UNMAKING THE BOMB
A FISSILE MATERIAL APPROACH TO NUCLEAR DISARMAMENT AND NONPROLIFERATION

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Part I: The problem

Fissile materials
Nuclear weapons
Stockpiles

Part II: What is to be done

Ending production and use
Storage and disposal
Verification
A tale of two isotopes

Chain-reacting uranium-235
- uranium in nature is 0.7% U-235
- highly-enriched uranium (HEU – mostly over 90% U-235)
- Hiroshima bomb used highly-enriched uranium

Chain-reacting plutonium-239
- Produced in reactors following neutron absorption
- Nagasaki bomb used plutonium

Modern thermonuclear weapons contain HEU and plutonium
Nuclear weapons
global inventory 1945–2014

Global nuclear weapons inventories and warheads in dismantlement queue (yellow)
c. 16,300 warheads

Hans Kristensen and Robert Norris, “Global Nuclear Weapon Inventories, 1945-2013”
Bulletin of the Atomic Scientists, 2013
Nuclear weapons and fissile materials
global inventory of weapon-grade uranium 1945-2014

2000 tons HEU, 65,000 warheads

HEU in global nuclear weapons inventories and warheads in dismantlement queue (yellow)

640 tons eliminated
Reserved for weapons
Naval fuel
HEU: Legacy of the Cold War

Gone! Blended down to low-enriched uranium for power-reactor fuel

Data for Russia highly uncertain ± 120 MT

10,000 nuclear warheads
Elimination of highly enriched uranium by blend-down
(Russian process)

500 tons of Russian HEU (90% U-235) – enough for 20,000 weapons blended down from 1993-2013 and sold to fuel U.S. nuclear reactors

141 tons of U.S. HEU blended down during same period

45 tons of U.S. HEU declared excess remaining to be down-blended
HEU for naval fuel

U.S. has over half of nuclear-powered vessels in the world
U.S. naval fuel stockpile is >100 tons of HEU
Sufficient for > 4,000 nuclear weapons
Could power U.S. nuclear navy for 50 years

Los Angeles Attack Submarine
21 non-weapon states and 9 weapon states left with more than 1 kg of HEU. Russia accounts for half the remaining research reactors worldwide.
Nuclear weapons and fissile materials
Global inventory of plutonium 1945–2014

500 tons military + civilian Pu

- 51,000 weapon equivalents
- 27,000 weapon equivalents
- 35,000 additional weapon equivalents
- 16,300 warheads

Global nuclear weapons inventories and warheads in dismantlement queue (yellow)
Civilian plutonium: A legacy of the Cold War and breeder reactor dream

Civilian plutonium originally separated from spent fuel to start up breeder reactors especially in France, Japan, Russia & UK

10,000 modern nuclear warheads
**1975: Predicted global need for plutonium breeders**

Uranium was expected to run out; plutonium needed to start breeder reactors. Today, uranium accounts for only a few percent of cost of nuclear power and is “adequate to meet projected requirements for the foreseeable future.”
What is to be done
Scientists and the nuclear danger

Princeton
October 3, 1954
Niels Bohr
James Franck
Albert Einstein
and I. I. Rabi

“the use of the new active materials…may be…a perpetual menace to human security”
Niels Bohr, Open Letter to the United Nations, June 9, 1950
Fissile material production for weapons has ended in the P5 states

Military production facilities have been converted to peaceful purposes or are being decommissioned in France, China, Russia, UK and the United States
The challenge of ending production of HEU

Continuing production of HEU

- for military use – India, Pakistan, possibly North Korea
- for civilian use – Russia (since 2012)

India increasing power of centrifuges and total capacity producing HEU for submarine fuel (and weapons)
The challenge of ending plutonium separation

Continuing production of plutonium

- for military use – Pakistan, India, Israel (North Korea)
- for civilian use – France, Russia, India, (Japan and China) and UK to stop upon completion of current contracts

Pakistan
Khushab-3 began operating in 2013
Khushab-2 began operating in 2009/10
Khushab-1 began operating in 1998
Khushab-4 is under construction
FM(C)T +

Fissile Material (Cutoff) Treaty
• “a non-discriminatory, multilateral and internationally and effectively verifiable treaty banning the production of fissile material for nuclear weapons or other nuclear explosive devices”

HEU and plutonium production for civilian use should end
• Would cap global and national stockpiles of fissile materials
• FM(C)T verification would be easier
Global fissile material stockpiles (by category) 2014

Assumptions for weapon equivalents. 3 kg of weapon-grade plutonium, 5 kg of reactor-grade plutonium, 15 kg of highly enriched uranium.
Ending use of HEU and plutonium

HEU reactor fuels

US naval fuel and Russian research reactors

Plutonium fuels

France, Russia, India (China)
for power reactors
### Moving to LEU for naval reactors

<table>
<thead>
<tr>
<th>Country</th>
<th>Nuclear ships and submarines</th>
<th>Naval fuel enrichment</th>
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<tbody>
<tr>
<td>U.S.</td>
<td>10 aircraft carriers, 72 submarines</td>
<td>90+%</td>
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<tr>
<td>U.K.</td>
<td>10 submarines</td>
<td>Same as U.S.</td>
</tr>
<tr>
<td>Russia</td>
<td>4 cruisers, 29 submarines (+7 icebreakers)</td>
<td>21-90+%</td>
</tr>
<tr>
<td>India</td>
<td>1 submarine</td>
<td>Average of 45%?</td>
</tr>
<tr>
<td>China</td>
<td>14 submarines</td>
<td>&lt; 20%?</td>
</tr>
<tr>
<td>France</td>
<td>1 aircraft carrier, 10 submarines</td>
<td>&lt; 10% going down to 5%</td>
</tr>
<tr>
<td>Brazil</td>
<td>submarines under development</td>
<td>&lt; 20%</td>
</tr>
<tr>
<td>Total</td>
<td>11 aircraft carriers, 136 submarines +</td>
<td></td>
</tr>
</tbody>
</table>

**United States:** In 2014, U.S. Office of Naval Reactors raised the possibility of developing LEU fuel for next generation vessels.

**Russia:** Developed LEU fuel for its new nuclear-powered icebreaker and for floating nuclear power plant.
Leave plutonium inside spent fuel in safe dry-cask storage until geological repositories become available

At Fukushima Daiichi: before and after the tsunami

U.S. Connecticut Yankee (old picture) Lingen NPP, Germany
Only elimination of fissile material can end its threat
Consolidation can reduce risks, but storage is vulnerable

About 245 tons of civilian plutonium stored at four sites in Europe and Russia (Sellafield, La Hague, Marcoule, Mayak)

July 2012 break-in through fences due to: “ineptitude in responding to alarms, failures to maintain critical security equipment, over reliance on compensatory measures, misunderstanding of security protocols…”
- official U.S. DOE report

Michael Walli (64); Sister Megan Rice (83); Gregory Boertje-Obed (57)
Megan Rice is serving a sentence of 35 months in prison, the others 62 months each
Dispose of separated plutonium in deep boreholes?
Several tons of plutonium could be disposed in a single borehole
Boreholes are then backfilled and sealed
Disarmament, transparency and verification
including citizen’s verification

Joseph Rotblat

Leo Szilard