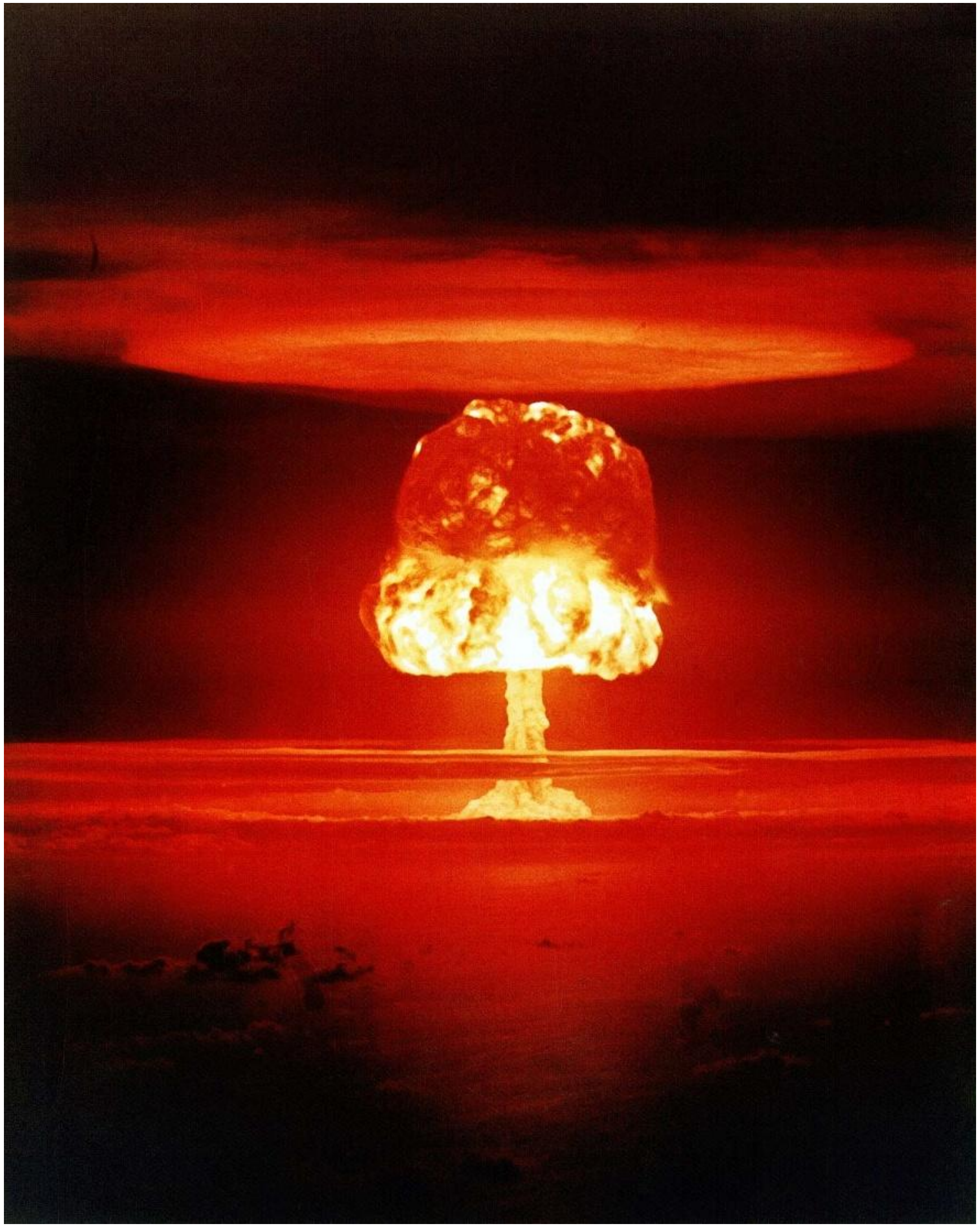


NE 502

NUCLEAR WEAPONS and FALLOUT PROTECTION

Dr. Fred Gunnerson
Director
UI Nuclear Engineering
fgunners@uidaho.edu
208.533.8107

SUMMER 2009

Mondays
6:00 – 8:30 pm MST
University Place CHE 304

University of Idaho
A LEGACY OF LEADING

INTRODUCTION TO NUCLEAR WEAPONS AND FALLOUT PROTECTION

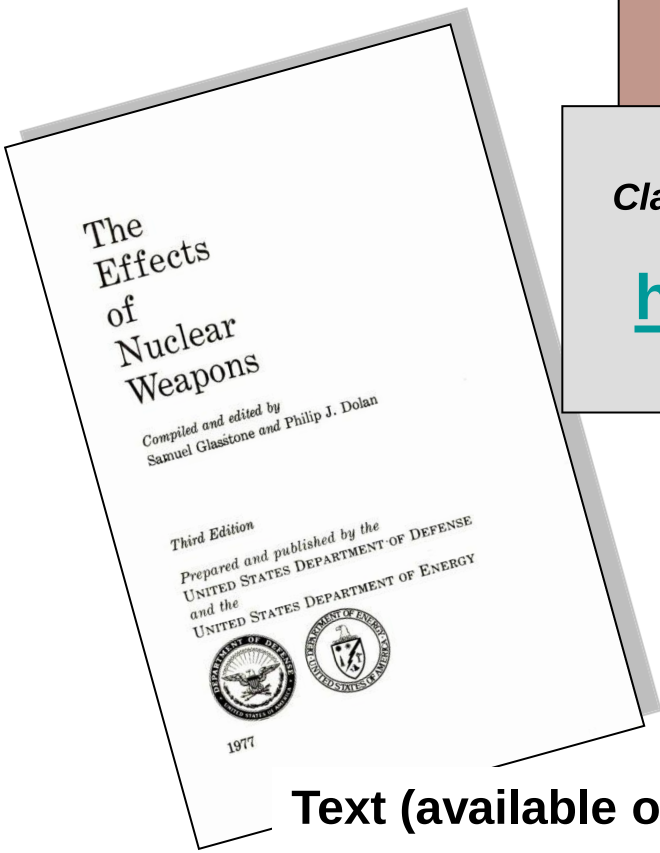
Summer Short Course

NE 502   1- credit hour

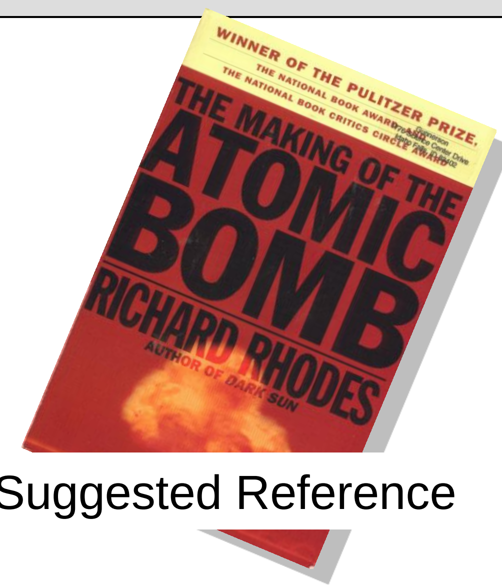
CLASS WEB SITE

Class information, lecture notes and homework assignments

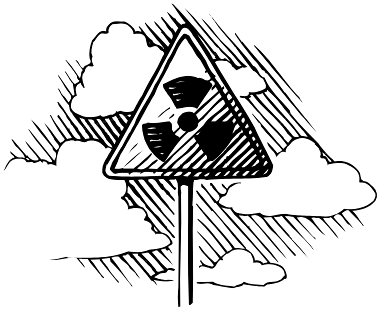
http://www.if.uidaho.edu/~gunner/



Text (available on web site)



Suggested Reference



INTRODUCTORY LECTURE

PART I: FUNDAMENTAL PRINCIPLES

fission / fusion / binding energy / critical mass

PART II: BASIC CONCEPTS OF WEAPON DESIGN

PART III: ENERGY RELEASE & EFFECTS

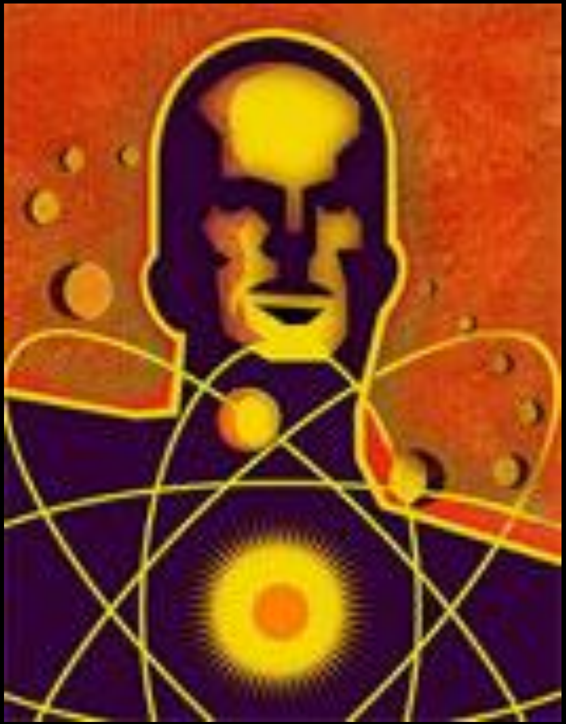
initial nuclear radiations
blast and shock
thermal radiation
residual nuclear radiation (fallout)

PART IV: WHO HAS NUCLEAR WEAPONS ?

SUMMARY / COMMENTS / QUESTIONS

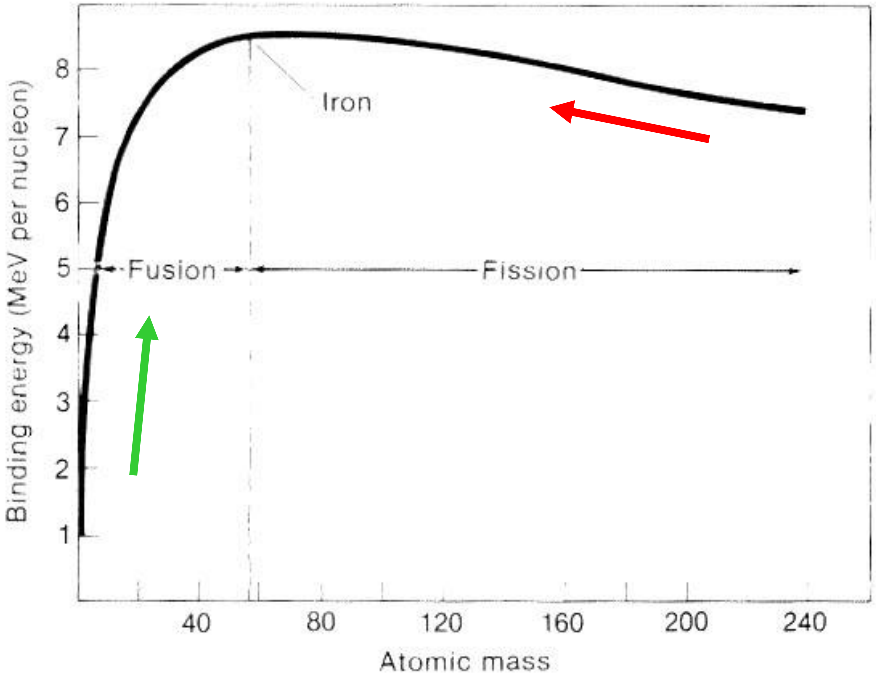
PART I

FUNDAMENTAL PRINCIPLES



SOME FUNDAMENTALS

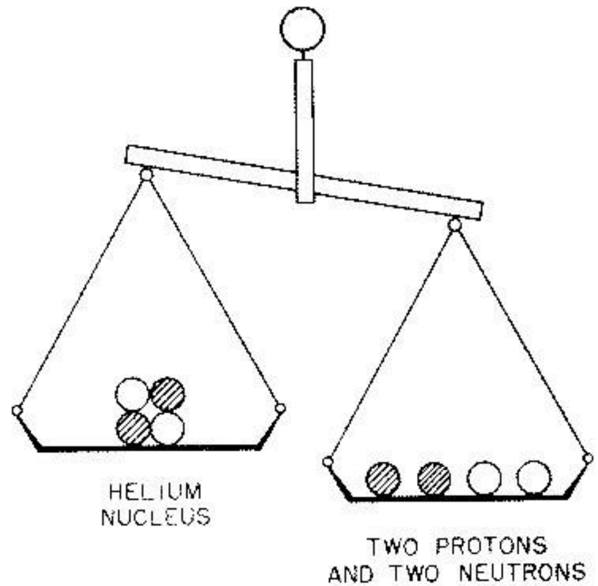
FISSION FUSION BINDING ENERGY



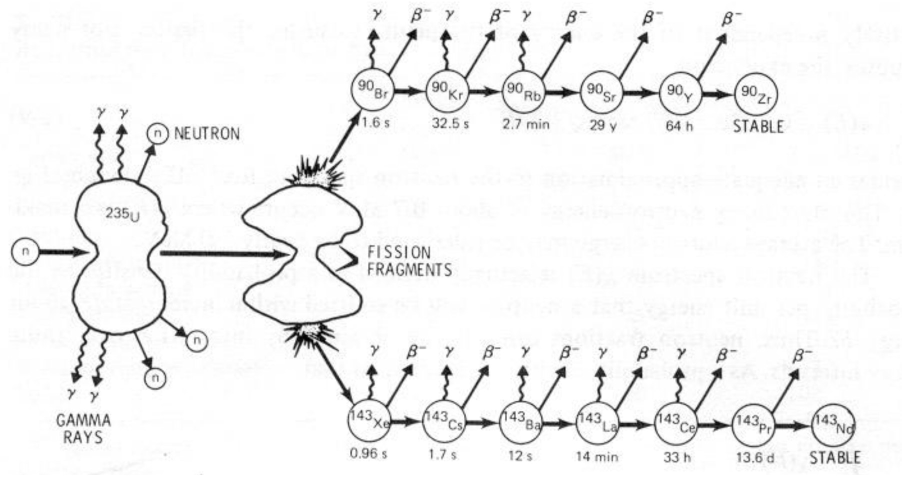
NUCLEUS

$\Delta E = \Delta mc^2$ = BINDING ENERGY

$$\Delta m = Z(m_p) + N(m_n) - (M_x - \cancelto{\sim 0}{Zm_e})$$



FISSION



Fuels… highly enriched (>90%)

U-235

Pu-239

ENERGY EQUILIVALENTS

1 kiloton of TNT =
1.16E06 kilowatt-hours
1.16E03 MW-hour
1,160 MW-hour
2.60E25 MeV

~ fission of $1.45(10)^{23}$ nuclei
~ 57 gm fissile material
~ one lifetime of energy

DISTRIBUTION OF FISSION ENERGY

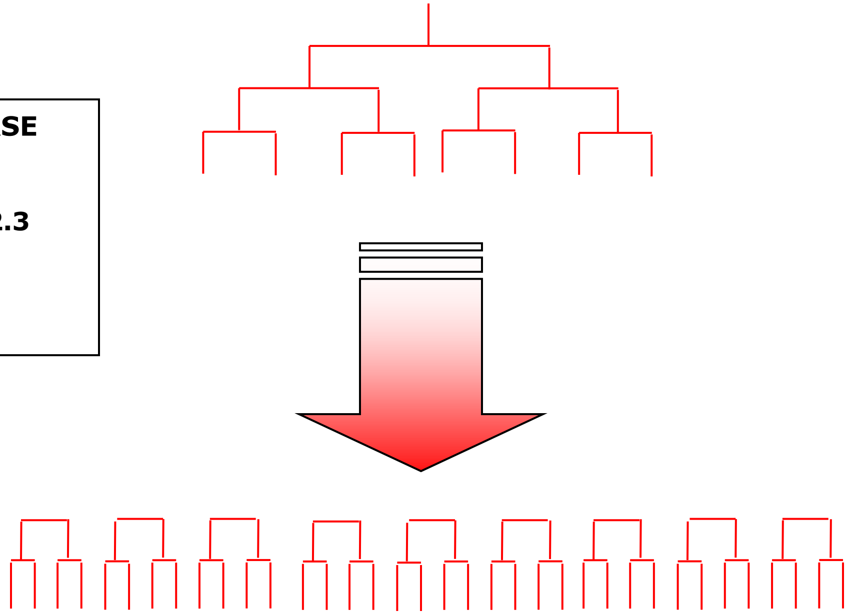
	MeV
Kinetic energy of fission fragments	165 ± 5
Instantaneous gamma-ray energy	7 ± 1
Kinetic energy of fission neutrons	5 ± 0.5
Beta particles from fission products	7 ± 1
Gamma rays from fission products	6 ± 1
Neutrinos from fission products	10
Total energy per fission	200 ± 6

CHAIN REACTION

RATE OF NEUTRON INCREASE

$$dN/dt = Nx/g$$
$$N = N_o e^{xt/g} \sim N_o 10^{n/2.3}$$

(U-235)



GENERATION
1
2
3
4
.
.
.
.
.
.
.
.
n-1
n

To generate ~0.1 kT of energy requires about 51 generations.

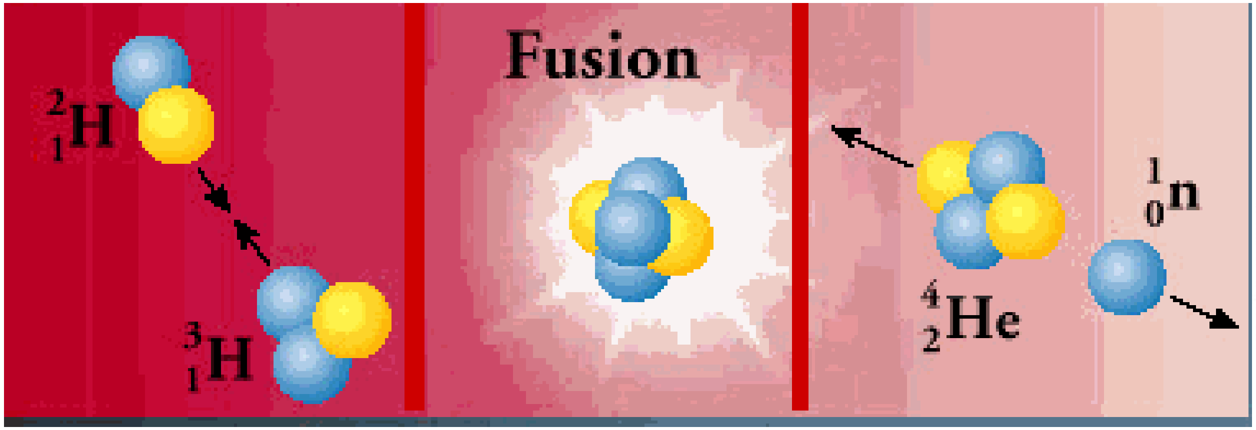
To generate ~100 kT of energy requires about 58 generations.

99.9% of the 100 kT energy is generated in the last 7 generations.

Time per generation ~ 10^{-8} s = one "shake"

Thus to get a 'good yield' from a weapon requires that the critical mass be held together ~60 shakes ~60(10)-8 seconds ~ 0.6 μs

FUSION



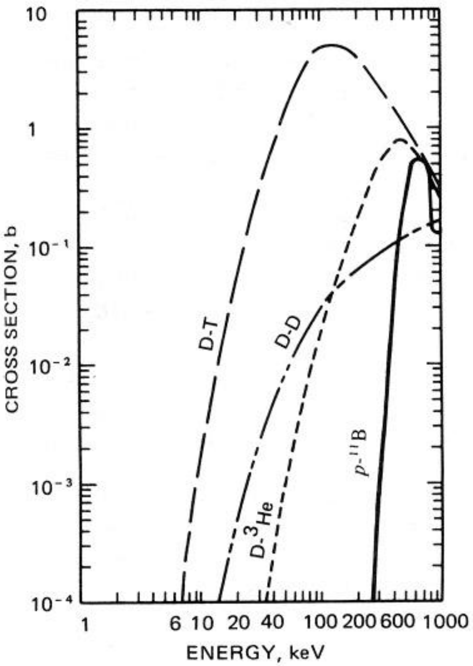


FIGURE 21-1
Reaction cross sections for selected fusion reactions.

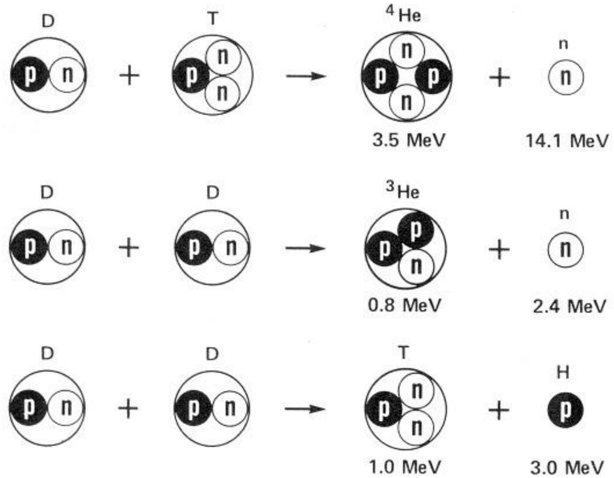


Figure 1. *Fusion reactions with deuterium (D) and tritium (T) nuclei. The numbers indicate how the fusion energy is divided between the products in each case. The neutrons (n) are not electrically charged, but the other products carry electrical charges.*

$E = (3/2)kT$

10 keV ~ 77,000,000 K

Critical Mass

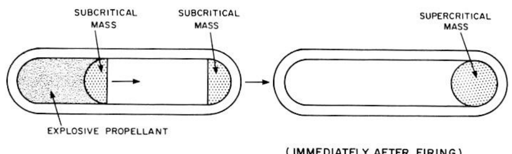


Figure 1.52. Principle of a gun-assembly nuclear device.

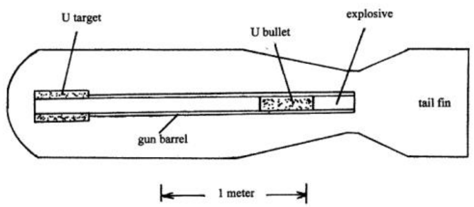


FIG. 26.1 Uranium fission nuclear weapon, gun type Little Boy.

TABLE 26.1
Critical Masses of U-235 and U vs. Enrichment

% U-235	U-235 (kg)	U (kg)
100	15	15
50	25	50
20	50	250
10	130	1300

$k_{eff} = 1$ (critical)

$k_{eff} > 1$ (super-critical)

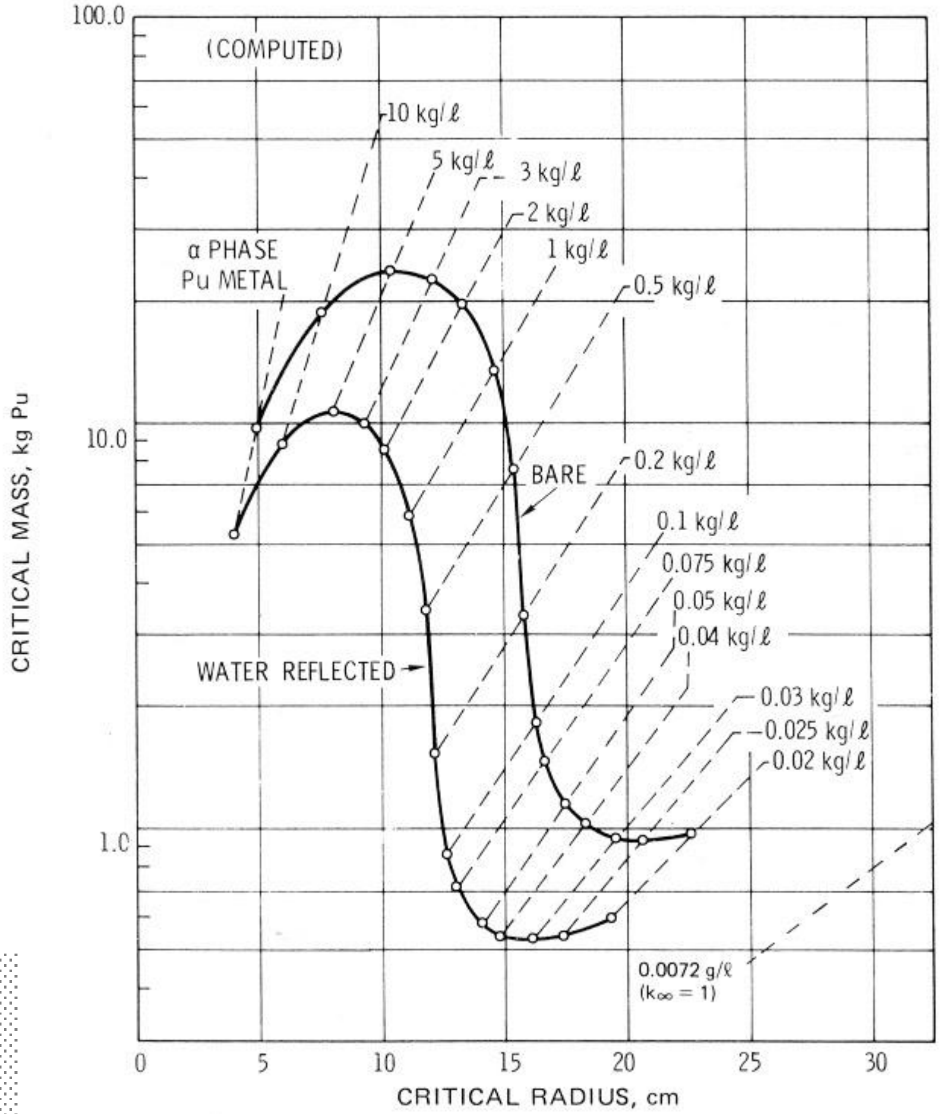
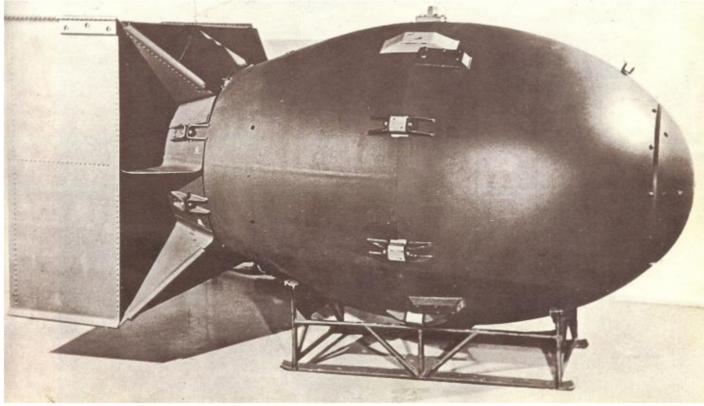


FIGURE 4-4
Computed mass and radius of critical ^{239}Pu–water spheres. (Adapted courtesy of E. D. Clayton, Battelle Pacific Northwest Laboratories.)

PART II
BASIC CONCEPTS OF WEAPON DESIGN

CRITICAL MASS



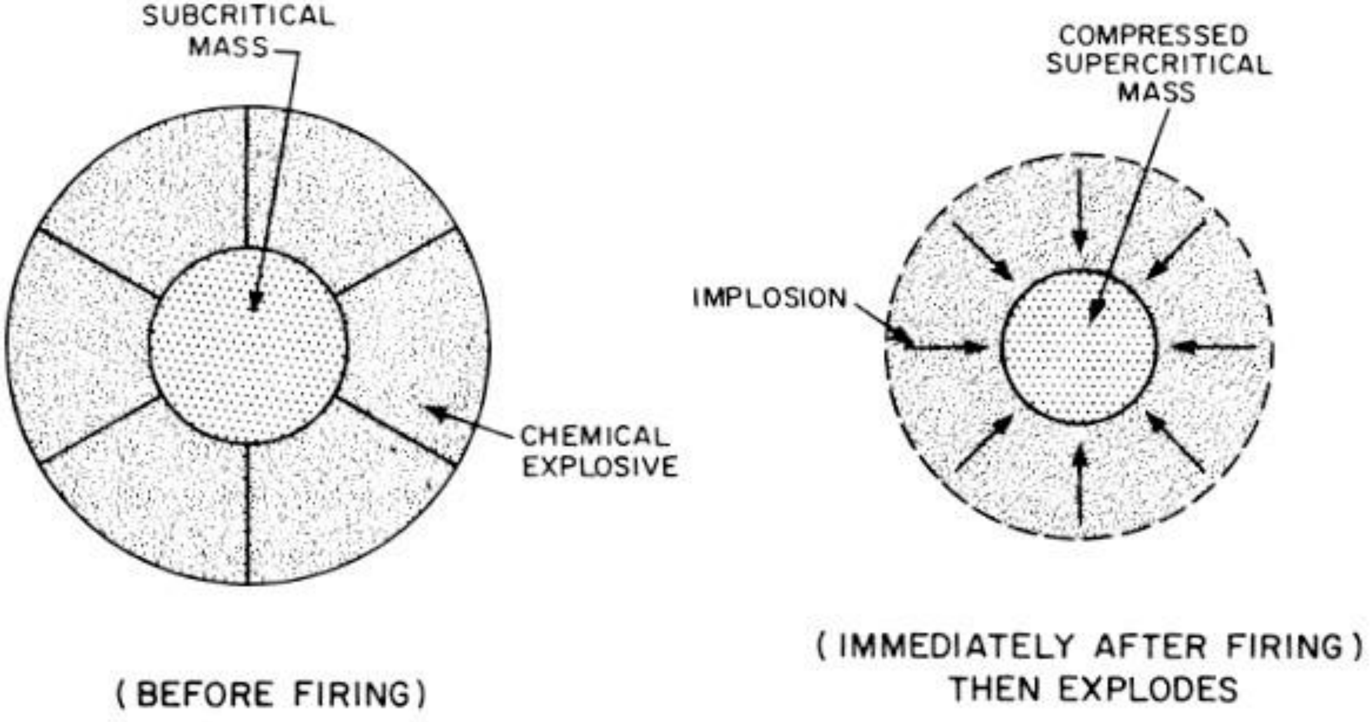
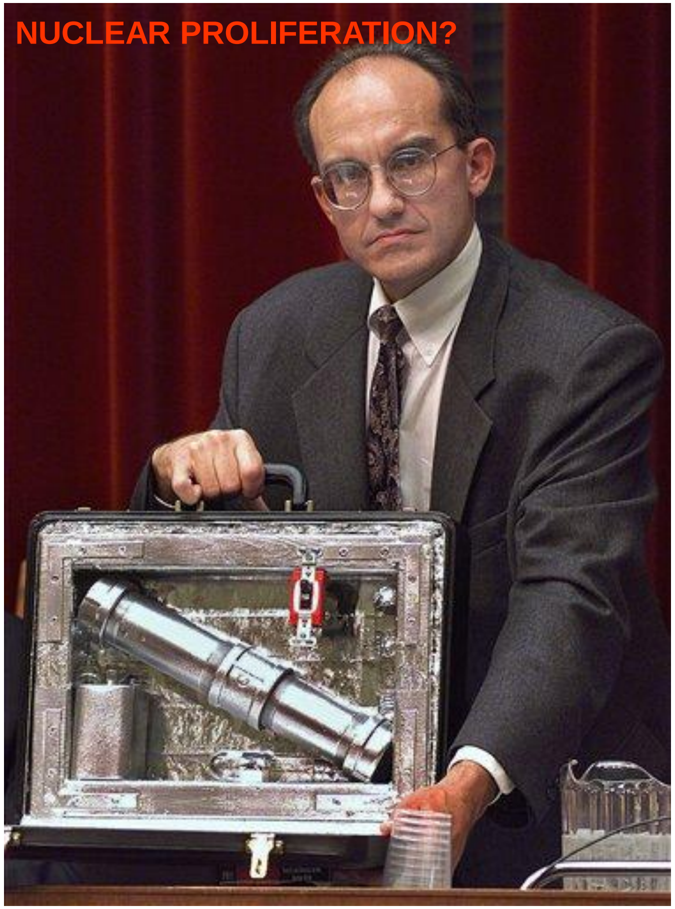
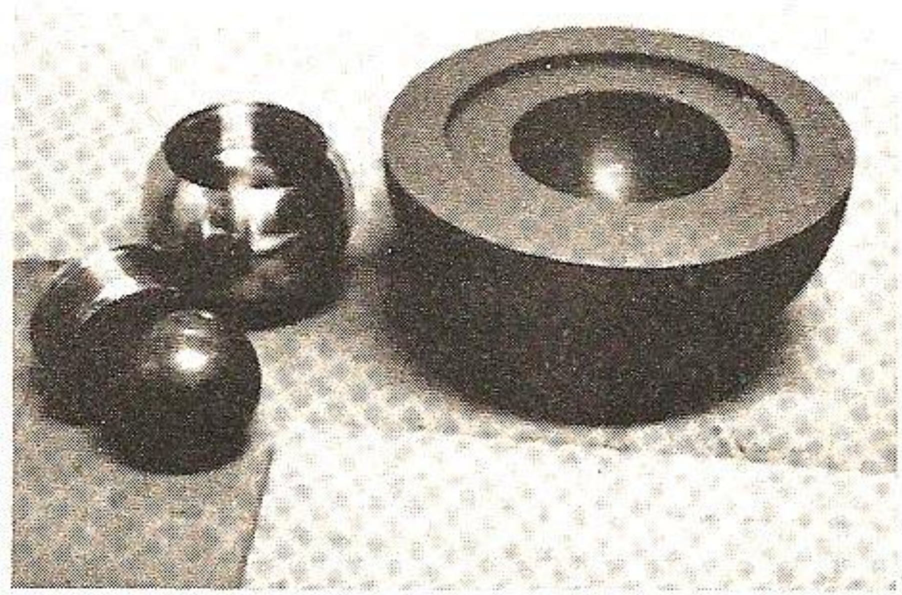


Figure 1.53. Principle of an implosion-type nuclear device.



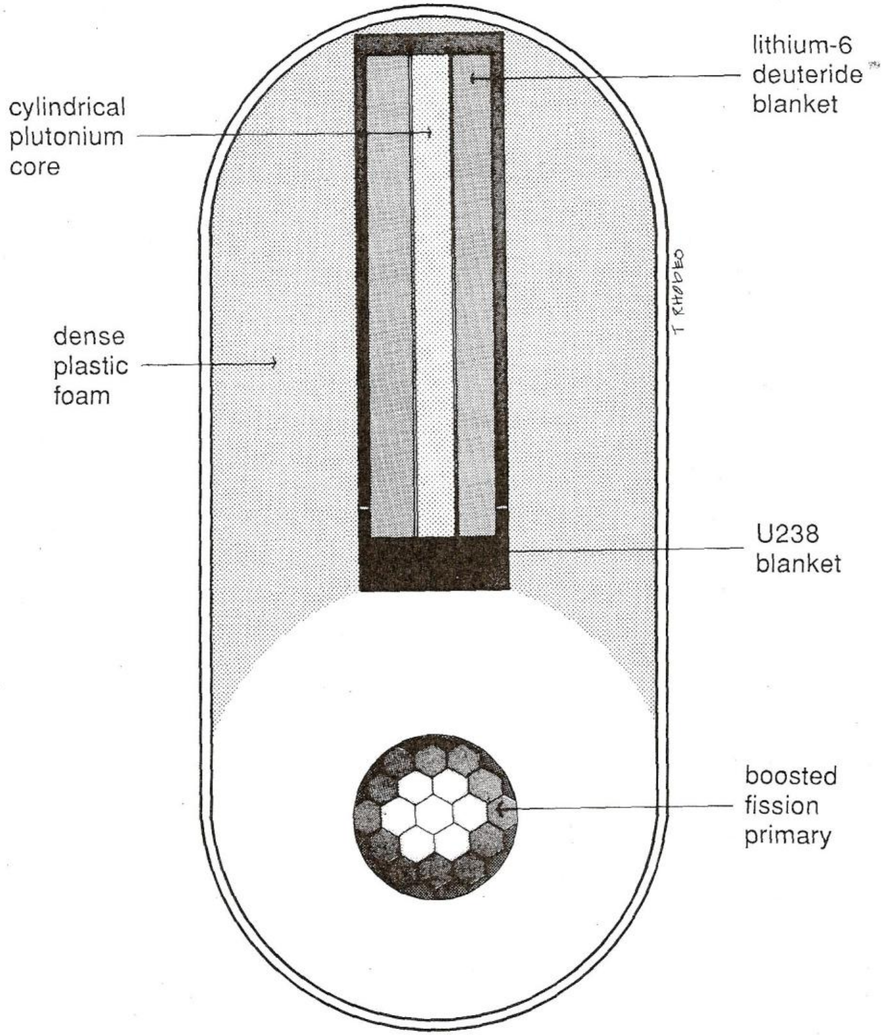
SUITCASE BOMB ?
Testifying before US Congress 1999


Sunday Times, London

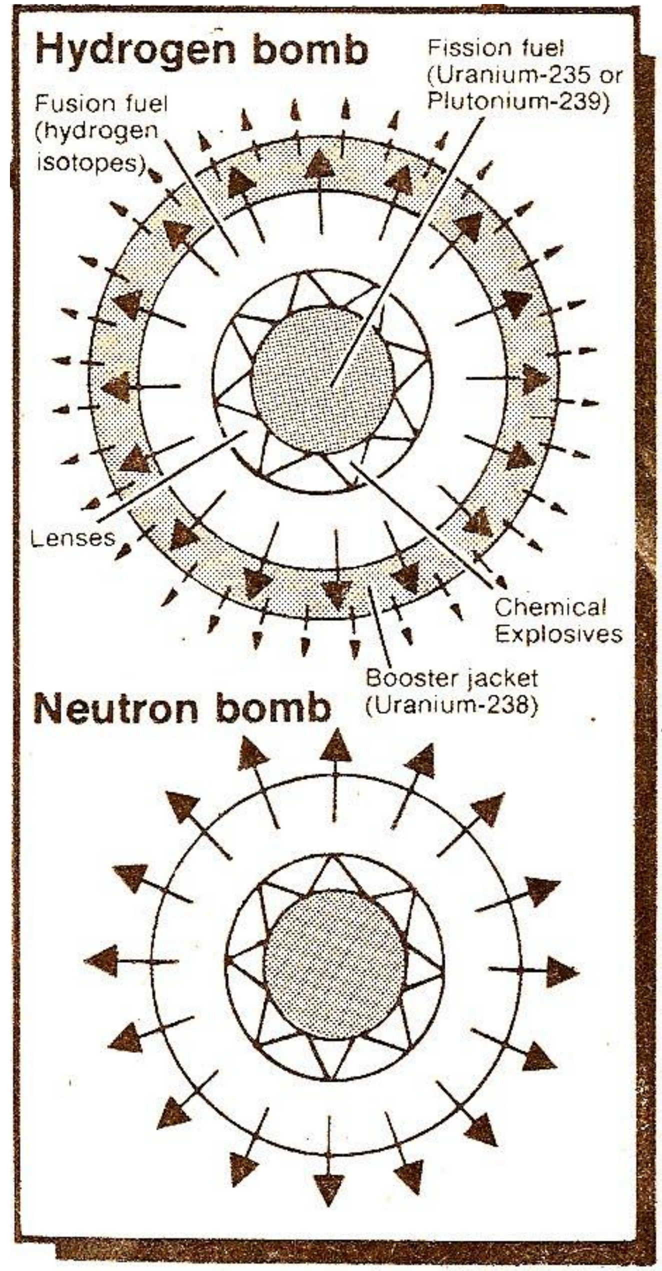
Bomb core. *Shown here is a model of what are alleged to be components of an Israeli nuclear weapon, including a shiny hollow beryllium sphere with its cap removed. It is meant to encase the small, dark plutonium core. The larger, half-sphere at right apparently represents explosive material that when detonated would trigger a nuclear explosion. The photograph is one of a series taken by a former technician, Mordechai Vanunu, at the Dimona underground nuclear facility in Israel.*

Science, March 1987

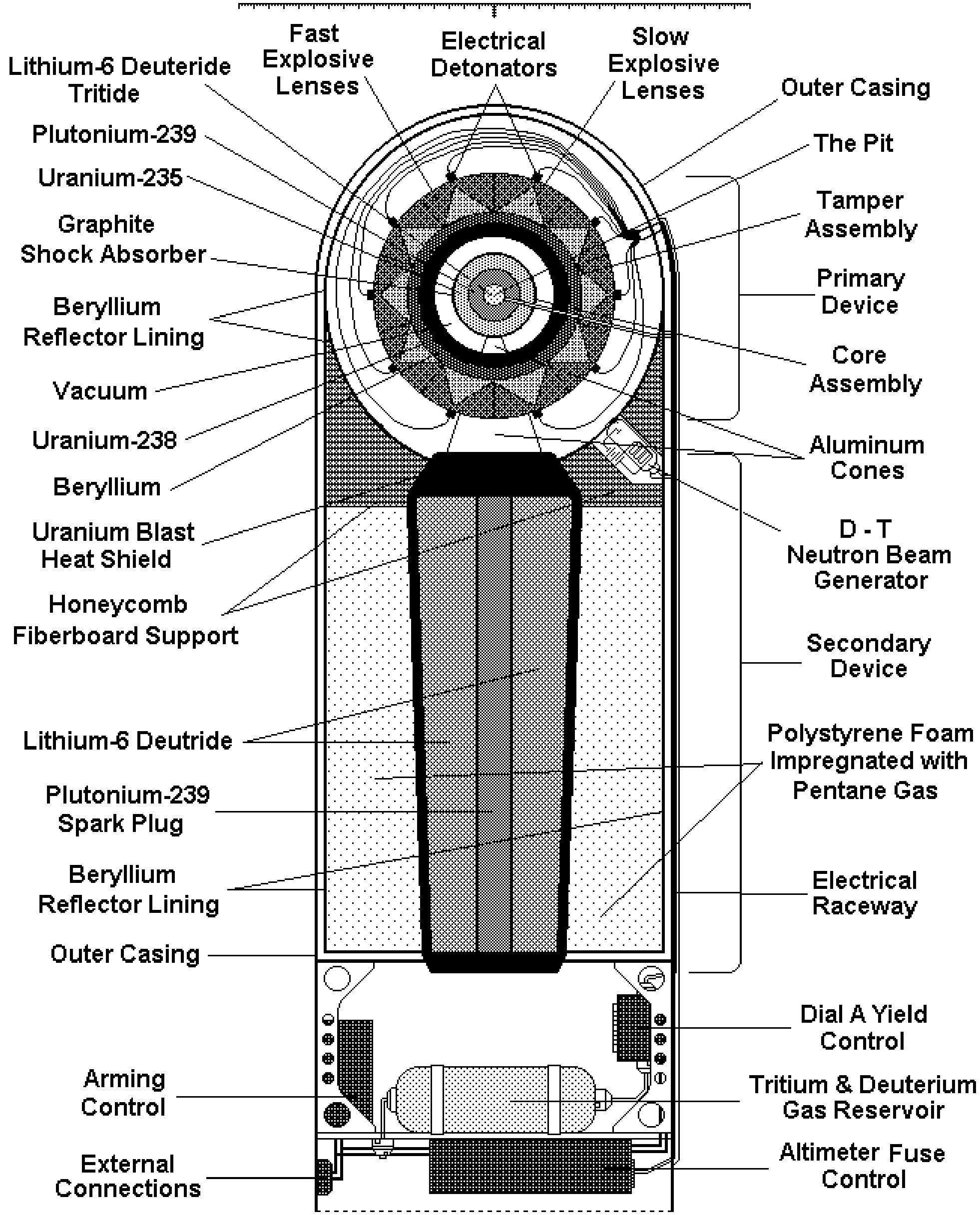
Geometry and Critical Mass



Fission – Fission – Fusion bomb

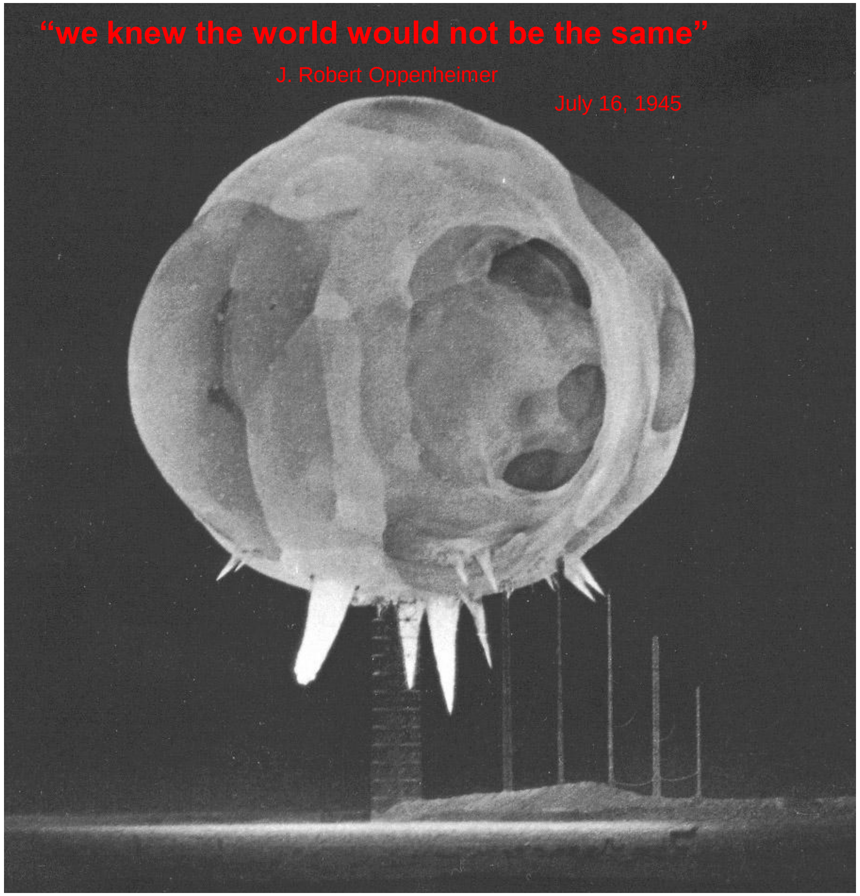


Source: Scientific American



Lithium-6 Deuteride
Tritide
Fast
Explosive
Lenses
Electrical
Detonators
Slow
Explosive
Lenses
Outer Casing
Plutonium-239
Uranium-235
The Pit
Tamper
Assembly
Graphite
Shock Absorber
Primary
Device
Beryllium
Reflector Lining
Core
Assembly
Vacuum
Uranium-238
Aluminum
Cones
Beryllium
D - T
Neutron Beam
Generator
Uranium Blast
Heat Shield
Honeycomb
Fiberboard Support
Secondary
Device
Lithium-6 Deutride
Polystyrene Foam
Impregnated with
Pentane Gas
Plutonium-239
Spark Plug
Beryllium
Reflector Lining
Electrical
Raceway
Outer Casing
Dial A Yield
Control
Arming
Control
Tritium & Deuterium
Gas Reservoir
External
Connections
Altimeter Fuse
Control

PART III
ENERGY RELEASE & EFFECTS



'Instant of Detonation'
NUCLEAR FIREBALL
(10^{-4} seconds after detonation)

PHOTO: US Army 1950 by Doc Edgerton et al., EG&G
"shutter speed: a hundred-millionth of a second"
From Nat'l Geo Oct 1987

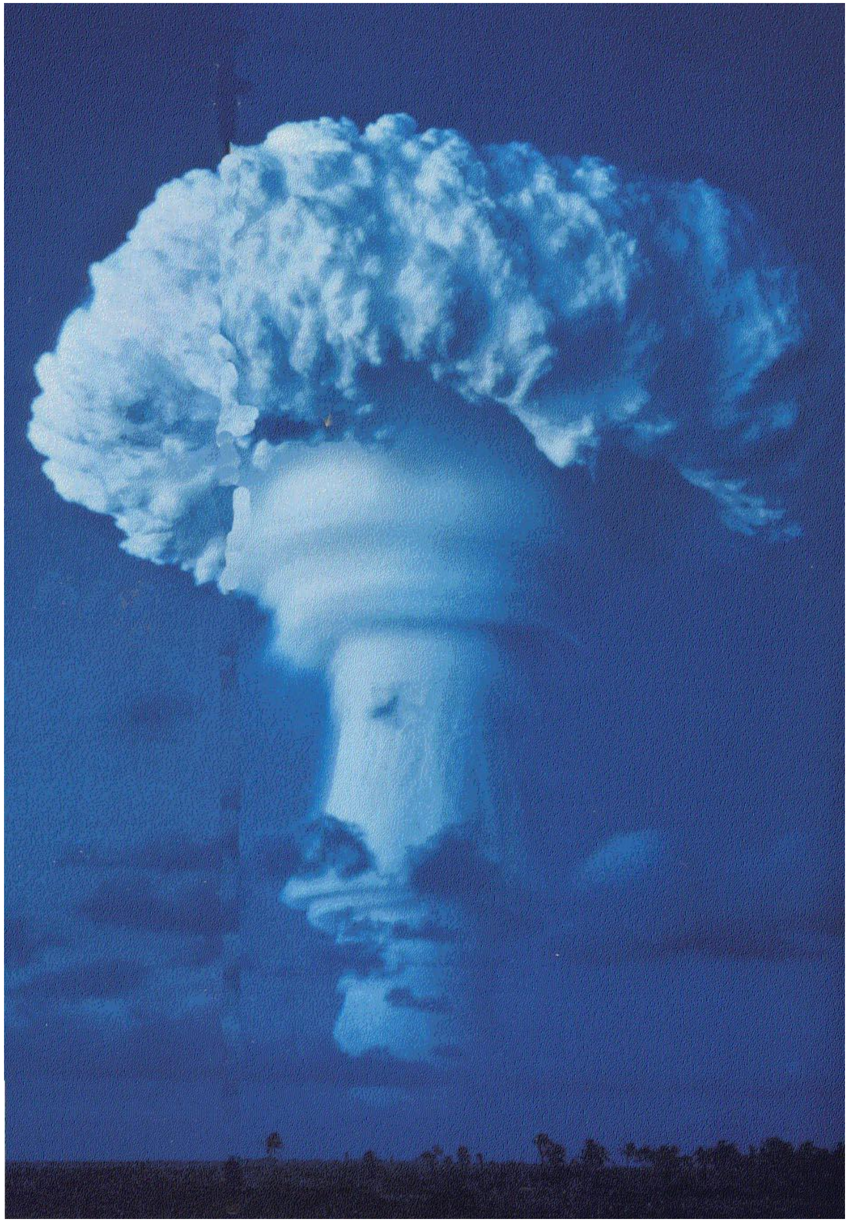
Fireball Diameter: **~33 ft @ 1E-06 sec**
~300 ft @ 1 ms (10-3 s)
~800 ft @ 80 ms = 0.08 sec

ENERGY RELEASE

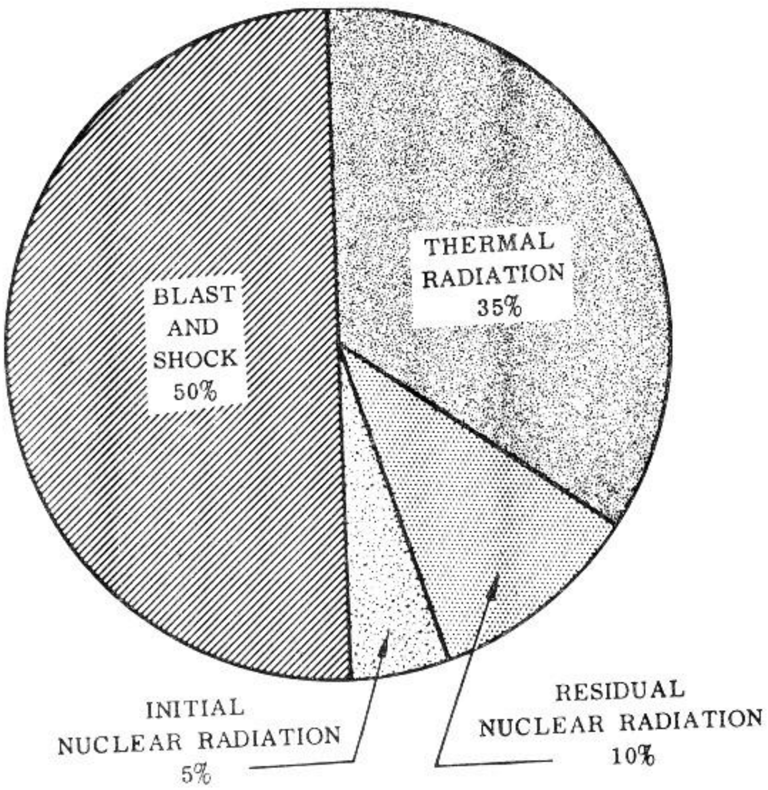
- **Initial nuclear radiations**
  prompt gammas and neutrons
- **Thermal radiation**
- **Blast and Shock**
- **Residual nuclear radiations**

The percentage of each depends on the type of blast, for example:

Subsurface
Surface
Atmospheric
Exo-Atmosphere (space)



ATMOSPHERIC BURST
Typical energy distribution



Interactions of Gamma and X-rays

- **Low Energy:**
  Photoelectric Effect dominates

- **Mid-Energy:**
  Scattering dominates
  Many types of scattering:
  Compton scattering
  (with free, unbound e-)
  Incoherent scattering
  (considers e- binding energy)
  Rayleigh scattering
  (considers nucleus recoil)

- **High Energy:**
  Pair Production dominates

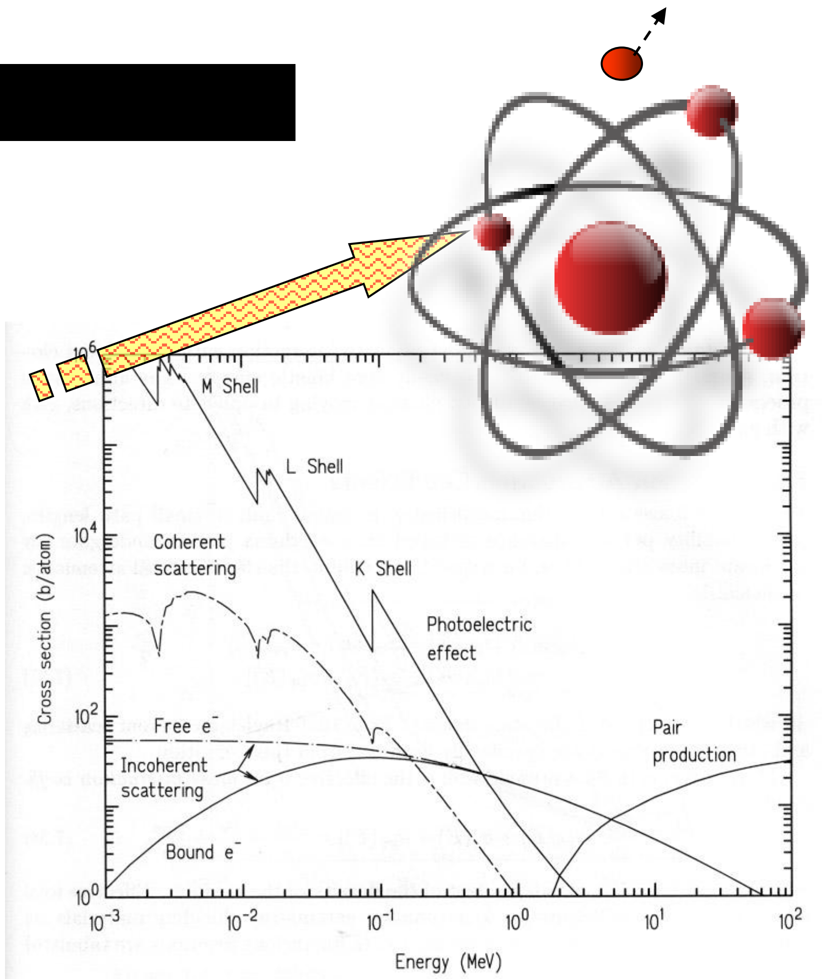


Figure 7.3. Comparison of scattering, photoelectric-effect, and pair-production cross sections for photon interactions in lead. From Shultis and Faw [1996].

"all interaction mechanisms result in electrons in motion"

INITIAL NUCLEAR RADIATIONS

Prompt gammas interacting with air to produce a current of electrons

ELECTROMAGNETIC PULSE (EMP)

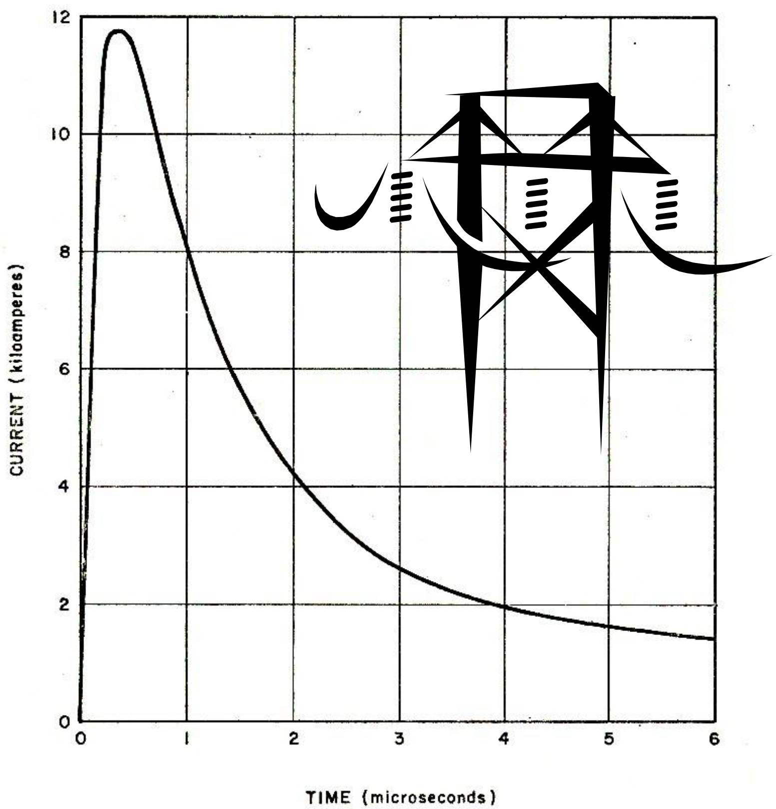
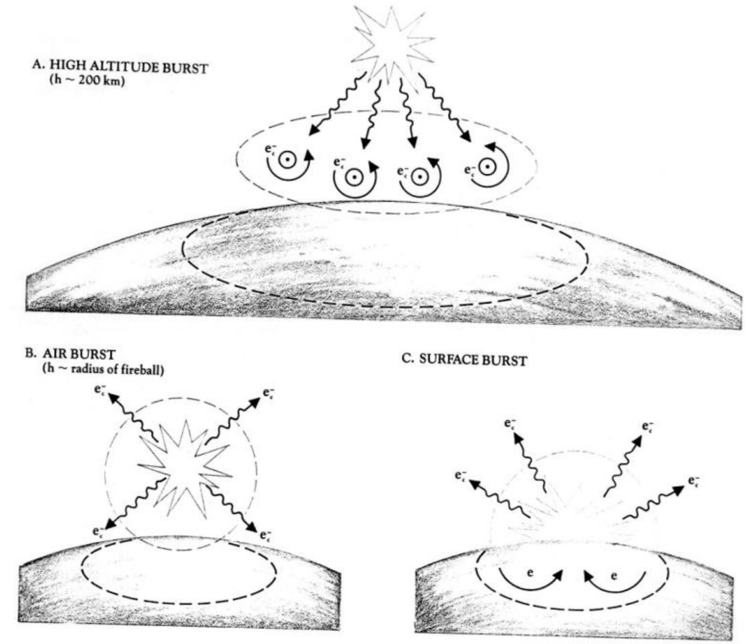
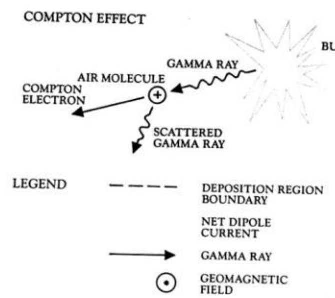


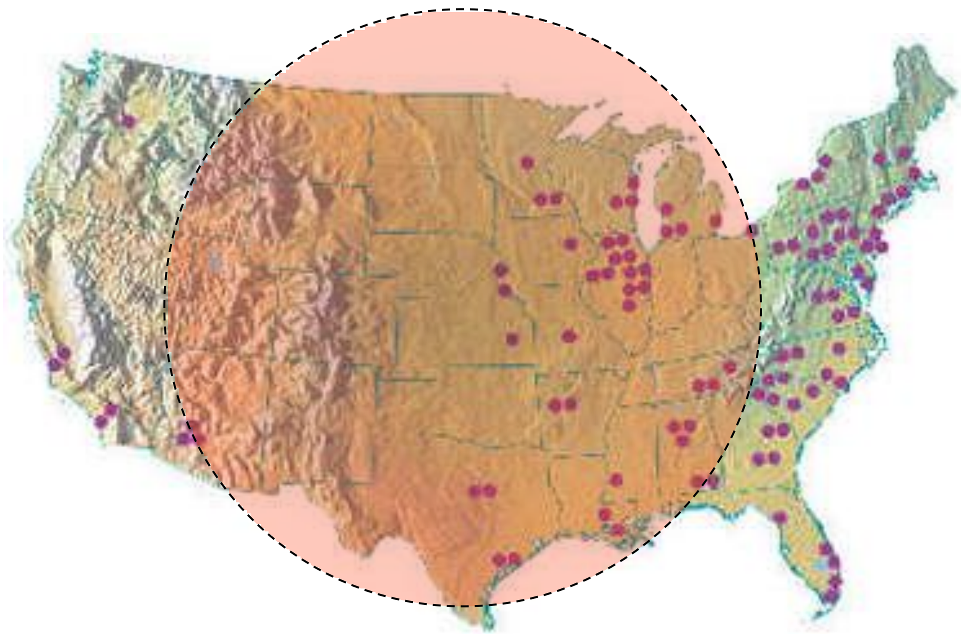
Figure 11.50. Typical form of the current pulse induced by the EMP from a high-altitude nuclear explosion in a long overhead power line. (The actual currents and times will depend to some extent on the conditions.)

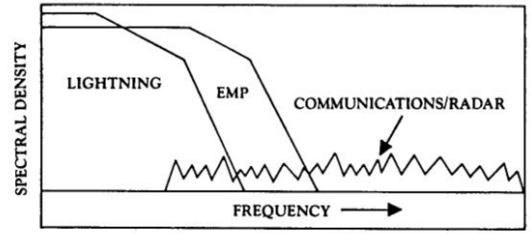




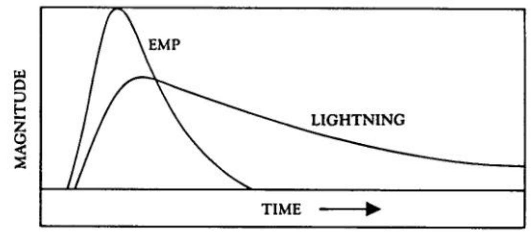
ELECTROMAGNETIC PULSE (EMP) GENERATION occurs when gamma rays interact with air molecules. Since air density is a function of altitude, the characteristics and effects of EMP depend upon the height of the burst above the earth. For a high altitude burst (A), electrons released due to the Compton process (insert) gyrate about geomagnetic field lines and create a strong radiated field over a wide area of the earth's surface. In the denser air at lower altitudes (B), attenuation of the Compton electrons occurs over a distance that is small compared to the electron's gyration radius about the geomagnetic field line. In this instance, the decreasing air density with increasing altitude results in a small net vertical "dipole" and consequently a relatively weak radiated field. At or near the surface (C), there is a very large vertical dipole current caused by air-earth interface asymmetry. Another effect of the ground-level burst is a strong azimuthal magnetic field at the surface due to electron return-current flow in the earth through the air-to-ground circuit path.

More EMP

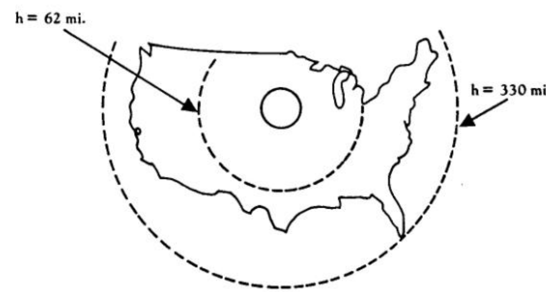




A. SPECTRUM COMPARISON



B. TIME COMPARISON



C. EMP GROUND COVERAGE FROM HIGH ALTITUDE BURSTS

FIGURE 5

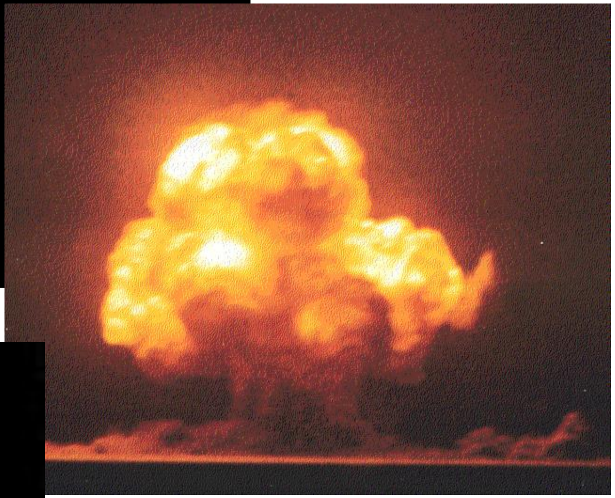
ENERGY DELIVERED BY ELECTROMAGNETIC PULSE (EMP) due to a nuclear burst occurs across a broad spectrum of frequencies (A), including those used for radio communications. Lightning energy is distributed across a somewhat narrower spectrum. Although the total energy delivered by a lightning discharge may be greater than in an EMP, the latter is delivered faster (B), usually too fast for conventional lightning arresters to be effective. The effective radius of EMP increases with altitude of the burst (C), and high altitude detonations blanket large regions of the earth with EMP energy. Peak intensity of the electromagnetic field due to this phenomenon may be as great as 50,000 volts per meter.

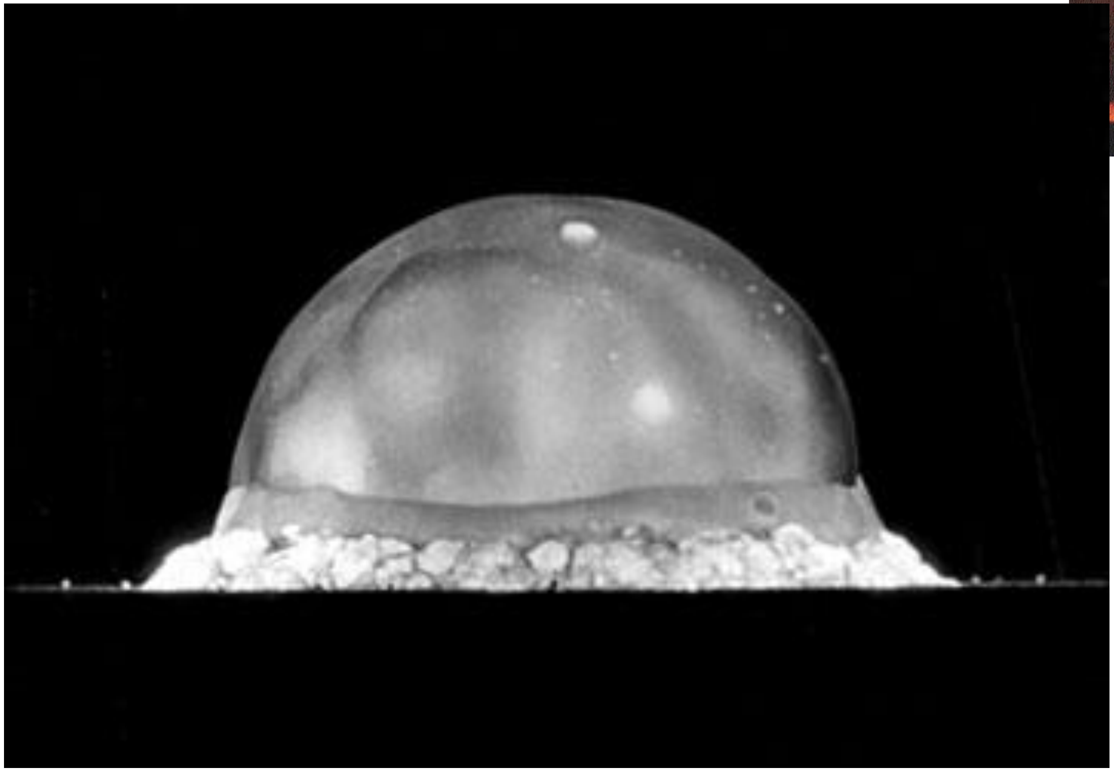
INITIAL NUCLEAR RADIATIONS

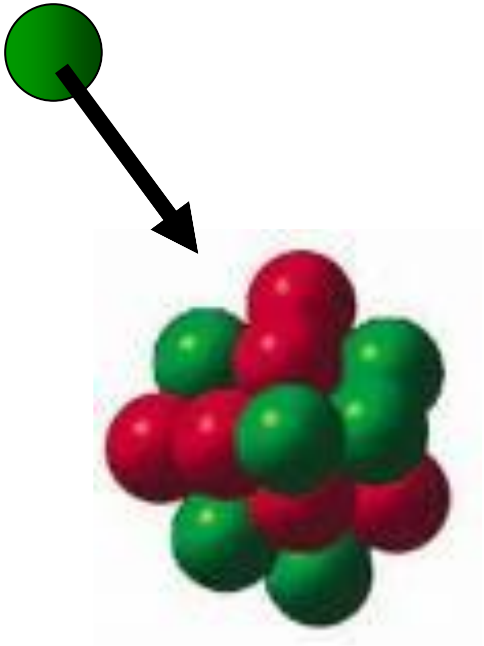
Neutron activation

A major concern if the fireball touches ground

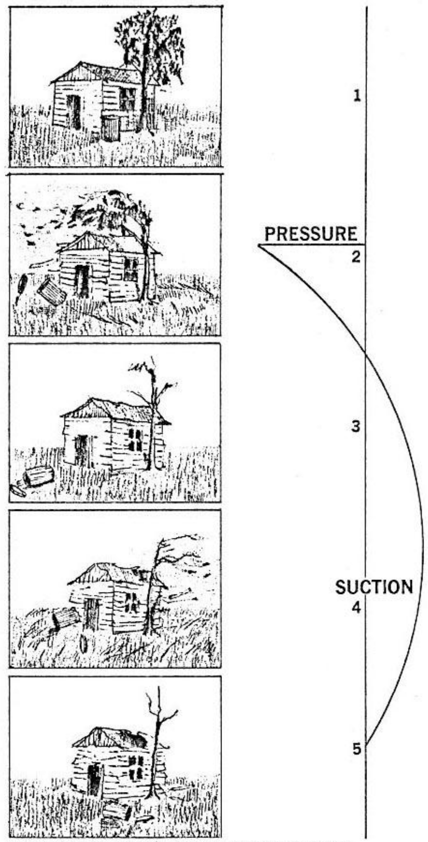
Contributes to later fallout







BLAST & SHOCK



SHOCK WAVE PHENOMENON

Wind Velocity at Various Distances from Ground Burst

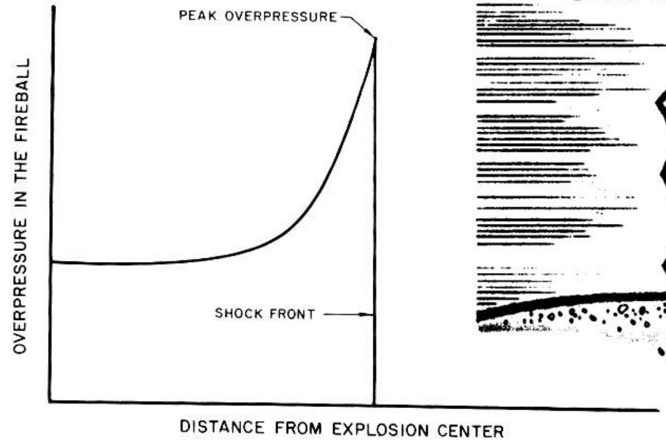
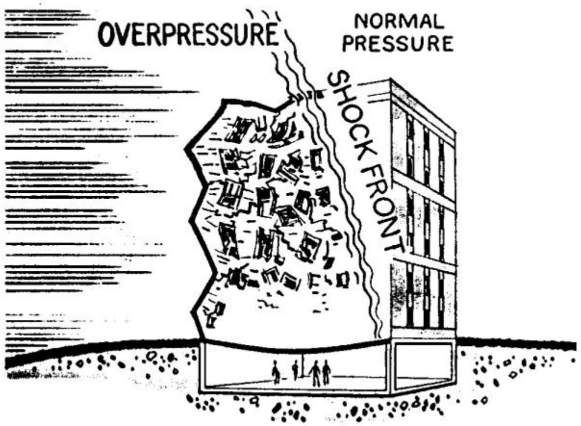


Figure 3.03. Variation of overpressure with distance in the fireball.



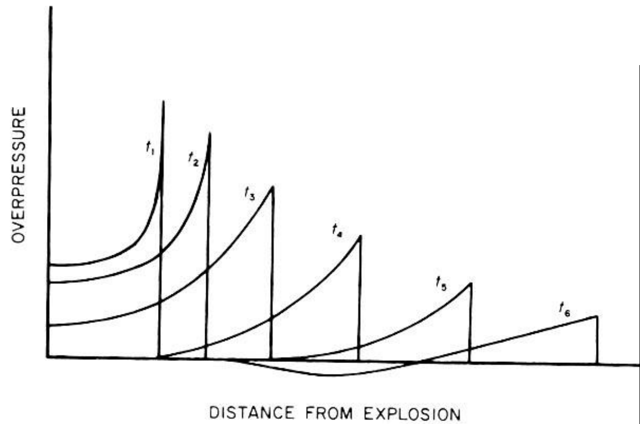
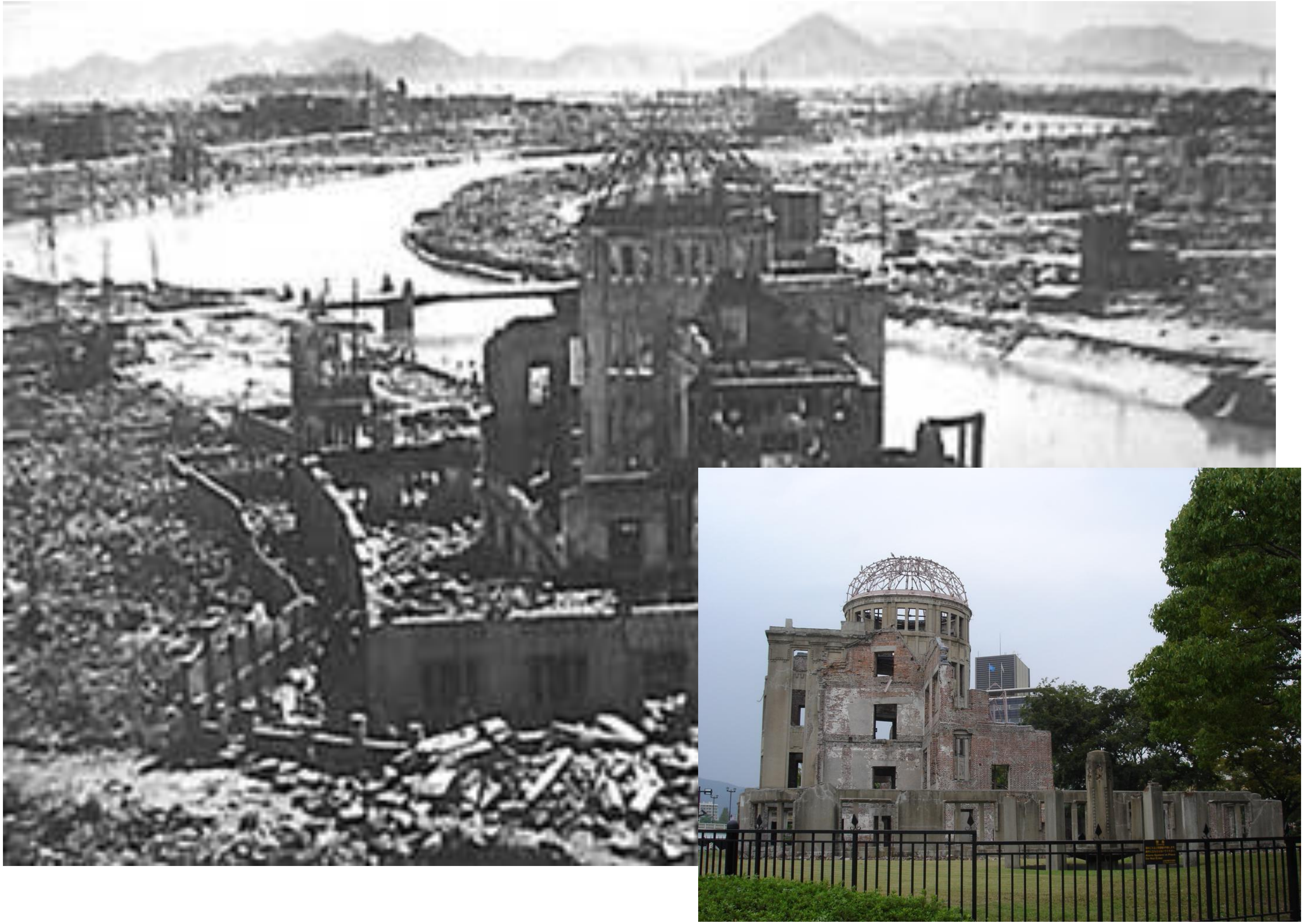


Figure 3.04. Variation of overpressure in air with distance at successive tim

OVER-PRESSURE (psi)	WIND SPEED (mph)
100	**~1,000**
10	**~550**
1	**~200**

BLAST DAMAGE

STRUCTURE	FAILURE	PSI
GLASS WINDOWS	SHATTERING	0.5 – 1.0
PARKED AIRCRAFT	FIELD MAINTENANCE REQUIRED TO RESTORE AIRCRAFT TO OPERATIONAL STATUS	
TRANSPORT		2
LIGHT LIAISON		1
HELICOPTER		1.5
WOOD SIDING PANELS, STANDARD HOUSING CONSTRUCTION	PANEL BLOWN IN	1 – 2
CORRUGATED STEEL OR ALUMINUM PANELING	CONNECTION FAILURE FOLLOWED BY BUCKLING	1 – 2
CONCRETE OR CINDER-BLOCK WALL (8 – 12 IN THICK) NOT REINFORCED	SHATTERING OF THE WALL	2 – 3
BRICK WALL PANEL (8 – 12 IN.THICK) NOT REINFORCED	SHEARING OR FLEXURE FAILURES	7 – 8
PERSONNEL		
	1% PROBABILITY OF FATALITY	35 – 45
	50% PROBABILITY OF FATALITY	45 – 55
	99% PROBABILITY OF FATALITY	55 – 65

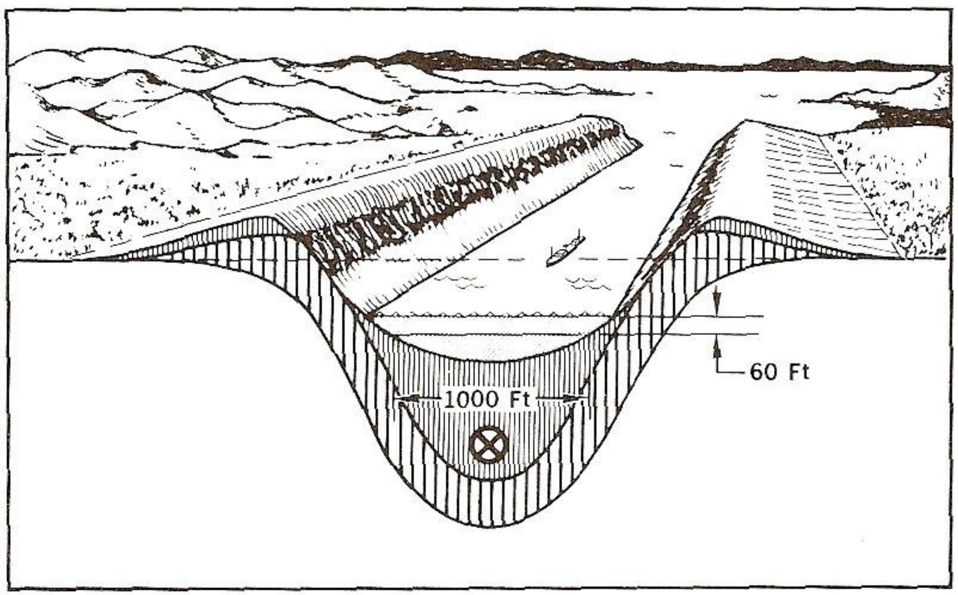


SHOCK & CRATERS

PROJECT PLOWSHARE
“Swords to Plowshares”
1960-1965

AEC Mission….*to develop, within years,*
a technology for using nuclear explosives
for peaceful purposes…

- Sea-level Panama Canal
- Mining
- Oil Production



A sea-level canal, dug by nuclear explosives, as shown in this cross-section drawing, would be 1000 feet wide and at least 60 feet deep.

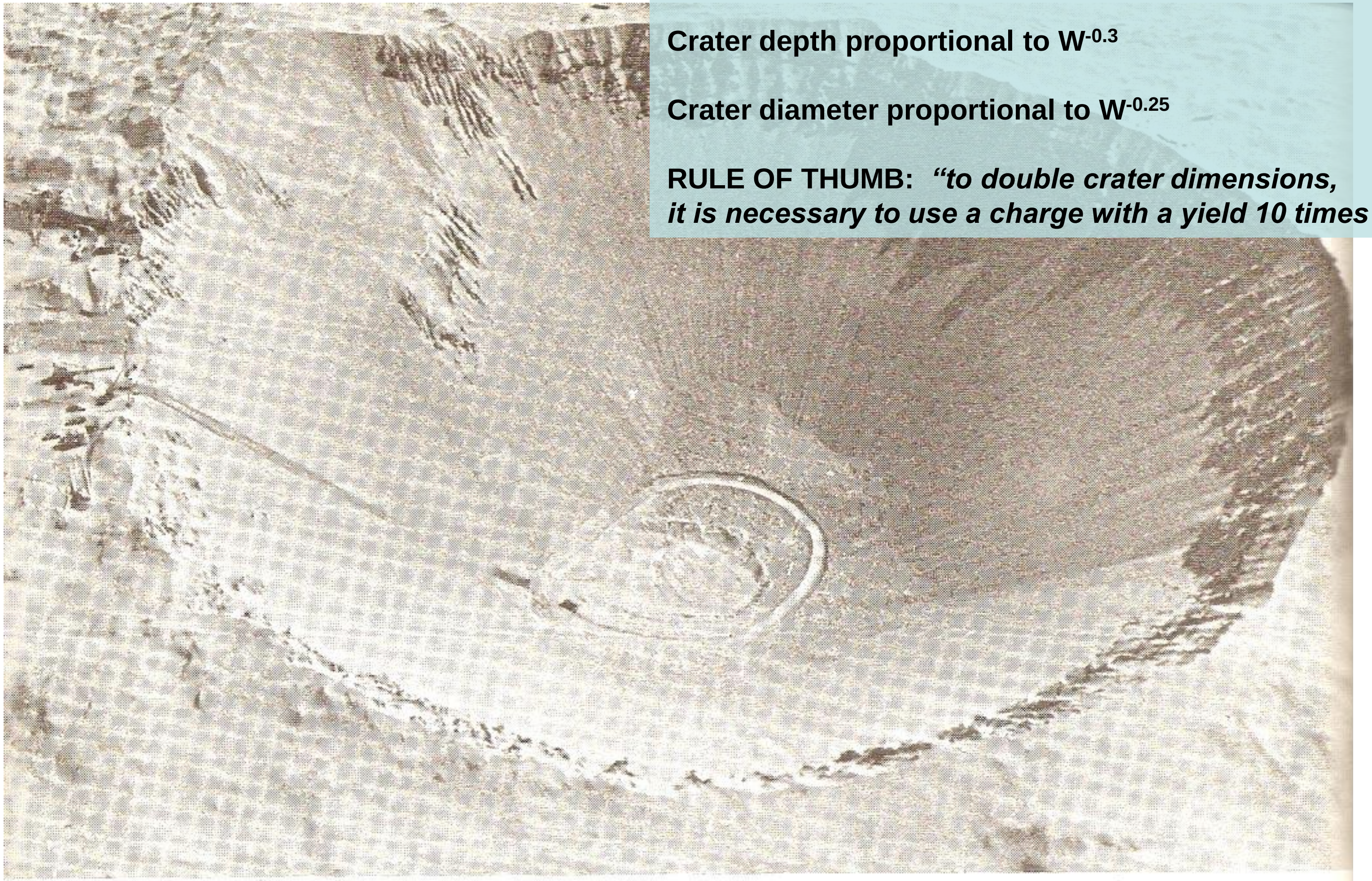
The 5 routes shown on this map have been studied as possible sites for the construction, with nuclear explosives, of a sea-level canal across the Central American isthmus.

W= weapon yield, kT

Crater depth proportional to $W^{-0.3}$

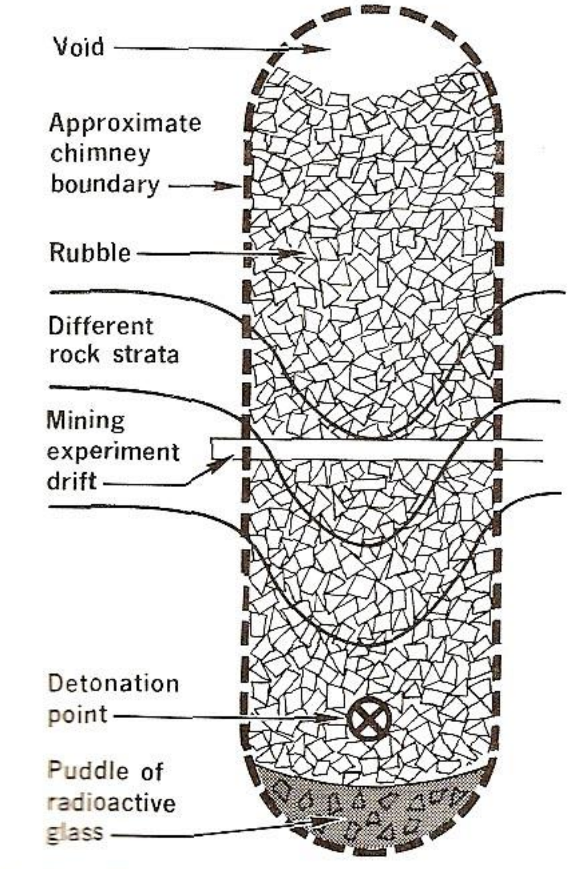
Crater diameter proportional to $W^{-0.25}$

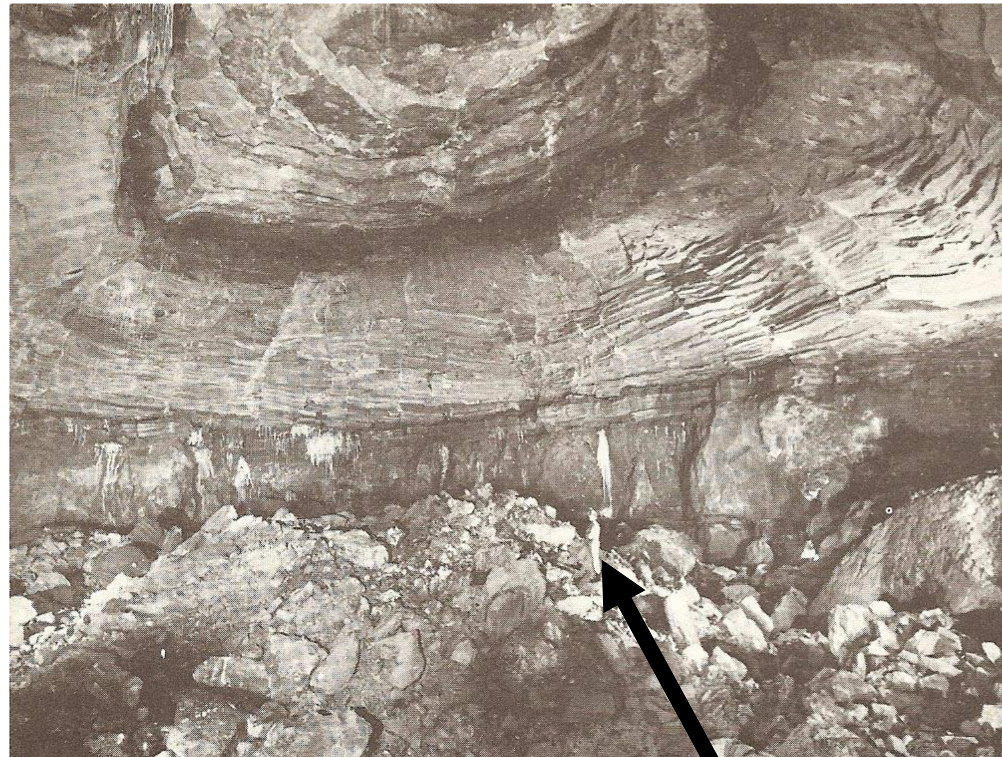
RULE OF THUMB: *“to double crater dimensions, it is necessary to use a charge with a yield 10 times as large”*



The 100-kiloton SEDAN event formed the largest excavation ever produced by a single man-made explosion. Note the size of automobiles and structures near the crater rim.

Nuclear Mining



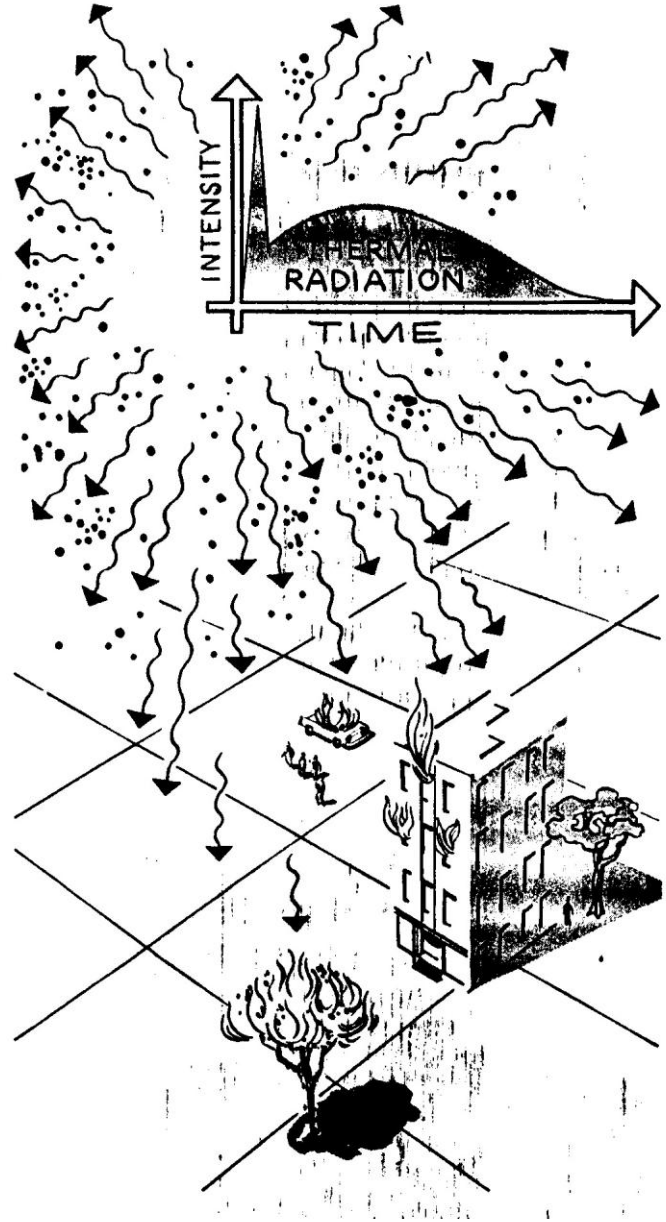


A hemispherical cavity about 75 feet high and 1[illegible] to 196 feet across remained from the GNOME explosion. Note man standing on rubble, right center.

Ore may be recovered using standard mining techniques after the ore body has been broken by a nuclear explosion.

If the chimney formed by an underground nuclear explosion reaches the surface, a depression results. Aerial view shows such a depression with equipment in the bottom.


THERMAL RADIATION


INTENSITY
THERMAL
RADIATION
TIME

EM & THERMAL RADIATIONS

Figure 12.70. Partial protection
miles from grounc
be 5.5 to 6 cal/cr

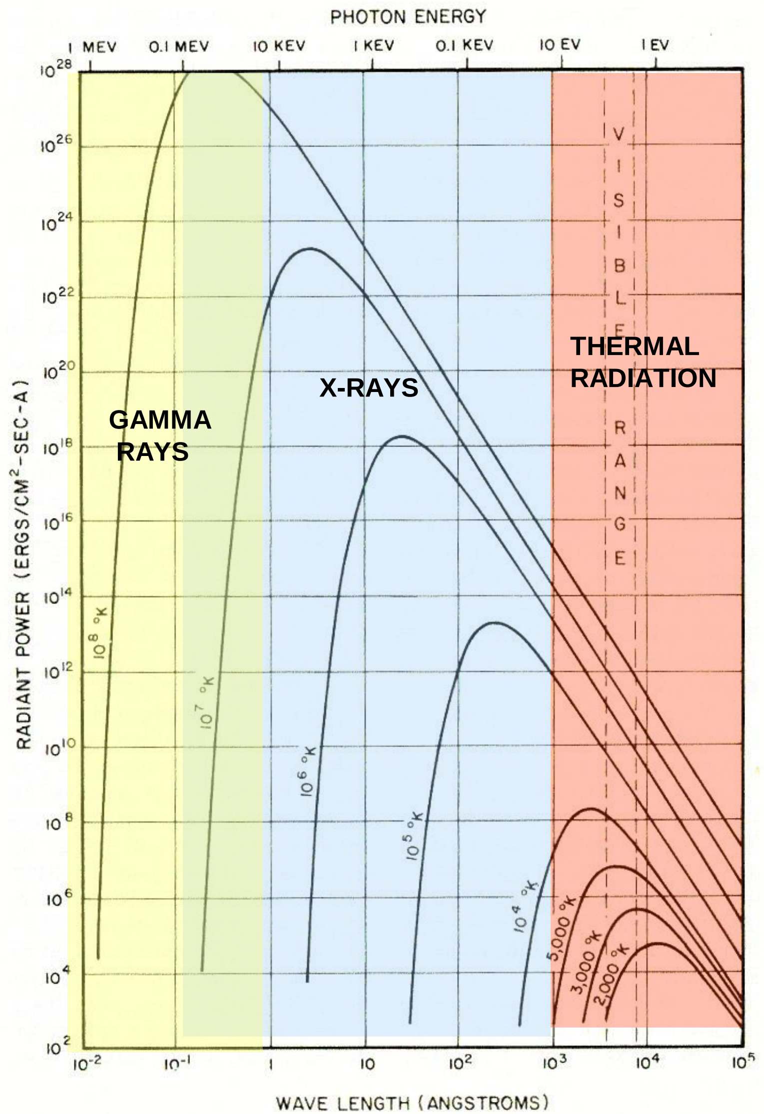
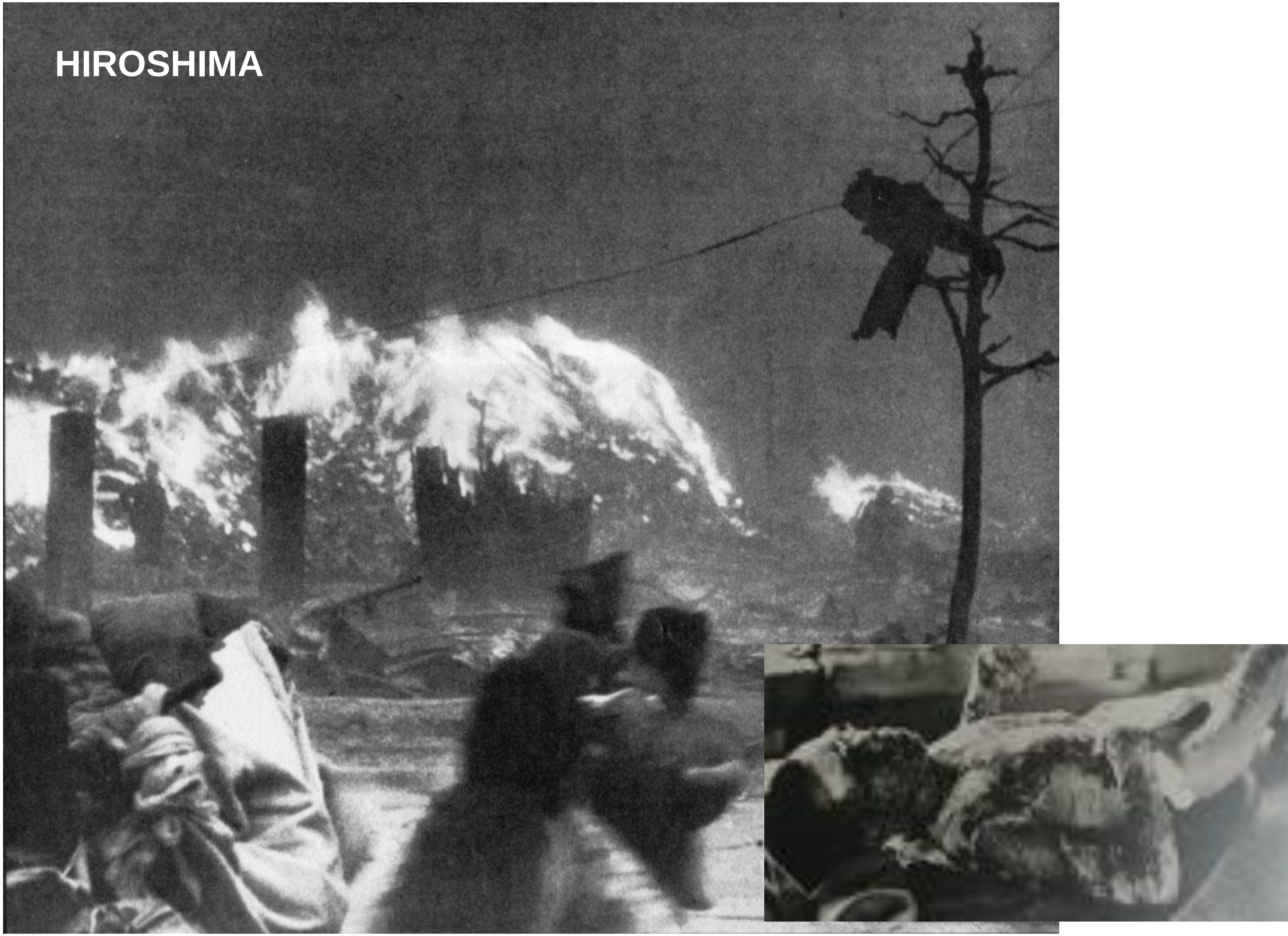


Figure 7.74. Radiant power of a black body as a function of wavelength at various temperatures.


HIROSHIMA

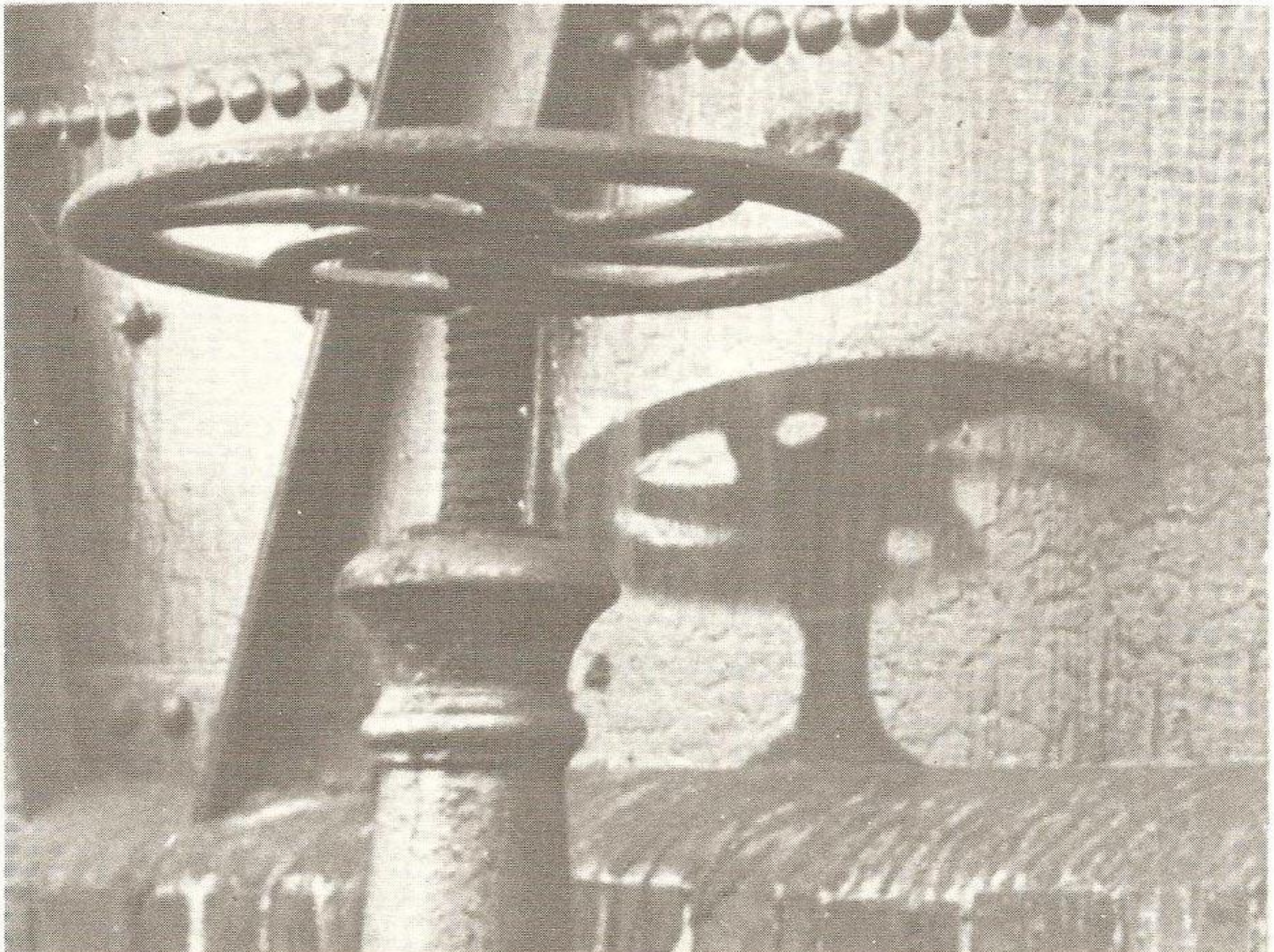


Figure 7.45b. Paint on gas holder scorched by the thermal radiation, except where protected by the valve (1.33 miles from ground zero at Hiroshima).

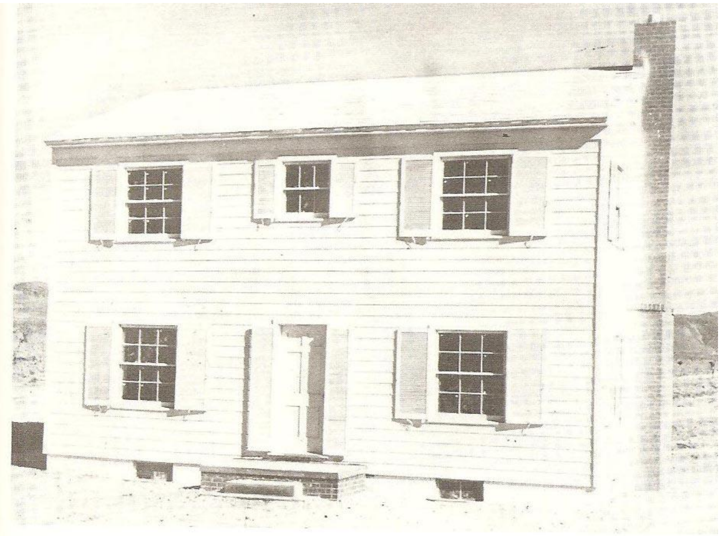


Figure 5.55. Wood-frame house before a nuclear explosion, Nevada Test Site.

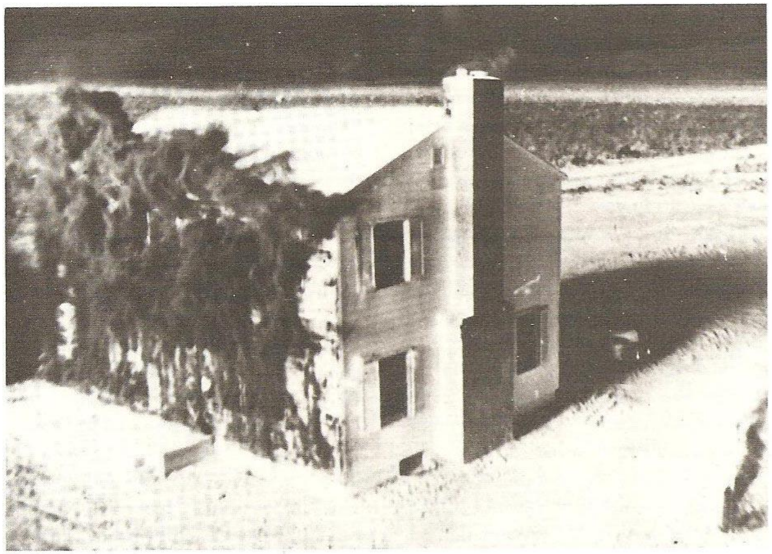


Figure 7.28a. Thermal effects on wood-frame house 1 second after explosion (about 25 cal/cm^2).

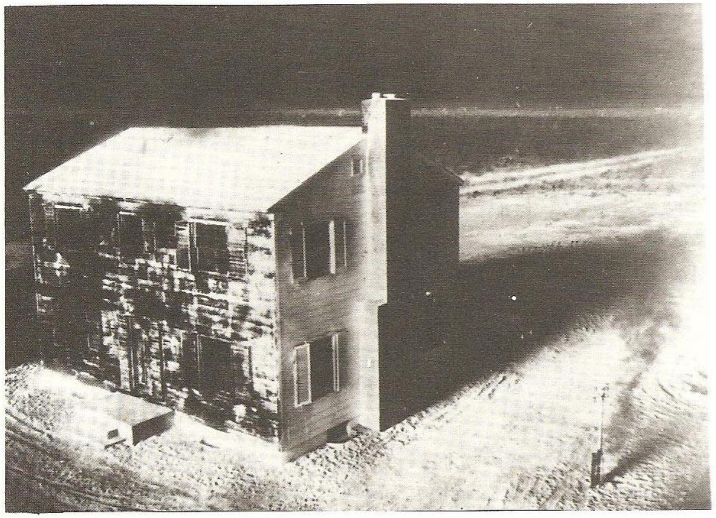
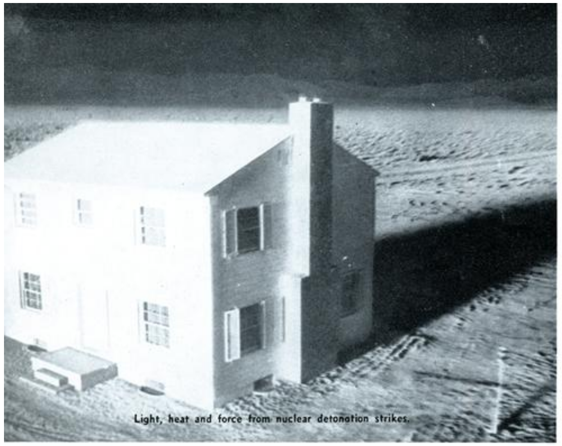


Figure 7.28b. Thermal effects on wood-frame house about ¾ second later.

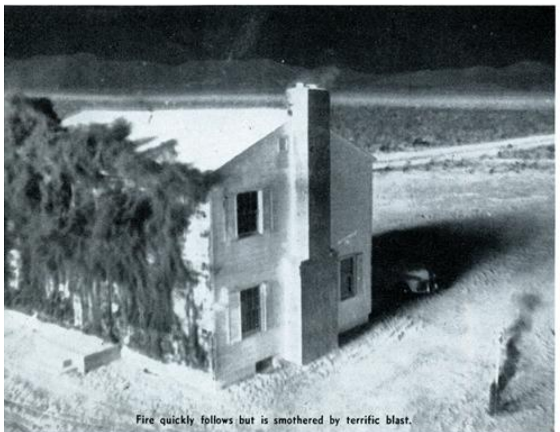
Figure 5.57. Wood-frame house after a nuclear explosion (5 psi peak overpressure).

1



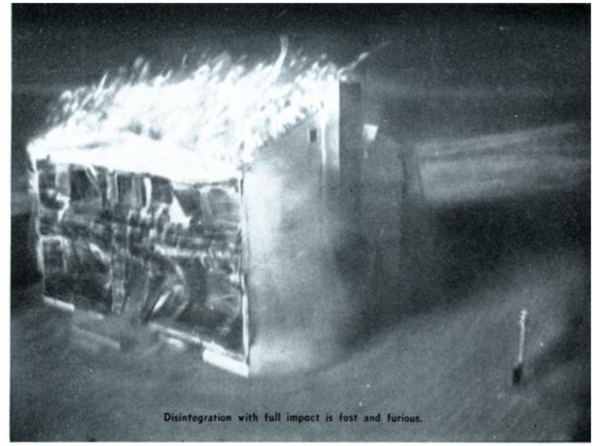
Light, heat and force from nuclear detonation strikes.

2



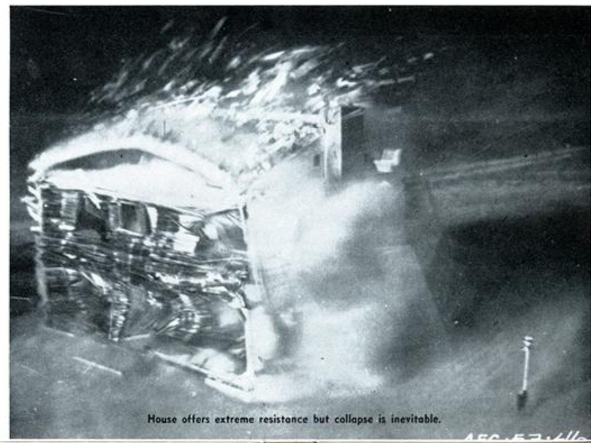
Fire quickly follows but is smothered by terrific blast.

3



Disintegration with full impact is fast and furious.

4



House offers extreme resistance but collapse is inevitable.

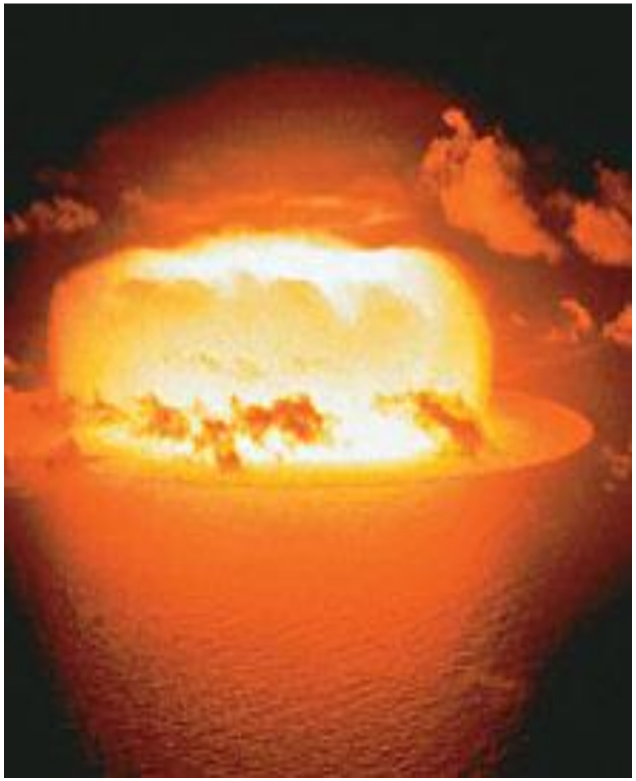
5

Tornadic force tears House Number One asunder like matches.

6

About 3,500 feet distant from "Ground Zero" at Yucca Flats, Nevada.

FLASH BLINDNESS & RETINAL BURNS



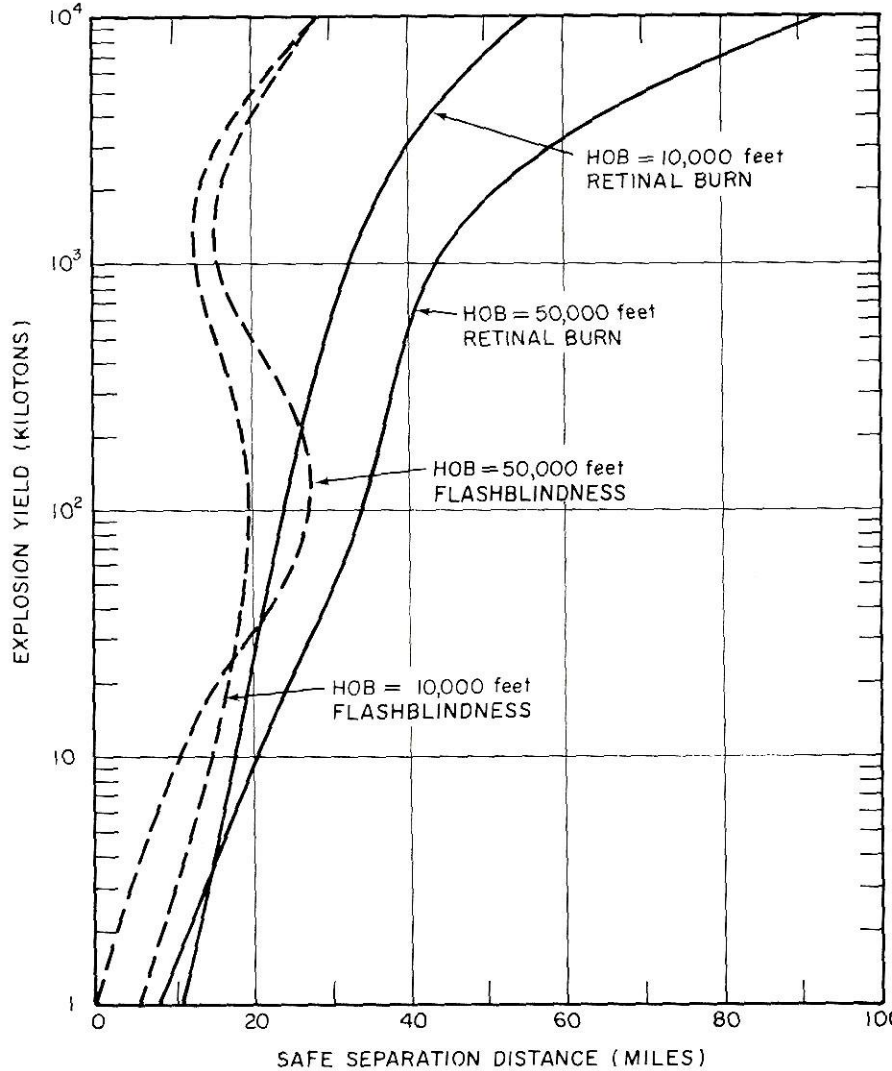


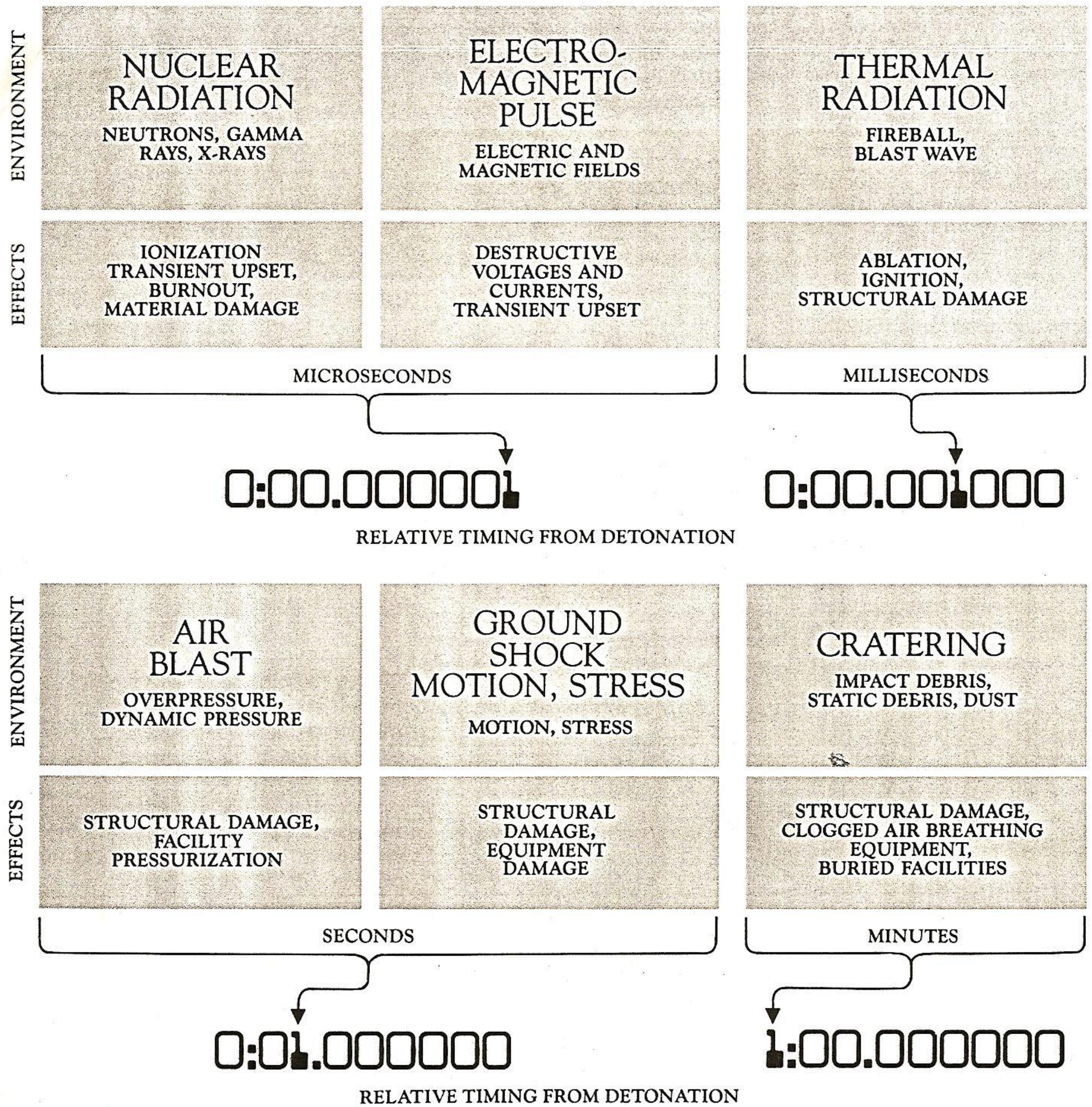
Figure 12.88a. Flashblindness and retinal burn safe separation distances for an observer on the ground, as a function of explosion yield, for burst heights of 10,000 feet and 50,000 feet on a clear day.

Range of Effects (100 kT)

EFFECT	~ RANGE
Ionizing Radiation (LD 50/30)	1600 m
Blast (50% causalities)	860 m
Thermal Radiation (50% causalities)	3200 m

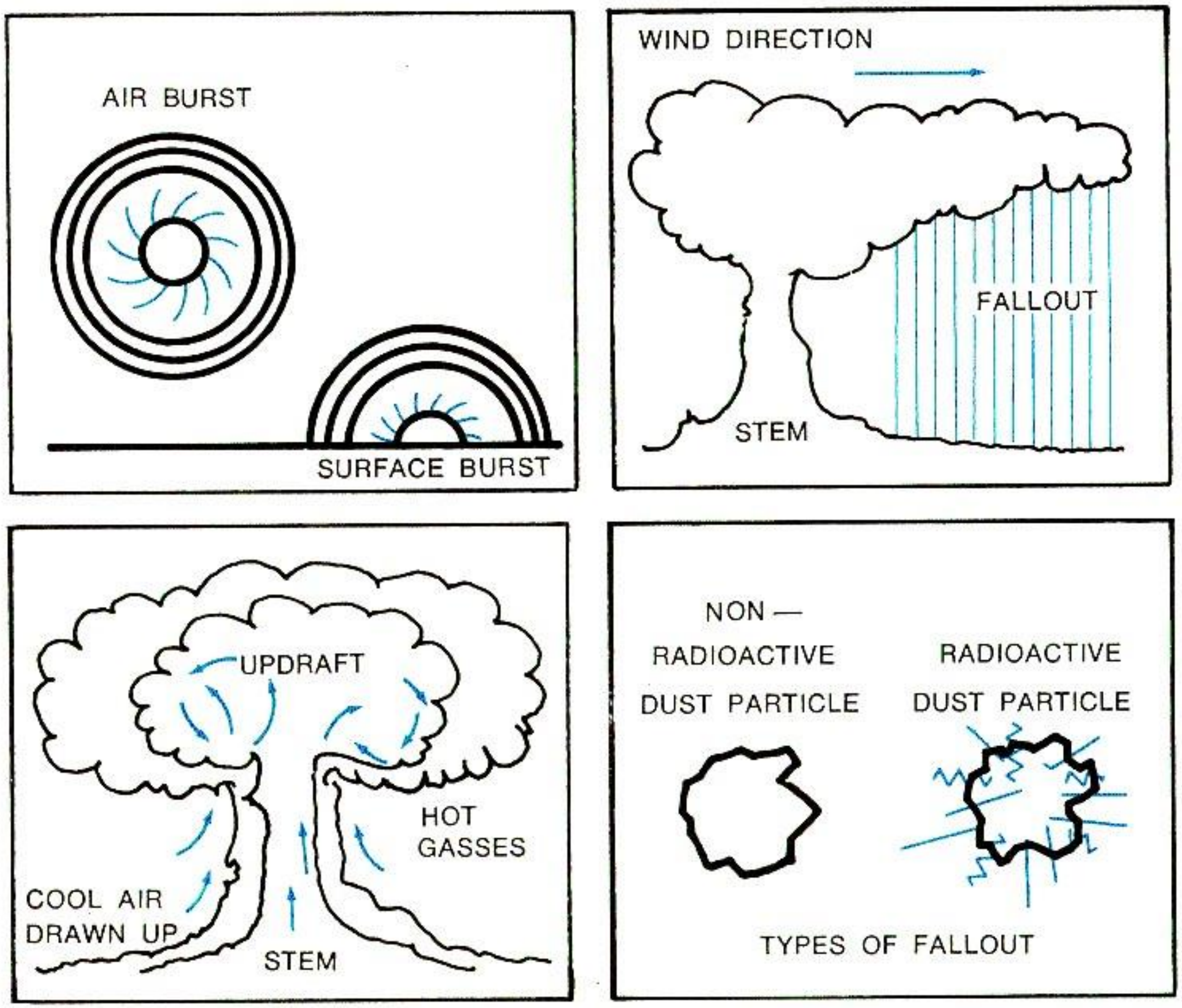
“relatively short range” effects when compared with EMP and fallout

Relative Timing of Events



Residual Radiation / Fallout

fission products + neutron activation



FALLOUT PARTICLES

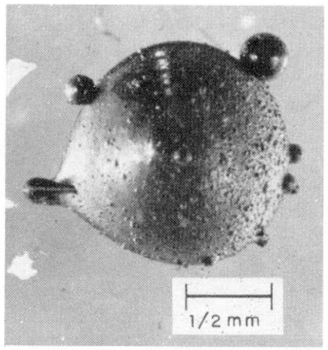


Figure 9.50a. A typical fallout particle from a tower shot in Nevada. The particle has a dull, metallic luster and shows numerous adhering small particles.

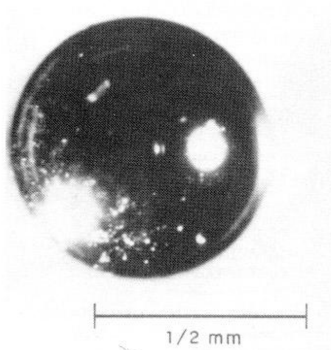


Figure 9.50b. A fallout particle from a tower shot in Nevada. The particle is spherical with a brilliant, glossy surface.

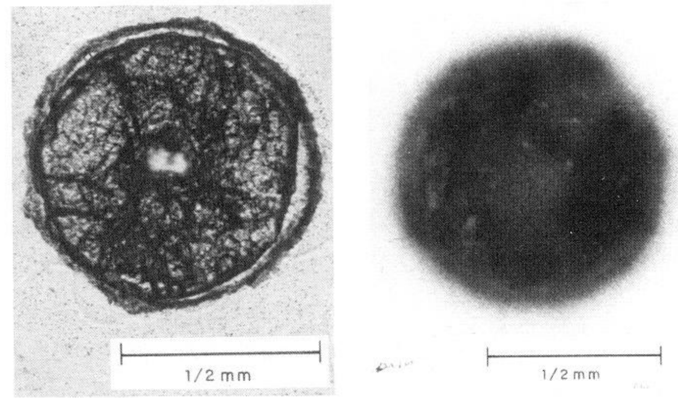


Figure 9.50c. Photograph (left) and autoradiograph (right) of a thin section of a spherical particle from a ground-surface shot at Eniwetok. The radioactivity is uniformly distributed throughout the particle.

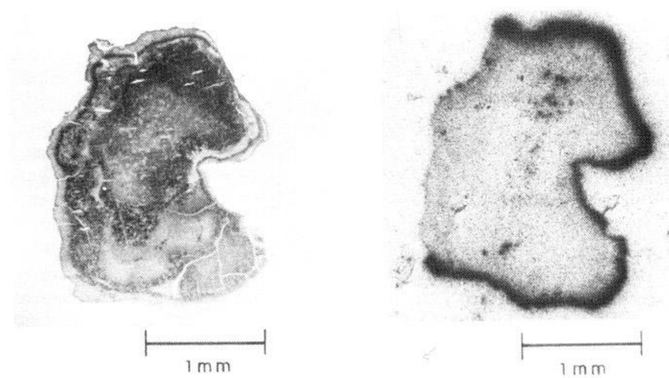


Figure 9.50d. Photograph (left) and autoradiograph (right) of a thin section of an irregular particle from a ground-surface shot at Bikini. The radioactivity is concentrated on the surface of the particle.

Figure 12.158a. Beta burn on neck 1 month after exposure.

Fallout Protection

'the entire periodic table of elements'

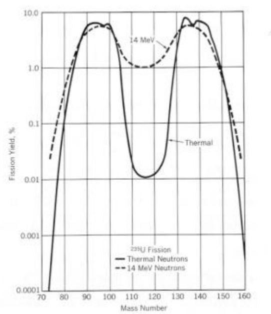


Fig. 5a Mass distribution of fission products from fission of uranium-235.

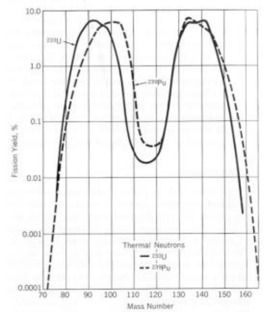
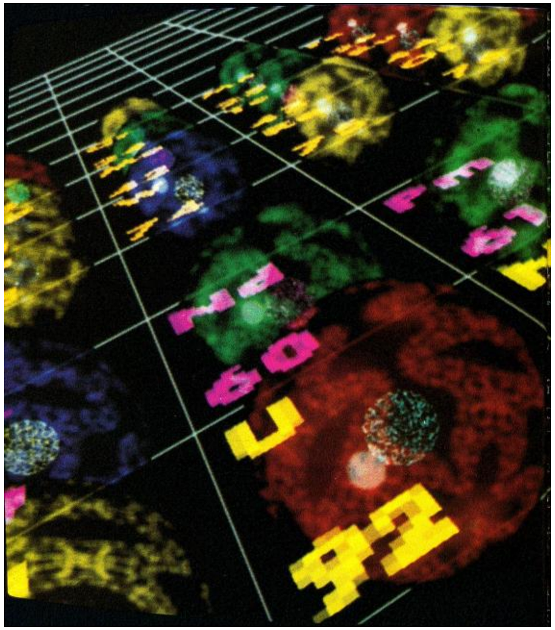
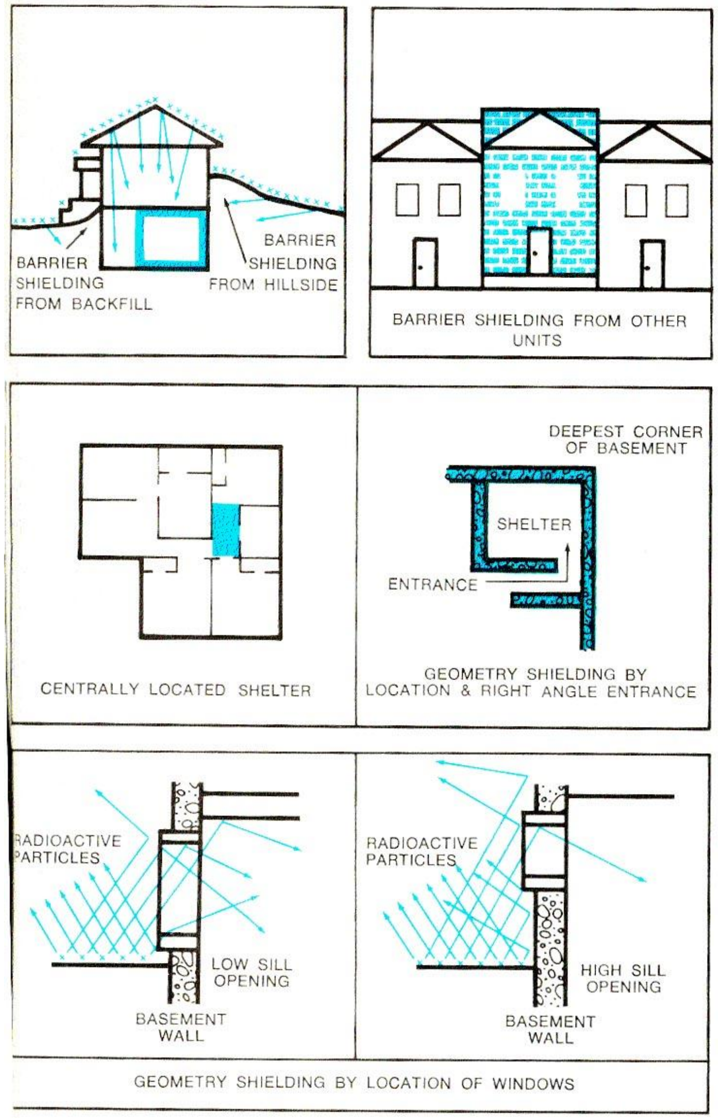


Fig. 5b Mass distribution of fission products from fission of uranium-233 and plutonium-239 by thermal neutrons.





Following Radioactive Fallout:
Which Foods are Safe to Eat?

FALLOUT PATTERN (15 MT ground burst BRAVO 1954 SP)

TOTAL ACCUMULATED DOSE (rads) at t = 96 hrs

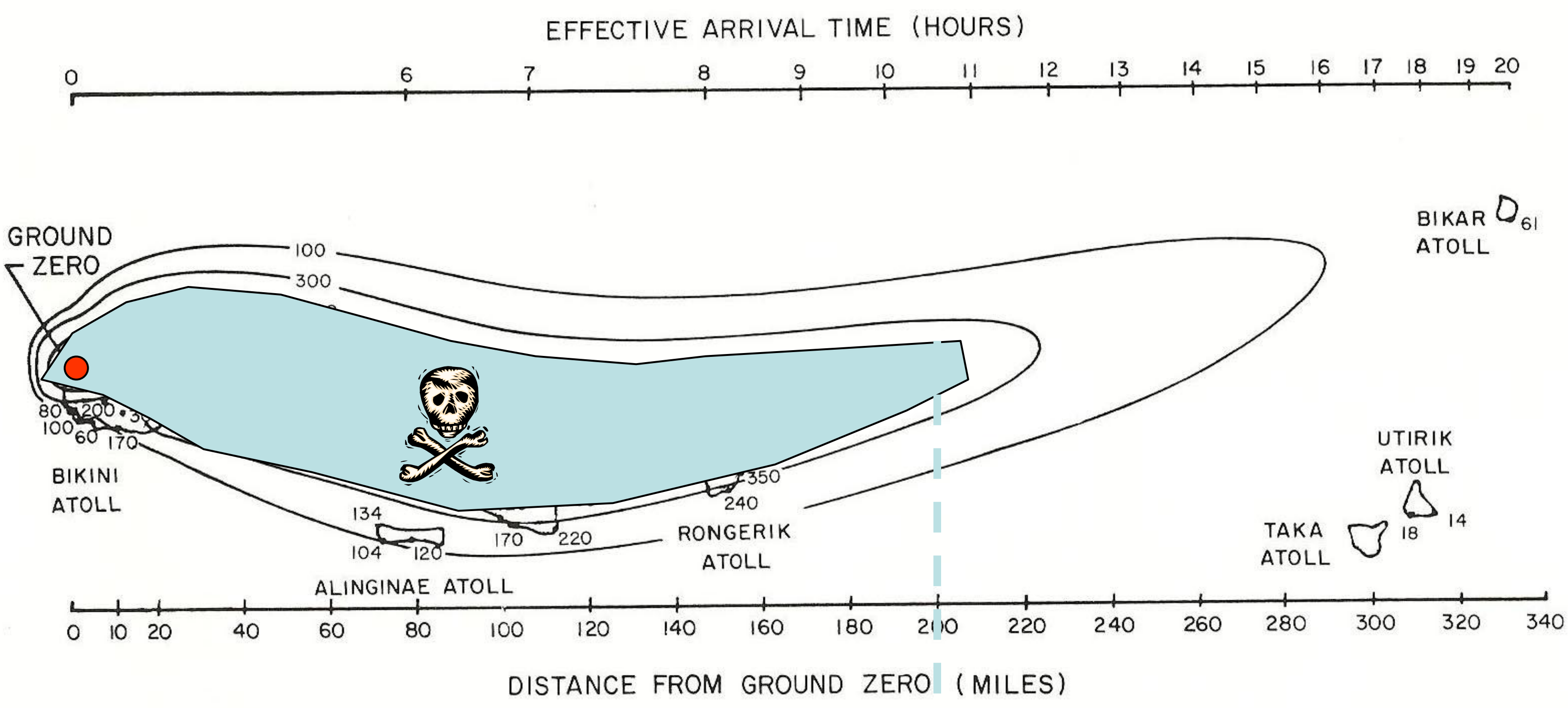


Figure 9.105. Esti

Δ

~ 200 miles

Lethal Dose ~ 450 rads ~ LD 50/30

Rongelap Atoll inhabited Evacuated after 44 hours, max dose ~ 175 rads

Dose-Rate Contours (ideal fallout patterns)

15 mph wind

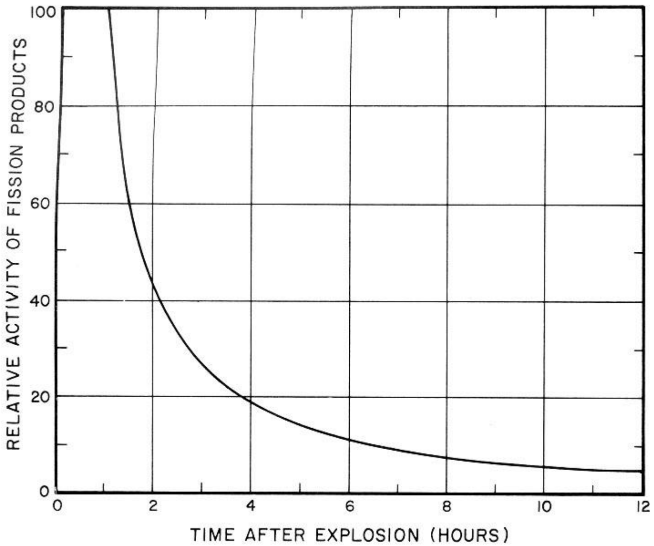


Figure 1.64. Rate of Decay of fission products after a nuclear explosion (activity is taken as 100 at 1 hour after the detonation).

"7-10 RULE"

Activity decreases by 10 for each 7 units of time

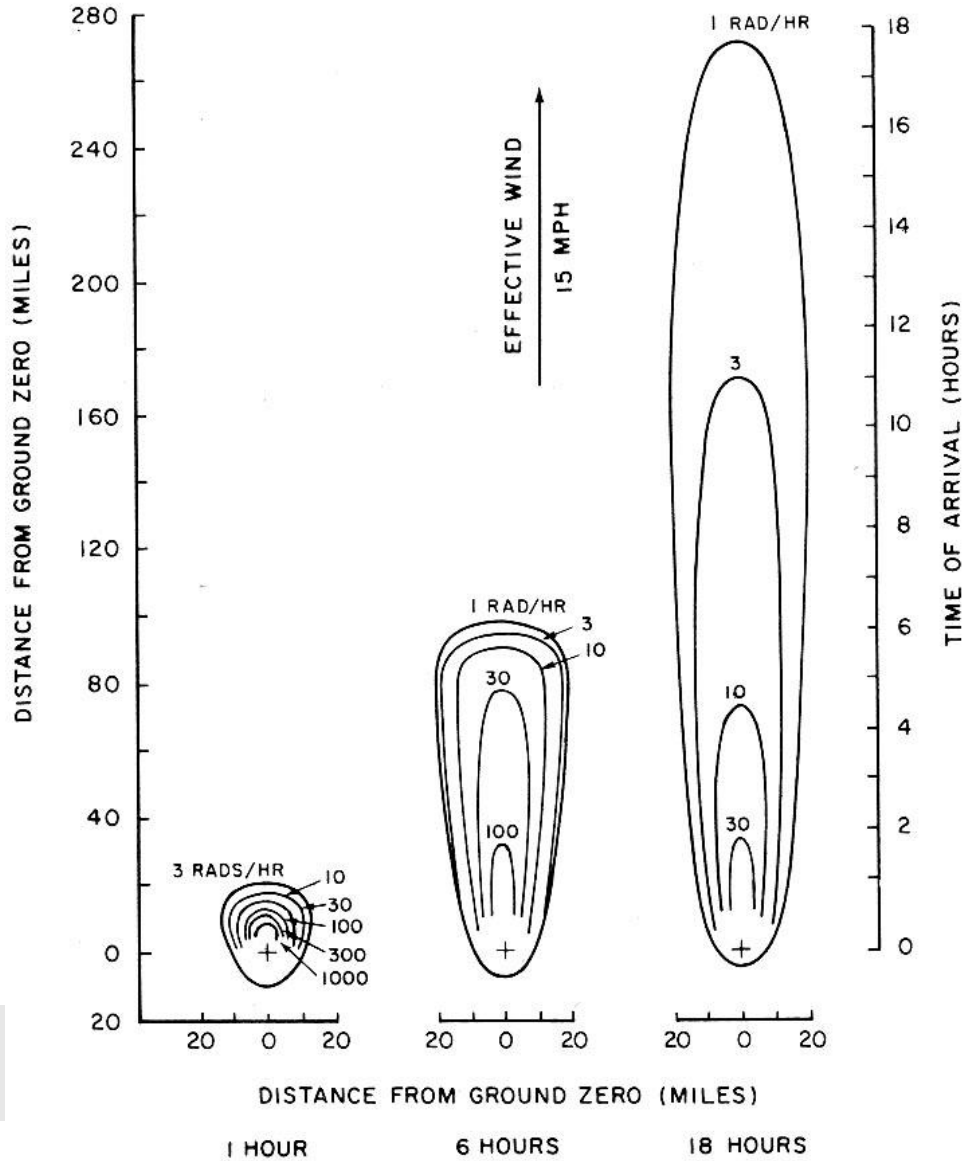


Figure 9.86a. Dose-rate contours from early fallout at 1, 6, and 18 hours after a surface burst with a total yield of 2 megatons and 1 megaton fission yield (15 mph effective wind speed).

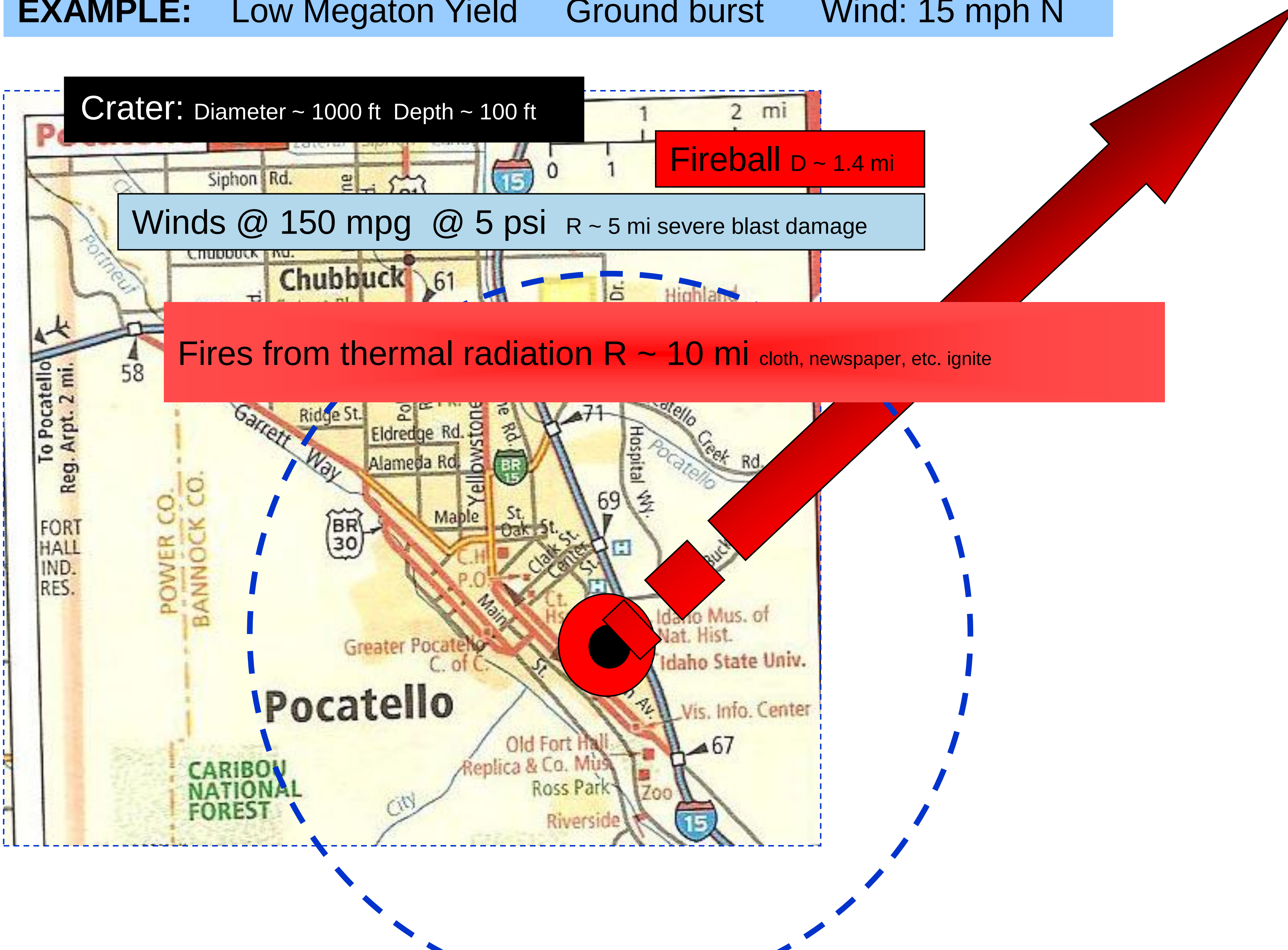
EXAMPLE: Low Megaton Yield Ground burst Wind: 15 mph N

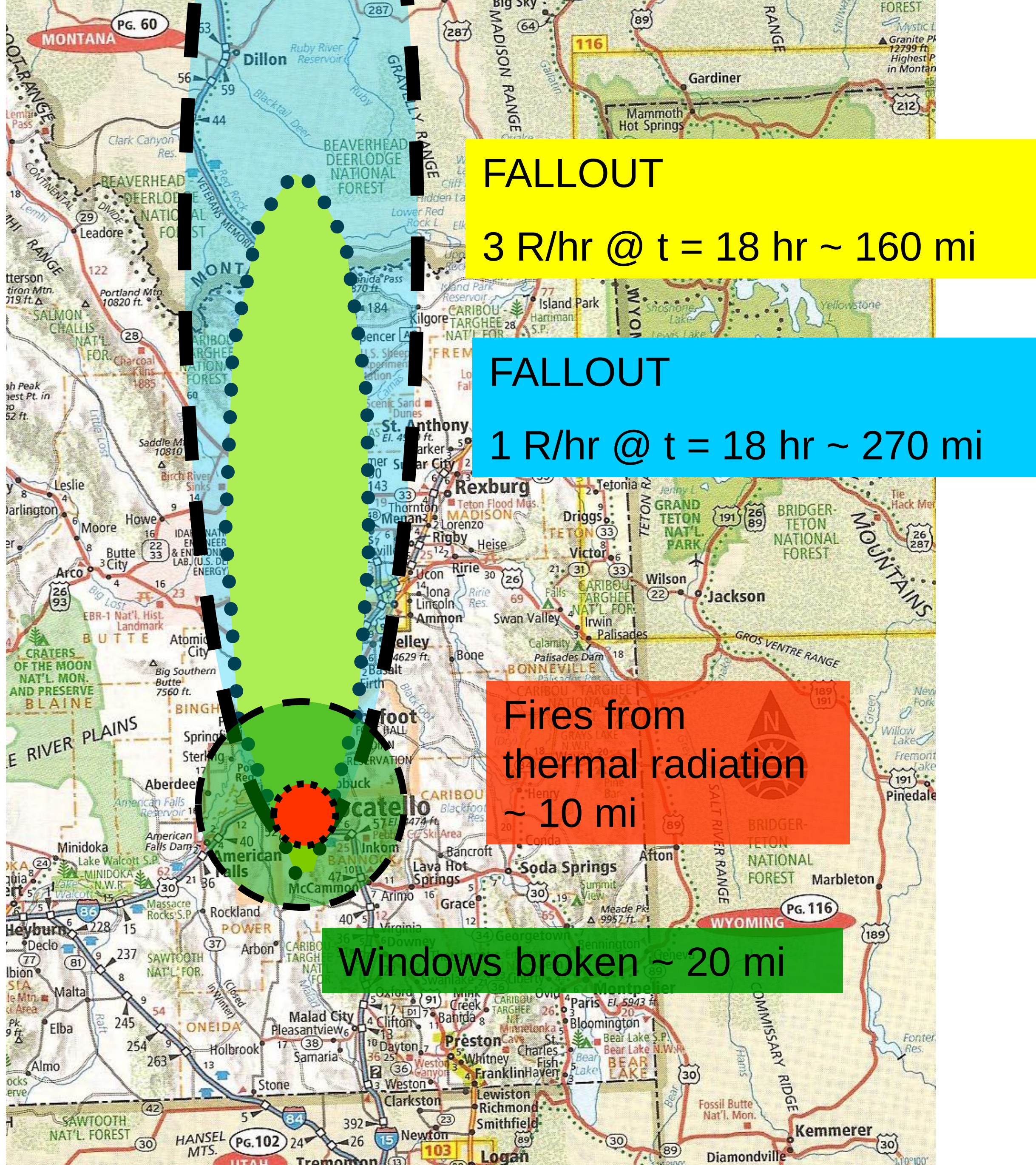
Crater: Diameter ~ 1000 ft Depth ~ 100 ft

Fireball D ~ 1.4 mi

Winds @ 150 mpg @ 5 psi R ~ 5 mi severe blast damage

Fires from thermal radiation R ~ 10 mi cloth, newspaper, etc. ignite

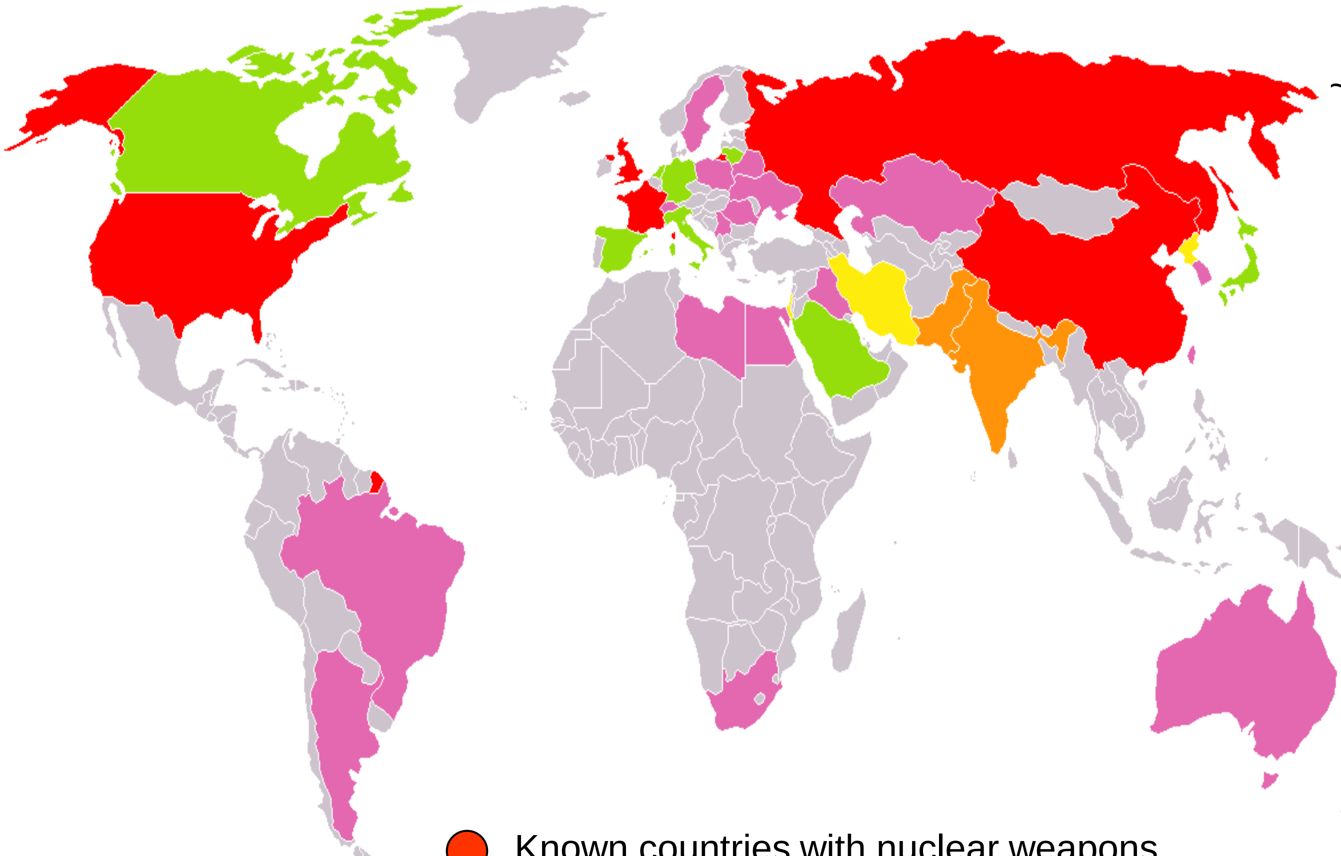


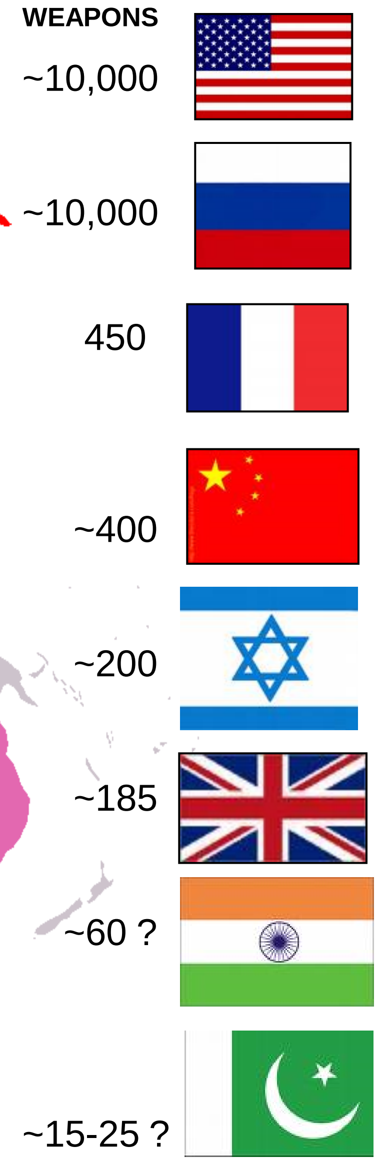

FALLOUT
3 R/hr @ t = 18 hr ~ 160 mi
FALLOUT
1 R/hr @ t = 18 hr ~ 270 mi
Fires from thermal radiation ~ 10 mi
Windows broken ~ 20 mi

PART IV

WHO HAS NUCLEAR WEAPONS ?
SUMMARY / COMMENTS / QUESTIONS

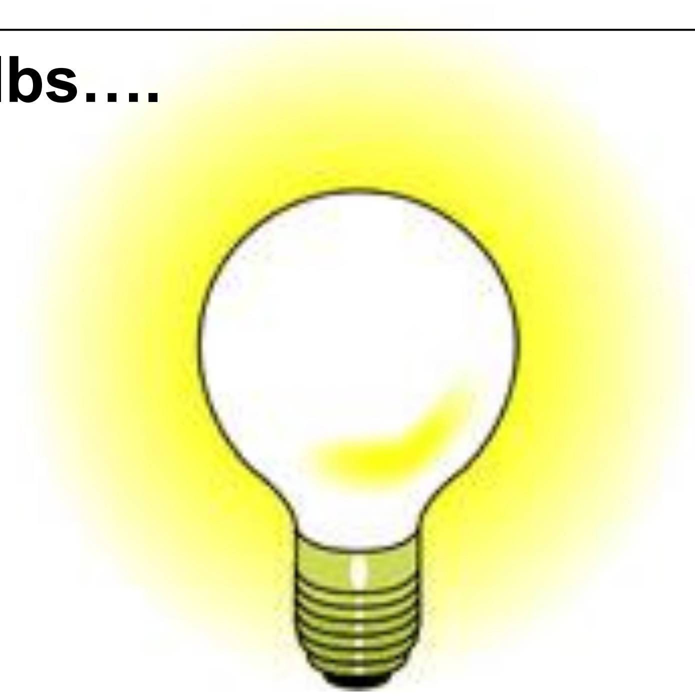
Who has nuclear weapons ?





- Known countries with nuclear weapons
- Other known nuclear powers
- Suspected of having or developing weapons
- Countries that have had nuclear weapons research
- Capable of developing weapons within years

One in every ten U.S. light bulbs….



is powered by uranium from a former Soviet warhead

ANS 2005

SUMMARY

FUNDAMENTAL PRINCIPLES

fission / fusion / binding energy / critical mass

BASIC CONCEPTS OF WEAPON DESIGN

geometry / ’60 Shakes’ / environment

ENERGY RELEASE & EFFECTS

initial nuclear radiations
blast and shock
thermal radiation
residual nuclear radiation (fallout - long range)

WHO HAS NUCLEAR WEAPONS ?

USA / Russia / France / China / Israel / Britain / India / Pakistan / Others?


QUESTIONS?
1951
NGS 1987