Hiroshima and Nagasaki

- The nuclear attack and its immediate impact
- Radiation sickness
- Long-term medical effects

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Hiroshima August, 1945
Prior to August 1945: Extensive Conventional Bombing Raids on Japanese Metropolitan Areas

Tokyo after fire bombing in March 1945
(by August 1945 General LeMay had ordered bomb raids on 67 Japanese cities)

Fatalities: ~ 100,000
16 square miles with ~260,000 buildings destroyed
The Attacks: August 6\textsuperscript{th} and August 9\textsuperscript{th}, 1945

509 Composite Group
Colonel Paul Tibbets
Stationed on Tinian

Approved targets:
Hiroshima, Kokura, Niigata and Nagasaki
The Attacks: August 6th and August 9th, 1945

Hiroshima
Weather Reconnaissance:
- 3 B-29: Hiroshima, Kokura, Nagasaki
- 1 B-29 for weapon delivery (“Enola Gay”)
- 2 B-29 for strike observation & measurements
  (Luis Alvarez on “The Great Artiste”)

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  (including two British Observers)
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Nuclear Explosion Terms to be Used

- Slant range
- Height of burst
- Ground range
- Depth of burst
- Ground zero
Energy Released in a Nuclear Explosion

The total energy released is the “yield” Y and is measured by comparison with explosive yields of TNT explosions.

Units used: kT of TNT = kilo Tons of TNT = 1000 Tons of TNT

For example, Little Boy had a yield of 16 kT TNT equivalent.

Modern thermo nuclear bombs can have 100s to 1000s of kT TNT equivalent explosive yield.

1000 kT = 1 Mega Ton = 1MT
Comparison with TNT

How much energy does nuclear weapons release (per weight of explosive) compared to conventional explosives?

about 1,000,000 times more!

Enola Gay → 1,600 bombers each carrying 20 bombs of 1000 pounds of TNT

1964: Operation Sailor Hat
500 tons of TNT

50 Bombers each carrying 20 bombs of 1000 pounds of TNT
Nuclear Explosions over Hiroshima and Nagasaki

August 6th, 8.15am
HOB: 1900 ft
Ground Zero: Shima Surgical Clinic
Explosive yield, equivalent to ~16,000 tons of TNT
Immediate fatalities: 70,000 – 80,000
Injuries: ~ 70,000

August 9th, 11.02am
HOB: 1650 ft
Ground Zero: near Mitsubishi Steel and Arms Works
Explosive yield, equivalent to ~21,000 tons of TNT
Immediate fatalities: 35,000 – 40,000
Injuries: ~ 60,000
Ground Zero: Shima Surgical Clinic – HOB 1900 ft
Explosive yield, equivalent to ~16,000 tons of TNT
Immediate fatalities: 70,000 – 80,000 (including ~20,000 soldiers related to 2\textsuperscript{nd} General Army HQ)
Injuries: ~70,000

Radius of destruction ~ 1.2 miles (blast and firestorm)
~70\% of all buildings destroyed, 6-7\% damaged
Hospitals severely damaged or destroyed
~90\% of doctors and nurses injured or killed
Effects of Nuclear Explosions

- 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.)

Trinitite forms at 2,200 – 2,700 °F within a radius of ~ 1000 ft from ground zero of the trinity test

→ serves as thermometer …
Formation of the Mushroom Cloud

Fireball

Stratosphere

Troposphere

UPDRAFT THROUGH CENTER OF TOROID

TOROIDAL CIRCULATION OF HOT GASES

STEM

COOL AIR BEING DRAWN UP INTO HOT CLOUD
Long-Term Physical Effects

• Fallout
  —From material sucked into fireball, mixed with weapon debris, irradiated, and dispersed
  —From dispersal of material from nuclear reactor fuel rods

• Ozone depletion (Mt bursts only)
  —Caused by nitrogen oxides lofted into the stratosphere
  —Could increase UV flux at the surface by ~ 2x to ~ 100x

• Soot injected into the atmosphere cools Earth (“nuclear winter”)
  —Caused by injection of dust, ash and soot into atmosphere
The amount of radioactive fallout is increased greatly if the fireball touches the ground.
Did the Fireball Touch the Ground at Hiroshima?

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.

For Example:

- Hiroshima $Y = 16 \text{ kT}$
  Fireball touches ground if $\text{HOB} < 600 \text{ ft}$
  However, HOB was $\sim 2000 \text{ ft}$

- Thermo Nuclear Weapon with $Y = 1000 \text{ kT} = 1 \text{ MT}$
  Fireball touches ground unless $\text{HOB} > 3000 \text{ ft}$
Effects of Thermal Radiation from Fire Ball

Shadow cast by flash
Effects of Thermal Radiation

Harmful direct effects on humans

• Skin burns
• Ignition of clothing, structures, surroundings
• Flash blindness
• Permanent retinal burns (with larger yields)

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

Burns depend on distance and protection available

Keloids resulting from burns
• 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.
Damage in Hiroshima

Atomic Dome near Ground Zero

T-shaped Aioi bridge was used for targeting
Damage in Hiroshima:
HOB ~ 1900 ft near Atomic Dome

Heat from fireball: Copper roof melted while steel Support remains!

Hiroshima Prefectural Industrial Promotion Hall

Hiroshima Peace Memorial
Firestorms in Hiroshima?

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

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 in Tokyo

Tokyo after fire bombing in March 1945
Firestorm in Hiroshima ?!

Mushroom cloud
~ 10 minutes after attack
(will dissipate soon!)

Smoke plume from fires following
the nuclear attack ~ 3 hours after attack

See for example The New York Times, 5-23-2016: https://nyti.ms/25cCy3b
30th DAY in Hiroshima: Those who escaped begin to die, victims of

THE ATOMIC PLAGUE

'I write this as a warning to the world'

DOCTORS FALL AS THEY WORK

Poison gas fear: All wear masks

3,320,173 AMAZES AMERICA

'Vert powerful in the world'

SMALL THEY FALL

MAN IS STABBED DURING DANCE

Forces may cut meat ration

SPAIN TO SHARE IN TANGIER

4.30pm LATEST

PRISONERS RUN JAP CITIES

W.D. New York
In Hiroshima, 30 days after the first atomic bomb destroyed the city and shook the world, people are still dying, mysteriously and horribly – people who were uninjured by the cataclysm – from an unknown something which I can only describe as atomic plague. Hiroshima does not look like a bombed city. It looks as if a monster steamroller had passed over it and squashed it out of existence. I write these facts as dispassionately as I can in the hope that they will act as a warning to the world.
Radiation Levels in Hiroshima

Median lethal dose
LD₁ – 2.5 Sv (1% fatality)
LD₅₀ – 5.0 Sv (50% fatality)
LD₉₉ – 8.0 Sv (99% fatality)

~25,000 fell victim to radiation sickness in the 4 months following the attack
The RERF systematically studies the surviving population of the nuclear attacks on Hiroshima and Nagasaki to study the health impact of radiation (http://www.rerf.or.jp)

Relative risk of death due to cancer from 1 Sv of radiation exposure (1950-1997) – occupational limit for radiation workers is 0.05 Sv/year

<table>
<thead>
<tr>
<th>Cancer</th>
<th>Relative Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leukemia</td>
<td>5.6</td>
</tr>
<tr>
<td>All other cancers</td>
<td>1.5</td>
</tr>
<tr>
<td>Esophageal cancer</td>
<td>2.2</td>
</tr>
<tr>
<td>Stomach cancer</td>
<td>1.4</td>
</tr>
<tr>
<td>Colon Cancer</td>
<td>1.5</td>
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<tr>
<td>Lung cancer</td>
<td>1.8</td>
</tr>
<tr>
<td>Breast cancer</td>
<td>1.8</td>
</tr>
<tr>
<td>Urinary bladder cancer</td>
<td>2.2</td>
</tr>
</tbody>
</table>
Excess relative risk for solid cancers vs attained aged for different ages at Exposure (10, 30 and 50 year old)

FIG. 3. Age-at-exposure and attained-age effects on solid cancer ERRs at 1 Gy by age at exposure and sex. Panel A shows how the radiation ERRs varied with attained age by sex (gray for females and black for males) and by age of exposure. This is a linear ERR model with multiplicative adjustment for smoking, sex-averaged age-at-exposure modification and sex-specific attained-age modification. Panel B shows how the female-to-male (F:M) ERR ratio varies with attained age at 1 Gy.
1. Cancers of specific organs have increased among nuclear bombing survivors.

2. Non-cancer diseases (cataract, benign thyroid tumor, heart disease, stroke, etc.) have also increased among survivors exposed to high doses of radiation.

3. Survivors exposed to high doses of radiation tend to show deterioration of the immune system similar to that observed with aging.

4. Many survivors exposed to high doses of radiation exhibit minor inflammatory reactions.

5. Research thus far has not indicated any genetic effects in A-bomb survivors' children.

6. Observations made to date have not confirmed increased mortality or cancer incidence among A-bomb survivors' children.
Psychological and Societal Challenges for Survivors, Hibakusha

1. Survivors severely impacted by post-traumatic stress disorder, often unable to participate in workforce. (Atomic-Bomb Numbness Syndrom)

2. No significant government assistance for hibakusha before mid 50s.

3. Hibakusha faced ostracism due to misconceptions of health impact of radiation.

4. Strong leadership for initiatives seeking to abolish nuclear weapons. For example, the International Campaign to Abolish Nuclear Weapons (ICAN)

No More Hibakusha.
No More Nuclear Weapons.