Physics 280: Session 8

Extra-Credit Essay Opportunity A
"The Mushroom Cloud & the Cinematic Imaginary"
Video and Panel Discussion
7:00 p.m. Tuesday, February 15
805 W. Pennsylvania Ave.

Plan for This Session

Student questions and discussion

"Weapons of mass destruction"

Module 3: Effects of nuclear explosions

Question for Discussion

Which of the following countries once had nuclear weapons but gave them up?

A. Belarus

B. Kazakhstan

C. Ukraine

D. South Africa

E. All of the above

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
- Possible effects of nuclear war

Effects of Nuclear Explosions

“Weapons of Mass Destruction”

"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

Chemical and biological weapons do not have this capacity.

Only nuclear weapons are "weapons of mass destruction"

Only nuclear weapons threaten the survival of the U.S.

Radiological Weapons

A radiological weapon is a device that spreads radioactive material.

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 highly radioactive material
- contaminate a larger area with more weakly radioactive material

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.

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.

The most deadly chemicals, such as nerve gases, are complicated to synthesize, extremely dangerous to handle, and difficult to use effectively.

A complex long-term effort would be needed to develop and effectively deliver such an agent.

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.

Biological Weapons

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

In order to cause mass casualties, substantial amounts of agents such as anthrax, smallpox, and plague would have to be converted into tiny particles and then dispersed in an aerosol.

Because these agents are so deadly, the required forms and the equipment needed to disperse them are difficult to come by.

A complex long-term effort would be needed to develop and effectively deliver such an agent.

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.

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..

Nuclear Weapons

In contrast to a chemical or biological agent, a "small" (10 kiloton) nuclear weapon detonated in a major city would kill more than 100,000 people and reduce tens of square kilometers to rubble almost instantly.

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.

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.

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.

Origin of the Term "Weapons of Mass Destruction"

In recent years some have sought to lump together as "WMD"—

- radiological weapons ("dirty bombs")
- chemical weapons
- biological agents
- nuclear weapons

Broadening the definition of "WMD" and using it in this way had two main purposes:

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

This language was politically motivated and 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 Physics 280, we will avoid the term "WMD". Instead, we will say what we mean: "nuclear weapons", "chemical weapons", or "biological weapons".

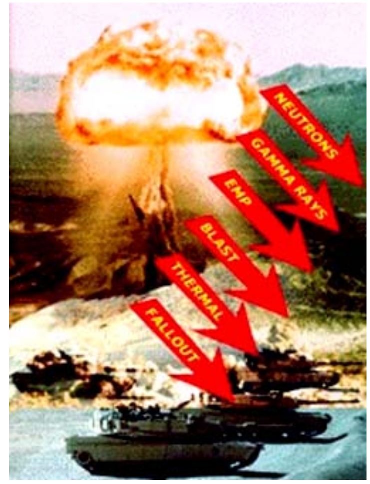
Overview of Nuclear Explosions

Read and Study

The Day After Midnight

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:

Energy Released in a Nuclear Explosion (Review)

The total energy released is the "yield" Y

Y is measured by comparison with TNT

By definition —

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

1 calorie = the energy required to heat 1 gram of H_2O by 1 degree Celsius (C) = 4.2 J

(1 dietary Calorie [Cal] = 1,000 calories = 1 kcal.)

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 —

- Soft X-rays (1 keV) ~ 80%
- Thermal energy of weapon debris ~ 15%
- Prompt nuclear radiations (n, γ, e^-) ~ 5%

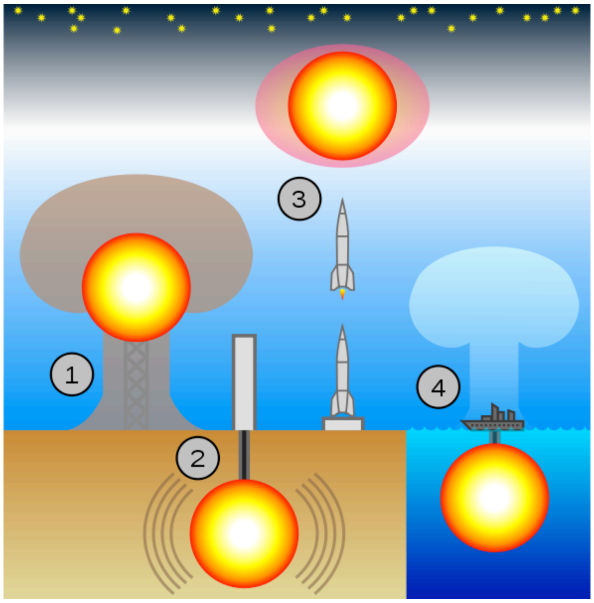
Subsequent Evolution of Nuclear Explosions

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 —

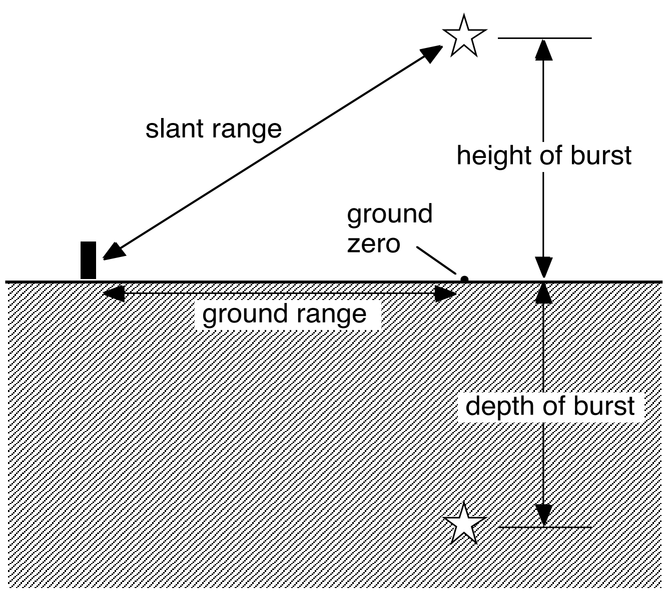
1. Air and surface bursts
2. Underground bursts

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 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 EMP and damage to satellites by particles trapped in the geomagnetic field

Underground Nuclear Explosions

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

Underground Nuclear Explosions

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

Underground Nuclear Explosions

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

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)

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

Types of surface bursts —

- Near surface burst: HOB > 0, but fireball touches the ground during its expansion
- Contact surface burst: HOB = 0
- Subsurface burst: HOB < 0, but warhead explodes only a few tens of meters below ground

The amount of radioactive fallout is increased greatly if the fireball ever 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

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%

iClicker Question

Which nuclear processes are important in the *primary* of a modern two-stage bomb?

A. fission

B. fusion

C. fission and fusion

Blank

iClicker Answer

Which nuclear processes are important in the *primary* of a modern two-stage bomb?

A. fission

B. fusion

C. fission and fusion

iClicker Question

Which nuclear processes are important in the *secondary* of a modern two-stage bomb?

A. fission

B. fusion

C. fission and fusion

Blank

iClicker Question

Which nuclear processes are important in the *secondary* of a modern two-stage bomb?

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B. fusion

C. fission and fusion

iClicker Question

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

A. No

B. Yes, but with difficulty

C. Yes, easily

Blank

iClicker Answer

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

A. No

B. **Yes, but with difficulty**

C. Yes, easily

iClicker Question

Which of the following countries once had nuclear weapons but gave them up?

A. Belarus

B. Kazakhstan

C. Ukraine

D. South Africa

E. All of the above

Blank

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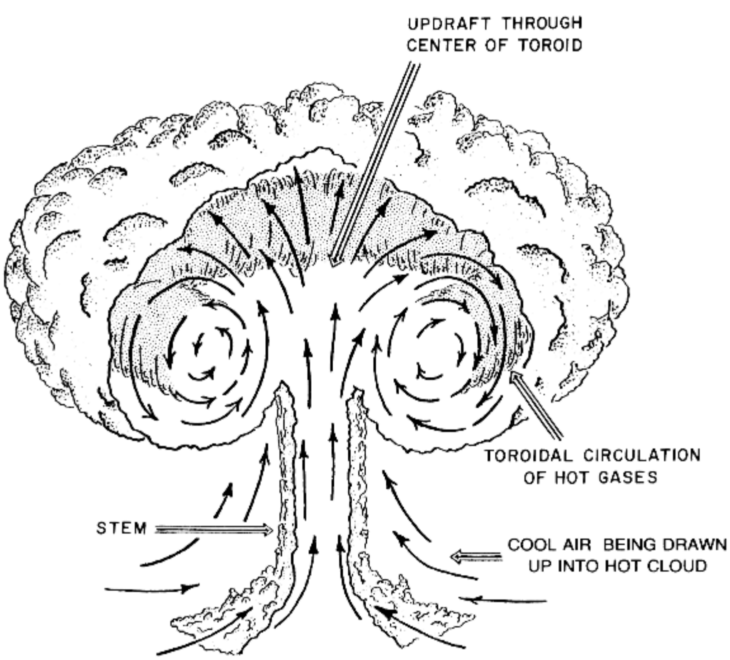
Formation of the Mushroom Cloud



Formation of the Mushroom Cloud

- A fireball forms and rises through the (unstable) 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

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

Short-Term Physical Effects of a 1 Mt Burst

- Prompt nuclear radiation (lasts ~ 10^{-3} s)
  - Principally γ , β, and neutron radiation
  - Intense, but of limited range
- Electromagnetic pulse (lasts ~ 10^{-9} s)
- Thermal radiation (lasts ~1–10 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 @ 5 mi
- Residual nuclear radiation (lasts minutes–years)
  - Principally γ and β radiation

Long-Term Physical Effects

- Fallout
  - From material sucked into fireball, mixed with weapon debris, irradiated, and dispersed
  - From dispersal of material from nuclear reactor fuel rods
- Ozone depletion (Mt bursts only)
  - Caused by nitrogen oxides lofted into the stratosphere
  - Could increase UV flux at the surface by ~ 2x to ~ 100x
- Soot injected into the atmosphere cools Earth (“nuclear winter”)
  - Caused by injection of dust and soot into atmosphere
  - Initial scientific studies indicated this is a big effect. Later studies indicated it is probably not as serious. The most recent, most sophisticated studies show these effects are very important.

Physics 280: Session 9

TODAY
Extra-Credit Essay Opportunity A
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Plan for This Session

Student questions and discussion

News and discussion: Iran's nuclear program

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

News and Discussion

The Washington Post

The Iranian slowdown

Thursday, January 13, 2011; A22

CONFIRMATION that the international campaign against Iran's nuclear program has made headway recently came from a seemingly unlikely source: Israel's intelligence chief. Last week, Meir Dagan, outgoing head of the Mossad intelligence agency, said that Iran could not now acquire a nuclear weapon before 2015, because of unspecified technical problems. That was a big change from previous Israeli estimates: In 2009, Israeli Prime Minister Binyamin Netanyahu said Iran could have a bomb by this year. For years, Israeli measures of the Iranian nuclear timeline have been ahead of those by U.S. intelligence agencies, which predicted in 2007 than Iran could acquire nuclear capability between 2010 and 2015.

News and Discussion

In Israel as in the United States, estimates of the Iranian threat may be swayed in part by debate over what to do about it; Mr. Dagan is reportedly an opponent of an Israeli military strike against Iran's nuclear facilities. Yet there appear to be solid reasons to conclude that U.N. and other Western sanctions and covert operations have hindered the Iranian program. An ingenious computer virus called Stuxnet may have put hundreds or even thousands of centrifuges used in uranium enrichment out of action; Iranian President Mahmoud Ahmadinejad publicly acknowledged last November that a virus had infected equipment. Two Iranian nuclear scientists were killed and another wounded in the last year in assassination operations Iran has blamed on Israel.

News and Discussion

At the same time, sanctions may have impeded Iran from acquiring the specialized materials, such as maraging steel and carbon fiber, that it needs to replace broken centrifuges or build the more advanced models it has claimed to develop. Without more advanced centrifuges, Iran would have trouble in any attempt to create a bomb out of the low-enriched uranium it has stockpiled. Experts believe it would take a year to manufacture bomb-grade material with the current machines, which means the effort - if conducted in known facilities - would probably be detected with plenty of time for Western nations to react.

News and Discussion

The Obama administration deserves credit, at least, for orchestrating the tightening of sanctions; the authors of Stuxnet have not been identified. But as Secretary of State Hillary Rodham Clinton emphasized this week, the changed timeline does not mean that the threat of Iran's program is over or that the urgency of confronting it is lessened. "We don't want anyone to be misled by anyone's intelligence analysis. This remains a serious concern," she said during a tour of Persian Gulf countries intended in part to win more support for sanctions enforcement. "We have time. But not a lot of time."

News and Discussion

Iran's nuke program _ how much time for diplomacy?

(AP) – Jan 20, 2011

ISTANBUL (AP) — The U.S. is joining five other world powers for talks with Iran this week publicly confident that international efforts have slowed Tehran's capacity to make nuclear arms and created more time to press Tehran to accept curbs on its atomic activities.

But the Federation of American Scientists is warning against complacency. It says there have been impressive improvements in the performance of the Iranian machines that enrich uranium — an activity that has provoked U.N. sanctions because it could be used to make nuclear weapons.

In a study shared with The Associated Press ahead of publication, the Washington-based organization argues that Iran last year appears to have increased efficiency of the machines that produce enriched uranium by 60 percent, giving it the technical capacity to produce enough material for a simple nuclear warhead in 5 months.

News and Discussion

Iran insists it is enriching only to make nuclear fuel, and Ivanka Barzashka, author of the Federation of American Scientists study, emphasizes that Tehran is unlikely to provoke the world — and increase the likelihood of attack — by kicking out IAEA inspectors and re-calibrating its centrifuges from making low-enriched to weapons grade uranium.

Olli Heinonen, who retired late last year as the IAEA deputy director general in charge of the agency's Iran file, called the likelihood of such a "breakout scenario" as a "suicidal mission" and noted that manufacturing nuclear warhead material is only one step in making a weapon. But he also said he cannot "dispute the correctness of the figures" in the study.

News and Discussion

Global Security Newswire
by National Journal Group
Daily news on nuclear, biological and chemical weapons, terrorism and related issues.

Iran's Uranium Enrichment Seen Regaining Momentum

Tuesday, Feb. 8, 2011

Official and independent analysts said Iran's uranium enrichment program is performing consistently, signaling its recovery following a temporary suspension in late 2010 and a possible computer-based strike, Reuters reported yesterday (see ***GSN***, Feb. 7).

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
  - Expansion is initially via photon diffusion, so $R \sim \text{const} \cdot t^{1/2}$
- 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

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" τ :

  τ = 60–70 % @ D = 5 miles on a "clear" day/night

  τ = 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

Examples of Flash Burns Suffered at Hiroshima and Nagasaki

Photo credit U S Department of Defense

The patient's skin is burned in a pattern corresponding to the dark portions of a kimono worn at the time of the explosion

Photo credit U S Air force

Burn injuries from nuclear blasts

Thermal Radiation Units (Details)

$$Q \equiv \text{fluence} = \frac{\text{energy}}{\text{unit area}} \quad .$$

Thus

$$[Q] = \frac{\text{calories}}{\text{cm}^2} \quad .$$

Definition of calory:

1 cal = heat required to raise temperature of 1 gram of H_2O 1 C

1 cal = 4.2 Joules = 4.2 Watt·s

[Note: Dietary calories are 1000 times larger and are written with a capital "C". 1 Cal = 1,000 cal]

Example:

A 1 kilowatt (kw) hot plate emits $\frac{2}{3} \times \frac{\text{cal}}{\text{cm}^2 \times \text{sec}}$.

Thus, if you were to hold your hand right (~ 1 cm) above such a hot plate, in 10 s you would receive a fluence of

$$Q = 10 \times \frac{2}{3} = 7 \text{ cal cm}^{-2} \Rightarrow \text{2nd degree burn!}$$

Classification of Burns

Degree	Damage to Skin	Symptoms
1st	Superficial, completely reversible; no scarring	Immediate persistent pain; affected area is red
2nd	Some skin cells survive; will heal in 2 weeks unless infection sets in	Persistent pain; scabs within 24 hours
3rd	All skin cells dead; scarring certain without skin grafts (no cells to regenerate skin)	Pain at edges of injured areas; skin looks normal, scalded, or charred

Effects of Thermal Radiation – 5

Q (cal/cm^2)	Consequences
2–6	Humans suffer 1st degree burns
5–8	Humans suffer 2nd degree burns
> 8	Humans suffer 3rd degree burns
15	Rayon fabric ignites
17	Cotton dress shirt ignites
18	Window Draperies ignite
20	Blue jeans ignite
30	Asphalt roofing ignites

Conflagrations Versus Firestorms

Conflagration —

- Fire spreads outward from the ignition point(s)
- 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, people are baked and asphyxiated

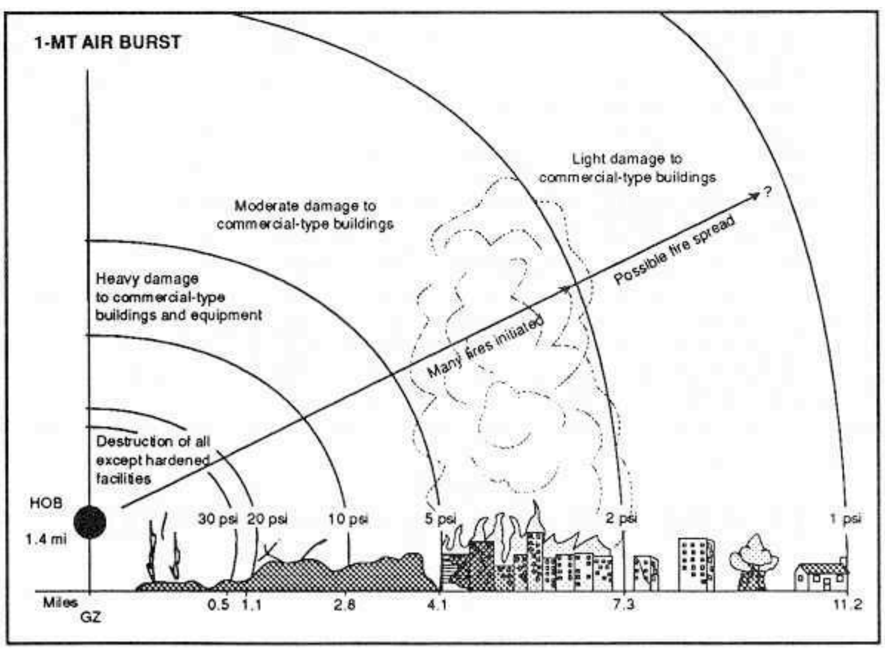
Effects of Nuclear Explosions

Effects of Blast Waves

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



Damaging Effects of a Blast Wave

- The blast wave is considered the most militarily significant effect of a nuclear explosion in the atmosphere
- Because its peak pressure P is proportional to Y/D^3, the distance at which P (and hence the damage) is of a given size is proportional to $Y^{1/3}$; this is called “cube-root” scaling
- 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

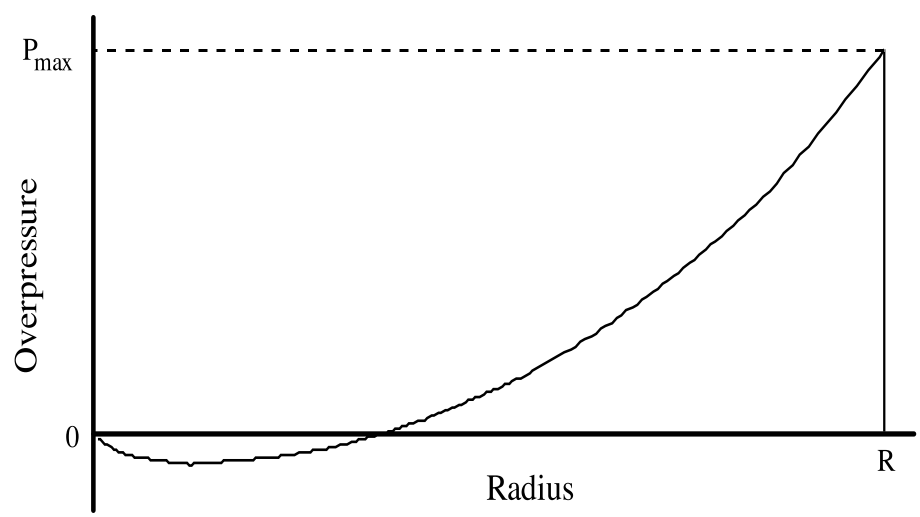
  - –A strong outward wind that produces dynamic pressure Q that blows structures and victims outward

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

Shape of a Blast Wave

A snapshot in time: Pressure vs. Radius

Shock Wave Pressure Distribution



Effects of Thermal Radiation and Blast on Houses

Effect of a 16 kt explosion on a house 1 mi away

(equivalent to a 1 Mt explosion on a house 5 mi away, but happens 10x faster)

Effects of Shallow Underground Nuclear Explosions

Example: The Sedan Test (100 kt, 1962)

Effects of Shallow Underground Nuclear Explosions

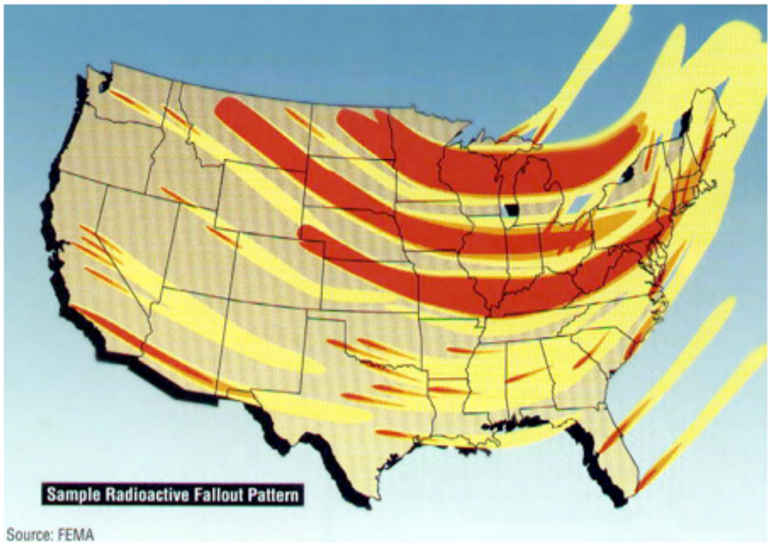
Effects of the Sedan Event (1962)

- 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

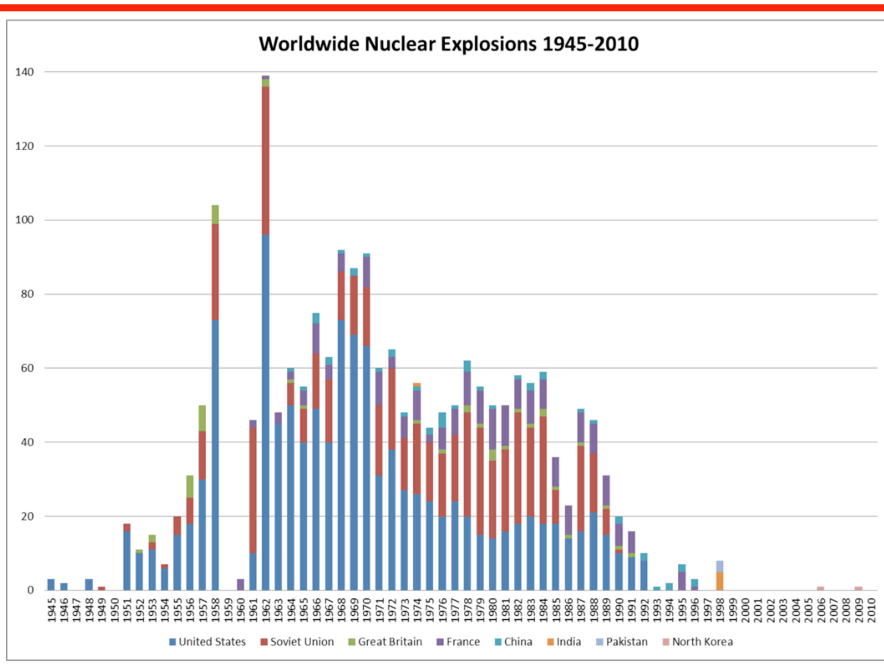
Example: The Sedan Test (100 kt, 1962)

Effects of Nuclear Explosions



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

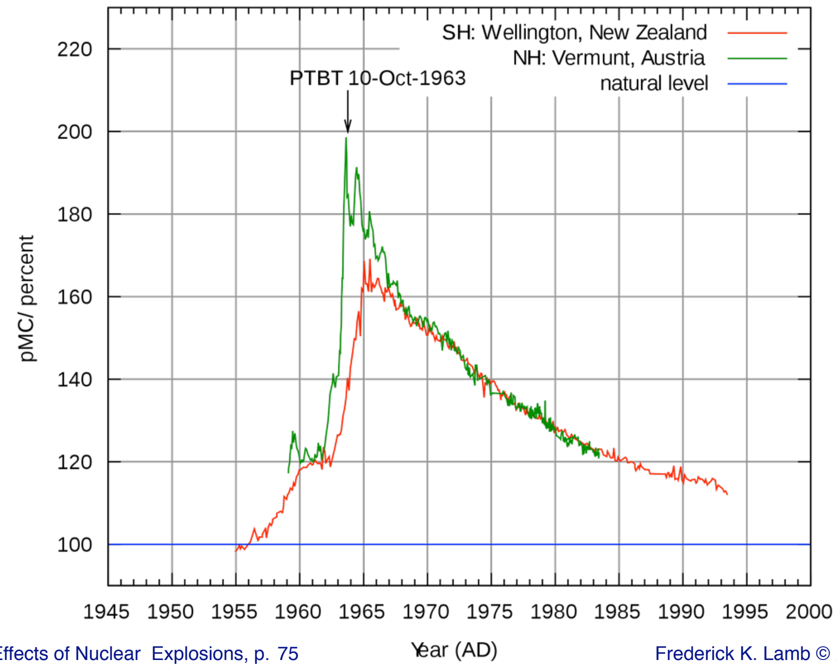
Effects of Nuclear Explosions



Credit: Wikipedia Commons

Effects of Nuclear Explosions

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



Nuclear Explosions in Air Produce a Characteristic "Double Flash" of Light

- The strong shockwave produced by a nuclear explosion heats the air through which it passes, making it opaque
- Consequently, once the shockwave is outside the fireball, an observer can see only the gas heated by the shockwave, which is cooler than the gas in the fireball
- As the shockwave expands it weakens, its brightness drops, and the explosion dims, ending the first flash
- A short while later the shockwave becomes so weak that it no longer makes the air through which it passes opaque
- At this point the much hotter fireball becomes visible again and the explosion brightens temporarily before fading as the fireball expands and cools
- This sequence of events produces the characteristic "double flash" of light of a nuclear explosion in the atmosphere, which sensors on satellites orbiting Earth can use to detect and identify air and surface bursts

iClicker Question

What is the fundamental limit on the yield of a thermonuclear bomb?

A. 1 kt

B. 100 kt

C. 1 Mt

D. 100 Mt

E. There is no limit

Blank

iClicker Answer

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iClicker 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”)

Blank

iClicker Answer

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A. Blast
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C. Electromagnetic pulse
D. Residual nuclear radiation (“fallout”)

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”)

Blank

iClicker Answer

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

A. Blast

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iClicker Question

Nuclear Weapon Effects

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

A. Prompt nuclear radiation

B. Electromagnetic pulse

C. Thermal radiation

D. Blast

E. Residual nuclear radiation ("fallout")

Blank

iClicker Answer

Nuclear Weapon Effects

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

A. Prompt nuclear radiation
B. Electromagnetic pulse
C. Thermal radiation
D. Blast
E. Residual nuclear radiation ("fallout")

Physics 280: Session 10

Extra-Credit Essay Opportunity B
“Fear, Anger, and the American Response to Terrorism”
Professor John Lynn
Northwestern University
12:00–1:00 p.m. Friday, April 8
University YMCA, 1001 S. Wright St.

Plan for This Session

Student questions and discussion

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

Tuesday: CBS Documentary “Ground Zero”

Question for Discussion

Which of the following is **not** a provision of the Nuclear Nonproliferation Treaty?

A. Nuclear weapons states must give up all their nuclear weapons.

B. Non-nuclear weapon states are guaranteed the right to enrich uranium and produce plutonium.

C. Non-nuclear weapon states must not accept or manufacture nuclear weapons.

D. Nuclear weapons states must not give nuclear weapons to non-nuclear weapon states or help them develop weapons.

E. All of the above are provisions of the treaty.

Effects of Nuclear Explosions

Effects of Nuclear Radiation

Non-Nuclear and Nuclear Radiation

Categories of non-nuclear electromagnetic radiation based on its energy —

- Radio frequency (RF) radiation
- Optical radiation: UV, VIS, IR (atomic and molecular transitions)
- X-rays (from electronic transitions in atoms)

Categories of nuclear radiation based on the particle involved —

- Alpha radiation: α (produced by nuclear decays)
- Beta radiation: $\beta^{\pm}$ (produced by nuclear decays)
- Gamma radiation: γ (electromagnetic radiation produced by de-excitation of nuclei)
- Neutrons: n (fission & fusion)
- Fission fragments and other heavy ions

Categories of Nuclear Radiation

Two categories of radiation based on its source —

- *Prompt nuclear radiation* from fission reactions in the weapon and from radioactive decay of fission fragments (~ 5% of Y)
- *Delayed nuclear radiation* from the radioactivity of the material in the weapon (e.g., the case) or later engulfed in the fireball (~ 5%–10% of Y)

Two categories of radiation based on when it is absorbed —

- *Initial radiation* (during the first minute): n, γ
- *Residual radiation* (after the first minute): n, γ, some β; α-radiation over very long times, if ingested

Effects of Radiation on Matter – 1

Two categories of radiation based on its effects —

- Non-ionizing radiation: RF, optical (IR, VIS, UV)
- Ionizing radiation: α, β, γ, n, fission fragments, heavy ions, most X-rays

These two categories of radiation have very different effects on matter —

- Non-ionizing radiation causes heating
  - — Very well understood
  - — Can damage biological systems if the temperature becomes too high
- Ionizing radiation breaks chemical bonds
  - — Generally well understood
  - — Long-term effects of very low level exposures are controversial, primarily because experiments and epidemiology are so difficult for this case

Effects of Radiation on Matter – 2

Important to distinguish two classes of materials —

- Inert matter
- Living matter (biological organisms)

Different measures are used to quantify —

- Physical exposure
- Biological exposure

Biological organisms have received the most attention (especially humans) —

- Ionizing radiation is the main concern
- Animals are more vulnerable than plants
- Higher animals are more vulnerable than (some) lower animals

Physical Effects of Ionizing Radiation – 1

Physical causes of biological effects—

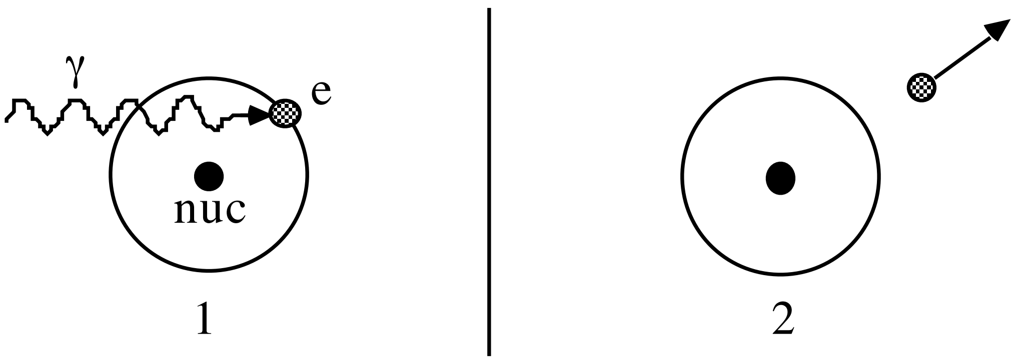
- Radiation strips electrons from atoms and molecules (this process is called “ionization”)
- Ionization changes the chemical properties of the atoms and molecules
- The changes in chemical properties can cause damage to biological molecules, cells, and tissues
- This damage may cause malfunction or death

Two modes of ionization—

- Direct ionization (charged particles and photons)
- Indirect ionization (neutrons)

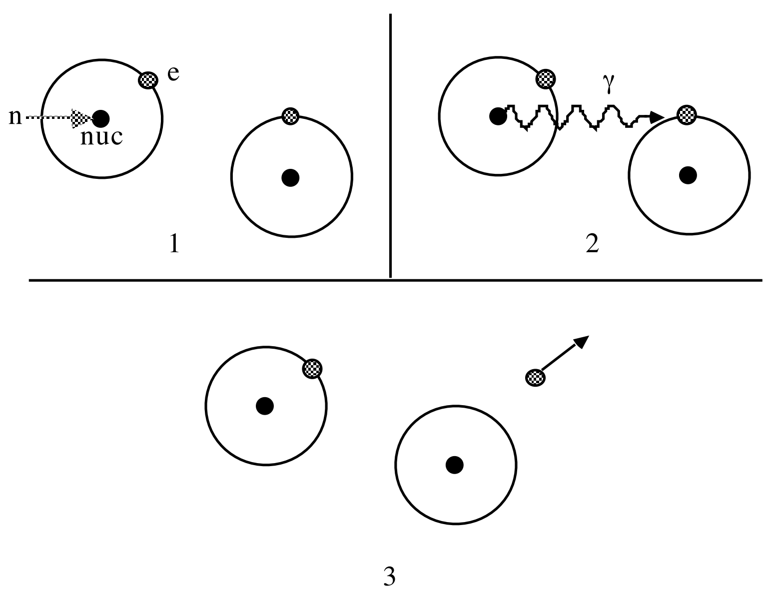
Physical Effects of Ionizing Radiation – 2

Direct Ionization



Physical Effects of Ionizing Radiation – 3

Indirect Ionization



The Bad News

A non-functional protein might be produced —

- Cell repair mechanisms may be affected
- Immunological pathways may be shutdown
- Cellular metabolism may be affected greatly

A protein with a different function might be produced —

- An enzyme that helps break down estra-diols (estrogen products) can easily be modified at the genetic level to convert testosterone to estrogen! (Most beers have this enzyme to begin with. Beer gut and saggy man-breasts, anyone?)

Damage caused by a large dose of radiation cannot be repaired —

- Radiation sickness is a good example
- Mammals exposed to lethal doses of radiation simply decay, their organ systems shutting down one by one

The Good News

Mutations like these happen all the time and are not a serious problem

The human genome is so large that most mutations occur in non-coding regions that contain only "junk"

If a single cell acquires a mutation it does not mean that every cell in the organism will misbehave —

- Cells produce minute amounts of enzymes, etc. Usually many, many cells must suffer the same mutation before the organism is seriously affected.

Cells have mechanisms for checking DNA damage —

- If a cell cannot repair the damage, it often enters a self-regulated death cycle (apoptosis), preventing itself from passing on the mutation(s) to its progeny.
- However, mutations sometimes interfere with this process, and the cell does pass on its bad attributes (cancer).
- Radiation sickness and burns are partially caused by cells that kill themselves.

Effects of Radiation (Review)

Ionizing radiation is the main concern —

- Breaks chemical bonds
- Can damage inert material
- Can damage biological systems
  - — Short-term ("acute") exposure: ~ 1 day or less
  - — Long-term ("chronic") exposure: days to years
- Mostly well-understood
  - — Exception: long- term effects of low levels of exposure received over long periods
  - — Example: cancer rates 20 to 40 years later

Non-ionizing radiation causes heating —

- If it produces a high temperature, harm can occur
- Well understood

Effects of Ionizing Radiation – 1

It's important to distinguish —

- **Source activity** = rate of particle emission (e.g., the number of particles emitted per second)
- **Physical dose-rate** (rate at which energy is absorbed)
- **Physical dose** (total energy absorbed; an integrated measure)
- **Biological dose-rate** (describes rate at which living tissue is affected)
- **Biological dose** (describes total consequences to living tissue; an integrated measure)
- *No unit has yet been defined to characterize genetic damage*

Effects of Ionizing Radiation – 2

Measuring *source activity* —

- Geiger Counters measure activity
  = number of nuclear decays per second
- Traditional unit: curie (Ci)
  - Definition: 1 Ci = 3.7 x 10^{10} decays per sec
  - Activity of 1 g of radium is 1 Ci
- Modern (SI) unit : becquerel (Bq)
  - Definition: 1 Bq = 1 decay per sec
- Examples of radioactive sources
  - Co-80 sources used in medicine: 100-1,000 Ci
  - Spent fuel from a 1 GW nuclear reactor: 5 x 10^{9} Ci (initially)
  - 1 Mt nuclear weapon: 10^{11} Ci (prompt radiation)
- The activity of a source tells you *nothing* about the physical or biological consequences!

Effects of Ionizing Radiation – 3

Physical effects —

- Characterized by the *physical* dose or exposure
  = total energy absorbed
- Measured by devices (such as film badges) that record the *cumulative* exposure
- The physical dose measures the overall effect of ionizing radiation on *inert* matter
- Traditional unit: rad (1 rad = 10^{-5} J/g)
- Modern (SI) unit: gray (1 Gy = 10^{-3} J/g = 100 rad)

Effects of Ionizing Radiation – 4

Biological effects —

- Characterized by the biological dose (or dose-equivalent)
- The biological dose is a good overall measure of the magnitude of the biological effect of interest
- The biological effect of a physical dose depends on
  - — The type and energy of the radiation
  - — The type of biological tissue (skin, cornea, etc.)
  - — The type of damage of interest

Effects of Ionizing Radiation – 5

Quality factor —

- The *quality factor* describes how much damage a given type of radiation causes; it depends on the *radiation*, the *tissue*, and the *type of damage*
- Traditional unit: rem ("roentgen equivalent mammal") (1 rem = quality factor x 1 rad)
- Modern (SI) unit: sievert (Sv) (1 sievert = quality factor x 1 gray)
- Rough conversion factor: 1 Sv = 100 rem

Examples of Exposures – 1

Dose rates due to natural background —

- 2 to 3 mSv/yr is a representative number (1 mSv = 10^{-3} Sv)
  - —Quoted natural background exposure rates have varied from 10^{-5} Sv/yr, up to 1 mSv/yr, but both are out of date!
  - —The estimated natural background exposure rate more than doubled when radon was discovered in buildings!

Maximum permissible dose rates (now?) —

- Max dose rate for workers in industry and medicine: 5.0 rem/yr (no more than 25 rem over a lifetime is allowed)
- Population must be protected if dose exceeds 25 rem
- Population must be evacuated if dose exceeds 75 rem

Examples of Exposures – 2

Examples of medical exposures —

- Modern chest X-ray = 20 mrem
- Heart X-ray (angiogram) ≈ 2 rem/image
- Cat scan ≈ 100 rem ~ 1 Sv per image

LD_{50} biological dose (Lethal Dose-50: healthy young adults have a 50% probability of survival with good medical attention)—

- LD_{50}= 450 rem = 4.50 Sv (acute exposure, whole body)

Very high doses —

- 10,000 rem: immediate neurological impairment
- 3,000 rem; death in hours
- 1,000 rem: death in days
- 450 rem: 50% chance of survival
- 300 rem: severe radiation sickness

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)

iClicker Question

Which of the following is **not** a provision of the Nuclear Nonproliferation Treaty?

A. Nuclear weapons states must give up all their nuclear weapons.

B. Non-nuclear weapon states are guaranteed the right to enrich uranium and produce plutonium.

C. Non-nuclear weapon states must not accept or manufacture nuclear weapons.

D. Nuclear weapons states must not give nuclear weapons to non-nuclear weapon states or help them develop weapons.

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E. All of the above are provisions of the treaty.

iClicker Question

The New START limits the number of strategic nuclear launchers the United States and Russia may deploy to

A. 1,550

B. 1,000

C.   900

D.   800

E.   700

Blank

iClicker Question

The New START limits the number of strategic nuclear launchers the United States and Russia may deploy to

A. 1,550

B. 1,000

C. 900

D. 800

E. 700

iClicker Question

The New START limits the number of strategic nuclear warheads the United States and Russia may deploy to

A. 1,550

B. 1,000

C. 900

D. 800

E. 700

Blank

iClicker Question

The New START limits the number of strategic nuclear warheads the United States and Russia may deploy to

A. 1,550

B. 1,000

C. 900

D. 800

E. 700

iClicker Question

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

A. No

B. Yes, but with difficulty

C. Yes, easily

Blank

iClicker Answer

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

A. No

B. **Yes, but with difficulty**

C. Yes, easily

Physics 280: Session 11

Extra-Credit Essay Opportunity B
“Fear, Anger, and the American Response to Terrorism”
Professor John Lynn
Northwestern University
12:00–1:00 p.m. Friday, April 8
University YMCA, 1001 S. Wright St.

Plan for This Session

Student questions and discussion

Video: CBS Documentary “Ground Zero”

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

Notes on the "Ground Zero" Video

A 1982 CBS News Documentary

- US and SU were both "weapon rich" (US: >12,000 NWs; SU: > 8,000 NWs)
- Stimulation of fears was similar to today, but much more intense
- Soviet capabilities were greatly *overstated*, U.S. capabilities were *understated*, the likely effects of nuclear war were being enormously *understated*
  - —Reagan administration: "with enough shovels, we will all survive"
  - —Briefing by White House Director of Emergency Communications
- Some 4,000 large-yield strategic nuclear weapons are still on high alert today

The consequences of a terrorist attack would be different from the consequences of a large nuclear attack; protective measures could be more effective

"Ground Zero" also provides an introduction to
Module 5: Delivery of Nuclear Weapons

Physics 280: Session 12

Extra-Credit Essay Opportunity B
"Fear, Anger, and the American Response to Terrorism"
Professor John Lynn
Northwestern University
12:00–1:00 p.m. Friday, April 8
University YMCA, 1001 S. Wright St.

Plan for This Session

Student questions

News and discussion: Iran's nuclear program

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

Module 4: Nuclear Terrorism

News and Discussion

The Washington Post

The Iranian slowdown

Thursday, January 13, 2011; A22

Israeli measures of the Iranian nuclear timeline have been ahead of those by U.S. intelligence agencies, which predicted in 2007 than Iran could acquire nuclear capability between 2010 and 2015.

News and Discussion

From Arms Control Wonk (Joshua Pollack)

Some Straight Talk About Iran

BY JOSHUA | 13 AUGUST 2010 | 12 COMMENTS

1) "To go nuclear." Anonymous officials like to talk about "going nuclear" without saying what they mean. Just what is it that Iran is supposed to be capable of doing in nine months, five days, and eight hours — give or take thirty-three seconds depending on the sighting of the new moon — that they cannot do now? Making heaps of highly enriched uranium? Presumably not. They're technically capable of doing that already, and have been for a few years now.

To "go nuclear" could mean, A) to accumulate the knowledge and materials necessary to fashion nuclear weapons. There's not much left for Iran to do on that front — possibly nothing at all. This is bad, but could be worse.

News and Discussion

Or it could mean, B) actually building nuclear weapons in secret. This is worse, but still denies Iran the potential political benefits of owning the bomb.

Or it could mean, C) doing what North Korea did between 2003 and 2009: renouncing treaty obligations, kicking out inspectors, building maybe half a dozen devices, and testing a couple of them. That's the worst.

Any journalist conversing with a Senior Administration Official who talks about when Iran will "go nuclear" really ought to ask them which of the above things they mean, because they're very different things.

News and Discussion

2) "To break out." This usually refers to Scenario (B) or (C) above. U.S. intelligence officials like to talk about this subject in terms of timelines, while carefully obscuring their assumptions. That leaves room for a variety of misunderstandings.

Before the Qom facility was exposed in September 2009, many assumed that Iran would someday decide to use its big facility at Natanz to make highly enriched uranium for a bomb, even though its location is known, it's full of cameras, and international inspectors visit frequently — probably more often than you realize.

Frederick K. Lamb © 2011

News and Discussion

As it turns out, though, the intelligence community had a good hunch that the Iranians would actually try to build a secret facility somewhere else instead, far from prying eyes. They even slipped that detail into the much-maligned 2007 National Intelligence Estimate. So it turns out that the official breakout-capability timelines involve activities like excavation and pouring concrete.

That's not to say that there's no technical component; it's possible that the Iranians wouldn't want to forge ahead until they get an improved breed of gas centrifuges working, because their current ones are terrible and would take a long time to do the work. Whether that sort of thing is factored into the IC's timelines, I don't know.

News and Discussion

3) "To achieve breakout capability." My personal favorite. This is related to the distinction between Scenario (A) above and Scenario (B) or (C). The *ability* to break out is not the same as the *intention* to do so. And by "intention" I don't mean "desire" — I mean "intention." Here's an example of desire without intention: "I'd really like to ride my motorcycle on a winding mountain road, but it's too risky."

The point is, Iran could dig a bunch of holes in mountainsides and even perfect the IR-3 or -4 or -5000 centrifuge, but that doesn't guarantee that they'd immediately complete a facility or two, quietly commence enrichment operations, build bombs, etc. They might wait for the heat to die down first, or hold the option in reserve against being attacked. By the same token, if they were really prepared to accept the risk, they could have started doing it today or last week or last year at Natanz with the machines they have, and just dared us to bomb it. *Breakout is fundamentally a political decision, not a technical threshold.*

News and Discussion

4) "Playing for time." And here's the bottom line. If Iran is going to achieve breakout capability at a hidden facility somewhere — call it Son of Qom — then bombing Natanz won't address that problem. It's often asserted, with an air of worldly maturity and sobriety, that a resort to arms will only provide a few years' breathing room. If Natanz were the only possible place in Iran to set up centrifuges, that would make a certain sense. But it isn't, so it doesn't. The truth is closer to the opposite. Iran today is at worst pursuing Scenario (A) or (B). Bombing Natanz is liable to produce Scenario (C), breakout *à la* Pyongyang, full speed ahead.

The name of the game today isn't bombing, it's intelligence. To play for time, we try to catch Iran at building the Son of Qom in preparation for Scenario (B). But when that happens, if we are clever, we won't bomb Son of Qom, opening the door to Scenario (C). Instead, we'll shut that sucker down with a press conference. That's intelligence, too, in the plain sense of the word.

Nuclear Explosions

Possible Effects of Nuclear War

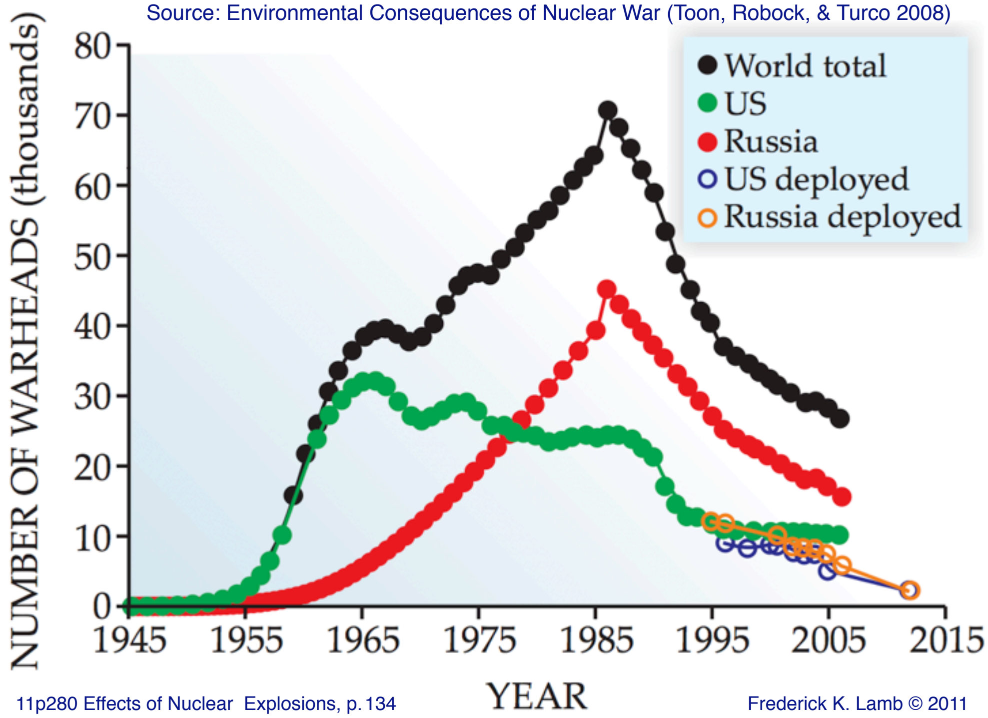
Possible Effects of Nuclear War

Read and Study

The Day After Midnight

Effects of Nuclear War

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



Effects of Nuclear War

Illustrative Effects

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

- produce the lowest temperatures for 1,000 years, lower than the Little Ice Age or 1816 ("the year without a summer")
- reduce precipitation in the Asian monsoon region by 40%
- substantially reduce the length of the growing season in the U.S. midwest

Mean time for the soot to decrease is 5 years

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

Effects of Nuclear War

Illustrative Effects

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)

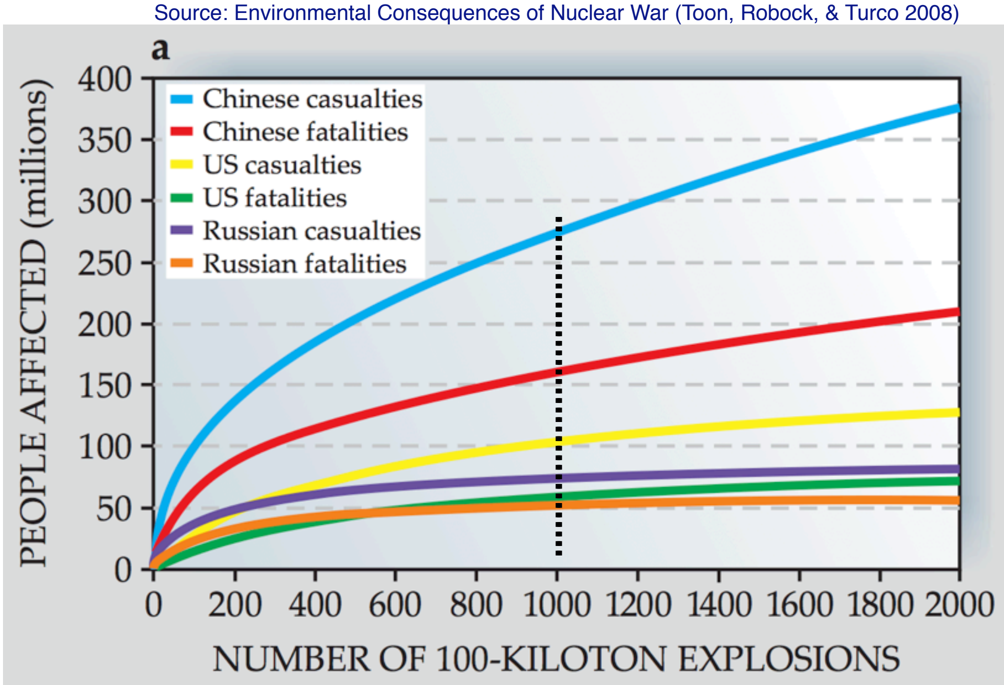
1,000 weapons detonated on Russia would *immediately* —

- 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

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



Effects of Nuclear War

Nuclear War Models

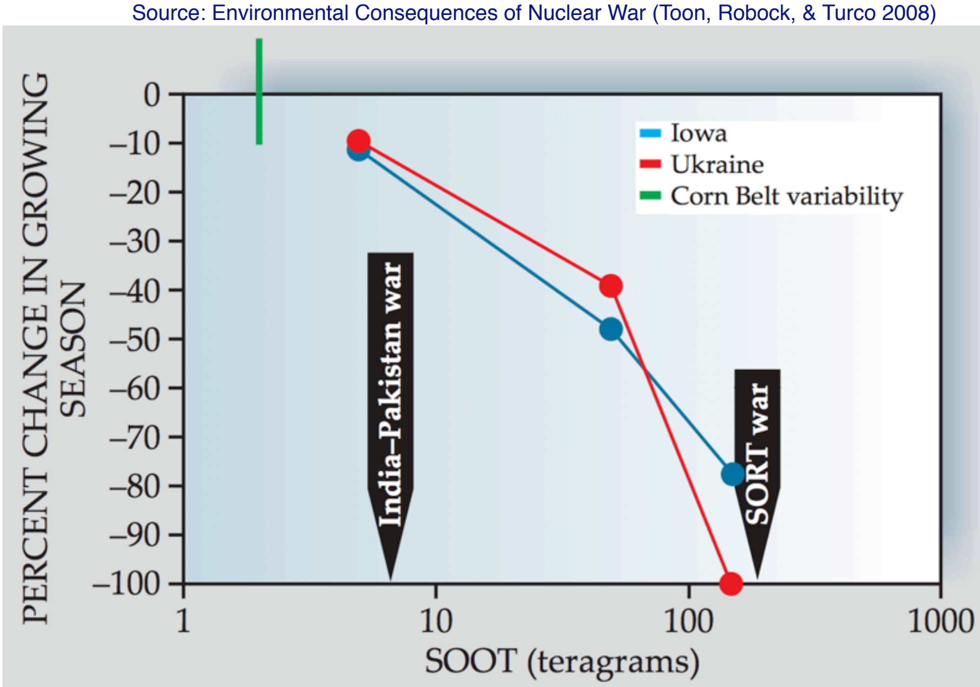
U.S.-Russian (“SORT”) war:
2200 x 2 weapons of 100-kt each = 440 Mt total

Regional nuclear war:
50 weapons of 15-kt each = 0.75 Mt total

Weapons are assumed to be targeted on industry.

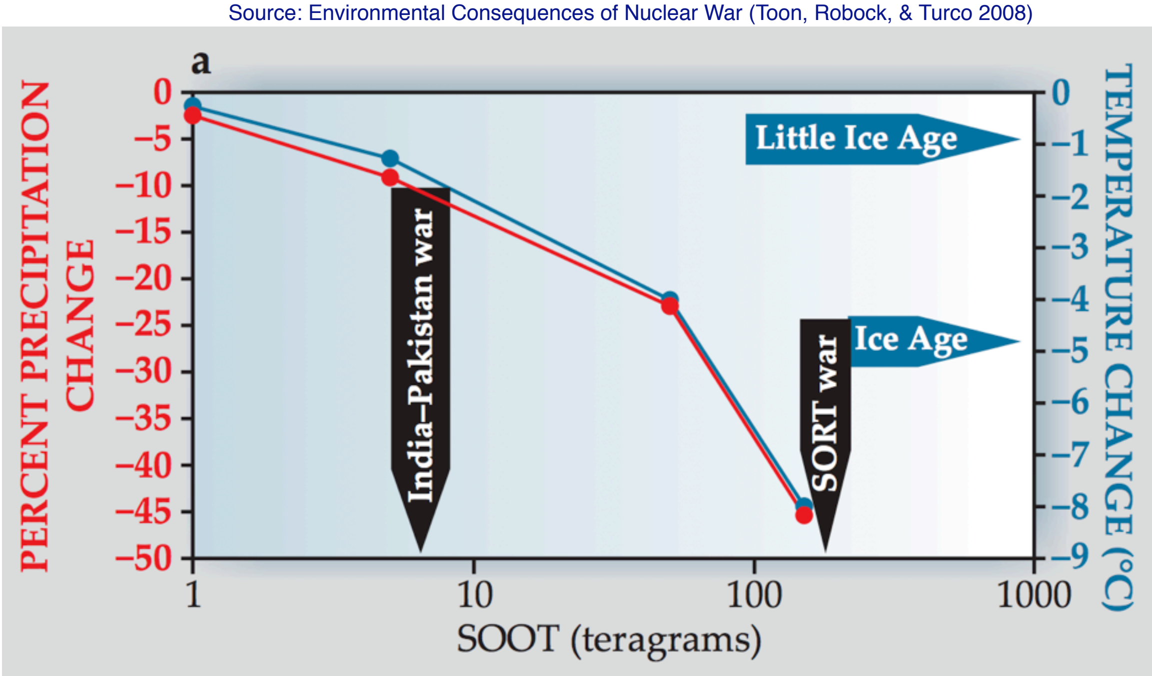
Effects of Nuclear War

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



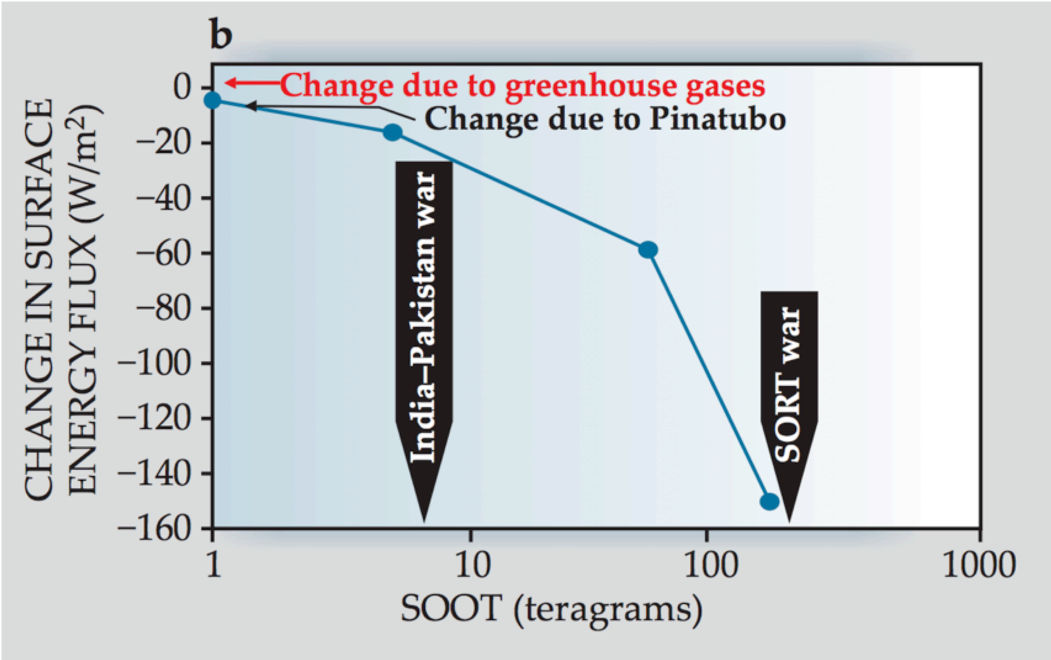
Effects of Nuclear War

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



Effects of Nuclear War

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



Effects of Nuclear War

Indirect Effects Would Be the Most Important

"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."

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

iClicker Question

Which nuclear processes are important in the *primary* of a *modern* two-stage bomb?

A. fission

B. fusion

C. fission and fusion

Blank

iClicker Answer

Which nuclear processes are important in the *primary* of a *modern* two-stage bomb?

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iClicker Question

Which nuclear processes are important in the *secondary* of a *modern* two-stage bomb?

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B. fusion

C. fission and fusion

Blank

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A. fission

B. fusion

C. fission and fusion

iClicker Question

What is the fundamental limit on the yield of a thermonuclear bomb?

A. 1 kt

B. 100 kt

C. 1 Mt

D. 100 Mt

E. There is no limit

Blank

iClicker Answer

What is the fundamental limit on the yield of a thermonuclear bomb?

A. 1 kt

B. 100 kt

C. 1 Mt

D. 100 Mt

E. There is no limit

iClicker Question

A 1,000 weapon attack on the United States would probably kill and injure about how many people?

A. 10 million

B. 20 million

C. 50 million

D. 70 million

E. 100 million

Blank

iClicker Question

A 1,000 weapon attack on the United States would probably kill and injure about how many people?

A. 10 million
B. 20 million
C. 50 million
D. 70 million
E. 100 million

iClicker Question

A 1,000 weapon attack on Russia would probably kill and injure about how many people?

A. 10 million
B. 20 million
C. 50 million
D. 70 million
E. 100 million

Blank

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A 1,000 weapon attack on Russia would probably kill and injure about how many people?

A. 10 million

B. 20 million

C. 50 million

D. 70 million

E. 100 million

End of Basic Slides

Supplementary Slides

This is supplementary information for those who are interested

Creation of the Blast Wave (Details)

- The pressure of the super-hot gas in the fireball is a million times greater than that of the surrounding air, so the fireball expands rapidly outward (the diameter of the fireball produced by a 1 Mt explosion is more than a mile across a few seconds after the explosion starts)
- The "bubble" of super-hot gas expands rapidly, pushing violently outward on the surrounding air and generating a very strong outward-moving shockwave
- Initially X-rays from the fireball rapidly penetrate and heat the surrounding air, causing the fireball to expand faster than either the gas inside or the shockwave
- The fireball expands more slowly with time and the rapidly expanding shockwave catches up and passes through fireball's surface; this is called "breakaway"
- From this moment onward the shockwave gets little push from the fireball; it propagates outward on its own

Properties of a Blast Wave (Details)

- A “blast wave” is a very strong shockwave called that moves outward at supersonic speeds; the larger the yield of the nuclear weapon, the faster it moves
- The mathematics of a blast wave are very elegant; the solution is often called “the Sedov-Taylor solution”
- This solution depends only on —
  - —the yield Y of the explosion (all other aspects of the source quickly forgotten)
  - —the density and pressure law of the surrounding air
- A blast wave is “self-similar”
  - — Its shape is the same for any yield and any radius
  - — The peak pressure fixes all other parameters
- The peak pressure P is proportional to Y/D^3
  - — Consequently the distance at which P is of a given size is proportional to $Y^{1/3}$; this is called “cube-root” scaling

Self-Similarity of Blast Waves

At early times following detachment from the fireball, the blast wave is *strong* and *self-similar*.

A wave is self-similar if the *shape* of the variation with radius of all physical quantities (such as the pressure, wind speed, etc.) *remains the same as the shockwave expands*.

It is because the shockwave is initially strong that it *becomes* self-similar —

- A strong shockwave that is *not initially* self-similar will *become* self-similar as it expands
- A strong shockwave that has *become* self-similar will *remain* self-similar as it expands, until cooling occurs

Properties of a Blast Wave

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Self-Similarity of Blast Waves

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Prompt Nuclear Radiation

Sources —

- n’s and γ’s produced during fission and fusion of the nuclear fuel in the weapon
- delayed n’s from nuclear material in the weapon
- γ’s from (n,γ)-reactions of n’s with weapon case and/or matter in the nearby environment

Characteristics —

- Mean free paths in air of ~ 20–200 m
- Mean free paths in tissue of ~ 20 cm
- Very effective in damaging living things

Range of Radiation and Blast

Range in meters of radiation and blast effects

Weapon	RadiationDose (rads)			Overpressure (psi)		
	8,000	3,000	650	17	6	3
1-kt fission	360	440	690	300	520	910
10-kt fission	690	820	1100	640	910	1520
1-kt ERW	690	820	1100	280	430	760

Physical Effects of Ionizing Radiation

With a few exceptions, nuclear radiation does *not* make the irradiated object radioactive —

- Neutron activation (activation by irradiation with neutrons)
  - — Adding neutrons can turn a stable isotope into a radioactive one that emits γ -rays or β–rays
  - — Measuring precisely the energy of photon (or electron) that is emitted can uniquely identify the chemical species
  - — used as standard laboratory and field diagnostic
- Irradiation by highly energetic photons (γ-rays) or electrons (β-rays) can also make stable nuclei radioactive

Irradiation of foods to kill harmful bacteria —

- Has been approved by the U.S. Department of Agriculture (DOA) and the Food and Drug Administration (FDA)
- Accepted by the public remains to be determined

Genetic Effects of Ionizing Radiation

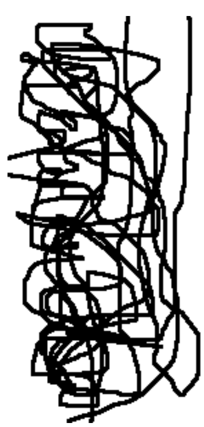
Radiation-Induced Mutations

…how one little error *could* mess things up

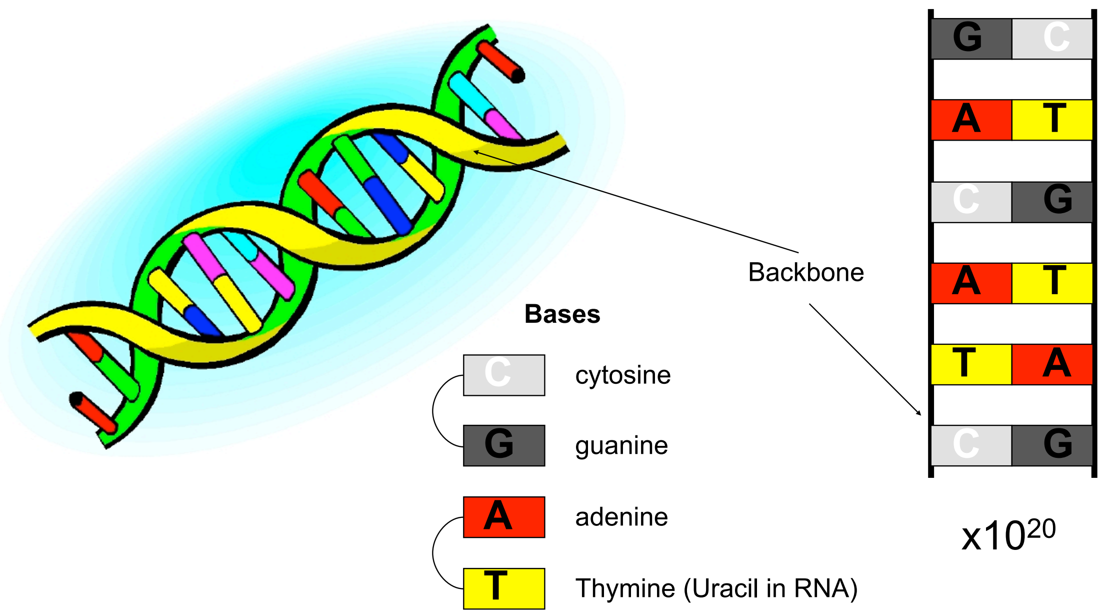
— Courtesy of Richard L. Styles
and Matthew K. Fischer

The Central Dogma of Molecular Biology

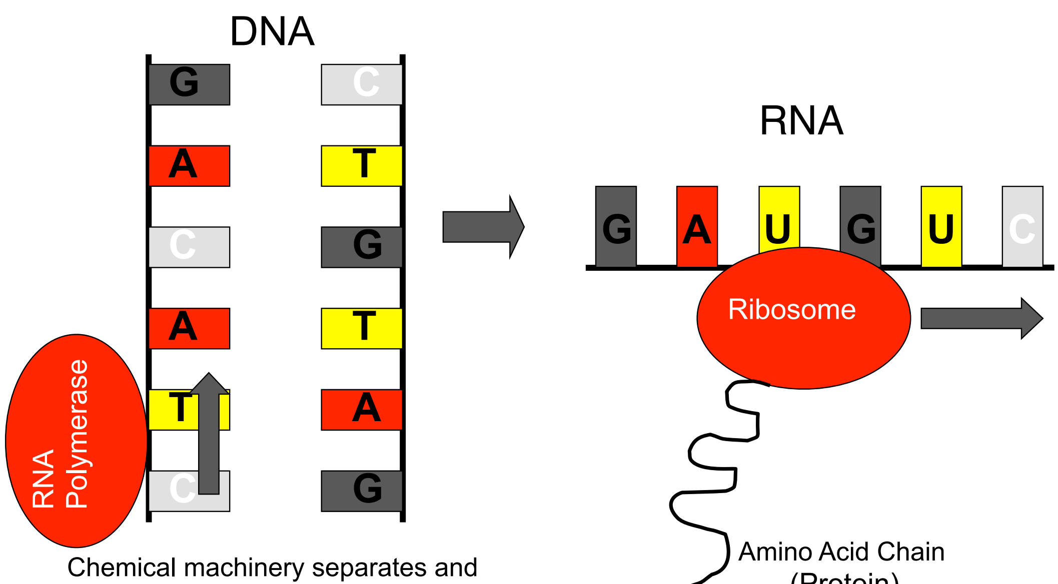
DNA (Huge, lots of junk) → *transcribed* → RNA (Small, only important information) → *translated* → Proteins (Amino Acid Chains)



DNA – Up Close and Personal

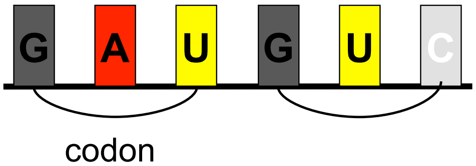


Translating the Information



Chemical machinery separates and reads both strands and assembles the appropriate amino acids.

The Code

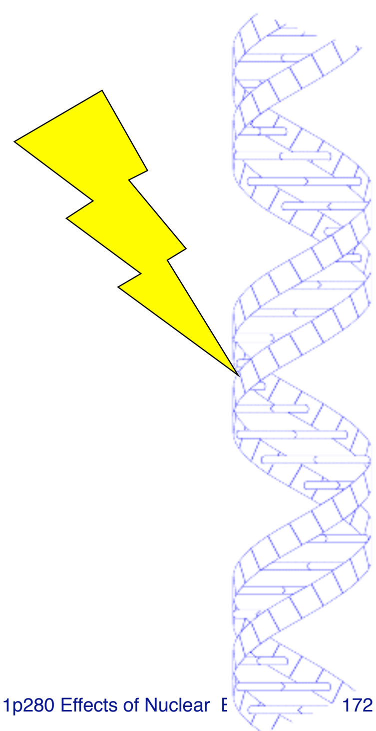


Every 3 bases make up a codon.

Codons tell the chemical machinery which of the 20 amino acids to recruit and add to the chain.

FIRST	SECOND				THIRD
-	U	C	A	G	-
U	Phe Phe Leu Leu	Ser Ser Ser Ser	Tyr Tyr Stop Stop	Cys Cys Stop Trp	U C A G
C	Leu Leu Leu Leu	Pro Pro Pro Pro	His His Gln Gln	Arg Arg Arg Arg	U C A G
A	Ile Ile Ile Met	Thr Thr Thr Thr	Asn Asn Lys Lys	Ser Ser Arg Arg	U C A G
G	Val Val Val Val/Met	Ala Ala Ala Ala	Asp Asp Glu Glu	Gly Gly Gly Gly	U C A G

Radiation-Induced Mutations



Silent

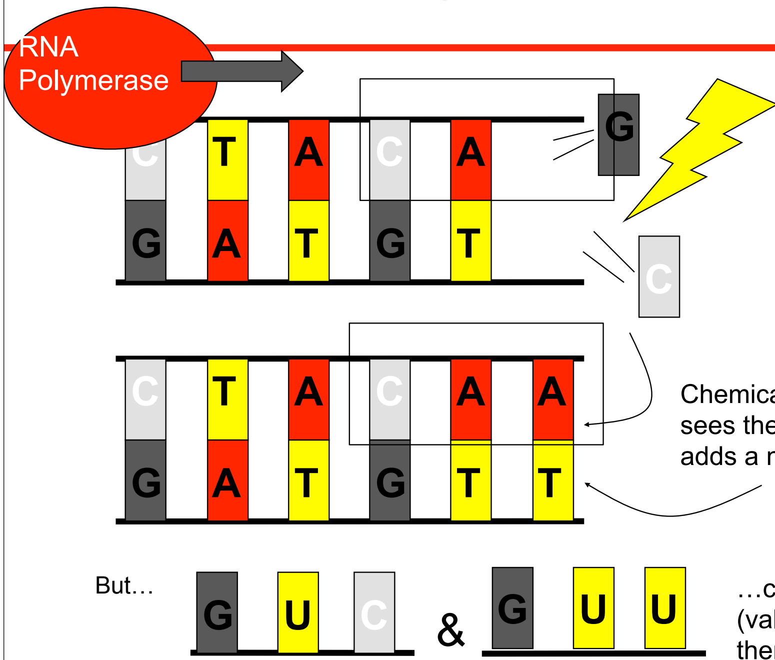
Missense

Nonsense

Frame-shift

Deletion

Silent Mutations

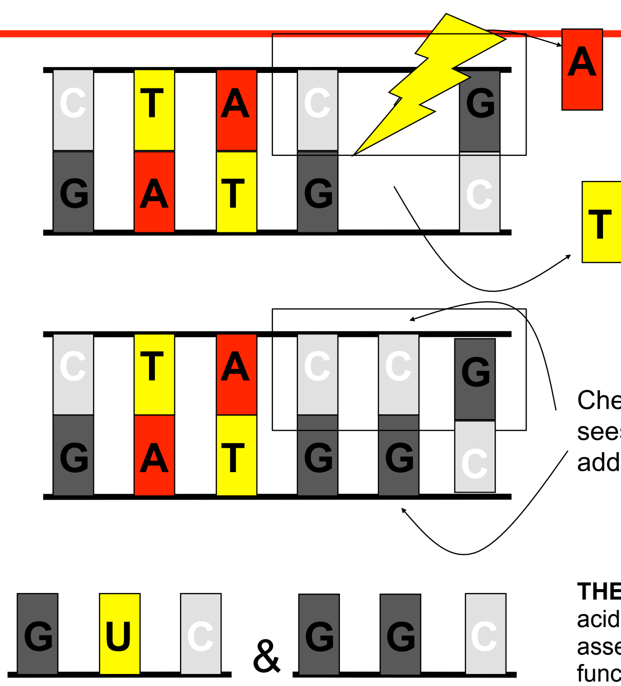


A subatomic particle knocks off a base pair

Chemical machinery quickly sees the missing bases and adds a new one at random

…code for the same amino acid (val). The resulting protein is therefore assembled as it would be normally

Missense Mutations

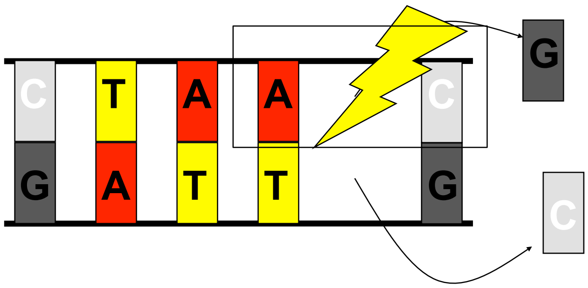


A subatomic particle knocks off a base pair

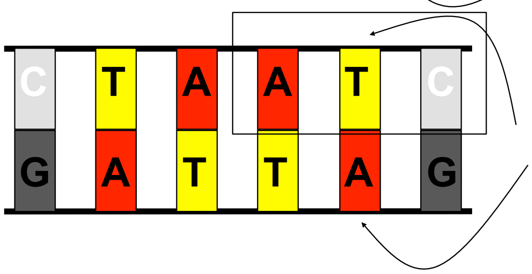
Chemical machinery quickly sees the missing bases and adds a new one at random

THESE codons code for **DIFFERENT** amino acids (val and gly). The resulting protein will be assembled differently, possibly changing its function or making it inactive.

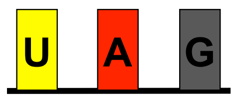
Nonsense Mutations



A subatomic particle
knocks off a base pair

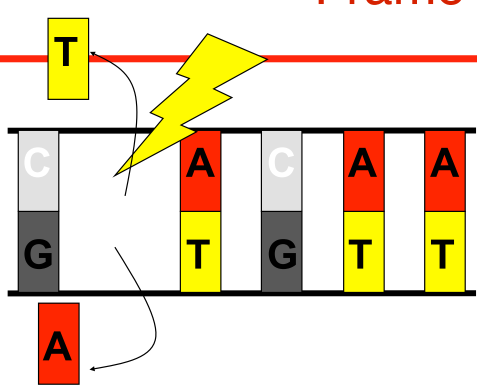


Chemical machinery quickly
sees the missing bases and
adds a new one at random



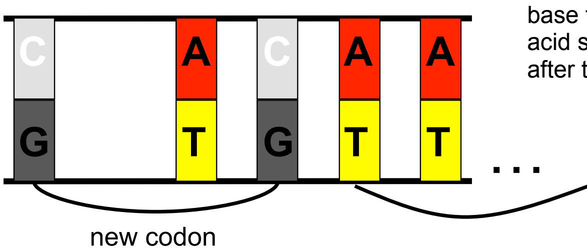
THIS codon tells the chemical machinery to **STOP** reading and making the protein. The would-be protein is not assembled all the way and will not function correctly as a result.

Frame-shift Mutation



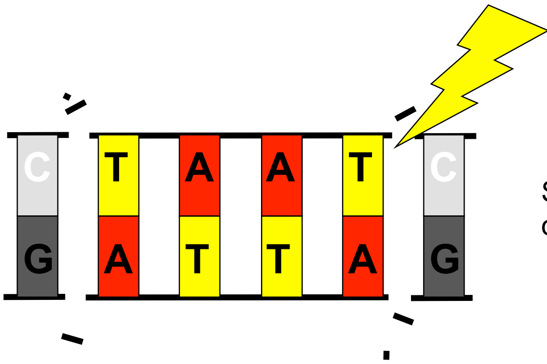
A subatomic particle
knocks off a base pair

This time, the chemical machinery does not see the missing bases. The reading frame is therefore shifted one base to the right. Different codons result in different amino acid sequences. This makes the protein entirely different after the point of mutation.

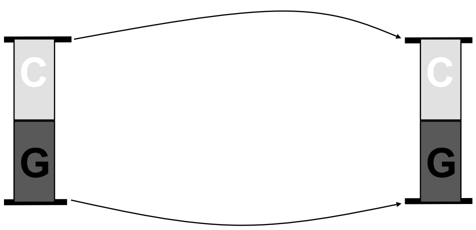


A subatomic particle could also break the DNA strand without knocking off a base pair, allowing the chemical machinery to insert a pair even though it is not necessary. The strand is then lengthened, and the reading frame is shifted to the left.

Deletion Mutations



Subatomic particle breaks the strand, cutting off an entire section of base pairs



The strands are ligated back together, and the strand can be read. However, without the coding DNA, the protein will not be assembled.

Effects of Ionizing Radiation

Difference between “dose” and “dose rate” —

- Dose rate = dose per unit time
- Physical dose rate (Gr/s, Gr/hr, mGr/yr, …)
- Biological dose rate (Sv/s, Sv/hr, mSv/yr, …)

Effects of Nuclear War

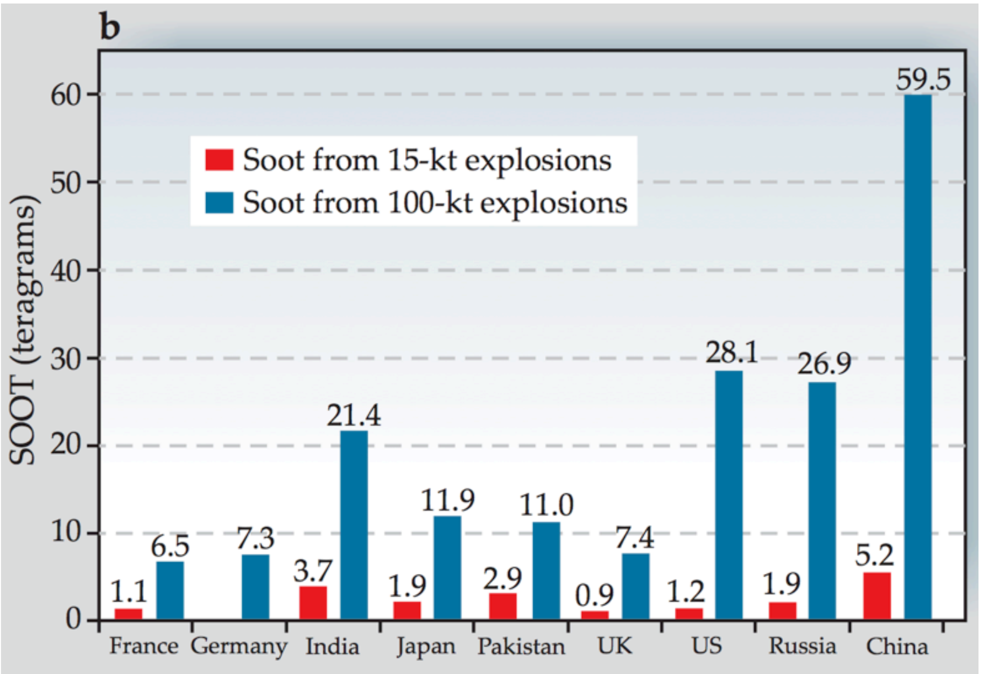
Nuclear War Models

U.S.-Russian ("SORT") war:
2200 x 2 weapons of 100-kt each = 440 Mt total

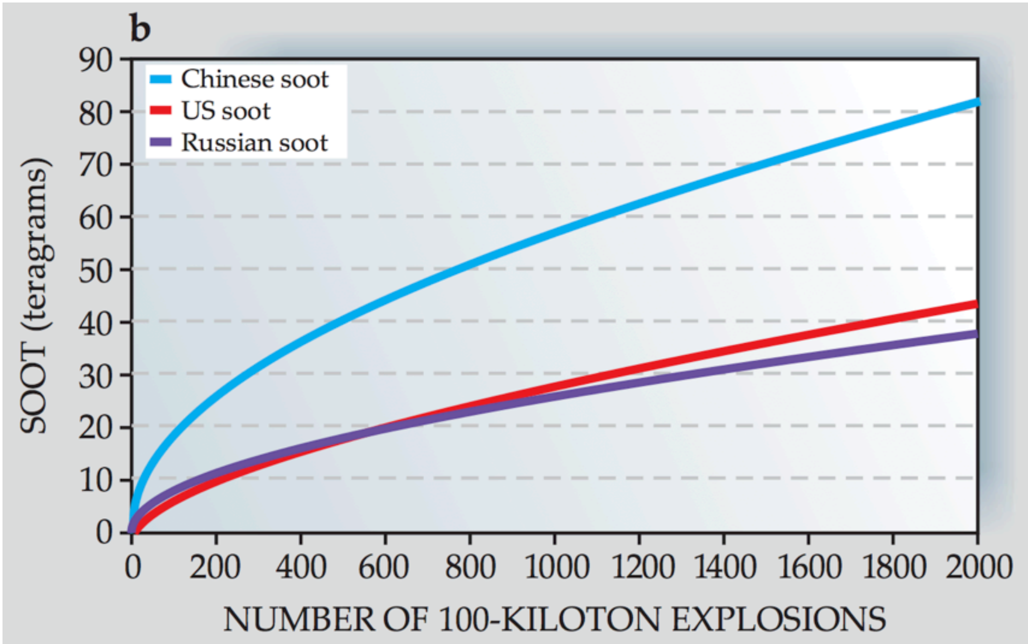
Regional nuclear war:
50 weapons of 15-kt each = 0.75 Mt total

Weapons are assumed to be targeted on industry.

Effects of Nuclear War



Effects of Nuclear War



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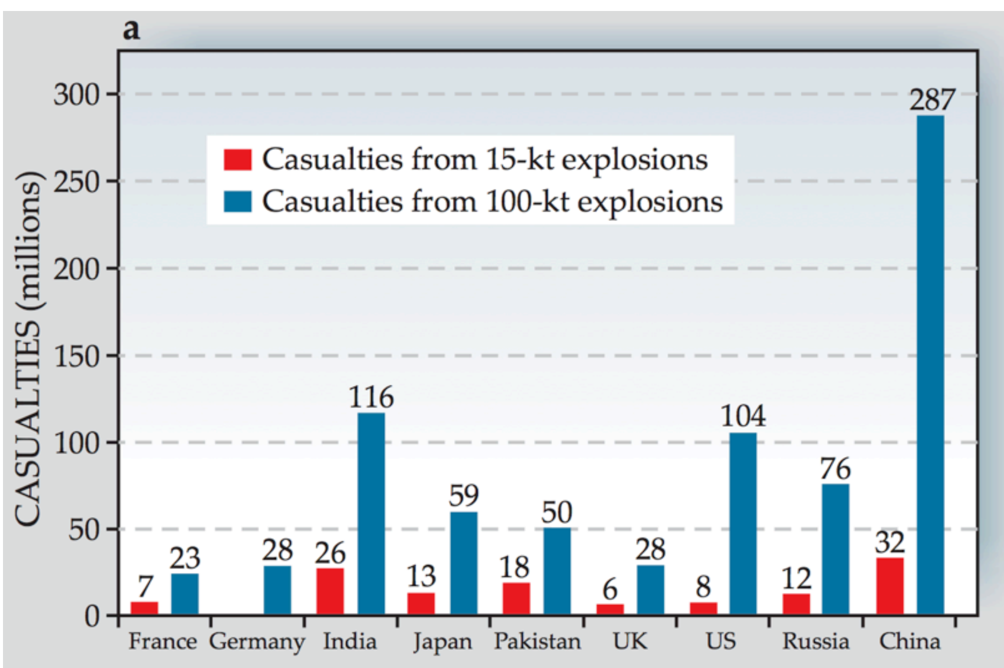
Effects of Nuclear War



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