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

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Revision 3e
PART 1

HOW THE NUCLEAR WORLD EMERGED
EVERYTHING BEGINS WITH URANIUM

Open pit uranium mine, Namibia
Source: www.wikipedia.org, Ikiwaner

Uranium ore (carnotite)
Source: www.mikalac.com
<table>
<thead>
<tr>
<th>MAKING FISSION MATERIALS</th>
<th>A TALE OF TWO URANIUM ISOTOPES</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>HIGHLY ENRICHED URANIUM</strong> (TYPICALLY: 90% U-235)</td>
<td>Made by isotope separation using, for example, gas centrifuges</td>
</tr>
<tr>
<td>Used in a simple gun-type assembly in Hiroshima bomb (50–60 kg)</td>
<td>A special concern for nuclear terrorism (“improvised nuclear device”)</td>
</tr>
</tbody>
</table>

**PLUTONIUM** (ALMOST ANY COMPOSITION, MADE FROM U-238)

- Made from U-238 in a nuclear reactor and separated from spent fuel
- Used in implosion assembly in Nagasaki bomb (6 kg)
- Small critical mass, preferred in modern fission primaries

Sources: [www.usec.com](http://www.usec.com), [www.centrusenergy.com](http://www.centrusenergy.com) (top) and [commons.wikimedia.org](http://commons.wikimedia.org), user: Nanking2012 (bottom)
Modern Thermonuclear Warhead

Typically contains an average 3–4 kg of plutonium and 15–25 kg highly enriched uranium

FRANCE
AMBIGUITY BY DESIGN
“Based on the premise of refraining from any military applications in the field of atomic energy, France therefore had to embark on a vast program of plutonium production.”
FRANCE

HOW MUCH FISSION MATERIAL IS ENOUGH?

FRANCE HAS FEWER THAN 300 NUCLEAR WEAPONS TODAY

The amount of fissile material in this weapons stockpile is on the order of 1–1.5 tons of plutonium and 3–5 tons of HEU.

FRANCE HAS MATERIAL FOR 1000+ NUCLEAR WEAPONS

Based on our estimates, on the order of 70–80% of the military plutonium and HEU are outside the weapons stockpile (and without apparent military use).

Sources: www.defense.gouv.fr (top) and www.francetnp.fr (bottom)
ISRAEL
A TURNKEY FISSION MATERIAL PRODUCTION COMPLEX
DIMONA REACTOR, 1964–2014

POSSIBLE OPERATIONAL HISTORIES AND CUMULATIVE PLUTONIUM PRODUCTION

SCENARIO A
- 1965: 40 MW
- 1975: 40 MW
- 1985: 40 MW
- 1995: 40 MW
- 2005: 40 MW
- 2015: Cumulative plutonium production: 520 kg

SCENARIO B
- 1965: 40 MW
- 1975: 70 MW
- 1985: 40 MW
- 1995: 40 MW
- 2005: 40 MW
- 2015: 720 kg

SCENARIO C
- 1965: 40 MW
- 1975: 70 MW
- 1985: 70 MW
- 1995: 70 MW
- 2005: 70 MW
- 2015: 870 kg

SCENARIO D
- 1965: 40 MW
- 1975: 70 MW
- 1985: 140 MW
- 1995: 70 MW
- 2005: 40 MW
- 2015: 870 kg

SCENARIO E
- 1965: 40 MW
- 1975: 70 MW
- 1985: 140 MW
- 1995: 70 MW
- 2005: 70 MW
- 2015: 1010 kg
MORE THAN EVER EXPECTED?

50 YEARS OF PLUTONIUM PRODUCTION AT DIMONA, 1964–2014

ISRAEL HAS AVAILABLE A LARGE PLUTONIUM STOCKPILE

Estimated inventory on the order of 850 kg ± 130 kg
with a current production rate of 10–18 kg/year, depending on
power level of Dimona (40–70 MW thermal)

PLUTONIUM MOST LIKELY A “BYPRODUCT” TODAY

Israel’s arsenal is believed to include 100–150 warheads; if our
estimates are correct, Israel has plutonium for 2–3 times as many
warheads (and could cease fissile material production)

Sources: authors’ archives (top) and Channel 10 (bottom)
SO, WHERE ARE WE NOW?
WHO CAN MAKE FISSION MATERIAL TODAY
ENRICHMENT AND REPROCESSING FACILITIES WORLDWIDE

Enrichment/reprocessing in weapon state
Enrichment/reprocessing in non-weapon state

Ernesto Resende
Gonio
Gronau
Natanz
Rokkasha
NUCLEAR WEAPONS AND FISSION MATERIALS

GLOBAL INVENTORIES, 1945–2014


Fissile material estimates and weapon-equivalents are authors’ estimates; assuming an average of 3 kg for weapon-grade and 5 kg for reactor-grade plutonium per weapon
PART 2

WHAT IS TO BE DONE
“A PERPETUAL MENACE TO HUMANKIND”

FOR 70 YEARS SCIENTISTS HAVE WARNED OF THE FISSION MATERIAL DANGER
FISSILE MATERIALS BY CATEGORY

GLOBAL STOCKPILE OF PLUTONIUM AND HIGHLY ENRICHED URANIUM, 2014

Weapon equivalents

- Military: 935 tons Plutonium, 143 tons Highly enriched uranium
- Naval: 290 tons
- Excess: 89 tons Plutonium, 63 tons Highly enriched uranium
- Civilian: 260 tons Plutonium, 61 tons Highly enriched uranium
- Disposed of: 658 tons Plutonium, 61 tons Highly enriched uranium

Assumptions for weapon equivalents: 3 kg of weapon-grade plutonium, 5 kg of reactor-grade plutonium, 15 kg of highly enriched uranium.
ENDING PRODUCTION AND USE
FISSILE MATERIAL PRODUCTION FOR WEAPONS HAS LARGELY ENDED
(NPT WEAPON STATES STOPPED DECADES AGO)

Shutdown of the last Russian plutonium production reactor ADE-2 in Zheleznogorsk, 2010
Source: U.S. Department of Energy

Demolition of the K-25 uranium enrichment plant began in December 2008 and has been completed in 2012
Source: Bechtel Jacobs
ENDING PRODUCTION
FOR MILITARY AND CIVILIAN PURPOSES

CONTINUING PRODUCTION OF HEU
For military use: Pakistan, India, and possibly North Korea
For civilian use: Russia, reportedly restarted in 2012 (for export)

CONTINUING PRODUCTION (AND SEPARATION) OF PLUTONIUM
For military use: Israel, India, Pakistan, and North Korea
For civilian use: France, Russia, India, (China, Japan)
United Kingdom will end reprocessing around 2020

Sources: U.S. DOE (top) and Getty Images (bottom)
ENDING USE

FOR MILITARY AND CIVILIAN PURPOSES

**HEU REACTOR FUEL**

US, UK, Russia, India; US has over half of all HEU naval reactors; Russia has over half of all HEU research reactors; over 125 HEU research reactors already retired (twice the number converted to LEU)

**PLUTONIUM FUEL**

France, Germany, the Netherlands, India, (and Japan) use MOX fuel for power reactors; Russia and China plan to do so; most countries store their nuclear spent fuel pending final disposal

**Sources:** U.S. Navy (top) and UK Decommissioning Authority (bottom)
ELIMINATING STOCKPILES
# Vulnerability of Storage

## A Matter of Time

### Storing Up Trouble

About 100 tons of HEU at U.S. HEUMF, Y-12, Oak Ridge, Tennessee

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

### July 2012 Y-12 Break-In

U.S. DOE finding: “ineptitude in responding to alarms, failures to maintain critical security equipment, over reliance on compensatory measures, misunderstanding of security protocols, poor communications”

Sources: U.S. DOE (top) and oakridgetoday.com (bottom)
DISPOSAL STRATEGIES

IRREVERSIBILITY, SECURITY, COST, INTERNATIONAL VERIFIABILITY

**DRY CASK STORAGE OF SPENT FUEL**

Most countries with nuclear power store their spent fuel pending final disposal in geological repository;

HEU reactor spent fuel also can be stored for such disposal

**DEEP BOREHOLE DISPOSAL OF PLUTONIUM**

Excess plutonium could be irreversibly emplaced in several kilometer-deep boreholes; holes are then backfilled and sealed;

several tons of plutonium could be disposed in a single borehole

Sources: gns.de (top) and panoramio.com, user: loisiko (bottom)
TRANSPARENCY AND VERIFICATION
## Transparency Scorecard, 2014

### Information on Nuclear Warhead and Fissile Material Inventories and Status

<table>
<thead>
<tr>
<th>Parameter</th>
<th>United States</th>
<th>Russia</th>
<th>Britain</th>
<th>France</th>
<th>China</th>
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<td>Yes (upper limit)</td>
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<td>Fissile material stockpiles</td>
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<td>Excess/Disposal</td>
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<td>Yes (nothing new)</td>
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<tr>
<td>Verification</td>
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<td>Partial (but no longer)</td>
<td>Partial (some plutonium)</td>
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DISARMAMENT, TRANSPARENCY, VERIFICATION

Leo Szilard, 1898–1964  
*Credit: AIP Archives*

Joseph Rotblat, 1908–2005  
*Credit: Petter Hönnemann*