Facilitating Nuclear Disarmament:

Verified Declarations of Fissile Material Stocks and Production

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Princeton University

AECL, Chalk River, December 15, 2009
Background

Nuclear Weapon and Fissile Material Stocks, 2009
## Nuclear Arsenals, 2009
*(GFMR 2009, based on estimates by NRDC/FAS)*

<table>
<thead>
<tr>
<th>Country</th>
<th>Nuclear Warheads</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>about 10,000 (of which 4200 are awaiting dismantlement)</td>
</tr>
<tr>
<td>Russia</td>
<td>about 10,000 (with a large fraction awaiting dismantlement)</td>
</tr>
<tr>
<td>France</td>
<td>fewer than 300</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>185</td>
</tr>
<tr>
<td>China</td>
<td>about 240</td>
</tr>
<tr>
<td>Israel</td>
<td>100-200</td>
</tr>
<tr>
<td>Pakistan</td>
<td>70-90</td>
</tr>
<tr>
<td>India</td>
<td>60-70</td>
</tr>
<tr>
<td>North Korea</td>
<td>fewer than 5</td>
</tr>
</tbody>
</table>
Modern Thermonuclear Warhead

A modern thermonuclear warhead may contain both plutonium and highly enriched uranium (Average estimated values are 4 kg and 25 kg of plutonium and HEU, respectively)
HEU Stockpiles, 2009

Global stockpile is about 1600 tons, over 99% is in weapon states

Metric tons [MT]

- Stockpile available for weapons
- Naval (fresh)
- Naval (irradiated)
- Civilian Material
- Excess (mostly for blenddown)
- Eliminated

Data for Russia highly uncertain ± 300 MT

10,000 warheads

China 20 MT* France 30 MT* India 0.6 MT* Israel 0.1 MT* Pakistan 2.1 MT* Russia 367 MT United States 124 MT NNW States 10 MT
The Naval HEU Problem in a Disarming World

Metric Tons HEU

Data for Russia highly uncertain

Today

If Russia and the U.S. reduced to 5000 warheads each

If Russia and the U.S. reduced to 1000 warheads each

200 warheads each for China, Russia, the U.S., and France/U.K.

- civilian
- excess
- naval (irradiated)
- naval (fresh)
- weapons

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Stockpiles of Separated Plutonium, 2009

Global stockpile is 500 tons, half is civilian and this stock is growing

Metric tons [MT]

- Military stockpile
- Excess military material
- Additional strategic stockpile
- Civilian stockpile, stored in country (Jan. 2008)
- Civilian stockpile, stored outside country (Jan. 2008)

Data for Russia highly uncertain ± 25 MT

10,000 warheads

Belgium: 0.0 MT
China: 4 MT*
France: 5 MT*
Germany: 1 MT
India: 0.7 MT*
Israel: 0.65 MT*
Japan: 8.7 MT
North Korea: 0.035 MT
Pakistan: 0.1 MT*
Russia: 44.9 MT
U.K.: 76.8 MT
United States: 53.9 MT

*Estimate

AECL, Chalk River, December 15, 2009
The Problem of Civilian Separated Plutonium in a Disarming World

Metric tons separated plutonium

<table>
<thead>
<tr>
<th>Data for Russia highly uncertain</th>
<th>Today</th>
<th>If Russia and the U.S. reduced to 5000 warheads each</th>
<th>If Russia and the U.S. reduced to 1000 warheads each</th>
<th>200 warheads each for China, Russia, the U.S., and France/U.K.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>92 + 25 tons</td>
<td>246 + 62 tons</td>
<td>246 + 24 tons</td>
<td>246 + 5 tons</td>
</tr>
</tbody>
</table>

- Civilian
- Excess
- Weapons
Verified Declarations of Fissile Material Stock and Production
Why Declarations Matter

“The U.K. believes that transparency about fissile material acquisition for defence purposes will be necessary if nuclear disarmament is to be achieved; since achieving that goal will depend on building confidence that any figures declared for defence stockpiles of fissile material are consistent with past acquisition and use. This report is a contribution to building such confidence.”

### Content of Declarations and Sequencing of Information Release

<table>
<thead>
<tr>
<th>Level of Detail</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Initial Declarations</strong> (unverified)</td>
<td></td>
</tr>
<tr>
<td>Aggregate</td>
<td>Total inventory</td>
</tr>
<tr>
<td>By Type</td>
<td>Historical production data for different materials (and selected characteristics)</td>
</tr>
<tr>
<td>By Site / Facility</td>
<td>Same by site/facility</td>
</tr>
<tr>
<td><strong>Detailed Declarations</strong> (verified)</td>
<td></td>
</tr>
<tr>
<td>By Item</td>
<td>Location, mass, composition of each item or container</td>
</tr>
</tbody>
</table>
Content of Initial Declarations

1. Material available for weapons
   (in warheads, warhead components and working stocks)

2. Material that has been declared excess for weapons purposes

3. Highly enriched uranium for naval and other military-reactor use

4. Civilian material
The 1996 and 2001 U.S. Declarations

Plutonium: The First 50 Years

United States plutonium production, acquisition, and utilization from 1944 through 1994

HIGHLY ENRICHED URANIUM: STRIKING A BALANCE

A HISTORICAL REPORT ON THE UNITED STATES HIGHLY ENRICHED URANIUM PRODUCTION, ACQUISITION, AND UTILIZATION ACTIVITIES FROM 1945 THROUGH SEPTEMBER 30, 1996

U.S. DEPARTMENT OF ENERGY
NATIONAL NUCLEAR SECURITY ADMINISTRATION
OFFICE OF THE DEPUTY ADMINISTRATOR FOR DEFENSE PROGRAMS

JANUARY 2001
REVISION 1
Example from the U.S. Declarations

Plutonium Production by Year and Site

Plutonium: The First 50 Years: United States Plutonium Production, Acquisition and Utilization from 1944 Through 1994
Example from the U.S. Declarations

Stockpile of Highly Enriched Uranium by Location (U.S. DOE Sites, 1996)

Example from the U.S. Declarations

Stockpile of Highly Enriched Uranium by Category

1994

- Stockpile available for weapons: 618 metric tons (741-100-23)
- Fresh naval fuel reserve: 100 metric tons
- Irradiated naval fuel: 151 metric tons
- Excess (to be used as civilian HEU): 23 metric tons
- Excess (irradiated, for direct disposal): 86 metric tons
- Excess (to be blended down): 23 metric tons
- Civilian HEU, fresh (about 10 tons)
- Civilian HEU, in spent fuel: 124 metric tons

1996

- Stockpile available for weapons: 457 metric tons (618-174+13)
- Fresh naval fuel reserve: 100 metric tons
- Irradiated naval fuel: 23 metric tons
- Excess (to be used as civilian HEU): 151 metric tons
- Excess (irradiated, for direct disposal): 23 metric tons
- Excess (to be blended down): 86 metric tons
- Civilian HEU, fresh (about 10 tons)
- Civilian HEU, in spent fuel: 124 metric tons

2009

- Stockpile available for weapons: 250 metric tons (457-200-7)
- Fresh naval fuel reserve: 100 metric tons
- Irradiated naval fuel: 23 metric tons
- Excess (to be used as civilian HEU): 124 metric tons
- Excess (irradiated, for direct disposal): 86 metric tons
- Excess (to be blended down): 23 metric tons
- Civilian HEU, fresh (about 10 tons)
- Civilian HEU, in spent fuel: 124 metric tons

*(151-124+52+7)
Approaches to Verifying Historic Production of Fissile Materials
Atmospheric Krypton-85 Levels

Atmospheric Krypton-85 Levels

Nuclear Archaeology

“A set of methods and tools to estimate historic fissile material production through on-site measurements at fissile-material production and storage sites”
In Graphite-moderated Reactors: Graphite Isotope-Ratio Method (GIRM)

Measurements of the degree of transmutation of trace elements in the graphite moderator of a production reactor to estimate the cumulative neutron flow through the graphite and thereby the cumulative plutonium production in this reactor

GIRM has been applied to several case studies of historical plutonium production, including the U.S. Hanford reactors, the U.K. Calder-Hall-type reactors, and the French Marcoule G-Series reactors
Nuclear Archaeology for Plutonium
(U.S. Hanford B Reactor, 1944-1968)
Nuclear Archaeology for Plutonium

(U.S. Hanford B Reactor, 1944-1968)
Nuclear Archaeology for Plutonium
(U.S. Hanford B Reactor, 1944–1968)
Jungmin Kang, “Using Graphite Isotope Ratio Method to Verify DPRK’s Declaration of Plutonium Production,” *under review*
North Korea’s Yongbyon Reactor
(Design based on the U.K. Calder Hall Reactor)

Photo: Keith Luse
Demolition of cooling tower, June 26, 2008
North Korea’s Yongbyon Reactor
# Plutonium Production Reactor Types

<table>
<thead>
<tr>
<th>Graphite moderated</th>
<th>Heavy-water moderated</th>
<th>Driver fuel with external DU targets</th>
</tr>
</thead>
<tbody>
<tr>
<td>H₂O cooled</td>
<td>CO₂ cooled</td>
<td></td>
</tr>
<tr>
<td>H₂O cooled</td>
<td>D₂O cooled</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>United States</th>
<th>Hanford</th>
<th>Savannah River</th>
</tr>
</thead>
<tbody>
<tr>
<td>Russia</td>
<td>“Tomsk-7”</td>
<td></td>
</tr>
<tr>
<td>U.K.</td>
<td>Calder Hall</td>
<td></td>
</tr>
<tr>
<td>France</td>
<td>G-Series</td>
<td>Célestin</td>
</tr>
<tr>
<td>China</td>
<td>“Jiuquan”</td>
<td></td>
</tr>
<tr>
<td>Israel</td>
<td></td>
<td>Dimona</td>
</tr>
<tr>
<td>India</td>
<td>Cirus/NRX</td>
<td>Dhruva</td>
</tr>
<tr>
<td>Pakistan</td>
<td>Khushab</td>
<td></td>
</tr>
<tr>
<td>DPRK</td>
<td>Yongbyon</td>
<td></td>
</tr>
</tbody>
</table>

Unit Cells of Early Natural-Uranium-Fueled Reactors

Nuclear Archaeology for Uranium Enrichment
Nuclear Archaeology for Uranium Enrichment
Novouralsk Tails Storage Area
Measurements on Uranium Tails

\[ \frac{^{235}U}{^{234}U_{\text{nat}}} \] ratio in depleted uranium tails

M. Sharp, “Applications and Limitations of Nuclear Archaeology,” *in preparation*
Integrated Assessment of Fissile Material Production
Integrated Operation of the U.S. Gaseous Diffusion Plants

Isotopics of Weapon-Grade Plutonium

93.8% Pu-239, produced from natural and pre-irradiated uranium

Production Modes Leave Characteristic Signatures in the Fissile Materials

- 100,000 kg of natural uranium → 100,000 kg of natural uranium (Reactors)
- 100,000 kg of natural uranium → 100,000 kg of natural uranium (Reactors)
- 100,000 kg of natural uranium → 100,000 kg of natural uranium (Reactors)
- 100,000 kg of natural uranium → 100,000 kg of natural uranium (Reactors)

Production Modes:
- Reactor → Reactor
- Reactor → Reactor
- Reactor → Reactor
- Reactor → Reactor

Enrichment:
- ENRICHMENT
- ENRICHMENT
- ENRICHMENT
- ENRICHMENT

Indicators:
- Clean HEU
- Low Pu-238 content in plutonium
- Low Pu-238 content in Pu and U-236 in HEU
- Low and high Pu-238 content in plutonium
The Way Forward

Verified Declarations of Fissile-Material Stocks and Production

Most former production facilities are already shut-down or in various stages of decommissioning

To retain the option of verifying declarations:
Need to preserve production reactors (and depleted uranium tails)
in a condition that will permit nuclear archaeology

Some precedents and many opportunities for cooperative initiatives

Start with joint demonstration exercises
to establish the methods and tools for all types of relevant plants