

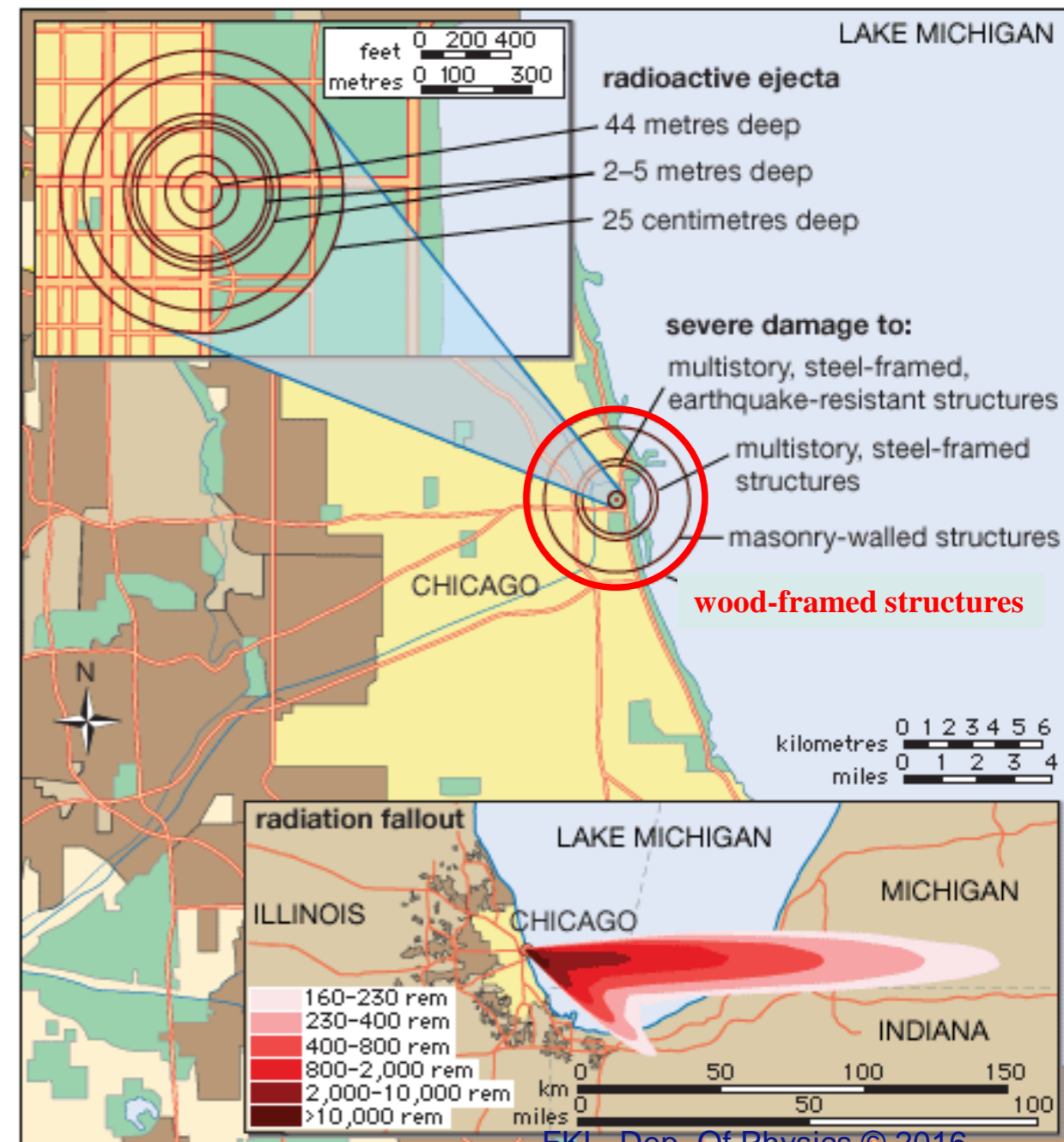
# Physics 280: Session 8

## Impact of a 500 kiloton device detonated in Chicago

### Plan for This Session

NEM summary

Module 3:  
Effects of nuclear explosions



# News: Historic Discovery of Gravitational Waves !

WATCH TRAILER

The New York Times | <http://nyti.ms/1Xlr2hB>

SCIENCE

## Scientists Detect Gravitational Waves, Proving Einstein Right

Dennis Overbye

OUT THERE FEB. 11, 2016

A team of physicists who can now count themselves as astronomers announced on Thursday that they had heard and recorded the sound of two black holes colliding a billion light-years away, a fleeting chirp that fulfilled the last prophecy of Einstein's general theory of relativity.

That faint rising tone, physicists say, is the first direct evidence of gravitational waves, the ripples in the fabric of space-time that Einstein predicted a century ago. And it is a ringing (pun intended) confirmation of the nature of black holes, the bottomless gravitational pits from which not even light can escape, which were the most foreboding (and unwelcome) part of his theory.

More generally, it means that scientists have finally tapped into the deepest register of physical reality, where the weirdest and wildest implications of Einstein's universe become manifest.

# Producing a Nuclear Explosion Using Plutonium

- As fuel in a nuclear reactor is exposed to long periods of neutron irradiation, heavier isotopes of plutonium build up, creating Pu-240, Pu-241, Pu-242.
- Pu with large quantities of Pu-240, Pu-241, Pu-242 is called “high burn-up” or “reactor-grade” plutonium. High burn-up Pu: ~ 40% Pu-239, ~ 30% Pu-240, ~ 15% Pu-241, and ~ 15% Pu-242
- . Producing a nuclear explosion is much easier if the plutonium is “weapon-grade” (defined as more than 93% Pu-239). As other isotopes have significantly higher spontaneous neutron emission. (A nuclear explosion with reactor-grade Pu has been demonstrated!)
- Reactor operations for Pu-production there for is characterized by short operation periods aiming to extract Pu-239 before other additional isotopes are formed in large quantity

# Summary Nuclear Explosive Materials (Very Important)

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- Uranium —
  - LEU:  $< 20\%$  U-235
  - Weapons-usable HEU:  $> 20\%$  U-235
  - Weapons-grade HEU:  $> 80\%$  U-235
- Plutonium —
  - Reactor-grade:  $< 80\%$  Pu-239 (e.g., light-water )
  - Fuel-grade: 80% to 93% Pu-239
  - Weapons-grade:  $> 93\%$  Pu-239

# Module 3: Effects of Nuclear Explosions

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## 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”

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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

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**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

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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 ... ?



# iClicker Question

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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.



# iClicker

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# iClicker Answer

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# iClicker Question

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

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

# iClicker

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# iClicker Answer

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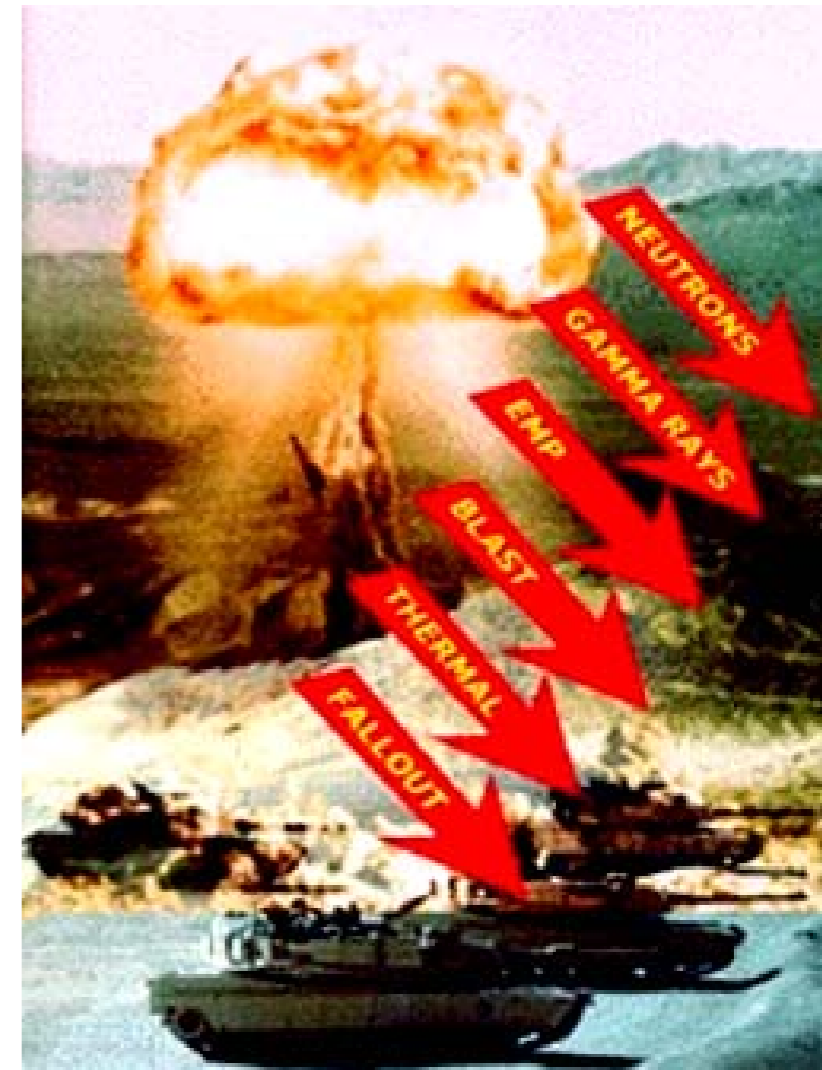
# Effects of Nuclear Explosions

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## 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

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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

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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.*

# iClicker Question

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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.

# iClicker

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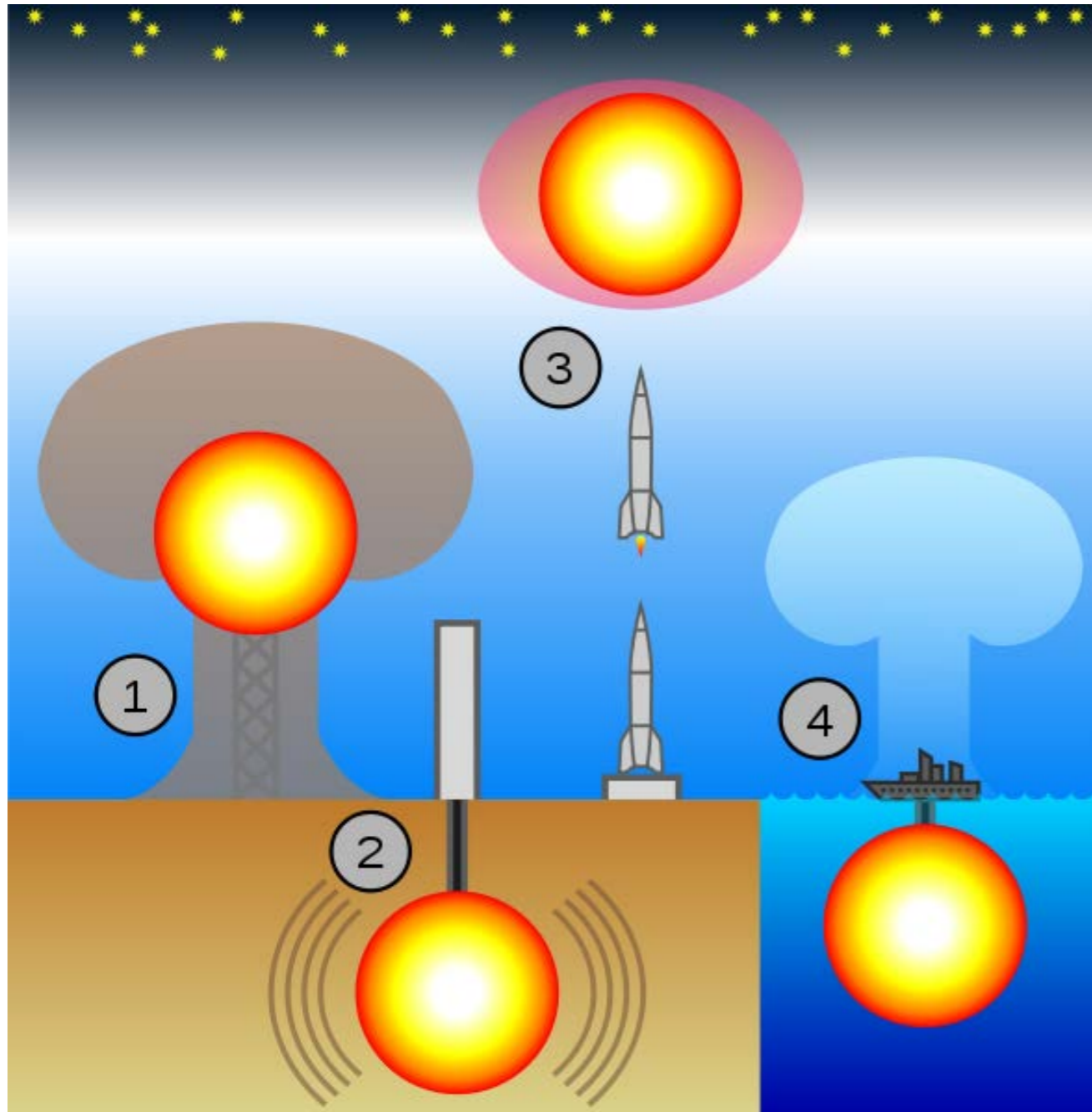
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# Nuclear Explosions

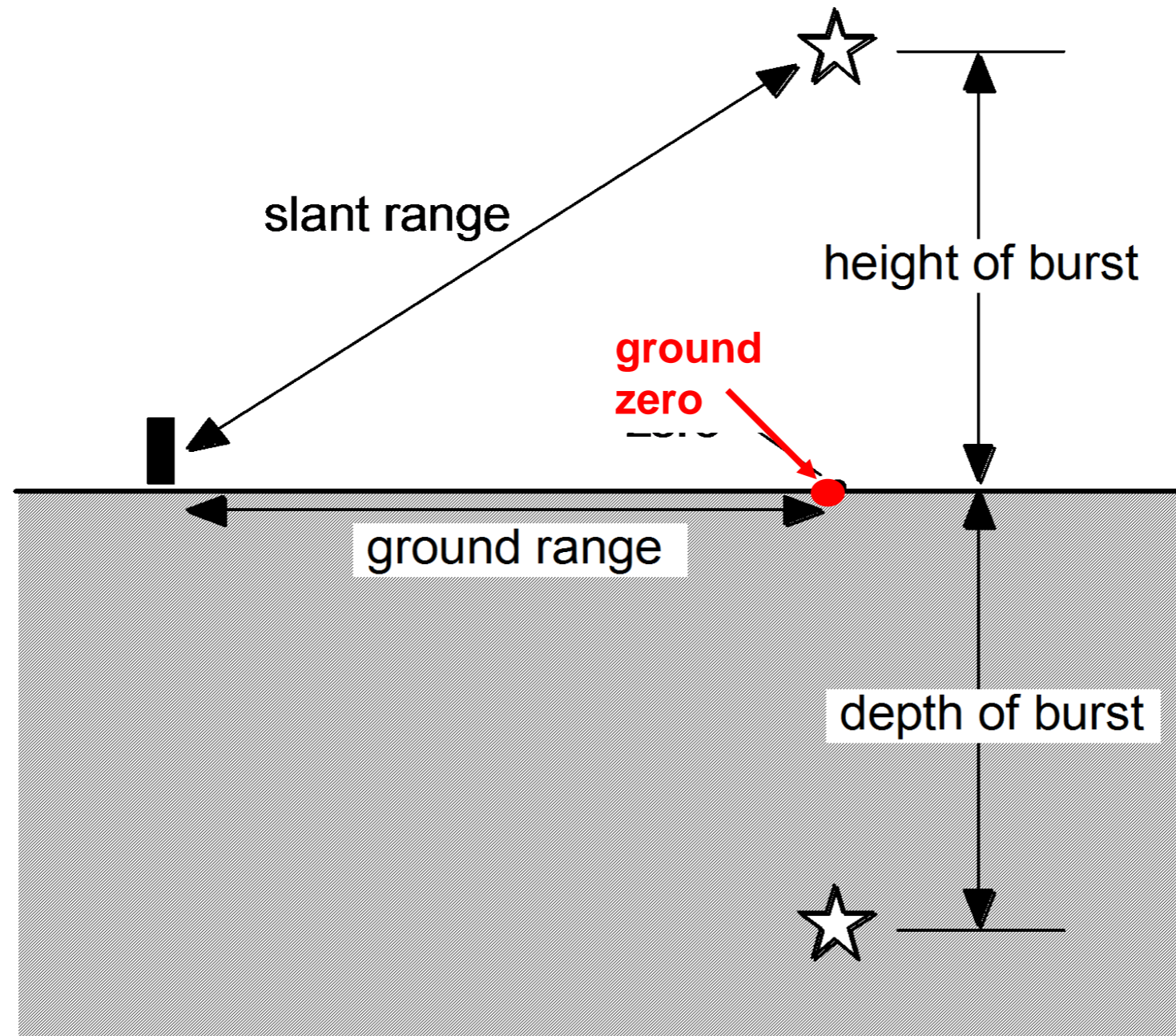


Credit: Wikipedia (nuclear weapons testing)

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



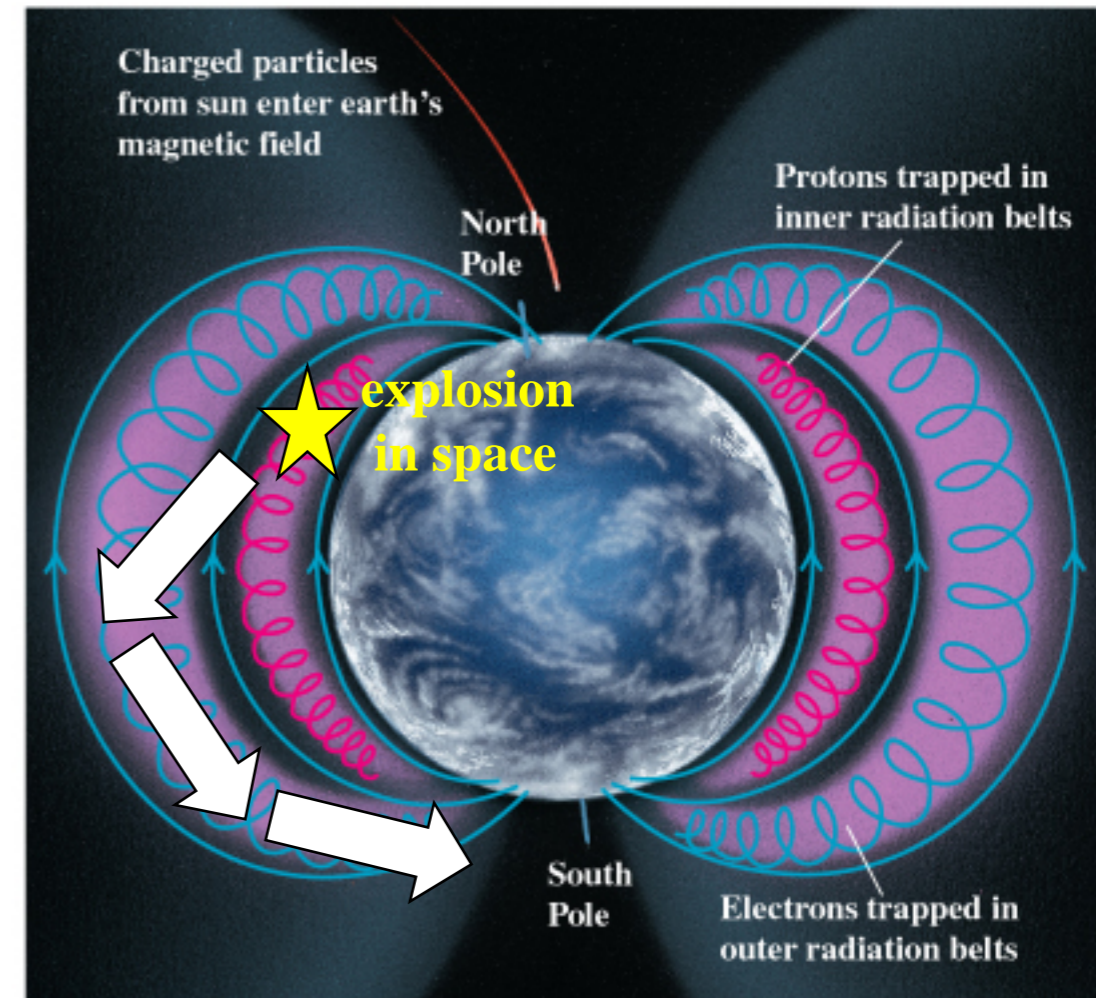
# Nuclear Explosions in Space

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)

Copyright © Addison Wesley Longman, Inc.



# Underground Nuclear Explosions

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## 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

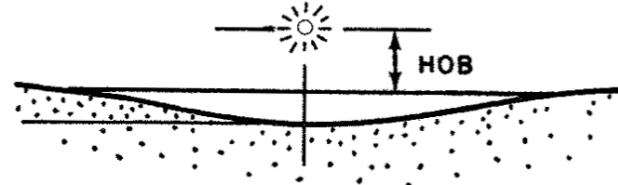


<http://www.nv.doe.gov/library/photos/testprep.aspx>

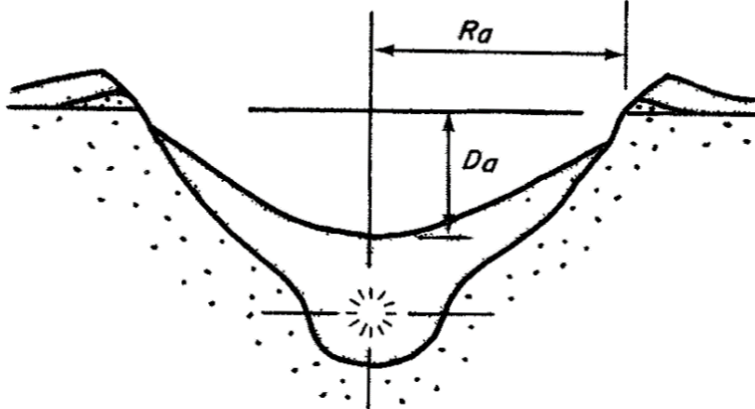
Nuclear weapon tests serve the acquisition of information/data concerning explosions of different warheads.

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

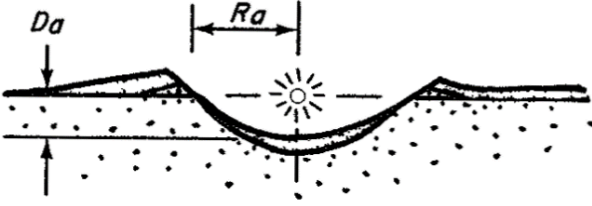
# Crater Formation vs DOB (depth of burst)



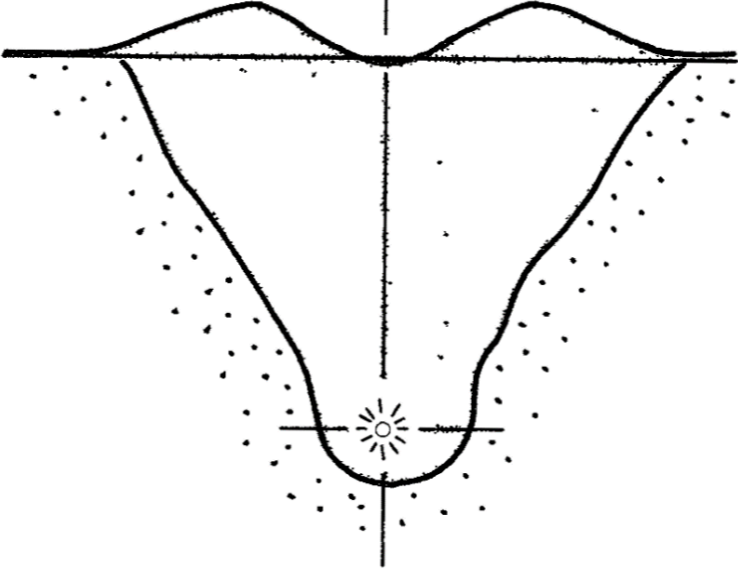
a. NEAR SURFACE BURST



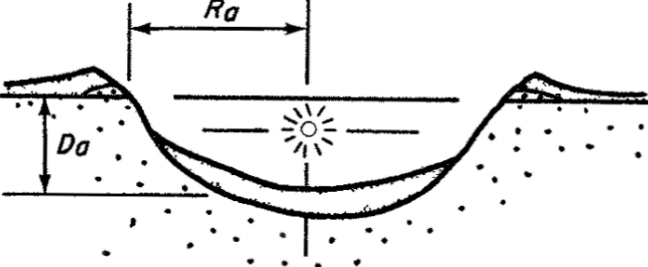
d. OPTIMUM DOB



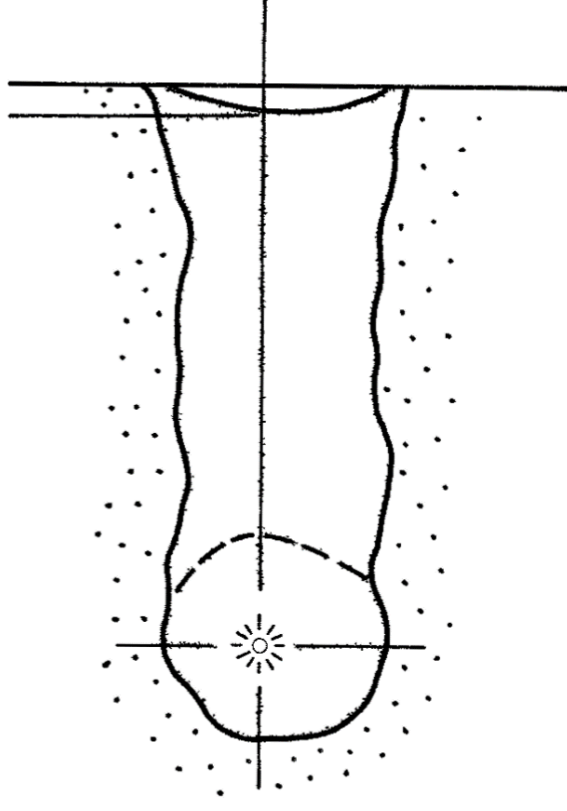
b. SURFACE BURST



e. DEEPLY BURIED



c. SHALLOW DOB



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>

# iClicker Question

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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.

# iClicker

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# iClicker Answer

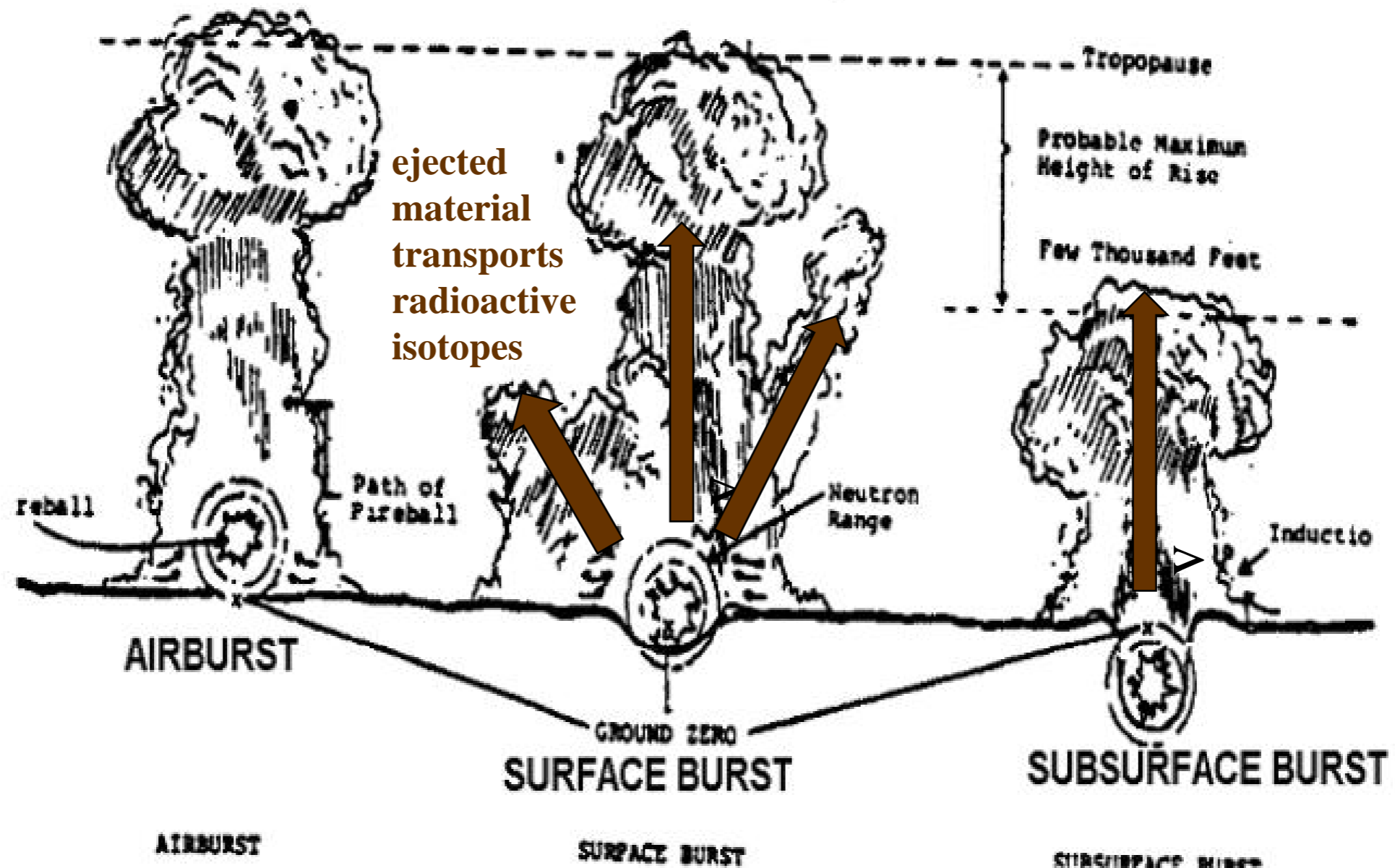
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# Nuclear Explosions in the Atmosphere or a Small Distance Underground



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

# Will the Fireball Touch the Ground?

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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

# Physics 280: Session 9

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## Plan for This Session

### Announcements & Questions:

RE3v1 will be due Thursday 2-18 at 1pm  
(.doc/.docx) and 2pm in class (paper copy)

→ make sure to print from pdf in case  
you are editing a google document!

### News

Module 3: Effects of nuclear explosions (cont'd)

# News: China's Military Calls for Putting Nuclear Forces on Alert

## Summary

For the first time, China is discussing putting its nuclear missiles on high alert so that they could be launched quickly on warning of an attack, similar to the current state of U.S. and Russian missiles. This would be a significant—and dangerous—change in Chinese policy. The experience with U.S. and Soviet/Russian warning systems, especially early in their deployment and operation when hardware and procedures were not yet reliable, illustrates the dangers of maintaining the option to launch on warning. Such risks are especially acute in a crisis.

Note: in the context of recent nuclear and missile tests in North Korea the US considers stationing THAAD missile defense in South Korea triggering concern from China and possibly contributing to an arms race setting nuclear capabilities against missile defense.

Union of Concerned Scientists

Gregory Kulacki, 1-2016

<http://www.ucsusa.org/sites/default/files/attach/2016/02/China-Hair-Trigger-full-report.pdf>

According to newly translated Chinese sources, discussions of putting missiles on high alert appear to stem from increasing Chinese military concerns about retaining a credible nuclear retaliatory capability in the face of accurate U.S. nuclear weapons, the development of high-precision conventional weapons, and missile defenses. In addition, U.S. unwillingness to acknowledge mutual vulnerability in bilateral nuclear talks with China creates the impression that the United States is still seeking to render itself invulnerable to a Chinese retaliatory strike. These sources suggest that the Chinese military, which is already developing more survivable mobile missiles and submarine-launched missiles, believes that putting the nation's missiles on high alert would be a step toward assured retaliation.

# The Telegraph, Feb-16: Arab States might Seek Nuclear Weapons

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**Arab states are seeking nuclear weapons to counter Iran, Israel warns**

**Defense minister Moshe Ya'alon says his country is seeing signs of a much-feared nuclear arms race in the Middle East**

[Israel](#) has picked up signs of the beginning of a nuclear arms race in the Middle East as Arab states seek nuclear weapons to counter [Iran](#), the Israeli defense minister has warned.

Moshe Ya'alon said Sunni Arab nations were not reassured by [last year's nuclear deal between Iran and six world powers](#) and were making their own preparations for nuclear weapons.

"We see signs that countries in the Arab world are preparing to acquire nuclear weapons, that they are not willing to sit quietly with Iran on brink of a nuclear or atomic bomb," Mr Ya'alon said.

The defense minister gave no evidence to back up his claims but Israel closely monitors the military activities of its Arab neighbors.

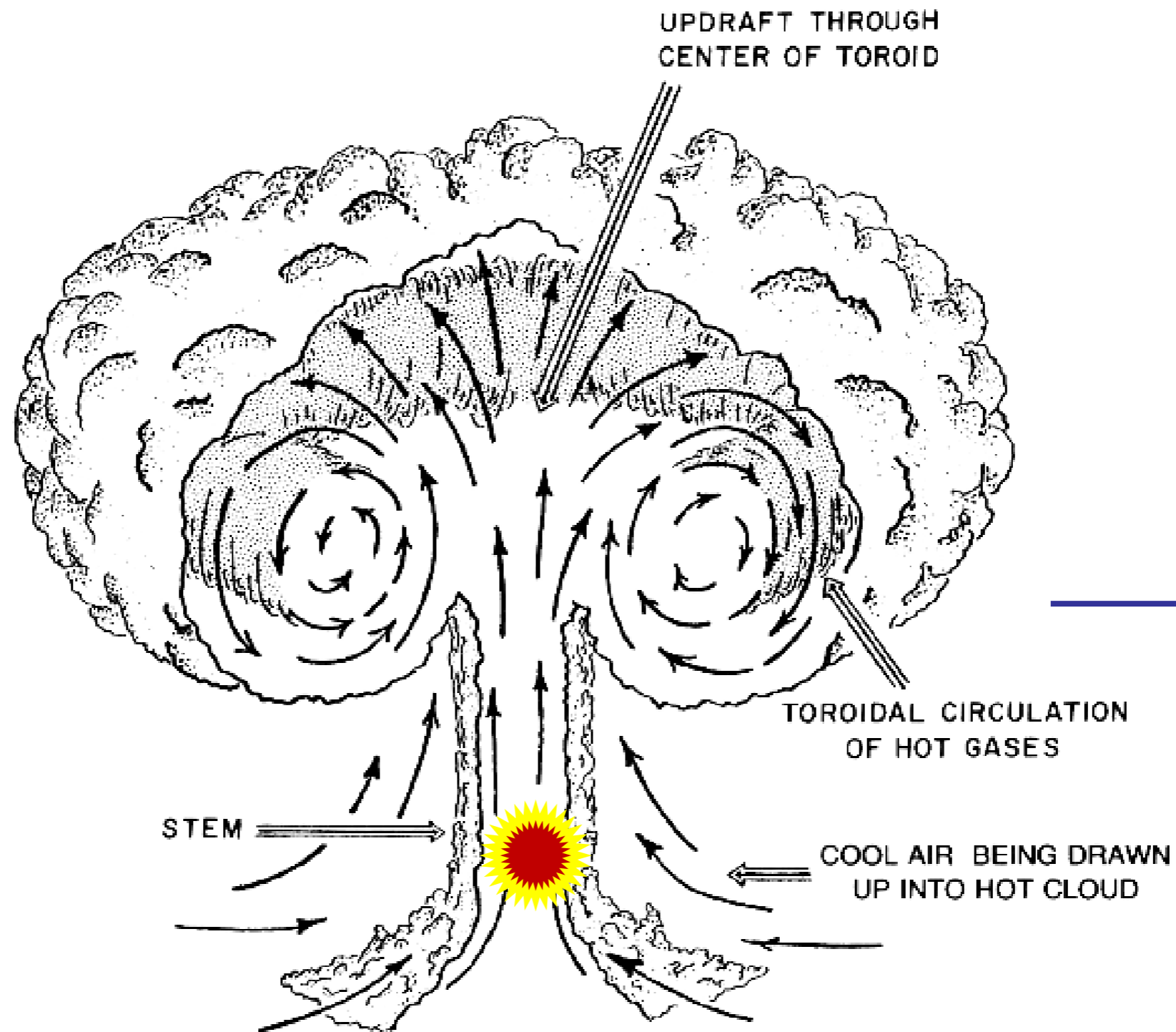
Israel and the Sunni Gulf countries do not have diplomatic ties but are known to talk through back channels and are united in their opposition to Iran.

# 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 ( $\sim 1$  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  $\gamma$ ,  $\beta$  and neutron radiation
  - Intense, but of limited range
- Electromagnetic pulse (peak at  $< 10^{-6}$  s)
- Thermal radiation (lasts  $\sim 10$  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

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- **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

# iClicker 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.

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# Nuclear Weapon Effects

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## 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

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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

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## 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

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## 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

# Examples of Flash Burns Suffered at Hiroshima and Nagasaki



(a)



(b)

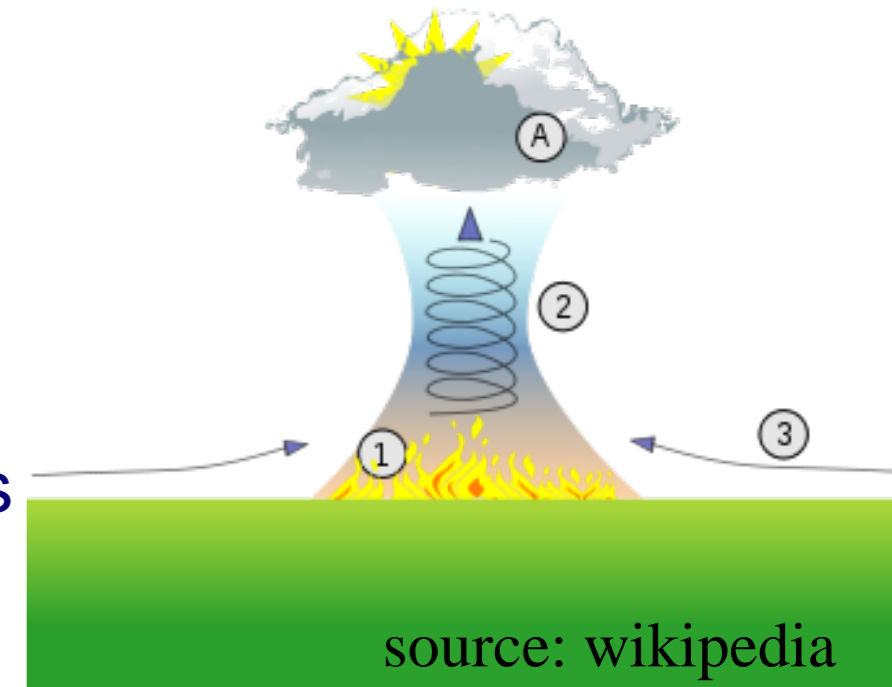
# Conflagrations Versus Firestorms

## 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



# Effects of Nuclear Explosions

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## Effects of Blast Waves

# Damaging Effects of a Blast Wave

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- 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

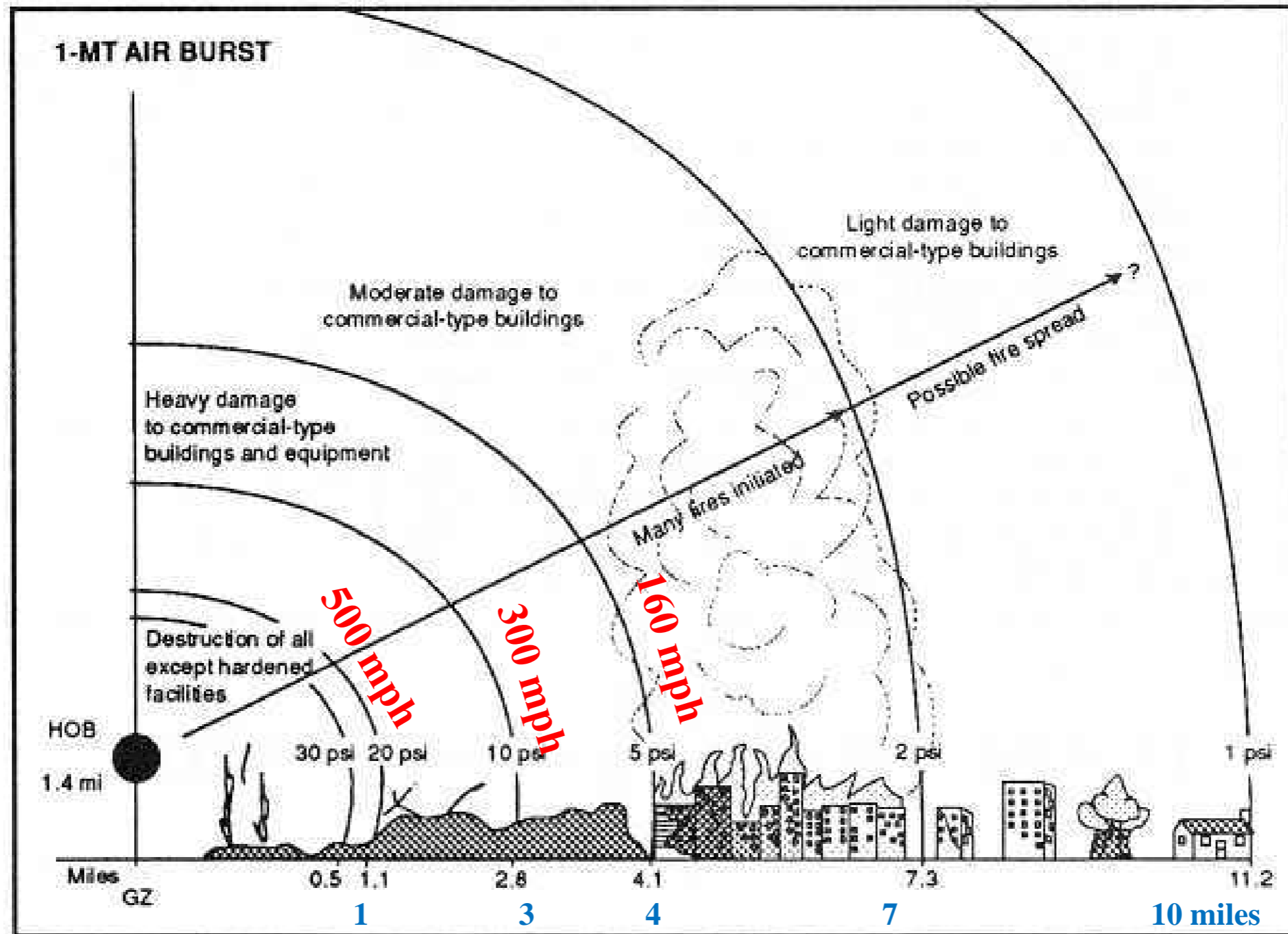
This is followed by

- 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



# Effects of Shallow Underground Nuclear Explosions

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## Effects of the Sedan Event (1962)

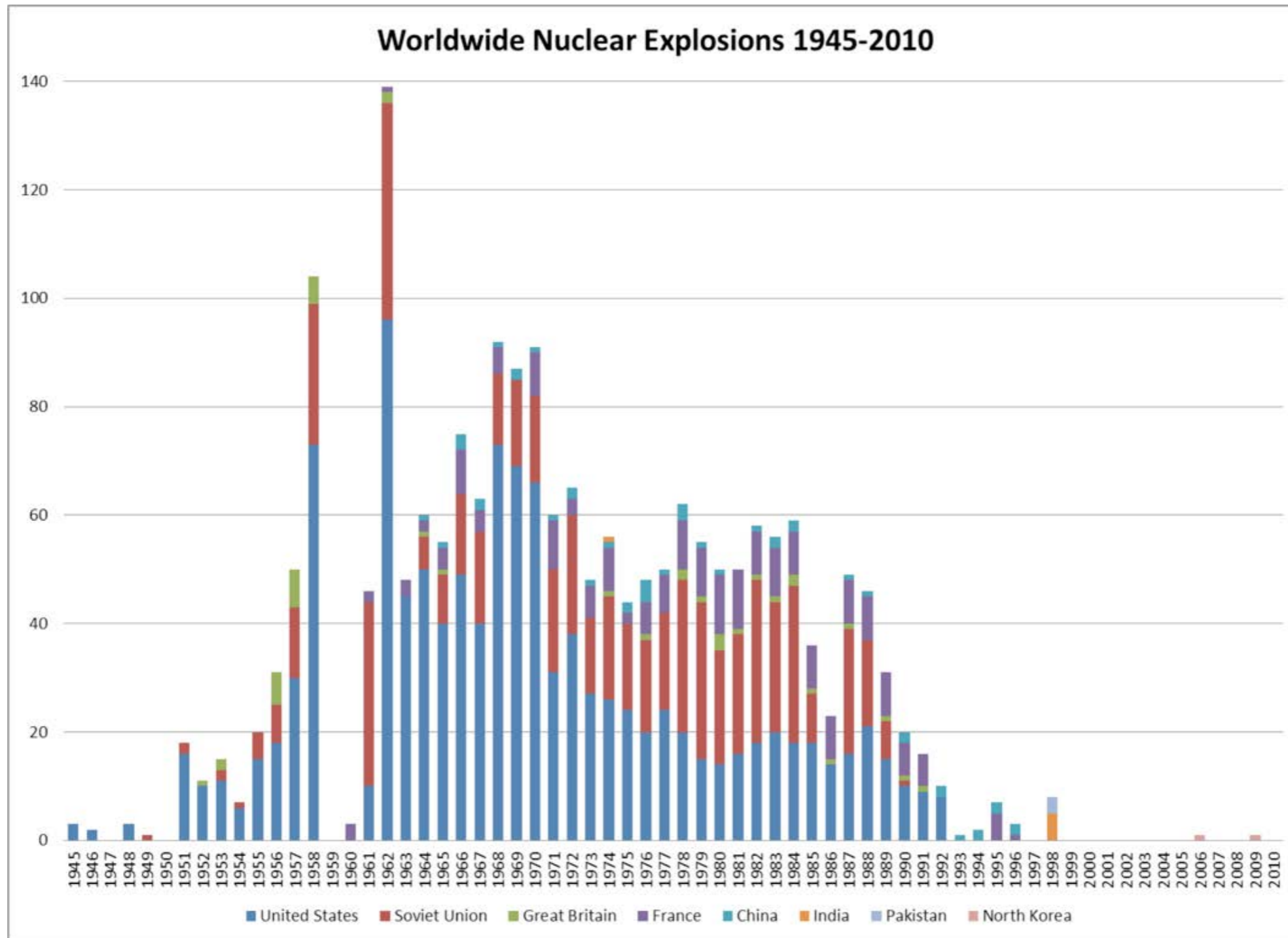
- Explosive yield: 100 kt
- Depth of burial: 635 feet
- Crater radius: 610 feet
- Crater depth: 320 feet
- Earth displaced: 12 million tons

# Effects of Shallow Underground Nuclear Explosions

Example: The Sedan Test (100 kt, 1962)

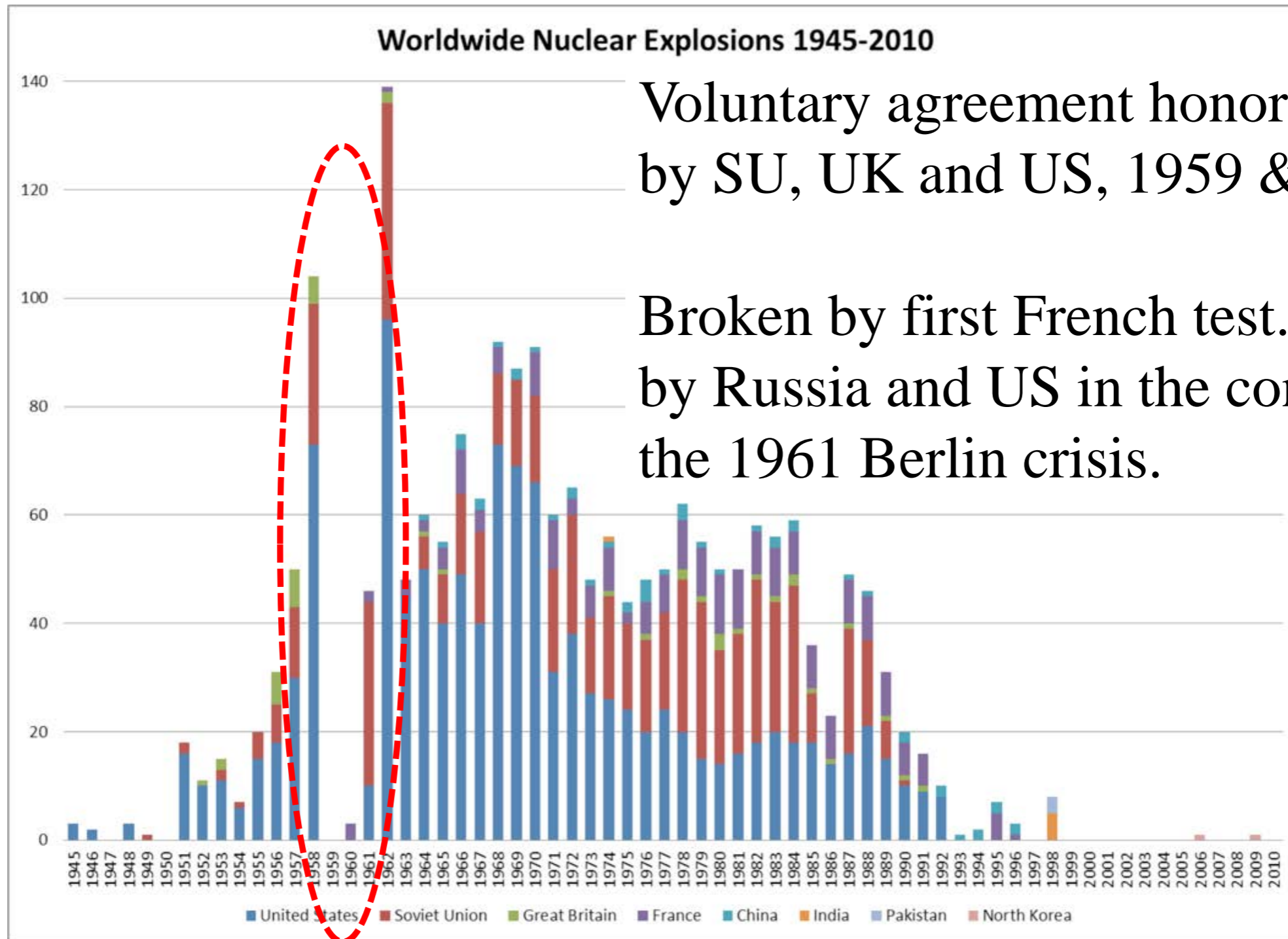


# Effects of Nuclear Explosions



Credit: Wikipedia Commons

# Test Moratorium 1959-1960

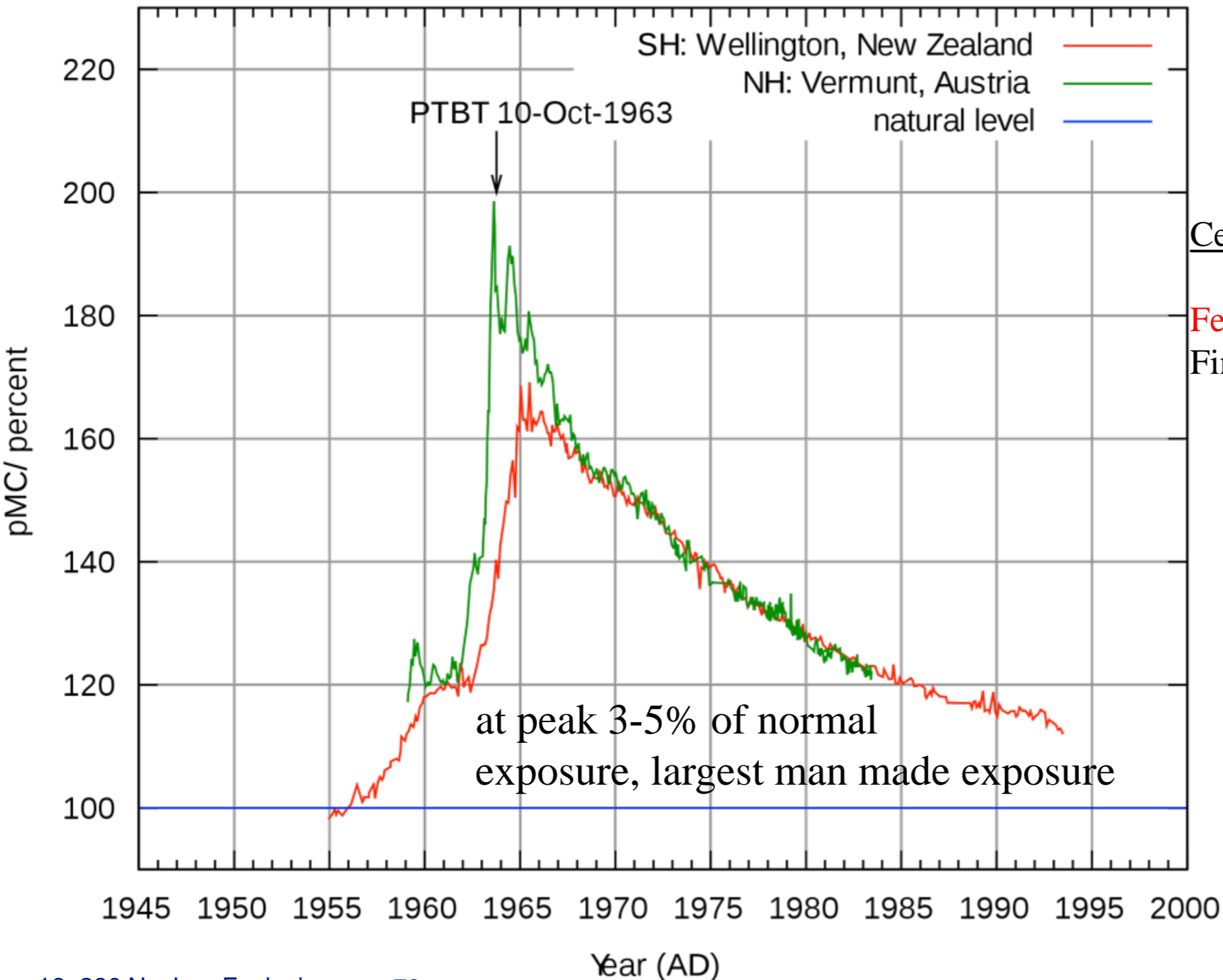


Credit: Wikipedia Commons



# Effects of Nuclear Explosions

$^{14}\text{C}/^{12}\text{C}$  in atmospheric  $\text{CO}_2$ . Source: Hakanomono (Wikipedia)



Centers for Disease Control and Prevention:

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

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

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

# Fallout Radiation from a 1 Mt Burst

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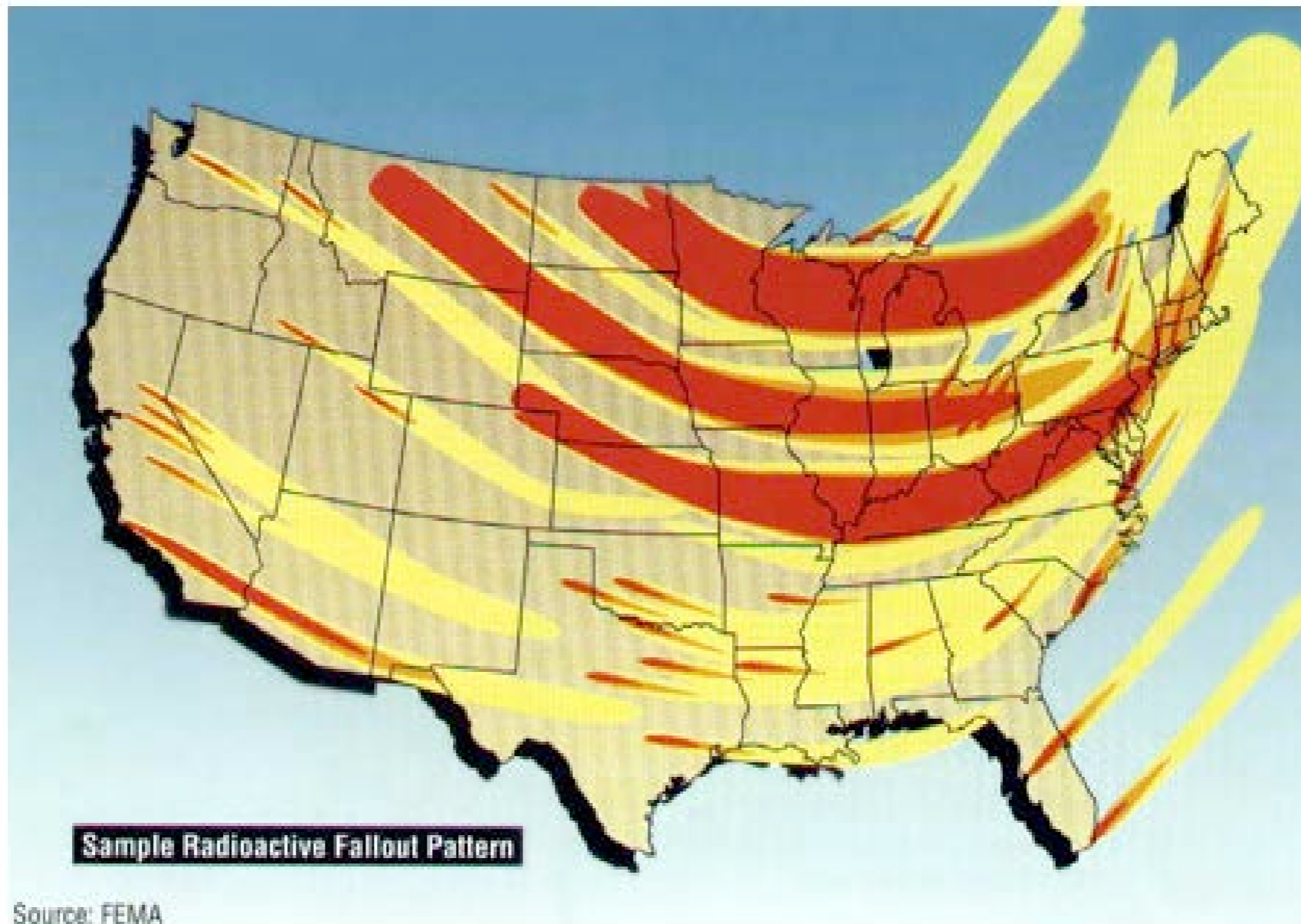
## Assume —

- 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

# iClicker Question

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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”)

# iClicker

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# iClicker Answer

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# iClicker 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”)

# iClicker

---



# iClicker Answer

---

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# iClicker Question

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## 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”)

# iClicker

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# iClicker Answer

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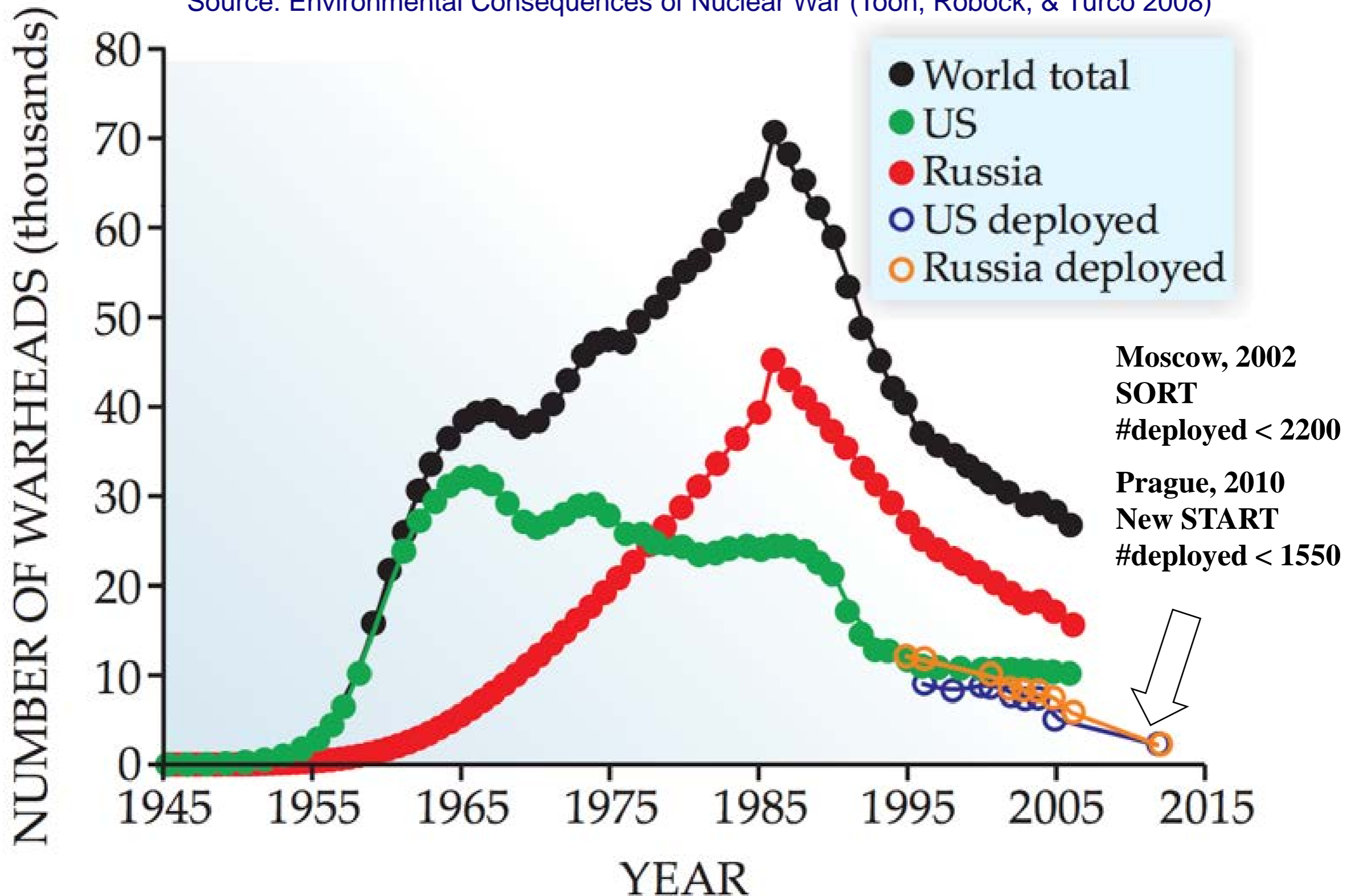
## Nuclear Weapon Effects

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- (E) Residual nuclear radiation (“fallout”)

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

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



# Effects of Nuclear War: Direct Causalities

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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)

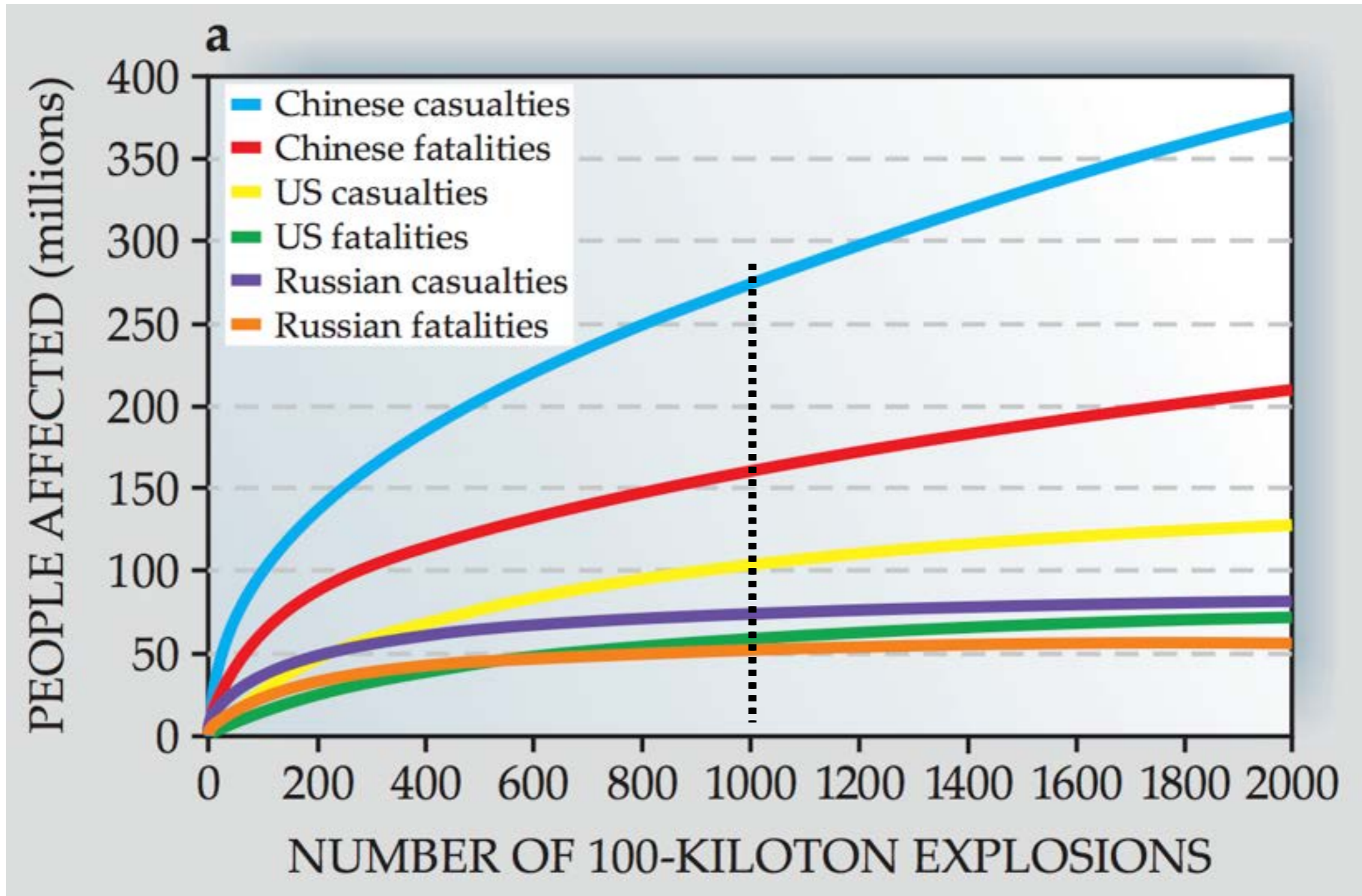
1,000 weapons detonated on Russia would *immediately* —

- 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

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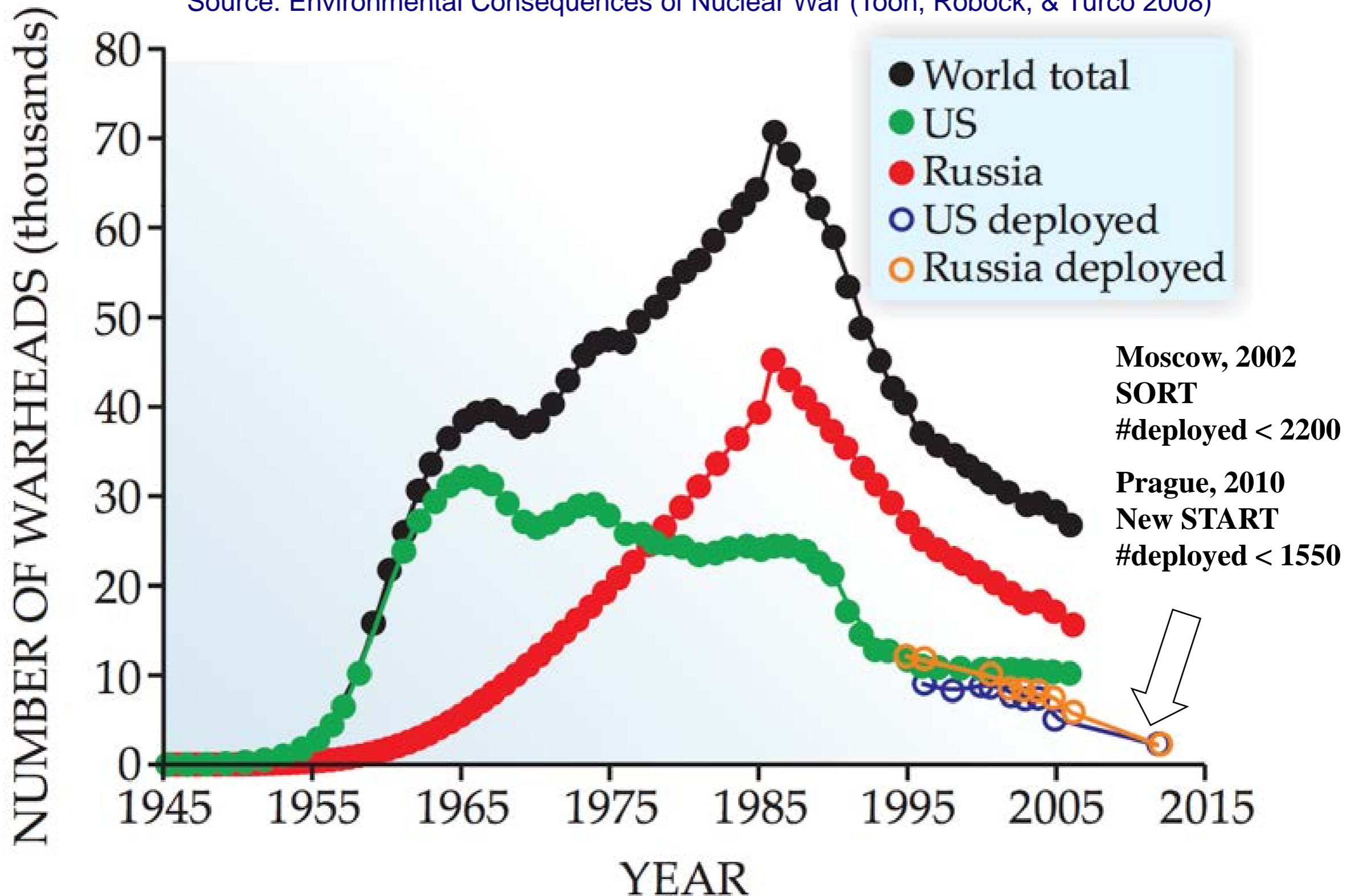
<b>Country</b>	<b>above 1 Million</b>	<b>100,000 - 1 Millions</b>	<b>10,000 to 100,000</b>
<b>China</b>	<b>59</b>	<b>354</b>	<b>385</b>
<b>Russia</b>	<b>12</b>	<b>203</b>	<b>1291</b>
<b>U.S.</b>	<b>10</b>	<b>285</b>	<b>3376</b>

**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)



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

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## 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)

# Physics 280: Session 10

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## Plan for This Session

RE3v1 is due at 2pm (now!)

Questions

Nuclear Explosions Conclusion: “Nuclear Winter”

“Ground Zero” Video presentation

# BBC: Trident lets UK Punch Above Weight - US Defense Secretary

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Britain must keep its Trident nuclear weapons system if it wants to play a significant role in the world, the US defence secretary has said.

Ash Carter told the BBC it was an "important part of the deterrent structure of Nato" and allowed the UK to punch above its weight.

MPs are expected to vote this year on whether to back government plans to renew the UK's four Trident submarines.

Labour is currently reviewing its support for the weapons.

Renewing the Trident fleet, which is due to become obsolete by the end of the next decade, is estimated by the government to cost £31bn, although opponents claim the final bill will be far higher.

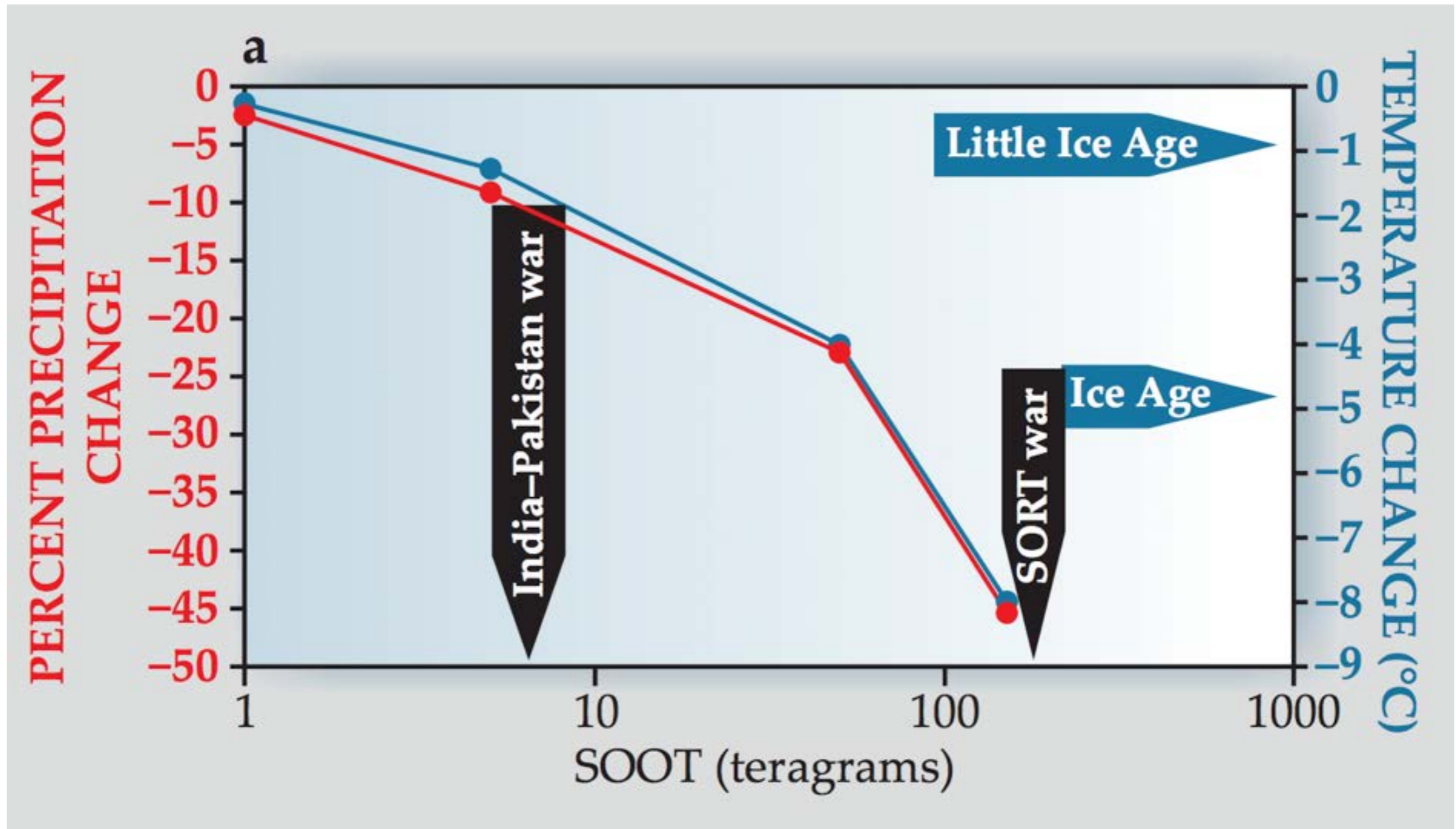
Asked whether the UK should be investing in a new fleet of submarines amid stretched defense resources, Mr Carter replied unequivocally that it should.

He said Trident aided the UK's "special relationship" with the US and helped it "continue to play that outsized role on the global stage that it does because of its moral standing and its historical standing".

"It's important that the military power matches that standing and so we're very supportive of it," he said.

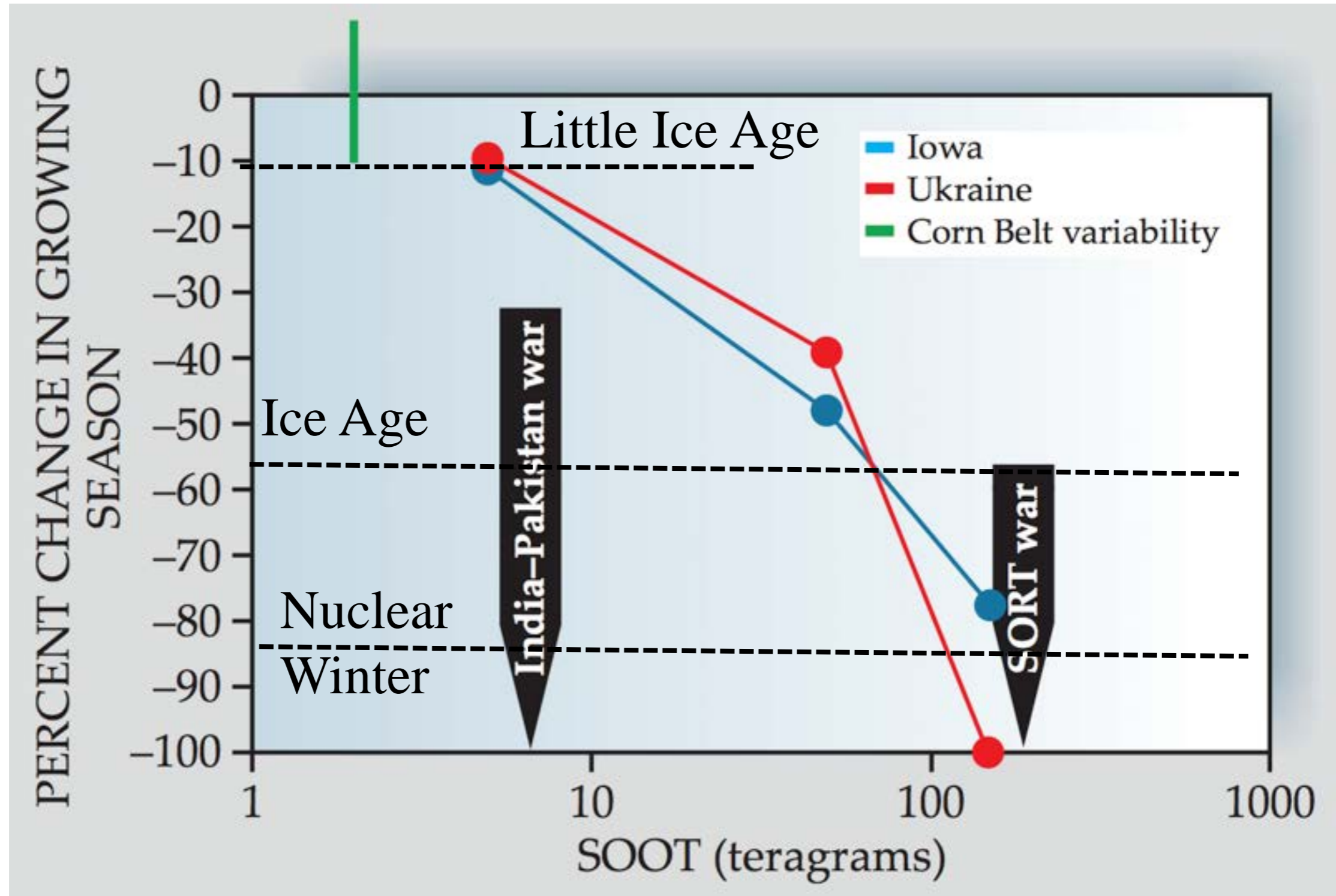
# Effects of Nuclear War: Change in Precipitation and Temperature

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



# Effects of Nuclear War: Percent Change in Growing Season

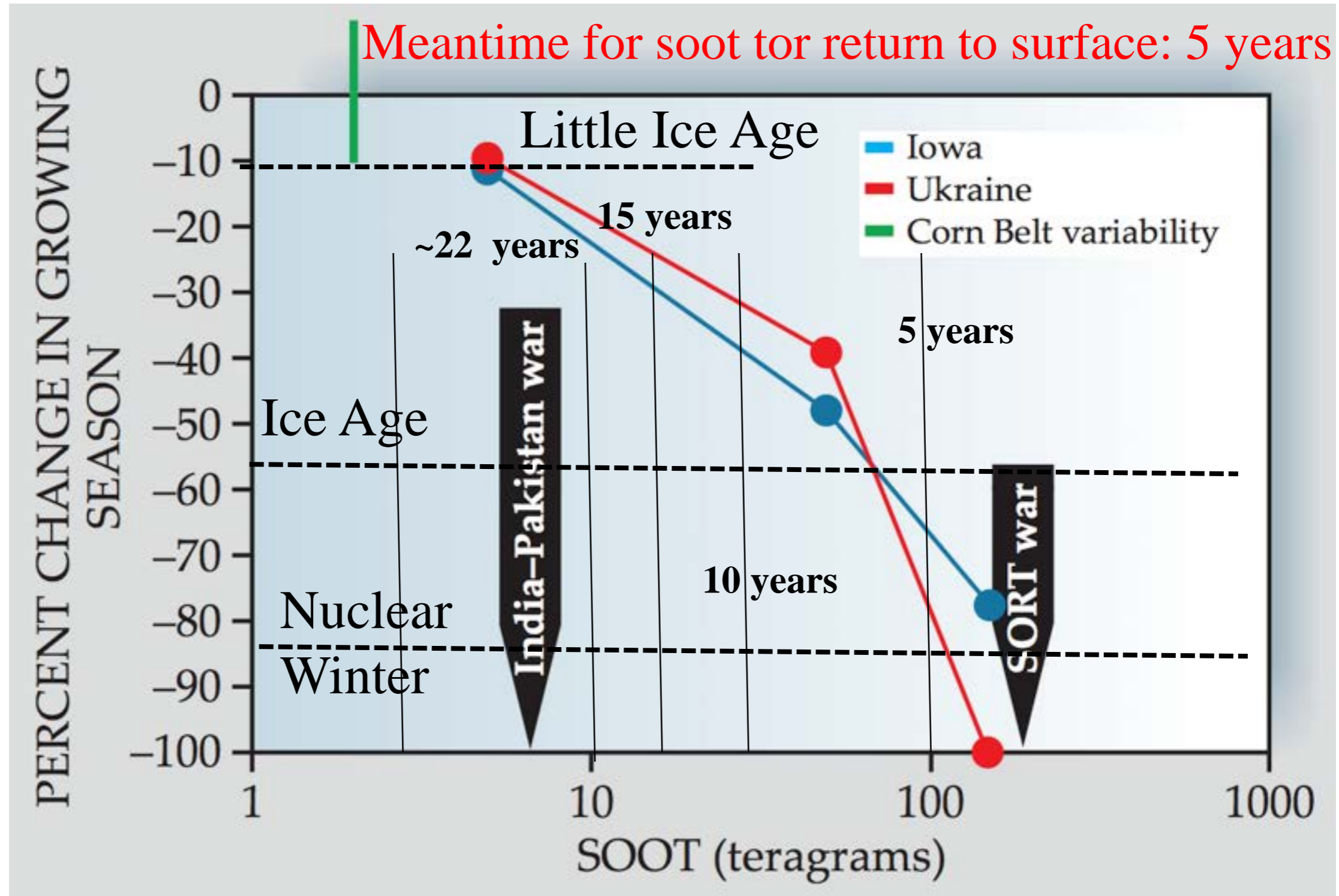
Source: Environmental Consequences of Nuclear War (Toon, Robock, & Turco 2008)





# 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.**”

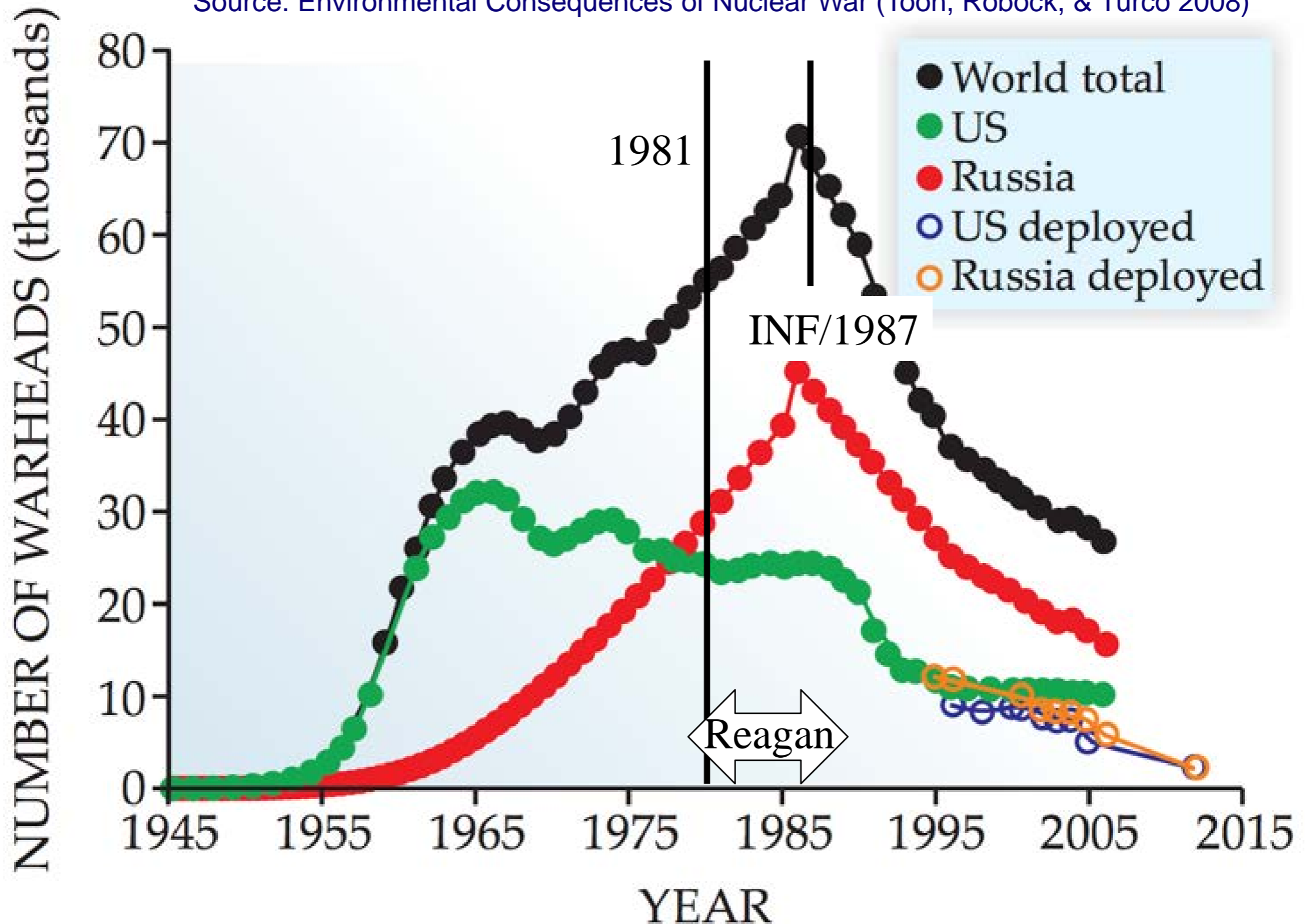
# Ground Zero

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

# Context: Arsenals at the Time of CBS Series

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



# Questions for Discussion

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

# iClicker Question

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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

# iClicker

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# iClicker Answer

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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



# iClicker Question

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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)

# iClicker

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# iClicker Question

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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)**

# How Long from Nuclear Winter to Little Ice Age?

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

