

Physics/Global Studies 280: Session 8

Plan for This Session

Announcements & Questions:

RPPv1 will be due Wednesday 2-18 at 10pm

First extra credit opportunities:

- (1) ACDIS seminar, Monday, February 16th, 5pm (due February 23rd, 10pm)
Fusion at Helion and Proliferation Risks of Fusion Deployment.
Michael Hu, Director of Nuclear, Chemical and Materials Engineering at Helion Energy
- (2) Bookreview, The New Yorker, August 31st 1946 (due March 23rd, 10pm)
- (3) Film Screening: First we bombed New Mexico, February 20th, 5pm (due March 2nd. 10pm)

News

Module 3

Effects of nuclear explosions

Iran Is at Work on Missile and Nuclear Sites, Satellite Images Show

Repairs at key missile sites began soon after they were hit by Israeli and U.S. strikes last year, but work at Iran's nuclear facilities has been slower.



A missile facility near Amand, Iran, targeted by Israel in June 2025. Source: Satellite images by Planet Labs. The New York Times



The New York Times

Iran appears to have rapidly repaired several ballistic missile facilities damaged in strikes last year, but it has made only limited fixes to major nuclear sites struck by Israel and the United States, a New York Times analysis of satellite imagery suggests.

The uneven pace of reconstruction offers clues about Iran's military priorities as the United States amasses forces near it and President Trump weighs new military action. If the United States were to attack, Iran would most likely retaliate with ballistic missiles targeting Israel and U.S. assets in the region.

The United States and Iran met in Oman on Friday in an attempt to stave off another conflict. The talks were a “good start” and “exclusively nuclear,” Iran's foreign minister told state media, adding that the two sides had agreed to continue discussions at a later date.

Trump says he 'insisted' to Netanyahu that U.S. talks with Iran continue

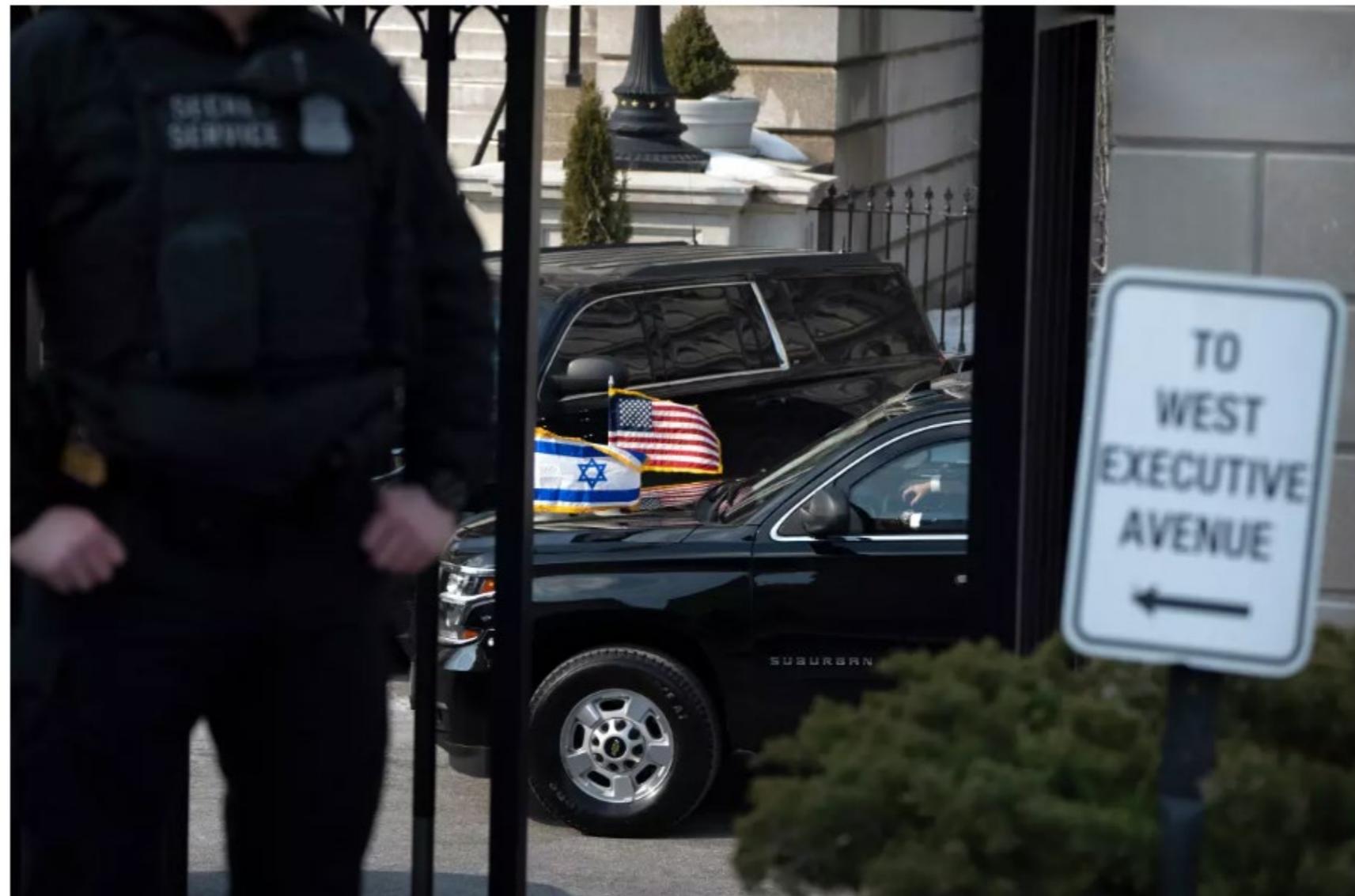
By Farnoush Amiri and Melanie Lidman

Feb. 11, 2026 Updated 3:28 PM PT

President Trump met privately with Israeli Prime Minister Netanyahu and vowed to pursue nuclear negotiations with Iran while maintaining military pressure if talks fail.

Netanyahu wants U.S.-Iran talks to address Tehran's ballistic missile program and its support for militant groups, including Hamas and Hezbollah.

The U.S. and Iran are engaging in indirect nuclear talks in Oman following last June's devastating 12-day war between Israel and Tehran.



A vehicle carrying Israeli Prime Minister Benjamin Netanyahu arrives at the White House on Wednesday. (Mark Schiefelbein / Associated Press)

Netanyahu pushes for more in Iran talks

Netanyahu's office said prior to the meeting that he wants the talks to include limits on Tehran's ballistic missile program and its support for militant groups such as Hamas and Hezbollah.

"I will present to the president our outlook regarding the principles of these negotiations — the essential principles which, in my opinion, are important not only to Israel, but to everyone around the world who wants peace and security in the Middle East," Netanyahu said Tuesday before leaving Israel.

But it remains unclear how much influence Netanyahu will have over Trump's approach toward Iran. Trump initially threatened to take military action over Iran's bloody crackdown on nationwide protests in January, then shifted to a pressure campaign in recent weeks to try to get Tehran to make a deal over its nuclear program.

Iran still is reeling from the 12-day war with Israel in June. The devastating series of airstrikes, including the U.S. bombing several Iranian nuclear sites, killed nearly 1,000 people in Iran and almost 40 in Israel.

Trump has said repeatedly that U.S. strikes “obliterated” Iran’s nuclear capabilities, though the amount of damage remains unclear. **Satellite photos of nuclear sites recently captured activity, prompting concern that Iran could be attempting to salvage or assess damage at the sites.**

Israel has long called for Iran to cease all uranium enrichment, dial back its ballistic missile program and cut ties to militant groups across the region. Iran always rejected those demands, saying it would accept limits on its nuclear program only in return for relief from international sanctions.

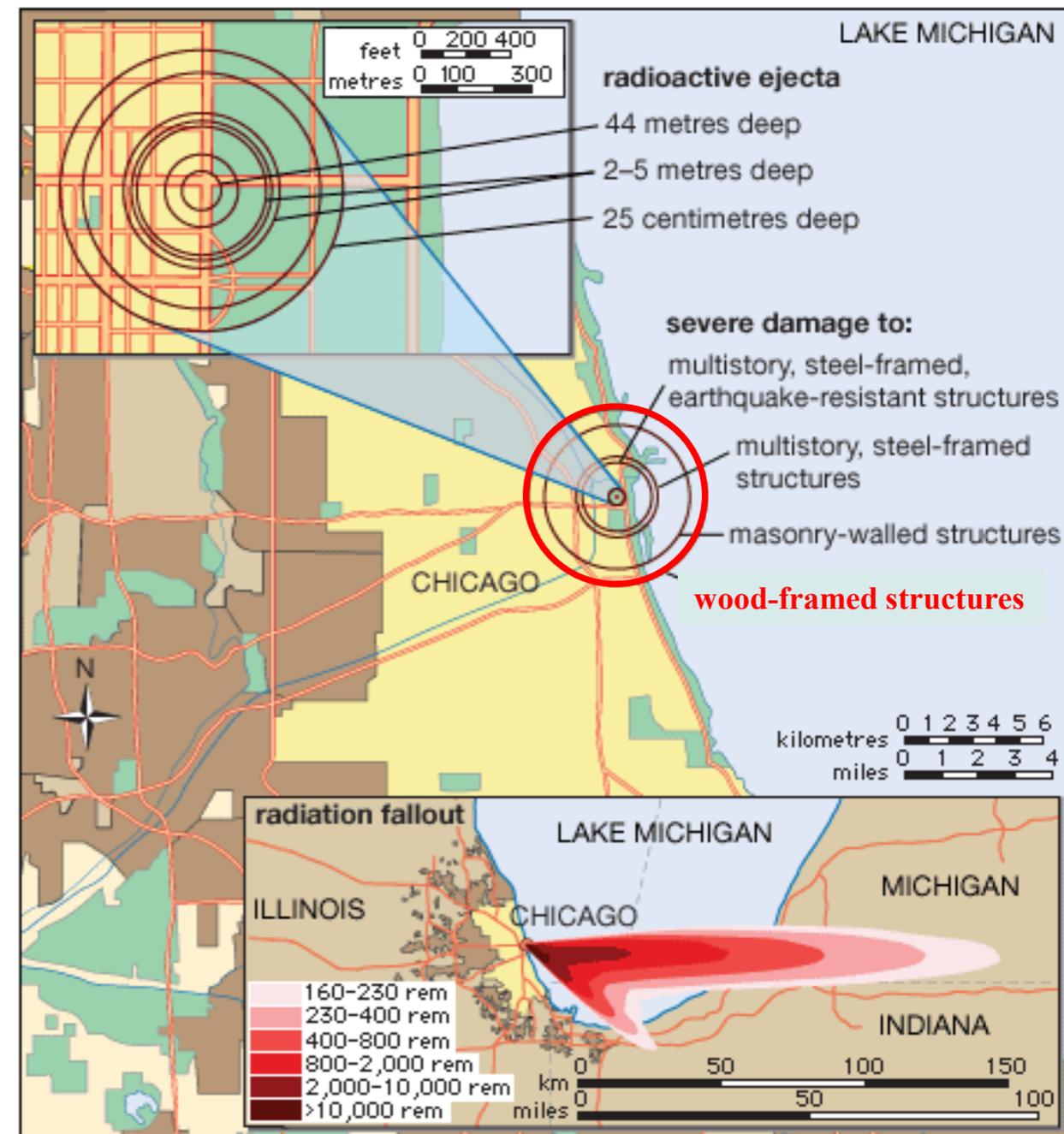
Washington has built up military forces in the region, sending an aircraft carrier, guided-missile destroyers, air defense assets and more to supplement its presence. Arab and Islamic countries, including Turkey and Qatar, have been urging both sides to show restraint, warning that any strike or retaliation could have destabilizing consequences for a region already strained by the Israel-Hamas war in Gaza.

Physics 280: Effects of Nuclear Explosions

Impact of a 500 kiloton device detonated in Chicago

Plan for This Session

Module 3: Effects of nuclear explosions



Module 3: Effects of Nuclear Explosions

Topics covered in this module —

- Weapons of mass destruction
- Overview of weapon effects
- Effects of thermal radiation
- Effects of blast waves
- Effects of nuclear radiation
- Global effects of nuclear war

Definition: “Weapons of Mass Destruction”

Even a simple fission device can release *a million times* more destructive energy per kilogram than conventional explosives.

Nuclear weapons are the only weapons that could —

- Kill millions of people almost instantly
- Destroy the infrastructure and social fabric of the United States

While the use of chemical and biological weapons can have grave consequences:

Only nuclear weapons are “weapons of mass destruction” and can threaten the survival of the U.S. and other nations.

Impact of the 15 kiloton detonation in Hiroshima on wood-framed structures



Chemical Weapons

A chemical weapon is a device that releases toxic chemicals.

Release of toxic chemicals in a city **would not cause mass destruction** but would —

- create fear
- disrupt normal activities
- possibly cause a large number of casualties.

Technically challenging to synthesize and effectively deliver chemical agents.

If dispersed effectively, a chemical agent could contaminate a substantial area.

If toxic enough, it might cause **100s or even 1,000s of casualties**, but it would not **destroy buildings or vital infrastructure**.

Precautions before and rapid medical treatment and decontamination after such a release would reduce substantially the number of casualties, especially for less deadly agents.

Historic Example: Chemical Weapons in WW I



**Gas attack during
World War I.**

**In World War I, 190,000 tons of gas caused
less than 1% of all combat deaths, still
~100,000 deaths 1915-1918**

Biological Weapons

Release of a biological agent would create fear and disrupt normal activities, but **would not cause mass destruction.**

Advanced technology would be needed to effectively deliver such an agent to large population.

In **countries with an effective public health service, prompt quarantine, vaccination, and other measures could reduce greatly the number of casualties,** the area affected, and the time required to get the disease under control.

In less-developed countries, a contagious deadly disease could be devastating.

A pathogen such as anthrax that does not produce contagious disease could be used to attack a particular building or area.

A pathogen such as smallpox that produces a deadly contagious disease would be a “doomsday” weapon, because it could kill millions of people worldwide, including the group or nation that released it.

Biological Weapons

Small pox > 300 millions deaths
world wide 1900 to 1979
mortality ~ 30%

Release of a biological agent would create fear and disrupt normal activities and **cause mass destruction.**

Advanced technology would be needed to effectively deliver such an agent to a target population.

In **countries with an effective public health service, prompt quarantine, and other measures could reduce greatly the number of casualties,** the area affected would be much smaller and the time required to get the disease under control.

In less-developed countries, a contagious deadly disease could be devastating.

A pathogen such as anthrax that does not produce contagious disease could be used to attack a particular building or area.

A pathogen such as smallpox that produces a deadly contagious disease would be a “doomsday” weapon, because it could kill millions of people worldwide, including the group or nation that released it.



Nuclear Weapons

In contrast to chemical or biological agents, a “small” (10 kiloton) nuclear weapon detonated in a major city would **kill more than 100,000 people and completely destroy tens of square kilometers of buildings and infrastructure.**

Even a crude nuclear device that fizzled would destroy many square kilometers of a city and kill tens of thousands of people.

A large (1 megaton) nuclear weapon could kill millions of people and destroy hundreds of square kilometers within a few seconds.

Unlike the effects of a chemical or biological weapon, the **devastating effects of a nuclear weapon on a city cannot be reduced significantly by actions taken before or after the attack.**

Those who survived a nuclear explosion would have to deal with severe physical trauma, burns, and radiation sickness. Vital infrastructure would be destroyed or damaged, and radioactivity would linger for years near and downwind of the explosion.

Radiological Weapons

A radiological weapon is a device that spreads radioactive material (most likely isotopes used would not be nuclear explosive nuclides!)

Such a weapon is a **weapon of mass *disruption*, not mass *destruction***.

Dispersal of a substantial quantity of highly radioactive material in a city would *not* —

- physically damage structures
- immediately injure anyone

It could —

- contaminate a few city blocks with radioactive material
- seriously disrupt city life and economics

If explosives were used to disperse the material, the explosion could cause a small amount of damage and some injuries.

Depending on their exposure to radiation and how they were treated afterward —

- **100s or perhaps even 1,000s of people could become sick**
- a larger number could have a somewhat higher probability of developing cancer or other diseases later in life

The main effect would be to create fear and disrupt normal activities.

Use of the Term “Weapons of Mass Destruction”

Avoid lumping together as “WMD”—

- radiological weapons (“dirty bombs”)
- chemical weapons
- biological agents
- nuclear weapons

Broadening the definition of “WMD” can have the following consequence:

- nuclear weapons appear no different from other weapons
- make chemical and biological weapons appear as dangerous as nuclear weapons and therefore a justification for war or even nuclear war

This language obscures the profound differences in

- the lethality and destructiveness of these weapons
- the timescales on which their effects are felt
- the possibility of protecting against them (or not)

In PHYS/GLBL 280, we will avoid the term “WMD”. Instead, we will say what we mean: “nuclear weapons”, “chemical weapons”, or “biological weapons”.

Theft of Nuclear Material in November 2013

Stolen cobalt-60 found in Mexico; thieves may be doomed

By Gabriela Martinez and [Joshua Partlow](#), Published: December 4

MEXICO CITY — Mexico's public-health scare turned into a logistical hurdle Thursday as authorities sought to safely put a stolen load of radioactive material back into its container.

As officials worked on the material, federal police and soldiers formed a cordon of several hundred yards around the field in Hueypoxtla where a container of highly radioactive cobalt-60 was abandoned after it was stolen from truck drivers transporting it to a storage facility in central Mexico.

The International Atomic Energy Agency (IAEA) said the “extremely dangerous” cargo of pellets used in hospital radiotherapy machines had been removed from its protective casing, but “there is no indication that it has been damaged or broken up” and there is “no sign of contamination to the area.”

The theft of the material sparked international concern because of the possibility that the cobalt-60 could be used ... ?



Lecture Question

The theft of Co-60 in Mexico caused international concern as

- (A) Co-60 is a fertile material and can be used to breed fissile nuclides.
- (B) Co-60 is a NEM and can be used in nuclear weapons.
- (C) Co-60 could be used in a radiological weapon.
- (D) Co-60 is radioactive, highly toxic and can be dispersed easily as a chemical weapon.

Lecture Question Answer

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Lecture Question

Could a terrorist group construct a workable bomb using reactor-grade plutonium?

- (A) No
- (B) Yes, but with difficulty
- (C) Yes, easily

Lecture Question Answer

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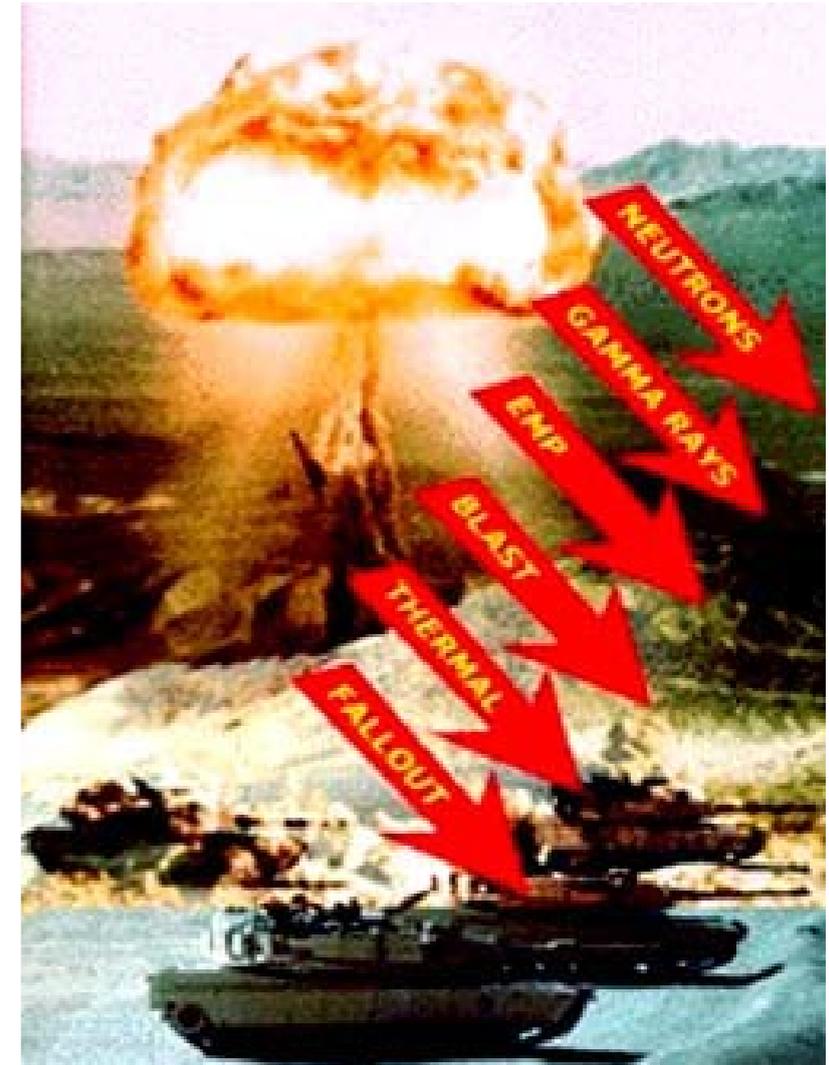
(C) Yes, easily

Effects of Nuclear Explosions

Overview of Nuclear Explosions

Effects of Nuclear Explosions (Overview)

- Effects of a single nuclear explosion
 - Prompt nuclear radiation
 - Electromagnetic Pulse (EMP)
 - Thermal radiation
 - Blast wave
 - Residual nuclear radiation (“fallout”)
 - Secondary effects (fires, explosions, etc.)
- Possible additional effects of nuclear war
 - World-wide fallout
 - Effects on Earth’s atmosphere and temperature
 - Effects on physical health, medical care, food supply, transportation, mental health, social fabric, etc.



Credit:

Nuclear Energy Released in a Nuclear Explosion

The total energy released is the “yield” Y

Y is measured by comparison with explosive TNT

Fission weapons: kTs to 100s of kTs of TNT

Thermo nuclear weapons: 100 kTs to few MTs of TNT

- 1 kiloton (kt) of TNT = 10^{12} calories
- 1 Megaton (Mt) of TNT = 1,000 kt = 10^{15} calories

Energy from a nuclear explosion is released in less than 1 micro second!

Initial Distribution of Energy From Any Nuclear Explosion (Important)

After ~ 1 microsecond —

- Essentially all of the energy has been liberated
- Vaporized weapon debris has moved only ~ 1 m
- Temperature of debris is $\sim 10^7$ C (\sim center of Sun)
- Pressure of vapor is $\sim 10^6$ atmospheres

The energy is *initially* distributed as follows —

- Low energy X-rays (1 keV) $\sim 80\%$
- Thermal energy of weapon debris $\sim 15\%$
- Prompt nuclear radiation (n, γ, β) $\sim 5\%$

Subsequent Evolution of Nuclear Explosions

What happens next depends on —

- The yield of the weapon
- The environment in which the energy was released

It is largely independent of the weapon design.

Lecture Question

A nuclear weapon test is carried out in space. A satellite 20 miles away is used to measure the energy released from the explosion. What does it find?

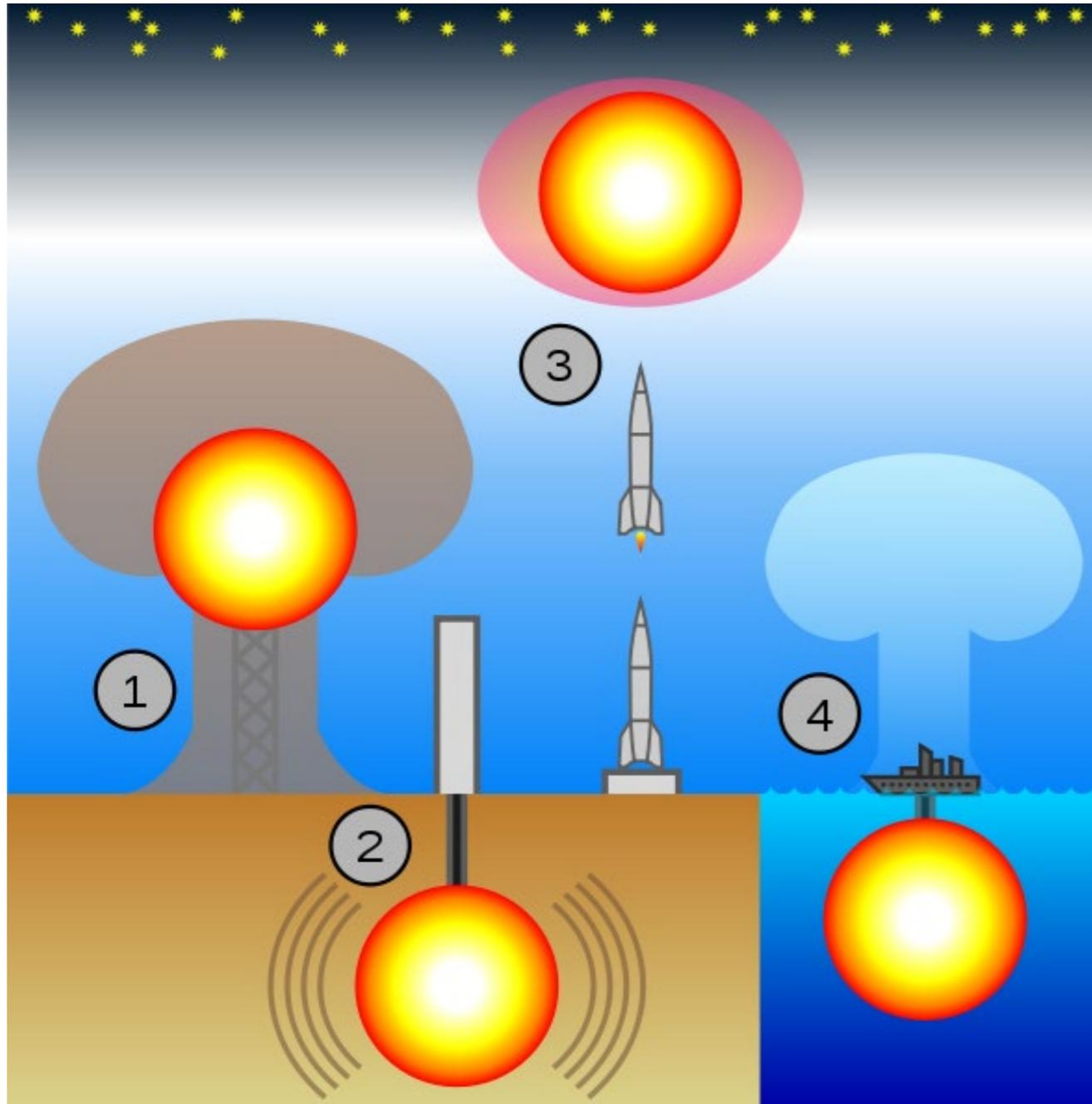
- (A) The low energy gamma rays have been absorbed by the weapon debris and almost all energy is in the kinetic energy of the debris.
- (B) 80% of the energy is carried by low energy gamma rays.
- (C) At the distance of the satellite the debris has slowed and all energy is carried by low energy gamma rays.

Lecture Question Answer

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Nuclear Explosions

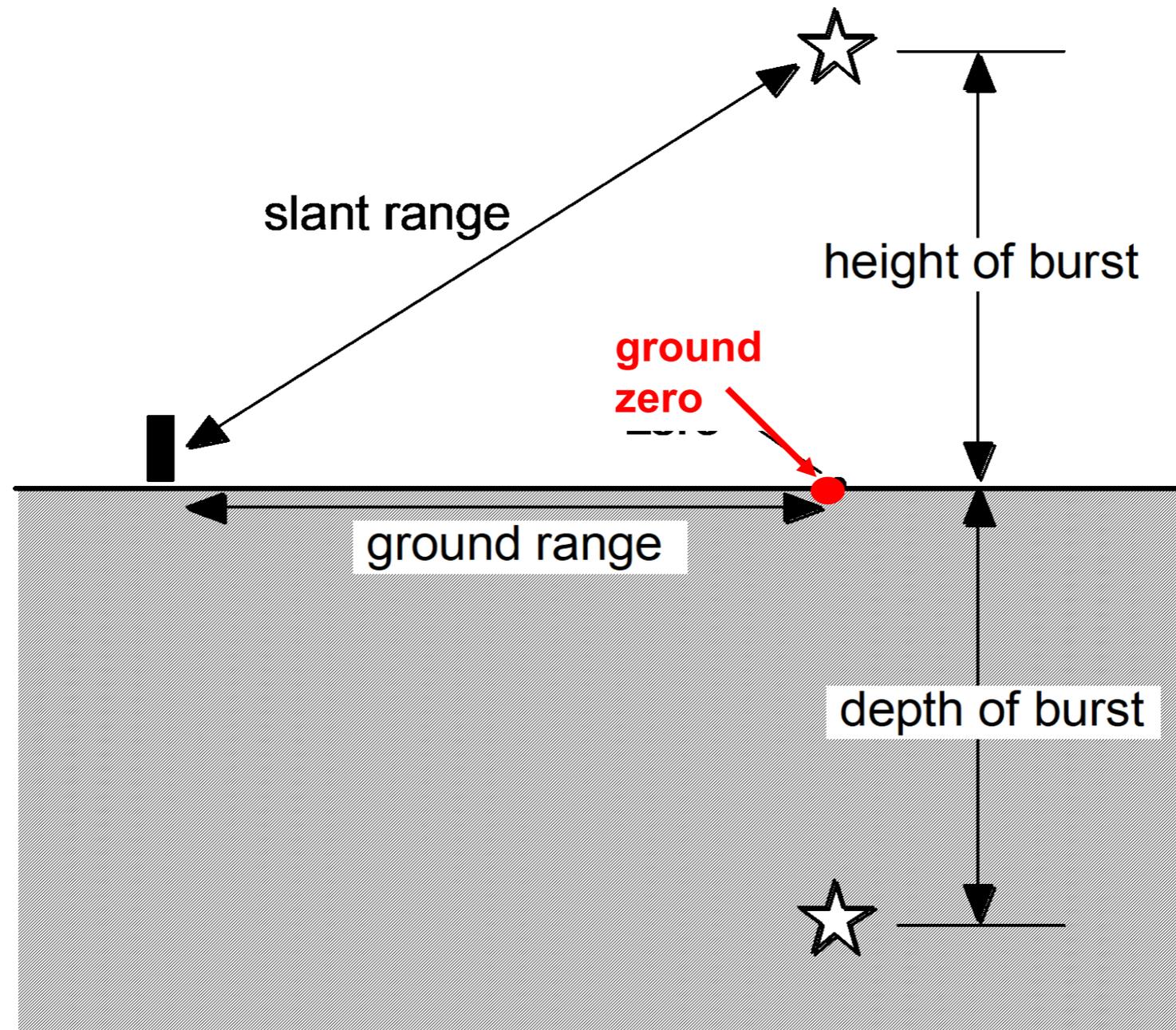


Credit: Wikipedia (nuclear weapons testing)

Possible environments —

1. Air and surface bursts
2. Underground bursts
- 3a. Explosions at high altitude (above 30 km)
- 3b. Explosions in space
4. Underwater bursts

Nuclear Explosion Geometries



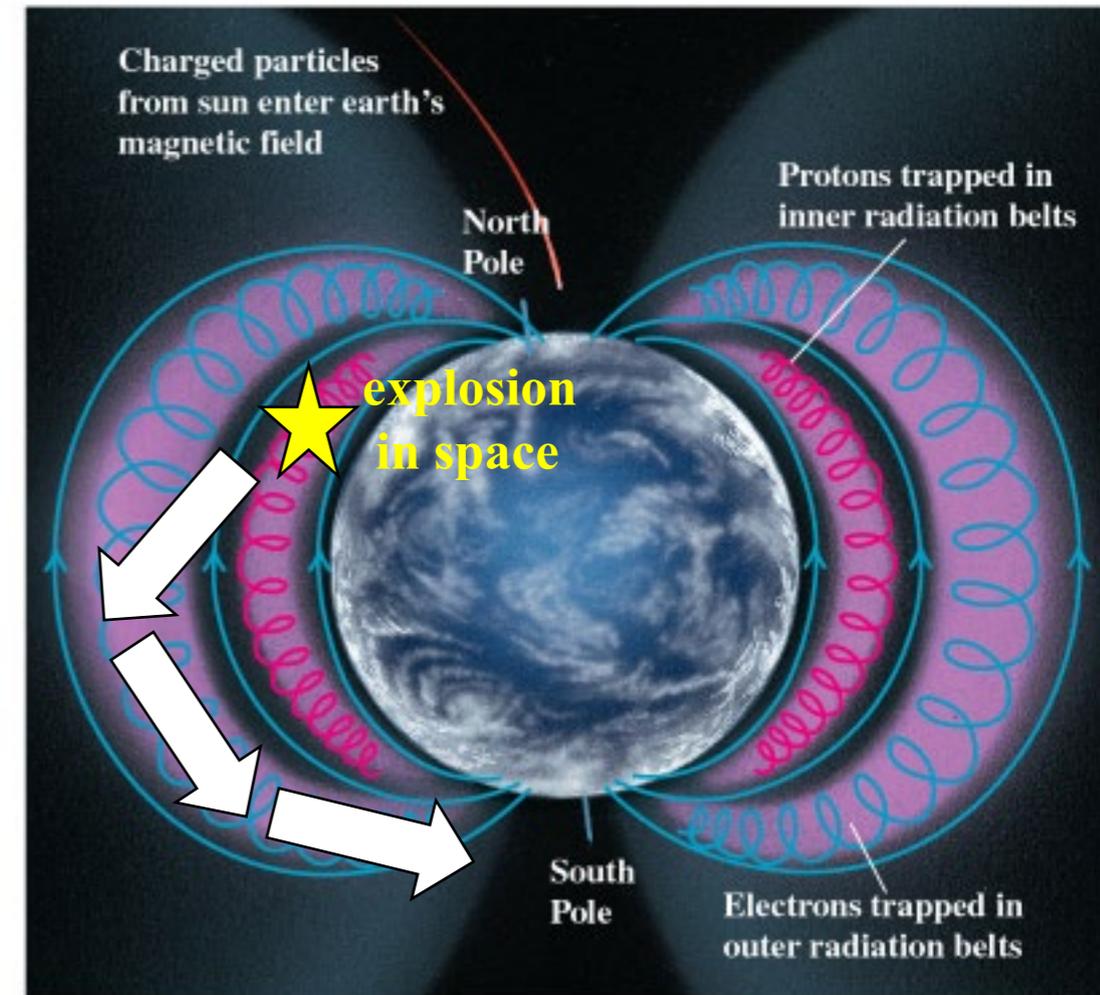
Nuclear Explosions in Space

The U.S. exploded nuclear weapons in space in the late in 1950s and early 1960s –

- Hardtack Series (Johnston Island, 1958)
 - Teak (1 Mt at 52 miles)
 - Orange (1 Mt at 27 miles)
- Fishbowl Series (1962)
 - Starfish (1.4 Mt at 248 miles)
 - Checkmate (sub-Mt at tens of miles)
 - Bluegill (sub-Mt at tens of miles)
 - Kingfish (sub-Mt at tens of miles)

Led to discovery of the Electromagnetic Pulse (EMP) and damage to satellites by particles trapped in the geomagnetic field

Charged particles trapped in the earth magnetic field
Van Allen Radiation Belt



(a)

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Underground Nuclear Explosions

Fully contained (no venting) —

- No debris from the weapon escapes to atmosphere
- No ejecta (solid ground material thrown up)
- Subsidence crater may form in hours to days
- No radioactivity released (except noble gasses)
- Characteristic seismic signals released

Partially contained (some venting) —

- Throw-out crater formed promptly (ejecta)
- Radiation released (mostly delayed)
- Characteristic seismic signals released
- Venting is forbidden for US and Soviet/Russian explosions by the LTBT (1974) and PNET (1974)

Underground Nuclear Explosions- Nevada Test Site



Subsidence Crater

<http://www.nv.doe.gov/library/photos/testprep.aspx>

Underground Nuclear Explosions: Test Deployment & Assembly

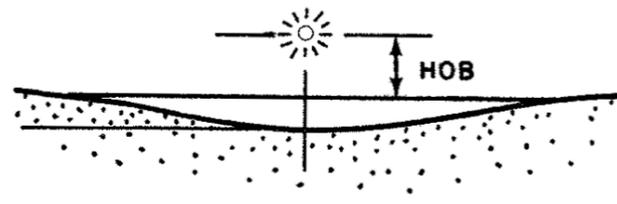


<http://www.nv.doe.gov/library/photos/testprep.aspx>

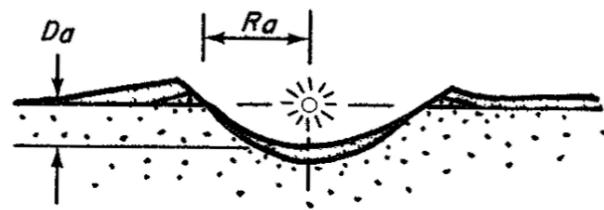
Nuclear weapon tests serve the acquisition of information/data concerning explosions of different warheads.

A large number of measurement probes were installed prior and readout during the explosion.

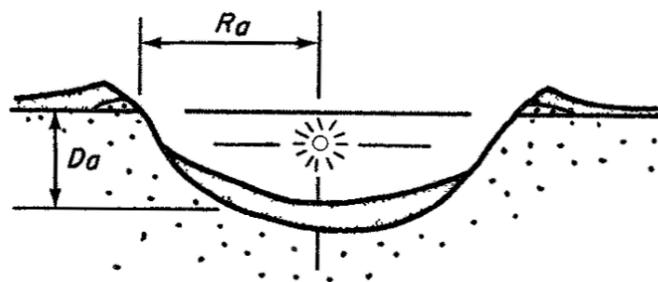
Crater Formation vs DOB (depth of burst)



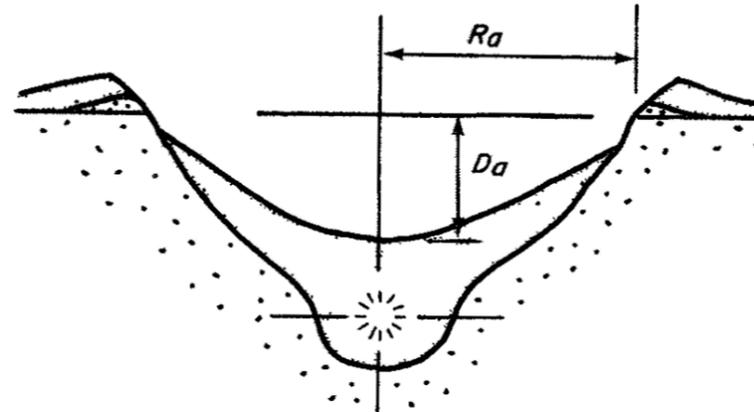
a. NEAR SURFACE BURST



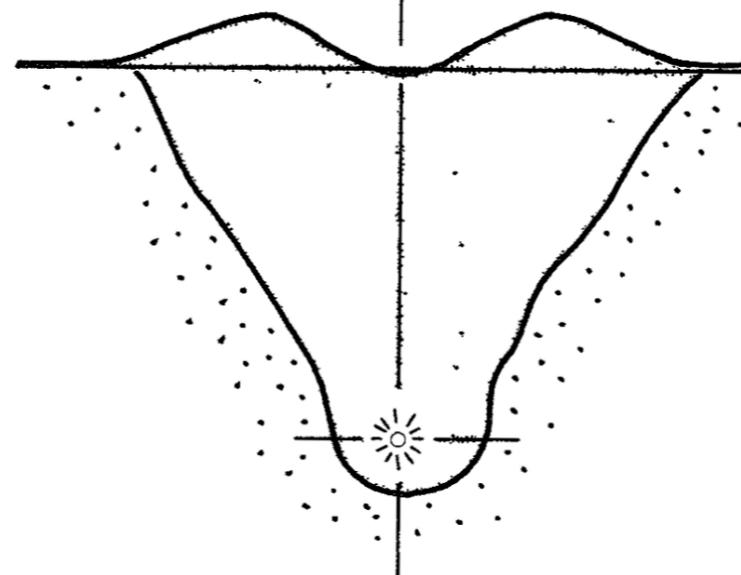
b. SURFACE BURST



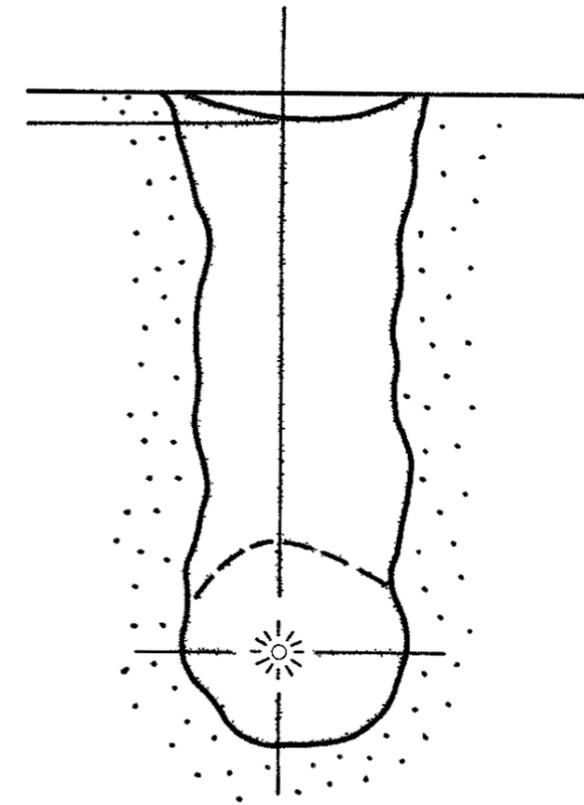
c. SHALLOW DOB



d. OPTIMUM DOB



e. DEEPLY BURIED



f. SUBSIDENCE CRATER

Underground Nuclear Explosions- Nevada Test Site



Total of 904 tests
at the Nevada test site

<http://www.nv.doe.gov/library/photos/craters.aspx>

Physics/Global Studies 280: Session 9

Plan for This Session

Announcements & Questions:

RPPv1 will be due tomorrow Wednesday 2-16 at 10pm and 2pm in class on Thursday (paper copy)

Office hours: today 3:30-6pm online (not in person in 428)

<https://illinois.zoom.us/j/3036810865?pwd=MTF3a0d0UkhnakdvVElyQit2RjAvdz09>

Meeting ID: 303 681 0865

Password: 557135

Module 3 continued: Effects of nuclear explosions

No Sunny Days For A Decade, Extreme Cold And Starvation: 'Nuclear Winter' And The Urgent Need For Public Education

Jamie Carter Senior Contributor ©

What would a “nuclear winter” be like? While there is no immediate sign of nuclear warheads being used in the Russia-Ukraine war, the risks of a nuclear exchange are surely at their highest for 40 years.

So why is there so little awareness of the potential consequences of the use of nuclear warheads? That's the question at the core of new research [published](#) today by the University of Cambridge's Centre for the Study of Existential Risk (CSER). It's based on a survey last month of 3,000 people in the US and UK that was designed to discover how much is known about “nuclear winter.”

It reveals a lack of awareness among US and UK populations of what a “nuclear winter” would entail. **Just 3.2% in the UK and 7.5% in the US said they had heard of “nuclear winter” in contemporary media or culture.**

In short, we need another Carl Sagan, the late popular scientist who in the early 1980s famously warned the world about the effects of nuclear war.

“There is an urgent need for public education within all nuclear-armed states that is informed by the latest research,” said Paul Ingram, CSER senior research associate. “We need to collectively reduce the temptation that leaders of nuclear-armed states might have to threaten or even use such weapons in support of military operations.”

No Sunny Days For A Decade, Extreme Cold And Starvation: 'Nuclear Winter' And The Urgent Need For Public Education

Jamie Carter Senior Contributor ©

A “**nuclear winter**” would be the result of a chain reaction that would go something like this:

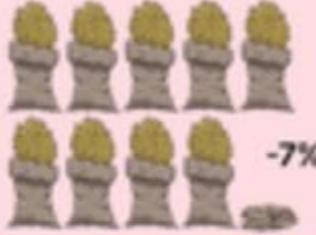
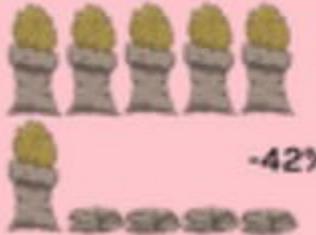
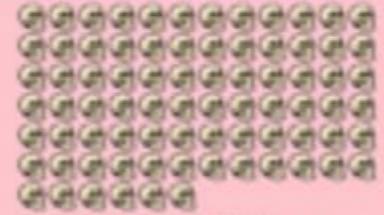
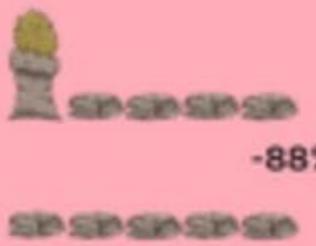
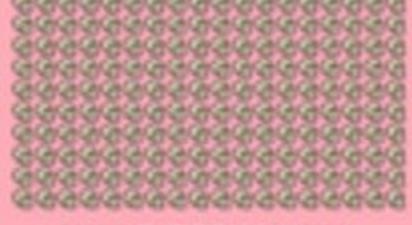
- Nuclear warheads striking cities would cause firestorms and send huge amounts of soot into the stratosphere.
- That soot would block out much of the Sun for up to a decade.
- Temperatures would drop around the world, leaving many places sub-zero.
- Mass crop failure. International trade in food suspended.
- Mass starvation of hundreds of millions of people in countries remote from the conflict.
- Soil and water close to where nuclear weapons were used would be contaminated.

A paper [published](#) in August 2022 in *Nature Food* modeling the amount of soot injected into Earth's atmosphere after the detonation of nuclear weapons predicted that more than five billion people could die from a war between the U.S. and Russia. The authors suggested that while the use of relatively few nuclear weapons may have a small global impact, “once a nuclear war starts, it may be very difficult to limit escalation.”

No Sunny Days For A Decade, Extreme Cold And Starvation: 'Nuclear Winter' And The Urgent Need For Public Education

Jamie Carter Senior Contributor ©

[Opinion Poll Survey: Public awareness of 'nuclear winter' is too low given current risks \(cser.ac.uk\)](https://www.cser.ac.uk)

Size of Nuclear War	Direct Fatalities	Ash & Soot in Atmosphere	Falling global Temperatures	Global Crop Failure	Additional Deaths from starvation
Limited war involving 100 smaller (15kT) nukes	 27 Million	5 MT 	 -1.3°C	 -7%	 225 Million
Limited war involving 250 larger (100kT) nukes	 127 Million	37 MT 	 -5.5°C	 -42%	 2,240 Million
Total nuclear war	 400 Million	150 MT 	 -12°C	 -88%	 over 5,000 Million

Lecture Question

In your opinion, can an underground nuclear weapon test be carried out undetected?

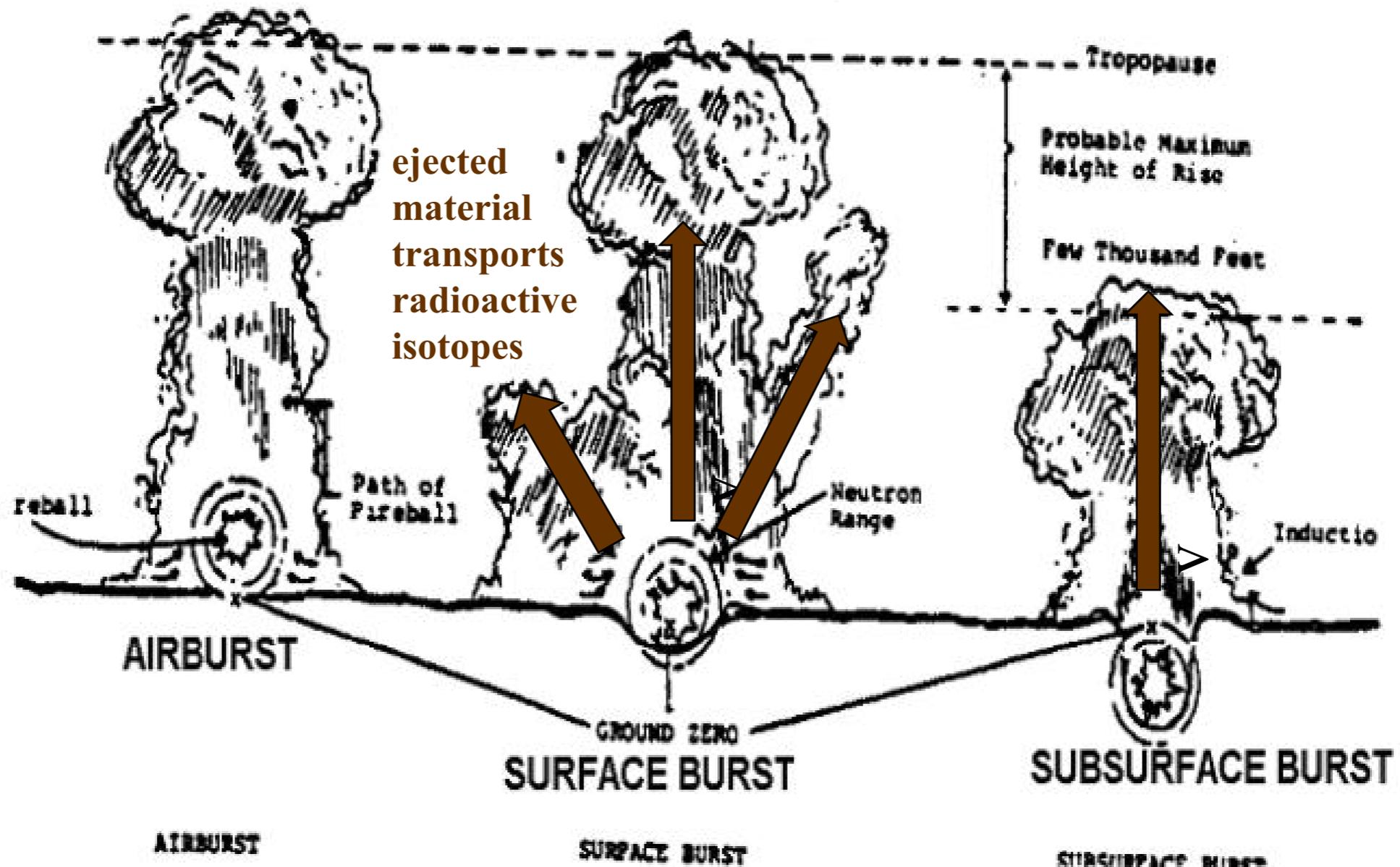
- (A) Yes, if tested at sufficient depth.
- (B) No, radioactive noble gases escape and can be detected.
- (C) No, seismic waves caused by the explosion can be detected.
- (D) No, sound waves from the explosion travel long distances through earth's crust and can be detected.

Lecture Question Answer

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Nuclear Explosions in the Atmosphere or a Small Distance Underground



The amount of radioactive fallout is increased greatly if the fireball touches the ground.

Will the Fireball Touch the Ground?

The HOB needed to prevent the fireball from touching the ground increases much more slowly than the yield—a 6x increase in HOB compensates for a 100x increase in Y.

Examples —

- $Y = 10 \text{ kt}$
Fireball touches ground unless $\text{HOB} > 500 \text{ ft}$
- $Y = 100 \text{ kt}$
Fireball touches ground unless $\text{HOB} > 1200 \text{ ft}$
- $Y = 1 \text{ Mt}$
Fireball touches ground unless $\text{HOB} > 3000 \text{ ft}$

Air and Surface Bursts

Sequence of events —

- Fireball forms and rapidly expands

Example: 1 Mt explosion

Time	Diameter	Temperature
1 ms ($= 10^{-3}$ s)	440 ft	—
10 s	5,700 ft	6,000 C

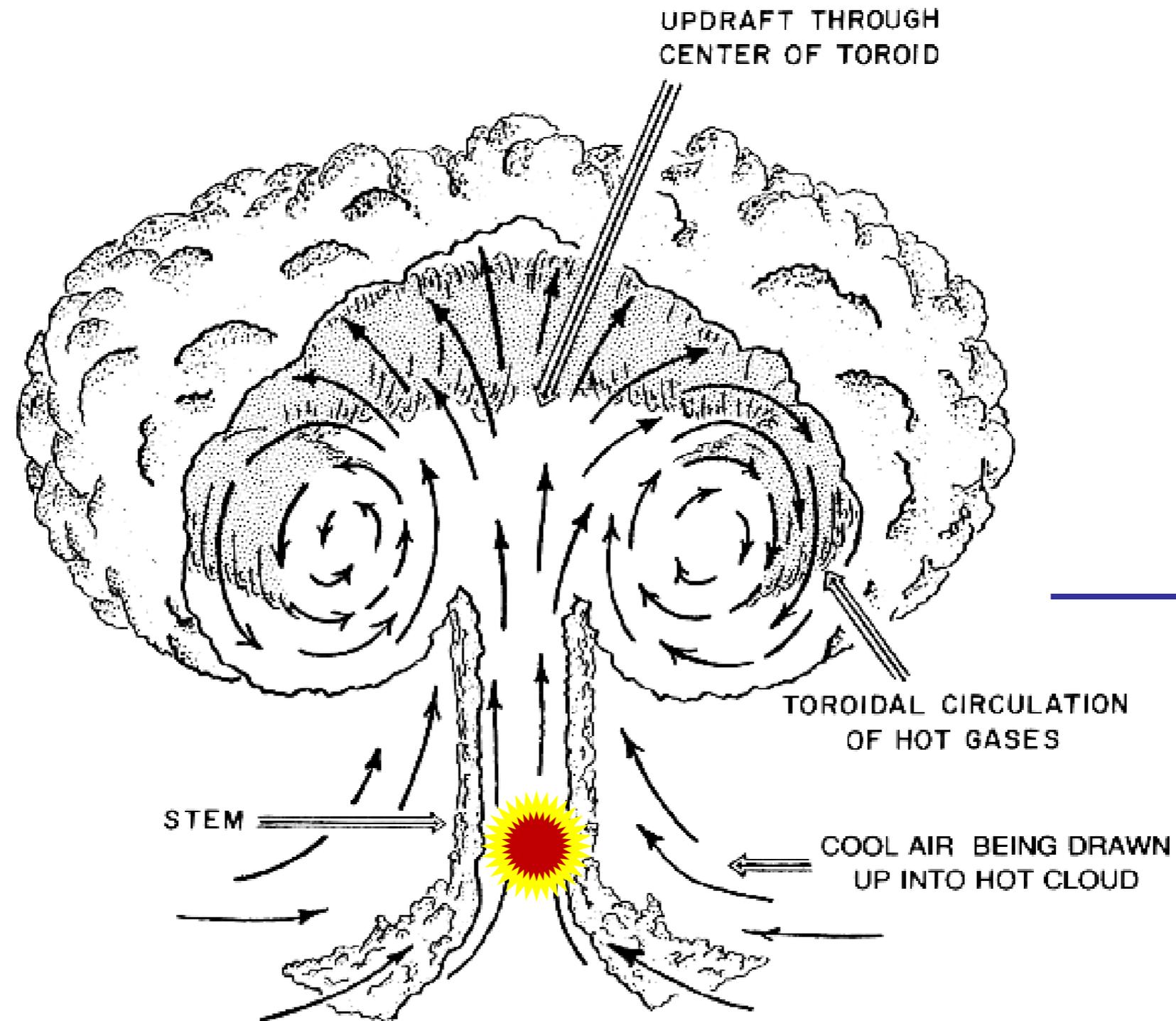
- Blast wave forms and outruns fireball
- Fireball rises and spreads, forming characteristic mushroom cloud

Formation of the Mushroom Cloud



- A fireball forms and rises through the troposphere, sucking surrounding air inward and upward
- The moving air carries dirt and debris upward, forming the stem
- The fireball slows and spreads once it reaches the stratosphere

Formation of the Mushroom Cloud



Fireball

Stratosphere

Troposphere

Radioactive Fallout from a Nuclear Burst



- Vaporized weapon debris is highly radioactive
- If the fireball touches the ground, rock and earth are also vaporized and become highly radioactive
- The radioactive vapor and particles are carried aloft as the fireball rises and spreads
- Radioactive vapor condenses on the particles in the mushroom cloud
- The cloud (“plume”) is carried downwind
- Large particles “rain out” near ground zero
- Smaller particles are carried much further

Final Distribution of the Energy of a Large Air Burst (Important)

The *final* distribution of the energy of a large (~ 1 Mt) explosion, in order of appearance —

- Prompt neutrino radiation (not counted in the yield) $\sim 5\%$
- Prompt nuclear radiation $\sim 5\%$
- Electromagnetic pulse $\ll 1\%$
- Thermal radiation $\sim 35\%$
- Blast $\sim 50\%$
- Residual nuclear radiation $\sim 10\%$

Short-Term Physical Effects of a 1 Mt Burst

- Prompt nuclear radiation (lasts $\sim 10^{-3}$ s)
 - Principally γ , β and neutron radiation
 - Intense, but of limited range
- Electromagnetic pulse (peak at $< 10^{-6}$ s)
- Thermal radiation (lasts ~ 10 s)
 - X-ray and UV pulses come first
 - Heat pulse follows
- Blast (arrives after seconds, lasts < 1 s)
 - Shockwave = compression followed by high winds
 - 5 psi overpressure, 160 mph winds @ 4 mi
- Residual nuclear radiation (lasts minutes–years)
 - Principally γ and β radiation

Long-Term Physical Effects

- **Fallout**
 - From material sucked into fireball, mixed with weapon debris, irradiated, and dispersed
 - From dispersal of material from nuclear reactor fuel rods
- **Ozone depletion (Mt bursts only)**
 - Caused by nitrogen oxides lofted into the stratosphere
 - Could increase UV flux at the surface by $\sim 2x$ to $\sim 100x$
- **Soot injected into the atmosphere cools Earth (“nuclear winter”)**
 - Caused by injection of dust, ash and soot into atmosphere

Lecture Question

Is there historic precedence for an explosion ejecting dust, ash and soot into the stratosphere cooling earth ?

- (A) Yes, following the nuclear attacks on Hiroshima and Nagasaki
- (B) Yes, following the nuclear weapon tests in the 60s
- (C) No, at any given time the yield of historic explosions was insufficient to transport very large amounts of dust and soot into the stratosphere.
- (D) Yes, following the eruption of the Laki fissure system on Iceland in 1783.
- (E) No, Vulcano eruptions cannot propel ash into the stratosphere.

Lecture Question Answer

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Nuclear Weapon Effects

Effects of Thermal Radiation

Thermal Radiation from the Fireball

- The fireball—like any hot object—emits electromagnetic radiation over a wide range of energies
 - Initially most is at X-ray energies
 - But the atmosphere is opaque to X-rays
 - Absorption of the X-rays ionizes (and heats) the air
 - The fireball expands rapidly and then cools
- Radiation of lower energy streams outward from surface of the fireball at the speed of light
 - Atmosphere is transparent for much of this
 - Energy cascades down to lower and lower energies
 - » Ultraviolet (UV) radiation
 - » Visible light
 - » Infrared (IR) radiation



1 Mt at 10s
Diameter ~ 1 mile
T ~ 6000 °C (sun surface)

Effects of Thermal Radiation – 1

The seriousness of burn injuries depends on —

- The total energy released (the yield Y)
- Transparency of the atmosphere (clear or fog, etc.)
- The *slant* distance to the center of the burst
- Whether a person is indoors or out, what type of clothing one is wearing, etc.

Effects of Thermal Radiation – 2

Duration and intensity of the thermal pulse —

- 1 s for 10 kt ; 10 s for 1 Mt
- In a transparent atmosphere, the heat flux at a distant point scales as $1/D^2$ where D is the slant range
- In a real atmosphere, absorption and scattering by clouds and aerosols (dust particles) cause a steeper fall-off with D ; given by the “transmission factor” T :
 $T = 60\text{--}70\% @ D = 5 \text{ miles on a “clear” day/night}$
 $T = 5\text{--}10\% @ D = 40 \text{ miles on a “clear” day/night}$
- Atmosphere transmission is as complicated and as variable as the weather

Effects of Thermal Radiation – 3

Typical characteristics —

- Thermal effects are felt before the blast wave arrives
- For $Y < 10$ kt, direct effects of thermal radiation are lethal only where blast is already lethal
- For $Y > 10$ kt, direct effects of thermal radiation are lethal well beyond where blast is lethal
- Direct effects of thermal radiation are greatly reduced by shielding
- Indirect effects of thermal radiation (fires, explosions, etc.) are difficult to predict
- Interaction of thermal radiation and blast wave effects can be important

Effects of Thermal Radiation – 4

Some harmful direct effects —

- Flash blindness (temporary)
- Retinal burns (permanent)
 - Approximately 13 mi on a clear day
 - Approximately 53 mi on a clear night
- Skin burns
- Ignition of clothing, structures, surroundings

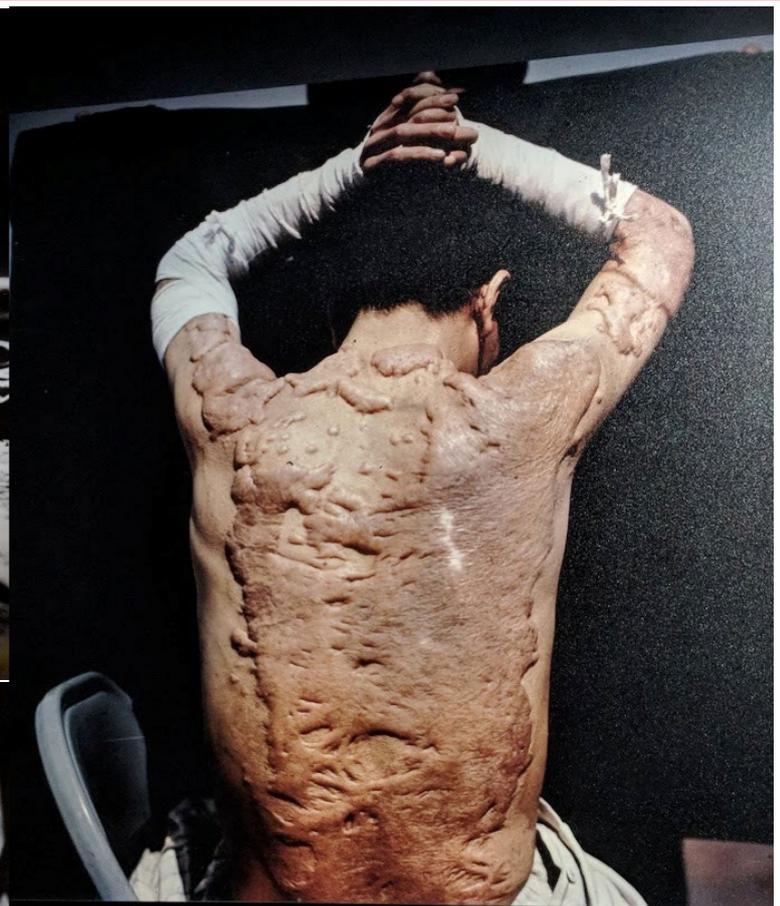
Types of burns —

- Direct (flash) burns: caused by fireball radiation
- Indirect (contact, flame, or hot gas) burns: caused by fires ignited by thermal radiation and blast

Effects of Thermal Radiation – 5



Examples of Flash Burns Suffered at Hiroshima



Keloids resulting from burns

Burns depend on distance and protection available

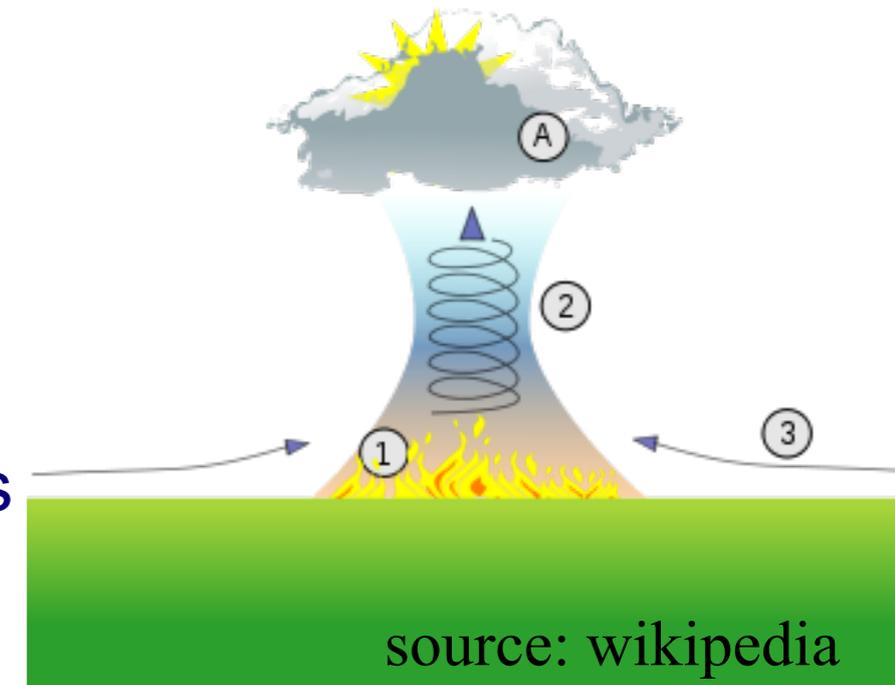
Conflagrations Versus Firestorms

Conflagration —

- Fire spreads outward from the ignition point
- Fire dies out where fuel has been consumed
- The result is an outward-moving ring of fire surrounding a burned-out region

Firestorm —

- Occurs when fires are started over a sizable area and fuel is plentiful in and surrounding the area
- The central fire becomes very intense, creating a strong updraft; air at ground level rushes inward
- The in-rushing air generates hurricane-force winds that suck fuel and people into the burning region
- Temperatures at ground level exceed the boiling point of water and the heat is fatal to biological life



Conflagrations Versus Firestorms



Hamburg after firestorm in July 1943
similar in Dresden, Tokyo and possibly in Hiroshima

Conflagrations Versus Firestorms



Tokyo after fire bombing in March 1945

Effects of Nuclear Explosions

Effects of Blast Waves

Damaging Effects of a Blast Wave

- The blast wave is considered the militarily most significant effect of a nuclear explosion in the atmosphere
- Like any shockwave, a blast wave produces —
 - A sudden isotropic (same in all directions) pressure P that compresses structures and victims

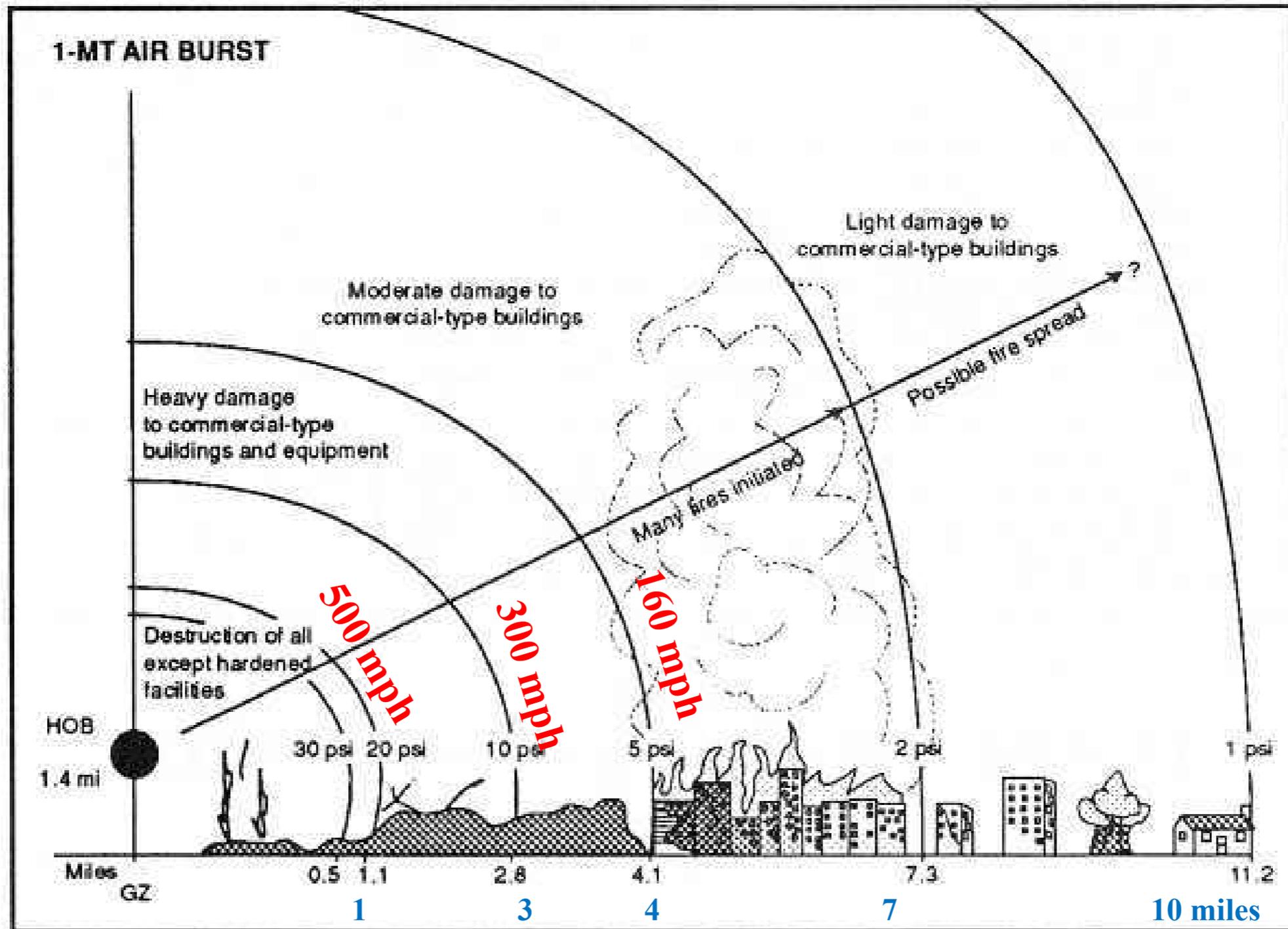
This is followed by

- A strong outward wind that produces dynamic pressure that blows structures and victims outward
- The two pressures are directly related; both are usually given in psi = pounds per square inch

Blast Wave Pressures and Winds

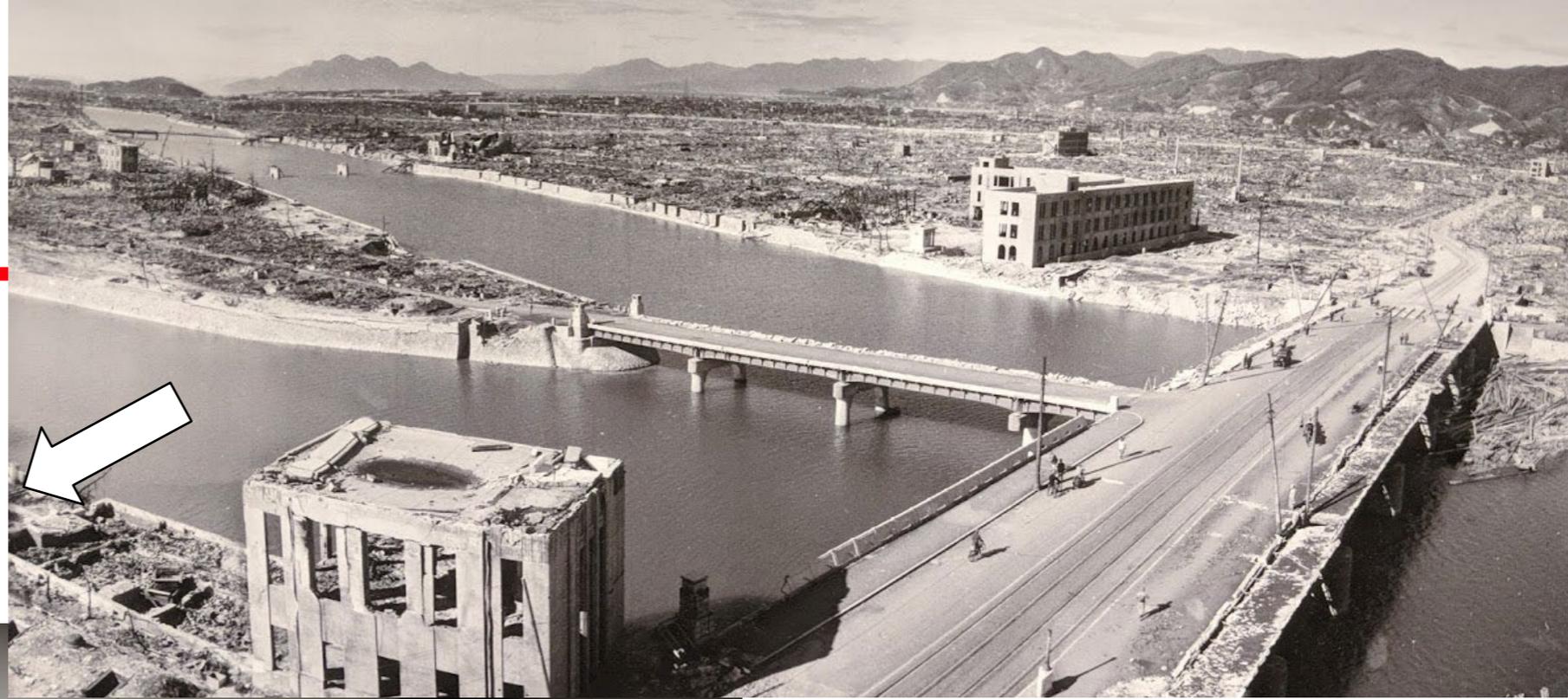
Pressure (psi)	Dynamic Pressure (psi)	Wind (mph)
200	330	2,078
150	222	1,777
100	123	1,415
50	41	934
20	8	502
10	2	294
5	1	163

Damaging Effects of a Blast Wave



Damage in Hiroshima

Atomic Dome
near
Ground Zero

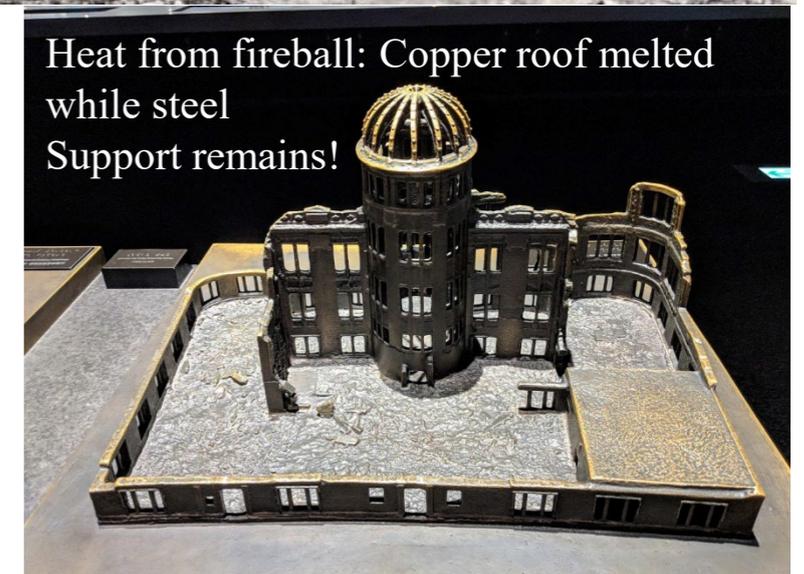
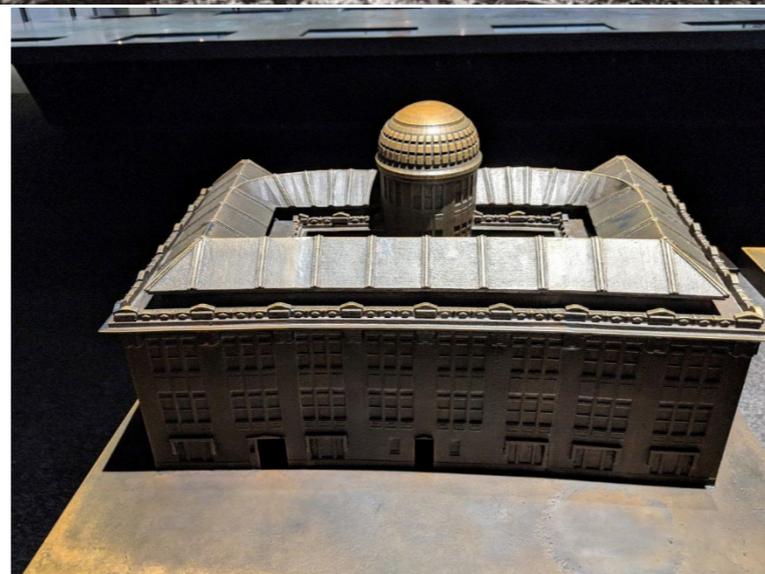


T-shaped bridge was
used for targeting

Damage in Hiroshima: HOB ~ 2000 ft above Atomic Dome



Hiroshima Prefectural Industrial Promotion Hall



Hiroshima Peace Memorial

Effects of Shallow Underground Nuclear Explosions

Effects of the Sedan Event (1962)

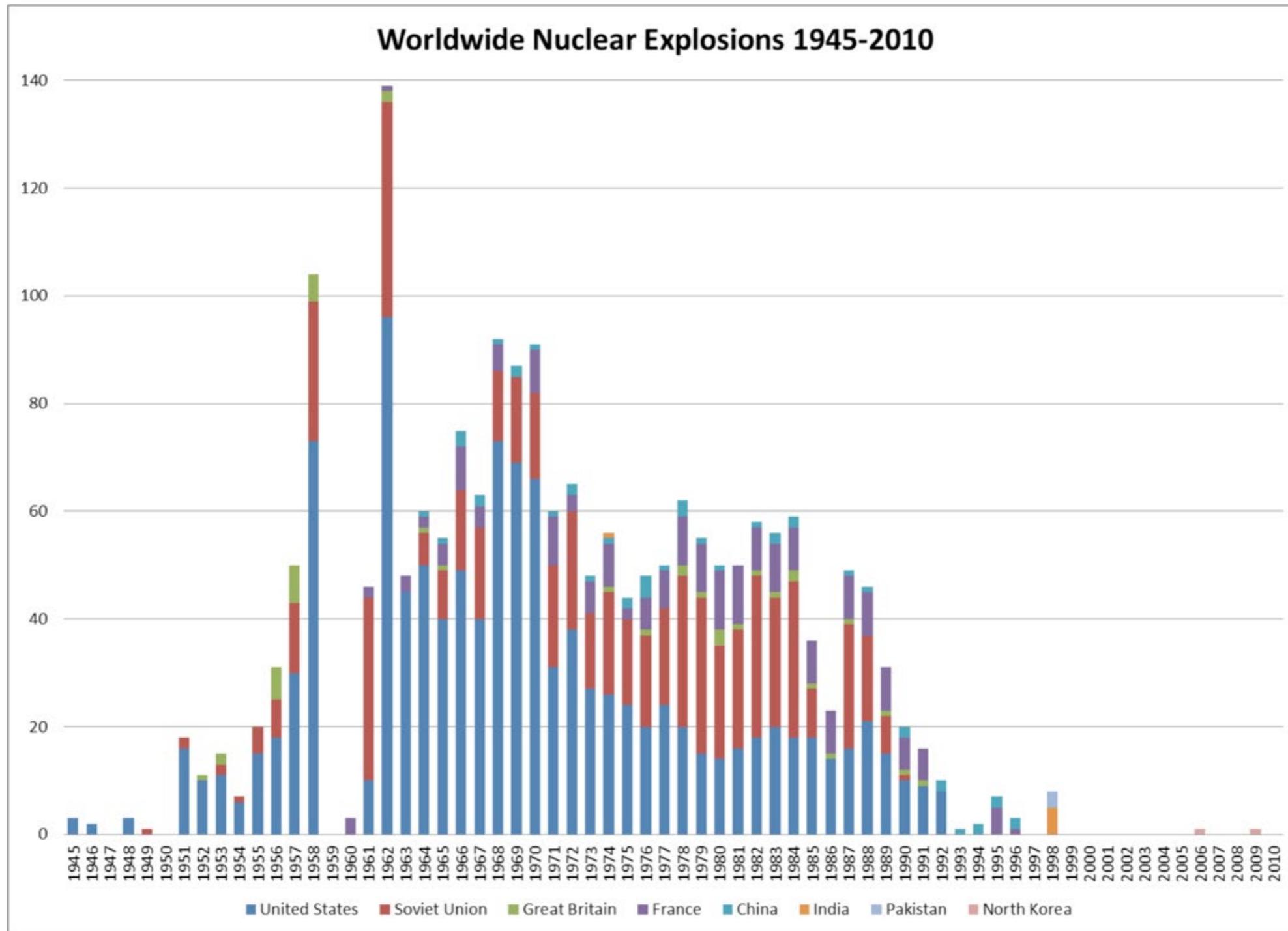
- Explosive yield: 100 kt
- Depth of burial: 635 feet
- Crater radius: 610 feet
- Crater depth: 320 feet
- Earth displaced: 12 million tons

Effects of Shallow Underground Nuclear Explosions

Example: The Sedan Test (100 kt, 1962)

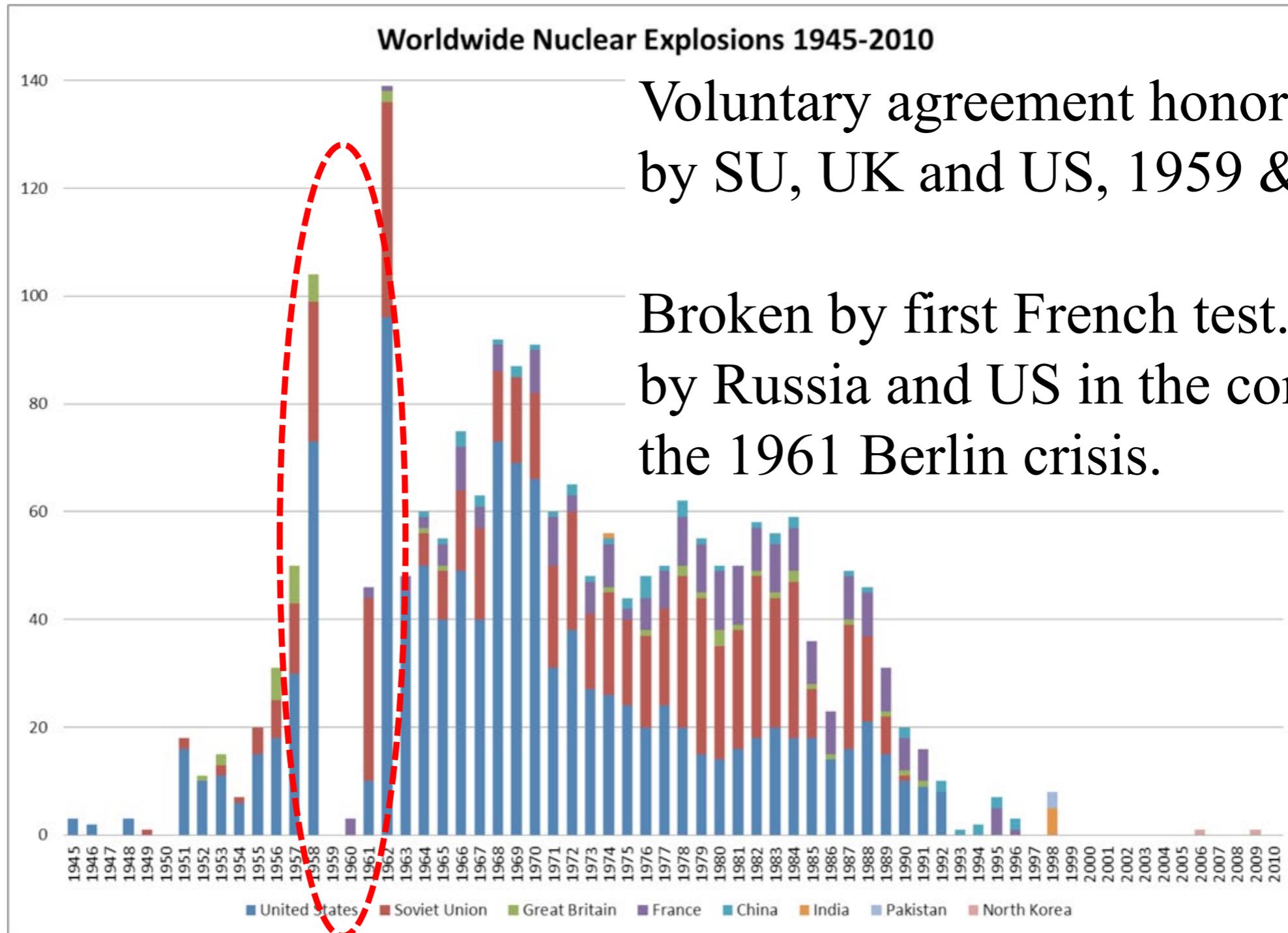


Effects of Nuclear Explosions



Credit: Wikipedia Commons

Test Moratorium 1959-1960



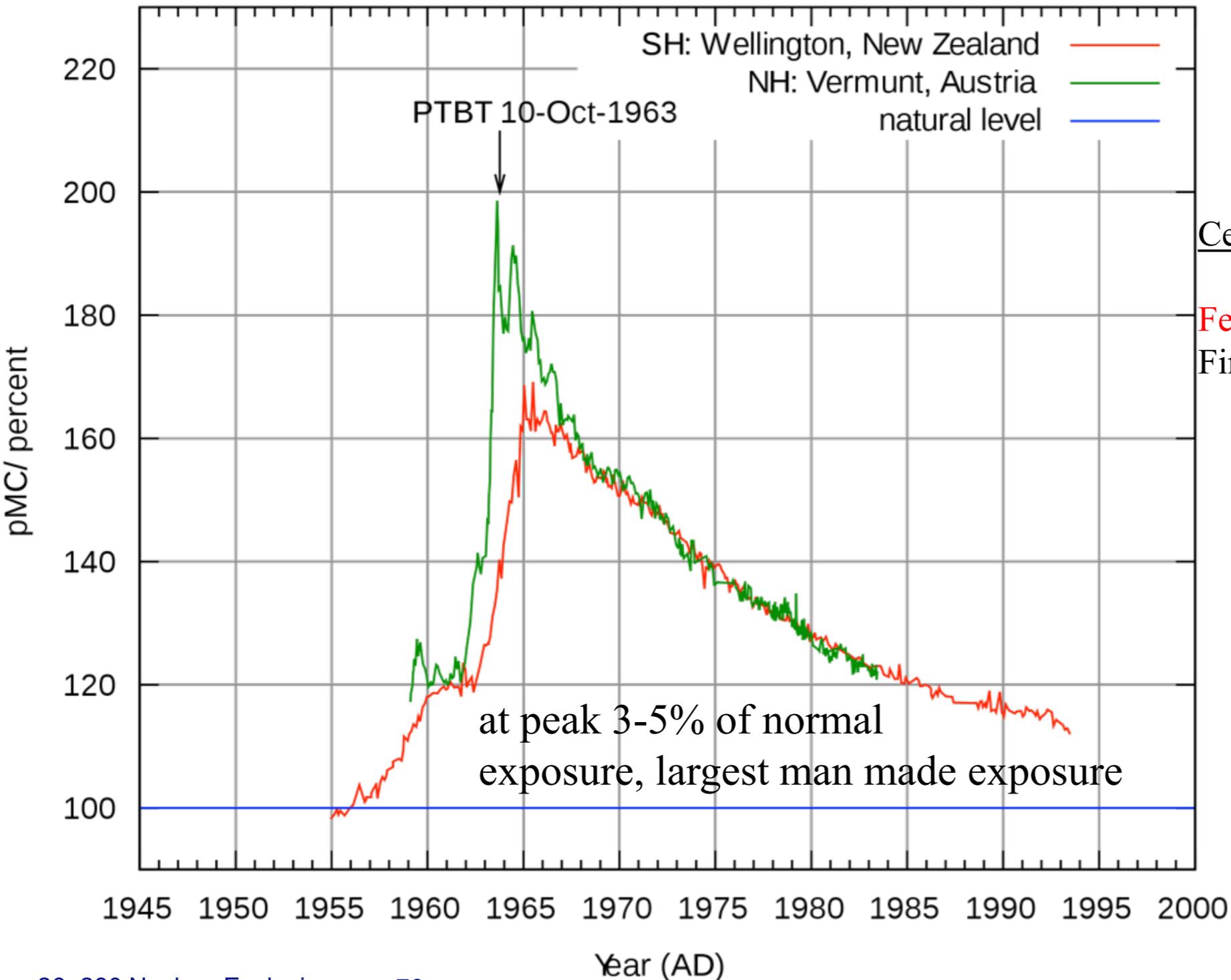
Voluntary agreement honored by SU, UK and US, 1959 & 1960

Broken by first French test. Broken by Russia and US in the context of the 1961 Berlin crisis.

Credit: Wikipedia Commons

Effects of Nuclear Explosions

$^{14}\text{C}/^{12}\text{C}$ in atmospheric CO_2 . Source: Hakanomono (Wikipedia)



Centers for Disease Control and Prevention:

Feasibility Study of Weapons Test Fall Out
Final report from April 2005

~ additional 11,000 cancer deaths
among US population alive in the
years from 1951 to 2000.

<http://www.cdc.gov/nceh/radiation/fallout/default.htm>

Fallout Radiation from a 1 Mt Burst

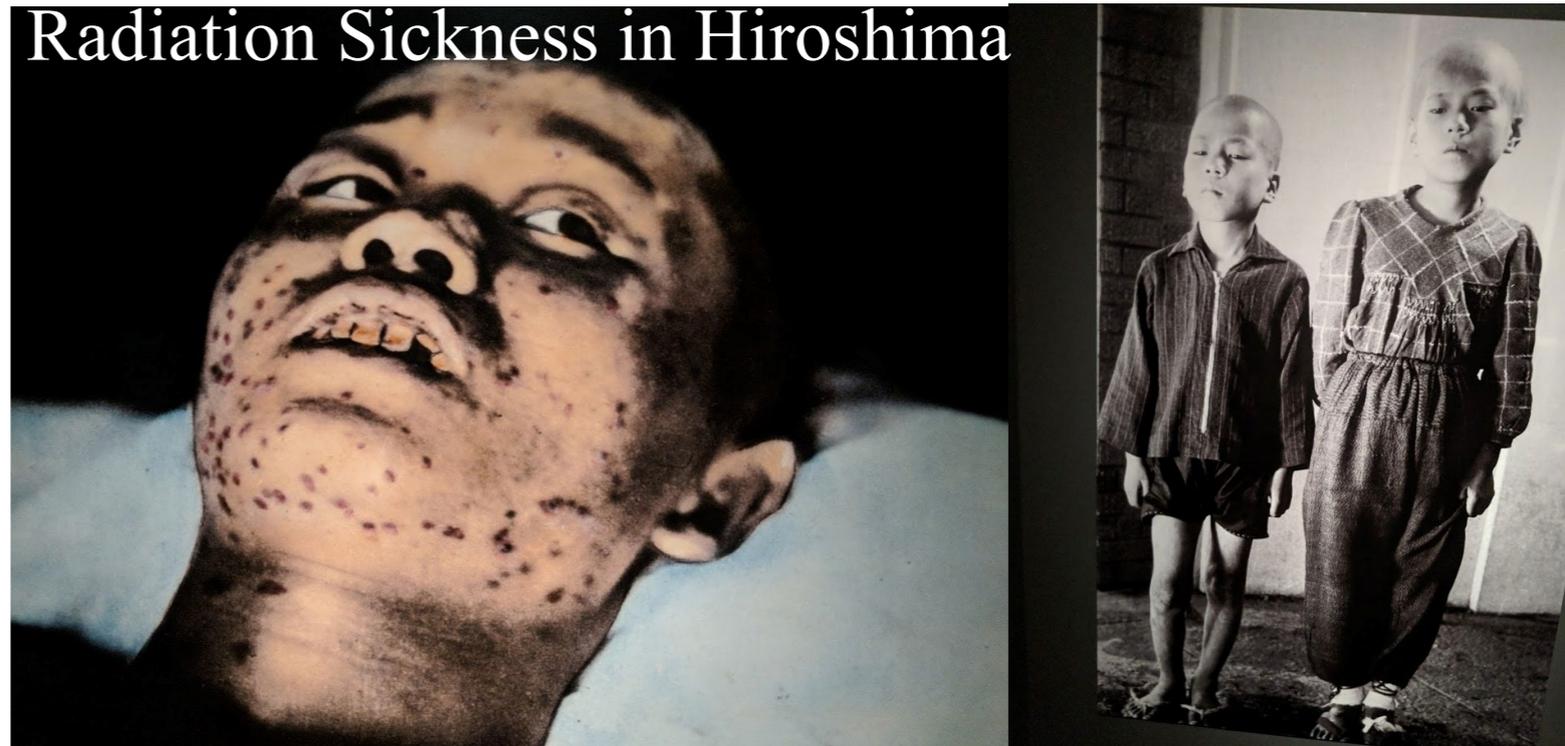
Assume —

- Surface burst
- Wind speed of 15 mph
- Time period of 7 days

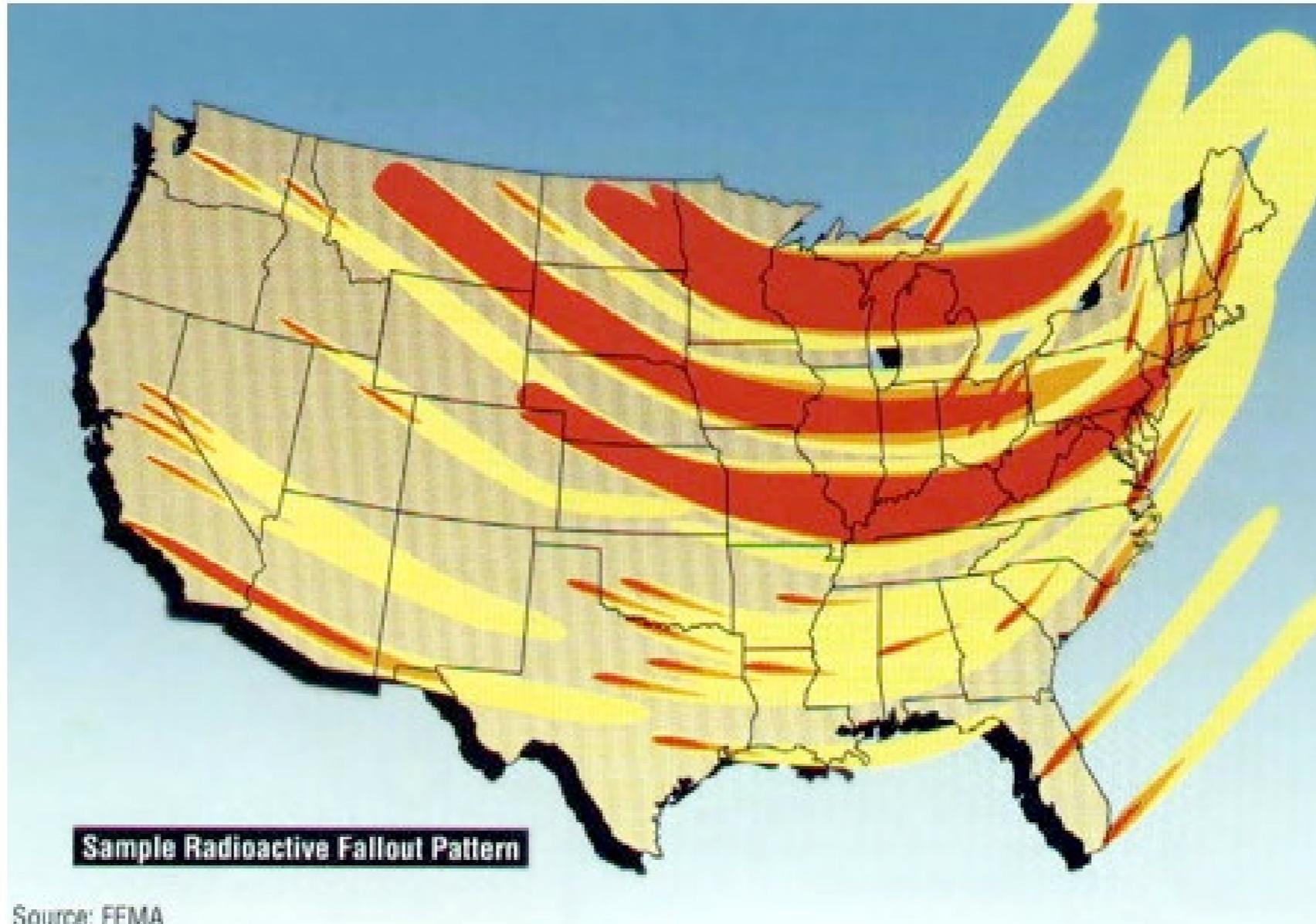
Distances and doses —

- 30 miles: 3,000 rem (death within hours; more than 10 years before habitable)
- 90 miles 900 rem (death in 2 to 14 days)
- 160 miles: 300 rem (severe radiation sickness)
- 250 miles: 90 rem (significantly increased cancer risk; 2 to 3 years before habitable)

Radiation Sickness in Hiroshima

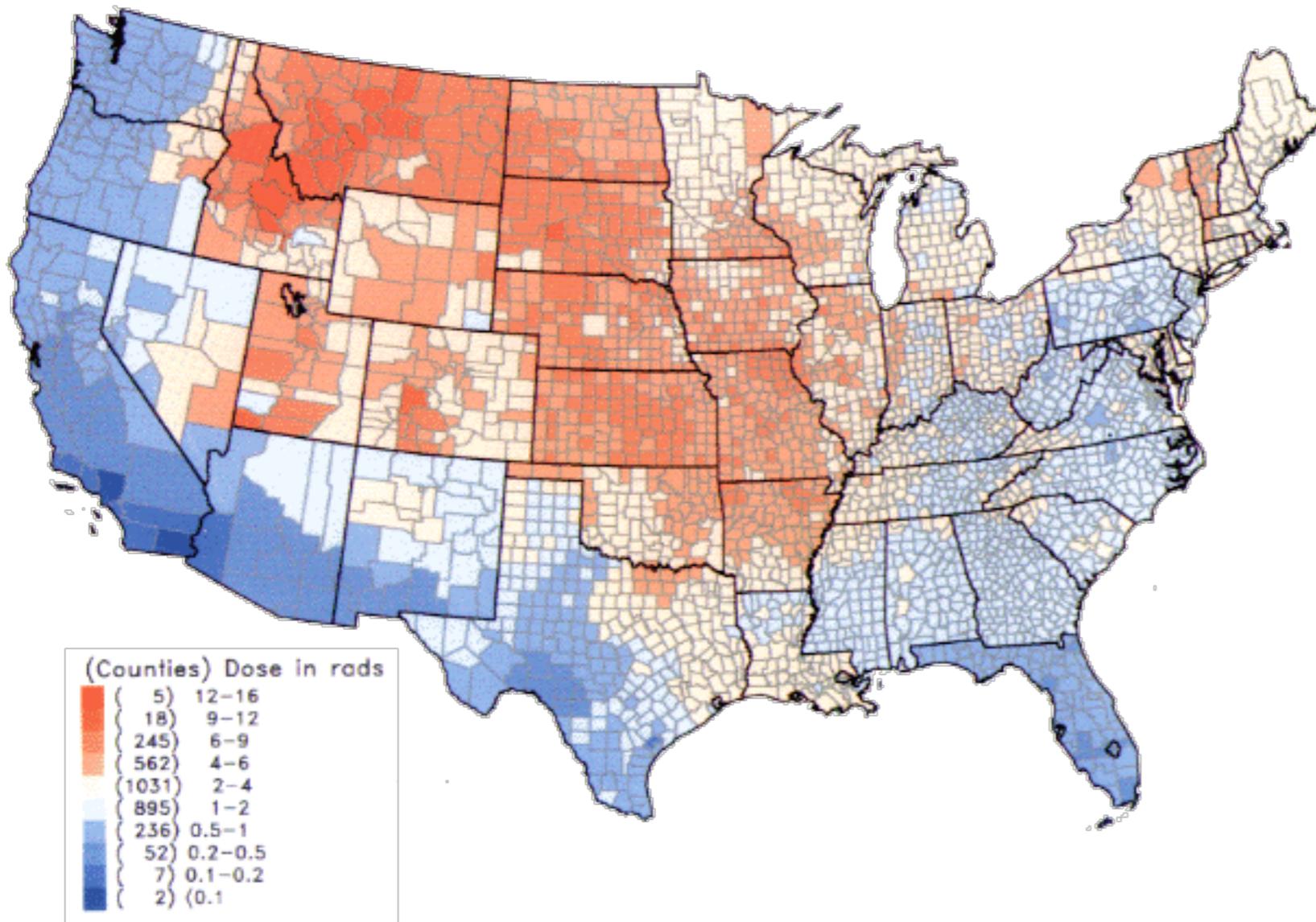


Effects of Nuclear Explosions



Map of nuclear fallout distribution after a potential nuclear attack on the United States. Source: FEMA

Per Capita Thyroid Doses from 1951-1962 Nuclear Testing at the Nevada Test Site



Centers for Disease Control,
Feasibility Study of Weapons Test
Fall Out:

“For example, the population of 3.8 million people born in the United States in 1951 will likely experience fewer than 1,000 extra fatal cancers as a result of fallout exposures, a lifetime risk of less than 0.03% or about 1 in 3800. This number may be compared with the approximately 760,000 fatal cancers that would be predicted in the absence of fallout.

It is expected that the largest number of excess cancer deaths would occur in the group of people born in 1951, because, on average, this group received higher doses at younger ages than groups born earlier or later.”

Physics/Global Studies 280: Session 10

Plan for This Session

Announcements & Questions:

Research Paper: the two members of an expert team can choose different topics!

Module 3 continued: Effects of nuclear explosions

Lecture Question

Which of the following effects of a Megaton explosion would be felt **first** 5 miles away?

- (A) Blast
- (B) Thermal radiation
- (C) Electromagnetic pulse
- (D) Residual nuclear radiation (“fallout”)

Lecture Question Answer

Which of the following effects of a Megaton explosion would be felt **first** 5 miles away?

- (A) Blast
- (B) Thermal radiation
- (C) Electromagnetic pulse
- (D) Residual nuclear radiation (“fallout”)

Lecture Question

Which of the following effects of a Megaton explosion would be felt **last** 5 miles away?

- (A) Blast
- (B) Thermal radiation
- (C) Electromagnetic pulse
- (D) Residual nuclear radiation (“fallout”)

Lecture Question Answer

Which of the following effects of a Megaton explosion would be felt **last** 5 miles away?

- (A) Blast
- (B) Thermal radiation
- (C) Electromagnetic pulse
- (D) Residual nuclear radiation (“fallout”)

Lecture Question

Nuclear Weapon Effects

Which effect listed below carries the largest fraction of the total energy of a Megaton nuclear explosion?

- (A) Prompt nuclear radiation
- (B) Electromagnetic pulse
- (C) Thermal radiation
- (D) Blast
- (E) Residual nuclear radiation (“fallout”)

Lecture Question Answer

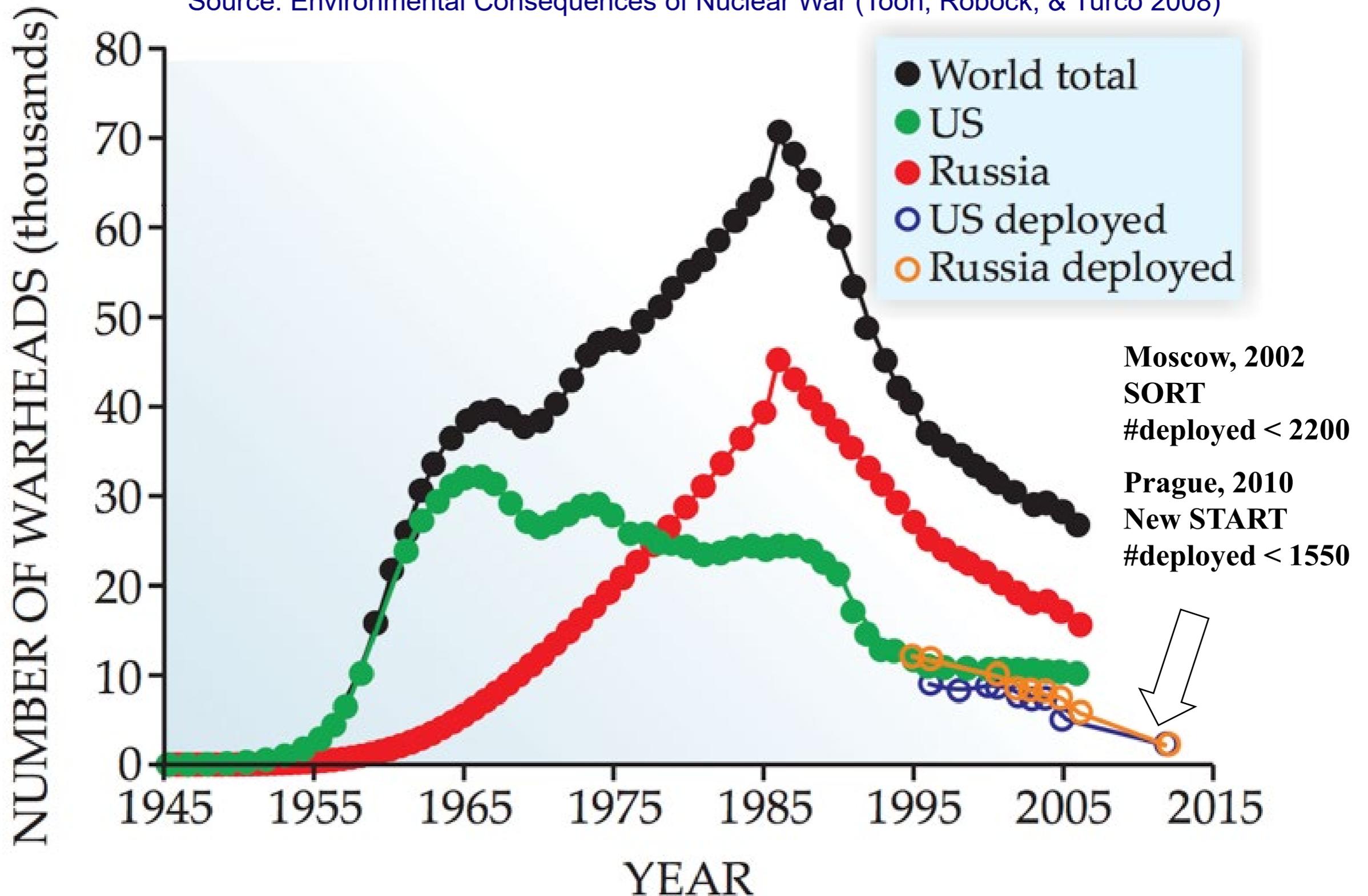
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- (D) Blast**
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Effects of Nuclear War – Input to War Scenarios for Illustration

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)



Effects of Nuclear War: Direct Causalities

For Illustration assume

War fought with 100kT Nuclear Weapons

1,000 weapons detonated on the United States would *immediately* —

- kill 60 million people (20% of the total population)
- injure an additional 40 million people (16% of the total population)

1,000 weapons detonated on Russia would *immediately* —

- kill 50 million people (30% of the total population)
- injure an additional 20 million people (20% of the total population)

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)

Physics/Global Studies 280: Session 10

Plan for This Session

RPPv1 is due today

News

Nuclear Explosions Conclusion: “Nuclear Winter”

“Ground Zero” Video presentation



FOREIGN AFFAIRS

America Needs to Reassure Japan and South Korea

How to Shore Up Washington's Eroding Credibility in Asia

BY KATRIN FRASER KATZ, CHRISTOPHER JOHNSTONE, AND VICTOR CHA
February 9, 2023

KATRIN FRASER KATZ is a Fellow at the Center for Strategic and International Studies and a Scholar in Residence at the University of Miami. From 2007 to 2008, she served as Director for Japan, Korea, and Oceanic Affairs at the National Security Council.

CHRISTOPHER JOHNSTONE is Senior Adviser and Japan Chair at the Center for Strategic and International Studies. At the National Security Council, he served as Director for East Asia from 2021 to 2022 and Director for Japan and Oceanian Affairs from 2014 to 2016.

VICTOR CHA is Senior Vice President and Korea Chair at the Center for Strategic and International Studies and a Professor at Georgetown University. From 2004 to 2007, he was Director for Asian Affairs at the National Security Council.



News

Last month, South Korean President Yoon Suk-yeol warned that in the face of mounting North Korean provocations, South Korea might consider building its own nuclear weapons or asking the United States to deploy tactical nuclear weapons to the South, as it did during the Cold War.

...

Allied apprehension about U.S. security commitments may seem puzzling in light of the Biden administration's emphasis on shoring up U.S. alliances and the broad alignment of the Biden, Yoon, and Kishida administrations on North Korea and regional policies. **But even at the best of times, maintaining the credibility of external deterrence commitments is a challenge. Doing so requires convincing allies not just that the United States has the capabilities to deter and defend against potential attacks against them but that it also has the will to use those capabilities—even if that means putting U.S. cities at risk.**

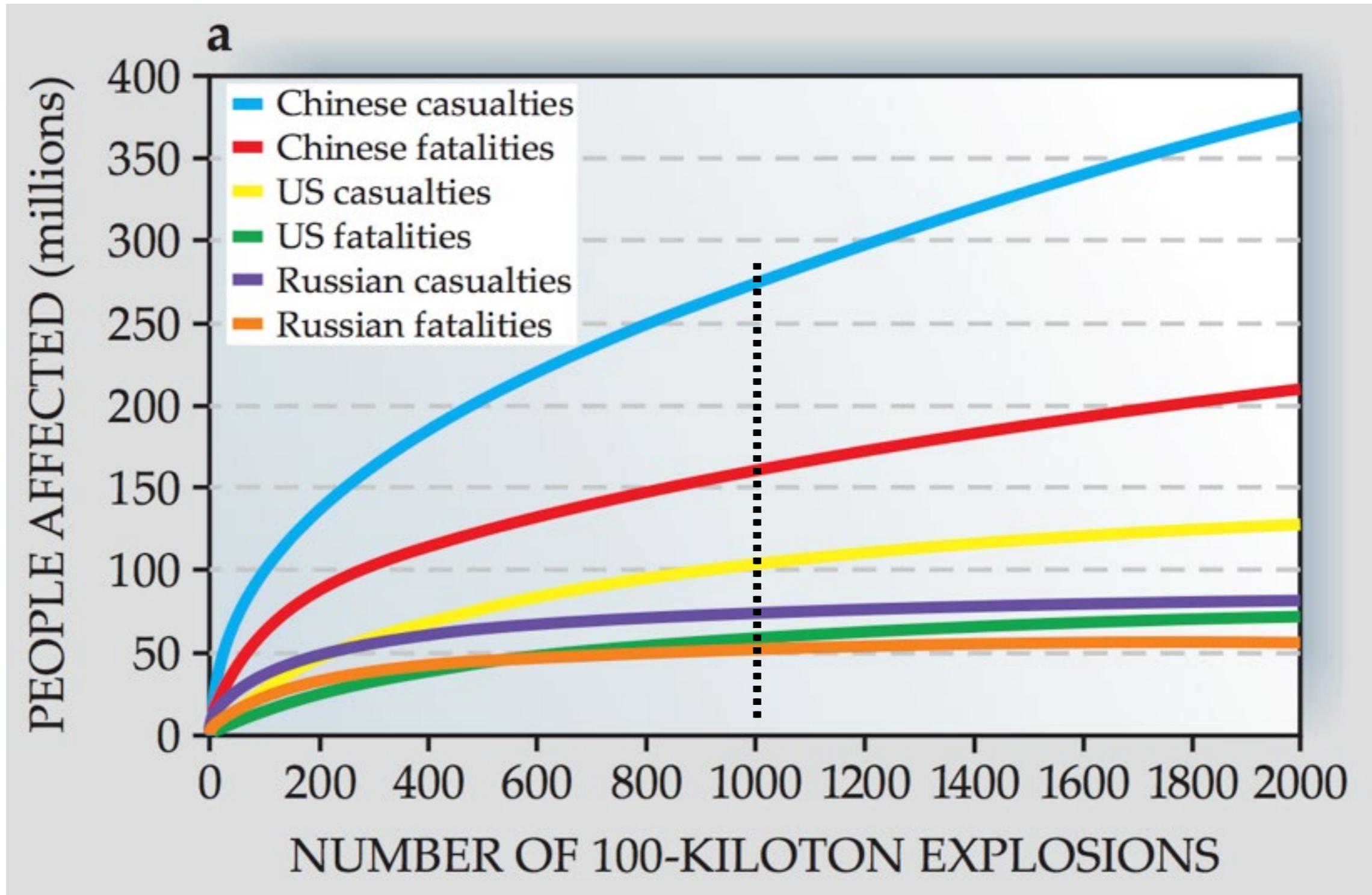
In recent years, however, the level of doubt among Japanese and South Korean officials has exceeded that normal baseline level. Rapidly intensifying threats—particularly from North Korea, China, and Russia—have created unique and urgent security challenges that Tokyo and Seoul worry the United States is **either unwilling or unable to address.** In 2022, for instance, **North Korea embarked on an unprecedented campaign of weapons development, testing over 90 cruise and ballistic missiles of various ranges**(one of which flew over Japan) and preparing for a nuclear test, which would be the seventh it has carried out since 2006.

China's sweeping military modernization is also fueling Japanese and South Korean security concerns.

After more than two decades of near double-digit growth in defense spending, including efforts to improve its missile capabilities and dramatically expand its nuclear arsenal, China is increasing its maritime and air activity near Japan, including making regular incursions into the territorial waters around the Senkaku Islands

Effects of Nuclear War: Direct Casualties

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)



Large Cities in China, Russia and the United States

Country	above 1 Million	100,000 - 1 Millions	10,000 to 100,000
China	59	354	385
Russia	12	203	1291
U.S.	10	285	3376

However, distribution of industrial capabilities is wider in the U.S.

Effects of Nuclear War: Two Scenarios for the Study of Longterm Environmental Effects

Nuclear War Models:

(I) U.S.-Russian (“SORT”) war:

2200 x 2 weapons of 100-kt each = 440 Mt total

(II) Regional nuclear war (eg. Pakistan – India):

50 weapons of 15-kt each = 0.75 Mt total

Weapons are assumed to be targeted on industry.

Effects of Nuclear War: Longterm Environmental Effects

SORT War ~ 4400 100 kT Warheads

A nuclear war between Russia and the USA could generate 200 Tg (200 million tons) of soot, sufficient to —

- Reduce average temperatures by ~14 Fahrenheit.
- Reduce precipitation by ~ 45%.
- Eliminate the growing season in large parts of Russia and nearby countries (eg. Ukraine).
- reduce the length of the growing season in the U.S. Midwest by ~75%.

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)

Effects of Nuclear War: Longterm Environmental Effects

Regional Conflict, India and Pakistan with ~ 100 15 kT Warheads

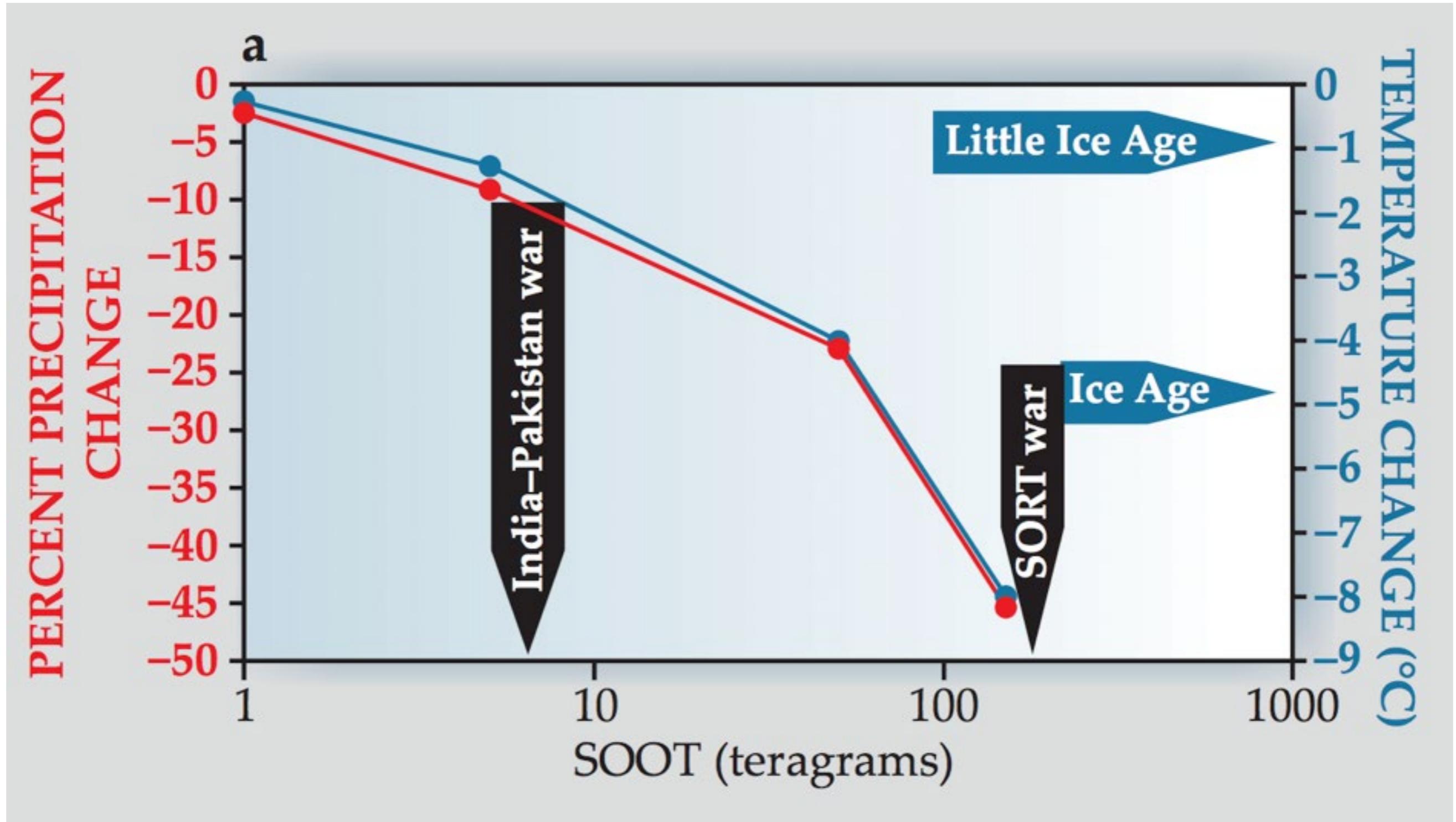
A regional war between India and Pakistan could generate 5 Tg of soot (5 million tons), sufficient to —

- produce the lowest temperatures for 1,000 years on the northern hemisphere, lower than the Little Ice Age or 1816 (“the year without a summer”)
- reduce precipitation in the Asian monsoon region by 40%
- reduce the length of the growing season in the U.S. Midwest by 10%.

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)

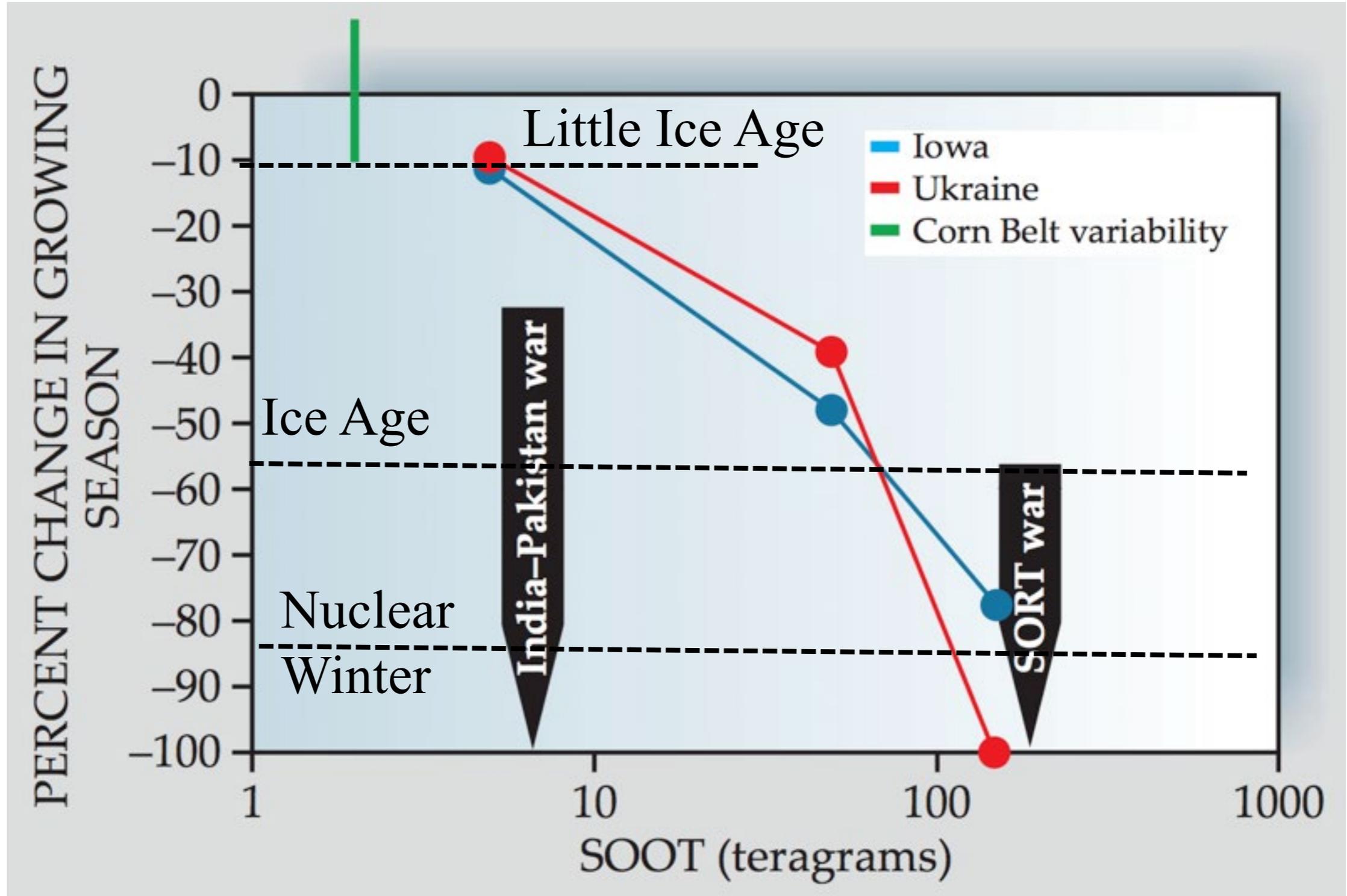
Effects of Nuclear War: Change in Precipitation and Temperature

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)



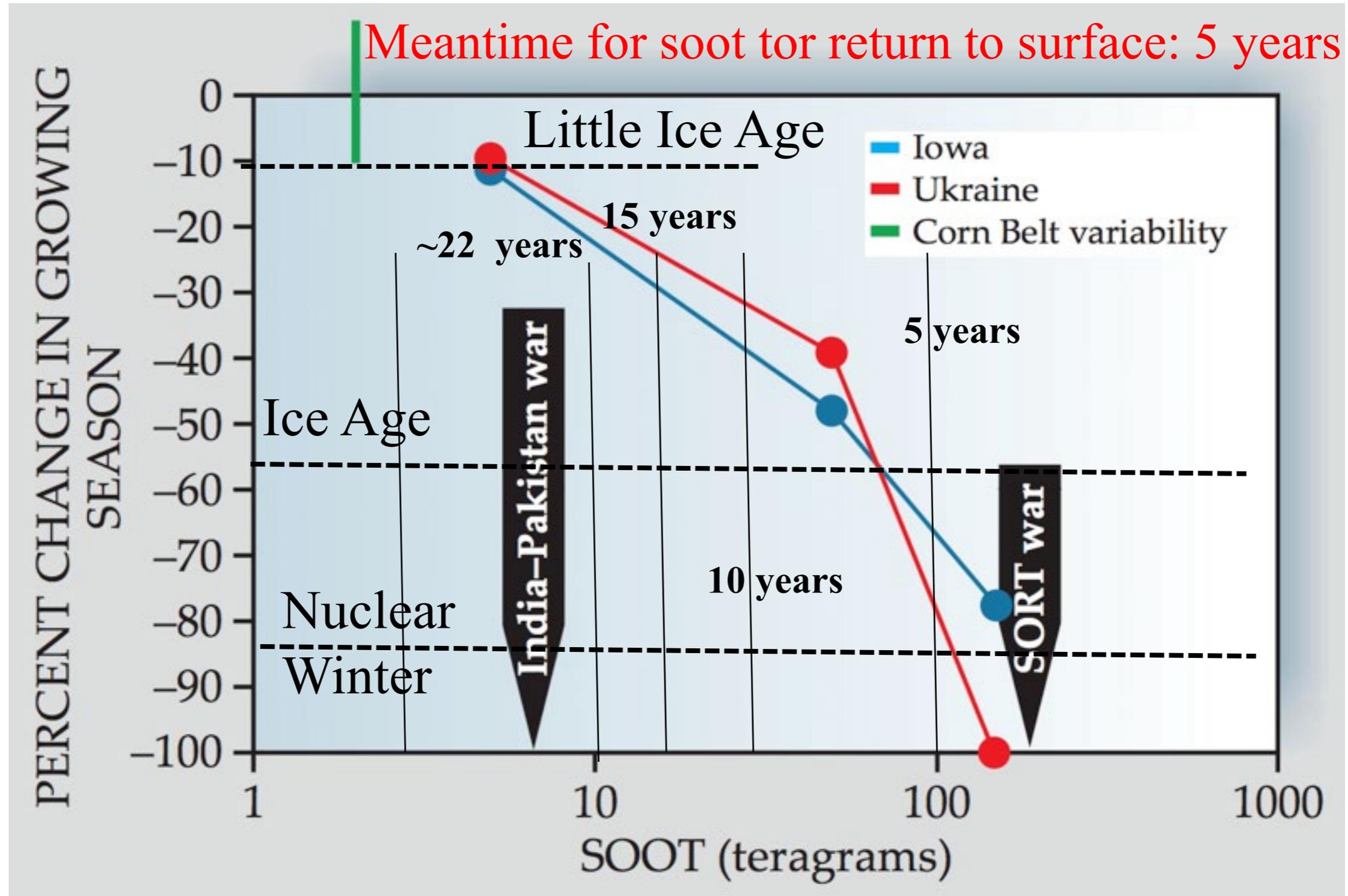
Effects of Nuclear War: Percent Change in Growing Season

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)



How Long from Nuclear Winter to Little Ice Age?

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)



Effects of Nuclear War

Indirect Effects Would Be the Most Important

– *“Environmental Consequences of Nuclear War”*

(Owen Toon, Alan Robock, & Richard Turco, *Physics Today*, December 2008)

“What can be said with assurance...is that the **Earth’s human population has a much greater vulnerability to the indirect effects of nuclear war**, including damage to the world’s —

- agricultural
- transportation
- energy
- medical
- political
- and social

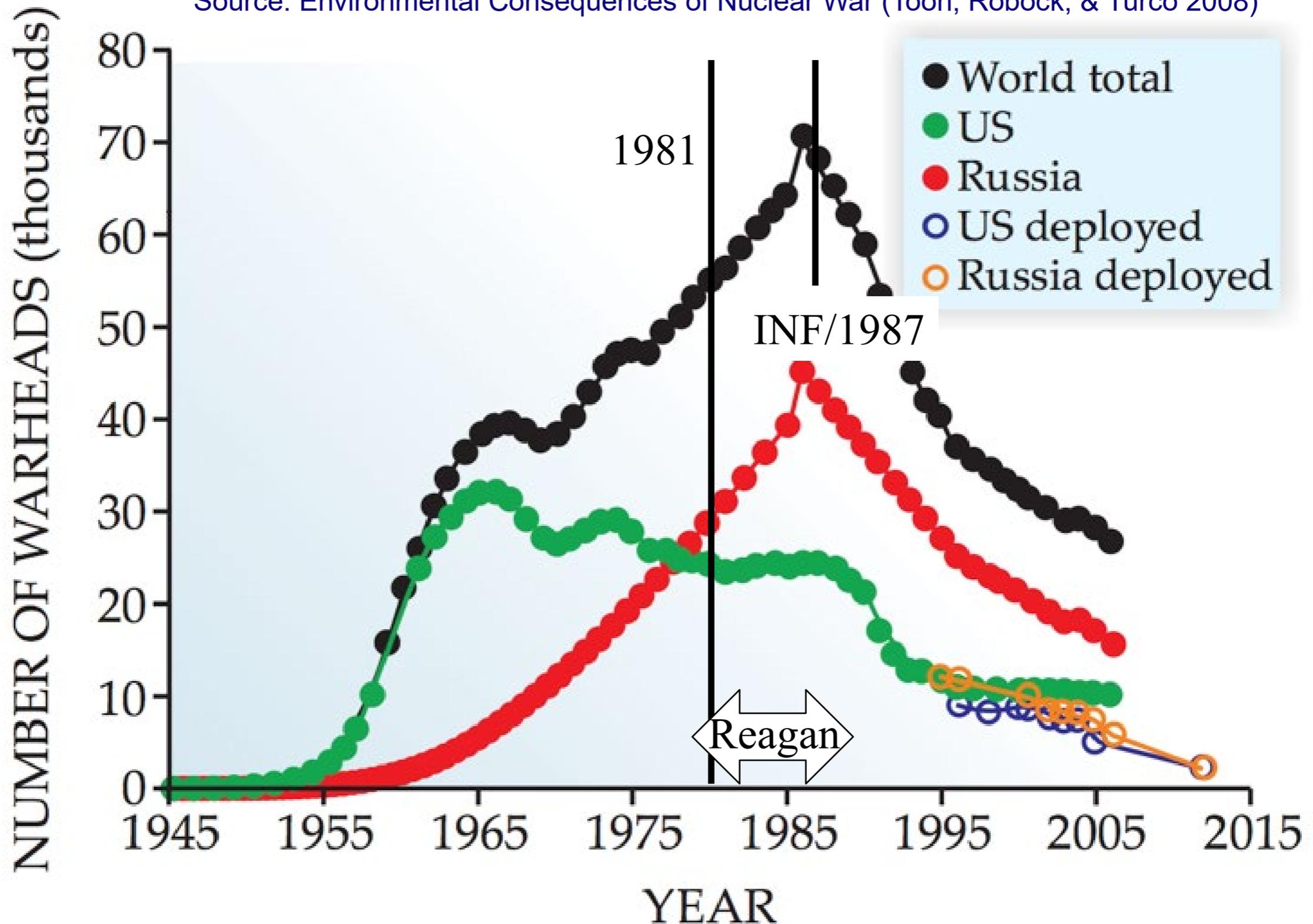
infrastructure **than to the direct effects of nuclear war.**”

Ground Zero

Video Presentation, Ground Zero
(from CBS Reports on The Defense of the United
States, aired June-14-1981)

Context: Arsenals at the Time of CBS Series

Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)



Questions for Discussion

- (A) Which imbalance in nuclear arsenals triggered the concern of military superiority of the SU ?
- (B) What is the TRIAD ?
- (C) Why would there be much more fall out in a US-Russian Nuclear War than following Hiroshima and Nagasaki?
- (D) Which society is more vulnerable to Nuclear War, Why?

Lecture Question

If Soot is transported to the upper atmosphere by an explosion or eruption, what is the meantime for the soot to return to earth's surface?

- (A) 1 year
- (B) 3 years
- (C) 5 years
- (D) 10 years

Lecture Question Answer

If Soot is transported to the upper atmosphere by an explosion or eruption, what is the meantime for the soot to return to earth's surface?

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- (C) 5 years**
- (D) 10 years

Lecture Question

What would be the impact of a U.S.-Russian (“SORT”) nuclear war with 2200 x 2 weapons of 100-kt each = 440 Mt total on the length of the growing season in the mid west of the United States of America?

- (A) Reduction by 5-10% (little ice age)
- (B) Reduction by 40-50% (last ice age)
- (C) Reduction by 70-80% (no “recent” historic precedence)

Lecture Question

What would be the impact of a U.S.-Russian (“SORT”) nuclear war with 2200 x 2 weapons of 100-kt each = 440 Mt total on the length of the growing season in the mid west of the United States of America

- (A) Reduction by ~10% (little ice age)
- (B) Reduction by 50-60% (last ice age)
- (C) Reduction by 80-90% (no “recent” historic precedence)