Nuclear Testing

8.S271
Class 3
Nuclear Weapons – History and Future Prospects

Michael V. Hynes, Ph.D.
Laboratory for Nuclear Science
MIT
Outline

- Overview of testing program
  - Wartime testing
  - Above ground testing
  - Underground testing

- Advances in weapon design
  - Levitated pits
  - Boosted primaries
  - Advances in explosive lenses
  - Two stage weapons
Trinity, Hiroshima, Nagasaki

Trinity event – July 16, 1945 near Socorro, NM – 5:29 local time
  • Implosion design using Plutonium that yielded about 20 kT

Hiroshima event – August 6, 1945 – 8:15 local time
  • Gun assembled device using HEU that yielded about 12 kT

Nagasaki event – August 9, 1945, 11:01 local time
  • Implosion design using Pu that yielded about 20 kT
Types of Nuclear Tests

1. Atmospheric
2. Underground
3. Exoatmospheric
4. Underwater

All lead to different weapons effects.

US test ranges –
• Pacific, Alaska, Nevada
• None currently in use
Nuclear Testing in the World

The graph shows the number of nuclear tests conducted by different countries from 1945 to 2009. The countries include the United States, the Soviet Union, the United Kingdom, France, the People's Republic of China, India, and North Korea. The x-axis represents the years, while the y-axis represents the number of tests. The graph indicates a peak in testing activity in the late 1950s and early 1960s, with a significant decrease in the late 1960s and 1970s.
Levitated Pits – Boosted Weapons

- Levitated pit
  - The explosive nuclear material separated from explosive lens
  - This vacuum space allows outside assembly to accelerate better before crushing pit
  - Results in more complete burning of pit material
  - See diagram to right that uses an aluminum cone
- Boosted weapons
  - By placing a small bit of material that compressed yields neutrons
  - Makes weapon yield more certain
  - In diagram to right tritium gas is the boosting material
Operation Sandstone

- Eniwetok Atoll
- Test levitated pits
  - Air gap inside tamper allowing tamper to accelerate to pit, giving higher compression
- Test composite pits
  - Mixes of Pu and U
- Improve theory of implosion design
  - Gun assembly on way out as too inefficient use of materials

X-RAY –
- Levitated composite pit – mix of U-235 and Pu-239
  - Aomon Island - 15-april-1948 – 37 kT
YOKE –
- Levitated U-235 pit
  - Aomon Island – 1-May-1948 – 49 kT
Zebra –
- Levitated U-235 pit
  - Runit Island – 15-May-1948 – 18 kT
- Results transformed way weapons built in US
- Now can imagine weapons by the 1000s not just 10s
**Operation Greenhouse**

<table>
<thead>
<tr>
<th>Test Name</th>
<th>Date</th>
<th>Location</th>
<th>Yield</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dog</td>
<td>8 April 1951</td>
<td>Pacific Proving Ground</td>
<td>70 kilotons</td>
<td></td>
</tr>
<tr>
<td>Easy</td>
<td>21 April 1951</td>
<td>Pacific Proving Ground</td>
<td>47 kilotons</td>
<td></td>
</tr>
<tr>
<td>George</td>
<td>9 May 1951</td>
<td>Pacific Proving Ground</td>
<td>225 kilotons</td>
<td>First thermonuclear experiment, deuterium core</td>
</tr>
<tr>
<td>Item</td>
<td>25 May 1951</td>
<td>Pacific Proving Ground</td>
<td>45.5 kilotons</td>
<td>First bomb with tritium &quot;boosting&quot;</td>
</tr>
</tbody>
</table>

- Pacific Proving grounds
- Boosted fission weapons – item event –
- 2 stage thermonuke – George shot operation
- Cylindrical Secondaries
# Operation Ivy

<table>
<thead>
<tr>
<th>Test name</th>
<th>Date</th>
<th>Location</th>
<th>Yield</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mike</strong></td>
<td>1 November 1952</td>
<td>Elugelab Island, Eniwetok</td>
<td>10.4 - 12 megatons</td>
<td>First hydrogen bomb</td>
</tr>
<tr>
<td><strong>King</strong></td>
<td>16 November 1952</td>
<td>Airburst 2,000 feet North of Runit Island, Eniwetok</td>
<td>500 kilotons</td>
<td>Largest pure-fission bomb up to that time</td>
</tr>
</tbody>
</table>

**Mike**

**King**
Operation Castle

- Castle bravo shot – March 1 1954 –
- First test of salt burners using Li-D as second stage
- Predicted at 6 MT –
- Yield at 15 megatons - largest US shot
Operation Redwing

- Redwing-Inca first test of air lens designs
- Makes nuclear weapons very compact
- Makes easily fieldable in multiple configurations
- Trying to get them to fit in missiles
- Swan device below is example of early design

U.S. Swan Device - 1956

- High explosive
- Beryllium
- Plutonium-239
- Tritium / Deuterium
- Air lens
Operation Dominic

Shot Bluestone, 1.27 megatons of TNT.

Shot Frigate Bird, 600 kilotons of TNT, as viewed from the submarine USS Carbonero. Only full-scale US test of a strategic missile system.

Shot Swordfish spray dome and plume with USS Agerholm in foreground. Full scale test of ASROC rocket launched depth charge.

- First tests of spherical secondaries
- First tests of exoatmospheric effects
- Discovery of high altitude EMP
Nuclear Weapon Testing Treaties

Limited Test Ban Treaty –
• August 5, 1963
• United States, the United Kingdom, and the Soviet Union
• Prohibits all nuclear tests except those underground

Threshold Test Ban Treaty –
• July 1974
• United States, the United Kingdom, and the Soviet Union
• Prohibits all nuclear tests exceeding 150 kT
<table>
<thead>
<tr>
<th>Date</th>
<th>Name</th>
<th>Yield (kT)</th>
<th>Country</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1945-07-16</td>
<td>Trinity</td>
<td>19</td>
<td>USA</td>
<td>First fission device test, first plutonium implosion detonation</td>
</tr>
<tr>
<td>1945-08-06</td>
<td>Little Boy</td>
<td>15</td>
<td>USA</td>
<td>Bombing of Hiroshima, Japan, first detonation of an enriched uranium gun-type device, first use of a nuclear device in military combat.</td>
</tr>
<tr>
<td>1945-08-09</td>
<td>Fat Man</td>
<td>21</td>
<td>USA</td>
<td>Bombing of Nagasaki, Japan, as of this writing the last use of a nuclear device in military combat.</td>
</tr>
<tr>
<td>1946-07-01</td>
<td>Test Able</td>
<td>23</td>
<td>USA</td>
<td>Bikini Atoll, the Crossroads tests were the fourth and fifth nuclear explosions conducted by the United States. Their purpose was to investigate the effect of nuclear weapons on naval ships. They were the first of many nuclear tests held in the Marshall Islands, and the first to be publicly announced beforehand and observed by an invited audience, including a large press corps.</td>
</tr>
<tr>
<td>1946-07-25</td>
<td>Test Baker</td>
<td>23</td>
<td>USA</td>
<td></td>
</tr>
<tr>
<td>1949-08-29</td>
<td>RDS-1</td>
<td>22</td>
<td>USSR</td>
<td>First fission weapon test by the USSR</td>
</tr>
<tr>
<td>1951-05-09</td>
<td>Test George</td>
<td>225</td>
<td>USA</td>
<td>“George” shot was physics experiment relating to the hydrogen bomb.</td>
</tr>
<tr>
<td>1952-10-03</td>
<td>Hurricane</td>
<td>25</td>
<td>UK</td>
<td>First fission weapon test by the UK</td>
</tr>
<tr>
<td>1952-11-01</td>
<td>Ivy Mike</td>
<td>10,400</td>
<td>USA</td>
<td>First cryogenic fusion fuel &quot;staged&quot; thermonuclear weapon, primarily a test device and not weaponized.</td>
</tr>
<tr>
<td>1953-08-12</td>
<td>Joe 4</td>
<td>400</td>
<td>USSR</td>
<td>First fusion weapon test by the USSR (not &quot;staged&quot;)</td>
</tr>
<tr>
<td>1954-03-01</td>
<td>Castle Bravo</td>
<td>15,000</td>
<td>USA</td>
<td>First dry fusion fuel &quot;staged&quot; thermonuclear weapon; a serious nuclear fallout accident occurred.</td>
</tr>
<tr>
<td>1956-11-22</td>
<td>RDS-37</td>
<td>1.600</td>
<td>USSR</td>
<td>First &quot;staged&quot; thermonuclear weapon test by the USSR (deployable)</td>
</tr>
<tr>
<td>1957-11-08</td>
<td>Grapple X</td>
<td>1.800</td>
<td>UK</td>
<td>First (successful) &quot;staged&quot; thermonuclear weapon test by the UK</td>
</tr>
<tr>
<td>1960-02-13</td>
<td>Gerboise Bleue</td>
<td>70</td>
<td>France</td>
<td>First fission weapon test by France</td>
</tr>
<tr>
<td>1951-10-31</td>
<td>Tsar Bomba</td>
<td>50,000</td>
<td>USSR</td>
<td>Largest thermonuclear weapon ever tested—scaled down from its initial 100 Mt design by 50%</td>
</tr>
<tr>
<td>1954-10-16</td>
<td>Shiva</td>
<td>22</td>
<td>PR China</td>
<td>First fission weapon test by the People’s Republic of China</td>
</tr>
<tr>
<td>1957-09-17</td>
<td>Test No. 6</td>
<td>3,300</td>
<td>PR China</td>
<td>First “staged” thermonuclear weapon test by the People’s Republic of China</td>
</tr>
<tr>
<td>1958-08-24</td>
<td>Canopus</td>
<td>2,600</td>
<td>France</td>
<td>First “staged” thermonuclear test by France</td>
</tr>
<tr>
<td>1974-05-18</td>
<td>Smiling Buddha</td>
<td>12</td>
<td>India</td>
<td>First fission nuclear explosive test by India</td>
</tr>
<tr>
<td>1998-05-11</td>
<td>Pokhran-II</td>
<td>60[14]</td>
<td>India</td>
<td>First potential fusion/boosted weapon test by India; first deployable fission weapon test by India</td>
</tr>
<tr>
<td>1998-05-28</td>
<td>Chagai-I</td>
<td>45[15]</td>
<td>Pakistan</td>
<td>First fission weapon test by Pakistan</td>
</tr>
<tr>
<td>1998-05-30</td>
<td>Chagai-II</td>
<td>12–20[16][17][18]</td>
<td>Pakistan</td>
<td>First fusion weapon test by Pakistan</td>
</tr>
<tr>
<td>2006-10-09</td>
<td>2006 North Korean nuclear test</td>
<td>~1</td>
<td>North Korea</td>
<td>First fission plutonium-based device tested by North Korea; likely resulted as a fizzle</td>
</tr>
<tr>
<td>2009-05-25</td>
<td>2009 North Korean nuclear test</td>
<td>5–15</td>
<td>North Korea</td>
<td>First successful fission device tested by North Korea</td>
</tr>
</tbody>
</table>

**Notable Nuclear Tests**
Outline

- Overview of testing program
  - Wartime testing
  - Above ground testing
  - Underground testing

- Advances in weapon design
  - Levitated pits
  - Boosted primaries
  - Advances in explosive lenses
  - Two stage weapons
Levitated Pits – Boosted Weapons

- Levitated pit
  - The explosive nuclear material separated from explosive lens
  - This vacuum space allows outside assembly to accelerate better before crushing pit
  - Results in more complete burning of pit material
  - See diagram to right that uses an aluminum cone
- Boosted Primary weapons
  - By placing a small bit of material that compressed yields neutrons
  - Makes weapon yield more certain
  - In diagram to right tritium gas is the boosting material
Advances in explosive lenses

- China Lake Naval Test Range selected as explosive development station
- Faster detonation velocities
  - Allows for smaller nuclear weapons
  - Easier to fit in missiles
  - Use of less nuclear material
  - Lighter weight
- More varied lens configurations
  - From spherical to oblong
  - From oblong to cigar shapes
  - Enables ability to fit into more varied delivery systems
Two Stage Weapons

- Primary stage used to detonate second stage
- Primary stage is like Nagasaki device
- Radiation case confines primary energy and focuses it on secondary stage
- Secondary stage is a fusion device
- This is the so called “Super” from Manhattan Project days
- Cylindrical configuration shown in figure
The B53
High yield strategic thermonuclear bomb

- Yield – 9 Megatons
- Weight – 8850 lb
- Length 150 in
- Diameter – 50 in
- Number in service – 50
- Design features
  - Two stage radiation implosion device
  - All Oralloy
  - Lithium-6 deuteride fusion fuel
  - Cyclotol or Comp B explosives
- Los Alamos Design
- Delivery by B52G
- Initial Deployment – 1962
- Retained in stockpile as hedge for deeply buried targets
The B61
Intermediate yield strategic and tactical thermonuclear bomb

- Yields – 0.3, 1.5, 60, 170 KT
- Weight – 695-716 lb
- Length 141 in
- Diameter – 13 in
- Number in service – 600 tactical, 750 strategic
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  - PBX-9404 or PBX-9502 explosives
- Los Alamos Design
- Delivery by B-52, B1, B-2B, F-15E, F-16, F/A-18, A-6, AV-8A, Tornado
- Initial Deployment – 1967
- Many models including MOD-11 for earth penetration
The W62
Intermediate yield strategic ICBM MIRV warhead

- Yield – 170 KT
- Weight – 253 lb (Warhead only)
- Length 39 in
- Diameter – 20 in
- Number in service – 610
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  - PBX-9404 or PBX-9502 explosives
- Livermore Design
- Delivery by Minuteman III ICBM
- Initial Deployment – 1970
The W76
Intermediate Yield Strategic SLBM MIRV Warhead

- Yield – 100 KT
- Weight – 362 lb
- Length ? in
- Diameter – ? in
- Number in service – 3000
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
- Los Alamos Design
- Delivery by Trident I C-4 or Trident II D5 on Ohio class Submarines
- Initial Deployment – 1978
The W78
Intermediate Yield Strategic ICBM MIRV Warhead

- Yield – 335-350 KT
- Weight – 700 - 800 lb (RV+warhead)
- Length 68 in (warhead)
- Diameter – 21 in (warhead)
- Number in service – 920
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
- Los Alamos Design
- Delivery by Minuteman III ICBM
- Initial Deployment – 1979
The W80
Intermediate Yield Strategic Cruise Missile Warhead

- Yield – 5, 150 KT
- Weight – 290 lb (warhead)
- Length 31 in (warhead)
- Diameter – 12 in (warhead)
- Number in service
  - Mod 0 (SLCM) – 350
  - Mod 1 (ALCM) – 1000
  - Mod 1 (ACM) - 400
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  - Highly enriched plutonium for Mod 0 to lower occupational dose
- Los Alamos Design
- Delivery by cruise missile
- Initial Deployment – 1981
The B83
High yield strategic thermonuclear bomb

- Yield – Low KT to 1200 KT
- Weight – 2408 lb
- Length 144 in
- Diameter – 18 in
- Number in service - 650
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  - Insensitive HE used
  - Hardened for supersonic delivery on hard targets
- Los Alamos Design
- Delivery by most US nuclear qualified aircraft
- Initial Deployment – 1983
The W84
Intermediate yield strategic cruise missile warhead

- Yield – 0.2 - 150 KT
- Weight – 300 - 350 lb (warhead)
- Length 41 in (warhead)
- Diameter – 12 in (warhead)
- Number in service – none
- Number in inactive stockpile - 350
- Design features
  - Based on W61 design
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  - Insensitive HE
- Livermore Design
- Delivery by ground launched cruise missile or other cruise design
- Initial Deployment – 1984
The W87
Intermediate yield strategic ICBM MIRV warhead

Example of modern two stage weapon

- Yield – 300 KT
- Weight – 440 - 600 lb (warhead)
- Length 69 in (RV + warhead)
- Diameter – 22 in (RV + warhead)
- Number in service - 525
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  - Insensitive HE
- Livermore Design
- Delivery by Peacekeeper, Minuteman III
- Initial Deployment – 1988

A modern thermonuclear
This W87 thermonuclear warhead is launched on an MX intercontinental missile. Packed into a multiple independently targeted re-entry vehicle (MIRV, shown below), it splits off from the missile to strike its target.

MIRV length: 5.7 feet  MIRV base diameter: 1.8 feet
Explosive power: 300,000 tons of TNT
The W88
Intermediate yield strategic SLBM MIRV warhead

- Yield – 475 KT
- Weight – 800 lb (RV + warhead)
- Length 69 in (RV + warhead)
- Diameter – 22 in (RV + warhead)
- Number in service - 400
- Design features
  - Two stage radiation implosion device
  - Beryllium reflected plutonium
  - D-T boosted
  - Lithium-6 deuteride fusion fuel
  -Insensitive HE
- Los Alamos Design
- Delivery by Trident II D5 SLBM
- Initial Deployment – 1989

Yup, This is the real deal
Questions?
Class Discussion

- Why so many tests?
- Why so many different designs?
- How did going underground change weapon testing and design?
- How did weapon effects measurements change?
Reminder: First Writing Assignment

- How much did the development and testing program cost?
- Was it worth it?

- Assignment length roughly 5-10 pages
- Due after 3rd Class -- February 18