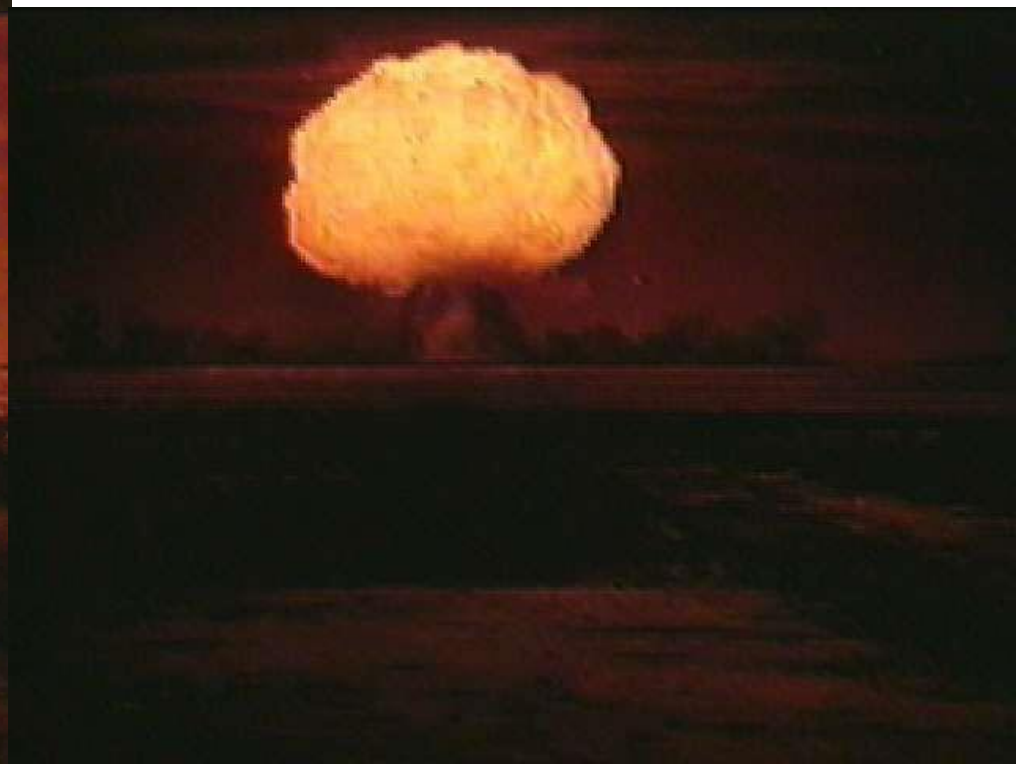
Radioactivity

Lecture 27

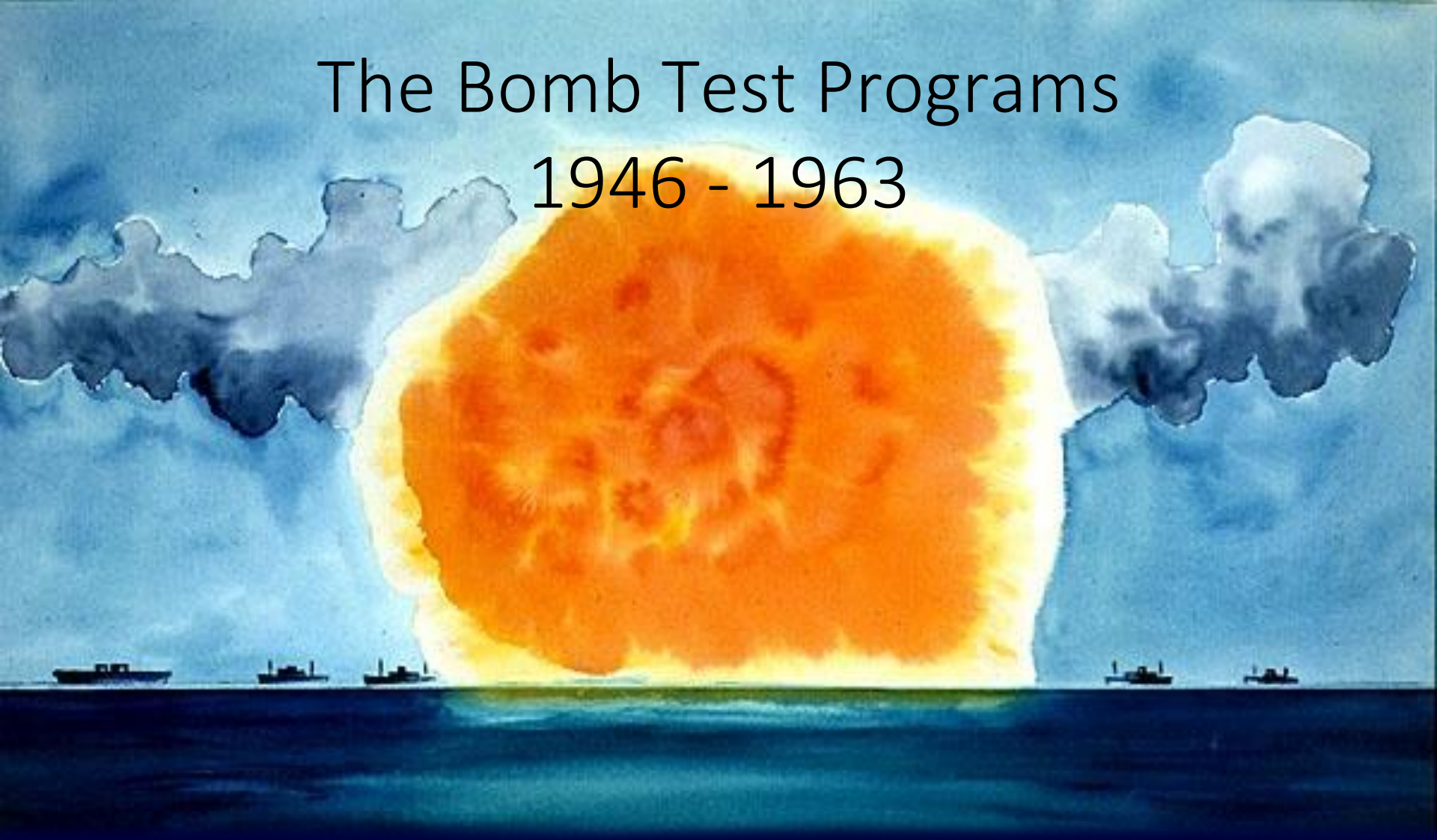
Radioactivity and War

The Dawn of the Nuclear Age

The first nuclear explosion occurred at 5:29:45 am on July 16, 1945 at Trinity site.



The Bomb Test Programs
1946 - 1963



Between 16 July 1945 and 23 September 1992 the United States of America conducted (by official count) 1054 nuclear tests, and two nuclear attacks. What are the reasons and results?

Art work by Grant Powell

List of US atmospheric Bomb tests

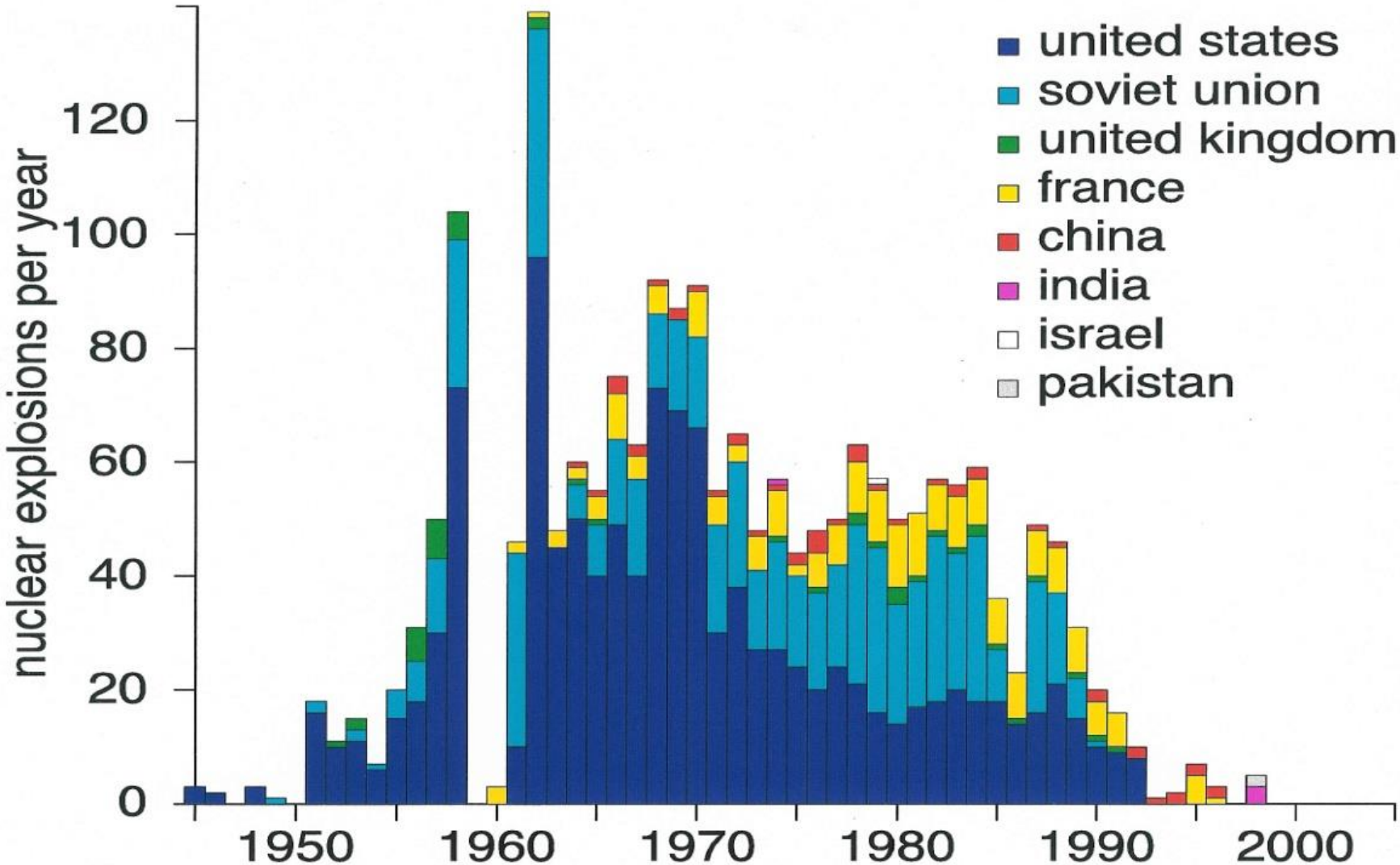
Operation	Year	Location	#
Crossroads	1946	Bikini Atoll	2
Sandstone	1948	Enewetak Atoll	3
Ranger	1951	Nevada Test Site	5
Greenhouse	1951	Enewetak Atoll	4
Buster-Jangle	1951	Nevada Test Site	7
Tumbler-Snapper	1951	Nevada Test Site	7
Ivy	1952	Enewetak Atoll	2
Upshot-Knothole	1953	Nevada Test Site	11
Castle	1954	Bikini Atoll Enewetak Atoll	6
Teapot	1955	Nevada Test Site	14
Wigwam	1955	Pacific Ocean	1

acific Atolls and Nevada desert areas

Project 56	1955	Nevada Test Site	4
Redwing	1956	Bikini Atoll Enewetak Atoll	17
Plumbbob	1957	Nevada Test Site	30
Project 58	1957	Nevada Test Site	2
Project 58 A	1958	Nevada Test Site	2
Hardtack I	1958	Bikini Atoll Enewetak Atoll Johnston Island	35
Argus	1958	South Atlantic	3
Hardtack II	1958	Nevada Test Site	37
Nougat	1961-1962	Nevada Test Site	32
Dominic (with Fishbowl)	1962	Christmas Island Johnston Island Central Pacific	36
Storax (with Sunbeam and Roller Coaster)	1962-1963	Nevada Test Site Nellis Air Force Range	56

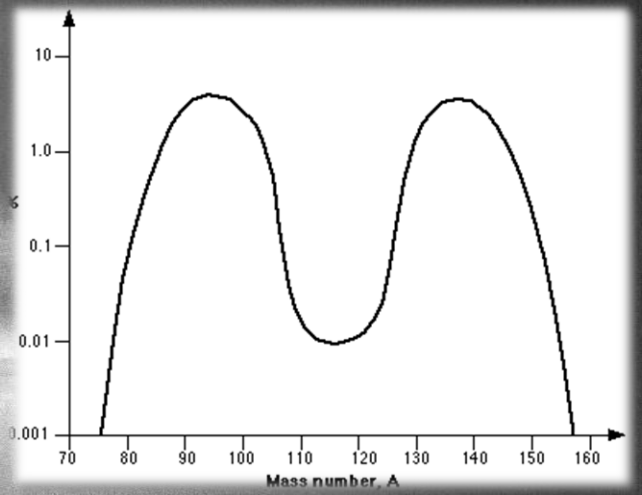
316 tests until October 10, 1963; Limited Nuclear Test Ban Treaty

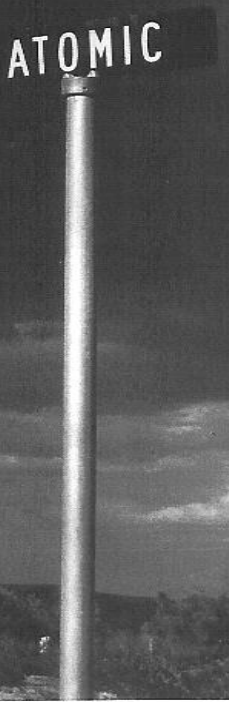
Cold War and the proliferation of Nuclear Testing



Delayed Radiation - Fallout

Fission of ^{235}U or ^{239}Pt generates a whole range of long-lived radioactive isotopes in the medium mass range A ≈ 80-160. There are about 40 ways of fission which produce ~ 80 radioactive species. These isotopes produce new radioactive isotopes by subsequent decay processes.





Principal Fallout Radioactivities

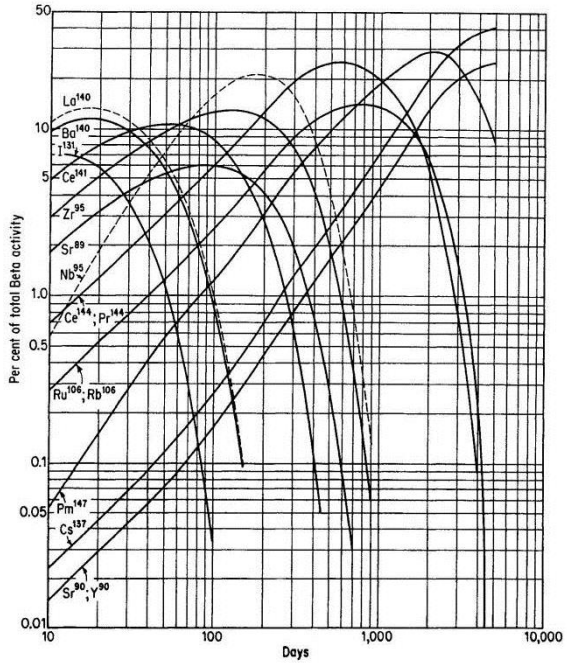


FIGURE 9-9 Yields of the principal radionuclides in the debris from megaton weapons. The differences from Fig. 9-8 occur because in such weapons fission occurs from both fast and thermal neutrons and in ^{238}U and ^{239}Pu as well as ^{235}U. [From Hallden *et al.* (1961).]

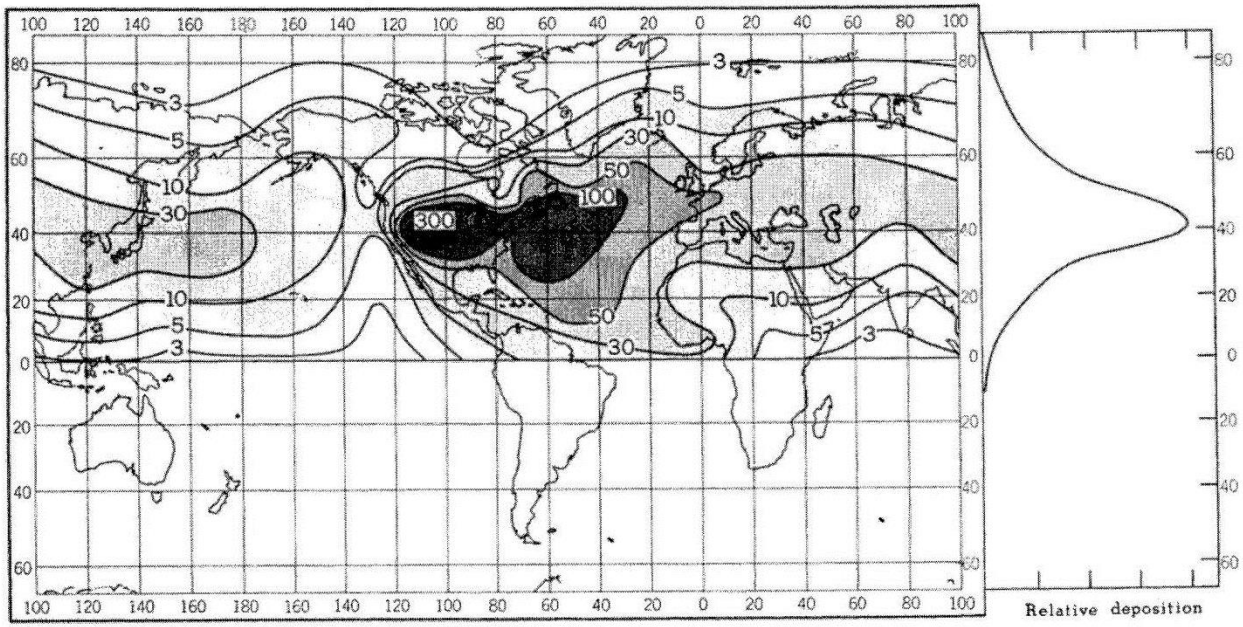


FIGURE 9-15 Worldwide radioactive fallout from nuclear weapons tests in Nevada in 1953. The explosions were in the kiloton range of yields, and debris was confined to the troposphere. The intensity of fallout is shown in relative units. [Reprinted with permission from Machta, L., List, R. J., and Hubert, L. F. (1956). World-wide travel of atomic debris. *Science* **124**, 474–477. Copyright 1956 American Association for the Advancement of Science.]

Approximate Yields of the Principal Nuclides per Megaton of Fission

Nuclide	Half-life	MCi[a]
^{89}Sr	53 d	20.0[b]
^{90}Sr	28 y	0.1[b]
^{95}Zr	65 d	25.0[b]
^{103}Ru	40 d	18.5[b]
^{106}Ru	1 y	0.29[b]
^{131}I	8 d	125.0[c]
^{137}Cs	30 y	0.16[b]
^{131}Ce	1 y	39.0[b]
^{144}Ce	33 d	3.7[b]

Radioactive fallout is not confined to the local neighborhood of the test site!

Isotopes of special importance

Especially dangerous are ^{131}I, ^{89}Sr, ^{90}Sr, and ^{137}Cs. This is due to both their relative abundance in fallout, and to their special biological affinity.

^{131}I is a β and γ emitter with a half-life of 8.07 d (specific activity 124,000 Ci/g) Its decay energy is 606 keV β, 364 keV γ. It constitutes some 2% of fission-produced isotopes - $1.6 \cdot 10^5$ Ci/kiloton. Iodine is readily absorbed by the body and concentrated in one small gland, the thyroid.

^{90}Sr is a β emitter (546 keV, no γ) with a half-life of 28.1 years (specific activity 141 Ci/g), **^{89}Sr** is a β emitter (1.463 MeV, γ very rarely) with a half-life of 52 d (specific activity 28,200 Ci/g). Each constitutes about 3% of total fission isotopes: 190 curies of ^{90}Sr and 3.8×10^4 curies of ^{89}Sr per kiloton. Due to their chemical resemblance to calcium these isotopes are absorbed and stored in bones. ^{89}Sr is an important hazard for a year or two after an explosion, but ^{90}Sr remains a hazard for centuries. Actually most of the injury from ^{90}Sr is due to its daughter isotope **^{90}Y** which has a half-life of only 64.2 h, so it decays as fast as it is formed, and emits 2.27 MeV β particles.

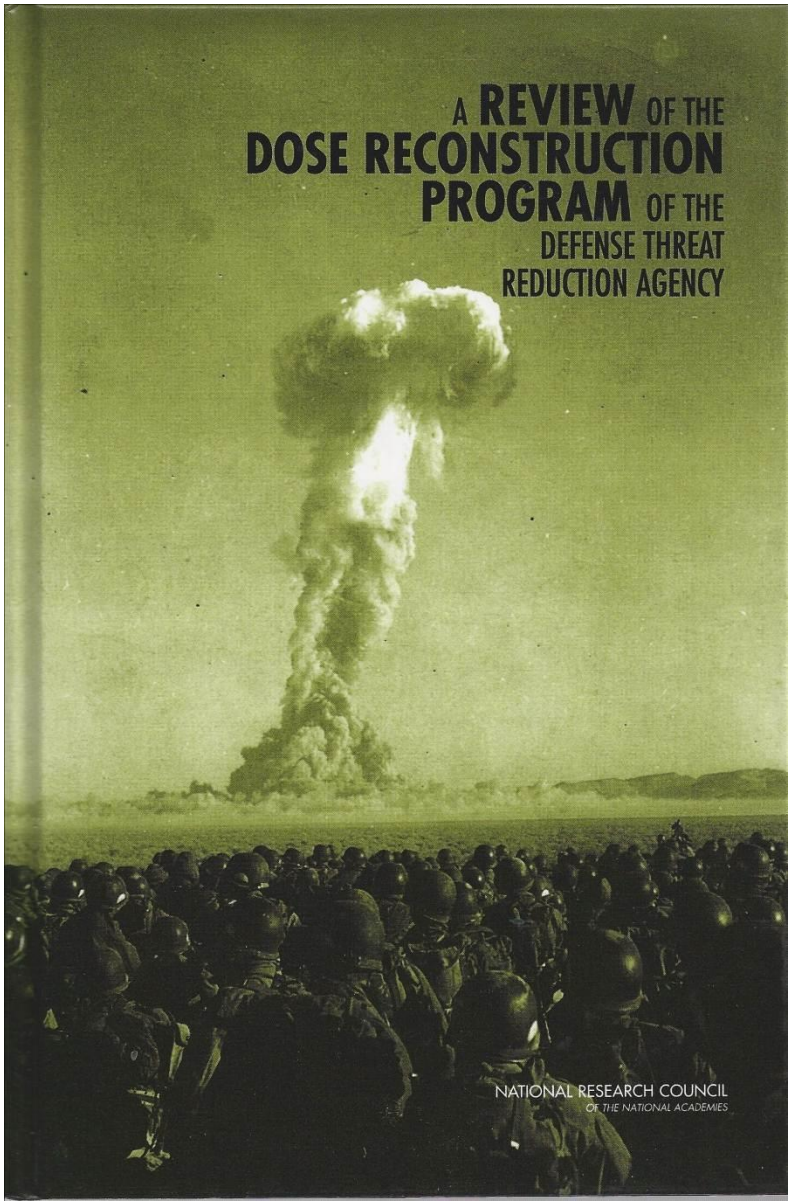
^{137}Cs is a β and γ emitter with a half-life of 30.0 y (specific activity 87 Ci/g). Its decay energy is 514 keV β, 662 keV γ. It comprises some 3-3.5% of total fission products - 200 Ci/kT. It is the primary long-term gamma emitter hazard from fallout, and remains a hazard for centuries.

Military Personal Tests

In 1951, every aspect of nuclear testing was controlled by the AEC. To get realistic results in atomic exercises, the military suggested that the men should be "stressed."

The military wanted the men to be placed closer to the atomic blasts to learn how to conduct atomic warfare on a future nuclear battlefield. To do that, the DOD would have to take control of personnel away from the AEC. By early 1953, the Pentagon had succeeded. When a nuclear test involved battlefield maneuvers, field commanders, would be responsible for the placement of their men near atomic detonations.

Exposure of US Military in Shot Hood



The fission of 57 grams of material produces $3 \cdot 10^{23}$ atoms of fission products (two for each atom of fissionable material). One minute after the explosion this mass is undergoing decays at a rate of 10^{21} disintegrations/sec ($3 \cdot 10^{10}$ curies).
It is estimated that if these products were spread over 1 km^2, then at a height of 1 m above the ground one hour after the explosion the radiation intensity would be 7500 rad/hr. 1 kT bomb would correspond to $1.2 \cdot 10^8$ rad/h spread over 1 km^2, a person has a surface of $S \approx 1.9$ $m^2 = 1.9 \cdot 10^{-6}$ km^2, its exposure is 230 rad/h; for a 10 kT bomb, the exposure is 2300 rad/h or 38 rad/min.

Radiation Distribution from Shot Hood

Area of ~7sqm

With an average contamination of 6.2 Ci

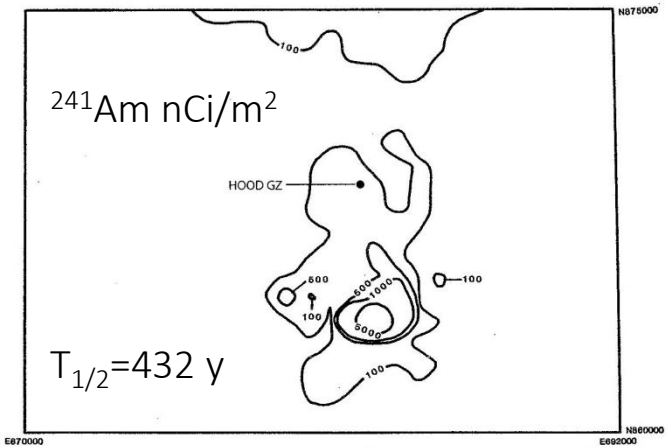


FIGURE E.1 Distribution of concentrations of ^{241}Am in surface soil (nCi m^{-2}) in vicinity of ground zero (GZ) of Operation PLUMBBOB, Shot HOOD based on measurements in middle 1980s (McArthur and Mead, 1987). Area shown is about 6.7 by 4.6 km.

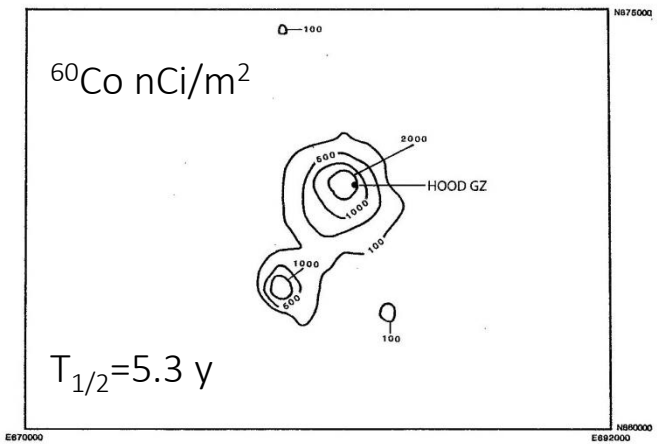


FIGURE E.2 Distribution of concentrations of ^{60}Co in surface soil (nCi m^{-2}) in vicinity of ground zero (GZ) of Operation PLUMBBOB, Shot HOOD based on measurements in middle 1980s (McArthur and Mead, 1987). Area shown is about 6.7 by 4.6 km.

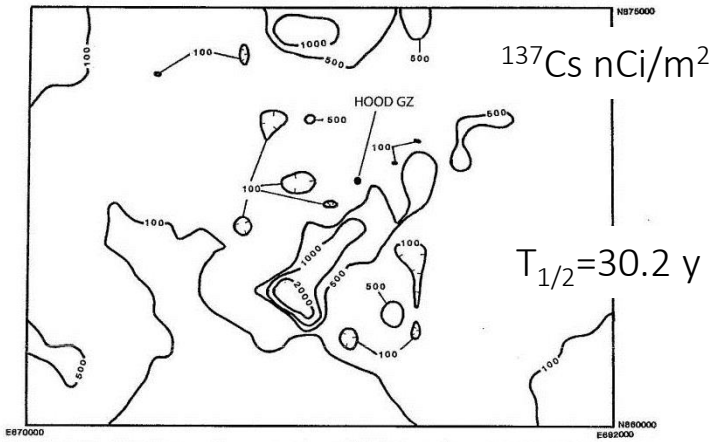


FIGURE E.3 Distribution of concentrations of ^{137}Cs in surface soil (nCi m^{-2}) in vicinity of ground zero (GZ) of Operation PLUMBBOB, Shot HOOD based on measurements in middle 1980s (McArthur and Mead, 1987). Area shown is about 6.7 by 4.6 km.

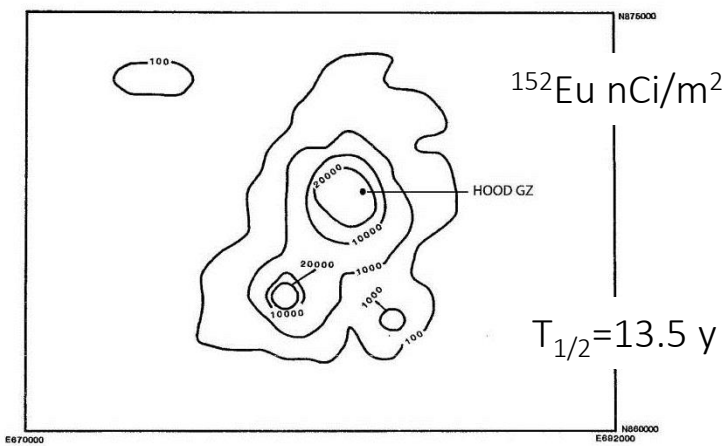
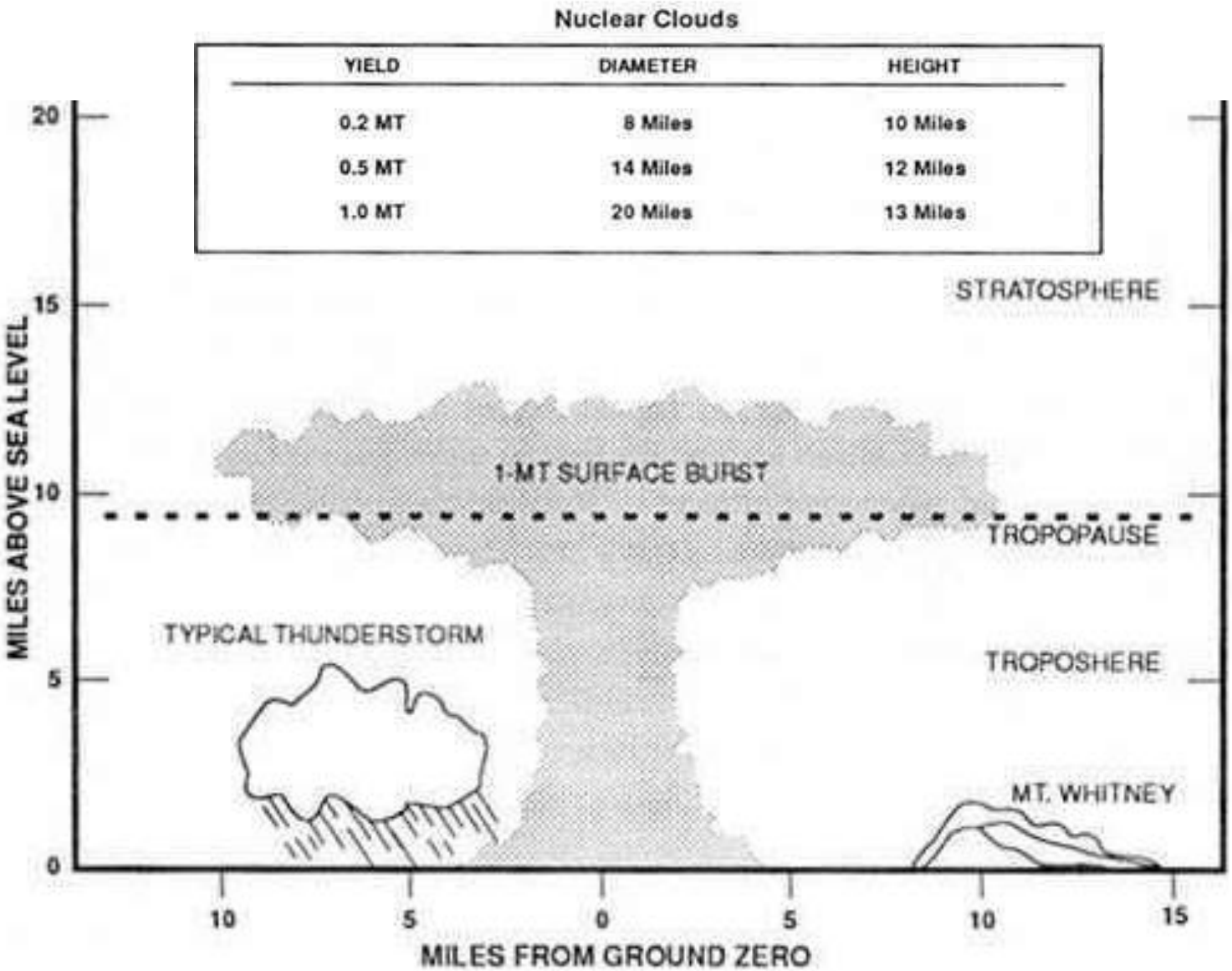
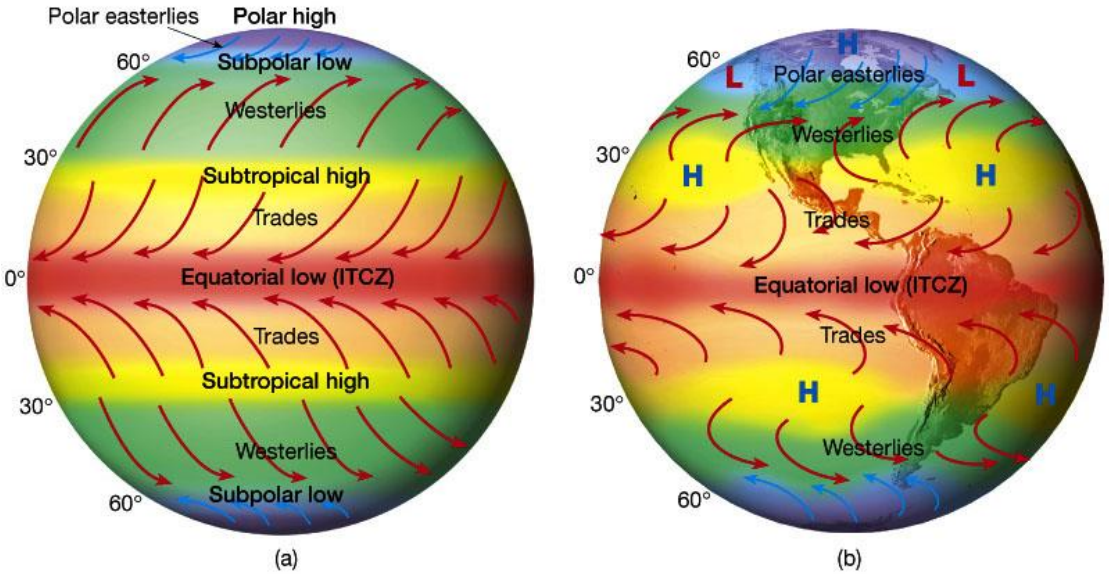


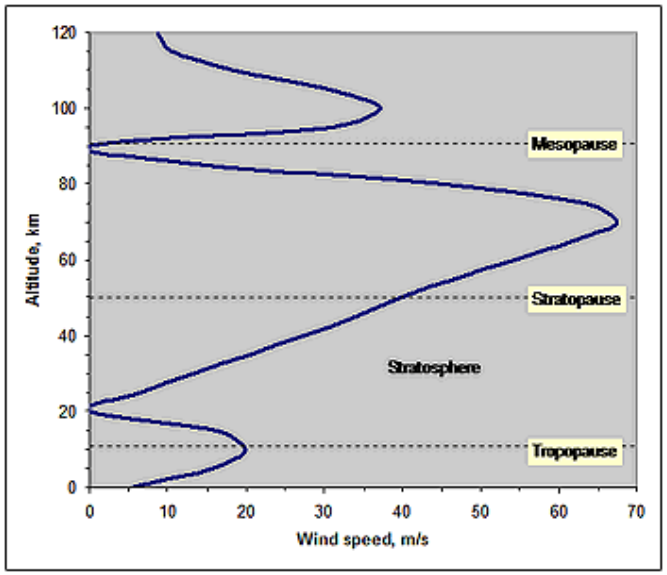
FIGURE E.4 Distribution of concentrations of ^{152}Eu in surface soil (nCi m^{-2}) in vicinity of ground zero (GZ) of Operation PLUMBBOB, Shot HOOD based on measurements in middle 1980s (McArthur and Mead, 1987). Area shown is about 6.7 by 4.6 km.

Emission into Stratosphere



Global wind patterns

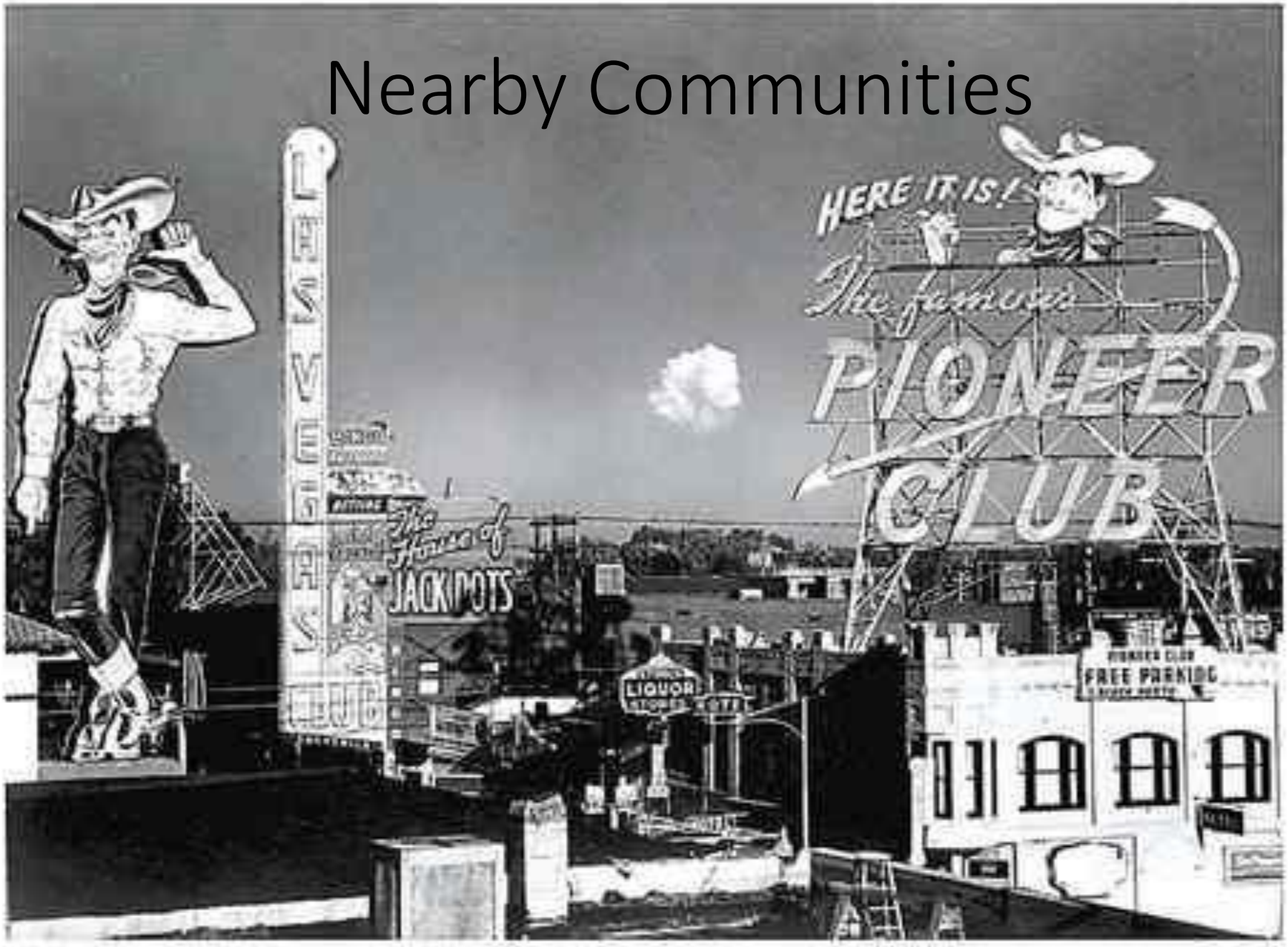




Prevailing east west oriented wind directions in the northern hemisphere (Westerlies), with very high wind velocities in the Tropopause and Stratopause altitudes!

Local pressure conditions affect direction of the cloud and subsequently fall-out distribution

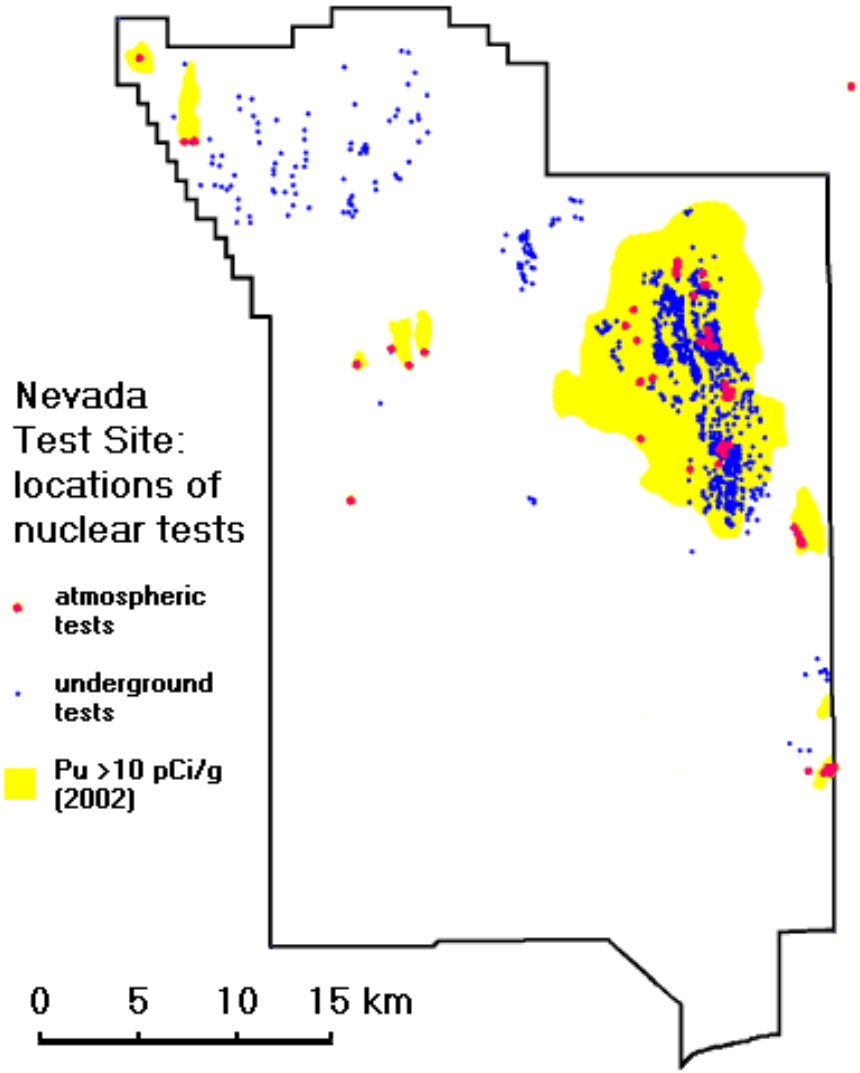
Nearby Communities



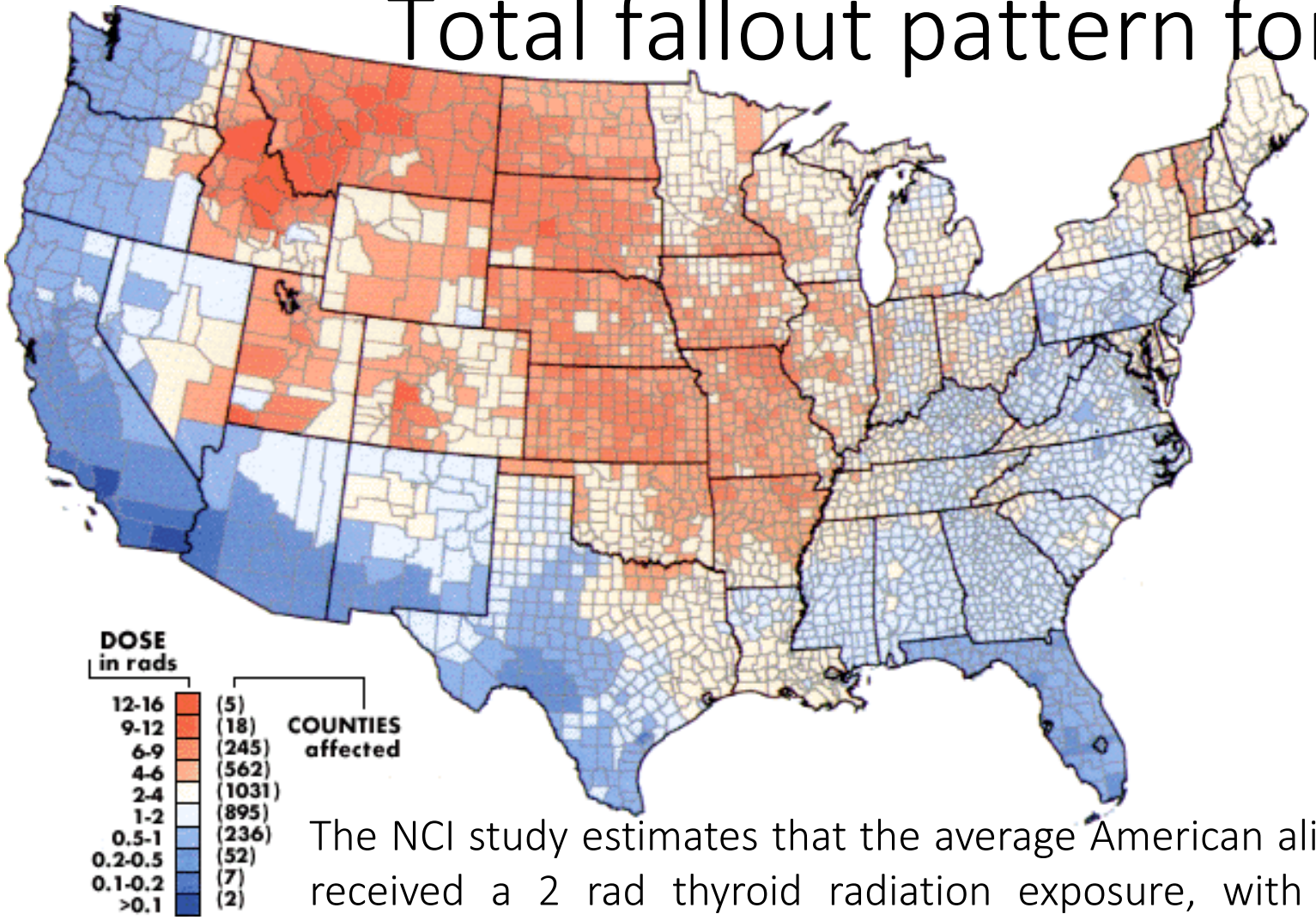
Atmospheric tests 1945-1963

Atmospheric bomb tests at the Nevada test site caused the production of large amounts of long-lived radioactivity in the atmosphere which was distributed by high altitude winds over the USA and Canada and even world wide.

As shown in a study of the National Cancer Institute NCI 1997 internal exposures to radioiodine ^{131}I from fallout was the most serious health risk of continental nuclear testing. Radioiodine concentrates in milk when consumed by cows when grazing, and subsequently concentrates in human thyroid glands when contaminated milk is ingested.



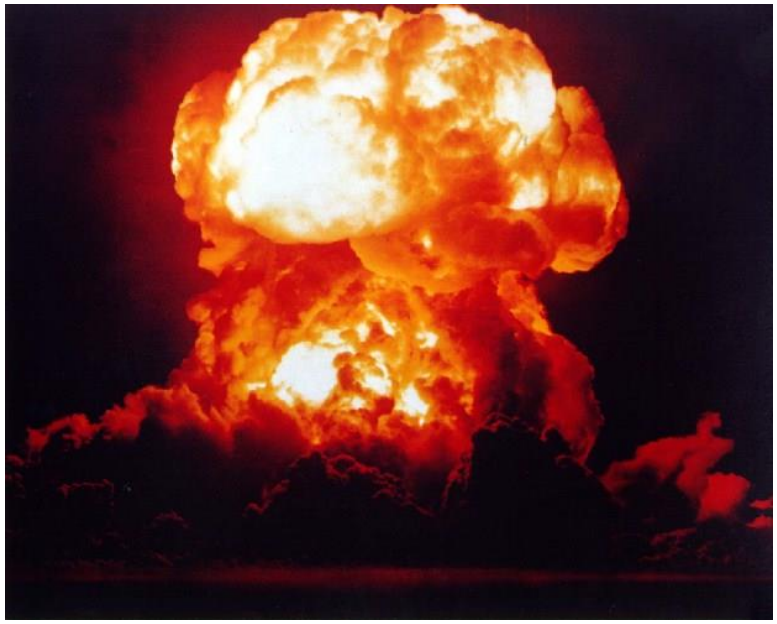
Total fallout pattern for ^{131}I



The NCI study estimates that the average American alive at the time received a 2 rad thyroid radiation exposure, with some people receiving up to 300 rads. It has been estimated that from 380 million person-rads of total exposure roughly 120,000 extra cases of thyroid cancer can be expected to develop, resulting in ~6,000 deaths.

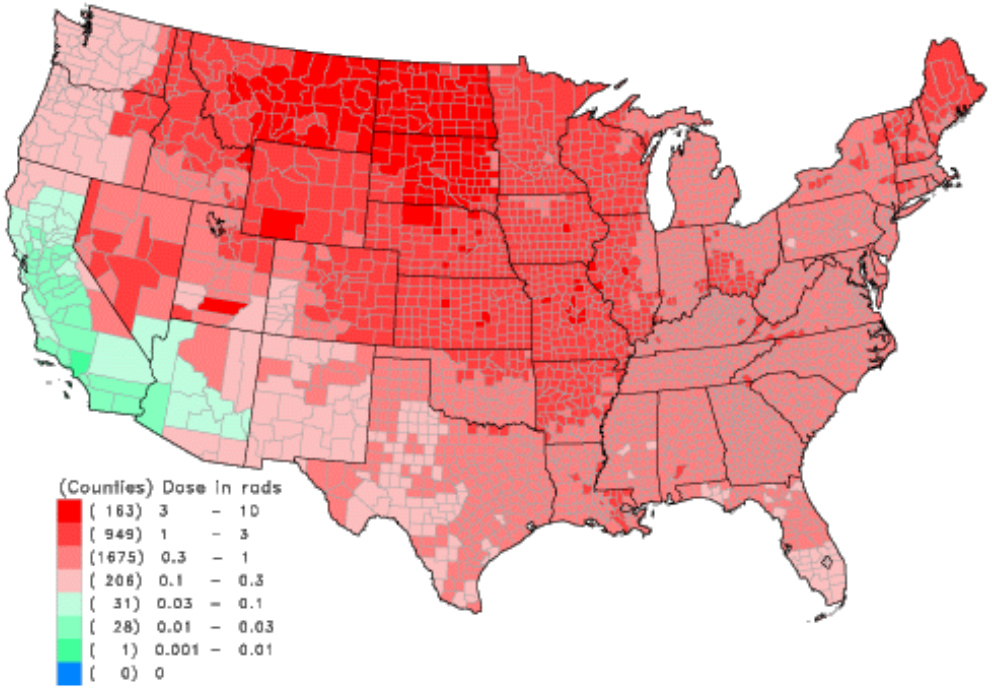
Plumbbob 1957

The Plumbbob test series released ~ 58,300 kCi (~$2 \cdot 10^{18}$ Bq) of radioiodine (^{131}I) into the atmosphere. This was more than twice as much as any other continental test series. This produced total civilian radiation exposure amounting to 120 million person-rads of thyroid tissue exposure (about 32% of all exposure due to continental nuclear tests). This has been estimated to cause about 38,000 cases of thyroid cancer, leading to some 1900 deaths.



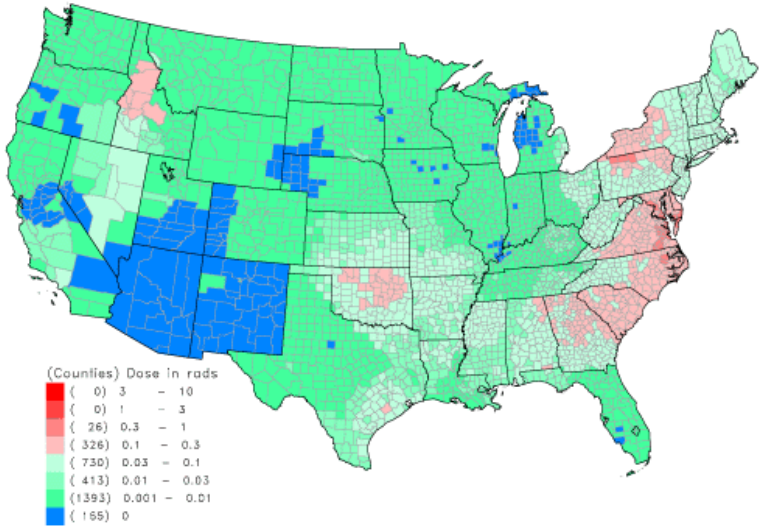
29 tests in 1957,
Nevada test site
16000 participants

Fig. PB/S/CD Per capita thyroid doses for the population of each county
Test Series: Plumbbob (1957)

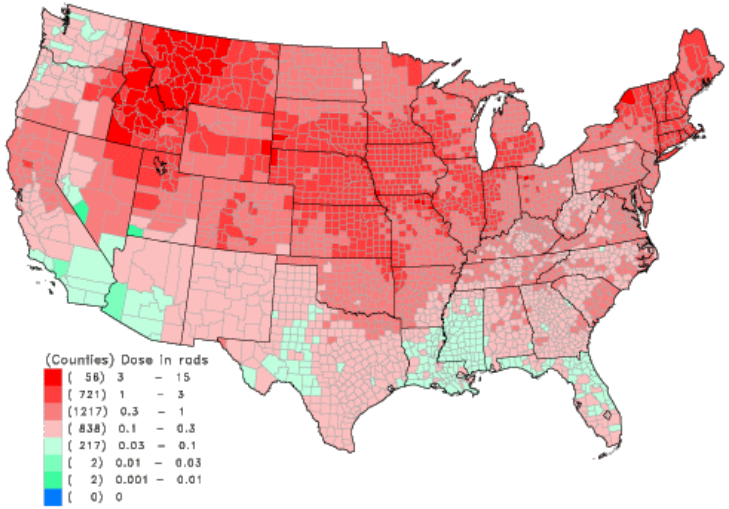


^{131}I Fallout from Nevada Tests

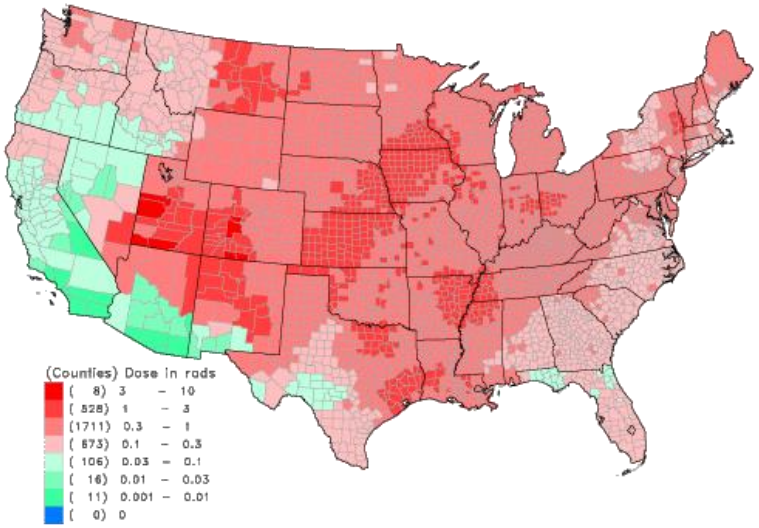
Per capita thyroid doses for the population of each county
Test Series: Buster-Jangle (1951)



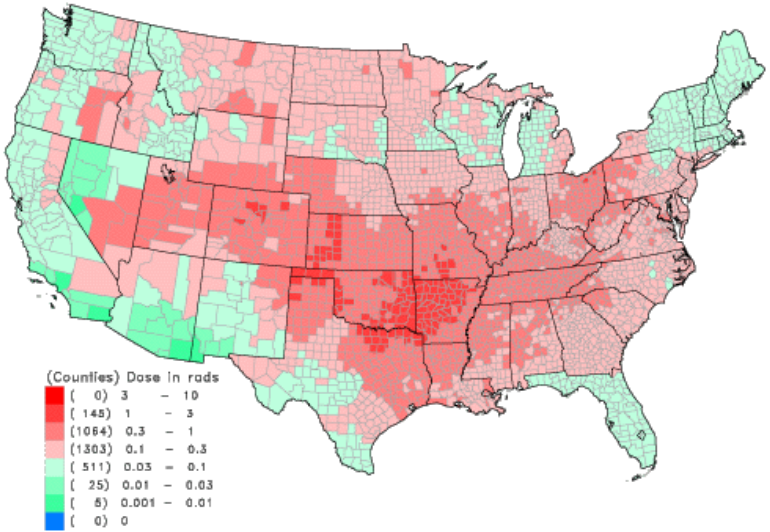
Per capita thyroid doses for the population of each county
Test Series: Tumbler-Snapper (1952)



Per capita thyroid doses for the population of each county
Test Series: Upshot-Knothole (1953)



Per capita thyroid doses for the population of each county
Test Series: Teapot (1955)

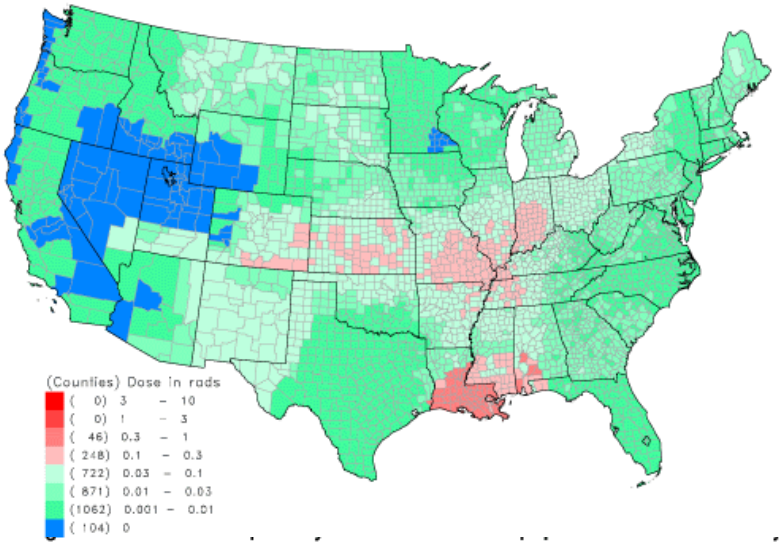


High altitude wind distribution of fallout from selected Plumbbob tests

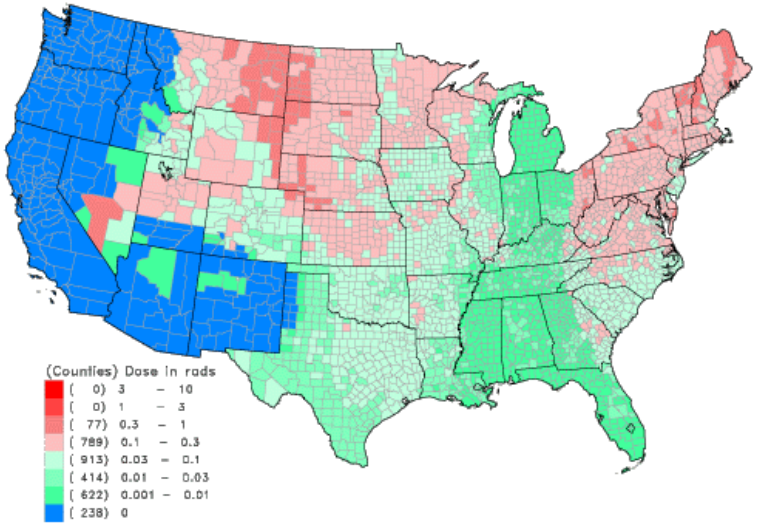
PLUMBBOB, PRISCILLA (6/24/57)

PLUMBBOB, DIABLO (7/15/57)

Test Series: Plumbbob Test: Priscilla (24 Jun 57)

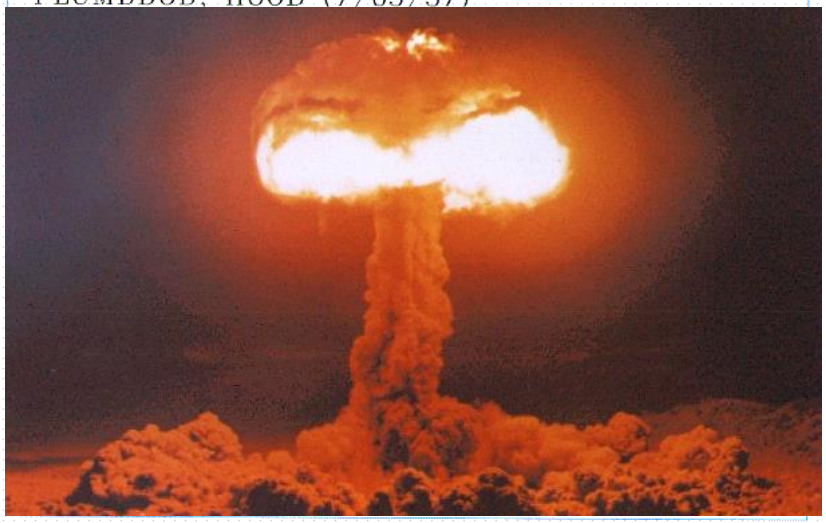


Test Series: Plumbbob Test: Diablo (15 Jul 57)

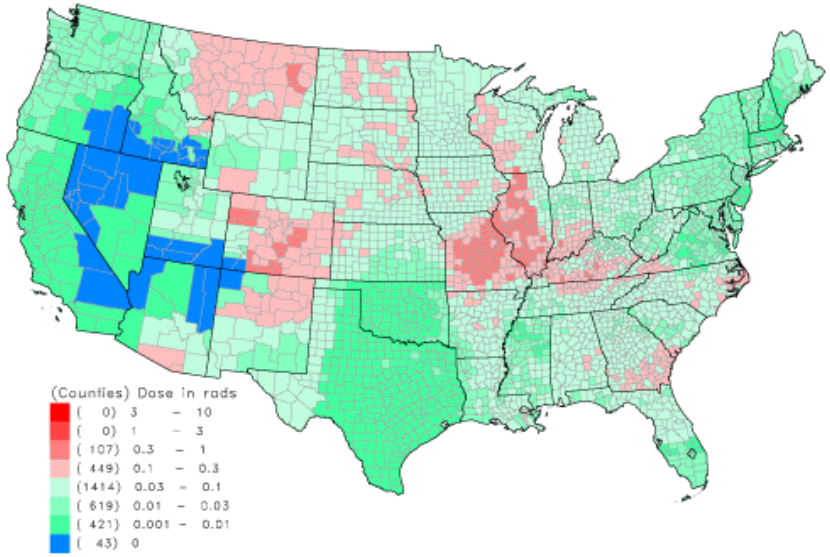


Hood & Stokes

PLUMBBOB, HOOD (7/05/57)

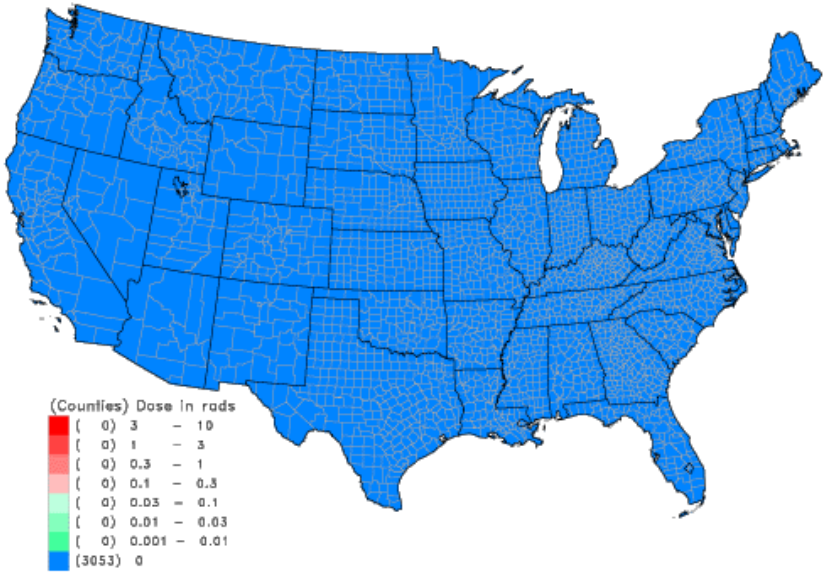


Test Series: Plumbbob Test: Hood (5 Jul 57)



PLUMBBOB, STOKES (8/07/57)

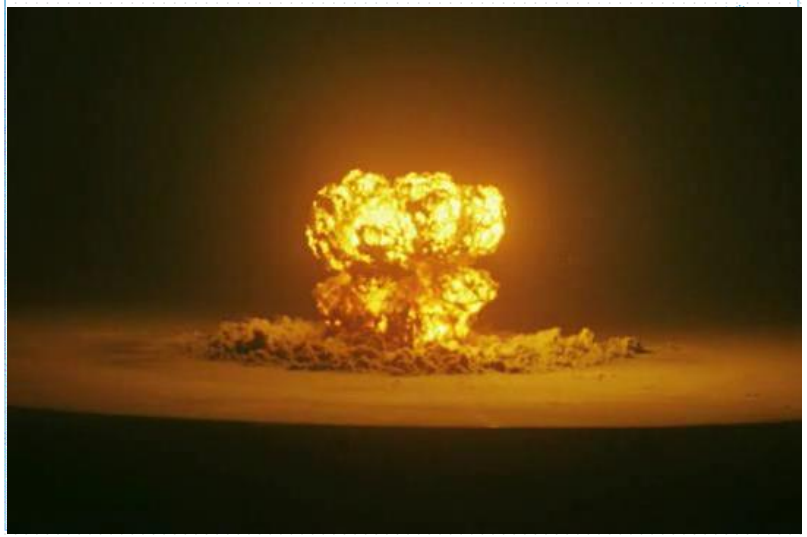
Test Series: Plumbbob Test: Stokes (7 Aug 57)



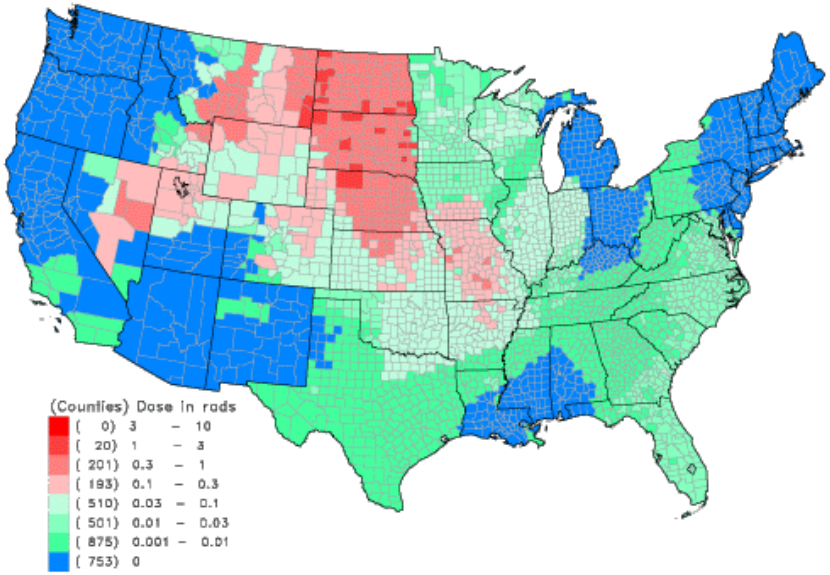
Shasta & Galileo

PLUMBBOB, SHASTA (8/18/57)

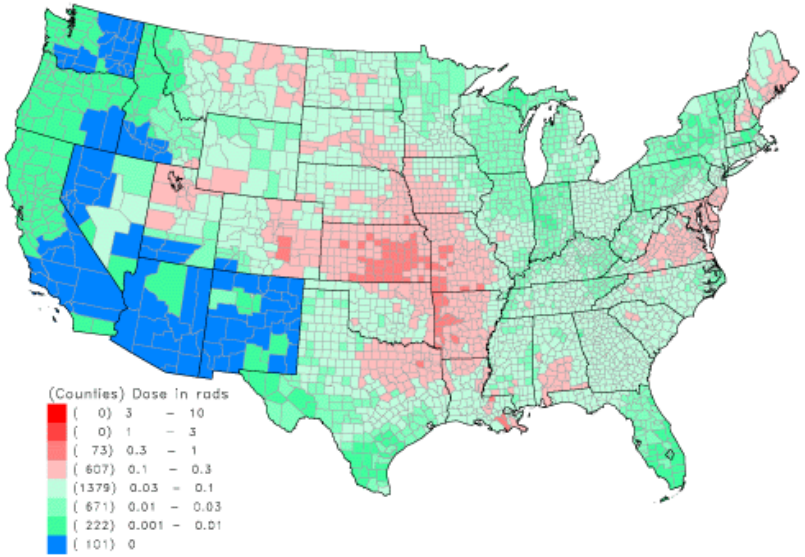
PLUMBBOB, GALILEO (9/02/57)



Test Series: Plumbbob Test: Shasta (8 Aug 57)



Test Series: Plumbbob Test: Galileo (2 Sep 57)

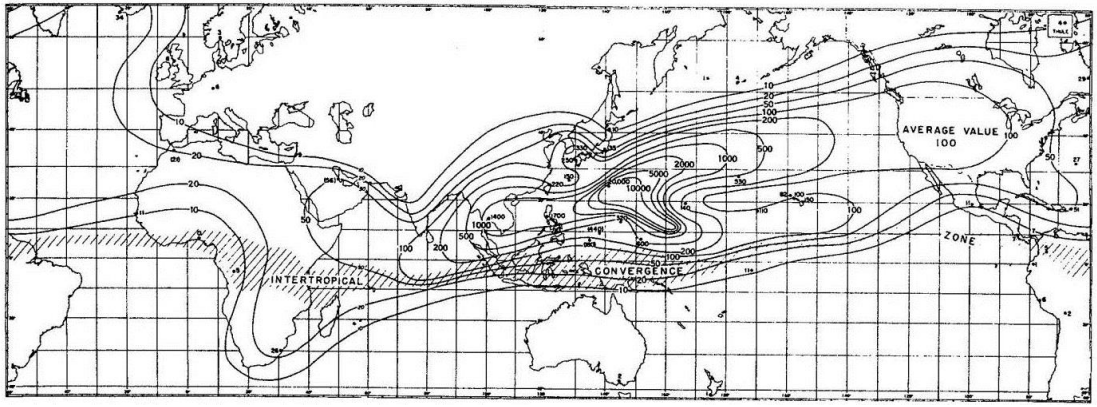


St. Josephs County, Indiana

Collective dose is a measure of the total amount of effective dose multiplied by the size of the exposed population.

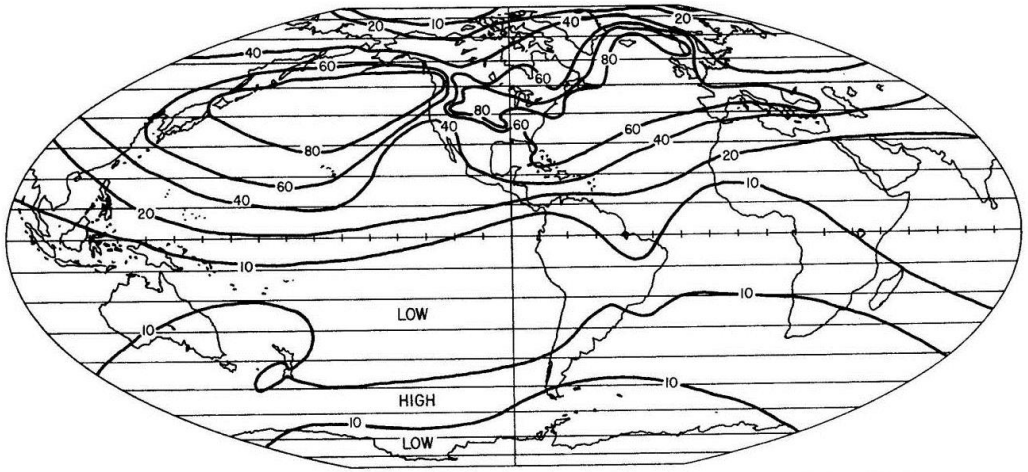
Test Series	Average doses (rad) resulting from		Collective doses (man.rad)	
	milk consumption	all exposure routes	milk cons.	all exposure routes
	GM (rad)	GM (rad)	GM (rad)	GM (rad)
Ranger 1951	0.000	0.000	40.	76.
Buster Jungle 1951	0.000	0.001	81.	218.
Tumbler Snapper 1952	0.948	1.155	207935.	253403.
Upshot Knothole 1953	0.470	0.567	103099.	124325.
Teapot 1955	0.088	0.118	19301.	25883.
Plumbbob 1957	0.573	0.707	125717.	155118.
Underground 1961-1970	0.099	0.131	21680.	28834.

Radioactive fall-out world wide



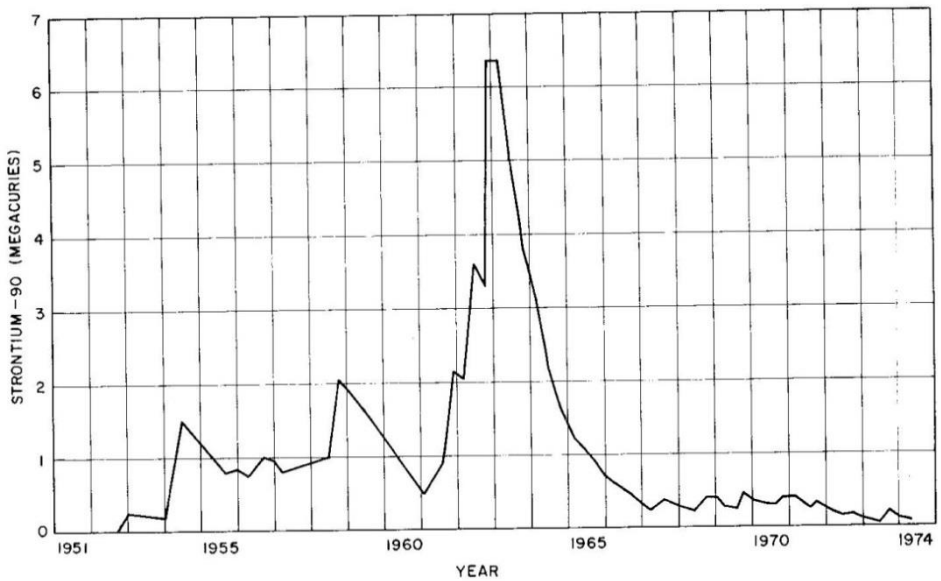
Radioactive fall-out from a megaton bomb explosion on the Marshall Islands in millicuries per 100 square miles 30 days after explosion. The radioactivity is primarily restricted to northern hemisphere

Ejection of material into the troposphere and the lower stratosphere and re-distributed over polar (3-12 months) or equatorial regions (8-24 months) depending on magnetic field and gravitational conditions. Fall-out removal times (defined in terms of half-life) ranges from 10 to 24 months depending on seasonal conditions, most rapid during spring, slow in summer.

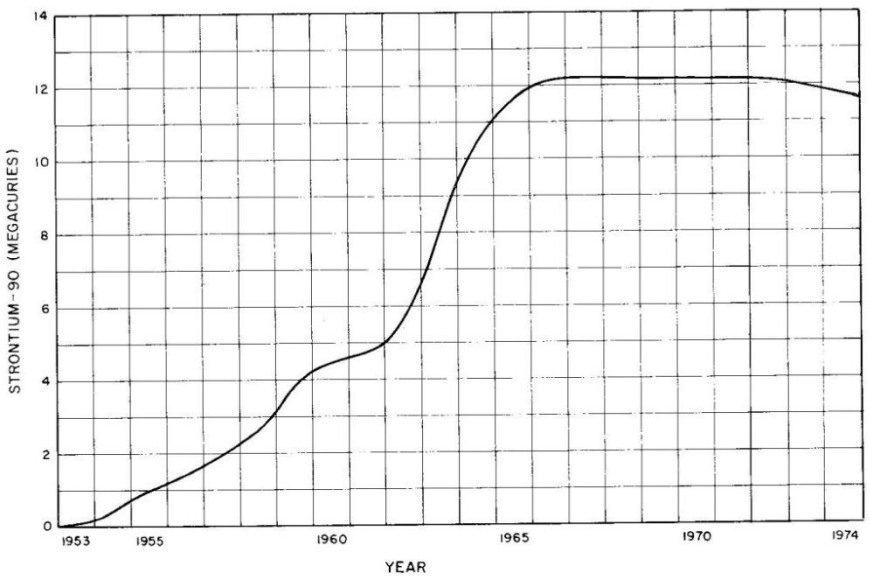


Isolines of cumulative ^{90}Sr in millicuries per square kilometer. Averaged over 2 years the radioactivity level becomes more dispersed

Deposition of ^{90}Sr in Earth's Stratosphere and Surface



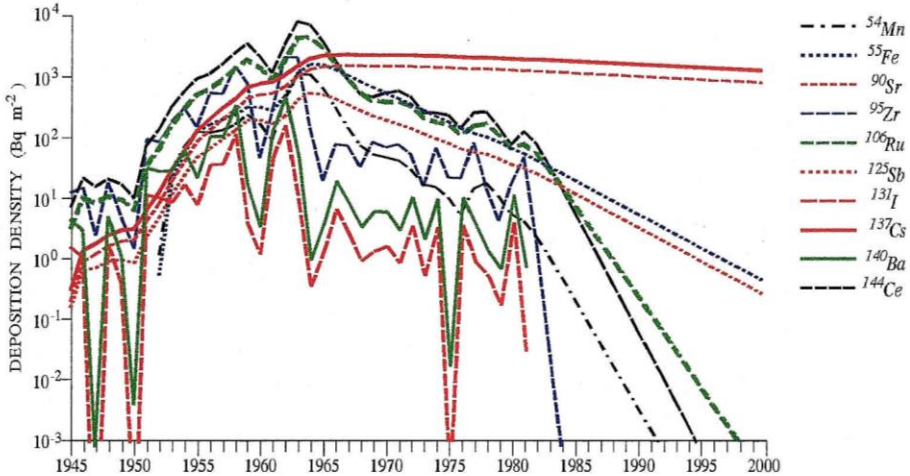
Stratospheric burden (or inventory) of strontium-90.



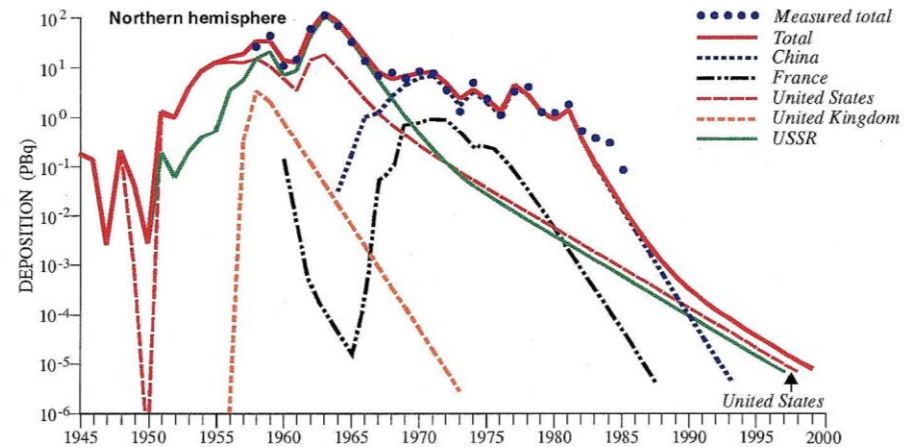
Surface burden (or inventory) of strontium-90.

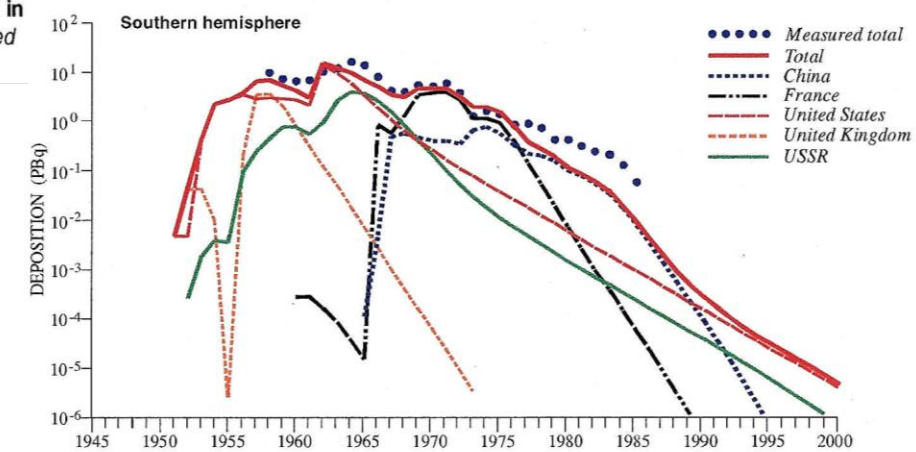
Atmospheric deposition correlates with the intensity of the test programs. The long-term activity is stored on earth surface due to fall-out or wash-out processes and distributes according to its chemical behavior.

Fallout Radioactivity



Worldwide population-weighted cumulative deposition density of radionuclides produced in atmospheric testing. *The monthly calculated results have been averaged over each year. Several short-lived radionuclides with half-lives and deposition patterns intermediate between ^{140}Ba and ^{95}Zr are not shown.*





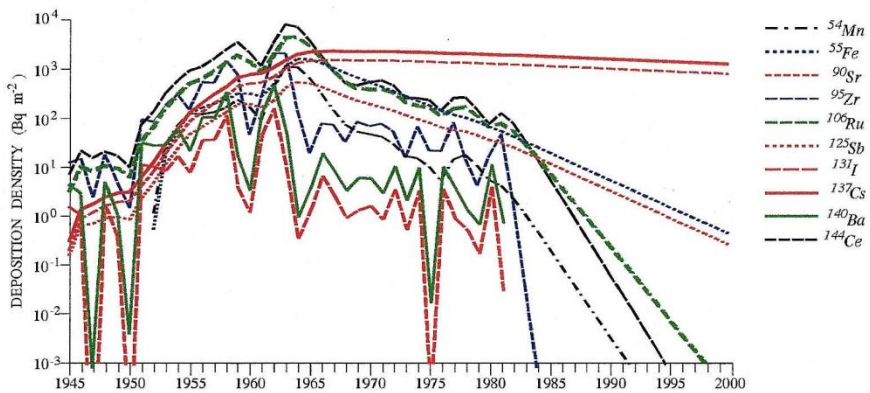
Components of strontium-90 deposition from test programmes of countries calculated from fission yields of tests with the atmospheric model.

^{90}Sr ($T_{1/2}$=28y) is stored in human bone material because of its close chemical resemblance to calcium.

1 PBq=10^{15} Bq

Human Exposure from Nuclear Tests

Average annual dose 360 mRem=3.6mSv



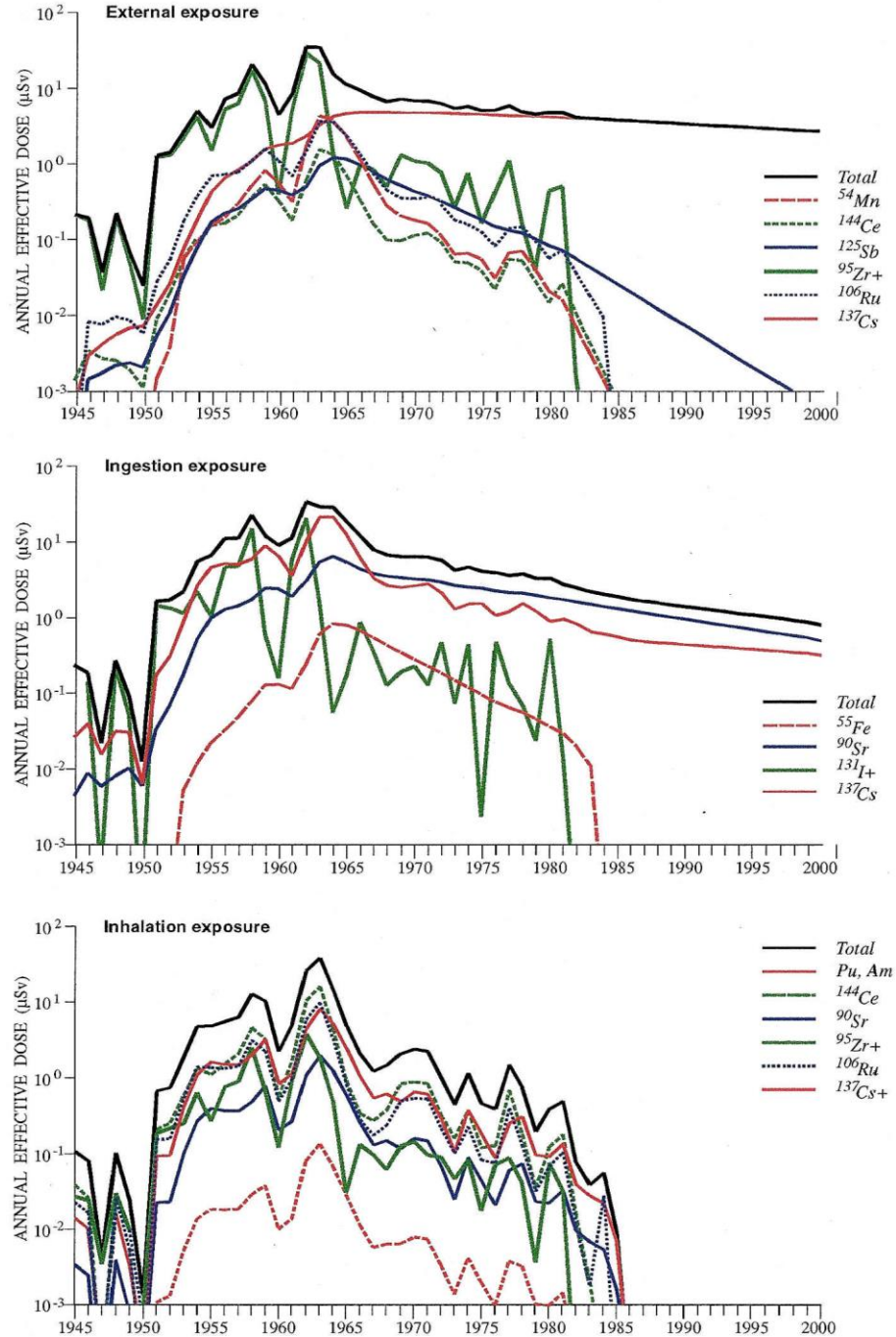
Worldwide population-weighted cumulative deposition density of radionuclides produced in atmospheric testing. *The monthly calculated results have been averaged over each year. Several short-lived radionuclides with half-lives and deposition patterns intermediate between ^{140}Ba and ^{95}Zr are not shown.*

External exposure: ^{95}Zr, ^{106}Ru, ^{140}Ba, ^{144}Cs

Ingestion exposure: ^{90}Sr, ^{131}I, ^{140}Ba

Inhalation exposure: ^{54}Mn, ^{55}Fe, ^{95}Sr, ^{125}Sb, ^{137}Cs

www.unscear.org/pdffiles/annexc.pdf

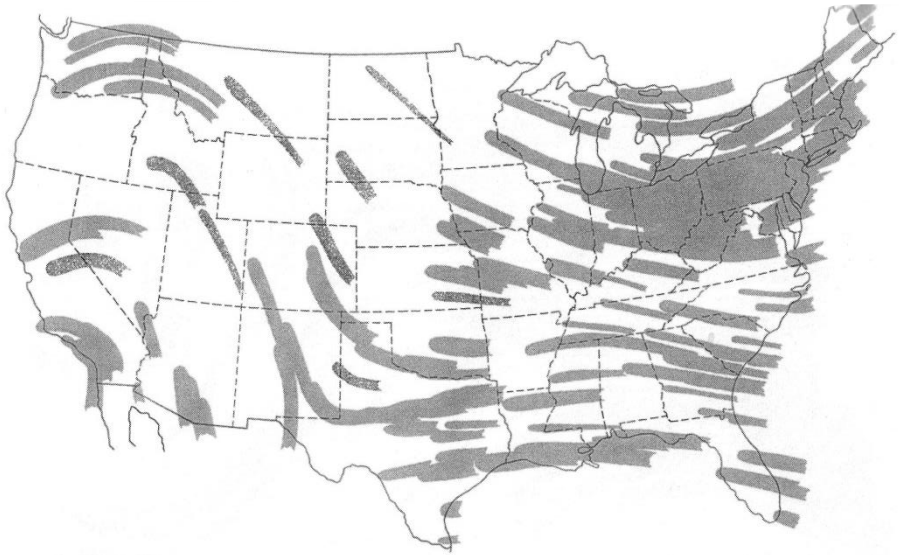


Worldwide average doses from radionuclides produced in atmospheric testing.

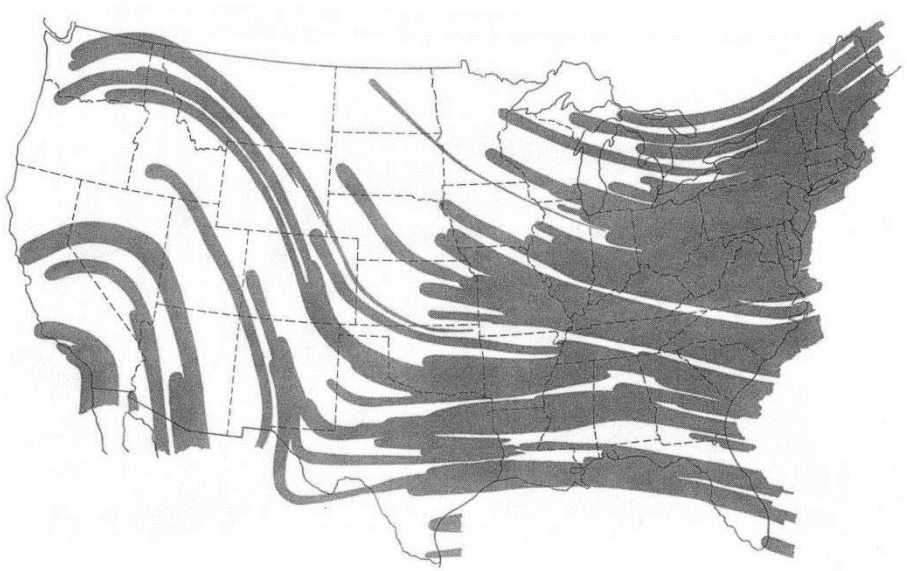
Invasion USA

Hypothetical Attack

with 223 bombs generating a total yield of 1453 Megatons. The radioactive fallout is spread according to the characteristic wind pattern and wind direction over the North American continent!



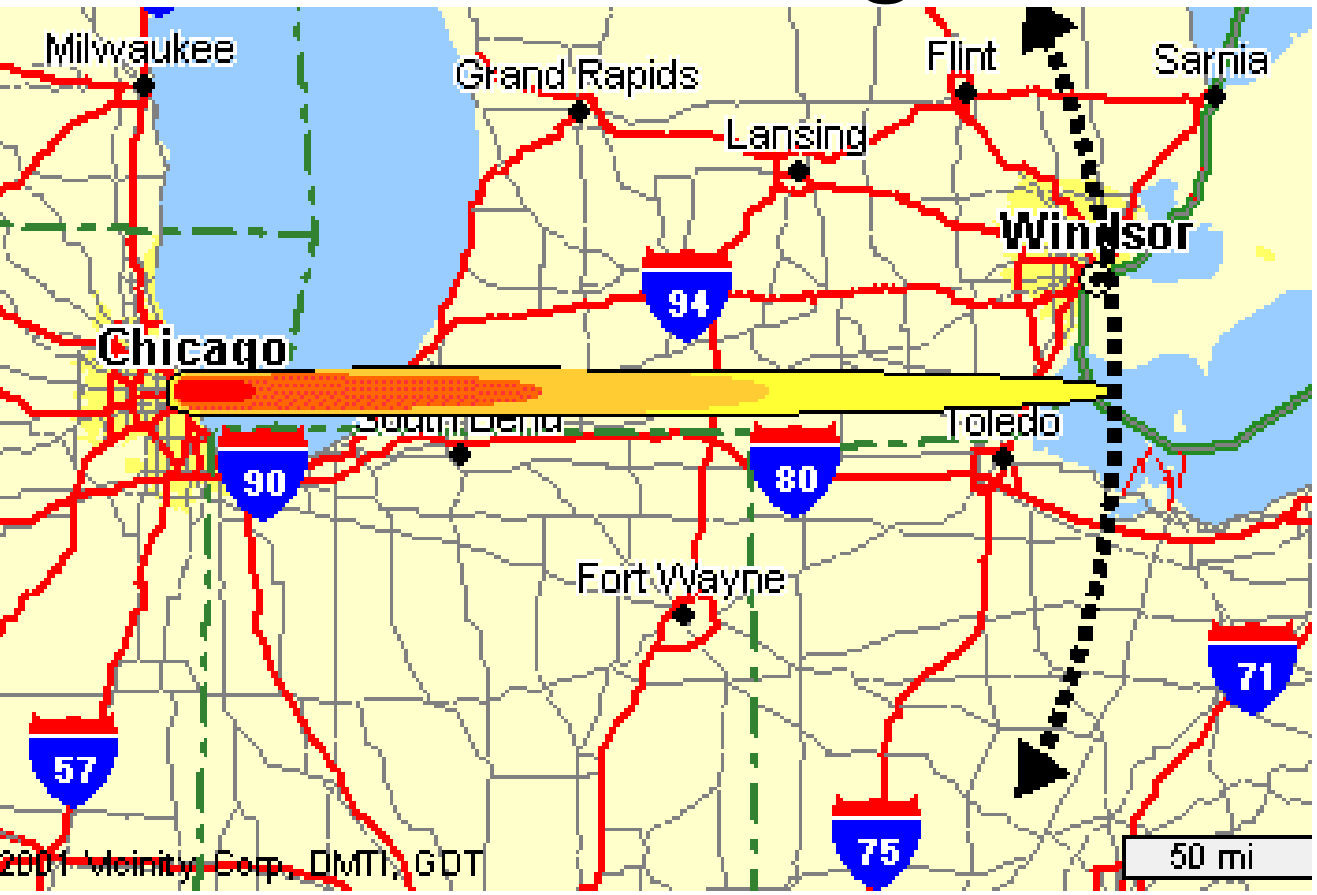
Fallout patterns at near lethal levels 7h after hypothetical attack.



Fallout patterns at near lethal levels 48h after hypothetical attack.

Medical Implications of Nuclear War, NRC 1986

Attack on Chicago



3,000 Rem = 30 Sv
Distance: 30 miles
Lethal dose within hours
10 years before area is safe

900 Rem = 9S v
Distance: 90 miles
Lethal dose:
2 – 14 days

300 Rem = 3 Sv
Distance: 160 miles
Extensive internal damage

90 Rem = 0.9 Sv
Distance: 250 miles
No immediate harmful effects, but decrease in white blood cells.
2 – 3 years before considered ‘safe’.

Based on 15 mph winds