

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

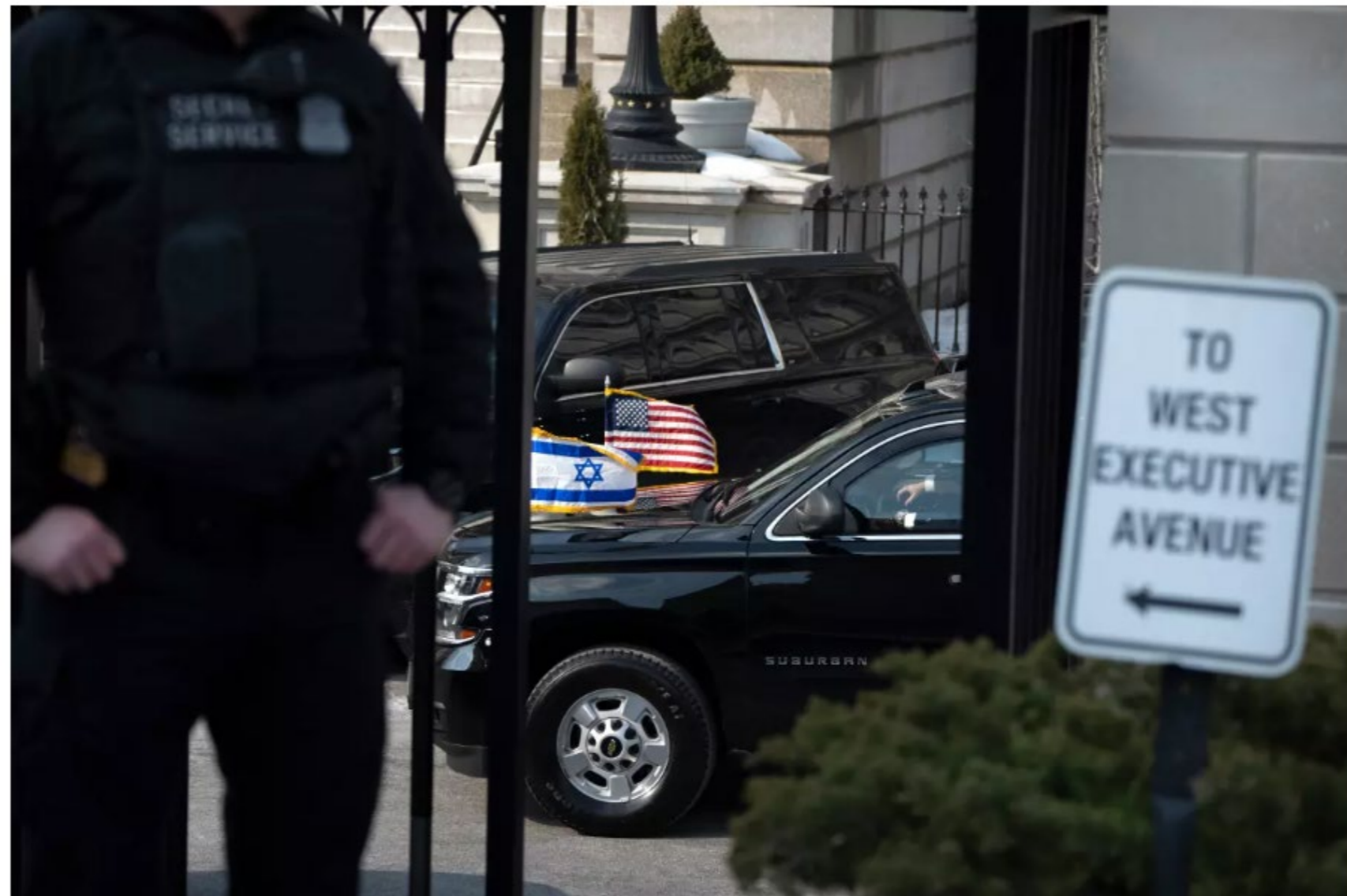
By Farnoush Amiri and Melanie Lidman

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.

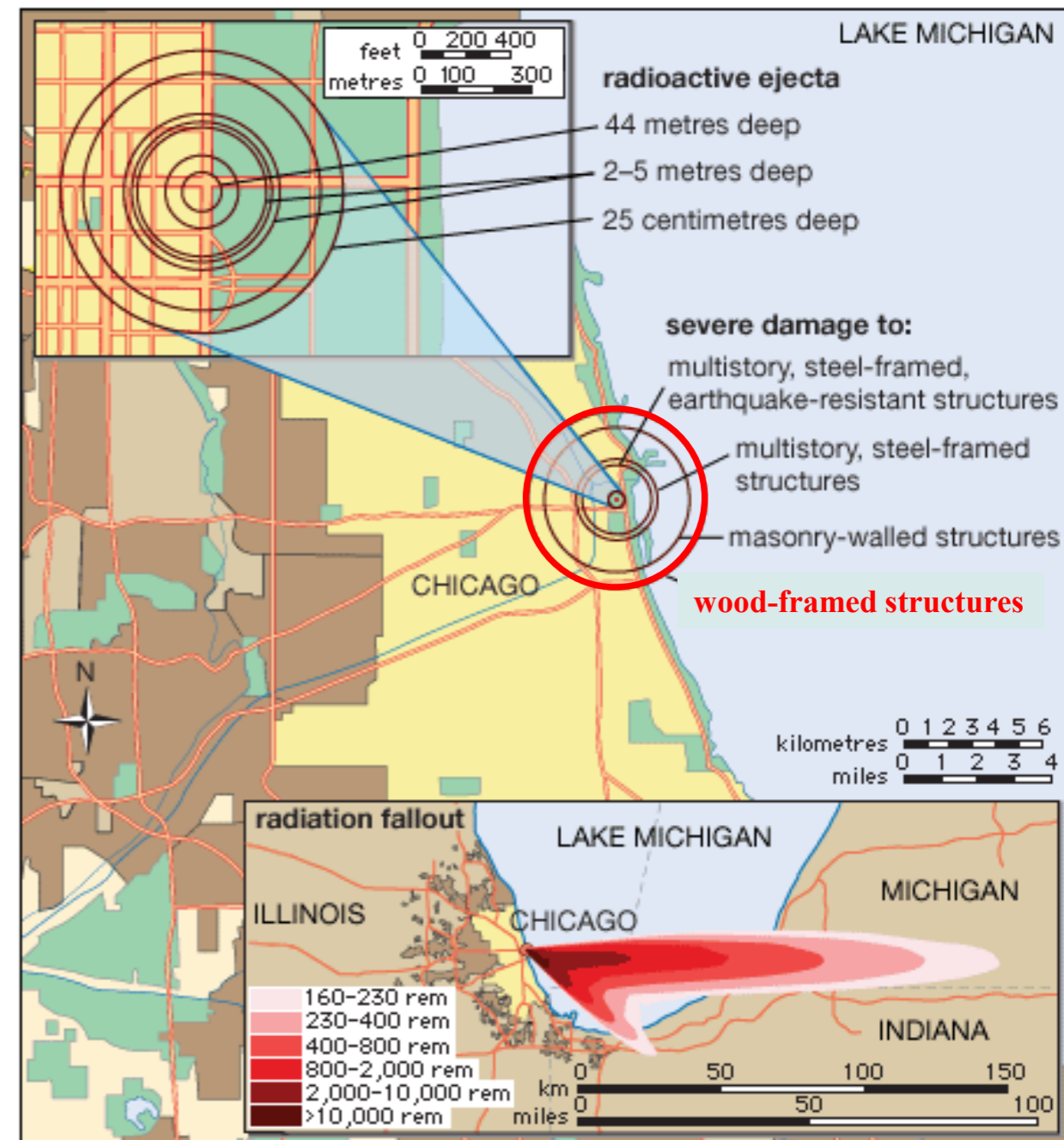
Washington has built up military forces in the region, sending an aircraft carrier, guided-missile destroyers, air defense assets and more to supplement its presence. Arab and Islamic countries, including Turkey and Qatar, have been urging both sides to show restraint, warning that any strike or retaliation 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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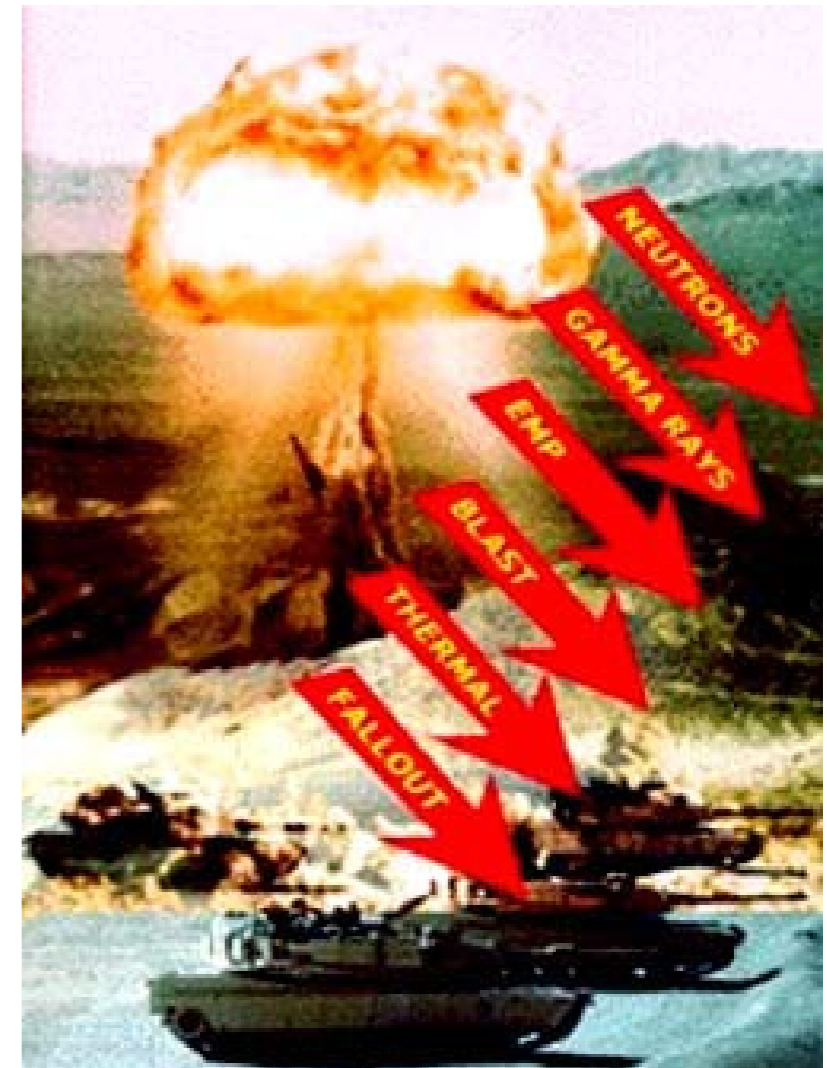
(C) Yes, easily

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?

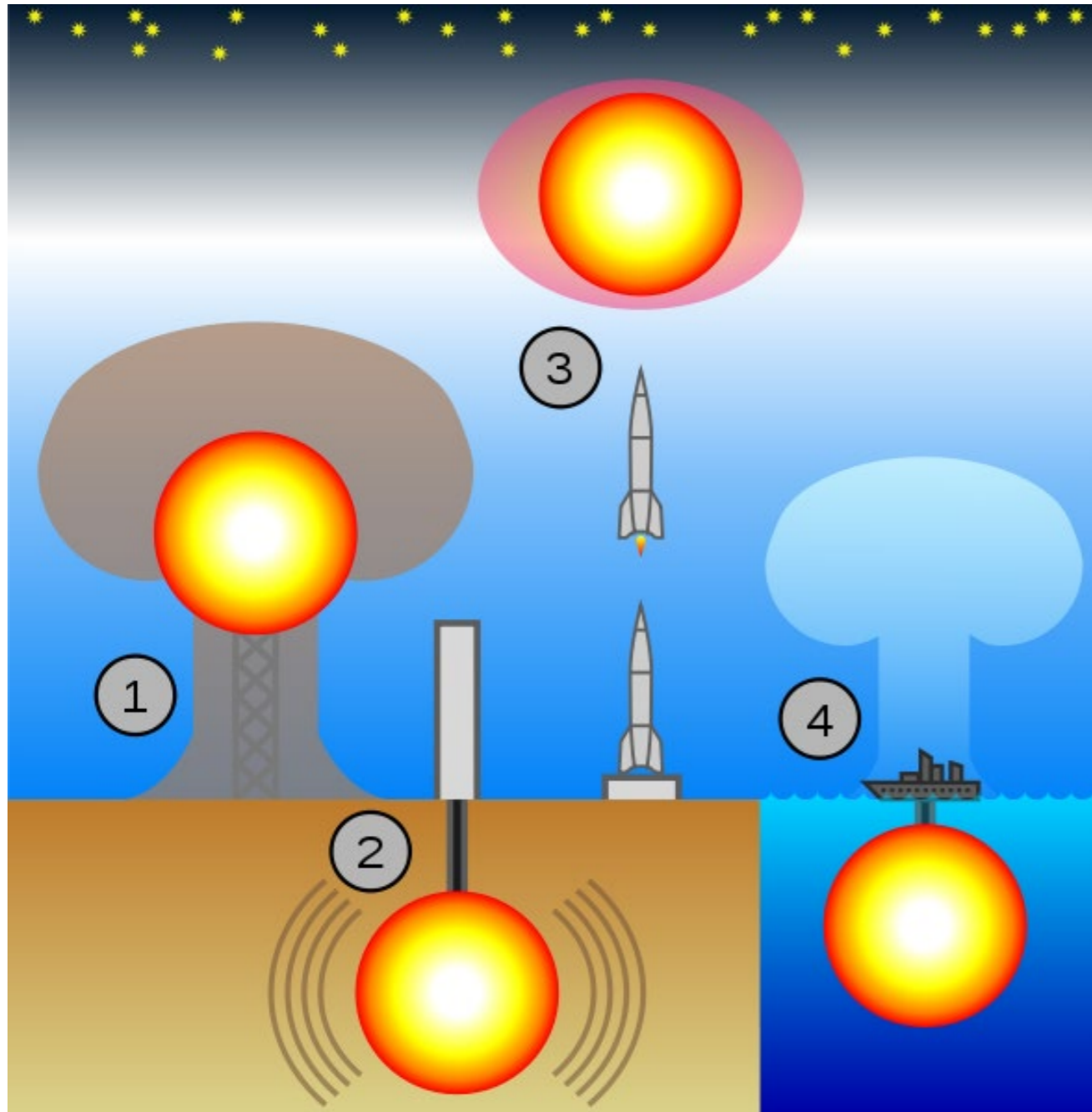
- (A) The low energy gamma rays have been absorbed by the weapon debris and almost all energy is in the kinetic energy of the debris.
- (B) 80% of the energy is carried by low energy gamma rays.
- (C) At the distance of the satellite the debris has slowed and all energy is carried by low energy gamma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

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Nuclear Explosions

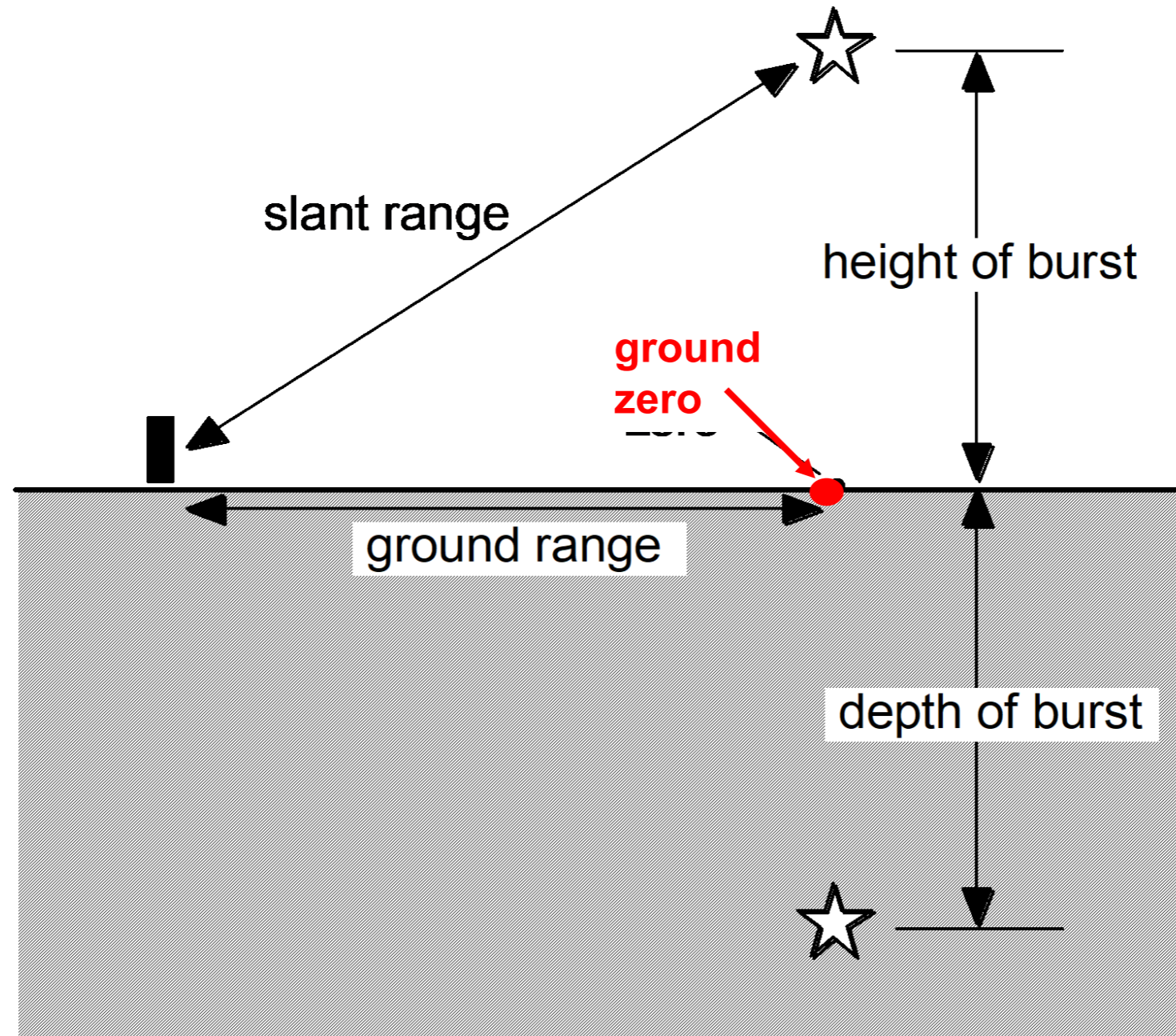


Credit: Wikipedia (nuclear weapons testing)

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



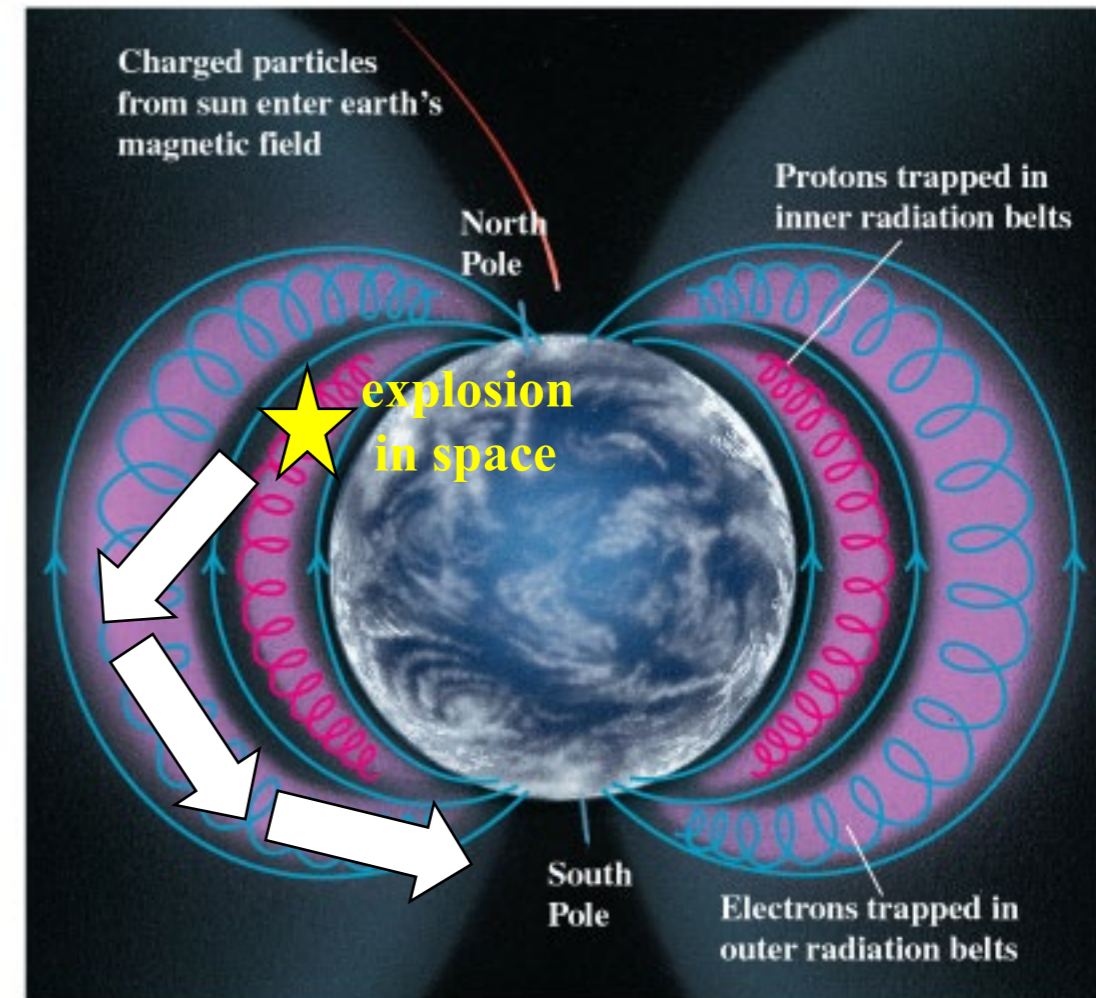
Nuclear Explosions in Space

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

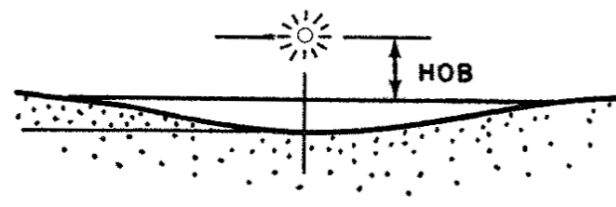


<http://www.nv.doe.gov/library/photos/testprep.aspx>

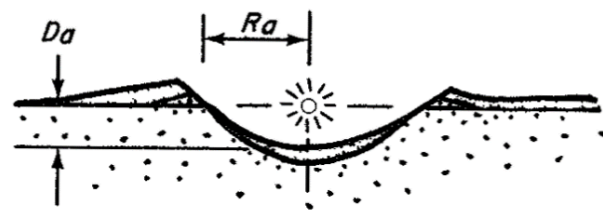
Nuclear weapon tests serve the acquisition of information/data concerning explosions of different warheads.

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

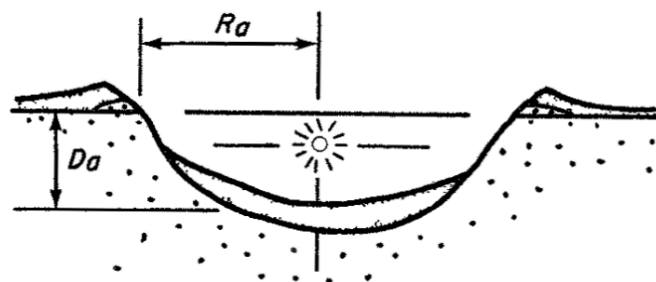
Crater Formation vs DOB (depth of burst)



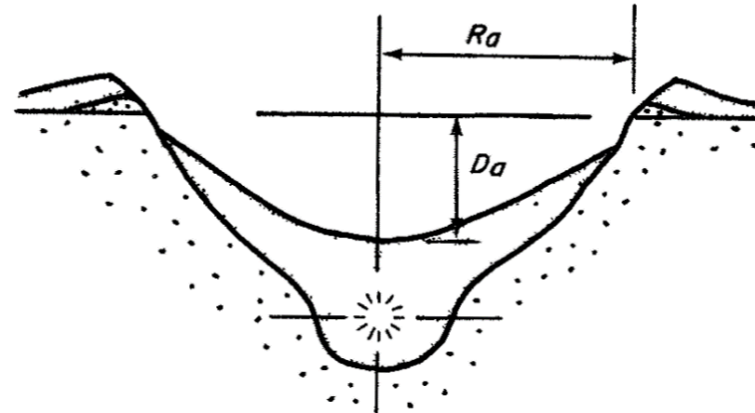
a. NEAR SURFACE BURST



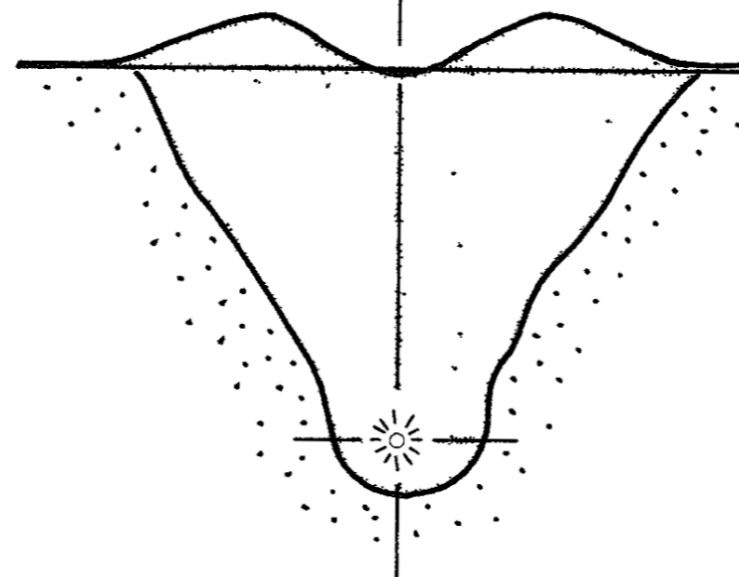
b. SURFACE BURST



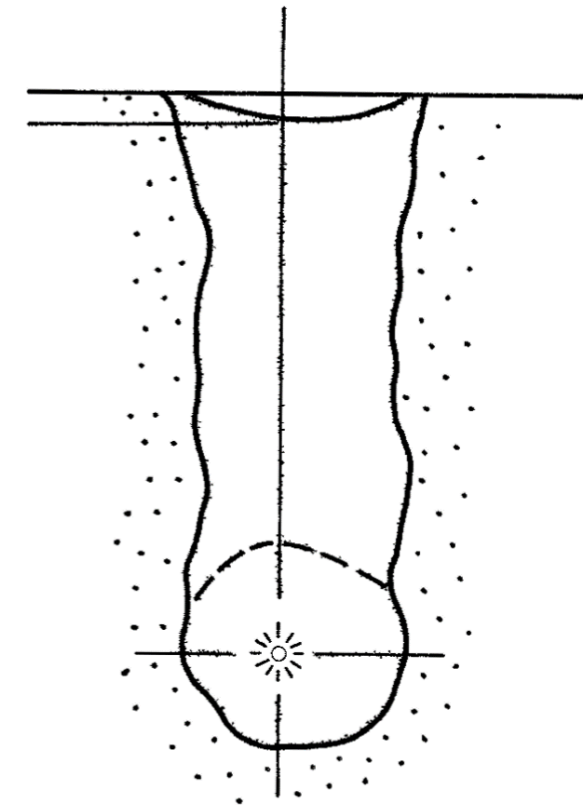
c. SHALLOW DOB



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 2-19 at 10pm

Office hours: today 5-7pm

News

Module 3 continued: Effects of nuclear explosions

Friedrich Merz holds talks with Emmanuel Macron over nuclear deterrence

Germany explores joining France's nuclear umbrella as European fears grow over the US reducing its military footprint



Emmanuel Macron, left, and Friedrich Merz. Talks underline the mounting anxiety in Europe over an expected reduction in the US military presence on the continent © Nicolas Tucac/AFP/Getty Images

Anne-Sylvaine Chassany and Henry Foy in Munich

Published FEB 13 2026 | Updated FEB 13 2026, 14:58

German Chancellor Friedrich Merz has initiated talks with France on strengthening Europe's nuclear deterrent as he urged the continent to bolster its defences and "repair" strained relations with the US. The discussions, centred on the possibility of Germany joining France's nuclear umbrella, underline mounting anxiety in Europe over an expected reduction in the US military presence on the continent, as Russia's full-scale war on Ukraine enters its fifth year. Opening the Munich Security Conference on Friday, Merz said Europe "must become a global political power with its own security strategy". "I have started initial talks with French President Emmanuel Macron about European nuclear deterrence," he said. He stressed these discussions were "strictly embedded in our nuclear participation within Nato" and insisted Germany will "not create zones of divergent security in Europe". He reminded the largely US and European audience of policymakers and security experts that the EU treaties contain a mutual defence clause — Article 42 — in the event of "armed aggression" against one of the EU member states. "We must now spell out how we want to organise this in a European way — not as a substitute for Nato, but as a self-supporting strong pillar within the alliance," he said.

...

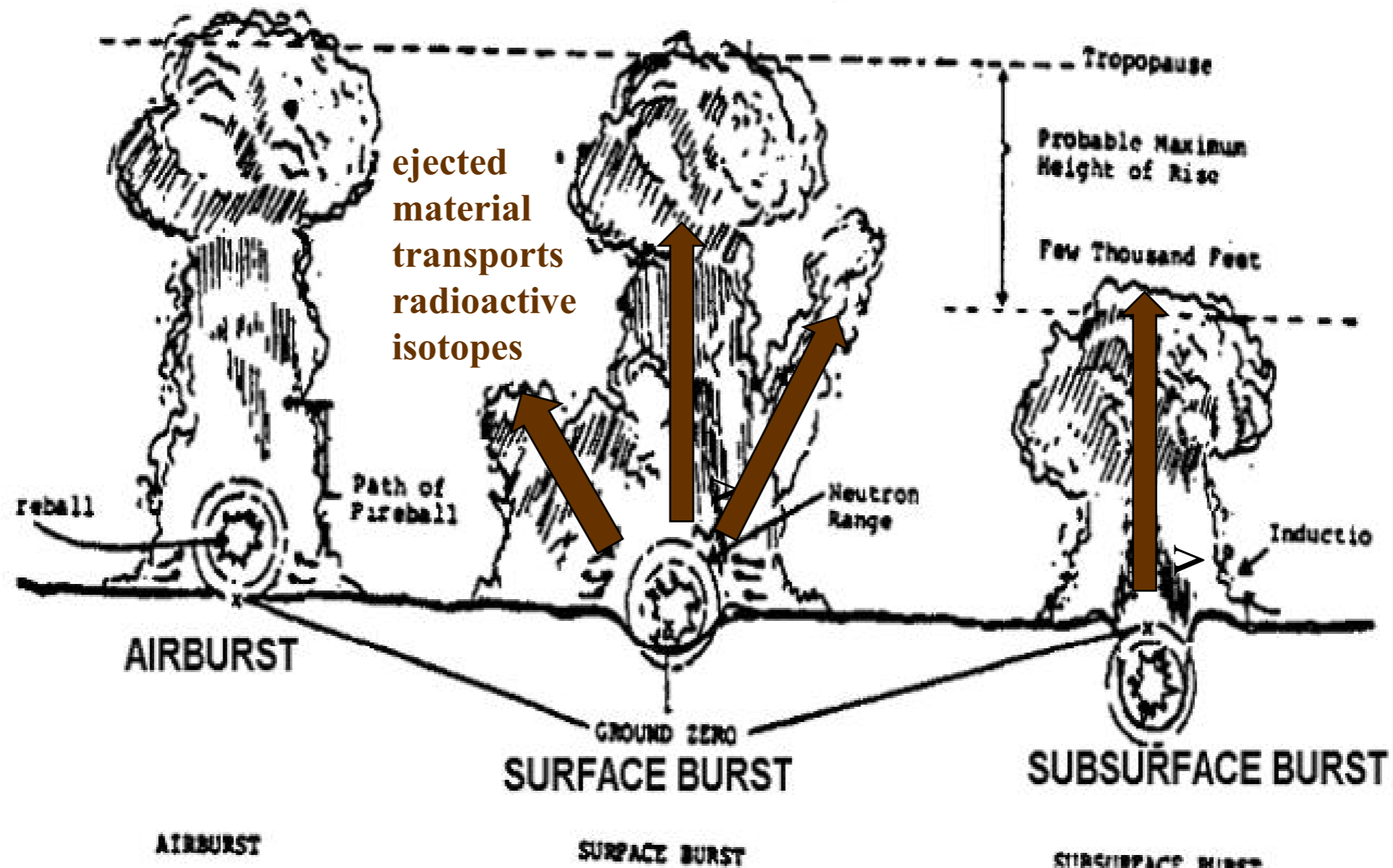
The US nuclear arsenal includes more than 100 gravity bombs stationed in Europe. These are under American control but, according to the nuclear sharing deal within Nato, are designed to be dropped by fighter jets flown by Belgium, Germany, Greece, Italy, the Netherlands and Turkey.

Macron plans to give a speech about nuclear deterrence later this month, according to several people close to the matter. **Unlike Britain's nuclear deterrent, France's arsenal sits outside Nato's nuclear sharing arrangements and does not rely on American technology. While the UK has full autonomy in firing the weapons, it cannot build, maintain or modernise them without US co-operation.**

Paris has long maintained that its “vital interests”, which underpin its nuclear doctrine, have a “European dimension”, deliberately preserving ambiguity over the circumstances in which a French president might authorise the use of atomic weapons.

Last year, Macron offered to “open the strategic debate” with interested European countries to determine “if there are new co-operations that may emerge”. Addressing the conference later on Friday, Macron confirmed he was holding a “strategic dialogue” with Merz and other countries “to see how we can articulate our national (nuclear) doctrine”.

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

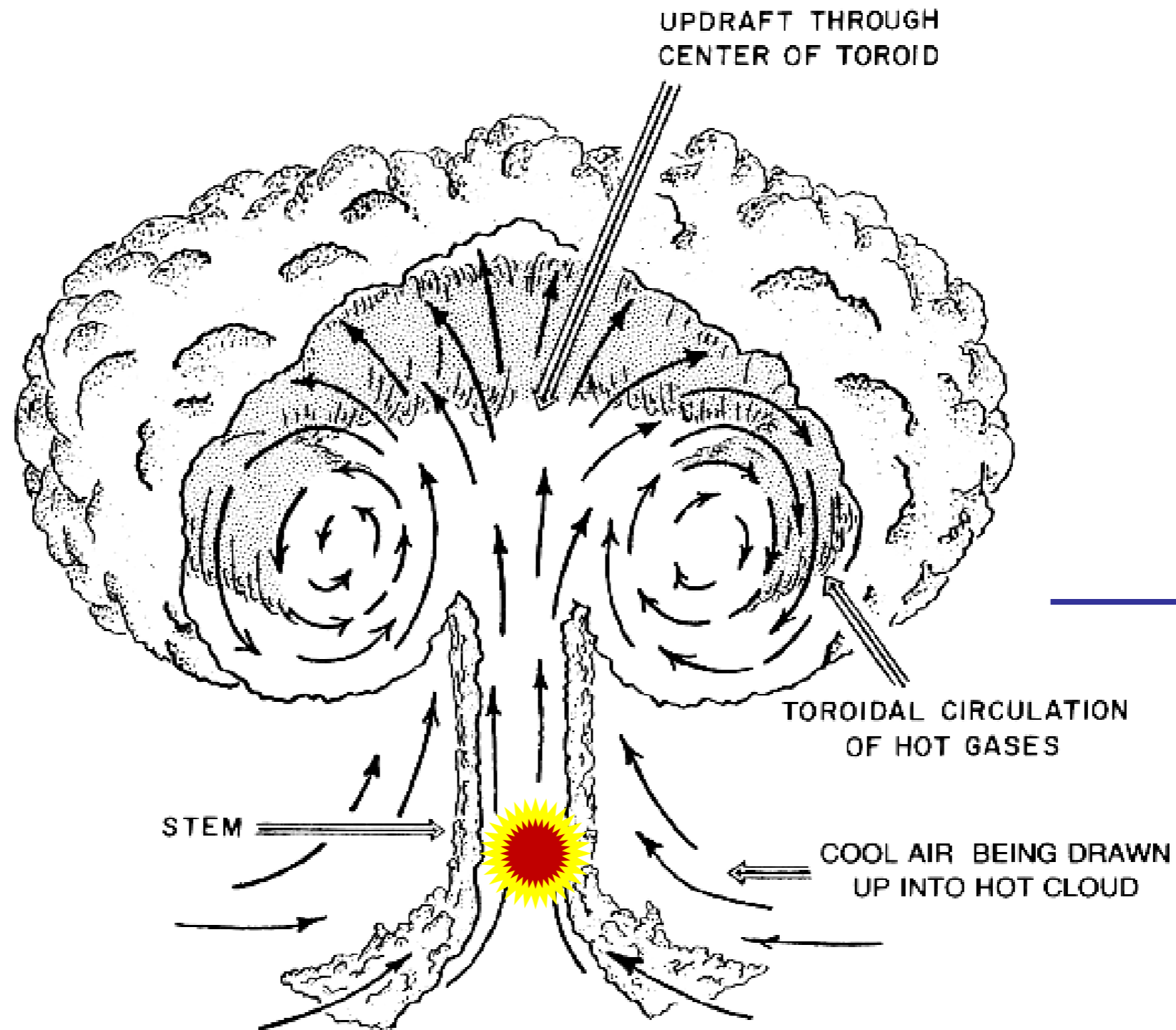
Formation of the Mushroom Cloud



- 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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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 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

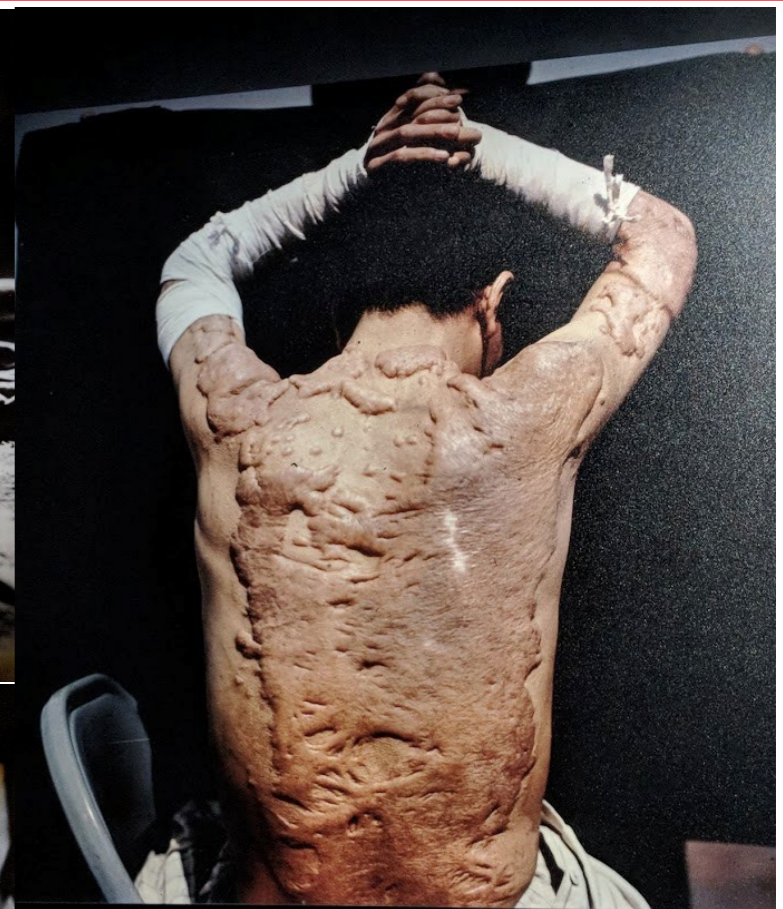
Types of burns —

- 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

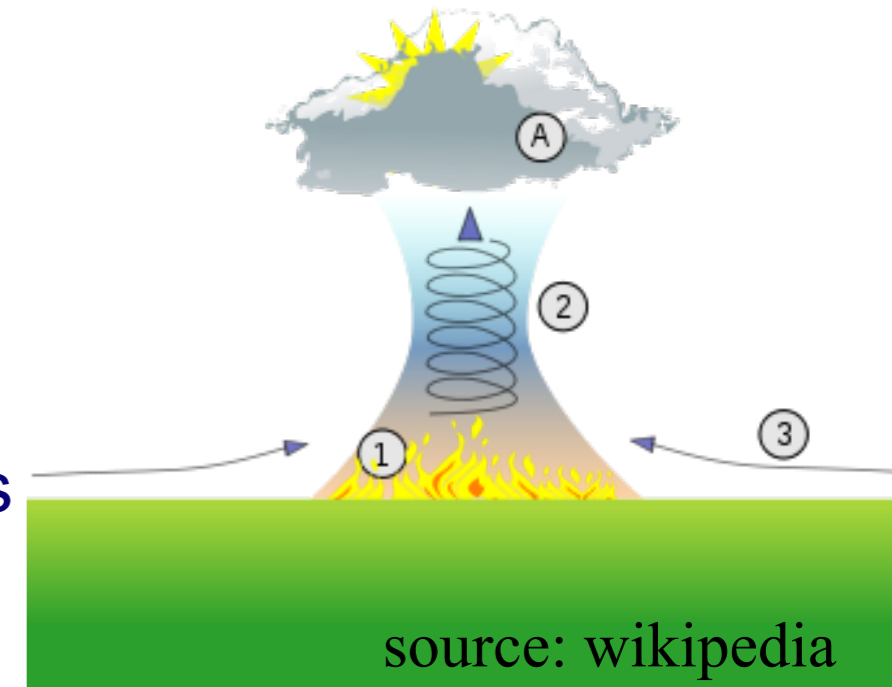
Conflagrations Versus Firestorms

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

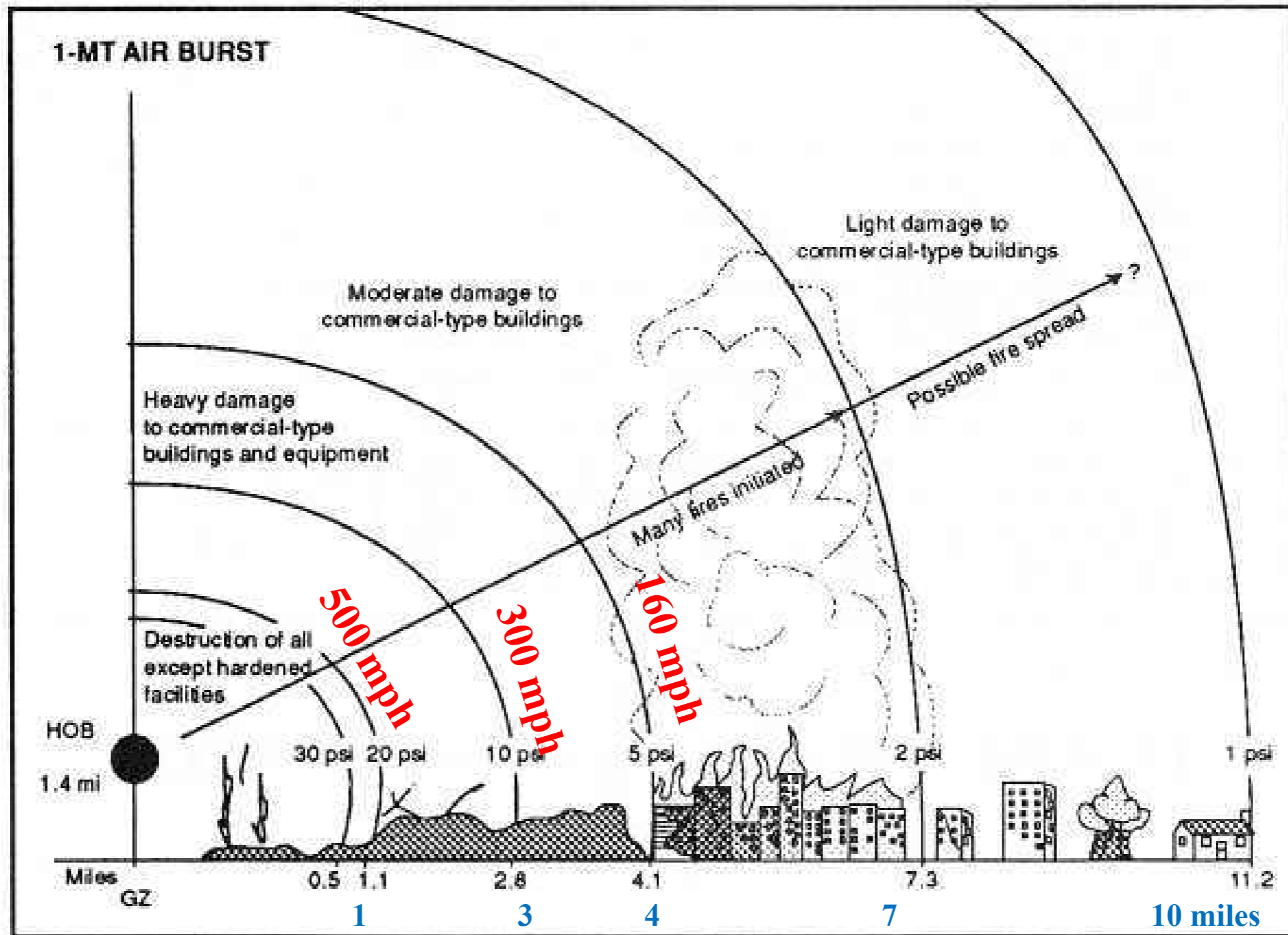
This is followed by

- 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

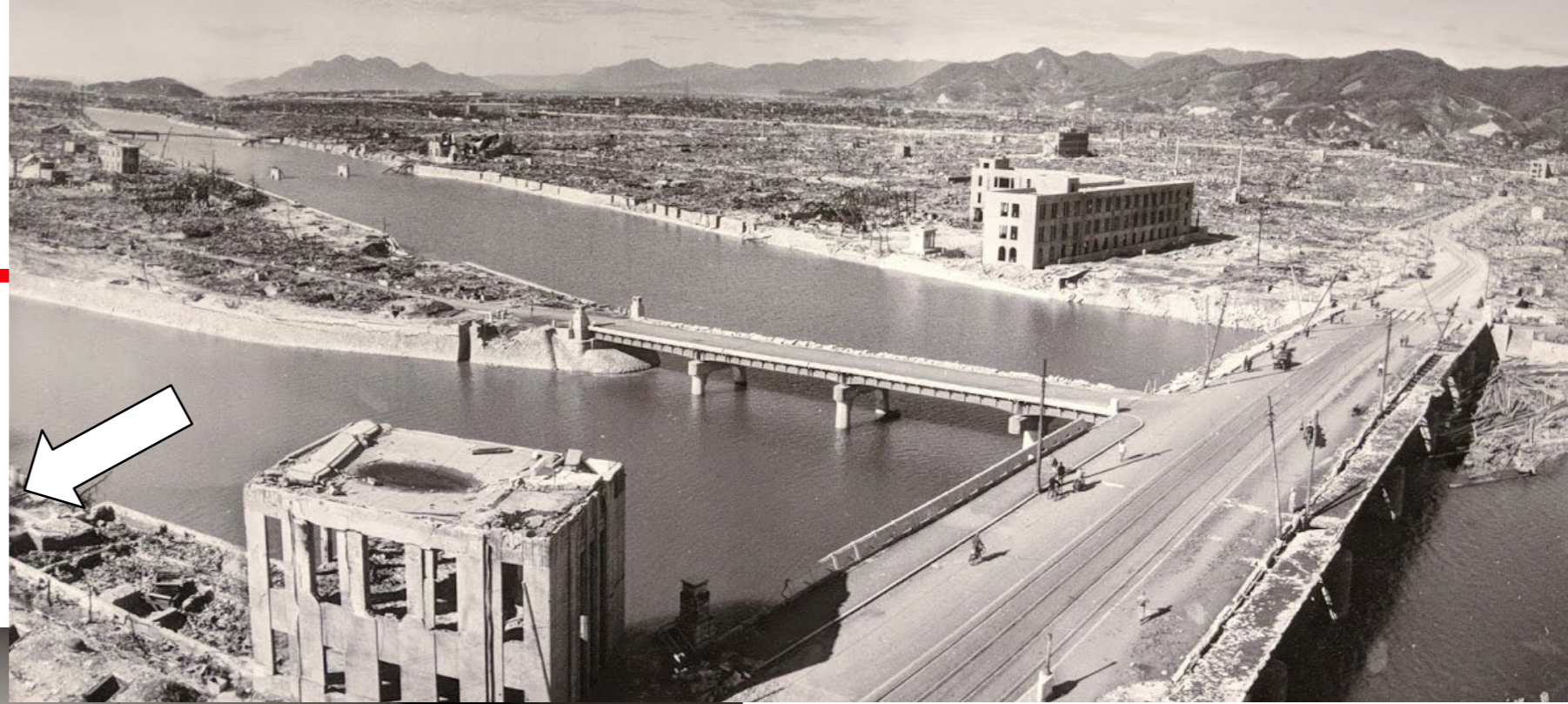
Pressure (psi)	Dynamic Pressure (psi)	Wind (mph)
200	330	2,078
150	222	1,777
100	123	1,415
50	41	934
20	8	502
10	2	294
5	1	163

Damaging Effects of a Blast Wave



Damage in Hiroshima

Atomic Dome
near
Ground Zero

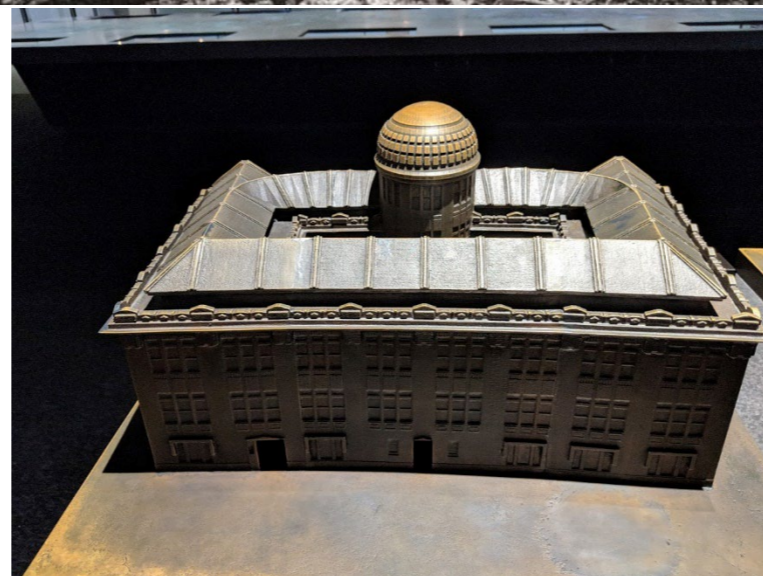


T-shaped bridge was
used for targeting

Damage in Hiroshima: HOB ~ 2000 ft above Atomic Dome



Hiroshima Prefectural Industrial Promotion Hall



Hiroshima Peace Memorial

Effects of Nuclear Explosions

Fall Out

Effects of Shallow Underground Nuclear Explosions

Effects of the Sedan Event (1962)

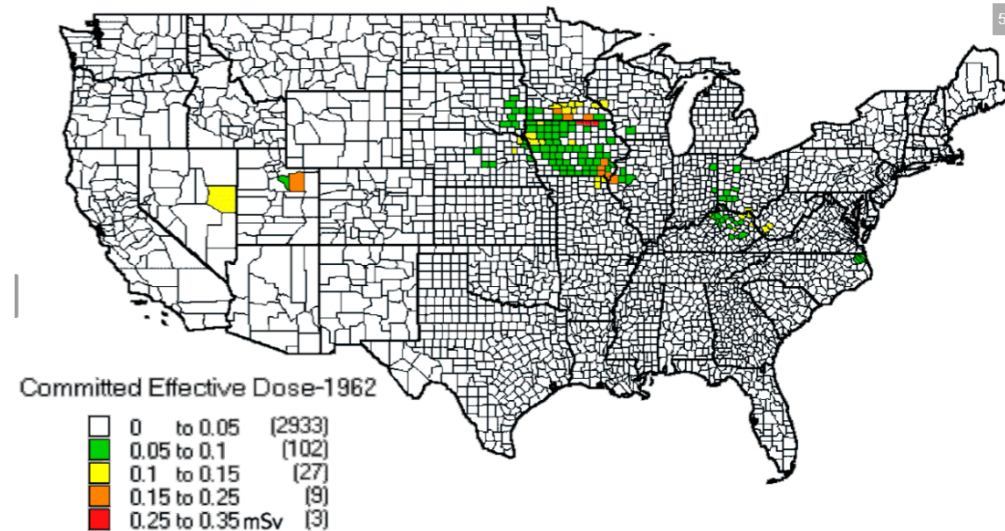
- Explosive yield: 104 kt
- Depth of burial: 635 feet
- Crater radius: 610 feet
- Crater depth: 320 feet
- Earth displaced: 11 million tons

Effects of Shallow Underground Nuclear Explosions

Example: The Sedan Test (104 kt, 1962)

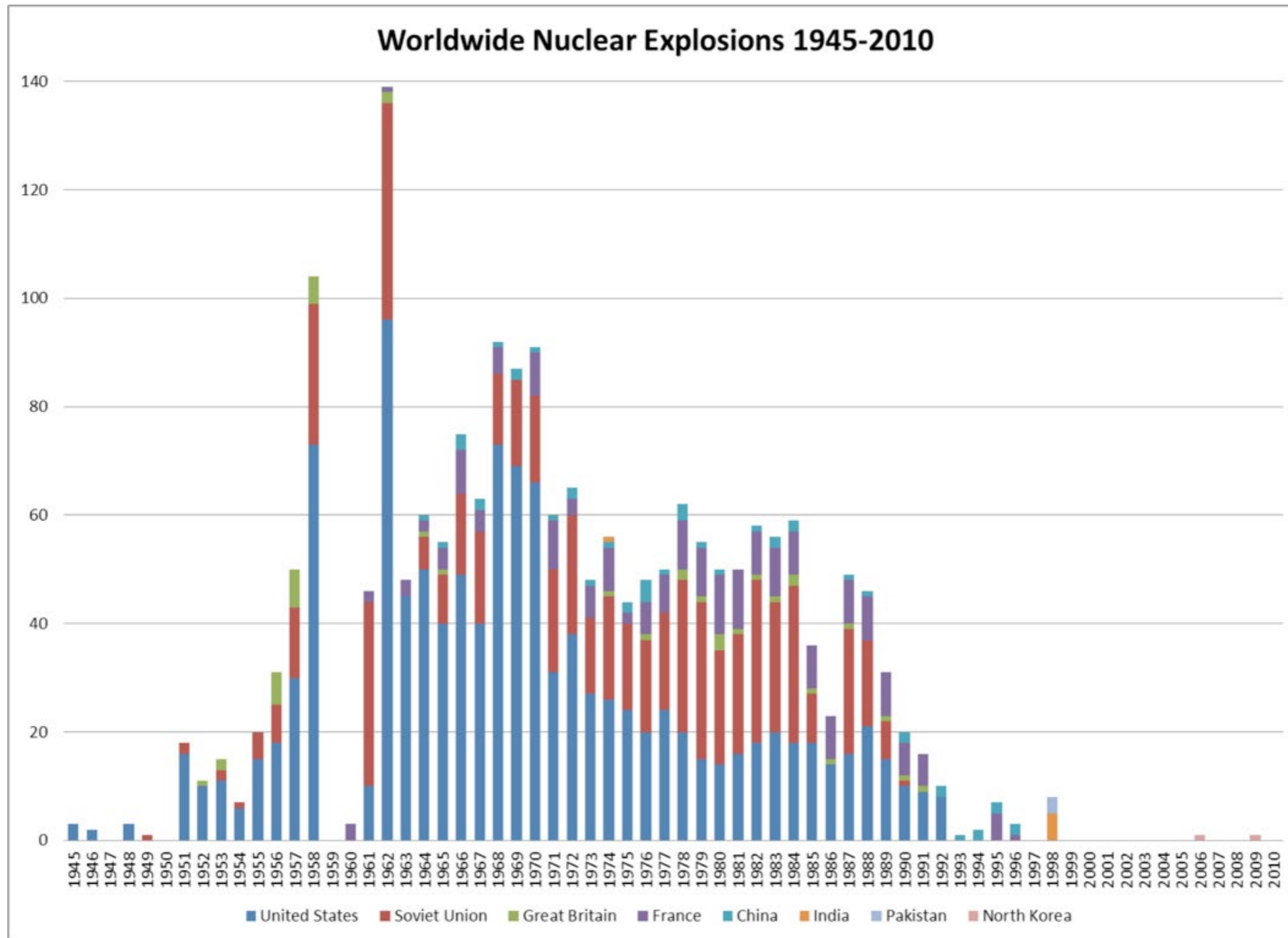


Depth of burst: 635 ft
Crater depth: 320 ft
Crater diameter: 122 ft
Displaced soil: 11,000,000 tons
Seismic waves: 4.75 - Richter scale



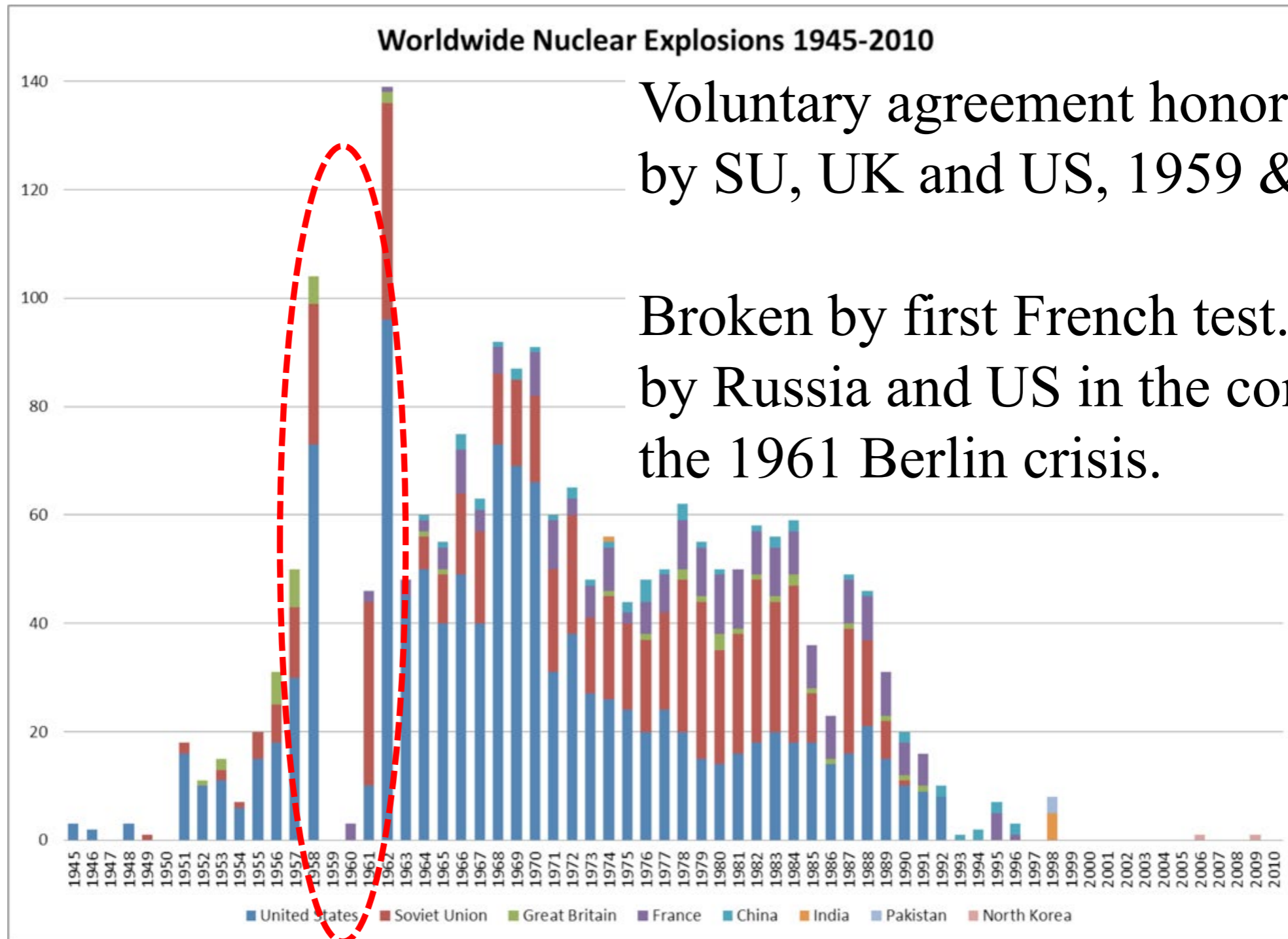
Dose to average exposed individual from SEDAN and Smallboy.
Number of counties in each group shown in parenthesis.

Effects of Nuclear Explosions



Credit: Wikipedia Commons

Test Moratorium 1959-1960



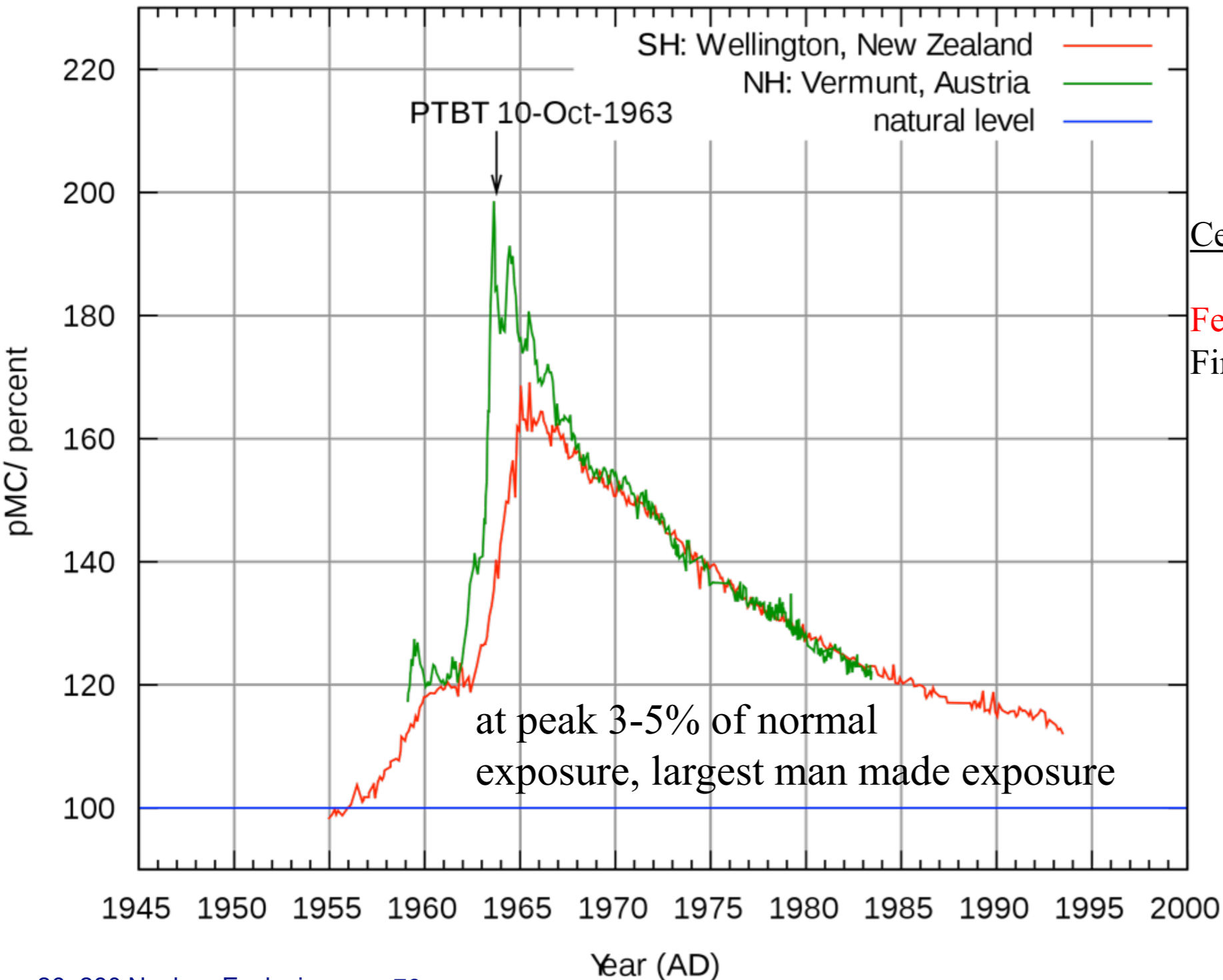
Voluntary agreement honored by SU, UK and US, 1959 & 1960

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)



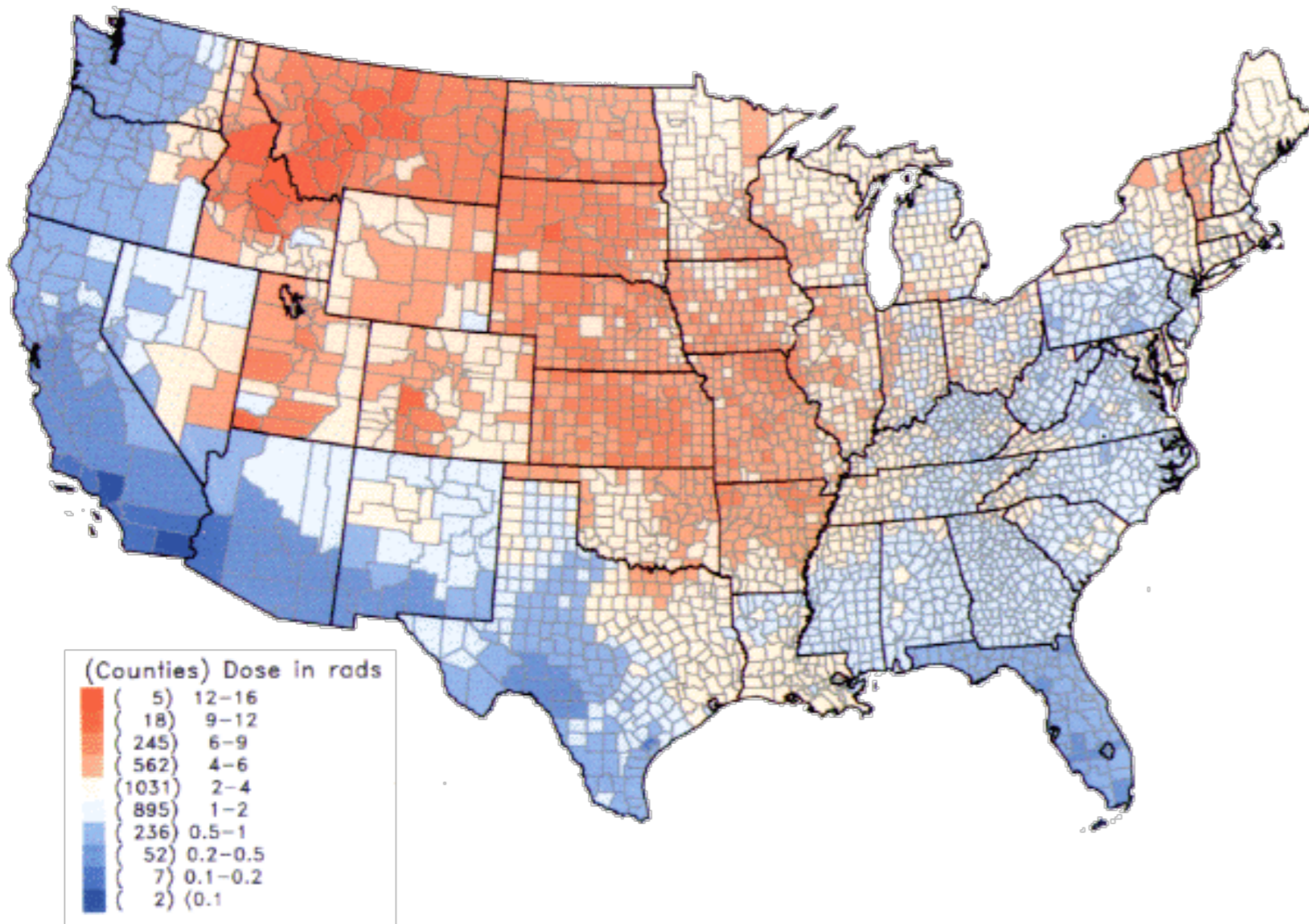
Centers for Disease Control and Prevention:

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>

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



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.”

Fallout Radiation from a 1 Mt Burst

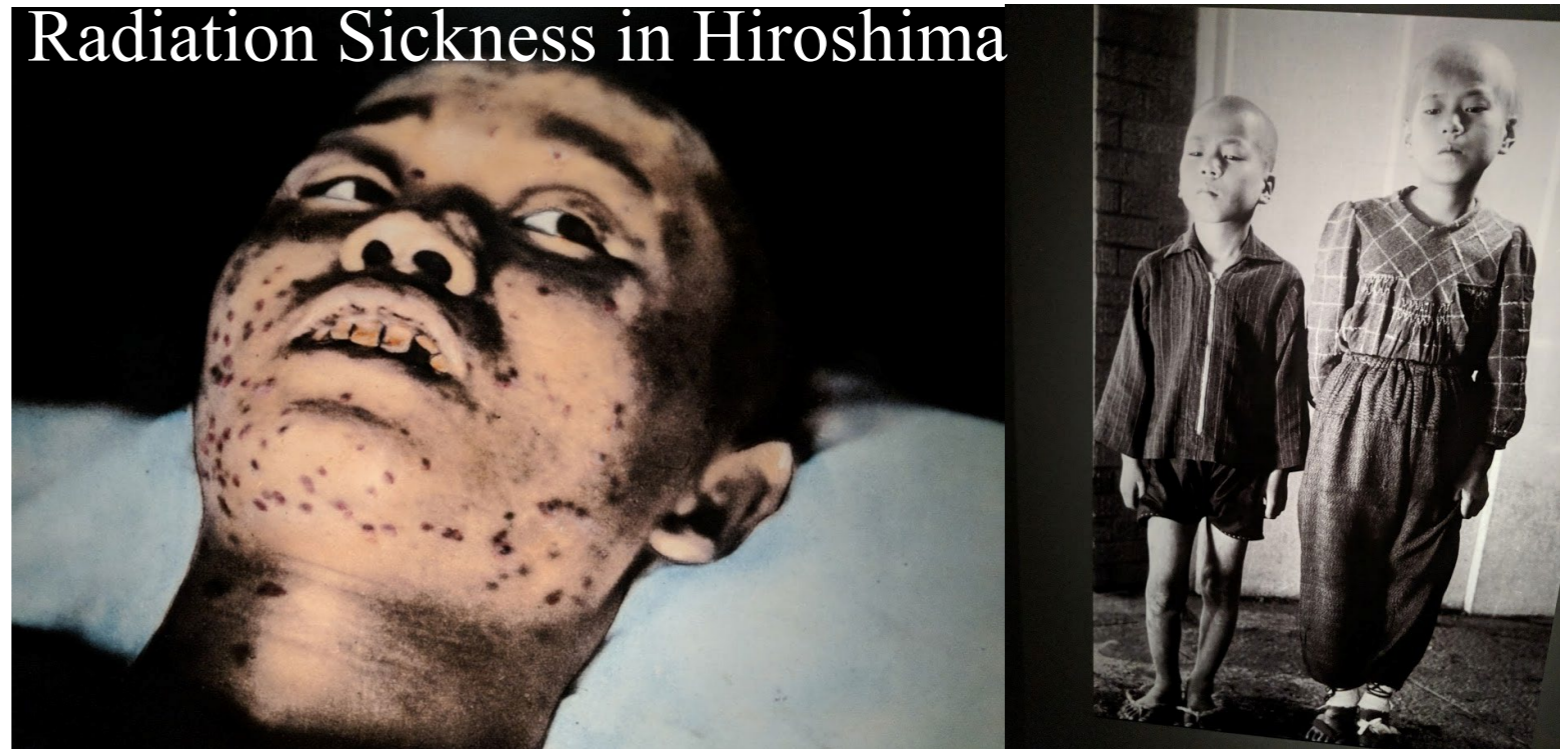
Assume —

- 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



Physics/Global Studies 280: Session 10

Plan for This Session

Second extra credit opportunity

ACDIS Film Screening - *First We Bombed New Mexico*, Friday, February 20th, 5pm.

5:00 PM Central Time, Illini Union 314AB

Immediately followed by a **Q&A** with Director Lois Lipman.

News

Nuclear Explosions Conclusion: Fallout and Nuclear Winter

US reveals new details of alleged Chinese nuclear test

By Jonathan Landay

February 17, 2026 5:14 PM CST · Updated February 17, 2026

WASHINGTON, Feb 17 (Reuters) - A senior U.S. official on Tuesday revealed what he said were new details of an underground nuclear test blast that China allegedly conducted in June 2020.

Assistant Secretary of State Christopher Yeaw told an event at the Hudson Institute think tank in Washington that a remote seismic station in Kazakhstan measured an "explosion" of magnitude 2.75 located 450 miles (720 km) away at the Lop Nor test grounds in western China on June 22, 2020.

"I've looked at additional data since then. There is very little possibility I would say that it is anything but an explosion, a singular explosion," said Yeaw, adding that [the data were not consistent with mining blasts](#).

["It's also entirely not consistent with an earthquake,"](#) said Yeaw, a former intelligence analyst and defense official who holds a doctorate in nuclear engineering. ["It is ... what you would expect with a nuclear explosive test."](#)

[The Comprehensive Test Ban Treaty Organization, which is charged with detecting nuclear test explosions, said that there was insufficient data to confirm Yeaw's allegation with confidence.](#)

News

A spokesperson for the Chinese embassy in Washington said the allegation about China conducting a nuclear test was "entirely unfounded" and an attempt "to fabricate excuses for resuming" U.S. nuclear testing.

"This is political manipulation aimed at pursuing nuclear hegemony and evading its own nuclear disarmament responsibilities," Chinese embassy spokesperson Liu Pengyu said in an emailed statement.

"China urges the U.S. to reaffirm the five nuclear-weapon states' commitment on refraining from nuclear tests, uphold the global consensus against nuclear tests, and take concrete steps to safeguard the international nuclear disarmament and non-proliferation regime," Liu added.

U.S. President [Donald Trump](#) is pressing China to join the U.S. and Russia in negotiating a replacement pact to New START, the last U.S.-Russia strategic nuclear arms limitation agreement, which [expired](#) on February 5.

CHINA DENIES NUCLEAR TESTING

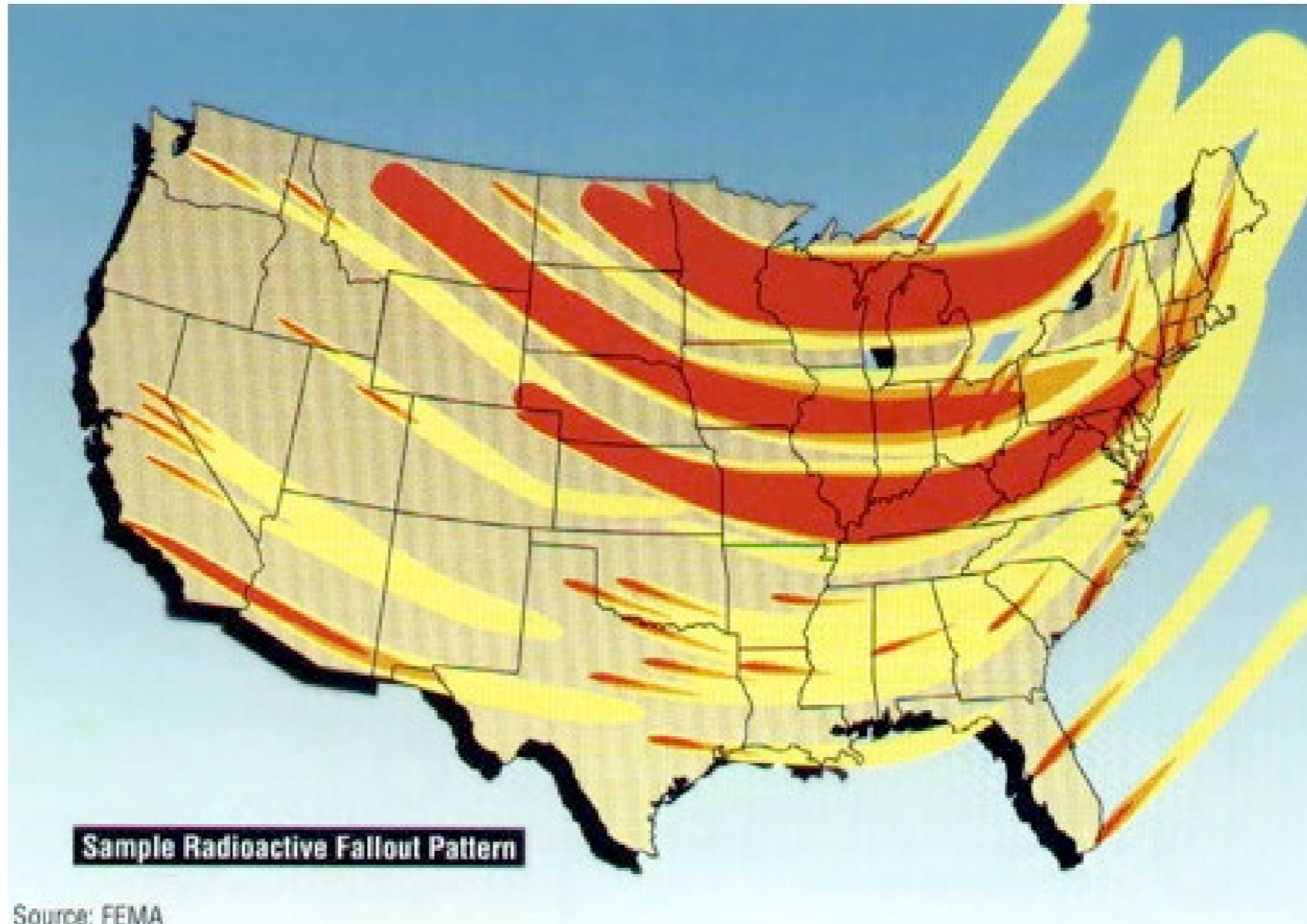
China, which has signed but not ratified the 1996 international treaty banning nuclear testing, denied setting off an underground nuclear test blast after the U.S. first leveled the allegation at an international conference earlier this month. China's last official underground test took place in 1996.

The PS23 seismic station in Kazakhstan is part of a globe-spanning monitoring system operated by the Comprehensive Test Ban Treaty Organization (CTBTO).

The organization's executive secretary, Robert Floyd, said in a statement that the PS23 station recorded "two very small seismic events" spaced 12 seconds apart on June 22, 2020.

The CTBTO's monitoring system can detect "events" consistent with nuclear test explosions with yields of 551 tons (500 metric tons) of TNT or greater, he said.

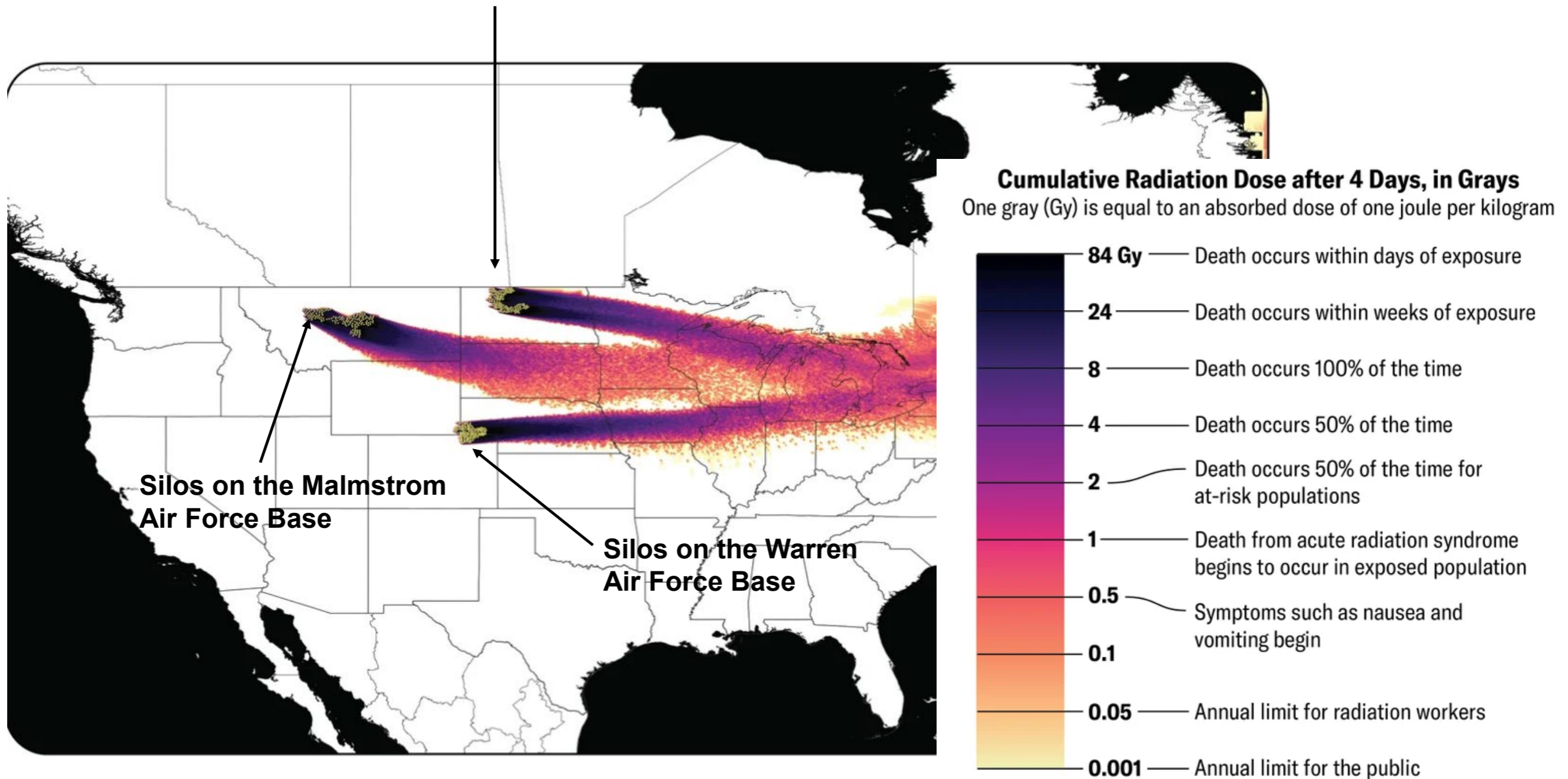
Effects of Nuclear Explosions



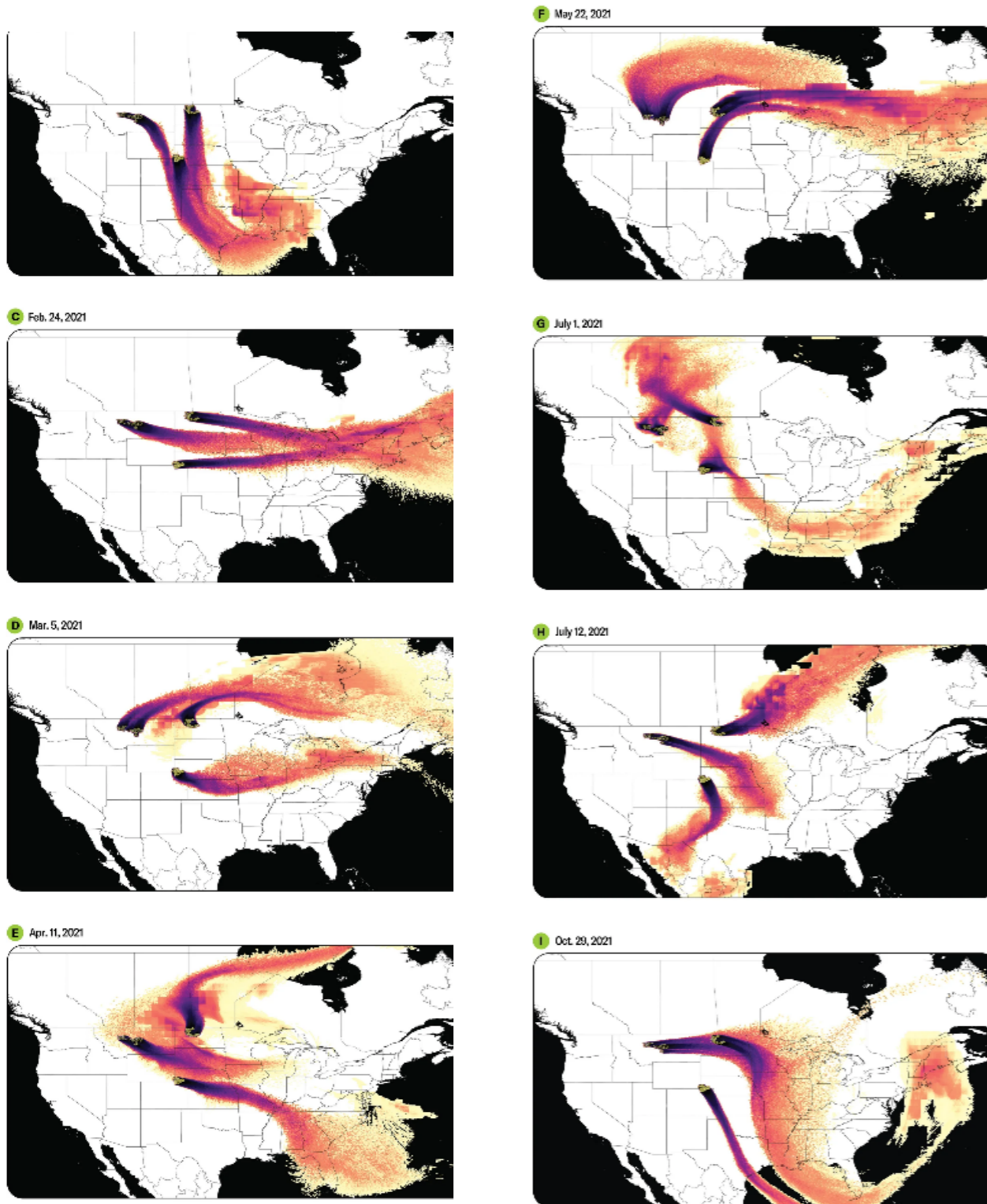
Map of nuclear fallout distribution after a potential nuclear attack on the United States. Source: FEMA

Simulation of radioactive fallout after a wide nuclear attack on US missile silos using wind patterns on and after February 24th, 2021, Sébastien Phillipe (Princeton, and Physicist Coalition for Nuclear Threat Reduction) in Scientific American, 12-1, 2023

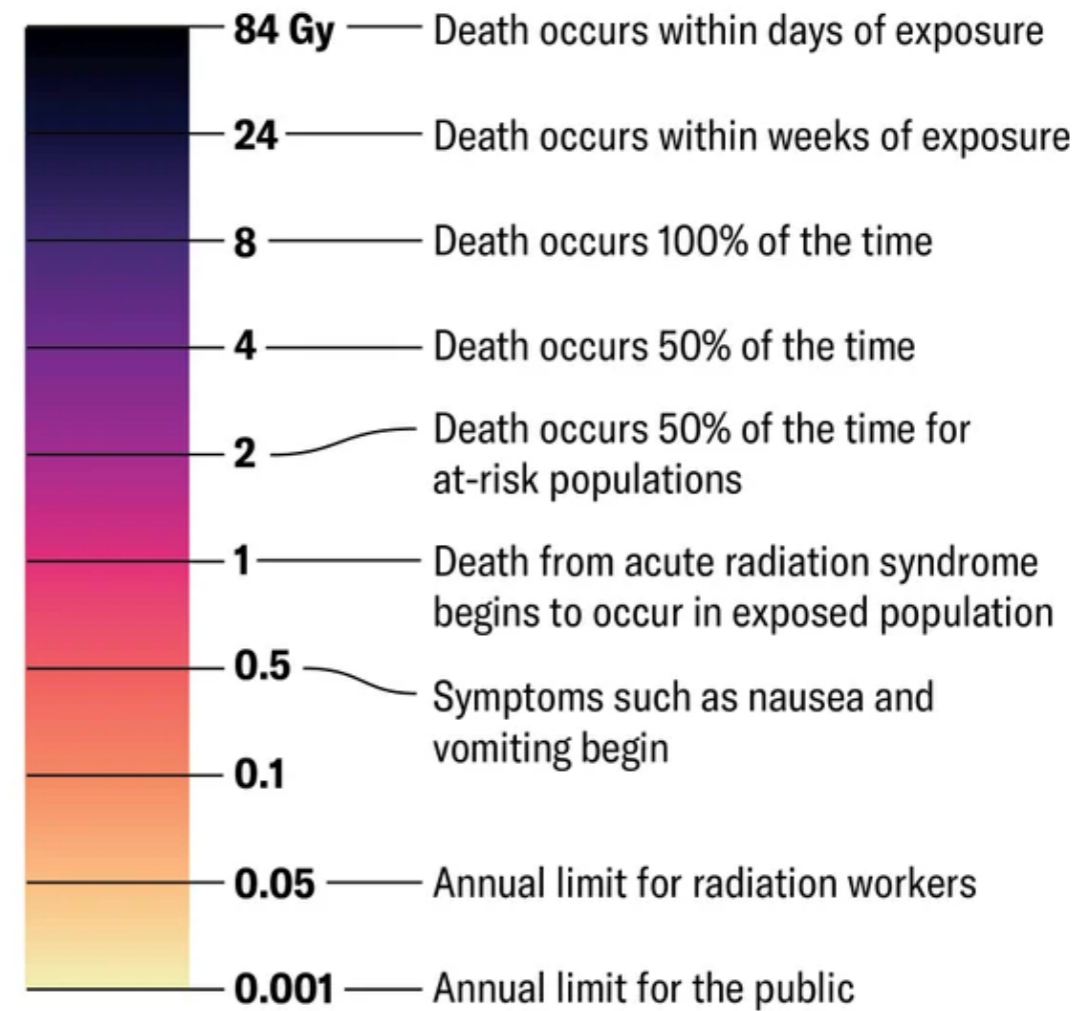
Yellow dots represent nuclear missile Silos on the Minot Air Force Base



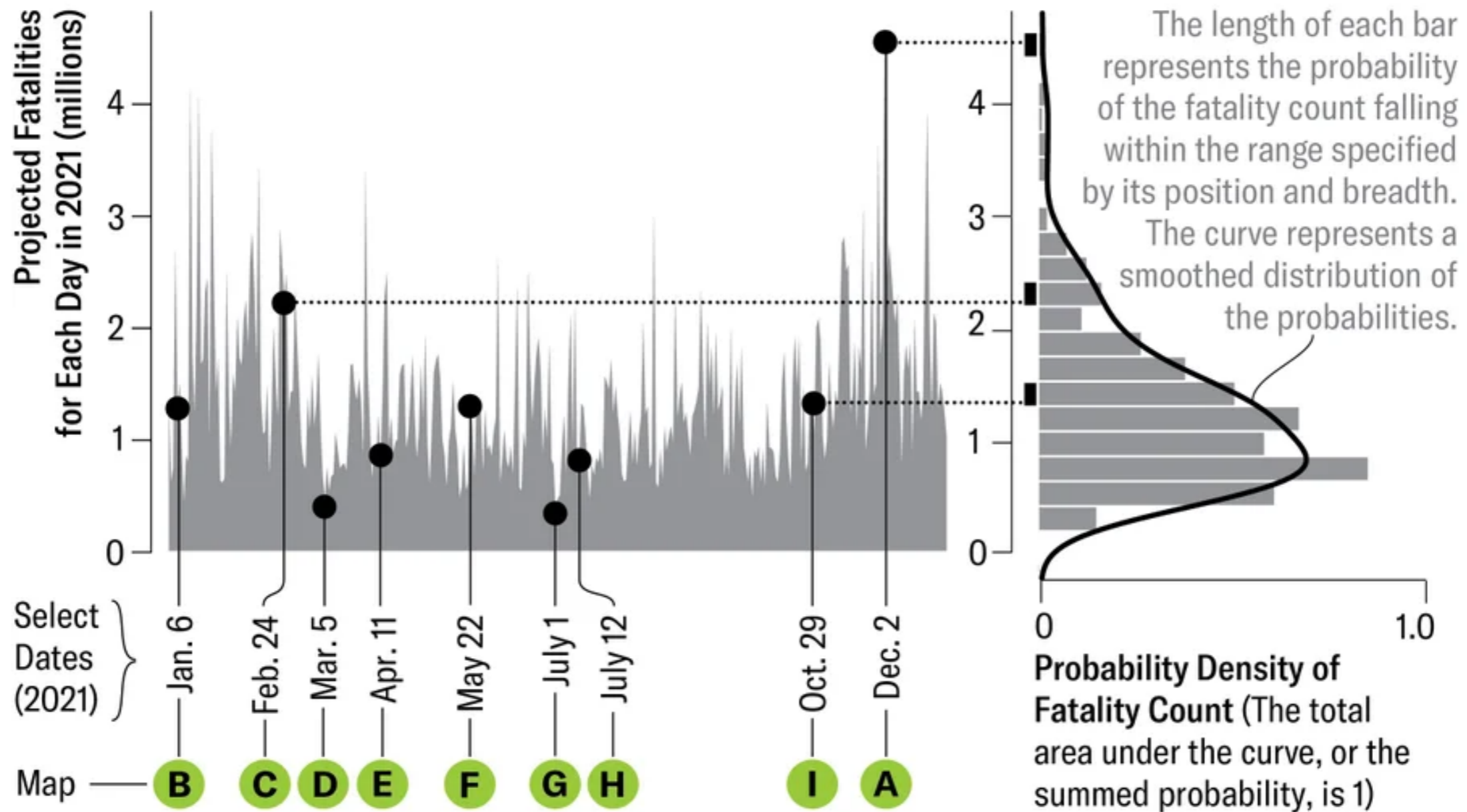
Simulations Carried out for Observed Wind Patterns for all days in 2021



Cumulative Radiation Dose after 4 Days, in Grays
 One gray (Gy) is equal to an absorbed dose of one joule per kilogram



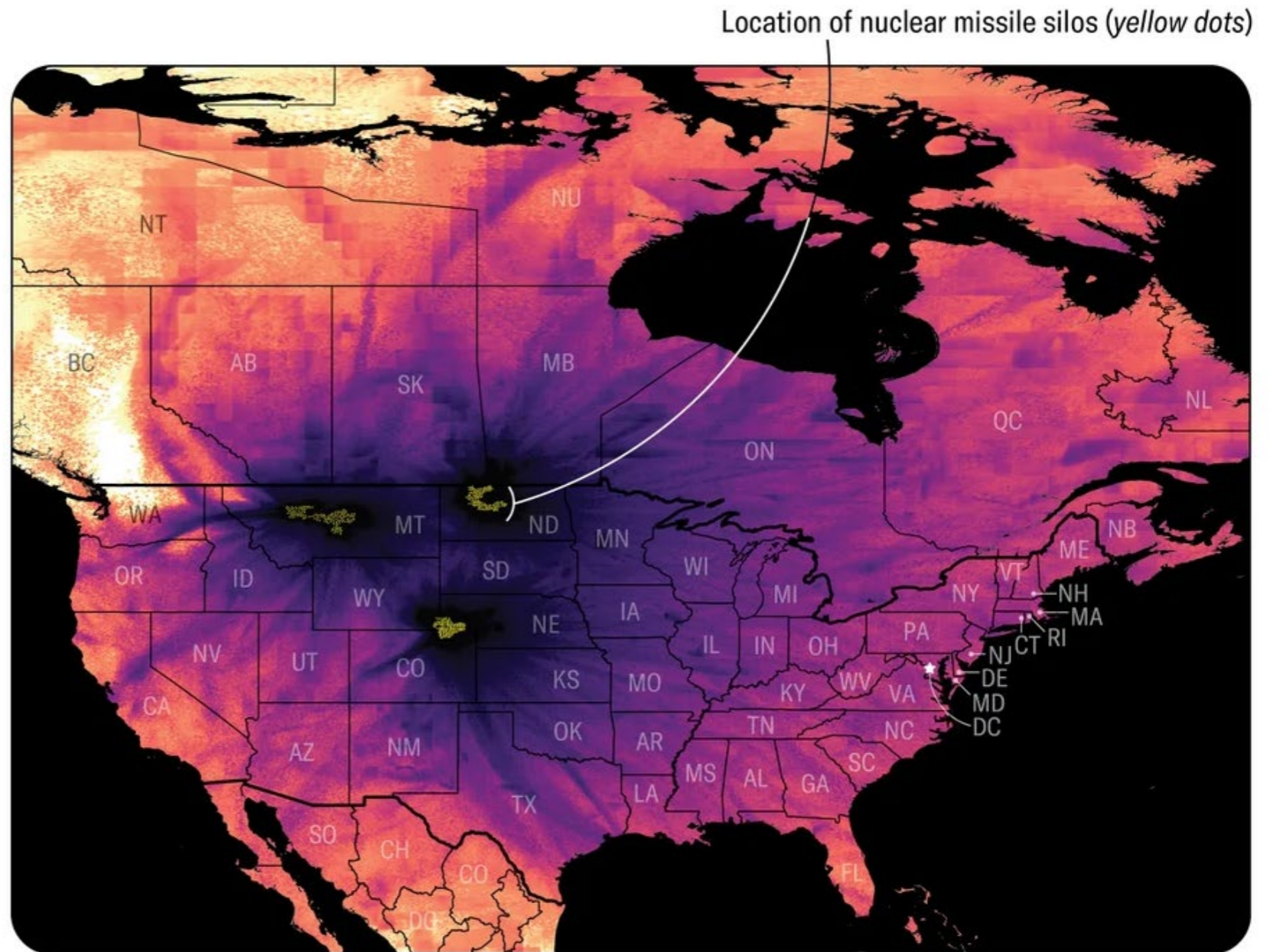
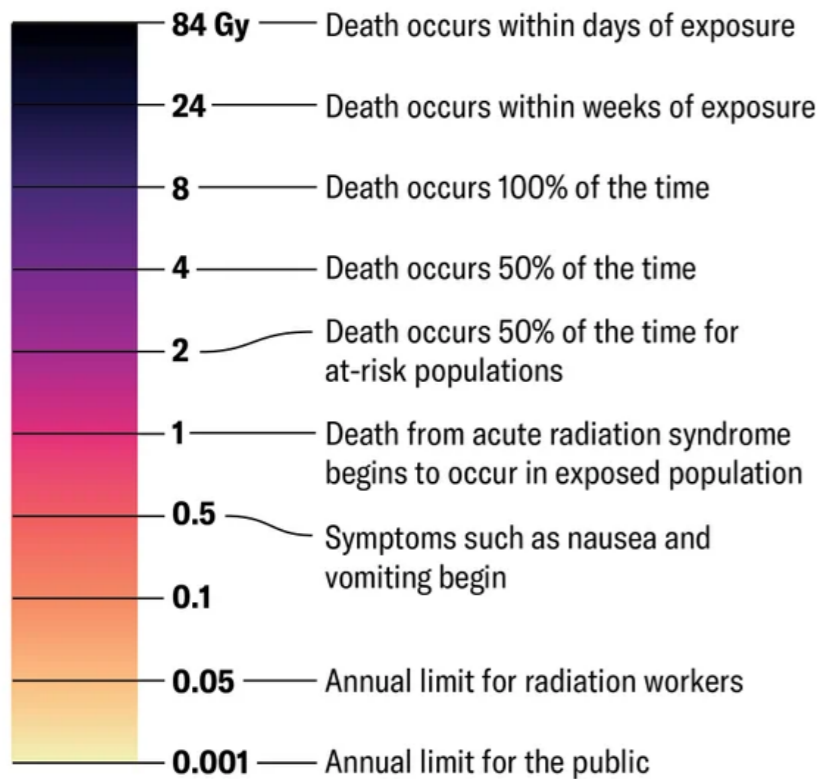
Projected Fatalities Through Fallout Induced Radiation Doses vs Day in 2021



Credit: Sébastien Philippe, Svitlana Lavrenchuk and Ivan Stepanov

2021 - Worst Case Cumulative Radiation Dose for All Locations

Cumulative Radiation Dose after 4 Days, in Grays
One gray (Gy) is equal to an absorbed dose of one joule per kilogram



Credit: Sébastien Philippe, Svitlana Lavrenchuk and Ivan Stepanov

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
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- (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

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”)

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)

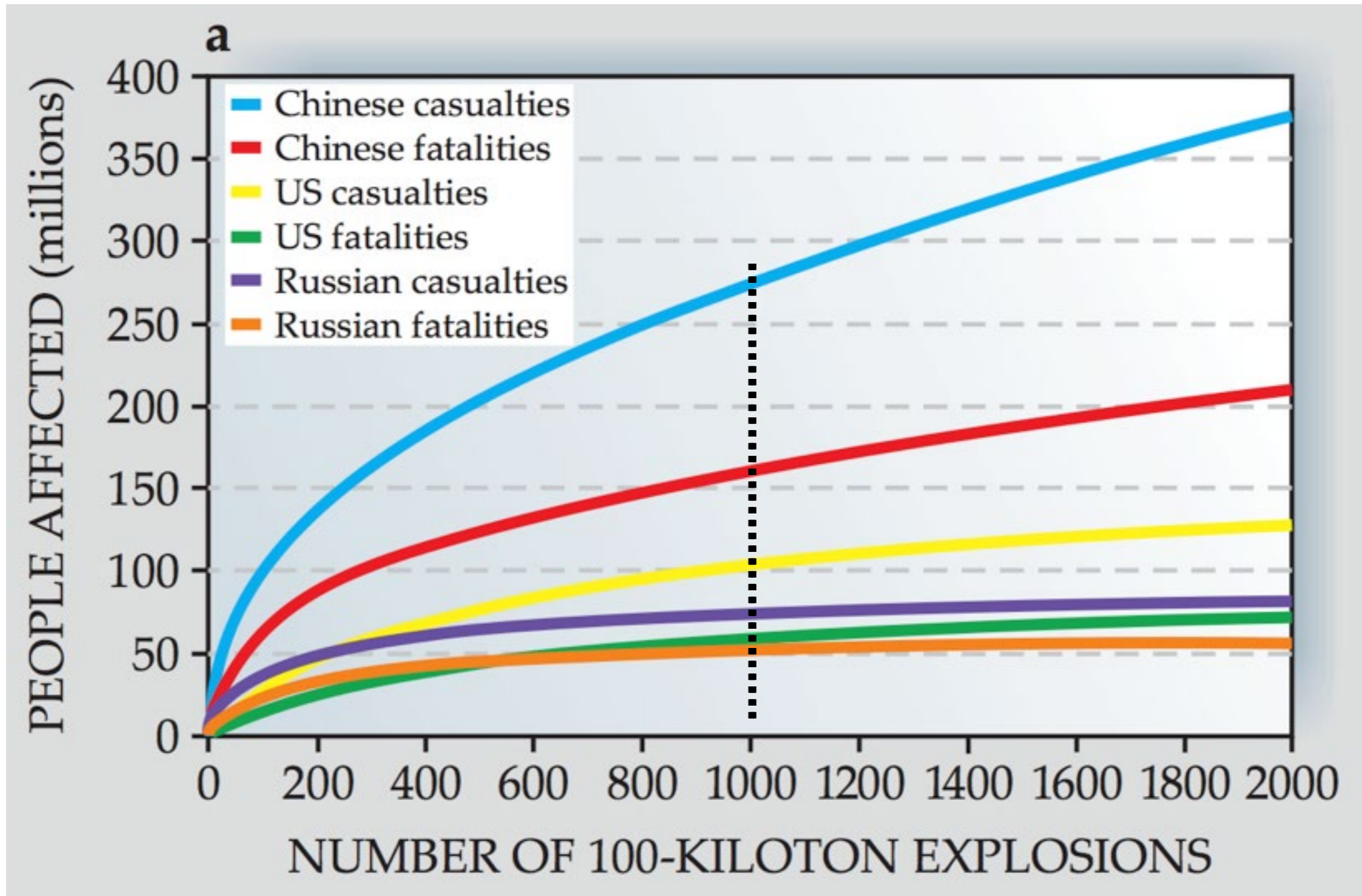
1,000 weapons detonated on Russia would *immediately* —

- 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)

Effects of Nuclear War: Direct Casualties

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

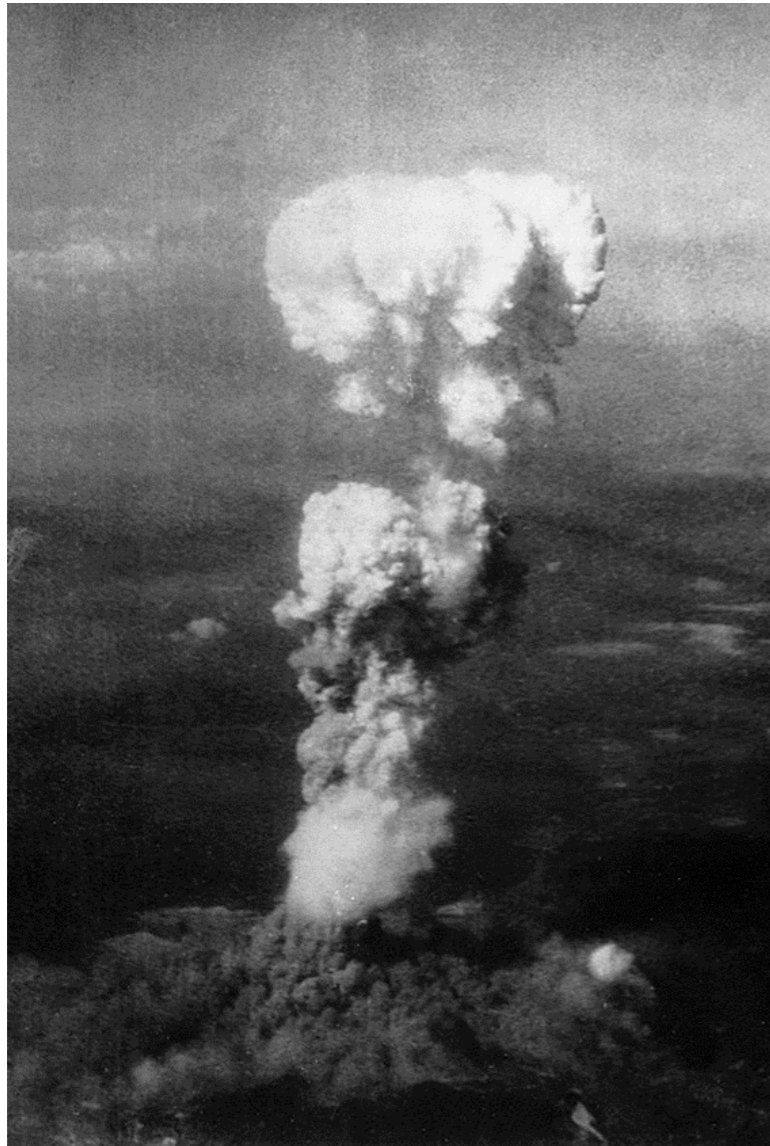


Large Cities in China, Russia and the United States

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.

Nuclear Winter

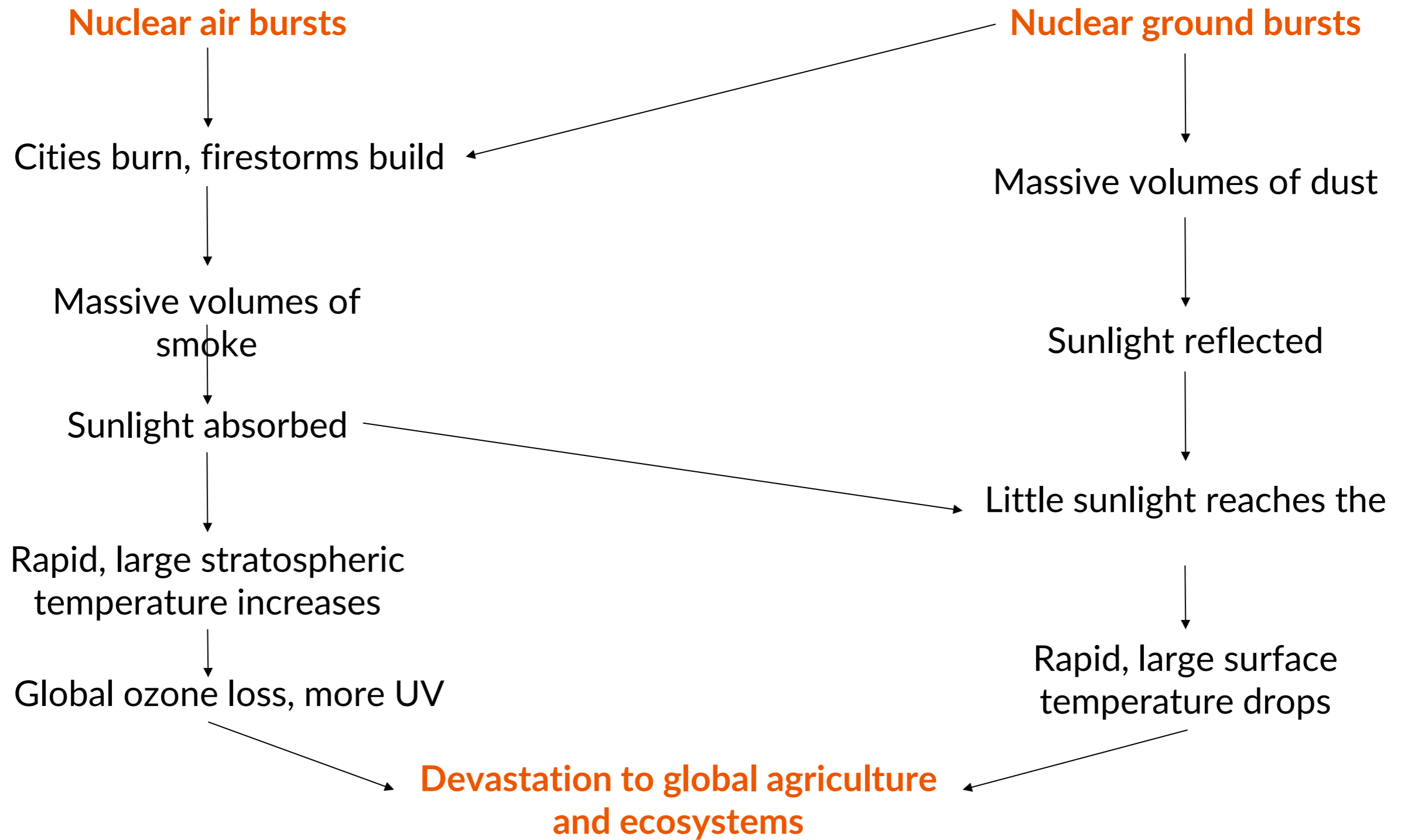


Musroom cloud, minutes after Hiroshima bombing, taken by Bob Carson, Enola Gay tail gunner

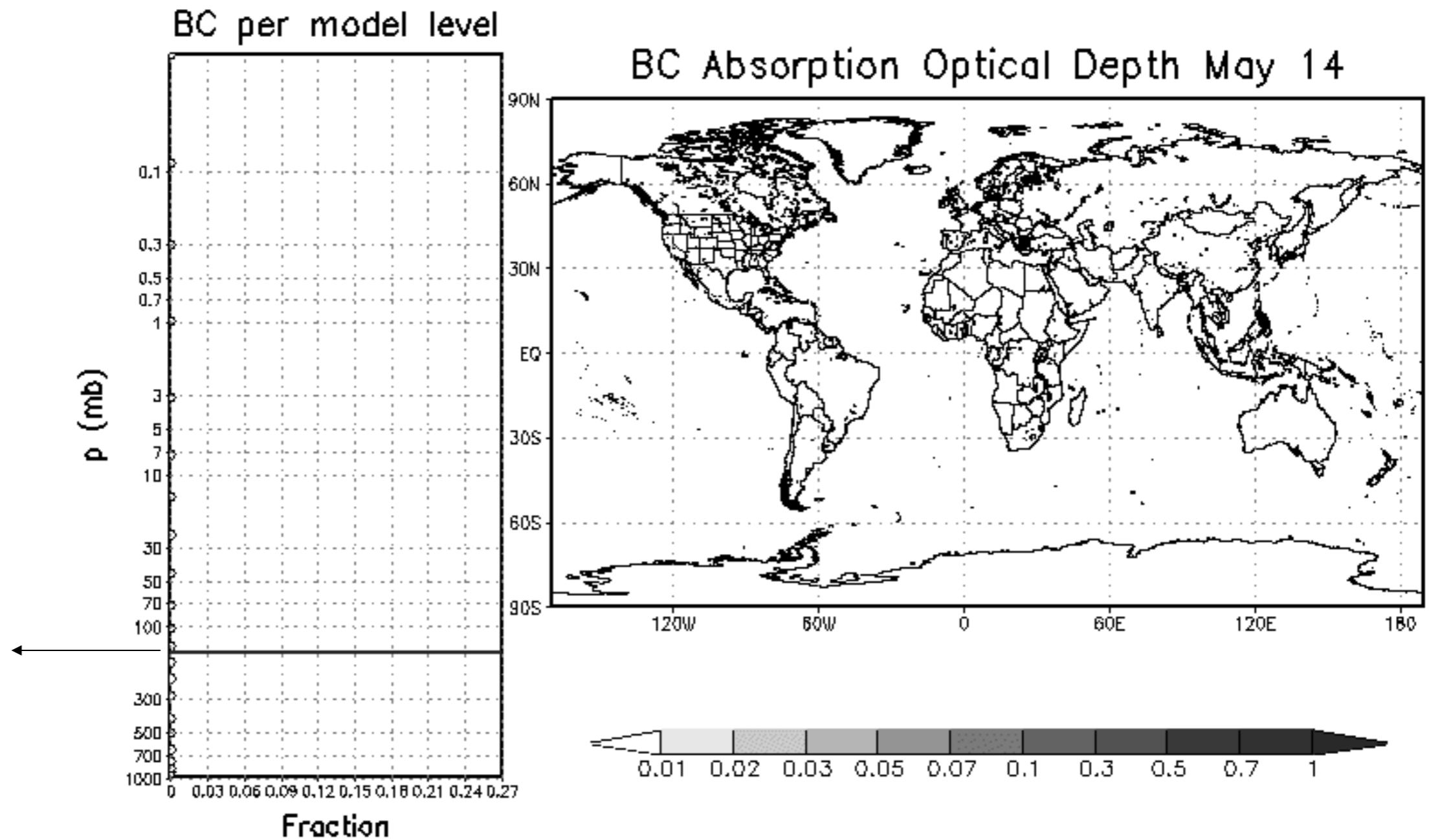


Pyrocumulonimbus smoke plume, more than 3 hours after the bombing

Nuclear Winter



Soot in Stratosphere after Nuclear Conflict between India and Pakistan



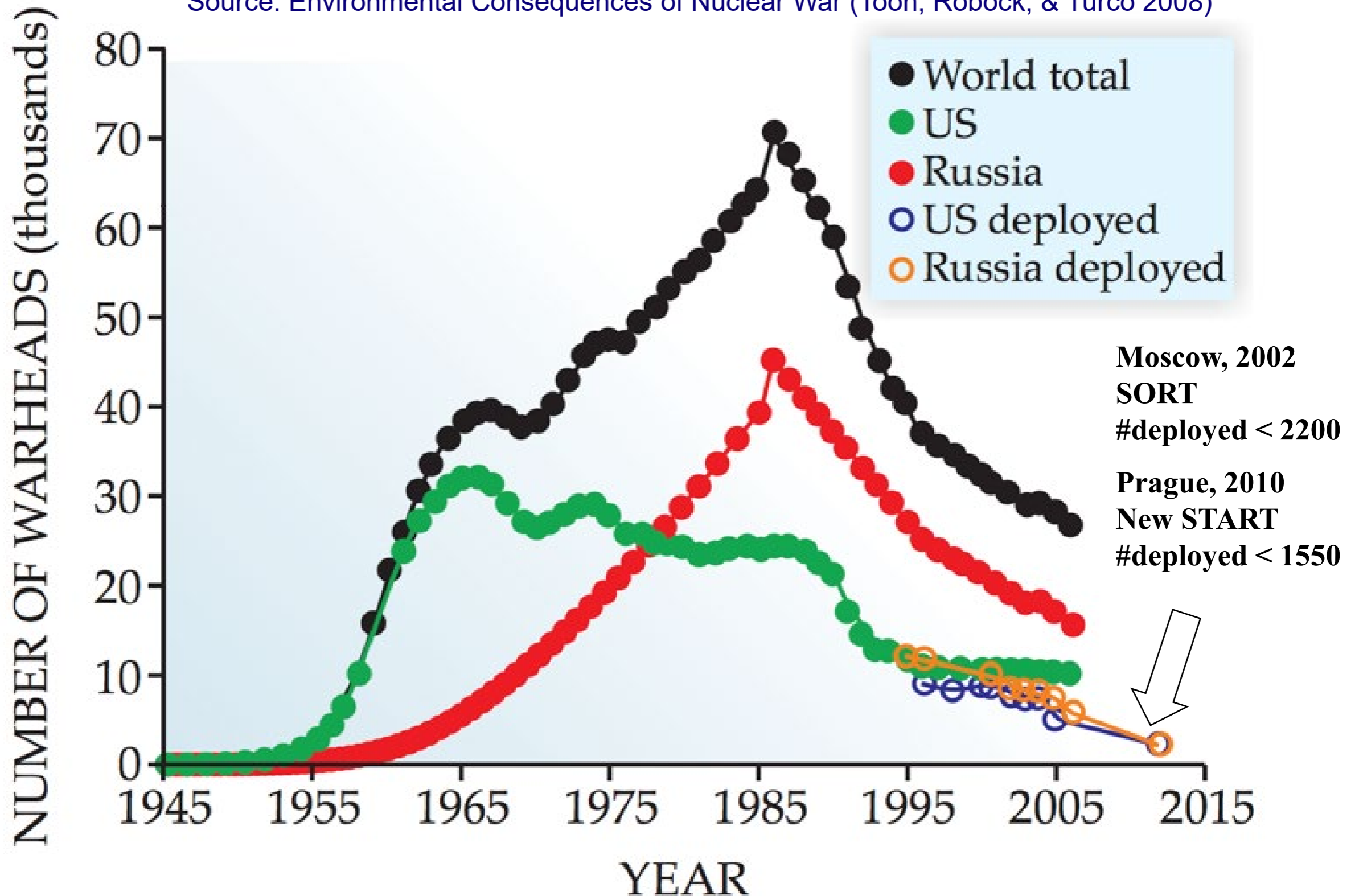
[Robock et al., 2007](#)

Key Assumptions

- Most targeted cities will experience large firestorms
- Soot from the all firestorms will loft into the stratosphere
- Soot will stay in the stratosphere for an extended period of time, leading to extended cooling conditions on the surface

Effects of Nuclear War – Input to War Scenarios for Illustration

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



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

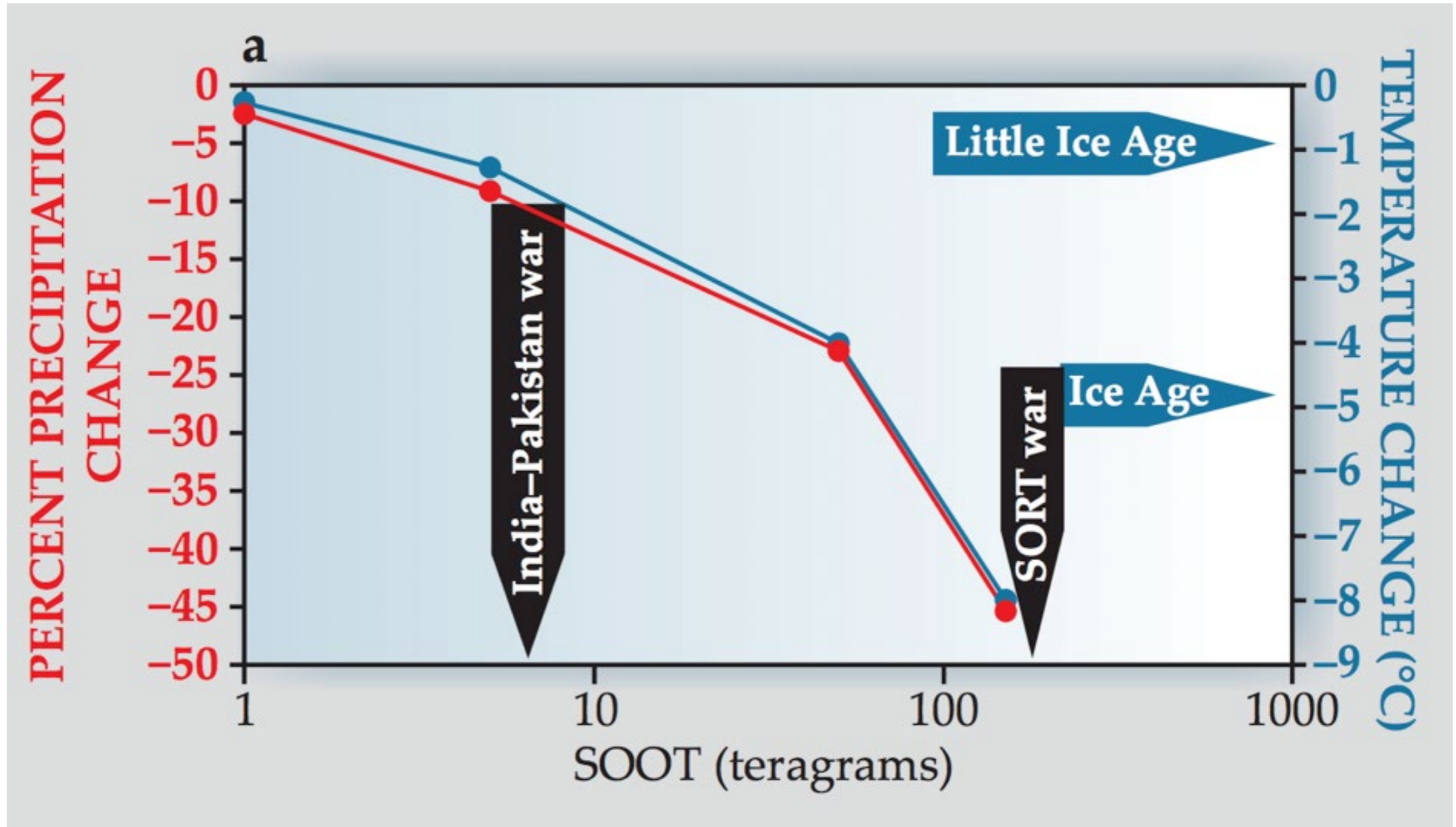
A regional war between India and Pakistan could generate 5 Tg of soot (5 million tons), sufficient to —

- 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)

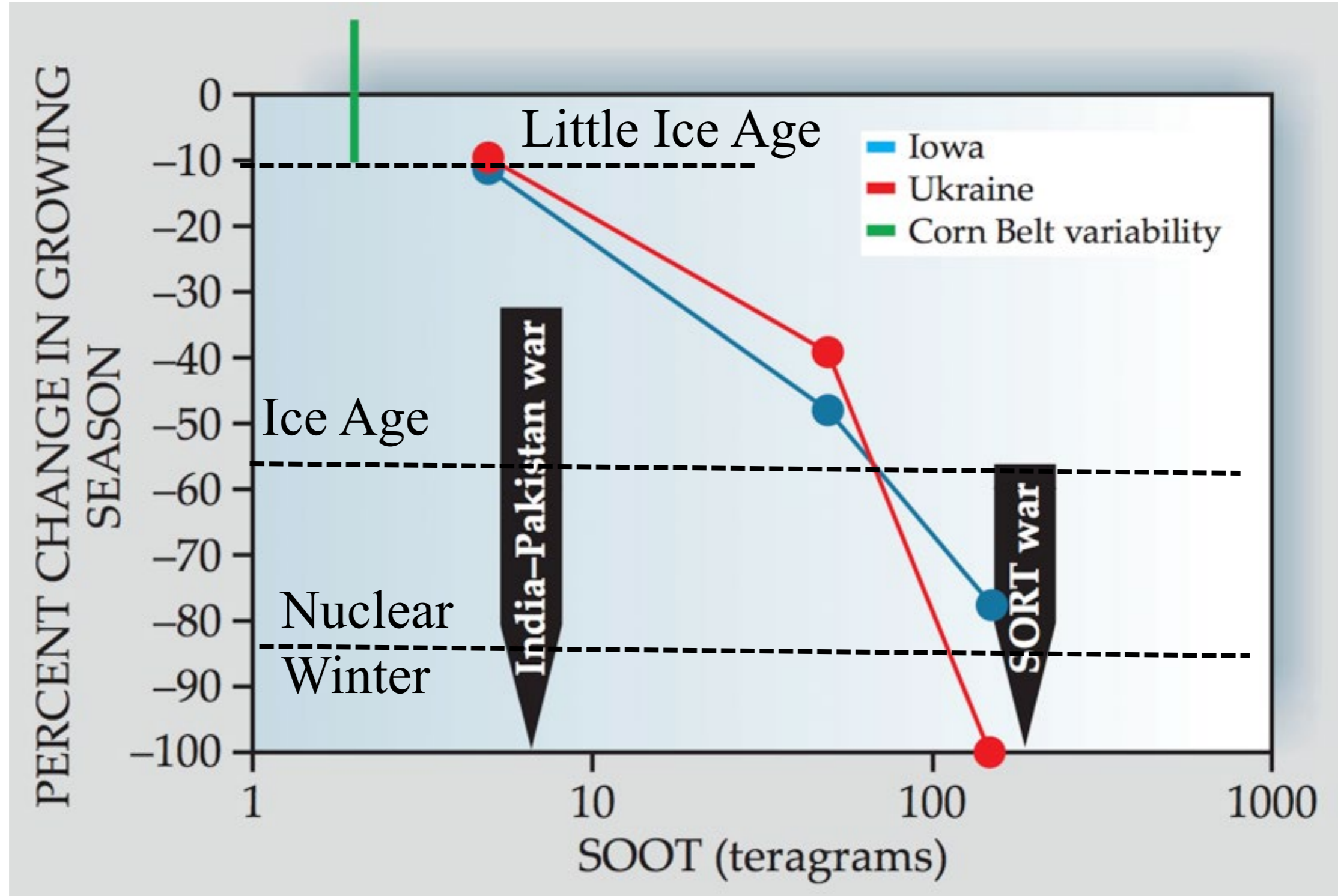
Effects of Nuclear War: Change in Precipitation and Temperature

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



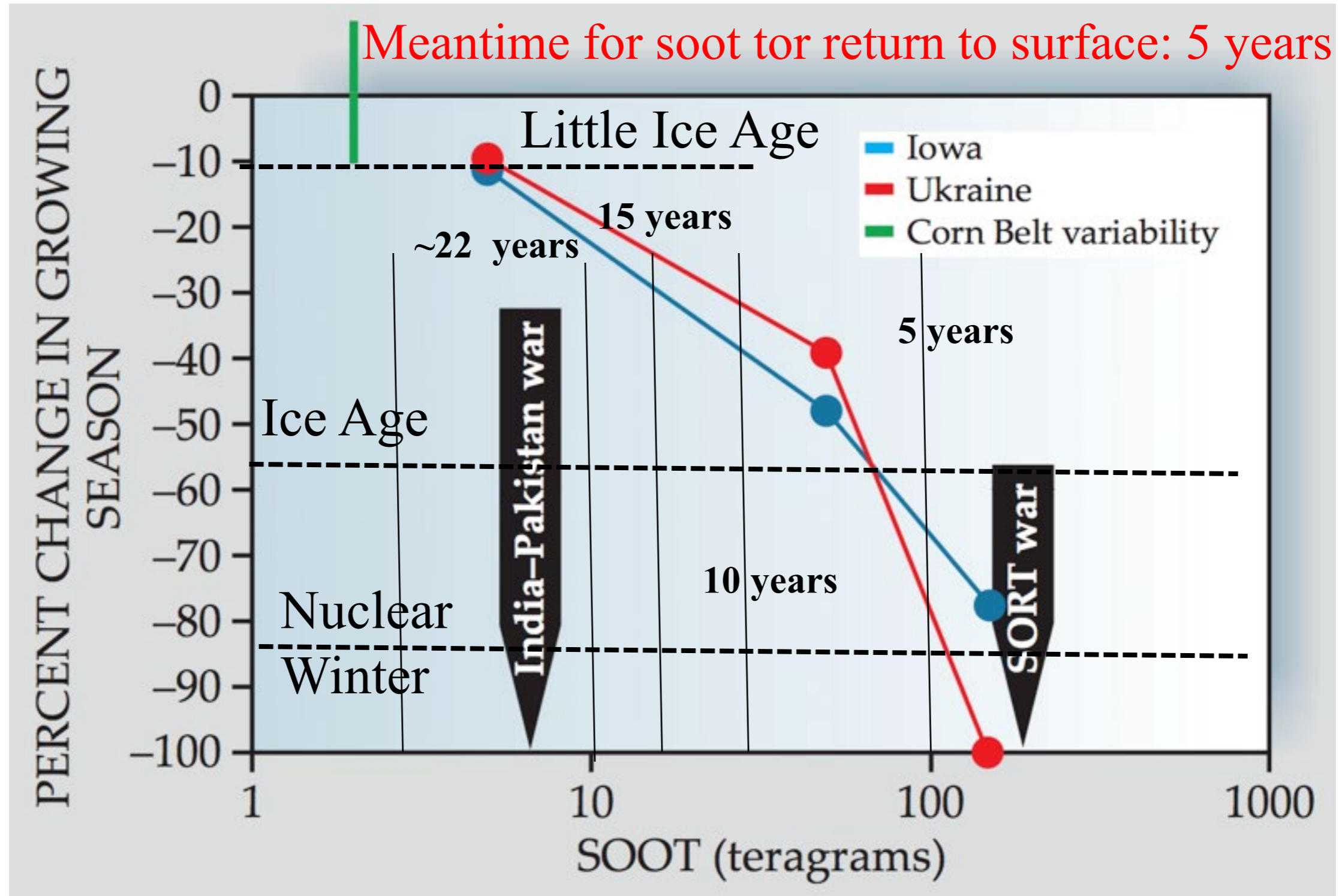
Effects of Nuclear War: Percent Change in Growing Season

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



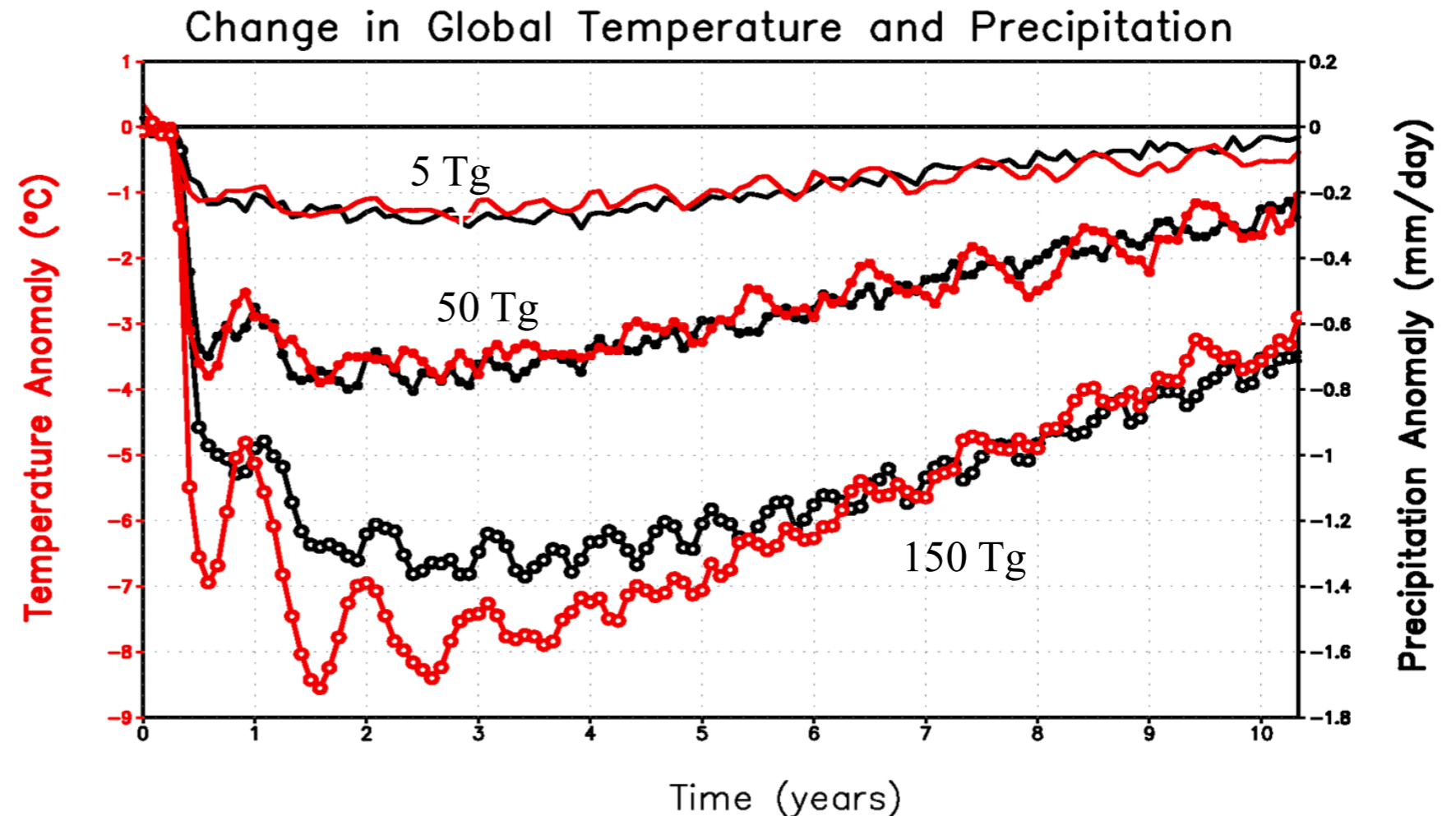
How Long from Nuclear Winter to Little Ice Age?

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



Global Temperature and Precipitation Decline

- Indian-Pakistan War
~ 1-1.5 degree Celsius drop in average temperature followed by slow recovery
- Significantly smaller impact relative to SORT war case
- Still significant impact on global agriculture

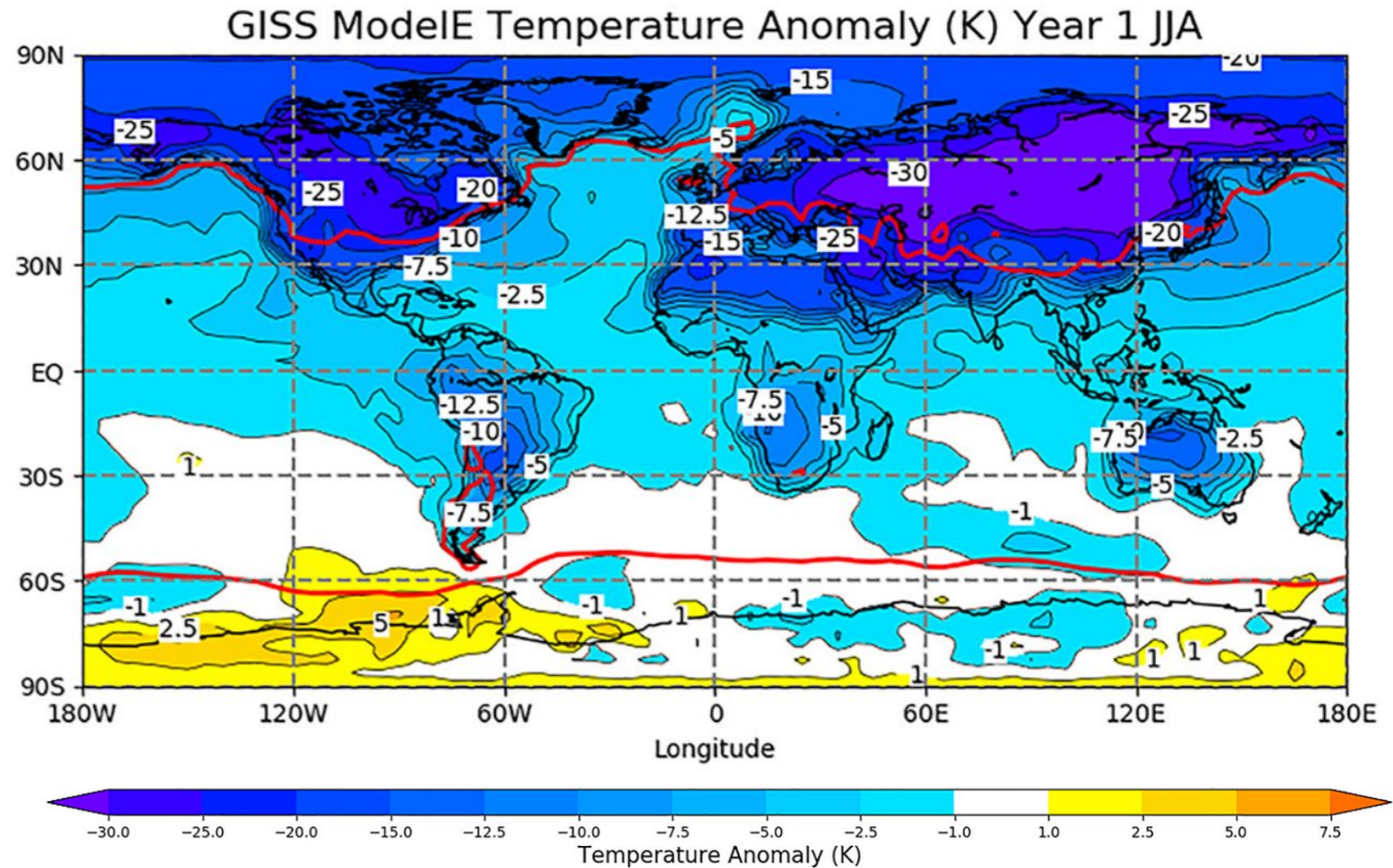


[Robock et al., 2007](#)

Global Temperature Drop (SORT War)

Temperature drop
June-July-August (JJA) after
soot injection

The **red contour** represents the
border north of which the
temperature is **below freezing**
during the summer.



Journal of Geophysical Research: Atmospheres / Volume 124, Issue 15 / pp. 8522-8543

Research Article | [Free Access](#)

Nuclear Winter Responses to Nuclear War Between the United States and Russia
in the Whole Atmosphere Community Climate Model Version 4 and the Goddard
Institute for Space Studies ModelE

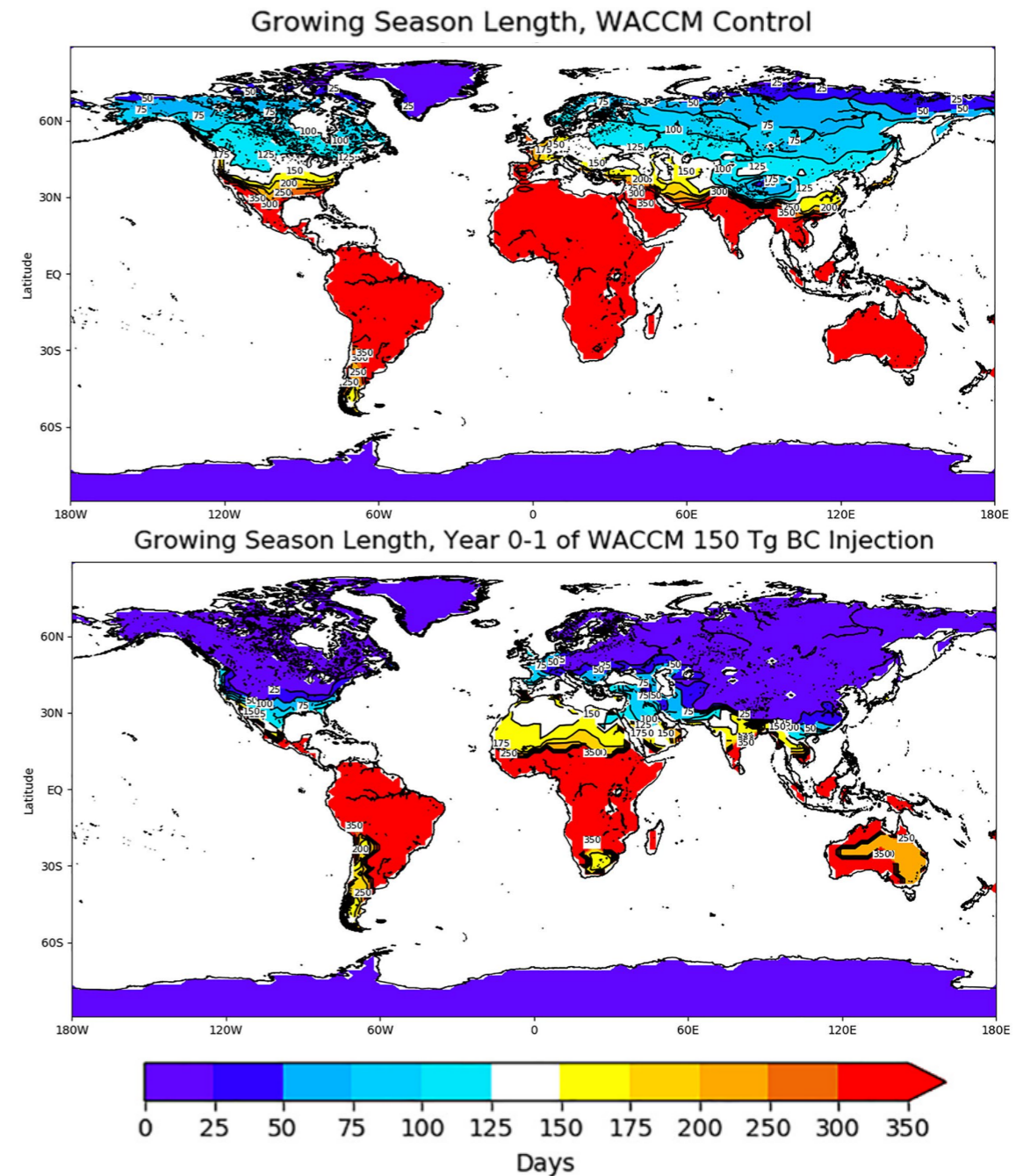
Joshua Coupe✉, Charles G. Bardeen, Alan Robock, Owen B. Toon

First published: 23 July 2019

<https://doi.org/10.1029/2019JD030509>

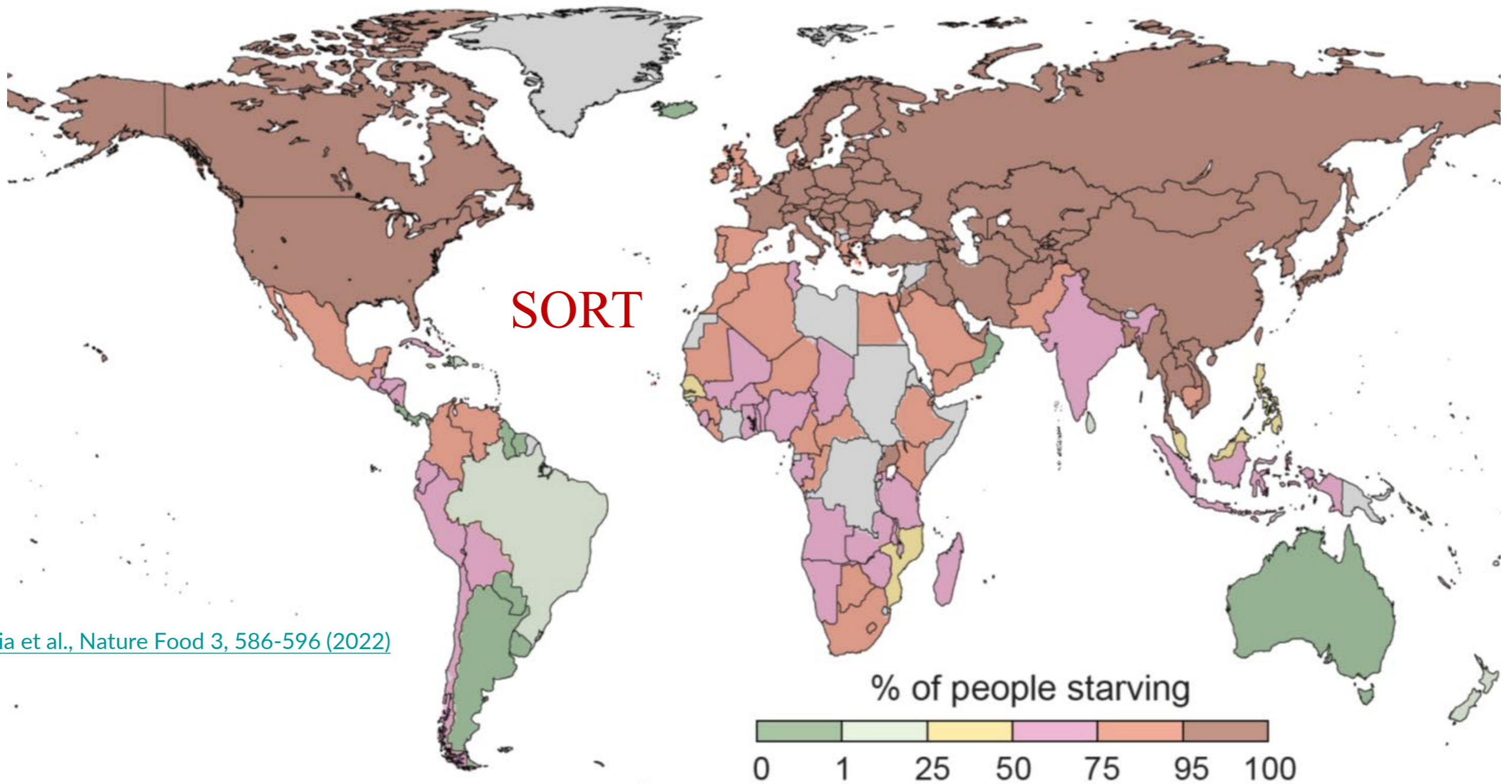
Change in growing season (SORT War)

- Length of growing season drops below **50 days** across most of US
- Most of Eastern European growing season reduced below **50 days**
- Russian growing season reduced below **25 days**



[Coupe et al., 2019](#)

Proportion of population that would starve to death Partial Livestock case, 150 Tg, 50% livestock feed to human consumption, no trade



[Xia et al., Nature Food 3, 586-596 \(2022\)](#)

Food availability changes (% of calories) in nations with nuclear weapons from the major food crops (maize, rice, soybean and spring wheat) and marine fish averaged over the **first five years** after simulated nuclear conflicts. The changes are **only from the climate impacts**.

Nations	5 Tg	16 Tg	27 Tg	37 Tg	47 Tg	150 Tg
China	-13.2	-38.5	-59.0	-71.1	-79.3	-97.2
France	-3.5	-16.6	-30.1	-29.4	-41.8	-97.5
India	-4.4	-5.5	-9.0	-14.6	-22.5	-57.1
Israel	2.7	-0.2	-5.9	-7.0	-15.7	-78.0
North Korea	-22.4	-76.8	-85.8	-89.4	-92.1	-99.5
Pakistan	-1.8	-2.1	-8.8	-20.0	-30.6	-65.7
Russia	-13.7	-53.6	-73.3	-80.6	-84.5	-99.7
United Kingdom	0.1	-23.1	-39.2	-57.9	-69.6	-99.5
United States	-10.5	-41.3	-59.3	-72.4	-81.5	-98.9
Global	-6.0	-18.7	-30.1	-38.3	-45.6	-79.0

[Xia et al., Nature Food 3, 586-596 \(2022\)](#)

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.”**

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?

- (A) 1 year
- (B) 3 years
- (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)