HIGHLY ENRICHED URANIUM, RESEARCH REACTORS, AND THE RISK OF NUCLEAR PROLIFERATION

(WITH A DISCUSSION OF “RECOMMENDATION 4”)

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World Stockpiles of Fissile Materials

- 1330 tons of highly-enriched uranium
- 510 tons of separated plutonium

Each block = 50 kg of HEU, the amount necessary to make a first-generation fission bomb; 27,600 bombs-worth total

Each block = 5 kg of Pu, the amount necessary to make a first-generation fission bomb; 99,000 bombs-worth total

Graphic by Alex Wellerstein, nuclearsecrey.com

'FISSILE MATERIALS BY CATEGORY

GLOBAL STOCKPILE OF PLUTONIUM AND HIGHLY ENRICHED URANIUM, 2016

Weapon equivalents

- Military: 147 tons (Plutonium), 927 tons (Highly enriched uranium)
- Naval: 285 tons (Plutonium), 89 tons (Highly enriched uranium)
- Excess: 56 tons (Plutonium), 280 tons (Highly enriched uranium)
- Civilian: 61 tons (Plutonium), 668 tons (Highly enriched uranium)
- Disposed of: 4.4 tons (Plutonium)

Assumptions for weapon equivalents: 4 kg of weapon-grade plutonium, 5 kg of reactor-grade plutonium, 12 kg of highly enriched uranium
(As of 2016, more than 220,000 weapon-equivalents in the global stockpile of fissile material)
HEU PRODUCTION HAS LARGELY ENDED
BUT CONTINUES IN NON-NPT WEAPON STATES ... AND NOW AGAIN IN RUSSIA

<table>
<thead>
<tr>
<th>Country</th>
<th>Military HEU production</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>1944–1992 (since 1964 for naval fuel only)</td>
</tr>
<tr>
<td>Russia</td>
<td>1949–1987/88 (but restarted civilian in 2012)</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1953–1963 (but imports from United States)</td>
</tr>
<tr>
<td>China</td>
<td>1964–1987/89 (unofficial)</td>
</tr>
<tr>
<td>France</td>
<td>1967–1996</td>
</tr>
<tr>
<td>South Africa</td>
<td>1978–1990</td>
</tr>
<tr>
<td>Pakistan</td>
<td>since 1983</td>
</tr>
<tr>
<td>India</td>
<td>since 1992</td>
</tr>
<tr>
<td>Israel</td>
<td>?</td>
</tr>
<tr>
<td>North Korea</td>
<td>ongoing (status and scale uncertain)</td>
</tr>
</tbody>
</table>

WHERE (CIVILIAN) HEU IS USED TODAY

Number of HEU-fueled civilian research reactors (74)

Approximate annual HEU consumption (490 kg)

WHY 20%?

IS IT A POLITICAL OR A TECHNICAL DEFINITION?

(IT IS INDEED TECHNICAL)
THE 1954 HAFSTAD MEMO

GUIDING PRINCIPLE

No foreign country ought to receive enough material to make a single nuclear explosive device with a yield of one kiloton TNT equivalent.


MINIMUM AMOUNT OF URANIUM REQUIRED FOR A (SMALL) NUCLEAR WEAPON

THE 1954 HAFSTAD MEMO

FINDINGS AND RECOMMENDATIONS

Only 2.3 kg of weapon-grade (93%-enriched) uranium are needed.

An enrichment of 10 percent was considered “safe in any quantity.”

Making a nuclear weapon using 20 percent enriched uranium would “require the utmost ingenuity,” but the minimum amount needed is (still) only on the order of 30 kg.

The memorandum went on to recommend exporting enriched uranium up to an enrichment level of 20 percent such that the total amount held by a foreign country does not exceed 30 kg.


THE 2016 NATIONAL ACADEMIES STUDY

DISCLAIMER: VIEWS ARE MY OWN (AND ARE NOT NECESSARILY THOSE OF THE COMMITTEE)

www.nap.edu/catalog/21818/reducing-the-use-of-highly-enriched-uranium-in-civilian-research-reactors
SEVEN RECOMMENDATIONS

1. Develop a 50-year interagency strategy and roadmap for neutron needs
2. Continue the development of very high-density LEU fuels for research reactors
3. Monitor the development of dispersion-type fuels as a backup for U.S. research reactors
4. Pursue an interim solution for conversion of high-performance research reactors
5. Engage Russia in conversion efforts through periodic workshops and scientific exchanges
6. Augment the annual progress reports of the M^3 program
7. Conduct independent technical review for robust project and risk management
TIMELINES HAVE EXPANDED (A LOT)

- **2004**: 9 years to complete
- **2005**: 9 years to complete
- **2006**: 9 years to complete
- **2007**: 11 years to complete
- **2008**: 10 years to complete
- **2009**: 9 years to complete
- **2010**: 10 years to complete
- **2011**: 9 years to complete
- **2012**: 13 years to complete
- **2013**: 17 years to complete
- **2014**: 21 years to complete

Additional Notes:
- Year of estimate
- +5 years since last year
### ENRICHMENT REQUIREMENTS
### FOR HIGH-PERFORMANCE REACTORS

<table>
<thead>
<tr>
<th>Reactor</th>
<th>U$_3$Si$_2$ 4.8 g(U)/cc</th>
<th>U$_3$Si$_2$ 5.8 g(U)/cc</th>
<th>UMo(8wt%) 8.0 g(U)/cc</th>
<th>Monolithic 16 g(U)/cc</th>
<th>Years to conversion</th>
</tr>
</thead>
<tbody>
<tr>
<td>ATR</td>
<td>35–40%</td>
<td>~ 30%</td>
<td>25–30%</td>
<td>LEU</td>
<td>14 years</td>
</tr>
<tr>
<td>HFIR</td>
<td>35–40%</td>
<td>~ 30%</td>
<td>25–30%</td>
<td>LEU</td>
<td>17 years</td>
</tr>
<tr>
<td>NBSR</td>
<td>~ 25%</td>
<td>LEU</td>
<td>LEU</td>
<td>LEU</td>
<td>12 years</td>
</tr>
<tr>
<td>MURR</td>
<td>~ 45%</td>
<td>~ 40%</td>
<td>~ 35%</td>
<td>LEU</td>
<td>12 years</td>
</tr>
<tr>
<td>MITR-II</td>
<td>~ 35%</td>
<td>~ 30%</td>
<td>20–25%</td>
<td>LEU</td>
<td>12 years</td>
</tr>
<tr>
<td>FRM-II</td>
<td>~ 50%</td>
<td>~ 35%</td>
<td>30%</td>
<td>LEU</td>
<td>n/a</td>
</tr>
<tr>
<td>BR-2</td>
<td>~ 27%</td>
<td>~ 22%</td>
<td>LEU</td>
<td>LEU</td>
<td>n/a</td>
</tr>
<tr>
<td>JHR</td>
<td>~ 27%</td>
<td>~ 22%</td>
<td>LEU</td>
<td>LEU</td>
<td>n/a</td>
</tr>
<tr>
<td>RHF</td>
<td>~ 27%</td>
<td>~ 22%</td>
<td>LEU</td>
<td>LEU</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Only uranium-silicide fuel at 4.8 g(U)/cc would be immediately available (and make possible an interim conversion on the order of 5 years or less)
Recommendation 4: To achieve the goal of using as little highly enriched uranium as possible during the many years that it will take to design and qualify appropriate low enriched uranium (LEU) fuel, the United States should pursue an interim solution that reduces the civilian use of weapon-grade material.

a. During this interim period, high performance research reactors should use dispersion silicide fuel enriched to the lowest practical level, which can be produced with technologies already known to be reliable. The precise enrichment level can be quickly determined by a focused, small-scale study.

b. The United States should downblend the remaining 20 metric tons of highly enriched uranium (HEU) designated for civilian research reactor use to this lowest practical enrichment level as soon as it has been determined.

c. The interim solution should be pursued in a way that does not compromise the long-term goal of eliminating HEU usage in civilian applications.
WHAT AN INTERIM CONVERSION COULD ACCOMPLISH

Avoid the use of up to 3.4 tons of weapon-grade HEU between now and 2035

Demonstrate U.S. commitment to international conversion efforts by maintaining an active domestic program and sustaining the technical expertise in the area

Attract scientists and engineers to work on reactor conversions and fuel development (who would otherwise find projects with a twenty-year time horizon of little interest)

If down-blending is pursued: Reduce the global stockpile of weapon-grade uranium Ideally, this material could also be offered for IAEA safeguards

Note: the proposition of an interim conversion step is not new. Both the U.S. RERTR Program and the IAEA International Nuclear Fuel Cycle Evaluation considered 45% as an interim step toward 20% enrichment when adequate fuel for a direct conversion was not available.
A SILENT DISASTER

RESUMPTION OF HEU PRODUCTION IN RUSSIA FOR EXPORT TO WESTERN CUSTOMERS

Main developments in 2015: “Production by the EKhZ [enrichment plant in Zelenogorsk] of highly enriched product for the uranium metal to be supplied to the Munich-II reactor”

First HEU production for civilian purposes; not under IAEA safeguards
Likely to make even more complicated discussions on Fissile Material Cutoff Treaty

fissilematerials.org/blog/2016/07/russia_confirmed_supplyin.html
**FINAL THOUGHTS**

**STATE OF PLAY 2017**

Remaining conversions are “hard” (politically or technically)
Few if any conversions expected for the next decade
Annual HEU demand will remain nearly constant for next 15–20 years

**WAY FORWARD / POSSIBLE NEXT STEPS**

Consider interim conversion step for remaining high-flux reactors
Remove incentive for ongoing HEU production in Russia
Consider “convert and upgrade” strategies (for research reactors)

*Source: Author*