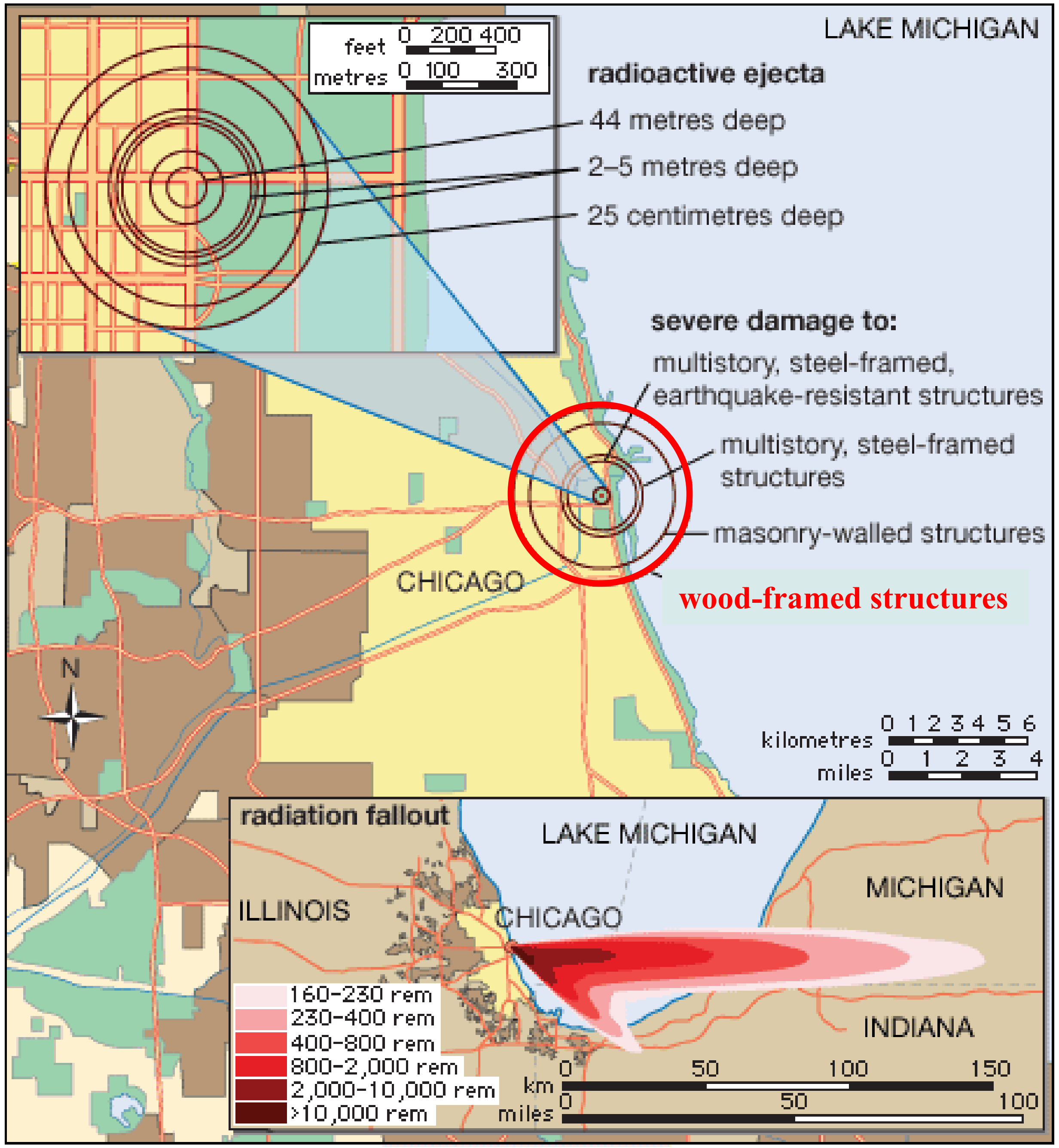
# Physics 280: Effects of Nuclear Explosions

## Plan for This Session

Module 3:
Effects of nuclear explosions

Impact of a 500 kiloton device detonated in Chicago



# 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




22p280 Nuclear Explosions, p.

# 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.

<u>Technically challenging to synthesize and effectively deliver chemical agents.</u>

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.

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# 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 … ?

# Physics/Global Studies 280: Session 8

## Plan for This Session

Announcements & Questions:

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

Office hours: today from 5-6 pm (404 Grainger Library)
Wed from 1-4pm & 5-7pm (404 Grainger Library or via Zoom)
see https://courses.physics.illinois.edu/PHYS280/sp2022/staff-info.html

Module 3 continued: Effects of nuclear explosions

# News

**American Physical Society Releases New Report on US Missile Defense**
**Capabilities of the US missile defense systems are likely to remain low for next 15 years**

**COLLEGE PARK, MD, February 9, 2022** — The capabilities of US systems intended to defend against the nuclear-armed intercontinental ballistic missiles (ICBMs) that North Korea may have or could obtain are currently low and will likely continue to be low for the next 15 years, according to a new technical report commissioned by the American Physical Society's Panel on Public Affairs.

Titled "Ballistic Missile Defense: Threats and Challenges," the report notes that despite decades of effort, no missile defense system thus far developed has been shown to be effective against realistic ICBM threats. ICBMs are ballistic missiles with a range of more than 3,500 nautical miles.

"With the Biden administration's review of missile defense expected later this year, it is critical to have a careful technical assessment of its capabilities that our leaders can use to more clearly evaluate the economic and security costs of pursuing missile defense systems, as well as a careful assessment of their possible benefits," said Frederick K. Lamb, chair of the study, physics professor at the University of Illinois at Urbana-Champaign, and a missile defense expert. "Having looked at the issue in detail, we have come to the conclusion that the current US missile defense system is unreliable and ineffective against even the small number of relatively unsophisticated nuclear-armed ICBMs that we considered, and that creating a reliable and effective defense remains a daunting challenge."

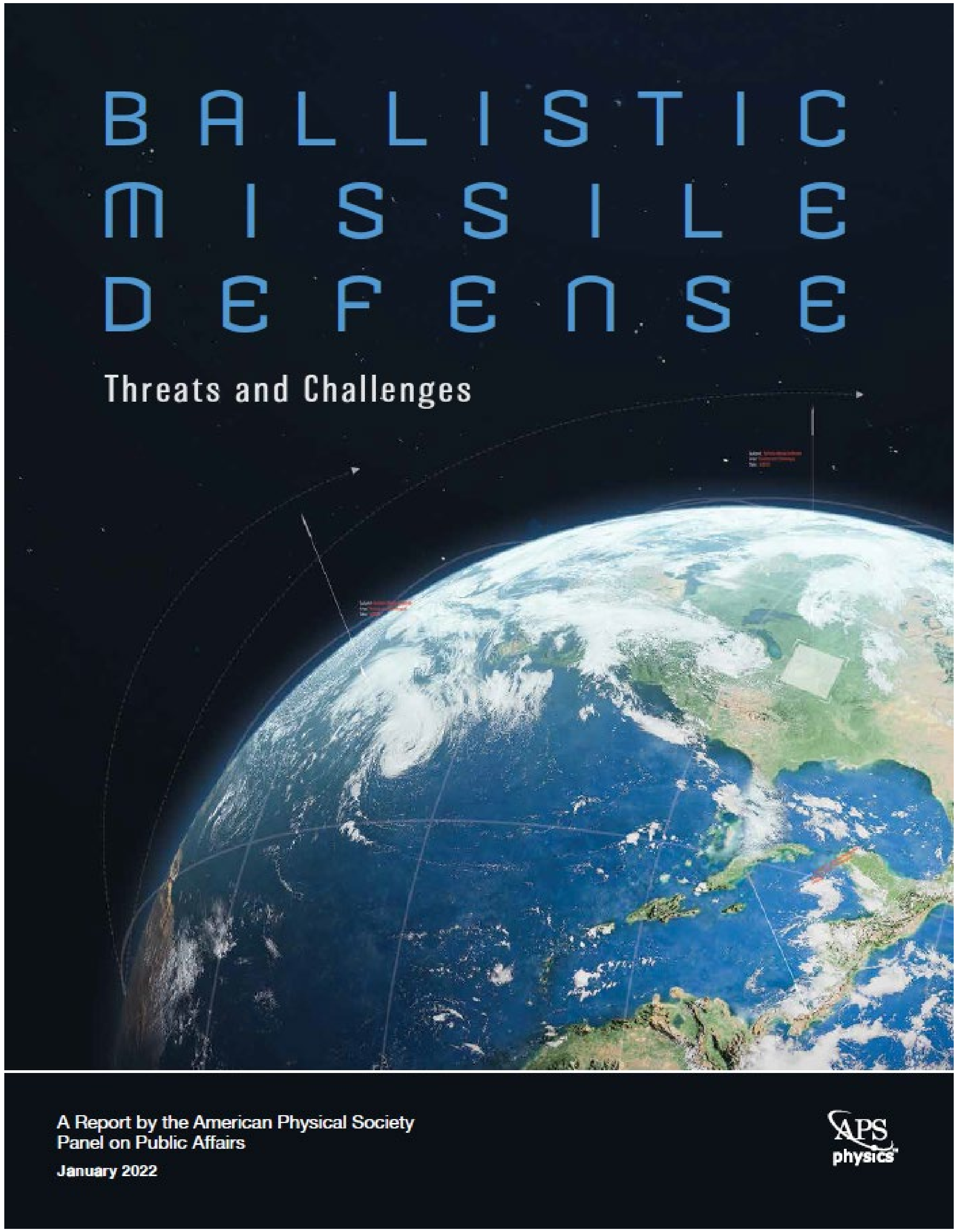
The report, the work of a 13-member study group of physicists and engineers, examined whether current and proposed systems intended to defend the United States against nuclear-armed North Korean ICBMs are—or could be made—effective in preventing a successful ICBM attack by North Korea on the United States.

….

"Despite decades of work and costs totaling more than $350 billion, the United States still has not been able to field a defense that would be able to intercept even a small number of relatively unsophisticated ICBMs reliably and effectively," said Lamb. "But even the pursuit of such a defense has wider implications, including giving Russia and China reasons to expand their nuclear arsenals. The costs and benefits of this effort need to be weighed carefully."

News

# American Physical Society Releases New Report on US Missile Defense Capabilities of the US missile defense systems are likely to remain low for next 15 years




## STUDY GROUP MEMBERS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*Institutions are listed for purposes of identification only. Any opinions, findings, conclusions, or recommendations expressed in this report are those of the Study Group members, and do not necessarily represent the official views, opinions, or policies of their institutions.*

**Dr. Coyle passed away as the study was ending.*

## ABOUT APS & POPA

Founded in 1899 to advance and diffuse the knowledge of physics, the American Physical Society (APS) is now the nation's leading organization of physicists with approximately 55,000 members in academia, national laboratories and industry. APS has long played an active role in the federal government; its members serve in Congress and have held positions such as Science Advisor to the President of the United States, Director of the CIA, Director of the National Science Foundation and Secretary of Energy.

This report was overseen by the APS Panel on Public Affairs (POPA). POPA routinely produces reports on timely topics being debated in government so as to inform the debate with the perspectives of physicists working in the relevant issue areas.

## AUTHORSHIP

The American Physical Society has sole responsibility for the contents of this report, and the questions, findings, and recommendations within.

## ACKNOWLEDGEMENTS


The Study Group is grateful to the many experts who were kind enough to brief the Study Group on issues related to the study or to answer our questions. We also wish to thank the technical and subject matter experts who generously agreed to serve as external reviewers and provided valuable comments and suggestions on the draft of the report they reviewed.

The Study Group wishes to express its appreciation to the APS Panel on Public Affairs for commissioning this study, for providing advice as it developed, and for reviewing and approving the final report. We also thank the APS Physics Policy Committee for its review of the report and the APS Council for reviewing the report and approving its release.

# 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 ~ $10^7$ C (~ center of Sun)
- Pressure of vapor is ~ $10^6$ atmospheres

The energy is *initially* distributed as follows —

| | |
|---|---|
| • Low energy X-rays (1 keV) | ~ 80% |
| • Thermal energy of weapon debris | ~ 15% |
| • Prompt nuclear radiation (n, $\gamma$, $\beta$) | ~ 5% |

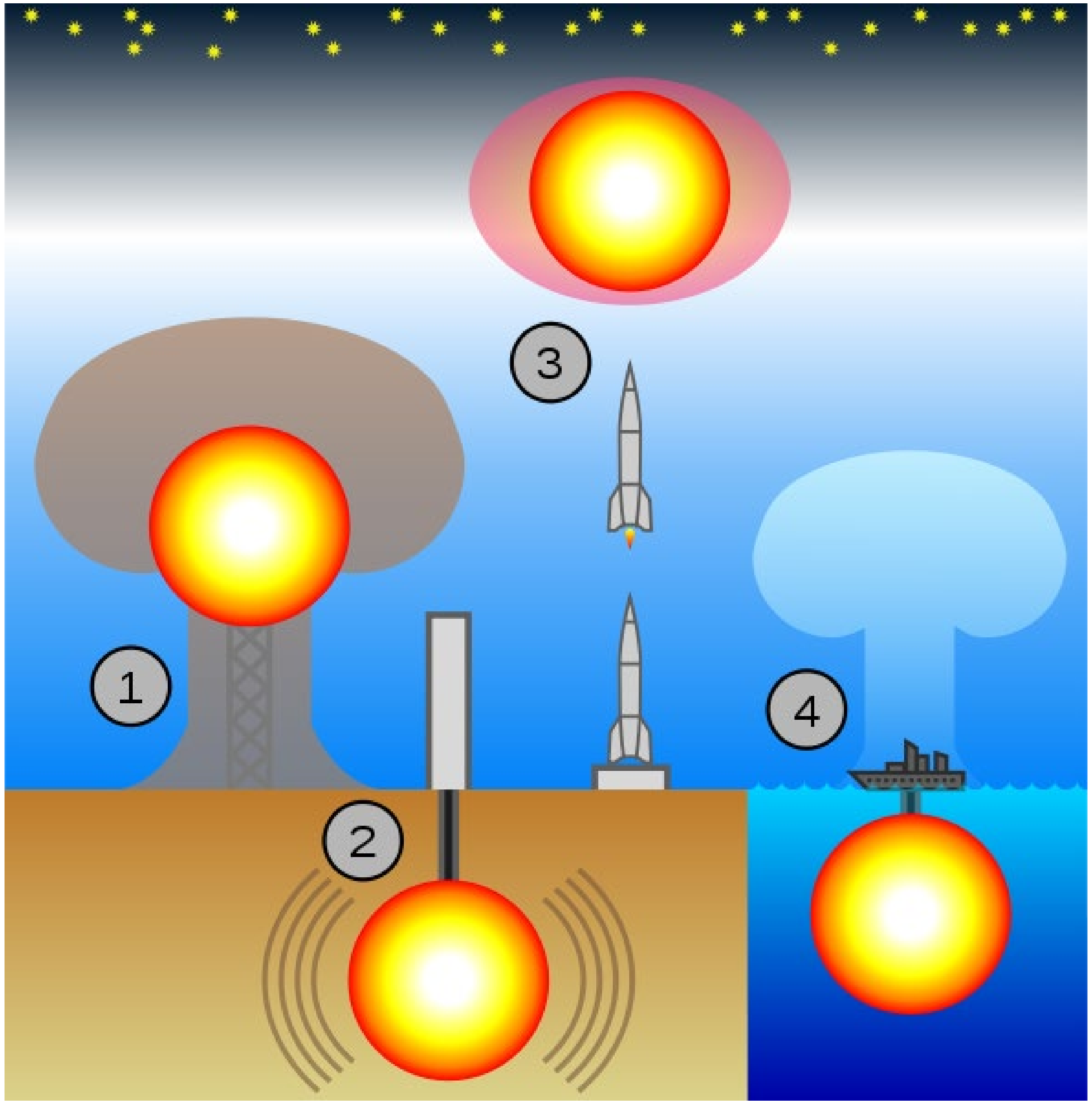
# Subsequent Evolution of Nuclear Explosions

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.*

# Nuclear Explosions



Credit: Wikipedia (nuclear weapons testing)

Possible environments —

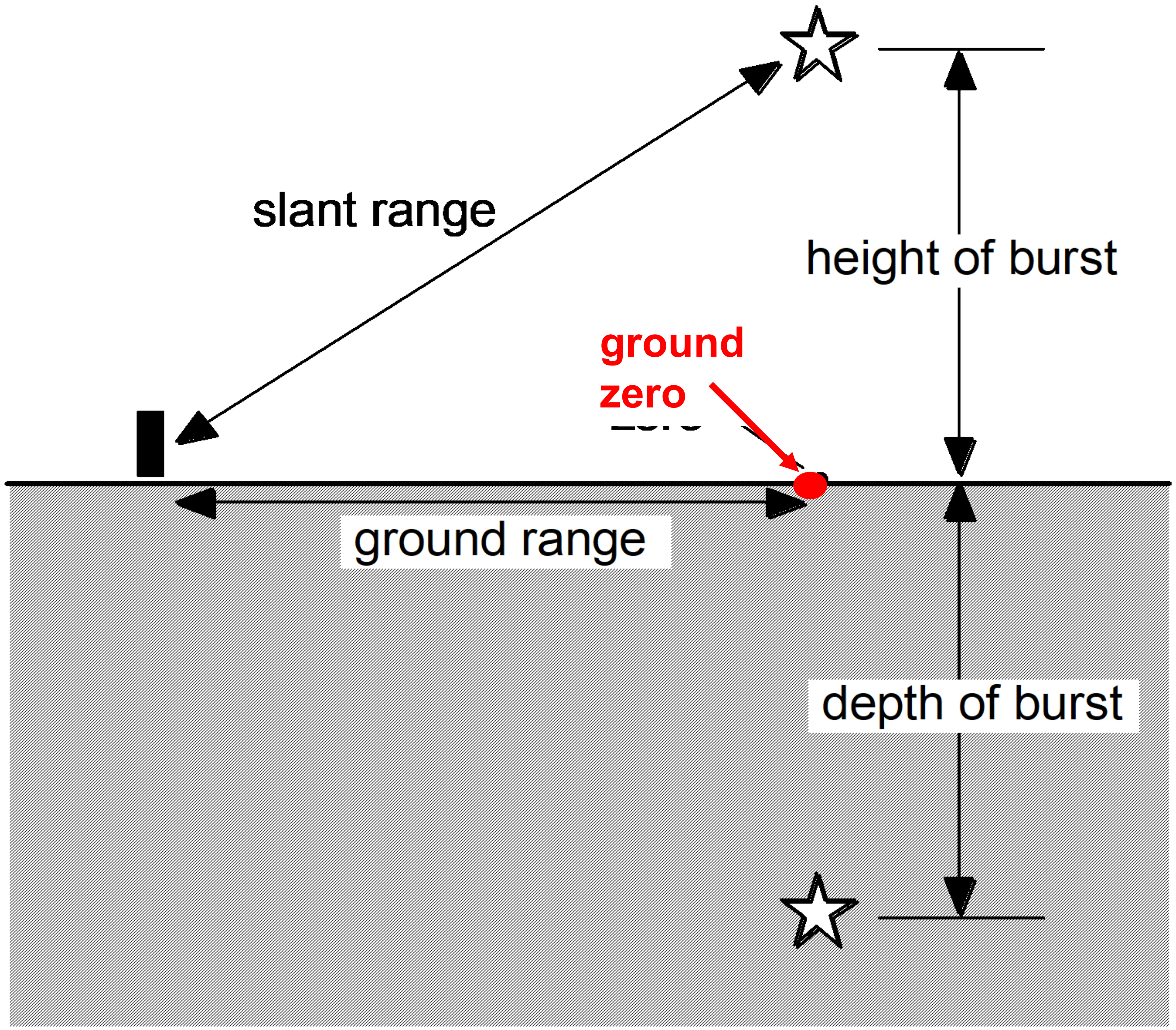
1. Air and surface bursts
2. Underground bursts

3a. Explosions at high altitude (above 30 km)

3b. Explosions in space

4. Underwater bursts

# Nuclear Explosion Geometries

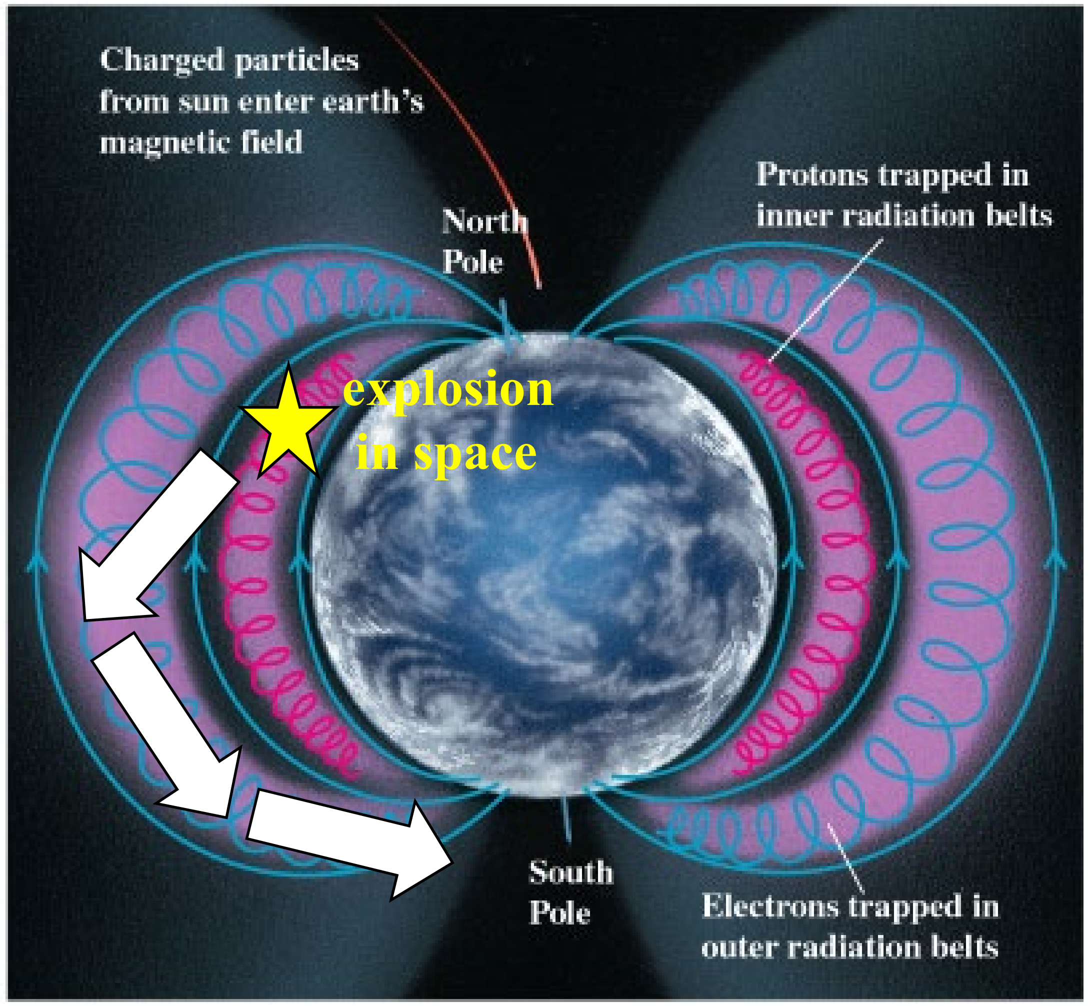


# Nuclear Explosions in Space

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)

**Charged particles trapped in the earch magnetic field**
**Van Allen Radiation Belt**




(a)



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

# 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


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

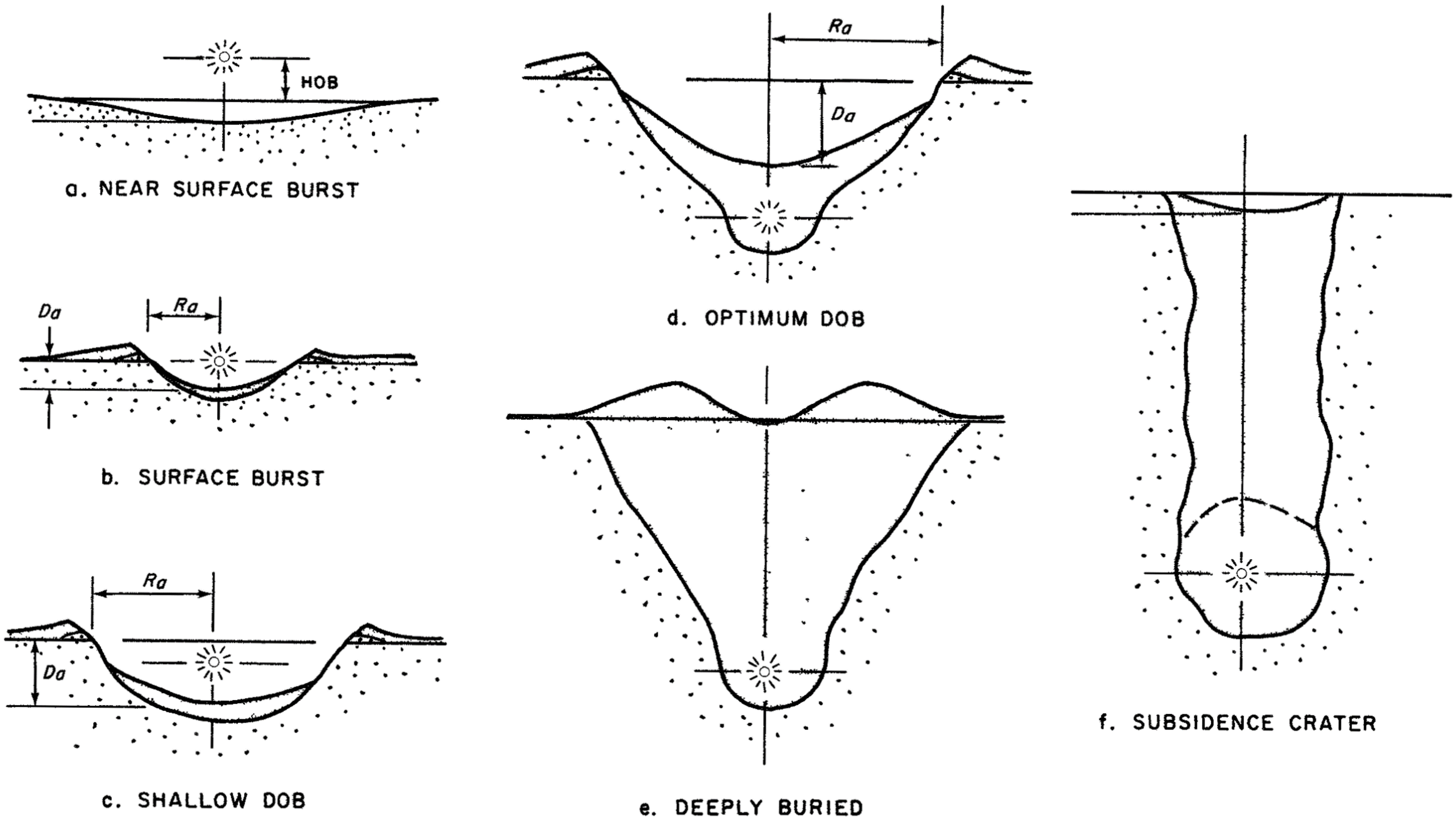
# Underground Nuclear Explosions: Test Deployment & Assembly

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)

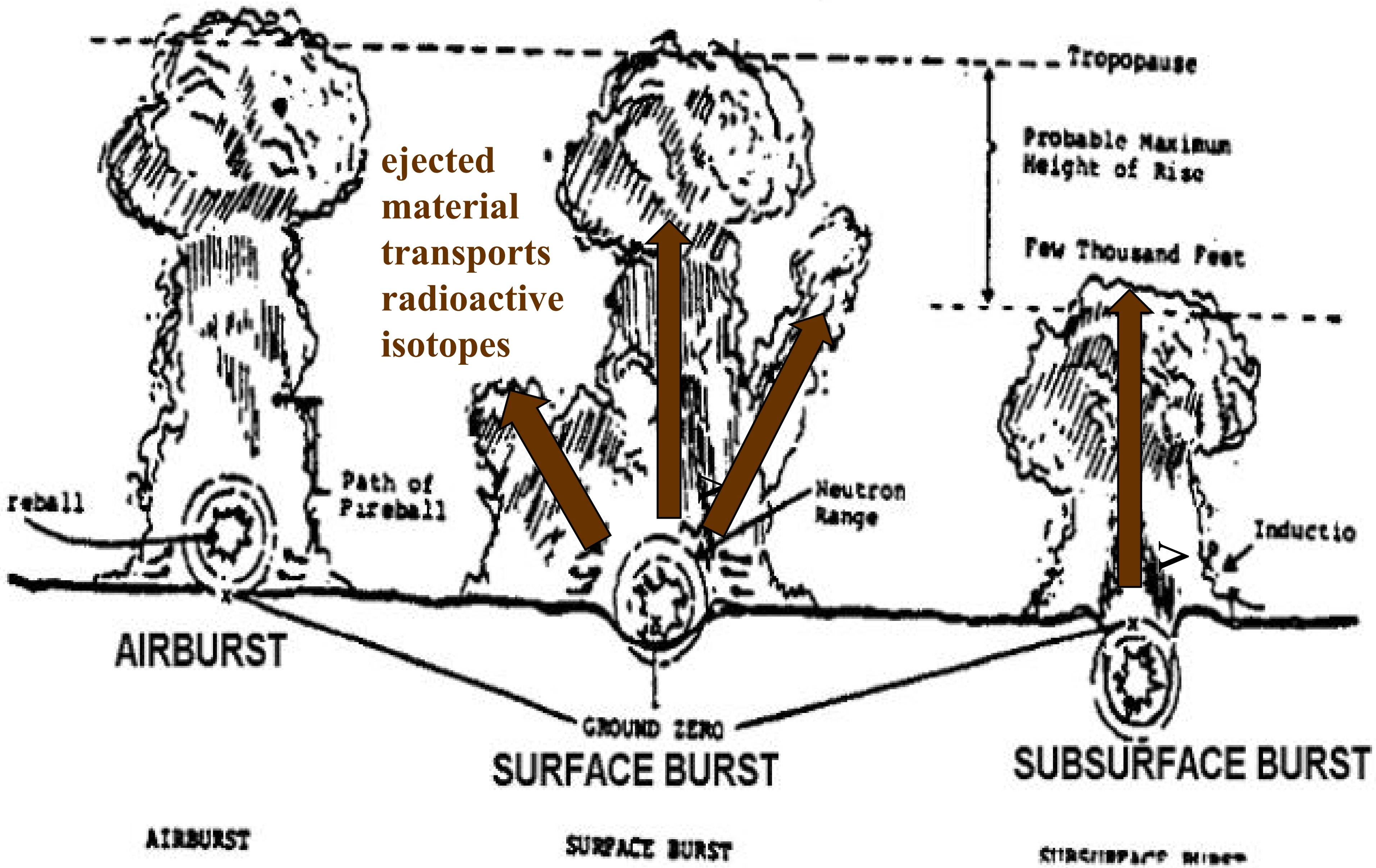


# Underground Nuclear Explosions- Nevada Test Site

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

Total of 904 tests
at the Nevada test site

# 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 kt
  Fireball touches ground unless HOB > 500 ft
- Y = 100 kt
  Fireball touches ground unless HOB > 1200 ft
- Y = 1 Mt
  Fireball touches ground unless HOB > 3000 ft

# Air and Surface Bursts

## Sequence of events —

- Fireball forms and rapidly expands

  Example: 1 Mt explosion

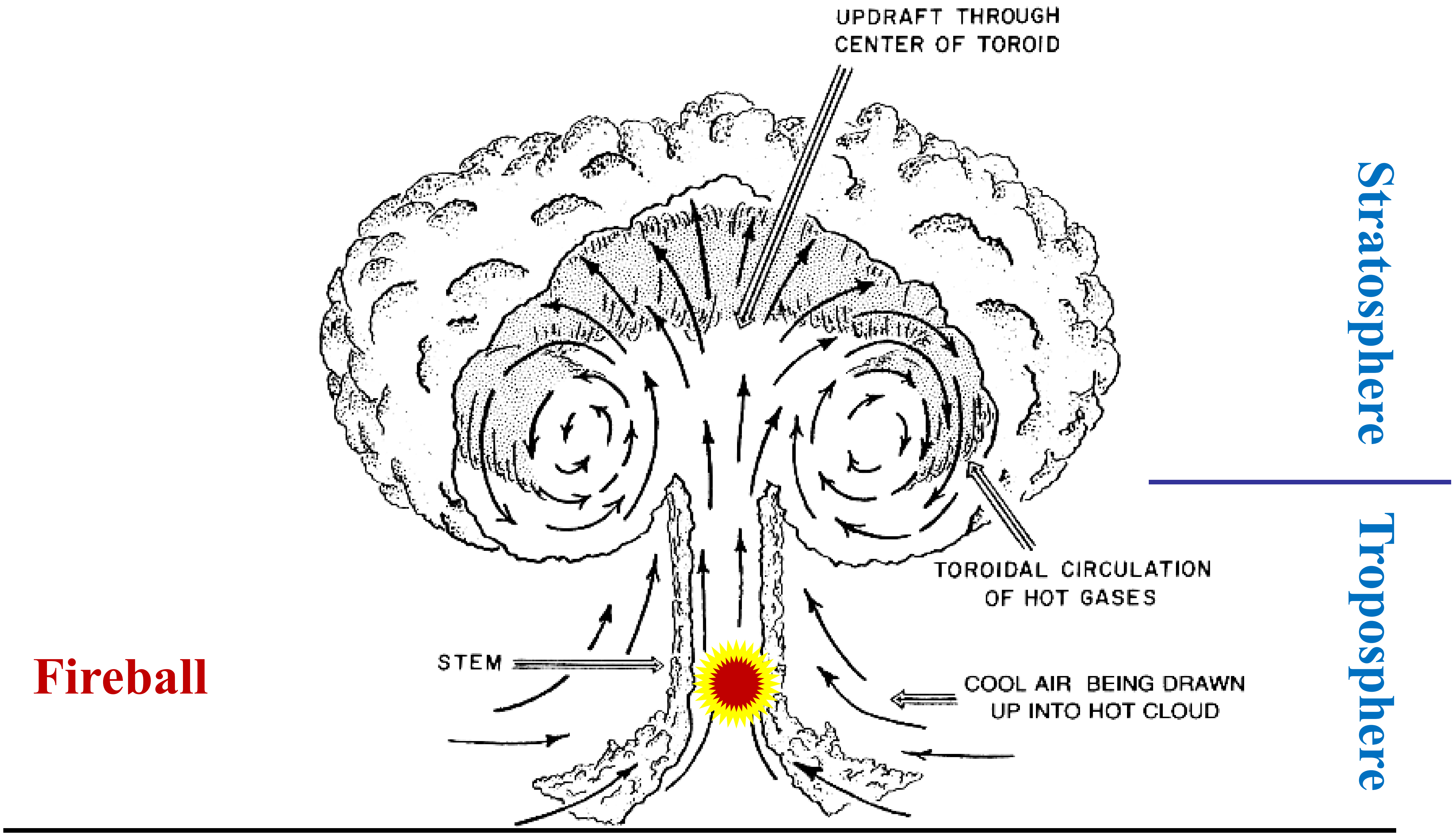
| Time | Diameter | Temperature |
|---|---|---|
| 1 ms (= $10^{-3}$ s) | 440 ft | — |
| 10 s | 5,700 ft | 6,000 C |

- 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



# 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) | ~ 5% |
| • Prompt nuclear radiation | ~ 5% |
| • Electromagnetic pulse | « 1% |
| • Thermal radiation | ~ 35% |
| • Blast | ~ 50% |
| • Residual nuclear radiation | ~ 10% |

# Physics/Global Studies 280: Session 9

## Plan for This Session

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Module 3 continued: Effects of nuclear explosions

# News

The New York Times | https://www.nytimes.com/2022/02/05/science/ukraine-nuclear-weapons.html

## *Ukraine Gave Up a Giant Nuclear Arsenal 30 Years Ago. Today There Are Regrets.*

When the Soviet Union collapsed, Ukraine turned over thousands of atomic weapons in exchange for security guarantees from Russia, the United States and other countries.

**By William J. Broad**

Feb. 5, 2022

At the end of the Cold War, the third largest nuclear power on earth was not Britain, France or China. It was Ukraine. The Soviet collapse, a slow-motion downfall that culminated in December 1991, resulted in the newly independent Ukraine inheriting roughly 5,000 nuclear arms that Moscow had stationed on its soil. Underground silos on its military bases held long-range missiles that carried up to 10 thermonuclear warheads, each far stronger than the bomb that leveled Hiroshima. Only Russia and the United States had more weapons.

The removal of this arsenal often gets hailed as a triumph of arms control. Diplomats and peace activists cast Ukraine as a model citizen in a world of would-be nuclear powers.

But history shows the denuclearization to have been a chaotic upheaval that shook with infighting, reversals and discord among the country's government and military. At the time, both Ukrainian and American experts questioned the wisdom of atomic disarmament. The deadly weapons, some argued, were the only reliable means of deterring Russian aggression.

Today Ukraine has no easy path to producing or acquiring the materials to build a bomb. Even so, the nuclear genie is once again stirring as Russian troops encircle the nation and wage a shadow war in its easternmost provinces.

Destruction of Missile Silo in Ukraine

Dismantling of Ballistic Missile

News

The New York Times | https://www.nytimes.com/2022/02/05/science/ukraine-nuclear-weapons.html

# *Ukraine Gave Up a Giant Nuclear Arsenal 30 Years Ago. Today There Are Regrets.*

In the summer of 1993, John J. Mearsheimer, a prominent international relations theorist at the University of Chicago who was no stranger to controversy, lent his voice to the issue of atomic retention. He argued in Foreign Affairs that a nuclear arsenal was "imperative" if Ukraine was "to maintain peace." The deterrent, he added, would ensure that the Russians, "who have a history of bad relations with Ukraine, do not move to reconquer it."

In Kyiv, the government in 1993 went so far as to consider seizing operational control of its nuclear missiles and bombers. But that never came to pass.

Instead, Ukraine punted. It demanded that, in exchange for nuclear disarmament, it would need ironclad security guarantees. That was the heart of the agreement signed in Moscow early in 1994 by Russia, Ukraine and the United States.

In late 1994, the pledges got fleshed out. The accord, known as the Budapest Memorandum, signed by Russia, Ukraine, Britain and the United States, promised that none of the nations would use force or threats against Ukraine and all would respect its sovereignty and existing borders. The agreement also vowed that, if aggression took place, the signatories would seek immediate action from the United Nations Security Council to aid Ukraine.

Destruction of Missile Silo in Ukraine

Dismantling of Ballistic Missile

# News

The New York Times | https://www.nytimes.com/2022/02/05/science/ukraine-nuclear-weapons.html

## *Ukraine Gave Up a Giant Nuclear Arsenal 30 Years Ago. Today There Are Regrets.*

What undid the diplomatic feat was the "collective failure" of Washington and Kyiv to take into account the rise of someone like Vladimir V. Putin, Steven Pifer, a negotiator of the Budapest Memorandum and a former U.S. ambassador to Ukraine now at Stanford University, said in an interview. After Russian troops invaded Crimea in early 2014 and stepped up a proxy war in eastern Ukraine, Mr. Putin dismissed the Budapest accord as null and void.


Destruction of Missile Silo in Ukraine

Dismantling of Ballistic Missile

# Short-Term Physical Effects of a 1 Mt Burst

- Prompt nuclear radiation (lasts ~ $10^{-3}$ s)
  - —Principally $\gamma$, $\beta$ 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 $\gamma$ and $\beta$ 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 ~ 2x to ~ 100x
- Soot injected into the atmosphere cools Earth (“nuclear winter”)
  - —Caused by injection of dust, ash and soot into atmosphere

# 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 $^{o}$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" $\mathrm{T}$ :

  $\mathrm{T}$ = 60–70 % @ $D$ = 5 miles on a "clear" day/night

  $\mathrm{T}$ = 5–10% @ $D$ = 40 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 —

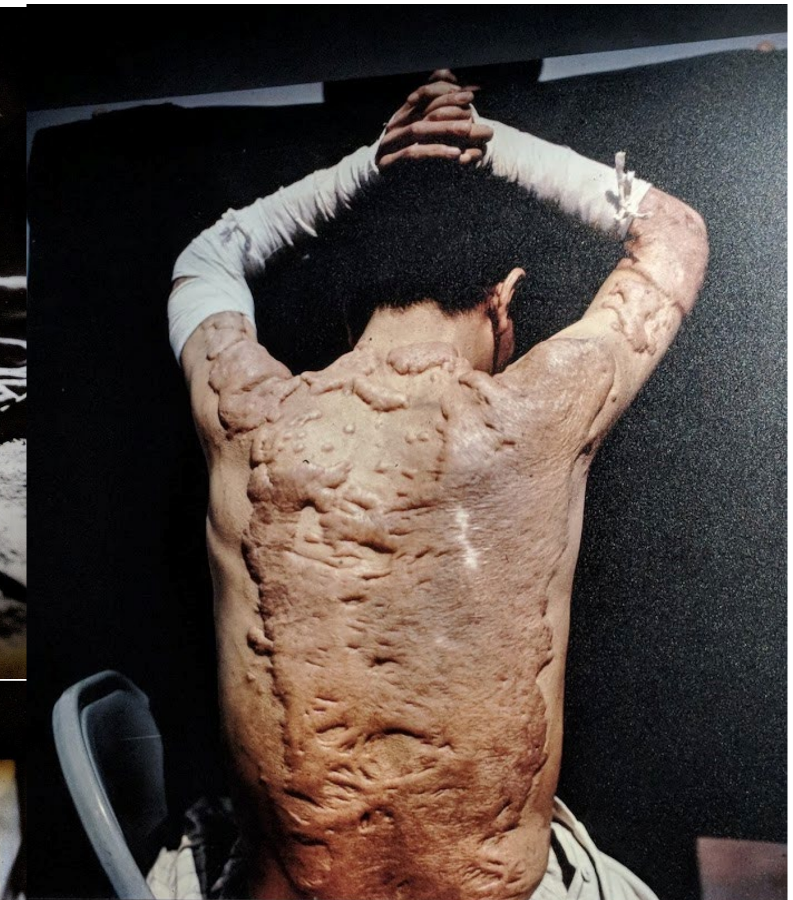
- Flash blindness (temporary)
- Retinal burns (permanent)
  - —Approximately 13 mi on a clear day
  - —Approximately 53 mi on a clear night
- Skin burns
- Ignition of clothing, structures, surroundings

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

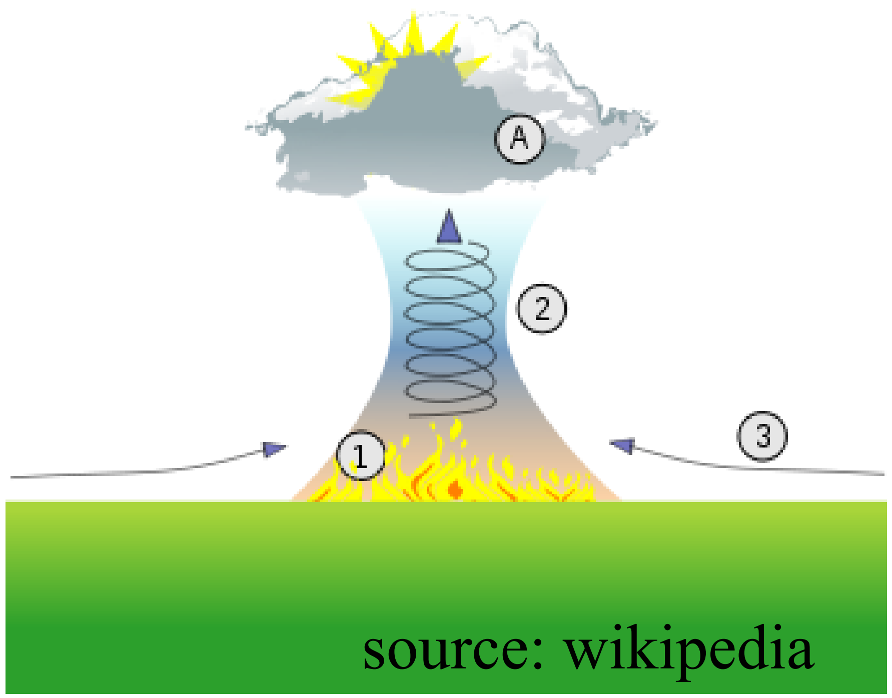
# Conflagrations Versus Firestorms

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 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

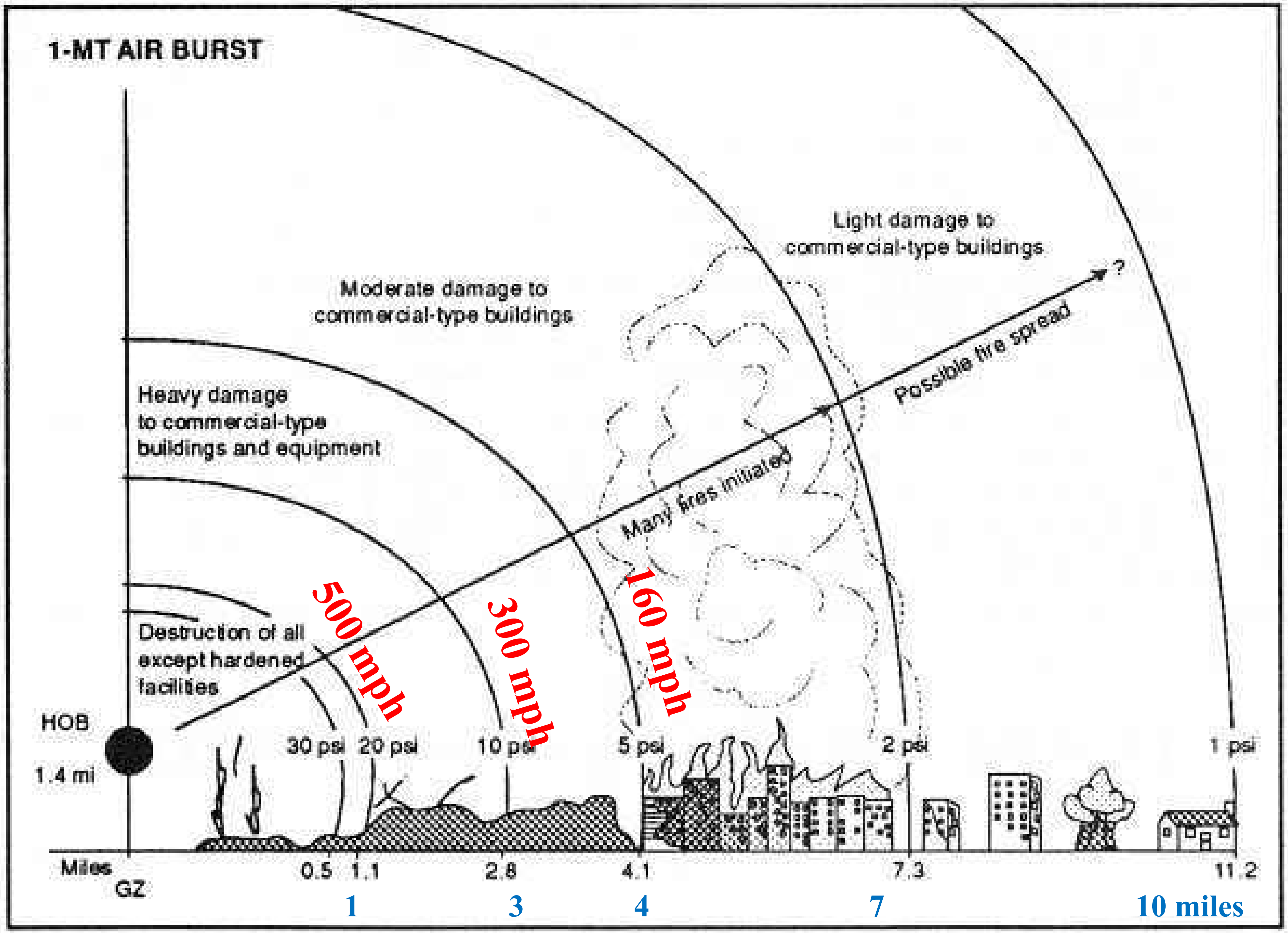
  – A strong outward wind that produces dynamic pressure that blows structures and victims outward

- The two pressures are directly related; both are usually given in psi = pounds per square inch

# Blast Wave Pressures and Winds

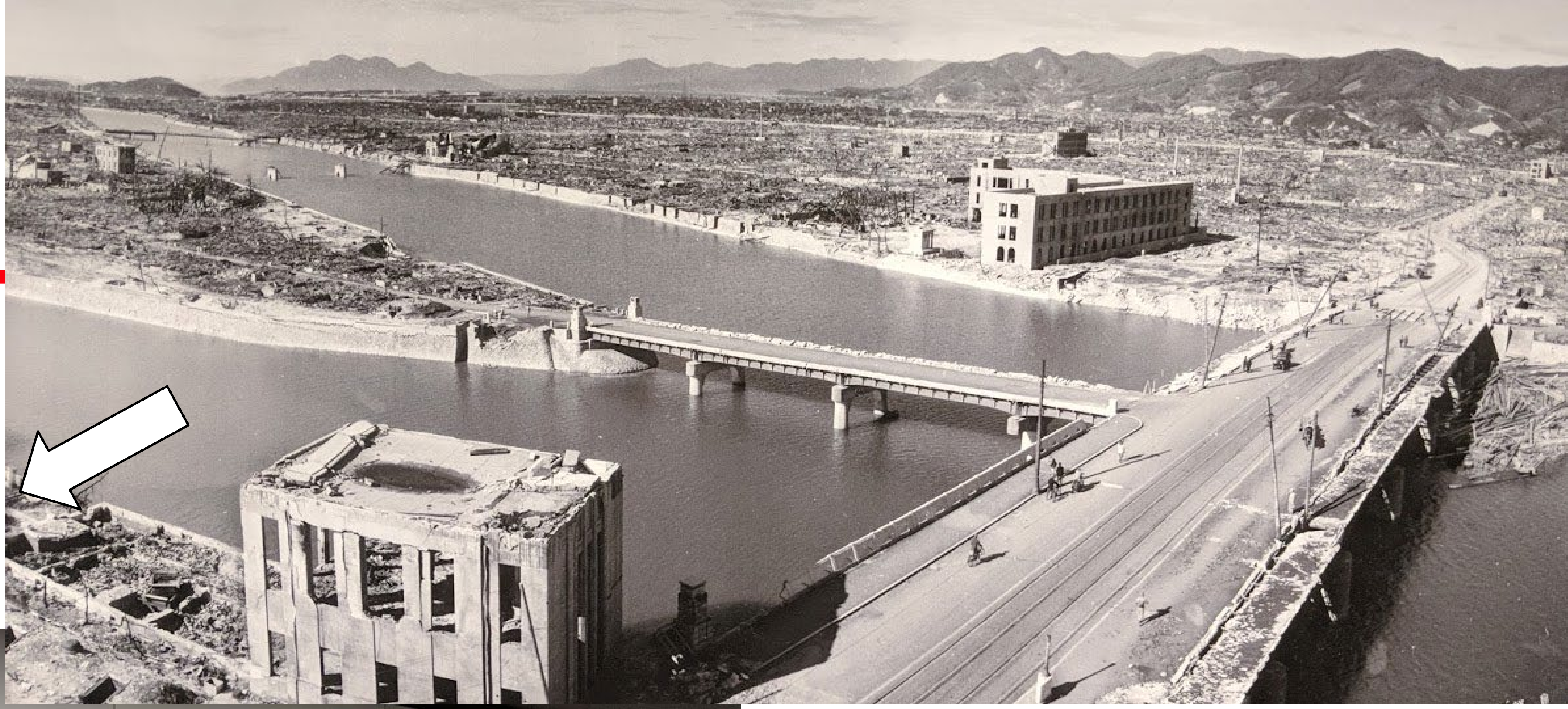
| Pressure (psi) | Dynamic Pressure (psi) | Wind (mph) |
|---|---|---|
| 200 | 330 | 2,078 |
| 150 | 222 | 1,777 |
| 100 | 123 | 1,415 |
| 50 | 41 | 934 |
| 20 | 8 | 502 |
| 10 | 2 | 294 |
| 5 | 1 | 163 |

# Damaging Effects of a Blast Wave



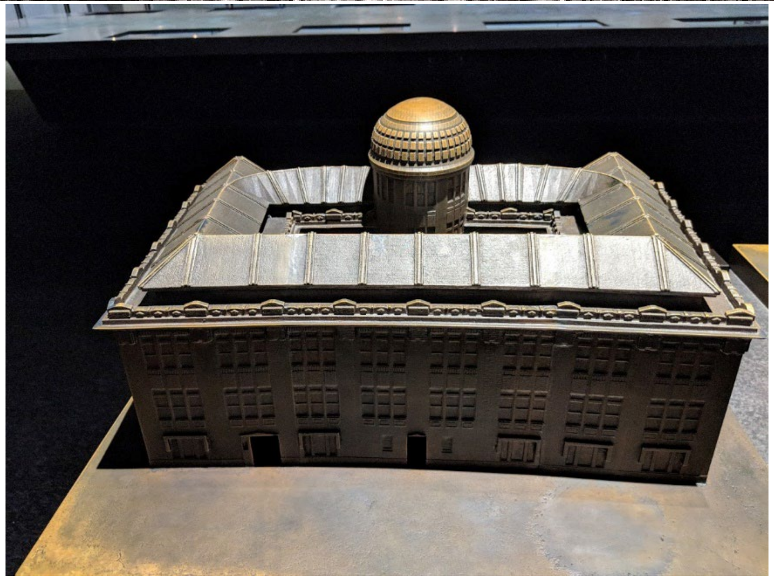
# Damage in Hiroshima

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

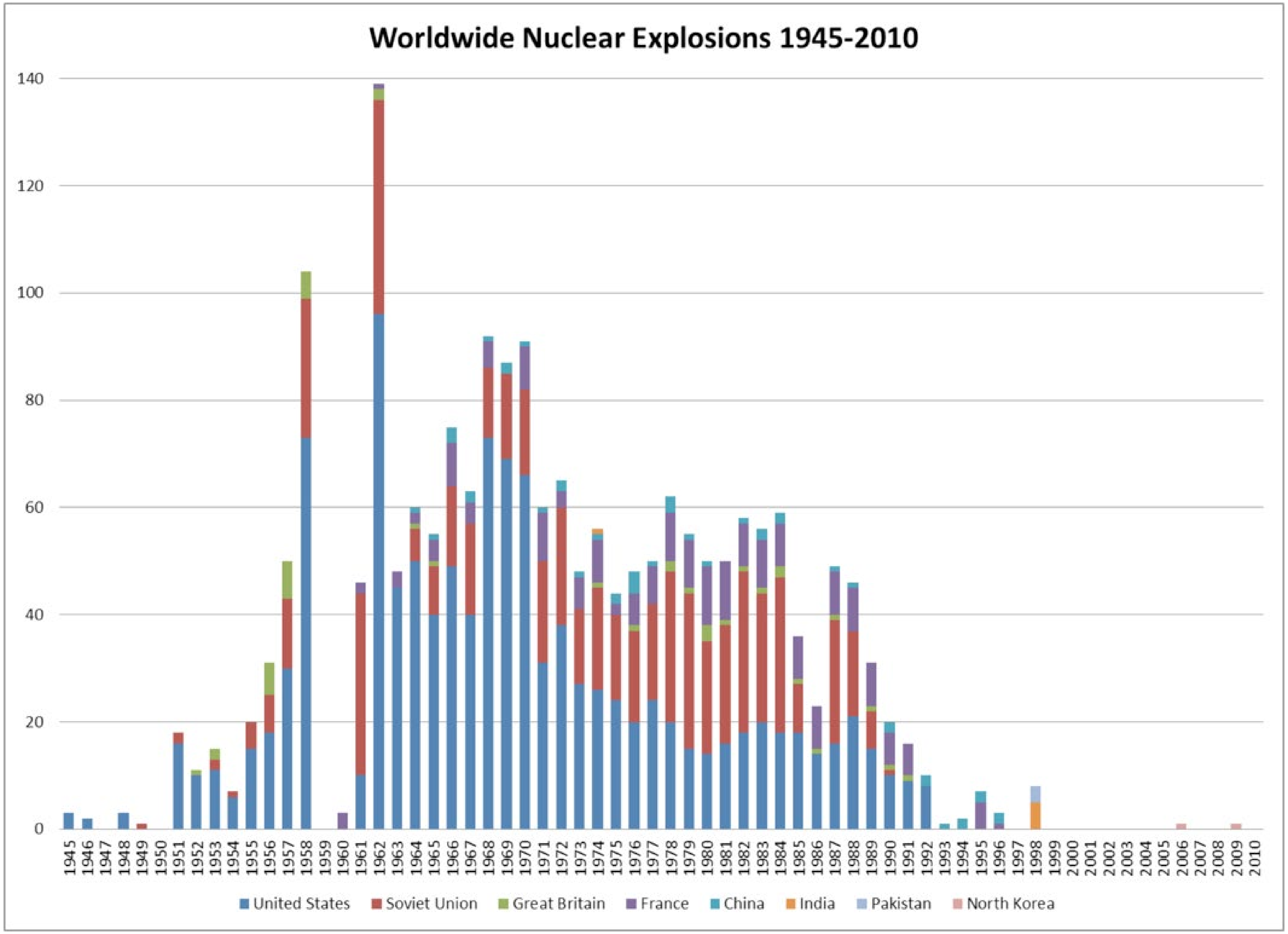
## Effects of the Sedan Event (1962)

- 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

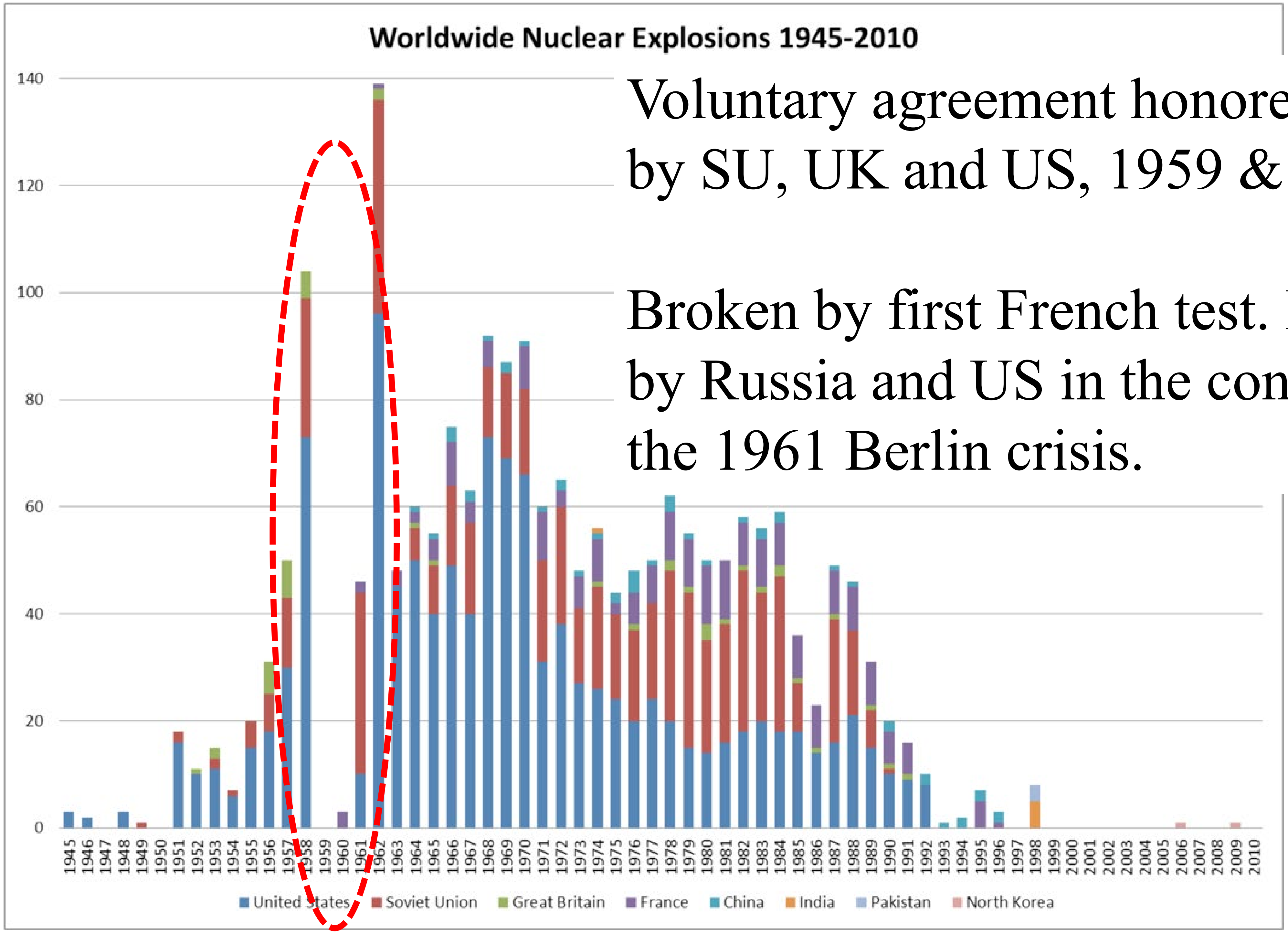
## Example: The Sedan Test (100 kt, 1962)

# Effects of Nuclear Explosions




Credit: Wikipedia Commons

# Test Moratorium 1959-1960



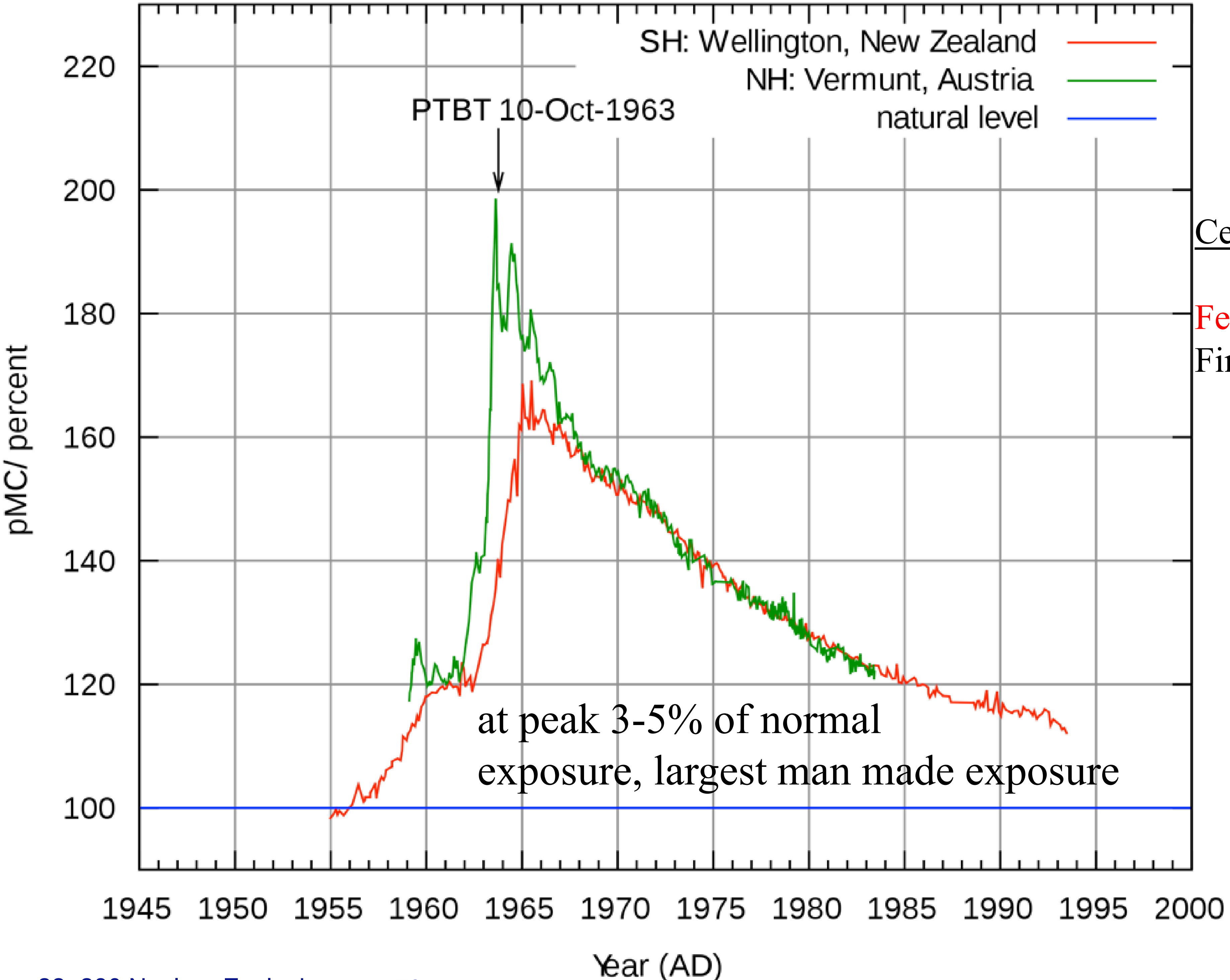

Voluntary agreement honored by SU, UK and US, 1959 & 1960

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

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



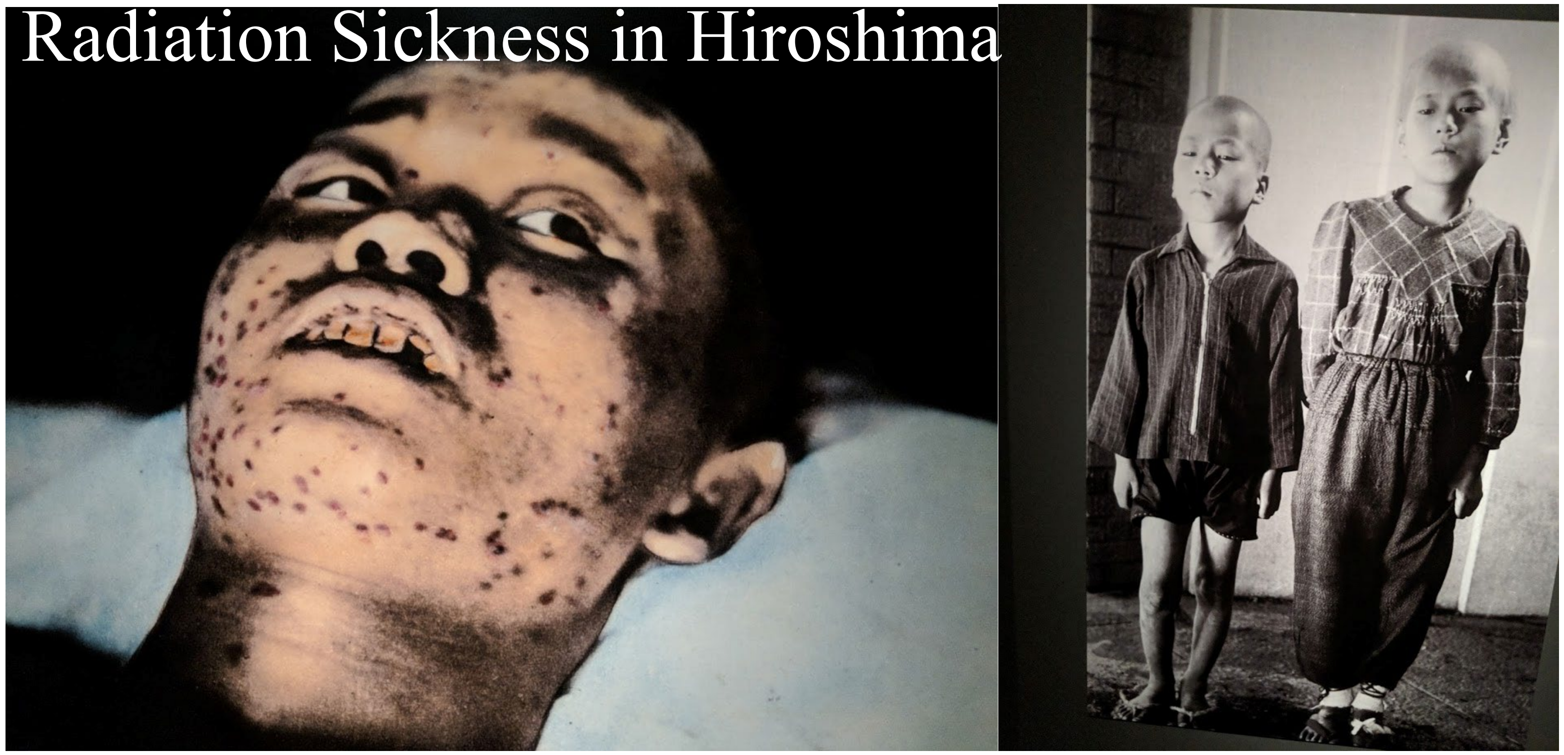

<u>Centers for Disease Control and Prevention:</u>

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



Radiation Sickness in Hiroshima

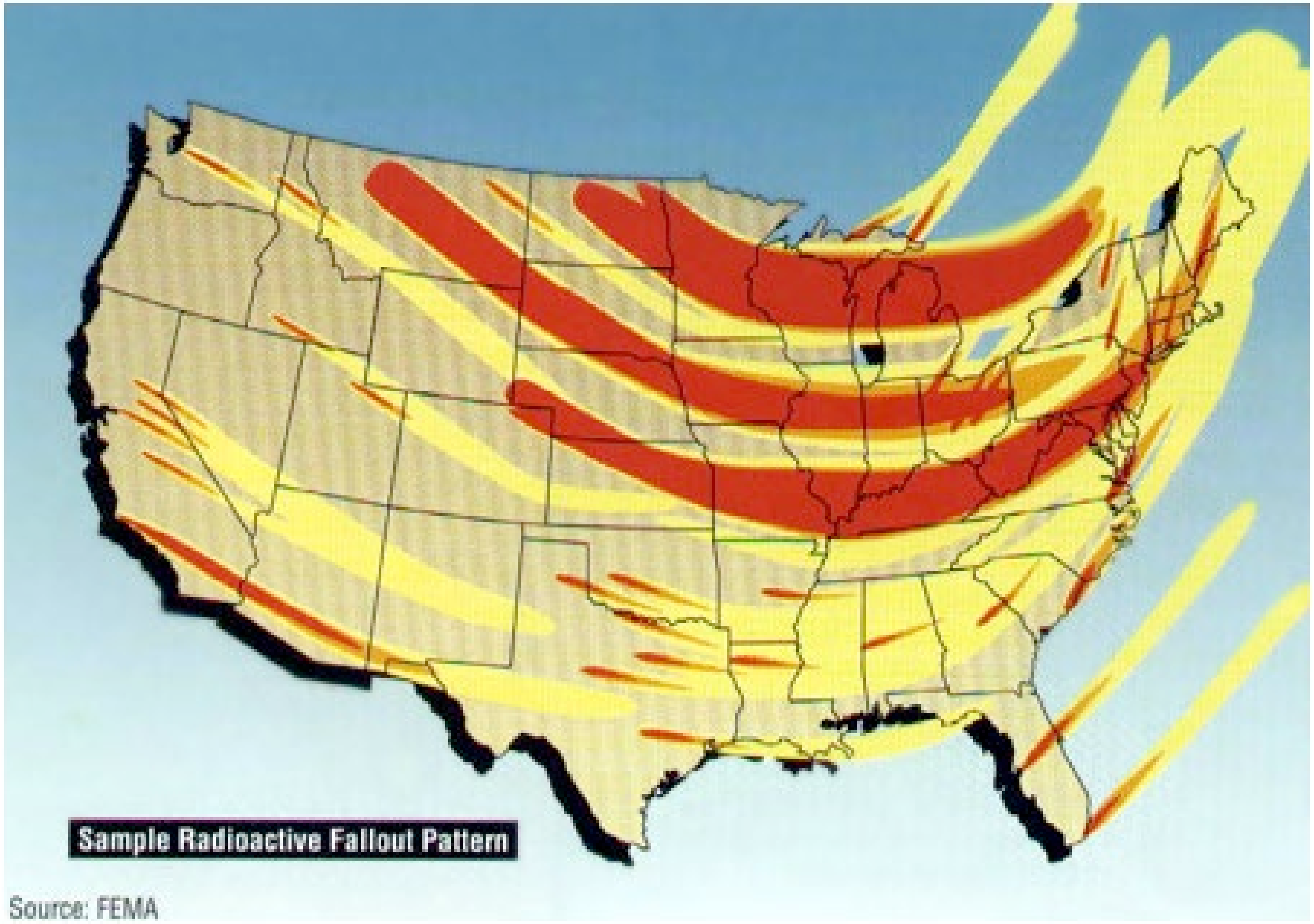
Assume —

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

Distances and doses —

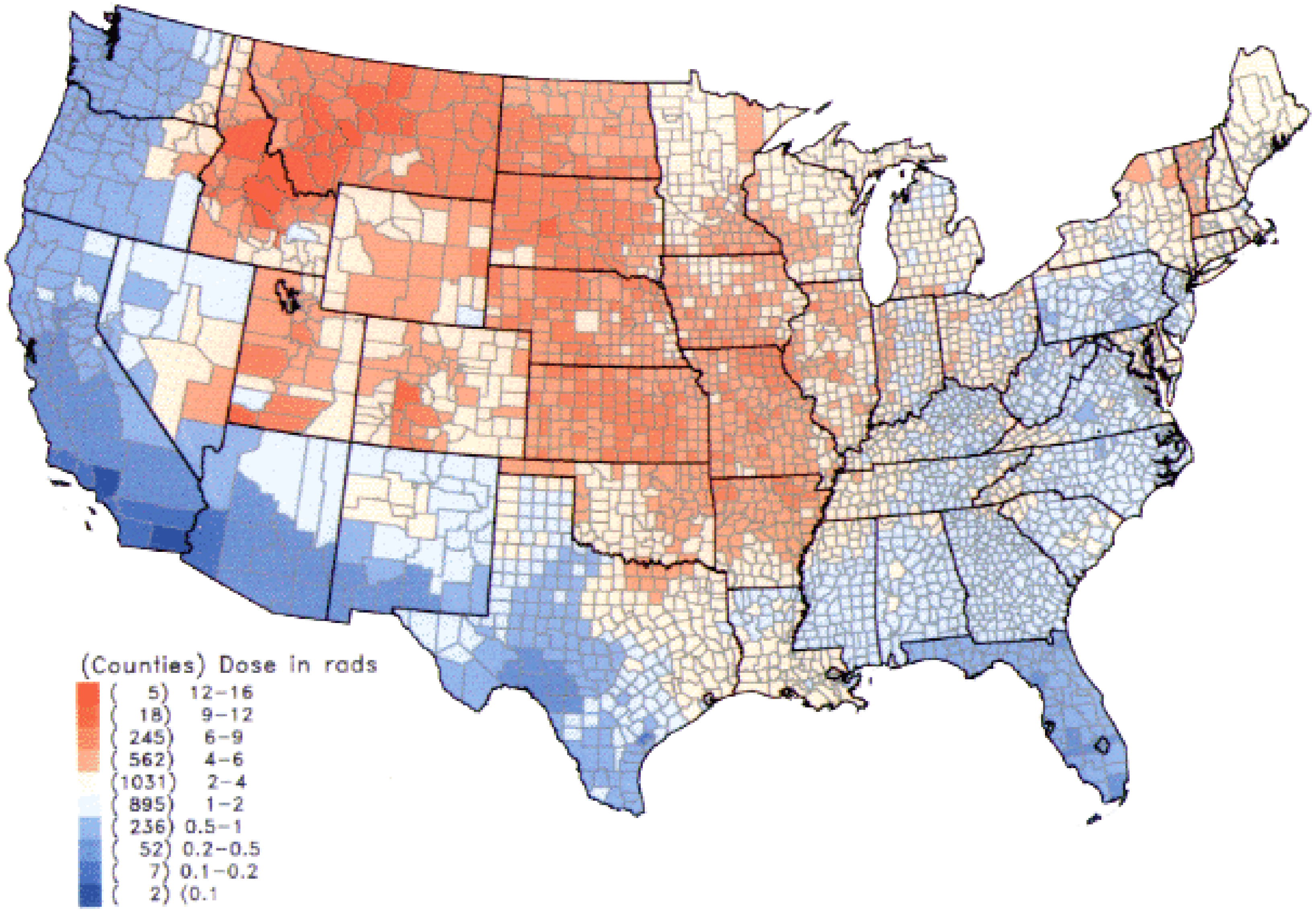
- 30 miles: 3,000 rem (death within hours; more than 10 years before habitable)
- 90 miles 900 rem (death in 2 to 14 days)
- 160 miles: 300 rem (severe radiation sickness)
- 250 miles: 90 rem (significantly increased cancer risk; 2 to 3 years before habitable)

# 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 Side



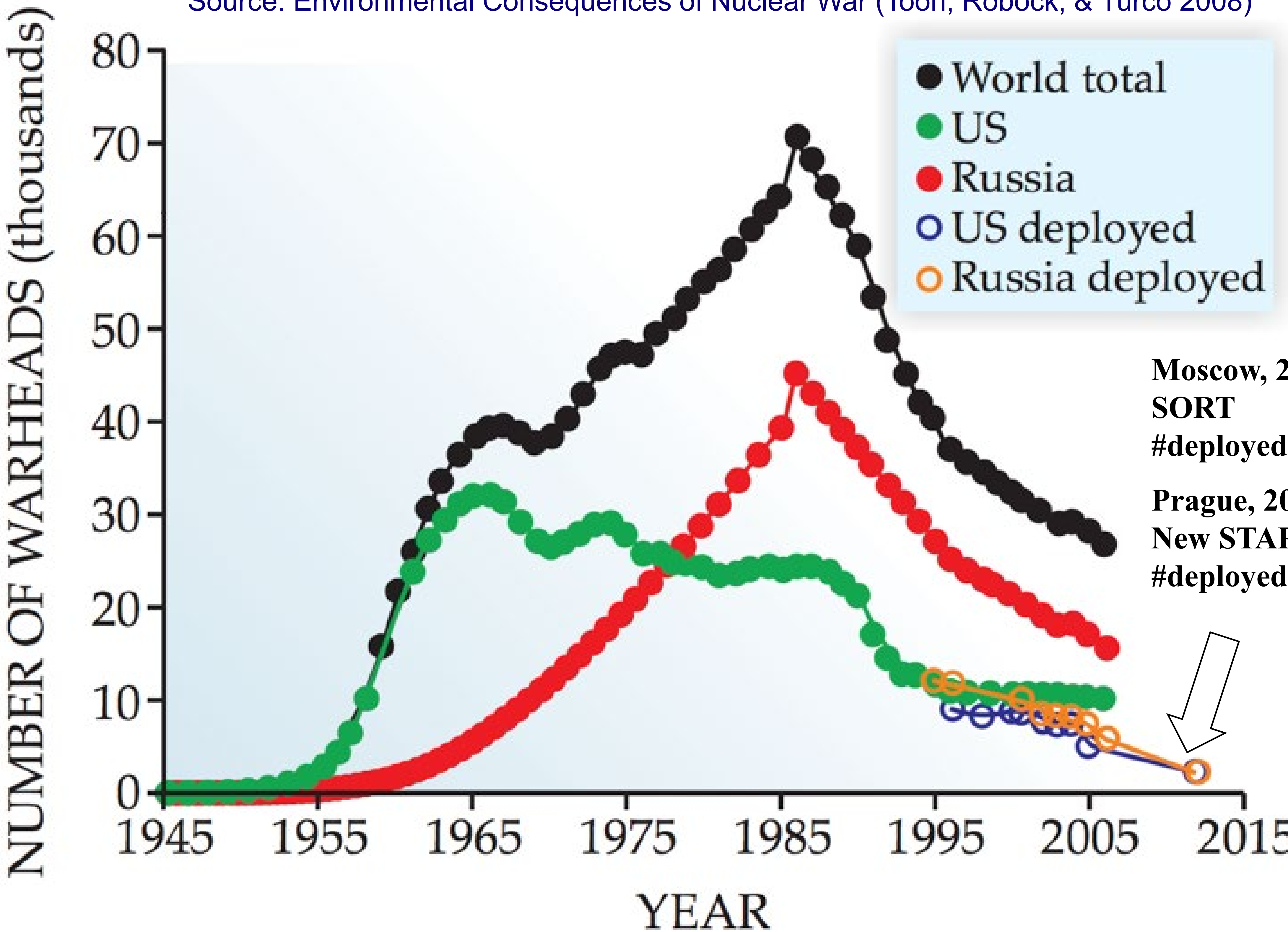

Centers for Disease Control, Feasibility Study of Weapons Test Fall Out:

"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."

# Effects of Nuclear War – Input to War Scenarios for Illustration

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




**Moscow, 2002**
**SORT**
**#deployed < 2200**

**Prague, 2010**
**New START**
**#deployed < 1550**

# 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)

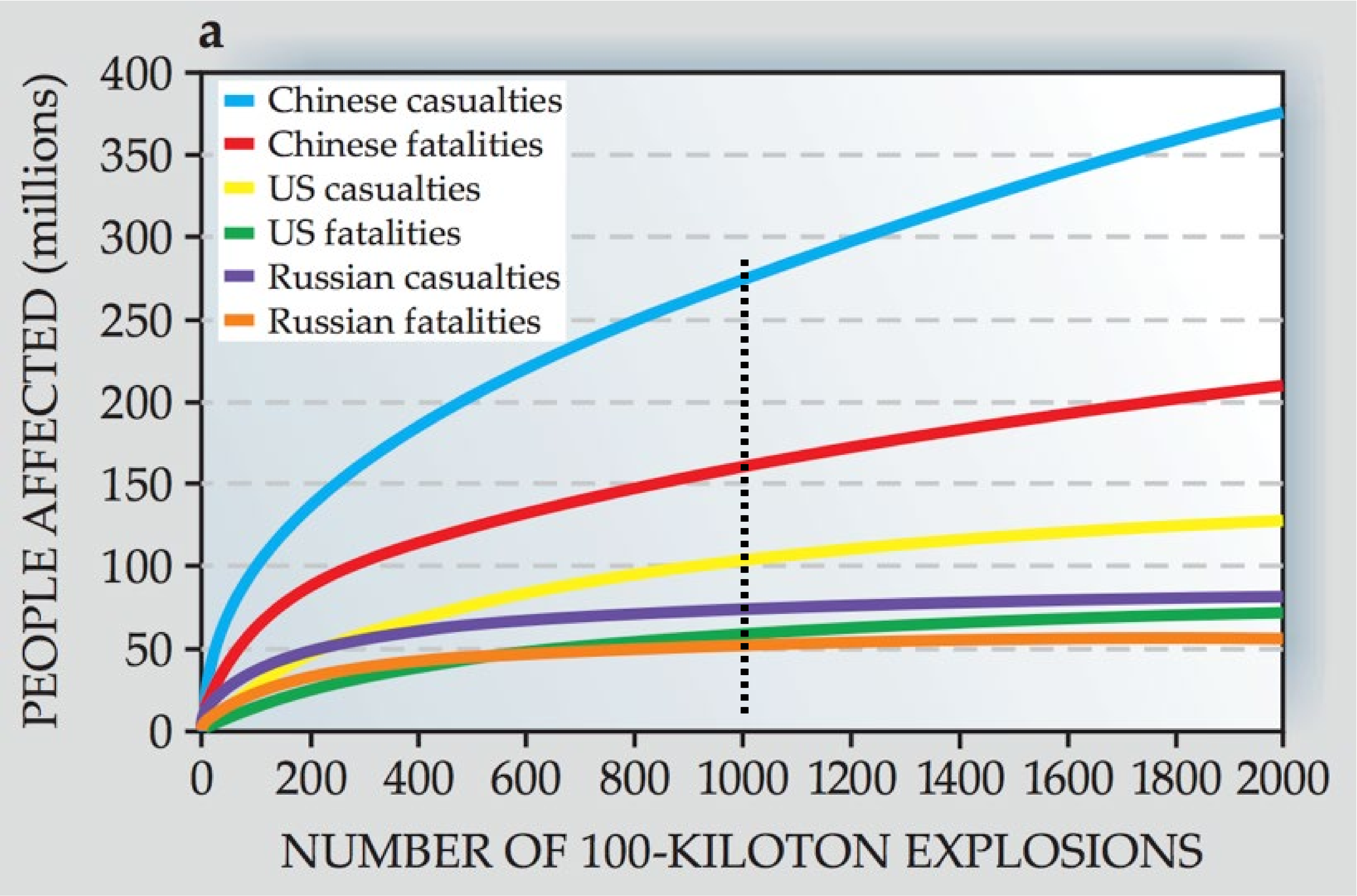
1,000 weapons detonated on Russia would *immediately* —

- 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 Causalities

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



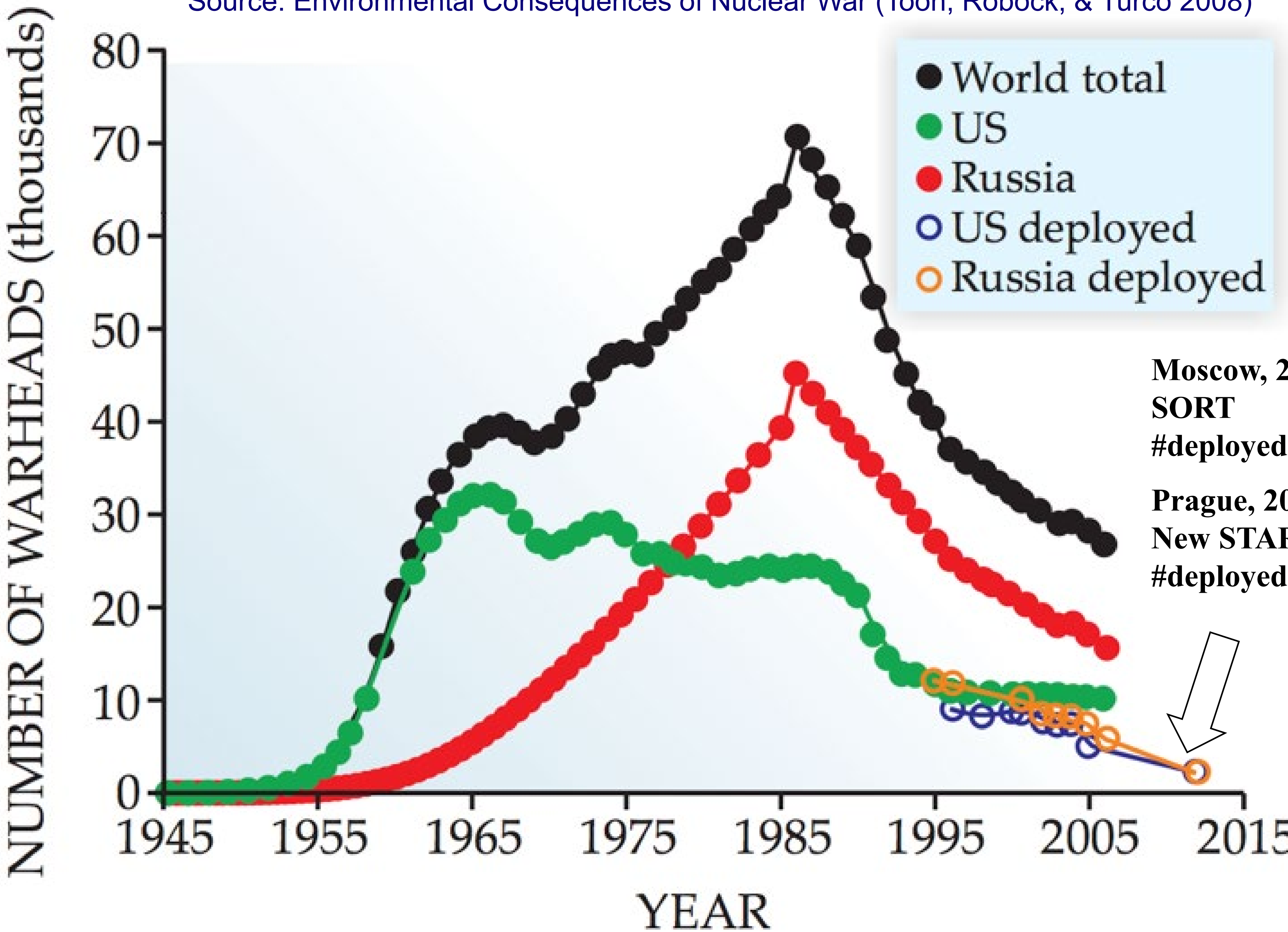
# Large Cities in China, Russia and the United States

| 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 – Input to War Scenarios for Illustration

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




**Moscow, 2002**
**SORT**
**#deployed < 2200**

**Prague, 2010**
**New START**
**#deployed < 1550**

# 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

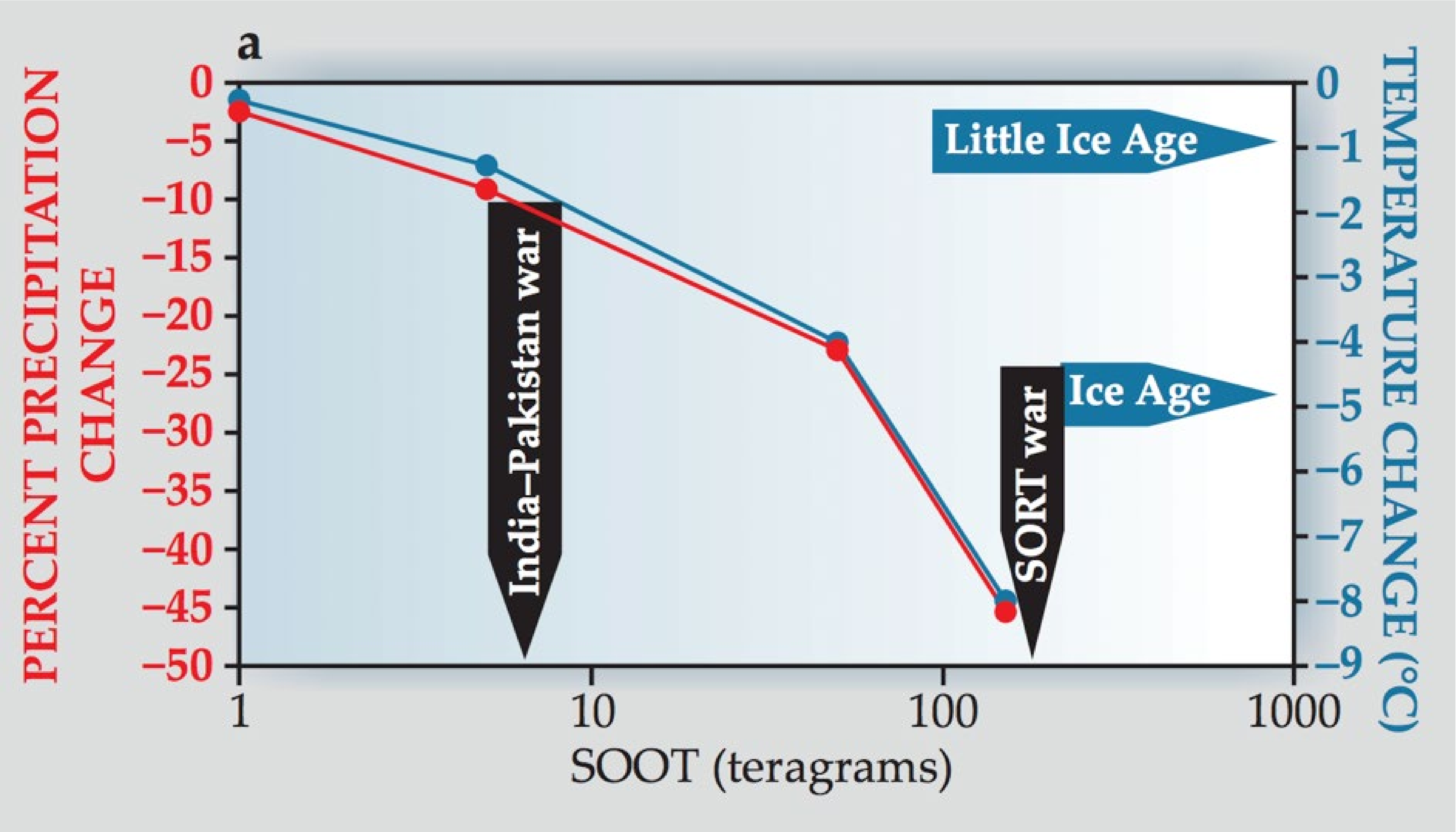
A regional war between India and Pakistan could generate 5 Tg of soot (5 million tons), sufficient to —

- 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)

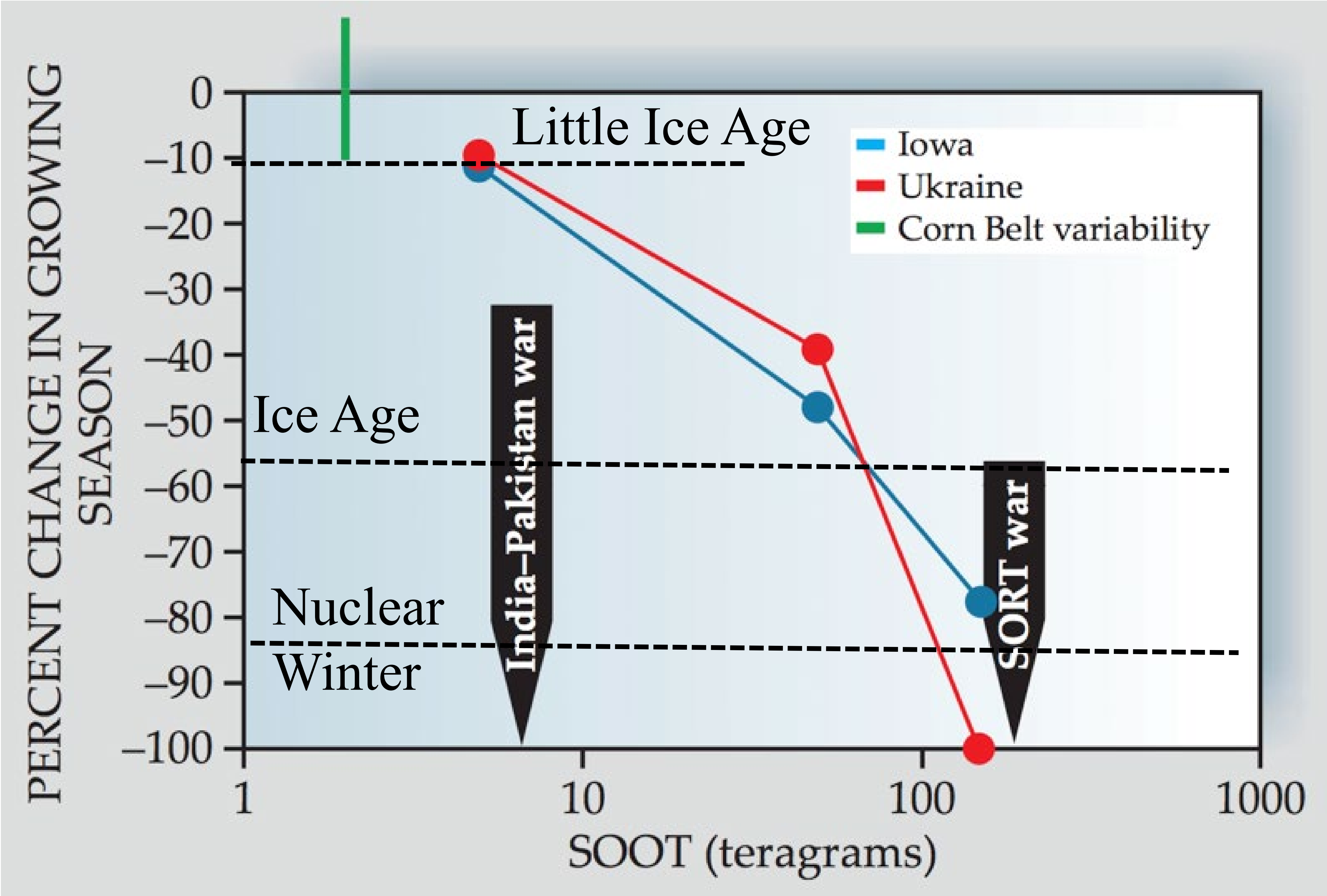
# Effects of Nuclear War: Change in Precipitation and Temperature

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



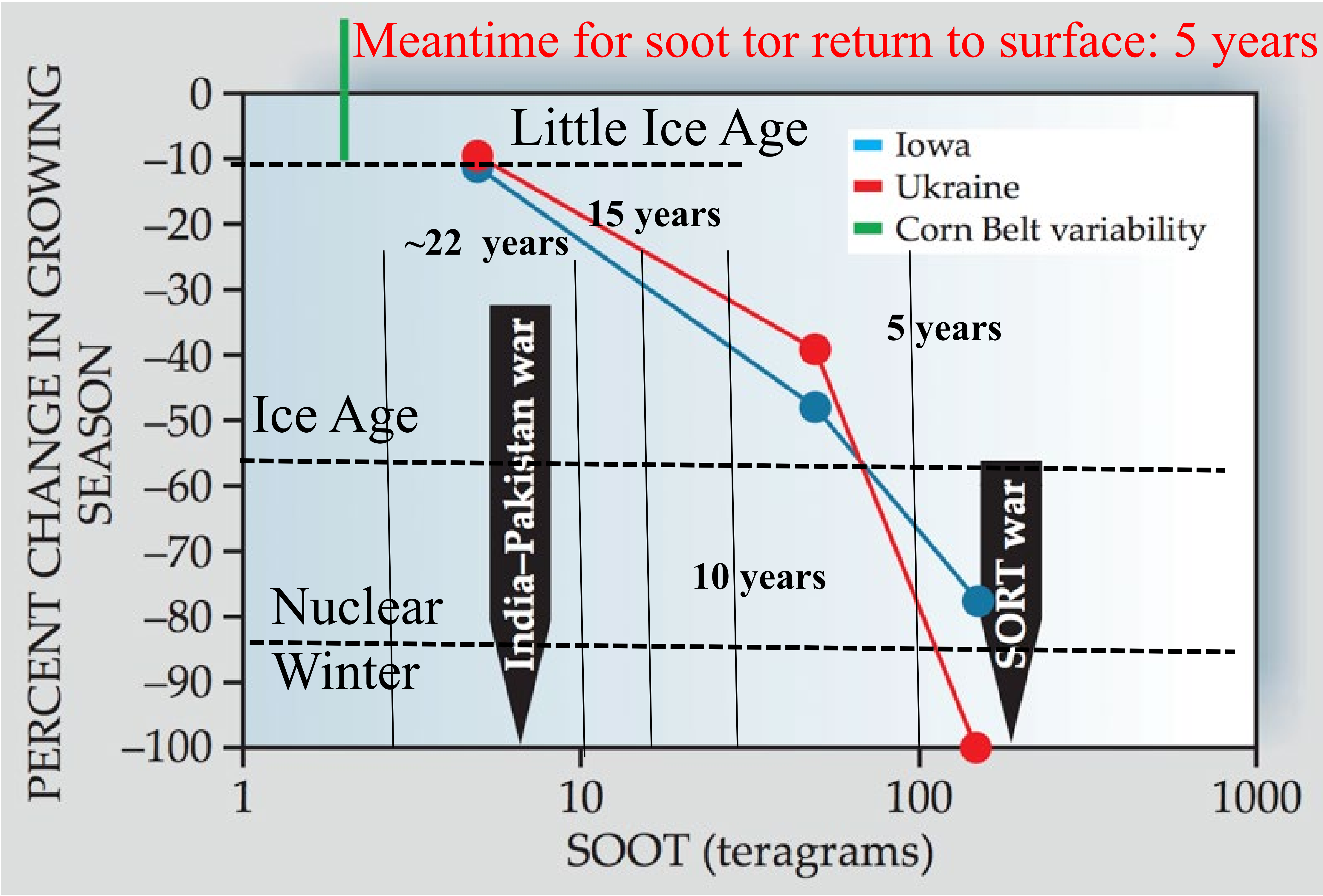
# Effects of Nuclear War: Percent Change in Growing Season

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."

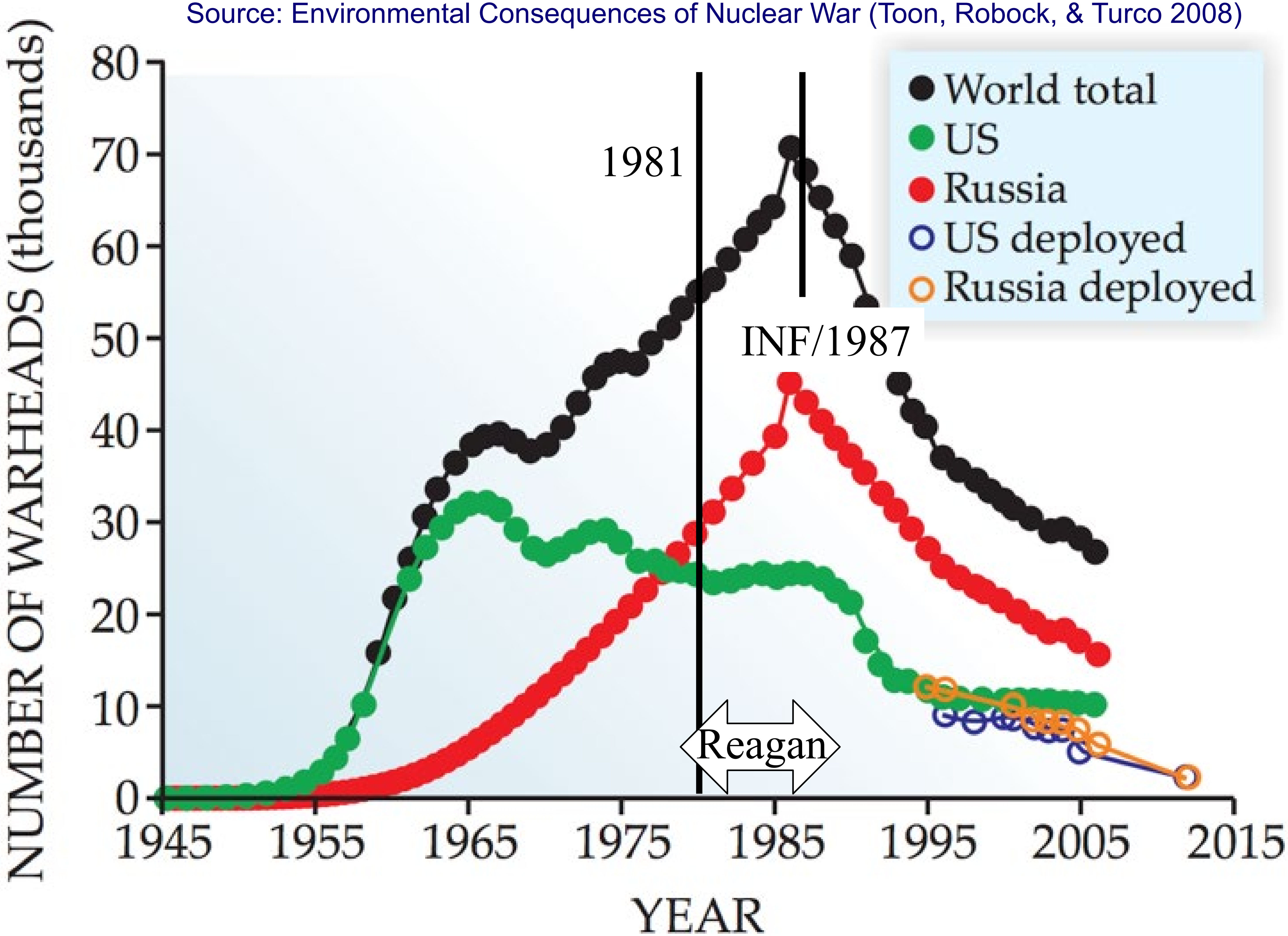
# Ground Zero

## 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)



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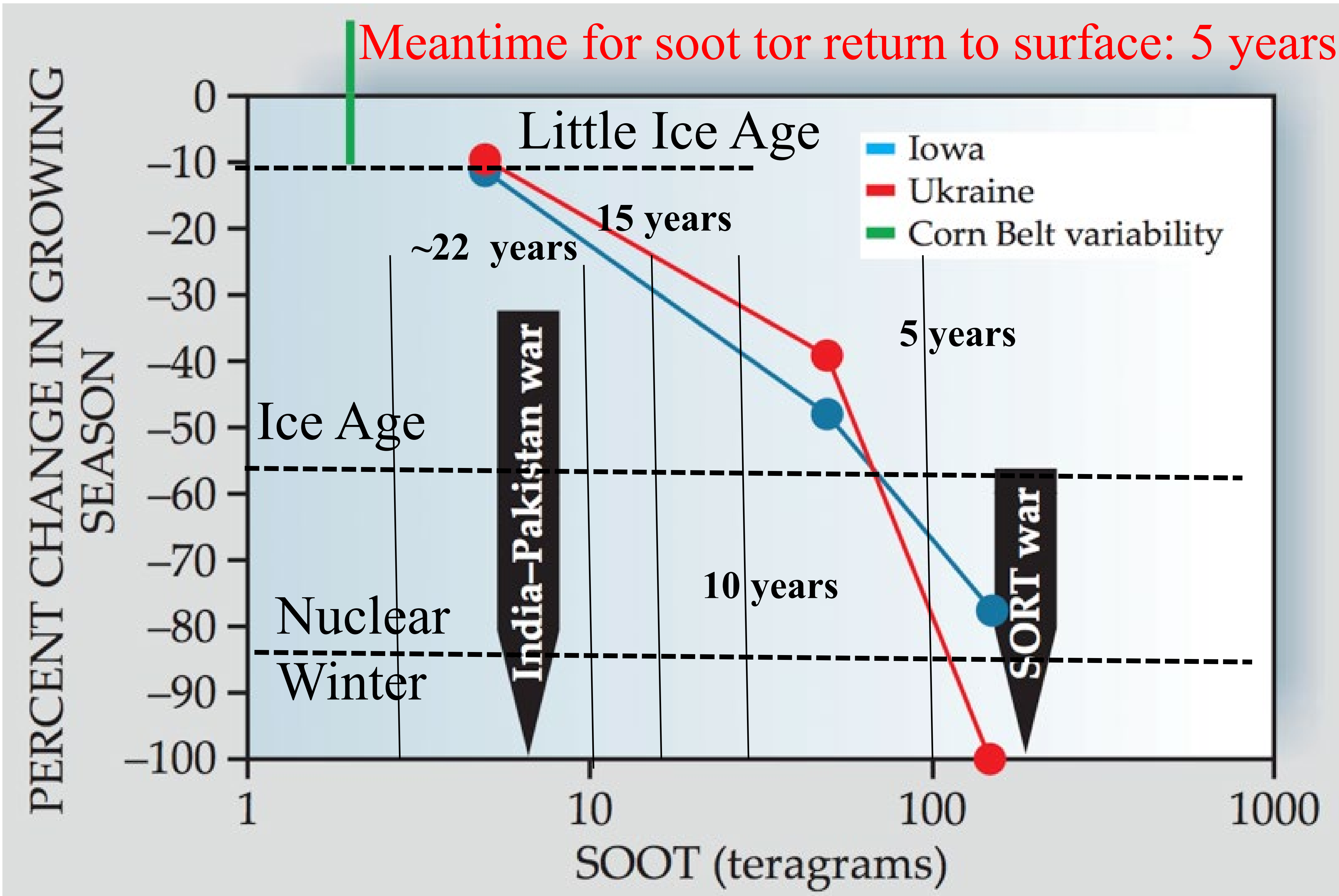

## Plan for This Session

RPPv1 is due at 2pm (now!)

News

Nuclear Explosions Conclusion: “Nuclear Winter”

“Ground Zero” Video presentation

News

# U.S. Revives Secret Program to Sabotage Iranian Missiles and Rockets

By David E. Sanger and William J. Broad

Feb. 13, 2019

WARSAW — The Trump White House has accelerated a secret American program to sabotage Iran's missiles and rockets, according to current and former administration officials, who described it as part of an expanding campaign by the United States to undercut Tehran's military and isolate its economy. Officials said it was impossible to measure precisely the success of the classified program, which has never been publicly acknowledged. But in the past month alone, two Iranian attempts to launch satellites have failed within minutes.

Those two rocket failures — one that Iran announced on Jan. 15 and the other, an unacknowledged attempt, on Feb. 5 — were part of a pattern over the past 11 years. In that time, 67 percent of Iranian orbital launches have failed, an astonishingly high number compared to a 5 percent failure rate worldwide for similar space launches. The setbacks have not deterred Iran. This week, President Hassan Rouhani singled out Tehran's missile fleets as he vowed to "continue our path and our military power." The Trump administration maintains that Iran's space program is merely a cover for its attempts to develop a ballistic missile powerful enough to send nuclear warheads flying between continents. Hours after the Jan. 15 attempt, Secretary of State Mike Pompeo note noted that Iran's satellite launchers have technologies "virtually identical and interchangeable with those used in ballistic missiles." Mr. Pompeo is in Warsaw this week with Vice President Mike Pence to lead a meeting of 65 nations on encouraging stability in the Middle East, including by expanding economic sanctions against Iran. It is largely an appeal to European allies who, while continuing to oppose President Trump's decision to abandon the 2015 nuclear accord with Iran, also agree that the missile tests must stop.

# News

# *U.S. Revives Secret Program to Sabotage Iranian Missiles and Rockets*

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Feb. 13, 2019