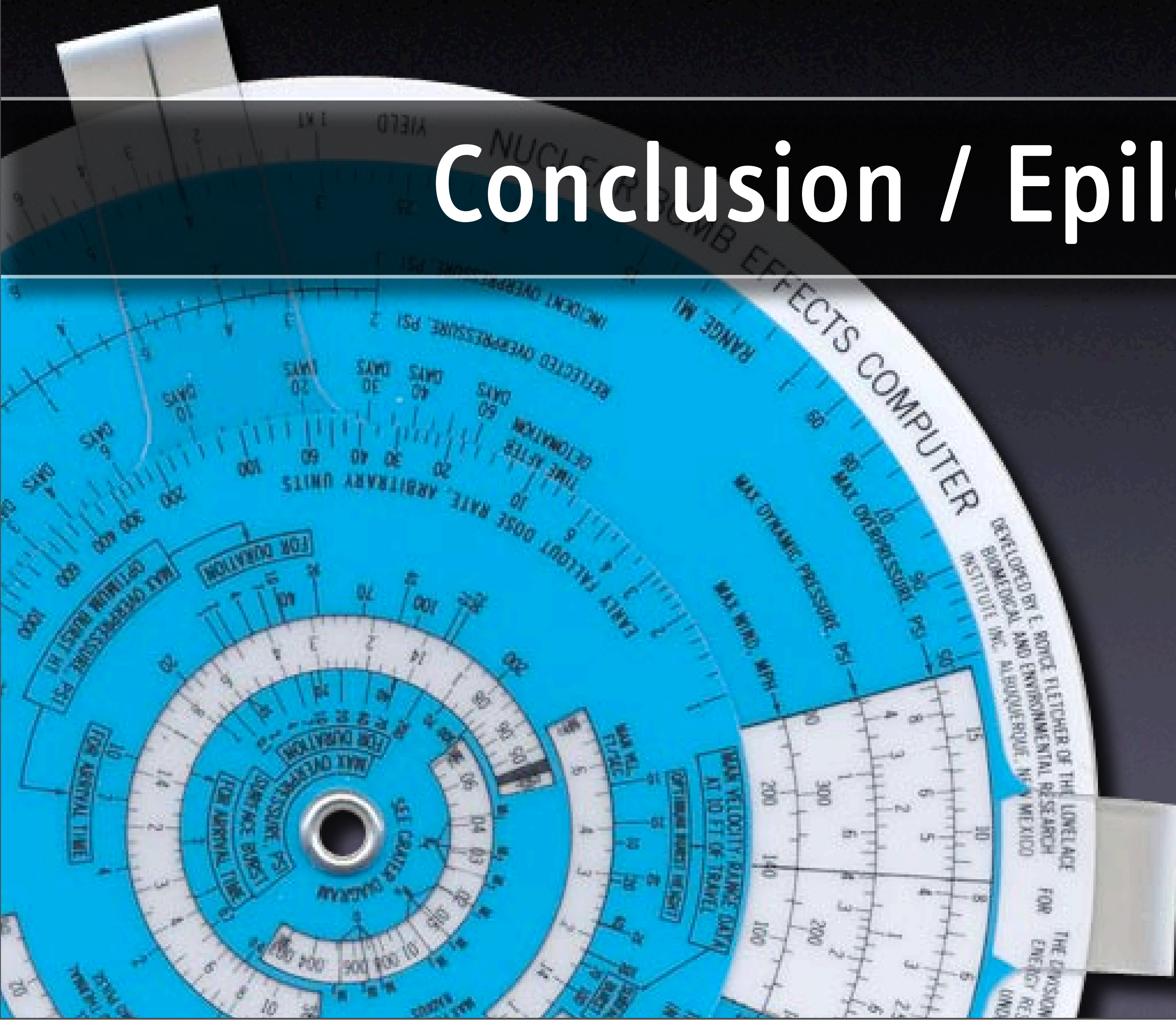
"[I]t seems reasonable to assume that the destruction of, say, 25 percent of its population (55 million people) and more than two-thirds of its industrial capacity would mean the destruction of the Soviet Union as a national society. Such a level of destruction would certainly represent intolerable punishment to any industrialized nation and thus should serve as an effective deterrent."

Secretary of Defense McNamara
November 21, 1962 memo to President Kennedy

TABLE 5.7
NRDC "Assured Destruction" Calculations Using 1999 World Population Data

Country	1999 LandScan Population	25% of the 1999 LandScan Population	Number of 475-kt Weapons Required to Threaten 25% of the Population
United States	258,833,000	64,708,250	124
Canada	28,402,320	7,100,580	11
United Kingdom	56,420,180	14,105,045	19
France	57,757,060	14,439,265	25
Germany	81,436,300	20,359,075	33
Italy	57,908,880	14,477,220	21
Spain	39,267,780	9,816,945	20
All NATO Member Countries[17]	754,933,329	188,730,000	300
Russia	151,827,600	37,956,300	51
China	1,281,008,318	320,252,079	368
North Korea	22,034,990	5,508,747	4
Iran	64,193,450	16,048,363	10
Iraq	20,941,720	5,235,430	4
Syria	14,045,470	3,511,368	2
Libya	5,245,515	1,311,329	2

Conclusion / Epilogue



"Duck and Cover"

Federal Civil Defense Administration, 1951

“The Day After”

ABC Television, November 1983