Impact of a 500 kiloton device detonated in Chicago

Plan for This Session

RE2v2 due today

NEM summary

Module 3:
Effects of nuclear explosions
38 North reports evidence that North Korea may have resumed Operation of the Yongbyon reactor in January.

The evidence consists of commercial satellite imagery showing a water plume that may indicate warm Cooling water release from the reactor complex.

38 North is a program of the U.S.-Korea Institute (USKI) at the Paul H. Nitze School of Advanced International Studies (SAIS) at John Hopkins University.

North Korea has restarted reactor to make plutonium, fresh images suggest

Water plume indicates activity at reactor in Yongbyon that produces plutonium for nuclear weapons program

A satellite image of North Korea's main nuclear site at Yongbyon on 22 January, with the water plume marked. Photograph: DigitalGlobe/Getty Images

Reuters
Saturday 28 January 2017 02.31 GMT

New commercial satellite imagery suggests North Korea has resumed operation of a reactor at its main nuclear site that is used to produce plutonium for its nuclear weapons program, a US thinktank said on Friday.
Washington’s 38 North project, which monitors North Korea, said previous analysis from 18 January showed signs that North Korea was preparing to restart the reactor at Yongbyon, having unloaded spent fuel rods for reprocessing to produce additional plutonium for its nuclear weapons stockpile.

It said in a report: “Imagery from January 22 shows a water plume (most probably warm) originating from the cooling water outlet of the reactor, an indication that the reactor is very likely operating.”

It said it was impossible to estimate at what power level the reactor was running, “although it may be considerable”. A 38 North Korea report last week said operations at the reactor had been suspended since late 2015.

North Korea has maintained its nuclear and missile programs in violation of repeated rounds of international sanctions.

News of the apparent reactor restart comes at a time of increasing concern about North Korea’s weapons programs, which could present the new administration of US president Donald Trump with its first major crisis.

A report by leading US-based nuclear expert Siegfried Hecker published by 38 North in September last year estimated North Korea had stockpiles of 32kg to 54kg of plutonium, enough for six to eight bombs, and had the capacity to produce 6kg, or approximately one bomb’s worth, a year.

North Korea also produces highly enriched uranium for atomic bombs and would have had sufficient fissile material for approximately 20 bombs by the end of last year, and the capacity to produce seven more a year, that report said.

In a New Year speech, North Korean leader Kim Jong-un said his country was close to test launching an intercontinental ballistic missile (ICBM) and state media has said a launch could come at any time.
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.
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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.
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 ... ?
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.
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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
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(C) Yes, easily
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: 17p280 Nuclear Explosions, p. 20
FKL, Dep. Of Physics © 2017
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!
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.*
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

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

Credit: Wikipedia (nuclear weapons testing)
Nuclear Explosion Geometries

- Slant range
- Height of burst
- Ground range
- Depth of burst
- Ground zero
Nuclear Explosions in Space

The U.S. exploded nuclear weapons in space in the late 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
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
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

Total of 904 tests at the Nevada test site

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

In your opinion, can 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.
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Nuclear Explosions in the Atmosphere or a Small Distance Underground

Types of bursts in the atmosphere —
- Air burst: fireball never touches the ground
- Surface burst: fireball touches the ground during its expansion

Types of surface bursts —
- Near surface burst: $H_{OB} > 0$, but fireball touches the ground during its expansion
- Contact surface burst: $H_{OB} = 0$
- Subsurface burst: $H_{OB} < 0$, but warhead explodes only a few tens of meters below ground

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

<table>
<thead>
<tr>
<th>Time</th>
<th>Diameter</th>
<th>Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 ms (= 10^{-3} s)</td>
<td>440 ft</td>
<td>—</td>
</tr>
<tr>
<td>10 s</td>
<td>5,700 ft</td>
<td>6,000 C</td>
</tr>
</tbody>
</table>

- Blast wave forms and outruns fireball
- Fireball rises and spreads, forming characteristic mushroom cloud
Plan for This Session

Announcements & Questions:

RE3v1 will be due Thursday 2-16 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: TBD
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

UPDRAFT THROUGH CENTER OF TOROID

TOROIDAL CIRCULATION OF HOT GASES

COOL AIR BEING DRAWN UP INTO HOT CLOUD

STEM

Troposphere

Stratosphere

Fireball
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
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%
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

• 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.
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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)
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” $T$:

  $T = 60–70\%$ @ $D = 5$ miles on a “clear” day/night

  $T = 5–10\%$ @ $D = 40$ 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
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

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

<table>
<thead>
<tr>
<th>Pressure (psi)</th>
<th>Dynamic Pressure (psi)</th>
<th>Wind (mph)</th>
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<tbody>
<tr>
<td>200</td>
<td>330</td>
<td>2,078</td>
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<td>150</td>
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<tr>
<td>5</td>
<td>1</td>
<td>163</td>
</tr>
</tbody>
</table>
Damaging Effects of a Blast Wave
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

Worldwide Nuclear Explosions 1945-2010

Credit: Wikipedia Commons
Test Moratorium 1959-1960

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


Credit: Wikipedia Commons
Effects of Nuclear Explosions

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

At peak 3-5% of normal exposure, largest man made exposure.

Centers for Disease Control and Prevention:

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

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

http://www.cdc.gov/nceh/radiation/fallout/default.htm
Fallout Radiation from a 1 Mt Burst

Assume —

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

Distances and doses —

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

Map of nuclear fallout distribution after a potential nuclear attack on the United States. Source: FEMA
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.”
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")
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Which of the following effects of a Megaton explosion would be felt last 5 miles away?

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(A) Blast
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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
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(C) Thermal radiation
(D) Blast
(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)

[Diagram showing the number of warheads over the years, with markers for World total, US, Russia, US deployed, and Russia deployed.]

Moscow, 2002
SORT
#deployed < 2200

Prague, 2010
New START
#deployed < 1550
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

<table>
<thead>
<tr>
<th>Country</th>
<th>above 1 Million</th>
<th>100,000 - 1 Millions</th>
<th>10,000 to 100,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>59</td>
<td>354</td>
<td>385</td>
</tr>
<tr>
<td>Russia</td>
<td>12</td>
<td>203</td>
<td>1291</td>
</tr>
<tr>
<td>U.S.</td>
<td>10</td>
<td>285</td>
<td>3376</td>
</tr>
</tbody>
</table>

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.
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 (e.g., 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)
Plan for This Session

RE3v1 is due at 2pm (now!)

Questions

Nuclear Explosions Conclusion: “Nuclear Winter”

“Ground Zero” Video presentation
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)

<table>
<thead>
<tr>
<th>Event</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nuclear Winter</td>
<td>~22 years</td>
</tr>
<tr>
<td>Little Ice Age</td>
<td>15 years</td>
</tr>
<tr>
<td>Ice Age</td>
<td>10 years</td>
</tr>
</tbody>
</table>

Meantime for soot to return to surface: 5 years
Effects of Nuclear War

Indirect Effects Would Be the Most Important

– "Environmental Consequences of Nuclear War"
  (Owen Toon, Alan Robock, & Richard Turco, Physics Today, December 2008)

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

• agricultural
• transportation
• energy
• medical
• political
• and social

infrastructure than to the direct effects of nuclear war.”
Ground Zero

Video Presentation, Ground Zero
(from CBS Reports on The Defense of the United States, aired June-14-1981)
Context: Arsenals at the Time of CBS Series

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

(A) Which imbalance in nuclear arsenals triggered the concern of military superiority of the SU?

(B) What is the TRIAD?

(C) Why would there be much more fallout in a US-Russian Nuclear War than following Hiroshima and Nagasaki?

(D) Which society is more vulnerable to Nuclear War, Why?
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
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 precedent)
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)
How Long from Nuclear Winter to Little Ice Age?

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

- Nuclear Winter: ~5 years
- Little Ice Age: ~22 years
- Ice Age: ~55 years

Meantime for soot to return to surface: 5 years