Options for Expanding Conversion of Russian Highly Enriched Uranium

A Report from the Nuclear Threat Initiative

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Working for a Safer World

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PREFACE

From 2003 to 2006, NTI conducted a series of studies to understand the cost and schedules associated with potential approaches to accelerate and expand the blend-down of Russian highly enriched uranium. A team of Russia specialists from FSUE Central Research Institute of Management, Economics and Information of Rosatom of Russia (FSUE ATOMINFORM) scoped and subsequently refined the costs and schedules for a series of alternative blend-down scenarios. In addition, NTI sponsored additional studies involving U.S. organizations and experts—these studies assessed costs and schedules of transporting uranium to and from the United States and the U.S. portion of several “two-stage” blend-down scenarios. An additional study subsequently considered potential incentives to accelerate or expand blend-down. Some of these studies have been previously published on the NTI web site or presented as papers at the 2008 annual meeting of the Institute for Nuclear Materials Management (INMM). The following report represents an overall summary of this research.

Because this work was completed several years ago, it is likely that some of the specific figures are no longer accurate. In addition, as the HEU purchase agreement reaches its currently agreed conclusion in 2013, options developed to accelerate the blend-down are no longer directly relevant due to the lead times for capital investments. NTI believes, however, that the analysis may prove useful in considering future blend-down options and is thus publishing this summary at this time.

We acknowledge the following individuals and organizations for providing the analysis on which this report is based: Matthew Bunn, Nigel Mote, Kevin Alldred, Norman Jacob, Jack Edlow and the Federal State Unitary Enterprise Central Research Institute of Management, Economics and Information of Rosatom of Russia (FSUE ATOMINFORM).

EXECUTIVE SUMMARY

Russia is presently processing 30 metric tons (MT) of highly enriched uranium (HEU) per year to produce low-enriched uranium (LEU) to fuel the world's nuclear power reactors. The U.S.-Russian HEU Purchase Agreement that made this possible has been very successful, but substantial inventories of HEU will remain when the agreement terminates in 2013. NTI, through its project with the Russian institute, FSUE ATOMINFORM, has examined options for increasing the amount of HEU blended down, and for overcoming the limitations in processing capacity, most particularly with the uranium enrichment capacity required to produce the blendstock. This report outlines the technology for HEU blend-down in Russia, describes the technological issues that must be confronted to increase the rate of HEU blend-down, and discusses the options for resolving them. These options include adding new industrial facilities in Russia, exploring two-stage blending regimes that could leverage the Russian capacities or make possible the use of U.S. facilities, and taking advantage of the revised isotopic limits in the most recent ASTM specification for commercial grade UF_6 to allow less enrichment intensive blendstocks to be used. Finally, this report considers the costs and timeframes for several specific blend-down scenarios.

INTRODUCTION

Russia presently provides almost 50% of the U.S. needs for enriched uranium by blending down 30 metric tons of uranium (MTU) of highly enriched uranium (HEU) each year according to the existing U.S.-Russia Highly Enriched Uranium Purchase Agreement (HEU Purchase Agreement).[1] This program has operated since 1995 and has been an important success, from both the nonproliferation and commercial perspectives. As of March 2008, some 327 metric tons of HEU have been converted to low-enriched uranium (LEU), equivalent to more than 13,000 nuclear weapons.

Russian HEU contains high levels of the uranium isotope U-234. To produce LEU that meets the internationally accepted ASTM standard and is therefore suitable for use in nuclear fuel, Russia constructed facilities for the oxidation, fluorination, and gas phase blending of HEU, and developed a specialized blending strategy in conjunction with the United States. The blending process starts with a special UF_6 blendstock with 1.5% U-235 derived by enriching depleted uranium tails. This blendstock is then mixed with HEU UF_6 to produce the desired LEU enrichment. The special blendstock has a very low U-234 content, which makes it possible to meet the ASTM specifications for the eventual LEU product.

This approach is effective in preparing a commercial product from the HEU, but it has the disadvantage that it requires a large amount of uranium enrichment capacity to be dedicated to blendstock production. Over the past several years, the demand for enrichment services has grown, and prices for uranium enrichment services have increased sharply. This makes it difficult to expand HEU blend-down using this process, as it is both expensive, and requires resources (i.e., enrichment services) that could be used more profitably in other ventures. It is generally believed that Russia will not extend the current program of blending down 30 MTU of HEU per year after the expiry of the current agreement in 2013.

The first phase of the joint NTI-ATOMINFORM project[2] examined alternative strategies for expanding HEU blend-down, taking into account the very limited existing free enrichment capacity. This scarcity of enrichment capacity is expected to persist over the medium term. The current supply-side difficulties in the uranium markets and the possibility to substitute enrichment services for uranium mean that the enrichment markets are likely to remain capacity limited even if substantial new capacity is added as planned by enrichment companies.

The options examined in the first phase of this study focused on blending down additional HEU in parallel with the existing program. However, the broader issues revealed by the study, and the scenario intercomparisons remain valid for the post–2013 period, even in the absence of the 30 MTU baseload from the existing agreement.

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[1] Agreement between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly-Enriched Uranium Extracted from Nuclear Weapons of 1993, available at www.nti.org/db/nisprofs/russia/fulltext/heudeal/heufull.htm.

[2] See *Joint Conceptual Analysis and Cost Evaluation of the Possibility of Accelerated Disposition of Highly Enriched Uranium No Longer Needed for Defense Purposes.* Final Report. FSUE ATOMINFORM, Moscow, 2005. Available on the web at: http://www.nti.org/c_press/analysis_HEUfinalrpt.pdf

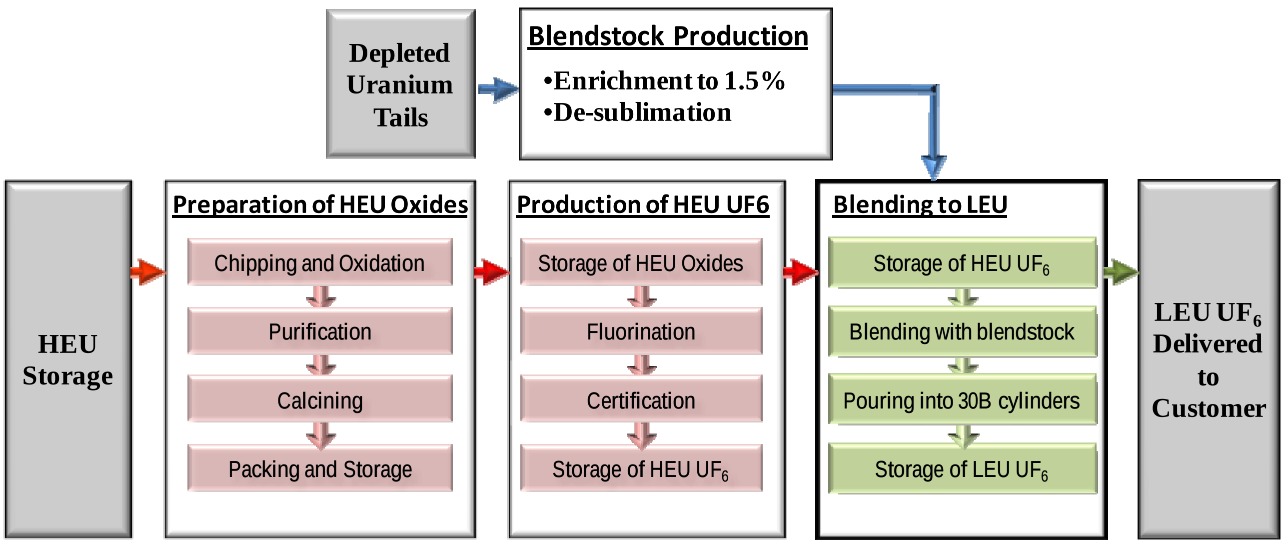
This report builds on the Phase 1 effort by examining the costs and timeframes for additional specific scenarios that might be envisioned to accelerate and expand blend-down of HEU in Russia.

CURRENT RUSSIAN BLEND-DOWN TECHNOLOGY

The current process for blending down Russian HEU is shown in Figure 1. The HEU is stored mainly in the form of HEU metal, which must first be converted to uranium oxide. The metal is cut into small pieces and then oxidized, and the resulting oxide mixture is then purified, packed, and stored.

In another facility, the HEU oxide is fluorinated to make UF_6, and again stored. In the final stage the HEU UF_6 is volatilized and blended as a gas with blendstock UF_6 to produce LEU, which complies with the internationally recognized specification ASTM C996-96. After appropriate quality controls the material is packed and shipped to the customer.

FIGURE 1: BLENDING OF RUSSIAN HEU



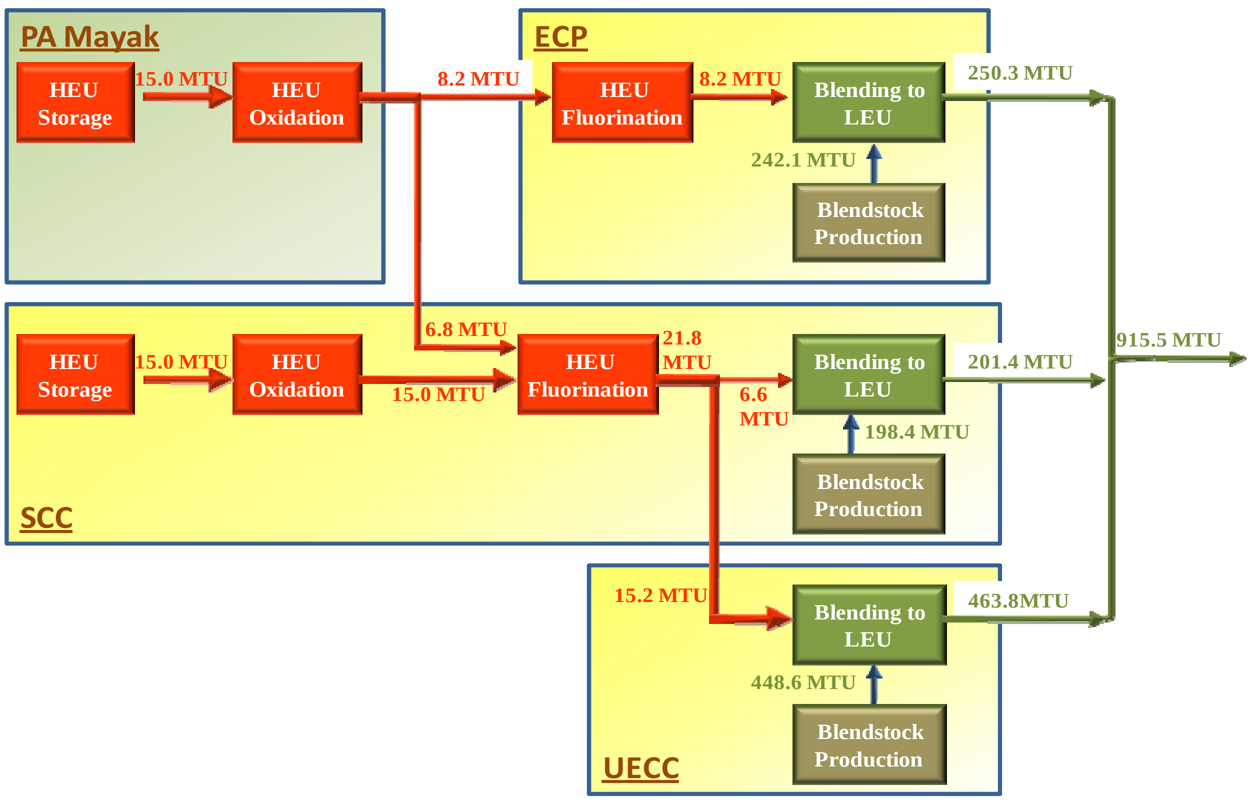
The existing HEU blend-down activities under the HEU Purchase Agreement take place at four sites in Russia: the PA Mayak site near Chelyabinsk that stores HEU and has the capability to oxidize it; the enrichment facilities of the Electrochemical Plant near Zelenogorsk (ECP) and those of the Urals Electrochemical Combine near Ekaterinburg (UECC) that can prepare blendstock and blend it with the HEU; and the Siberian Chemical Combine site near Seversk (SCC) that has the capability to perform all steps in the HEU blending-down process. Table 1 shows the capabilities of the four sites.

TABLE 1: HEU PROCESSING CAPABILITIES AT THE RUSSIAN NUCLEAR SITES

	PA Mayak	ECP	SCC	UECC
HEU storage	✓		✓	
HEU oxidation	✓		✓	
HEU fluorination		✓	✓	
Blendstock production		✓	✓	✓
HEU-LEU blending		✓	✓	✓
LEU packaging		✓	✓	✓

Because the processing capacities are distributed between the sites, the HEU must be transported between sites for the successive processing stages, as is shown schematically in Figure 2. The HEU is stored at the PA Mayak and SCC sites, where it is oxidized, and in the SCC case, is also fluorinated. The oxidized HEU from PA Mayak is transported to ECP and SCC for fluorination to UF_6. After fluorination, the HEU UF_6 at ECP is blended down to produce slightly more than one-third of the final LEU. HEU UF_6 from SCC is primarily transported to UECC for blend-down, with a smaller quantity being retained on the SCC site for blend-down.

FIGURE 2: INVOLVEMENT OF RUSSIAN SITES IN HEU BLEND-DOWN



TECHNICAL OPTIONS FOR EXPANDING HEU BLEND-DOWN

The most obvious approach to expanding the blend-down of HEU is to process more HEU using the same technological approach as the HEU Purchase Agreement. This approach was evaluated during Phase 1 of the NTI-ATOMINFORM joint project, which determined that a much greater additional uranium enrichment capacity would be required than could be made available from existing Russian facilities. Therefore, to blend-down additional HEU using this approach would require new enrichment capacity to be funded and installed, and would substantially delay the start of the expanded HEU blend-down program.

As developed during Phase 1, there are options to reduce this bottleneck in enrichment capacity. These include increasing the U-235 content of the final LEU; using higher assay uranium tails to make the blendstock to reduce the amount of enrichment required; making the final LEU compliant with the most recent ASTM C996-04 specification that includes a higher limit on the U-234 isotope and thus allows alternative schemes for blendstock preparation; and using a two-stage downblending procedure that allows re-use of limited enrichment capacities, flexibility in blendstock preparation for the first phase, and/or the use of U.S. facilities for the second stage of the blending. These options are discussed in more detail below.

Producing LEU with 4.95% U-235 Enrichment

Producing LEU with a slightly higher final enrichment of 4.95% U-235, rather than the 4.4% U-235 reference value for the existing HEU blend-down program, has two advantages. First, this would require less blendstock, and therefore less enrichment effort, than blending to 4.4% U-235, and the 4.95% material is preferred by some LEU customers.

Preparing Blendstock from Higher Assay Depleted Uranium Tails

The amount of enrichment required to make the blendstock strongly depends on the quality of the depleted uranium tails. It is normal to consider 0.3% tails for most analyses, because this is commonly used as a reference value in commercial transactions, and this has been a typical assay of uranium enrichment tails in the West. In Russia, however, policies on tails management were different from those in the West, and the average tails assays are believed to be much lower.

Using depleted uranium of a higher U-235 assay would reduce the amount of enrichment required for the blendstock, and therefore address a key issue in the expanded downblending analysis. If needed, these tails could be imported from the West. The U.S. inventory of tails, for example, has significant amounts of material with an assay above 0.4% U-235.

Using the Current ASTM Specification for the Final LEU

The downblending program for the HEU Purchase Agreement produces LEU that is compliant with specification ASTM C996-96 in which the allowed content of the U-234 isotope in the LEU must be less than 10×10^3 μg/gU-235.

In 2004, the ASTM published an updated version of the LEU specification, C996-04, which would make possible up to 11.0×10^3 μg/gU-235 in the downblended LEU product. For the purposes of HEU disposition this is a significant change, as it simplifies the requirements for blendstock preparation. For example, the 1.5% enriched blendstock could be prepared from natural uranium rather than depleted uranium tails, with substantial savings in the amount of enrichment effort required.

Of course, from a financial perspective, the savings in enrichment effort must be balanced against the purchase costs of the natural uranium. However, the nonproliferation benefits of using natural uranium are significant because the time delays and higher costs associated with creating sufficient additional enrichment capacity would be mitigated, and the value of the natural uranium used would be recovered when the LEU is sold.

Two-Stage Blend-Down

Another option to mitigate the need to construct enrichment capacity is to blend the HEU in two stages. The first stage would produce LEU of 19% U-235, thus meeting the primary nonproliferation requirement to convert the HEU to LEU, and the second would produce the final LEU of less than 5% U-235, as required for commercial power reactor fuel. This two-stage process opens the door to several favorable blending-down options and benefits.

Less enrichment capacity is required to support the blending to 19% U-235 than for blending directly to the final LEU enrichment level. Thus, a given amount of HEU can be blended down to 19% U-235 more quickly, and at less cost. From a technical perspective, the intermediate 19% enriched material could be stored such that the enrichment capacity used in Stage 1 could be reused for Stage 2. This would require storage for a substantial period that would raise other commercial and political questions. However, any period of storage of the 19% LEU would allow the addition of enrichment capacity to be phased to match the available industrial and financial resources without hindering the start of the expanded disposition effort.

The two-stage process would also allow the blending strategy to be optimized. For example, the Stage 1 blending could use natural uranium as the blendstock, thus completely avoiding the need for enrichment services. In this case, the Stage 2 blendstock would be adjusted to compensate for the increased U-234 level in the intermediate product. For example, a blendstock of 1.62% U-235 that is prepared from 0.3% U-235 depleted uranium tails could be used to meet the desired ASTM C996-96 specification. This could be achieved by adding enrichment capacity in Russia for the blending in Stage 2, or by shipping the intermediate product to the United States, and making use of U.S. enrichment capacity. Again, the two-stage blending allows the enrichment capacity issue to be managed in a way that expedites the blending process and makes best use of the resources available.

Presently, the Russian enrichment sites do not produce LEU at 19% enrichment. Material enriched to 19% cannot be withdrawn, or reintroduced, to the blending process using the existing LEU offtake or HEU input mechanisms because of the criticality safety concerns and equipment incompatibilities. To support a two-stage blend-down strategy for HEU, the blending facilities would need to be modified to permit the safe withdrawal and reintroduction of the 19% U-235 material.

In addition, transport and storage container designs for uranium with an assay of 19% U-235 would need to be adapted to the Russian facility requirements, licensed, and the containers manufactured. Although designs exist for storage and transportation containers that can accept 19% UF_6, these are not presently used in Russia. Using U.S. facilities for blending down the 19%

U-235 intermediate LEU to the final LEU enrichment value could avoid the limitations in Russian processing capacity.

Capacities and Transportation

The uranium enrichment capacity is the most severe bottleneck because of the costs and timescales required to install new capacity. However, there are other industrial processes that must also be considered. These include the facilities for fluorinating HEU and blending HEU and LEU, and equipment and buildings for storing and transporting the various intermediate and final products. The existing HEU blend-down program uses most of the available capacity for these processes within Russia. Thus, any proposal for expanding the HEU blending must consider the available industrial capacities, and the needs for capacity expansion. Excess capacities for each production stage are summarized in Table 2.

As seen in Table 2, the existing HEU blending-down program uses facilities and equipment at four Russian nuclear sites, and transports material between the sites to make best use of the available industrial infrastructure. Using available capacities thus must also consider the transportation burden between sites and seek to balance using existing capacities and adding new capacities with the transportation implications.

TABLE 2: EXISTING INDUSTRIAL CAPACITIES FOR HEU BLEND-DOWN

	Available Capacities, MTU Equivalent HEU/yr				
Production Stage	**PA Mayak**	**SCC**	**ECP**	**UECC**	**Total**
Oxidation of HEU comprising					
Chipping and oxidation	2.5	10			12.5
Purification	2.5	15			17.5
Calcining	2.5	7			9.5
Certification	2.5	10			12.5
HEU Oxide interim storage	2.5	11			13.5
Fluorination of HEU comprising					
HEU Oxide interim storage		2.2	0.4	—	2.6
HEU fluorination	—	2.2	1.8	—	4.0
HEU certification	—	2.2	1.8	—	4.0
HEU UF_6 interim storage	—	4.4	2.9	4.0	11.3
HEU blend-down comprising	—				
UF_6 interim storage		4.4	2.9	4.0	11.3
HEU Blend-down		4.4	2.9	4.8	12.1
Pouring LEU into 30B containers		2.4	6.5	4.6	13.5
<5% LEU interim storage	—	6.4	0.6	1.8	8.8
1.5% blendstock production	—	0.4	0.3	0.9	1.6
4.4% LEU production					13.9
12% and 19% LEU production					0

An additional factor to consider is that the Russian industrial capacity is typically added in modular increments. At each nuclear site, the preference is to replicate the existing facilities, using the proven and licensed designs that are available. Thus the amount of new capacity is not necessarily matched to the program requirement. Rather, there are optima in the amounts of additional HEU that would be processed, which represent the best use of the new facilities that would be constructed for the blend-down program. These issues were taken into account in the NTI-ATOMINFORM analyses.

Blend-Down Scenarios

The NTI-ATOMINFORM study considered the issues discussed above, and developed eight specific scenarios for detailed analysis, which are summarized in Table 3. In developing these scenarios, the following guiding principles were used.

- All major new facility investments were proposed to occur at SCC to minimize intersite transfers of HEU and make maximum use of the SCC infrastructure;
- Using different blendstocks for HEU blend-down would be considered, including enriched blendstocks prepared from Russian tails, U.S. tails, and natural uranium, as well as directly using natural uranium without enrichment;
- Two-stage versus single-stage blend-down would also be investigated;
- The implications of the updated ASTM LEU product specification would be investigated.

In addition, two annual rates of HEU blend-down were selected to best match the first two optima in available processing capacity, additional processing capacity and transportation complexity. As can be seen from Table 2, with the exception of preparing blendstock, sufficient industrial capacity exists to process an additional 4 MTU of HEU annually subject to a small investment in the interim oxide storage capabilities. Accordingly, the "A" scenarios shown in Table 3 assumed an additional blending-down rate of 4 MTU annually. To increase the rate of disposition further requires adding significant new industrial capacity, with a resulting optimum at 12.5 MTU of additional HEU to be blended down annually, which was the assumption for the "B" scenarios in the table.

TABLE 3: SUMMARY OF SCENARIOS ANALYZED

Scenario	**A11**	**A12**	**A13**	**A14**		**B11**	**B12**	**B13**		**B14**	
				-R	**-U.S.**			**-R**	**-U.S.**	**-R**	**-U.S.**
HEU /yr	4 MTU/yr					12.5 MTU/yr					
LEU specification											
C996-96	✓		✓	✓		✓	✓	✓		✓	
C996-04		✓			✓				✓		✓
Two-stage blending				✓	✓			✓	✓	✓	✓
Blendstock source material											
Stage 1	0.3%	nat.	0.3%	0.3%	0.3%	0.3%	0.4%	0.3%	0.3%	nat.	nat.
Stage 2				0.3%	nat.			0.3%	nat.	0.3%	nat.
Blendstock material											
Stage 1	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	1.5%	nat.	nat.
Stage 2				1.5%	nat.			1.5%	nat.	1.62%	nat.
Final LEU enrichment	4.95%	4.95%	4.4%	4.4%	4.95%	4.4%	4.4%	4.4%	4.95%	4.4%	4.95%

The individual scenarios were created to examine the alternative strategies discussed above. Scenario A11 and A13 follow the technological approach of the existing HEU blend-down program, although scenario A11 uses a final LEU enrichment levels of 4.95% rather than 4.4% U-235 to reduce the enrichment effort required. Scenario A12 adopts the current ASTM C996-04 specification, and assumes using natural uranium rather than tails as the source material for the blendstock. This decreases the uranium enrichment requirements to the point that the existing unused enrichment capacity is sufficient, and no additional enrichment capacity need be constructed. Scenario A14 uses a two-stage blending strategy, in which the HEU is blended down in the first step to 19%, and subsequently blended down to 4.4%/4.95% in a second step.

Scenario B11 uses the existing HEU blend-down technology. Scenario B12 assumes that a higher tails assay of 0.4% U-235 would be used as the source material for the blendstock, and scenarios B13 and B14 assume two-stage blending. Scenario B13 uses uranium tails as the source material, and B14 uses a natural uranium blendstock (without enrichment) for the first stage, and uranium tails containing 0.3% U-235 to produce 1.62% enriched blendstock in the second stage. Using higher assay U.S. tails for blendstock production also reduces uranium enrichment requirements.

The NTI-ATOMINFORM joint analysis only considered scenarios in which all steps would occur in Russia. To complement the joint analysis, NTI performed an independent assessment for transporting 19% U-235 intermediate LEU to the United States and then blending it down to a produce a final LEU containing 4.95% U-235 for each of the two-stage blending-down options in the joint study. In Table 3, these additional scenarios are shown as A14-U.S., B13-U.S., and B14-U.S.

Two technological options were evaluated for blend-down in the United States. The first option considered converting the UF_6 enriched to 19% U-235 to oxide, followed by dissolution to uranyl nitrate and blend-down as a liquid to provide a low-enriched solution with 4.95% U-235. It was assumed that natural uranium oxide would be dissolved to provide the blendstock. The resulting low-enriched uranyl nitrate solution would have an isotopic composition compliant with that in ASTM C996-04, would be directly provided to a U.S. fuel fabricator. The second option assumed gas phase blending of the 19% LEU UF_6 to 4.95% U-235, similar to the process used in the Russian current HEU blend-down program. Natural uranium hexafluoride would be used as the blendstock. This resulting LEU would be compliant with ASTM C996-04, and suitable for the conventional nuclear fuel markets.

Specific details of all of the scenarios are shown in Appendix 1. The NTI independent assessment of options that involve transportation to the United States are described in Appendices 2 and 3.

STUDY RESULTS

This section describes the timelines and costs for the HEU blend-down scenarios. The scenarios in which all work would be performed in Russia are presented first in Tables 4–6. These results are then integrated with the independent NTI assessments (Appendices 2 and 3), and summarized in Table 7.

Timelines

Table 4 shows the lead times[3] for the HEU blend-down scenarios. Note that the lead times are largely determined by the need to install new uranium enrichment capacities for blendstock production. The time to install this capacity for the 4 metric tons HEU per year scenarios ranges from 11 to 26 months, with Scenario A12 being the shortest due to not needing to create new enrichment capabilities. For the 12.5 metric tons HEU per year, the overall lead times range from 40 to 57 months.

TABLE 4: ESTIMATED LEAD TIMES FOR INDUSTRIAL CAPACITY INSTALLATION (MONTHS)

<table>
<tr><th>Process Stage</th><th>Blend-Down Stage</th><th>A11</th><th>A12</th><th>A13</th><th>A14</th><th>B11</th><th>B12</th><th>B13</th><th>B14</th></tr>
<tr><td>U_3O_8 production</td><td></td><td>—</td><td>—</td><td>—</td><td>—</td><td>11</td><td>11</td><td>11</td><td>11</td></tr>
<tr><td>UF_6 production</td><td></td><td>11</td><td>11</td><td>11</td><td>11</td><td>15</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td rowspan="2">Blendstock</td><td>Stage 1</td><td rowspan="2">23</td><td rowspan="2">—</td><td rowspan="2">23</td><td>—</td><td rowspan="2">46</td><td rowspan="2">40</td><td>14</td><td>—</td></tr>
<tr><td>Stage 2</td><td>24</td><td>43</td><td>46</td></tr>
<tr><td rowspan="2">Blending</td><td>Stage 1</td><td rowspan="2">—</td><td rowspan="2">—</td><td rowspan="2">—</td><td>14</td><td rowspan="2">14</td><td rowspan="2">14</td><td>14</td><td>14</td></tr>
<tr><td>Stage 2</td><td>16</td><td>18</td><td>18</td></tr>
<tr><td rowspan="2">LEU cylinder filling and certification</td><td>Stage 1</td><td rowspan="2">—</td><td rowspan="2">—</td><td rowspan="2">—</td><td>—</td><td rowspan="2">12</td><td rowspan="2">12</td><td>—</td><td>—</td></tr>
<tr><td>Stage 2</td><td>—</td><td>12</td><td>12</td></tr>
<tr><td rowspan="2">LEU storage</td><td>Stage 1</td><td rowspan="2">—</td><td rowspan="2">—</td><td rowspan="2">—</td><td>12</td><td rowspan="2">11</td><td rowspan="2">11</td><td>13</td><td>13</td></tr>
<tr><td>Stage 2</td><td>—</td><td>11</td><td>11</td></tr>
<tr><td rowspan="2">Overall</td><td>Stage 1</td><td rowspan="2">23</td><td rowspan="2">11</td><td rowspan="2">26</td><td>14</td><td rowspan="2">46</td><td rowspan="2">40</td><td>15</td><td>15</td></tr>
<tr><td>Stage 2</td><td>24</td><td>57</td><td>46</td></tr>
</table>

For the two-stage blend-down scenarios, A14, B13, and B14, HEU blend-down can begin when the Stage 1 investments are complete. Hence, the two-stage blending approach would allow the start of blend-down for up to 12.5 metric tons HEU per year after only 14 to 15 months. The lead times are limited in Scenario A14 by the need to create facilities to process 19% LEU and in Scenarios B13 and B14 by the investments in highly enriched UF_6 production facilities.

The overall timescale for the two-stage scenarios cannot be determined without specifying the period of interim storage of the intermediate LEU. However, the minimum overall lead time would be determined by the consecutive installation of uranium enrichment capacity for the two blending stages. The overall minimum timescales therefore vary from 24 months for Scenario A14, in which there is no Stage 1 enrichment capacity requirement, to 57 months for Scenario B13.

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[3] The lead times for expanded HEU blend-down were derived from preliminary schedules for constructing and commissioning the required industrial facilities in accordance with methods and standards used for industrial planning in the Russian Federation.

Cost Estimates

Estimates of total capital investments necessary for the expanded blend-down of HEU are given in Table 5. The capital cost estimates[4] for the blend-down scenarios include (1) capital costs for the new and modernized facilities; (2) decommissioning costs of additional plants and facilities; and (3) additional maintenance costs for newly built facilities. This also includes the blending section, a unit for filling transport containers with the LEU product, storage facilities, transport vehicles, and an analytical laboratory.

TABLE 5: ESTIMATED CAPITAL EXPENDITURES ($ MILLIONS)

Process Stage	Stage	A11	A12	A13	A14	B11	B12	B13	B14
U_3O_8 production		—	—	—	—	1.4	1.4	1.4	1.4
UF_6 production		0.3	0.3	0.3	0.3	14.6	14.6	14.6	14.6
Blendstock	Stage 1	68.9	—	95.0	—	538.7	391.9	4.7	—
	Stage 2				73.3			448.0	544.0
Blending	Stage 1	—	—	—	1.8	7.1	7.1	2.1	2.1
	Stage 2				74.8			94.5	94.5
LEU cylinder filling and certification	Stage 1	—	—	—	—	3.5	3.5	—	—
	Stage 2				—			3.5	3.5
LEU storage	Stage 1	—	—	—	1.5	0.6	0.6	6.4	6.4
	Stage 2				—			0.6	0.6
Transportation		2.6	2.6	2.6	2.6	6.74	6.7	6.7	6.7
Total	**Stage 1**	**71.8**	**2.9**	**97.9**	**6.2**	**572.7**	**425.4**	**35.9**	**31.2**
	Stage 2				**148.1**			**546.6**	**642.6**
Grand total		**71.8**	**2.9**	**97.9**	**154.3**	**572.7**	**425.4**	**582.5**	**673.8**

As shown in Table 5, the capital investments for expanded HEU blend-down are mainly determined by the cost of installing additional uranium enrichment capacity. These costs comprise some 80% to 97% of the total capital expenditure for most scenarios. Using higher assay tails for blendstock preparation reduces the requirements for uranium enrichment work, and thereby the overall scenario capital costs.

At 4 metric tons HEU per year expanded blend-down, the lowest estimated costs are for Scenario A12, in which blendstock is produced from natural uranium, and no additional uranium enrichment capacity is required. The requirement for new facilities to handle the 19% LEU intermediate product is a significant cost component of the two-stage scenario that can

[4] The costs of uranium enrichment capacity are proprietary to the Russian Federation. Therefore, the cost estimate was based on average costs of uranium enrichment capacity installation worldwide.

mask other cost effects. For example, the two-stage Scenario A14 has the highest estimated capital costs for the 4 metric tons HEU per year scenarios, despite a relatively modest requirement for new enrichment capacity. The two-stage Scenario B13 has higher estimated capital costs than its sibling, the single-stage Scenario B11, which is otherwise similar.

At 12.5 metric tons per year increment in HEU blend-down, the estimated capital costs rise significantly because of the need for additional industrial capacities. The lowest estimated capital costs for the 12.5 metric ton per year scenarios are for scenario B12, which assumes that U.S. tails with an enrichment level of 0.4% (0.4% tails) are used for blendstock production. In this case, the additional capital expenditure is estimated at $425 million. The corresponding figure for scenario B11, which is similar but assumes that 0.3% Russian tails are used, is estimated as $573 million.

Using natural uranium for the Stage 1 blend-down reduces the immediate need for new enrichment capacity and therefore reduces both the cost and timescales for the initial scenario implementation. However, this schedule acceleration and cost deferment is achieved at the cost of additional capital for new 19% LEU facilities and the eventual need for extra enrichment capacity to produce a higher quality Stage 2 blendstock.

Table 6 shows the estimated operating costs, expressed as millions of dollars per metric ton HEU, for each step in the process. Note that enrichment costs and purchase of either natural or depleted uranium for blendstock production were not calculated for this report. Although enrichment services would not be needed for scenario A12, assuming an enrichment cost of $20/ separative work units (SWU),[5] enrichment services for other scenarios are estimated at approximately $5 million per year for the 4 metric ton scenarios and approximately $20–25 million per year for the 12.5 metric ton scenarios.

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[5] The figure of $20/SWU has been previously estimated (Bukharin, O. Russia's *Gaseous Centrifuge Technology and Uranium Enrichment Complex*, 2004 and Bunn, M. *The Cost of Rapid Blend-Down of Russian HEU*, July 11, 2001)—open market prices are approximately 4–5 times higher. Note that we have made the assumption that there would be no additional operating costs to use the existing surplus enrichment capacity.

Table 6: Estimated Operating Costs for HEU Blend-Down Facilities ($ million/MT HEU)

<table>
<tr><th>Process Stage</th><th>Site</th><th>Blend-Down Stage</th><th>A11</th><th>A12</th><th>A13</th><th>A14</th><th>B11</th><th>B12</th><th>B13</th><th>B14</th></tr>
<tr><td rowspan="2">U_3O_8 production</td><td>PA Mayak</td><td></td><td colspan="4">—</td><td colspan="4">0.007</td></tr>
<tr><td>SCC</td><td></td><td colspan="4">—</td><td colspan="4">0.017</td></tr>
<tr><td rowspan="2">UF_6 production</td><td>ECP</td><td></td><td colspan="4">0.001</td><td colspan="4">—</td></tr>
<tr><td>SCC</td><td></td><td colspan="4">—</td><td colspan="4">0.096</td></tr>
<tr><td>Blend-stock production</td><td></td><td></td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td rowspan="2">Blending</td><td rowspan="2">SCC</td><td>Stage 1</td><td colspan="3" rowspan="2">—</td><td>—</td><td colspan="2" rowspan="2">0.05</td><td colspan="2">0.03</td></tr>
<tr><td>Stage 2</td><td>1.85</td><td colspan="2">0.72</td></tr>
<tr><td>LEU cylinder filling and certification</td><td>SCC</td><td></td><td colspan="4">—</td><td colspan="4">0.06</td></tr>
<tr><td rowspan="2">LEU storage</td><td rowspan="2">SCC</td><td>Stage 1</td><td colspan="3" rowspan="2">—</td><td rowspan="2">0.05</td><td colspan="2" rowspan="2">0.003</td><td colspan="2">0.54</td></tr>
<tr><td>Stage 2</td><td colspan="2">0.003</td></tr>
<tr><td rowspan="2">Transportation</td><td rowspan="2">SCC</td><td>Stage 1</td><td rowspan="2">0.59</td><td rowspan="2">0.58</td><td rowspan="2">0.63</td><td>0.30</td><td rowspan="2">0.43</td><td rowspan="2">0.82</td><td colspan="2">0.26</td></tr>
<tr><td>Stage 2</td><td>0.36</td><td colspan="2">0.14</td></tr>
</table>

The enrichment effort required to produce blendstock from tails is very sensitive to the tails assay. If higher assay tails are used, less enrichment capacity would be required to produce a blendstock with an assay of 1.5% or 1.62 % U-235. This therefore provides an opportunity to minimize installing new enrichment capacity and to minimize the time and cost required to implement expanded HEU blend-down. To investigate the time and cost implications in more detail, the NTI analysis examined the alternatives of using 0.3% tails and 0.4% tails.

The implications of the tails assay level is potentially significant because it is widely believed that the Russian tails inventory is significantly depleted in U-235, with typical assays below 0.2% U-235. Using such low assay tails in the current program to prepare blendstock to blend down 30 metric tons of HEU could increase the enrichment capacity needed by more than 1 million SWU per year.[6]

Put another way for example, if higher assay tails material from the U.S. tails stockpiles were to be used to prepare blendstock, more than 1 million SWU per year could be freed to expand HEU blend-down as well as to make more SWU available for sale in the commercial markets. Thus, making U.S. tails available to Russia to support the HEU blend-down would facilitate expanding HEU blend-down both technically and economically.

[6] It has been suggested that Russia is currently enriching (secondary) uranium tails created during enrichment of uranium tails from Western Europe to create the blendstock. See Diehl, P. *Re-enrichment of West European Depleted Uranium Tails in Russia*, 2004, available at: www.wise-uranium.org, and Bukharin, O. Russia's *Gaseous Centrifuge Technology and Uranium Enrichment Complex*, 2004, available at: www.ransac.org/Documents/bukharinrussianenrichmentcomplexjan2004.pdf.

Basis and Uncertainties of Scenario Costs

Finally, it is important to note the key assumptions and uncertainties of the cost and schedule estimates, including:

- Expanded operations would not affect the current 30 metric tons per year rate of blend-down, nor would they alter the technical approach for the underlying blend-down activity;
- All existing system reserves would be used before new capacity is considered;
- All new construction would be limited to SCC unless expansion of existing capabilities allowed for maximum effective use of existing reserves at the other Russian facilities involved: PA Mayak, ECP, and UECC;
- Natural uranium, with a U-234 content of 54 ppm to be used as a blendstock in the U.S. blend-down scenarios;
- 5B transport containers for international shipments of 19% LEU would be available and licensed;
- All LEU shipments would use surface transportation;
- Security requirements and quantities allowed per shipment of 19% LEU are unknown;
- The capital and direct costs estimates for the Russian scenarios presented here are based on 2004 prices for building materials, equipment, labor and power resources in compliance with the regulatory requirements, economic indices, and the taxation basis valid in the Russian Federation at that time. The ruble costs then were converted to dollars using the 2004 dollar/ruble exchange rate.

Due to proprietary information considerations and the politically sensitive nature of the process, full transparency into how certain elements of the estimates were developed was not provided, or was obscured by use of ranges and indices that represent analogous costs in the West. The cost estimates for the facilities in the Russian Federation do not include a confidence range and were calculated in 2004 U.S. dollars.

For the scenarios involving operations within the United States (Appendix 3), cost estimates for the U.S. Stage 2 blend-down facilities were calculated in 2007 U.S. dollars and are projected to be within a range of -10% to +30% of the estimated cost. To allow comparison to the Russia-only scenarios, the Russian estimates were adjusted to reflect price escalation between 2004 and 2007, using indices issued by the Russian Federal State Statistics Service (Rosstat) and exchange rates published by the Russian Central Bank. Producer prices for industrial goods in Russia rose by a factor of 1.461 between 2004 and mid-2007. In the same period, the ruble fell by a factor of 1.105 against the U.S. dollar. Taken together, the Russian inflation and ruble/dollar exchange rate movements suggest that the U.S. dollar-denominated costs for Russian facilities should be escalated by 61%.

After escalation, the calculated total capital cost of the various "A" scenarios ranged from $7 million to $250 million, driven largely by the need to install additional enrichment capacities for blendstock production, as noted in the previous sections. The total estimated capital costs of the "B" scenarios range from about $160 million to $1,090 million. These are largely driven by the need to install additional enrichment capacities to produce blendstock.

The estimated costs and schedules for each scenario are summarized in Table 7. Note that the costs and schedules for Stage 2 blend-down and transportation for A14-U.S., B13-U.S., and B14-U.S. are developed in Appendices 2 and 3.

TABLE 7: ESTIMATED COSTS, SCHEDULES, AND VALUES FOR EXPANDED HEU BLEND-DOWN

Scenario	Stage	LEU U-235 (%)	ASTM Spec (C)	Schedule (months)	New Enrichment Capacity (kSWU/yr)	New Enrichment Capital Cost ($M)	Other Capital Cost ($M)	Total Capital Cost ($M)	Total Direct Cost ($M)/yr	Total Transport Cost to U.S. ($M)	LEU Produced (MT/yr)	Product Value[a] ($M/yr)
	4 MT HEU/yr Scenario											
A11		4.95	996-96	23	204	111	7	118	3.9	2.8	102.6	359
A12		4.95	996-04	11	0	0	7	7	3.7	2.8	102.6	359
A13[b]		4.4	996-96	26	281	153	7	160	4	3.2	122.1	366
A14-RU	Stage 1	19	N/A	14	0	0	10	251	16.5	3.2	122.1	366
	Stage 2	4.4	996-96	24	217	118	123					
A14-U.S.	Stage 1	19	N/A	14	0	0	10	46	12.3	21.7	87.0	234
	Stage 2	4.95	996-04	48	0	0	36					
	12.5 MT HEU/yr Scenario											
B11		4.4	996-96	46	1,277	867	63	930	13.4	10	381.5	1,144
B12		4.4	996-96	40	927	630	63	693	21.1	12.6	381.5	1,144
B13-RU	Stage 1	19	N/A	15	14	8	50	946	37.8	10	381.5	1,144
	Stage 2	4.4	996-96	57	1,061	721	167					
B13-U.S.	Stage 1	19	N/A	15	14	8	50	168	49.8	80.1	272.1	733
	Stage 2	4.95	996-04	48	0	0	110					
B14-RU	Stage 1	19	N/A	15	0	0	50	1093	37.8	10	381.5	1,144
	Stage 2	4.4	996-96	46	1,289	876	167					
B14-U.S.	Stage 1	19	N/A	15	0	0	50	158	49.8	77.4	262.7	733
	Stage 2	4.95	996-04	48	0	0	108					

Note: *Other Capital Cost* includes cost for all other equipment, including transportation/storage containers but excluding new enrichment capital cost. *Total Capital Cost* includes new enrichment capital cost and other capital costs defined above. *Total Direct Cost* includes shipping, storage, and blend-down cost, but due to proprietary data restrictions excludes cost for enrichment of the diluents. *Transportation Cost* to the United States includes capital cost of transportation containers and direct cost of shipping from Russia to the United States to include shipping U.S. tails to Russia for scenario B12.

[a] At August 2008 market prices.

[b] These scenarios use same approach as the current blend-down program and may be considered "reference scenarios" in assessing the advantages and disadvantages of approaches on which the other scenarios are based.

BLEND-DOWN SCENARIOS

The previous sections of this report described the scenarios considered in this study and the associated schedules and costs. This section discusses the results, briefly outlines additional possibilities that may be attractive, and describes remaining issues and uncertainties of which policymakers should be aware.

The discussion has been organized around the 4 and 12.5 metric tons per year scenarios, and the effects of key variables explored in the range of scenarios.

4 Metric Tons HEU per Year Scenarios

Expanding the rate of blend-down using the same approach as the HEU Purchase Agreement would require an estimated investment of more than $150 million; constructing the necessary facilities would take more than two years.

By far the fastest and lowest-cost of the 4 metric ton approaches, however, would be blend-down to 4.95% LEU to meet the ASTM C996-04 specification. This approach is estimated to require an investment of less than $10 million, and take only one year to achieve the full expansion of 4 metric tons per year to the current 30 metric tons per year rate.

The blend-down of an additional 4 metric tons per year to 4.95% U-235 in compliance with the ASTM C996-96 specification would require provision of additional enrichment capacity with an estimated cost of $160 million. This additional capacity could be available in less than two years.

Two-stage blend-down would allow the current rate of blend-down to be expanded with an investment of approximately $10 million for the first stage blend-down, with the expanded rate for that stage starting in slightly more than one year. The facilities required for Stage 2 blend-down in Russia would cost approximately $250 million and take approximately two years to complete. The facilities required for Stage 2 blend-down in the United States would cost approximately $21 million and take approximately four years to complete. However, in both cases the investment in the Stage 2 facilities could be deferred, and this would provide several benefits in managing blend-down to the final LEU product. Moreover, there are approaches that could avoid the need for any new enrichment capacity, thereby significantly reducing costs. These issues and approaches are described below.

12.5 Metric Tons HEU per Year Scenarios

The two direct blend-down scenarios examined would each require an investment approaching $1 billion in new facilities, which would take between three and four years to construct. By comparison, the four two-stage blend-down scenarios offer the possibility of expanding the rate of HEU blend-down starting in little more than one year.

Expanding the rate of blend-down using the current approach would require the highest investment and the longest lead time of all of the 12.5 metric tons per year scenarios. The other approaches considered all offer advantages both in terms of cost and schedule.

Direct blend-down using 0.4% tails to produce 1.5% enriched blendstock would reduce the need for provision of a new enrichment capacity. However, this scenario would still require an investment of more than $700 million and constructing the facilities would take more than three years.

Two-stage blend-down would allow the current rate of blend-down to be expanded starting in little more than one year, and with an investment of less than $60 million, using either natural uranium or 1.5% enriched blendstock produced from tails as the Stage 1 blendstock. The facilities required for Stage 2 blend-down in Russia would cost approximately $1 billion and take between three and four years to construct—unless approaches that would avoid the need for additional enrichment capacity for Stage 2 blend-down were used, as discussed later in this section. The facilities for two-stage blend-down in the United States would cost approximately $62 million and take four years to construct. However, as noted above for Stage 2 blend-down in the 4 metric tons per year scenarios, investment in the Stage 2 facilities could be deferred, and this would provide several benefits in managing blend-down to the final LEU product.

Effects of Key Variables

Varying the LEU Specification: Final Enrichment

Producing 4.95% LEU rather than the 4.4% LEU used for the existing HEU blend-down program would have three advantages.

First, it would require less blendstock, and therefore less enrichment effort. As a result, in those scenarios where construction of new enrichment capacity is required, the amount of new capacity would be reduced and this would reduce both the cost and schedule for starting expanded HEU blend-down.

Second, 4.95% LEU is preferred by many utilities and fuel fabricators. Many fuel designs used today require uranium enrichments above 4.4% and uranium supplied to fuel fabricators at this enrichment level must be blended with higher enrichment uranium for use in fabricating fuel of these designs. 4.95% U-235 is the highest enrichment than can currently be accepted by fuel fabricators for producing fuel for commercial nuclear power plants.

Third, the quantity of 4.95% LEU produced would be approximately 20% less than the equivalent quantity of 4.4% LEU. Consequently, the cost of packaging and transportation of LEU to the customer would be lower.

Varying the LEU Specification: ASTM Specification

The blend-down program for the HEU Purchase Agreement produces LEU that is compliant with the U-234 specification of ASTM C996-96. Changing the product specification to allow higher levels of U-234 in compliance with ASTM C996-04 would be significant, as it would simplify the requirements for blendstock preparation. (Scenarios that would not require meeting ASTM specifications at all are discussed below.)

For the direct blend-down scenarios that use 1.5% enriched blendstock, this change would allow natural uranium to be substituted for tails in the blendstock preparation. This would reduce the required enrichment effort by more than 60%.

In the two-stage scenarios, changing to the ASTM C996-04 specification would allow natural uranium to be used directly as the Stage 2 blendstock, avoiding the need for later investments in additional enrichment capacity. This analysis assumed using U.S.-origin natural uranium blendstock in the United States. Stage 2 blend-down scenarios; a similar approach could in principle be implemented in Russia with careful selection of blendstock materials.

From a financial perspective, the savings in enrichment effort must be balanced against the purchase costs of the natural uranium. The uranium costs are likely to be substantially smaller than the costs of the enrichment effort that would be saved, however. Moreover, the nonproliferation benefits of using natural uranium are significant because it would make it possible to avoid the time delays and higher costs associated with building additional enrichment capacity.

It is necessary to note, however, that the higher U-234 limits in ASTM C996-04 have not yet been adopted by all utilities and fuel fabricators. Some will still only accept material that complies with ASTM C996-96. It is expected that material meeting the specification of ASTM C996-04 will be generally accepted in future, although on what timescale the change is likely to take place is uncertain.

Using Higher Assay Tails for Blendstock Preparation

The amount of enrichment required to make blendstock strongly depends on the quality of the tails from which the blendstock is produced. For this analysis, it has been assumed that 0.3% tails are used for blendstock production, because this is commonly used as a reference value in commercial transactions, and it has been a typical assay of tails in the West.

In Russia, however, policies on tails management have differed from those in the West, and the average tails assays available in Russia today are believed to be much lower than 0.3%. In that case, the effect of using 0.4% tails for producing blendstock would be greater than 25% savings in enrichment effort indicated by this analysis.

Providing Russia with 0.4% tails would thus allow the rate of HEU blend-down to be increased by at least 33% using only the enrichment capacity that is currently dedicated to blendstock production. In the remaining years of the HEU Purchase Agreement, this would allow production of sufficient additional blendstock to expand the rate of blend-down by 10 metric tons HEU per year, without providing any additional enrichment capacity. Because the tails being used for the HEU Purchase Agreement are believed to have assays possibly as low as 0.18%, the rate of blend-down could actually be expanded significantly more than this—and 0.3% tails would also be useful.

Using depleted uranium of a higher U-235 assay than is currently used in Russia would therefore address a key issue in the expanded blend-down analysis. If needed, these tails could be imported from the West. The U.S. inventory of tails, for example, has significant amounts of material with an assay above 0.4% U-235. An offer to provide high-assay tails, and thereby reduce Russia's costs to blend HEU to LEU that meets ASTM specifications, could also be an important incentive to help convince Russia that is in its interests to blend-down large quantities of HEU beyond the 500 metric tons covered by the HEU Purchase Agreement. This possibility is discussed in the next section. Decisions on disposition of high-assay U.S. tails should take these possibilities into account.

The analysis also shows that the blend-down of HEU to produce LEU that meets the ASTM C996-04 specification can be achieved using blendstock produced by enriching natural uranium. Although this would require the use of currently expensive natural uranium, it would avoid using an enrichment work that would cost even more, in the current market.

Transporting higher assay tails to Russia for producing blendstock would require procuring shipping containers and providing storage facilities both in the country supplying the tails and in Russia. The cost of these facilities and the transportation operations to support an increase in blend-down by 12.5 metric tons per year are estimated to be only a small fraction of the value of resulting reduction in enrichment requirements.

Two-Stage Blend-Down in Russia

This analysis considered several two-stage scenarios in which HEU was processed and blended to 19% LEU in the first stage, and then further blended for commercial use. The virtue of these scenarios is that they minimize the amount of blendstock required to get the HEU converted to LEU, making it possible to get the HEU blended to intermediate LEU quickly and at relatively low initial cost. Because facilities for processing and storing 19% LEU are not currently available, however, they require some up-front investment in new equipment. Moreover, unless some of the approaches discussed below are used, later investments in additional enrichment capacity would be needed for the second-stage blend-down.

For expanding blend-down by 4 metric tons per year, the cost and time required to provide these new capabilities are probably not worthwhile. For expanding blend-down by 12.5 metric tons per year, however, the two-stage blend-down approach may well be attractive—particularly if combined with some of the approaches discussed below, which could avoid the need for large later investments in additional enrichment capacity.

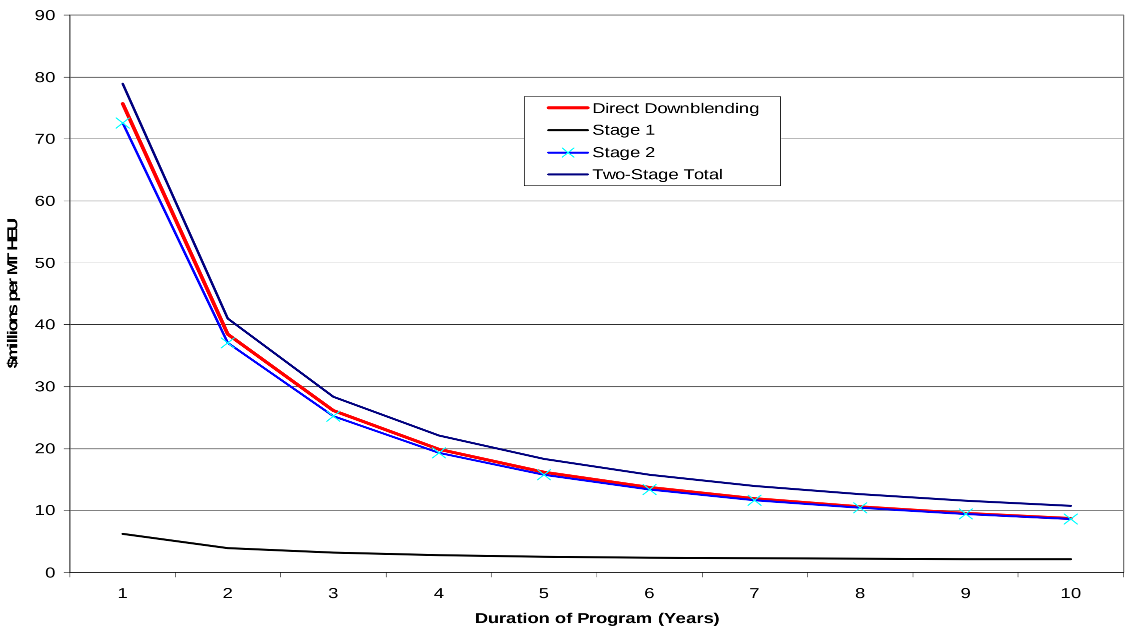
The reduction in blend-down costs available using the two-stage approach can be seen in Figure 3. For an expanded blend-down program of 12.5 metric tons per year, but lasting only one year, the cost of blend-down HEU would be more than $70 million per metric ton. By comparison, the cost for Stage 1 blend-down would be approximately $6 million per metric ton. From Figure 3, it can also be seen that the additional cost of Stage 2 blend-down would be close to the cost of direct blend-down—and the full cost of two-stage blend-down would be slightly higher than for direct blend-down.

However, the intention of investing in either direct or two-stage blend-down facilities would be to expand blend-down for a program lasting several years, if not longer. As the duration of the program considered increases, the unit cost of blend-down decreases and, for a ten-year program using direct blend-down, the unit cost would be close to $6 million per metric ton. For

Stage 1 blend-down, the cost would be less than $1 million but adding the cost of Stage 2 blend-down would result in total costs of more than $8 million per metric ton (unless approaches that did not require investment in additional enrichment capacity for Stage 2 blend-down were used).

As noted in earlier, however, moving to a two-stage approach would allow construction of the Stage 2 facilities to be deferred, potentially for many years, and this would reduce the net present value of the investment required. Figure 4 shows the effect of two-stage blend-down on the investment profile for a 12.5 metric tons HEU per year blend-down program with a duration of ten years.

FIGURE 3: HEU BLEND-DOWN COSTS FOR DIRECT AND STAGE 1 BLEND-DOWN

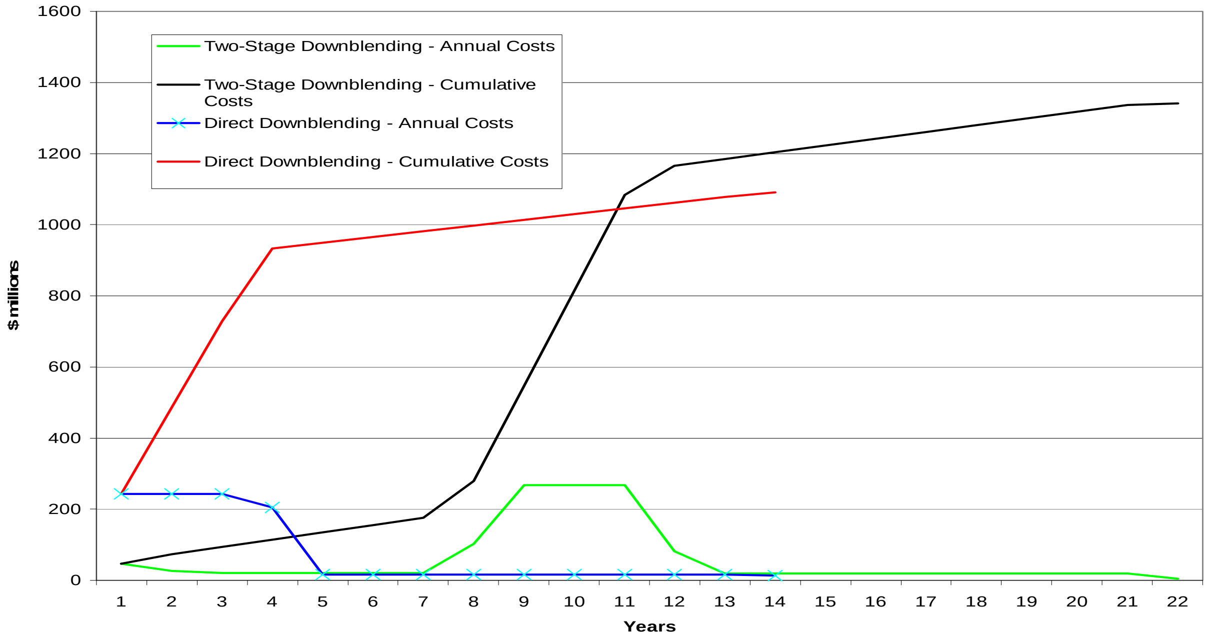


Direct blend-down in this case would require an investment of more than $900 million over a period of almost four years before blend-down operations could start. The total investment would then reach more than $1.1 billion by the time all of the HEU had been converted to LEU in year 14.

By comparison, Stage 1 blend-down of all of the additional 125 metric tons of HEU covered in this hypothetical case to LEU, albeit at 19% enrichment, could be completed in less than 12 years for a total investment of approximately $260 million. If Stage 2 facilities are then constructed to allow Stage 2 blend-down to start as Stage 1 ends, the total investment for the two-stage scenario would be more than $1.3 billion. However, as can be seen from Figure 4, more than $1 billion of this investment could be deferred for approximately eight years. Not only would this reduce the net present value of the investment, it would also offer flexibility in managing Stage 2 blend-down.

In practice, investment in new enrichment capacity for either direct blend-down or Stage 2 blend-down might not be required, as discussed below, greatly reducing these investment costs. In any case, Stage 2 blend-down facilities would not need to be constructed according to any predetermined schedule but could be phased to meet demand for the final product - and as funding is available. Moreover, as noted above, deferring final blend-down would allow the need to meet ASTM specifications, or possibly to supply LEU to later generation reactors that use uranium enrichments above 5% to be taken into account in designing and constructing the Stage 2 blend-down facilities.

FIGURE 4: INVESTMENT PROFILES FOR EXPANDED BLEND-DOWN BY 12.5 METRIC TONS/YEAR



Two-Stage Blend-Down in the United States

Each of the two-stage scenarios examined would require investment in additional enrichment capacity, if Stage 2 blend-down is done in Russia. The analysis thus considered three scenarios that include transportation of the intermediate product at 19% U-235 to the United States for Stage 2 blend-down, but to meet the specification of ASTM 996-04, rather than ASTM C996-96.This would avoid the need for producing 1.5% blendstock from tails, and thus much of the cost of Stage 2 blend-down. (In principle, such Stage 2 blend-down with natural uranium could also be done in Russia, but this case was not specifically examined in this study.)

Shipping the intermediate product from Russia for blend-down in the United States would require procuring many transport containers and constructing storage facilities in the United States. Also, as for Stage 2 blend-down in Russia, it would require constructing new facilities for handling and blend-down 19% enriched UF_6, because there are no facilities available in the United States today that can perform this operation. Nevertheless, the capital cost of the facilities required for Stage 2 blend-down in the United States, using natural uranium, is estimated to be significantly smaller than the capital cost of the facilities that would be required in Russia, including investment in new enrichment capacity to produce 1.5% enriched blendstock. The operating costs for a U.S. blend-down facility, however, are estimated to be higher than for the equivalent facility in Russia and this will start to offset the savings in capital costs after eight or nine years of operation.

It should be noted that the value of the final LEU product from Stage 2 blend-down in the United States is only approximately 65% of the value of the product from direct blend-down in Russia. This is primarily because blend-down with natural uranium produces lower quantities of the final product than blend-down with 1.5% enriched uranium produced by re-enriching tails. The value, however, of the U.S. blended LEU *added to* the value of the enrichment services that could be freed up by not producing 1.5% enriched blendstock would be higher than the value of the LEU produced from direct blend-down.

Potential Market Impact

The amount of nuclear-generated electricity is expected to rise significantly, driven by the rapid expansion of developing economies, high fossil fuel prices, and concerns about global warming. Nuclear fuel supplies must be expanded, but this presents significant challenges. Current uranium mine production is little more than 60% of current requirements and cannot be quickly increased. Several years of sustained investment are required for mineral exploration and mine development before new supplies can reach the markets.

In an efficient market, price pressure from tightening supplies stimulates investments in production. However, the liquidations of surplus nuclear material from the U.S. and Russian military stockpiles starting in the mid-1990s artificially suppressed market prices and needed investments were deferred. As a result, the uranium mining industry does not have an adequate “pipeline” of new projects and is now struggling to respond to the rising uranium demand.

Uranium prices started to rise from 2004 in response to unexpected supply side events and a perception of impending supply shortages. Reacting to and compounding the market supply deficit, many nuclear power plant (NPP) operators began to rebuild security-of-supply inventories, and hedge funds became active in the uranium markets as speculative investors. As a consequence, uranium market prices climbed by more than 500% from 2004 to mid-2007, then fell by 50% during the following year, and are now again starting on an upward trend.

The turbulence in the uranium markets has affected the markets for enrichment services (SWU). Although SWU supply has been historically well matched to demand, demand for SWU has sharply increased because SWU can partially substitute for uranium in producing LEU fuel. However, SWU production cannot be increased quickly because of the highly specialized, capital intensive facilities required. As a consequence, SWU prices have risen by some 60% since 2004 and continue to increase.

Market instability is not only a commercial problem, but also can prejudice nonproliferation goals because it encourages countries to establish domestic nuclear fuel cycle capabilities in order to ensure control of energy supplies. In the current market environment, the LEU produced by expanded blend-down of Russian HEU could benefit the nuclear fuel markets by helping resolve the short-term supply shortfalls.

The scenarios examined by NTI would result in additional LEU equivalent to between 2% and 6% of current market demand. At face value, this is a small quantity of material that would not be expected to significantly perturb or harm the world markets. However, the nuclear fuel markets are inelastic and particularly sensitive to inventory liquidations, so the introduction of the material into the market must be carefully structured to avoid a damaging market effect. This is not only good policy, but also important to mitigating the political opposition from market suppliers.

The under-investment in uranium production that led to the current supply problems is generally attributed to the damaging effects of earlier liquidations of U.S. and Russian government inventories. Consequently, even with the gathering momentum of the "nuclear renaissance," unexpected, or unpredictable, releases of additional uranium and SWU from governmental inventories could affect the investment climate for nuclear fuel production. Avoiding market damage requires a prudent approach to the sale of material, for example by:

- Selling material only under multiyear contracts, rather than competing for business in the thinly-traded and volatile spot markets. One scenario would be to manage the expanded HEU blend-down material as if it were a "virtual mine" or a "virtual enrichment plant," contracting for sales well in advance of the start of blend-down, at prices that are related to the typical cost of production at the time of sale;
- Avoiding market-related price mechanisms unless bounded by price floors. Market related pricing has the potential to follow and magnify falls in market prices caused by the release of the material itself, potentially driving prices down to damaging levels;
- Tailoring of rates of sale to match and compensate for known supply disruptions, for example the expiry of the HEU Purchase Agreement in 2013;
- Retaining LEU inventories by Russia for use in its domestic program;
- Forming industry partnerships to market the uranium and SWU content of the LEU. For example, the Cameco–AREVA–NUKEM consortium that was established to market the uranium from the existing HEU Purchase Agreement allowed the HEU-derived uranium to be introduced to the market in a manner that complements, rather than competes with, the suppliers' interests. By working with a consortium, rather than a single organization, the disadvantages of monopolistic supply have been avoided.
- Creating a Strategic LEU Available to provide security of supply assurances in the event of unforeseen supply disruptions. Normally this material would be held off-market, and would only be released according to predetermined criteria, ensuring that market participants are able to understand and predict the eventual market effect and take this into account in developing their purchasing policies. Creating a fuel available could also be used to support other significant nonproliferation initiatives.

These mitigation measures could also be combined, such that the final market damage mitigation strategy could use more than one means of avoiding market damage.

Legal Aspects of Expanded HEU Blend-Down

The HEU Purchase Agreement is the starting point for any consideration of expanded HEU blend-down because it refers to the possibility of such an expansion.

In principle, the scenarios that include the temporary storage of LEU in the United States would present legal issues for civil liability for nuclear damage during LEU transport and storage, the transfer of property rights, and liability for accidental loss of a product in storage. However, these legal issues are routinely addressed in commercial sales/purchase contracts, according to an established framework of international trade law, bilateral agreements, and business practice and are not problematic.

In the absence of a nuclear cooperation agreement between the United States and Russia under Section 123 of the Atomic Energy Act of 1954, the export of uranium tails from the United States to Russia would have to be controlled by a specific intergovernmental agreement between the two countries.

Potentially Attractive Classes of Scenarios Not Examined in the Joint Study

This report has focused on the particular classes of scenarios examined in detail in the joint study. Additional scenarios may also offer attractive possibilities that policymakers should consider. In particular, policymakers may want to consider scenarios in which the LEU to be blended from HEU is used for LEU fuels fabricated in Russia (which could drastically reduce the enrichment requirements for blendstock production), and scenarios in which the LEU blended from HEU is used as part of the normal process of filling commercial LEU contracts, minimizing or eliminating the need for investment in additional enrichment capacity for expanded blend-down rates.

Using Blended LEU for Russian-Fabricated Fuels

The requirement for large investments in additional enrichment capacity to produce blendstock in many of the scenarios discussed in this report is driven by (1) the need to meet ASTM specifications for unrestricted commercial use in the United States and elsewhere; and (2) the low-assay tails that Russia has available from which to produce blendstock.

Russian fabrication plants, however, do not rely on the ASTM specifications. If Russia blended HEU to LEU and then used that LEU to fuel Russian-designed reactors whose fuel is fabricated in Russia (including both reactors in Russia and Russian-exported reactors elsewhere), there may be no need to blend the HEU with 1.5% enriched blendstock, and hence no need to invest in additional enrichment capacity to produce this blendstock. The HEU could be blended with natural uranium or even with depleted tails. In the case of blending with tails, the HEU could be transformed into commercially usable LEU with no requirement for either scarce enrichment work or scarce natural uranium. This would reduce dramatically both the capital costs and the lead-times for the 12.5 metric ton scenarios in this report, and might make still faster blend-down rates a realistic possibility.

As described in more detail below, using HEU-derived LEU in Russia's own fabrication facilities could generate similar revenue to that which could be obtained by exporting the blended LEU. Every metric ton of LEU blended from HEU used to fuel Russian-designed reactors would free up an additional metric ton of new-production LEU for export, which could be sold at world prices. Of course, as with other approaches to HEU blend-down, mechanisms to mitigate any negative market effects of such additional supplies should be used.

Using LEU Blended from HEU to Fill Commercial Contracts

To implement the HEU Purchase Agreement, Russia uses a portion of its enrichment capacity to produce blendstock to blend 30 metric tons of HEU each year, and the rest of its enrichment capacity to meet commercial contracts, both for domestic use and for export. The scenarios for expanded blend-down examined in this study assume that additional LEU blended from HEU would be produced *in addition to* the LEU needed to meet Russia's commercial contracts. Hence, producing more blendstock would require investment in additional enrichment capacities.

A more attractive scenario is that Russia would draw on the LEU from HEU as *part of* fulfilling its commercial contracts. Every kilogram of LEU produced from blend-down HEU would require either the same number of SWU or fewer SWU than if the same kilogram had been produced by enriching natural uranium. (The number of SWU required per kilogram of LEU is about the same if the HEU is blended with 1.5% enriched material produced by stripping low assay tails to meet the ASTM C996-96 specification. As noted above, with richer tails for blendstock production or more recent ASTM specifications, the number of SWU per kilogram of LEU produced is substantially lower; and in some cases, particularly if the blended LEU is used in Russian fabrication plants that do not rely on the ASTM specifications, the need for SWU for blend-down could be eliminated entirely.) In the net, therefore, the total requirement for enrichment capacity to supply Russia's share of the commercial LEU market would be smaller, not larger, even at very high rates of HEU blend-down, so no additional investment in enrichment capacity would be needed.

This is potentially a critically important point, as it could eliminate the largest costs and longest delays for the scenarios considered in this study. Such approaches should be considered in more detail.

Such approaches are particularly important for two-stage scenarios, as those scenarios have low initial costs traded off against substantial later costs for adding enrichment capacity for second-stage blend-down. But such additional investments in new enrichment capacity might not be needed. Once HEU had been blended to 19%, Russia could draw on this stock for further blending to commercial levels as needed to meet its LEU contracts, thereby producing each kilogram of LEU with far fewer SWU and less uranium than would be required to produce it by enriching natural uranium (and hence generating larger profits than it would by enriching LEU from natural uranium). Indeed, the initial blending to 19% could be done with natural uranium (at the cost of needing 1.62% enriched blendstock for the final blending, if the LEU was to be sold in a way that required meeting ASTM C996-96 specifications). This approach would eliminate the need for any enrichment for the initial blending to 19%, along with the need for investment in additional enrichment capacity for the second-stage blend-down.

CONCLUSIONS

This phase of the study has examined several specific alternative scenarios that illustrate how HEU downblending could be accelerated and expanded. In addition to the quantitative aspects of the results presented here, it will be important to consider related issues that may provide additional incentives to pursue further blend-down. These issues have been discussed previously.[7]

The United States and Russia should strongly consider implementation of the low-cost 4 metric ton HEU per year scenarios, even for the remainder of the current 500-metric ton HEU Purchase Agreement. These scenarios can be implemented quickly and cheaply. Over the longer term, the United States and Russia should also pursue blend-down of large quantities of additional HEU beyond the current 500-metric ton HEU Purchase Agreement. In that context, the two countries should also consider the 12.5 metric tons of HEU per year scenarios, and seek to increase the rate of blend-down by an even greater margin.

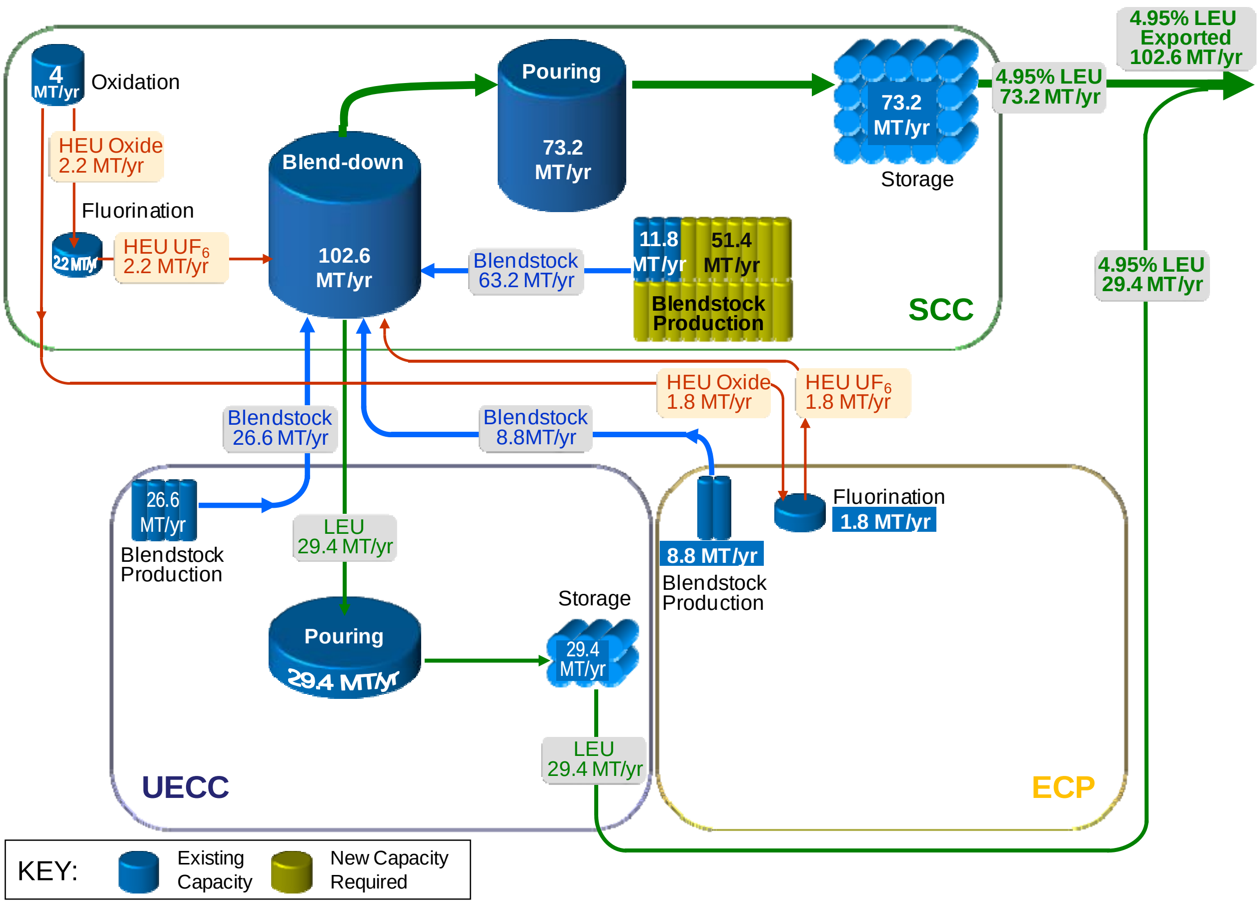
[7] Bunn, M. *Expanded and Accelerated HEU Downblending: Designing Options to Serve the Interests of All Parties*, INMM Annual Meeting 2008. An adaptation of this paper is provided as Appendix 4.

APPENDIX 1: DETAILED ASSESSMENT OF EACH EXPANDED HEU BLEND-DOWN SCENARIO

SCENARIO A11: SINGLE-STAGE HEU BLEND-DOWN TO 4.95% LEU (ASTM C996-96)

Scenario A11 (Figure 5) is identical to the process used for blend-down under the HEU Purchase Agreement, except for the LEU product enrichment, which is changed to 4.95% U-235.

FIGURE 5: SCHEMATIC OF SCENARIO A11



Highly Enriched U_3O_8 Production

There is sufficient available U_3O_8 production capacity at SCC to satisfy the requirements of scenario A11 without using available capacity at PA Mayak.

Highly Enriched UF_6 Production

Sufficient capacities to process 4 metric tons HEU per year of highly enriched U_3O_8 to highly enriched UF_6 are available at SCC and ECP (2.2 and 1.8 metric tons HEU per year respectively).

To be able to make use of the available fluorination plant capacity at ECP, however, the storage facility for highly enriched U_3O_8 must be fitted with a third standard module. This would provide extra container storage places for 3-liter containers, sufficient to support a blend-down rate of 1.4 metric tons HEU per year.

Blendstock Production

An additional 98.6 metric tons per year of 1.5% enriched blendstock would be required. To prepare this from Russian tails would require at least 391 kSWU per year of additional enrichment capacity. An estimated 187 kSWU per year of capacity is available: 46.8 kSWU per year at SCC, 105.4 kSWU per year at UECC, and 35.1 kSWU per year at ECP; hence SCC would need to install 204 kSWU per year of new enrichment capacity at the isotope separation plant (ISP).

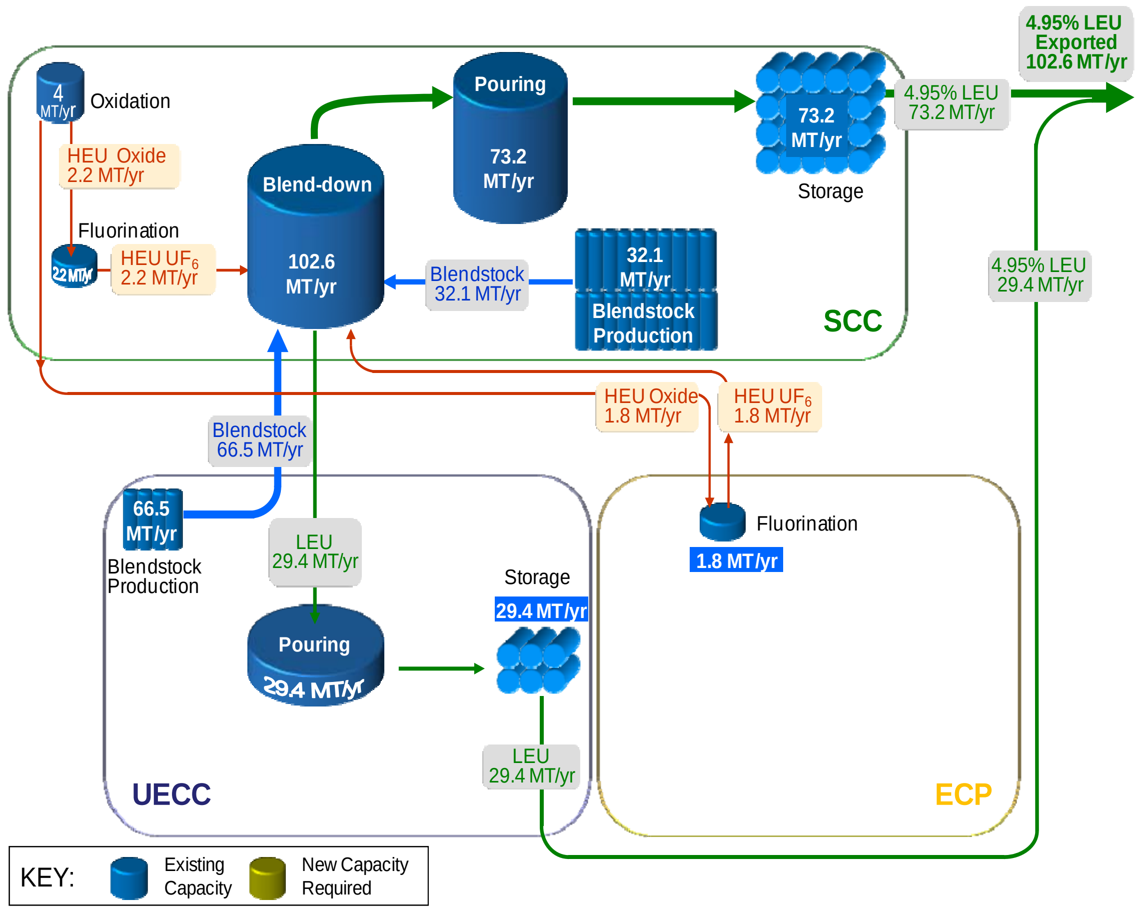
LEU Production

There is sufficient available capacity at SCC and UECC to meet the scenario requirements.

SCENARIO A12: SINGLE-STAGE HEU BLEND-DOWN TO 4.95% LEU (ASTM C996-04)

As noted above, the more permissive U-234 specification in ASTM C996-04 allows the 1.5% enriched blendstock to be prepared from natural uranium rather than tails (Figure 6). The scenario is otherwise identical to Scenario A11.

FIGURE 6: SCHEMATIC OF SCENARIO A12



Highly Enriched U_3O_8, UF_6, and LEU Production

The needed capacity enhancements are as described in scenario A11.

Blendstock Production

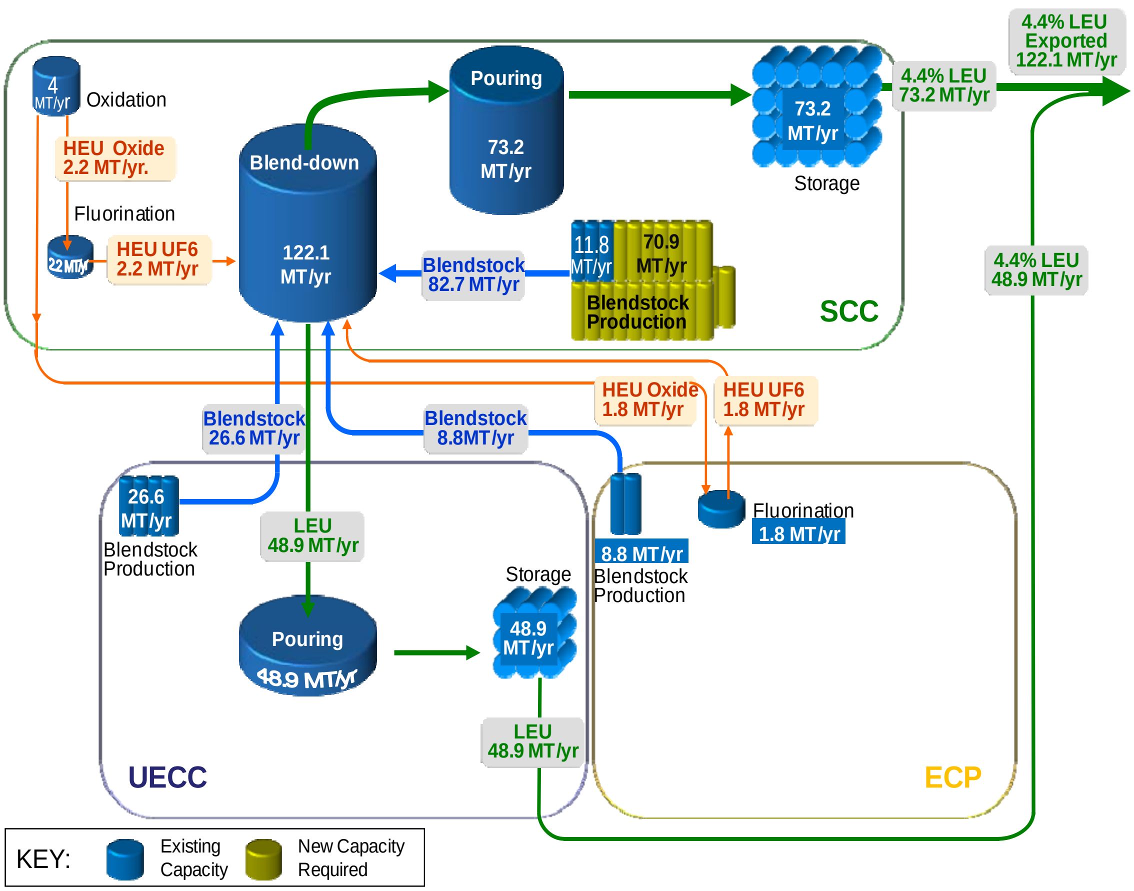
Preparing the required 98.6 metric tons per year of 1.5% blendstock from natural uranium would require 143.8 kSWU per year; this requirement can be met using the available enrichment capacities at SCC and UECC.

SCENARIO A13: SINGLE-STAGE HEU BLEND-DOWN TO 4.4% LEU (ASTM C996-96)

This scenario differs from Scenario A11 only in the final LEU enrichment (Figure 7) and is equivalent to the current HEU blend-down operations under the HEU Purchase Agreement. More blendstock is required, in comparison to Scenario A11, and therefore, a greater uranium enrichment effort, 468.4 kSWU per year, is needed. The capacities of SCC's ISP would need to be increased by 281 kSWUper year, after taking the available capacity of 187 kSWU per year into account.

The needed capacity enhancements for all other production stages are as described in scenario A11.

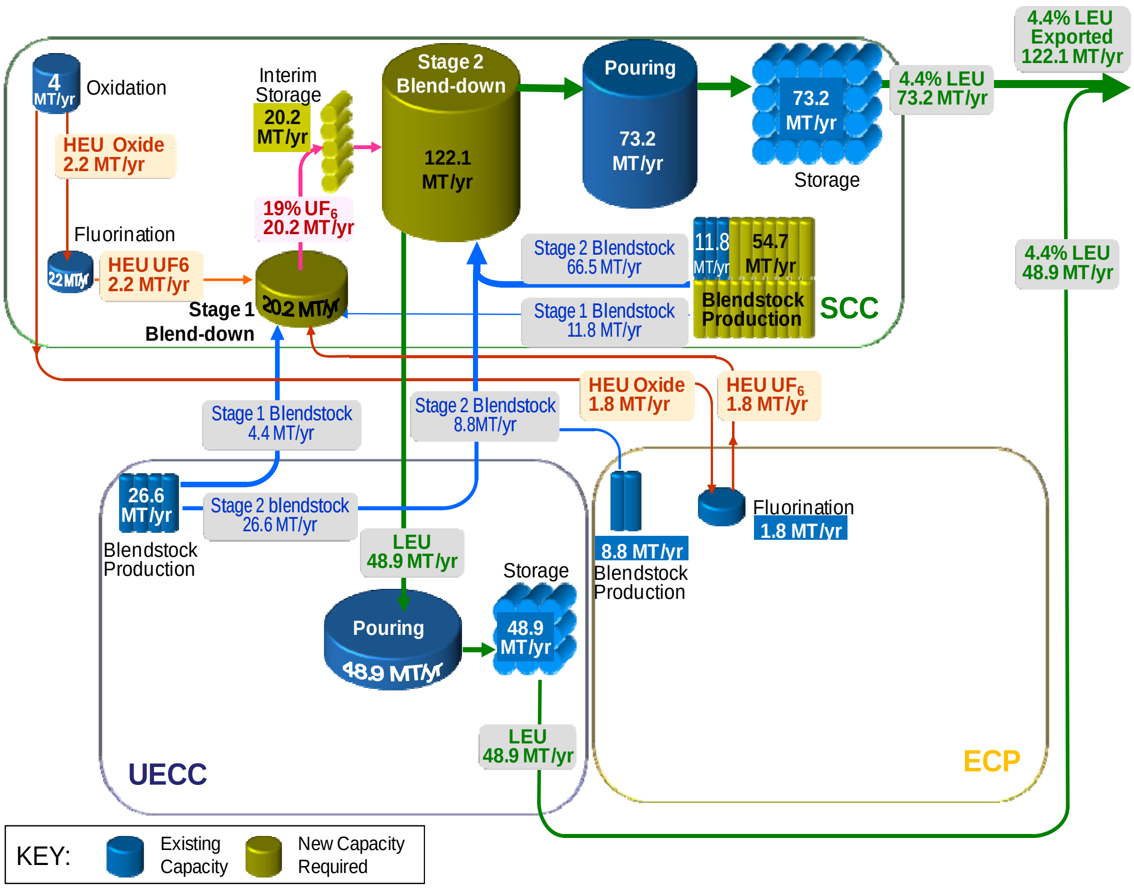
FIGURE 7: SCHEMATIC OF SCENARIO A13



SCENARIO A14: TWO-STAGE HEU BLEND-DOWN TO 4.4% LEU (ASTM C996-96)

Scenario A14 (Figure 8), in common with the other two-stage HEU blend-down scenarios, includes three distinct phases:

FIGURE 8: SCHEMATIC OF SCENARIO A14



Phase I: HEU blend-down to 19% LEU (Stage 1 blend-down);

Phase II: Interim storage of 19% LEU;

Phase III: Blend-down of 19% LEU to <5% LEU (Stage 2 blend-down) and delivering the final product to the Customer.

As it was noted above, the Russian LEU facilities are licensed only to handle enrichments of up to 5% U-235. Therefore, a new blending plant that includes a 19% LEU cylinder filling facility and analytical laboratory, as well as containers and premises for long-term storage of 19% LEU must be constructed and licensed.

Highly Enriched U_3O_8 UF_6 Production

The needed capacity enhancements are as described in scenario A11.

Blendstock Production

The Stage 1 blend-down to 19% LEU would require 16.2 metric tons per year of 1.5% enriched blendstock, in turn requiring 64.4 kSWU per year. The Stage 2 blend-down to 4.4% LEU would require 101.8 metric tons per year of blendstock produced using 404 kSWU per year.

The available enrichment capacity would suffice for the Stage 1 blend-down. However, the Stage 2 blend-down would require the ISP capacity at SCC to be increased by 217 kSWU per year.

LEU Production

For the Stage 1 blend-down, SCC would need additional capacities at the ISP to blend-down 4 metric tons HEU per year of highly enriched UF_6 to 19% LEU, and would need to create areas for interim storage of 20.2 metric tons per year of 19% LEU. The second mixing Stage 2 blend-down would require construction of facilities to accept 20.2 metric tons per year of 19% LEU for blend-down to 4.4% LEU.

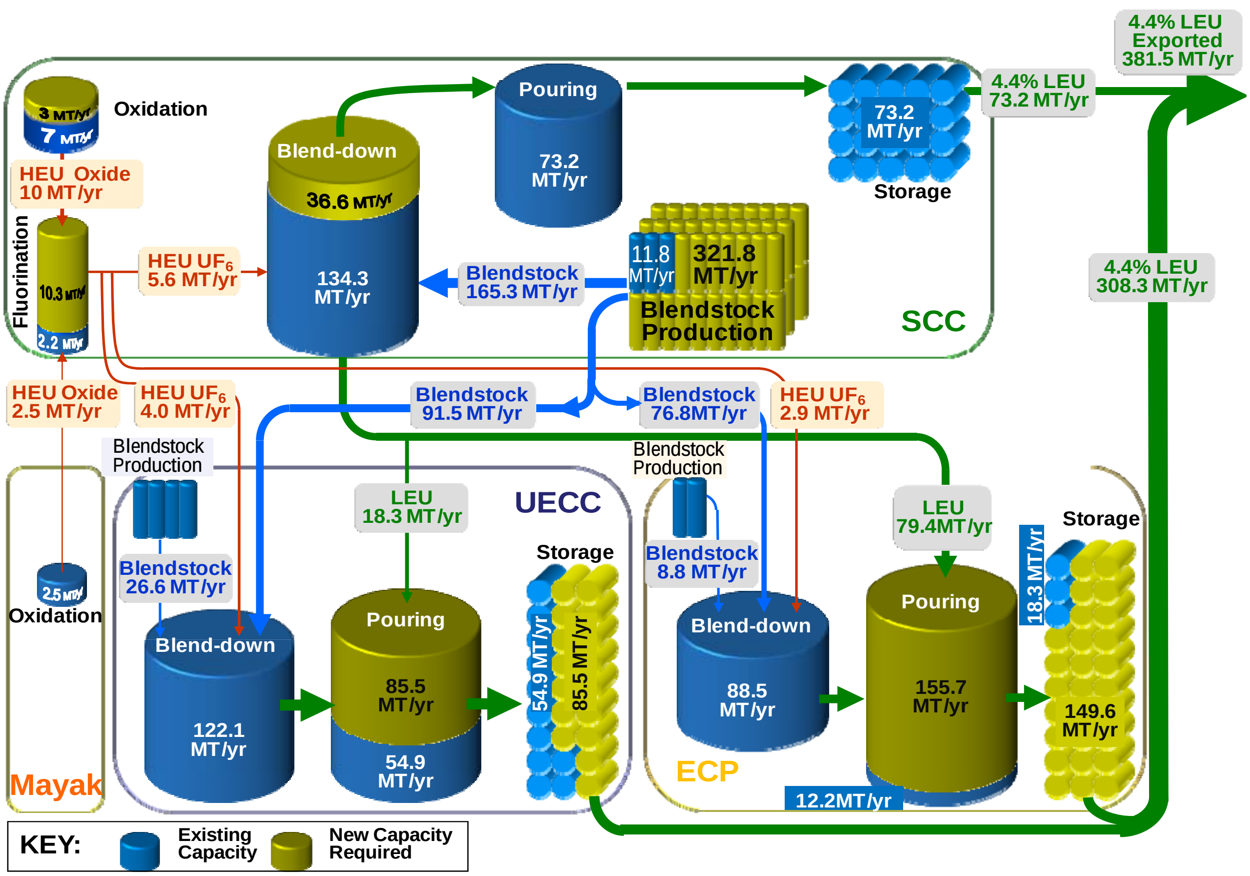
To meet these capacity requirements, SCC would need to erect a new building at the ISP close to building 2 and linked to it by pipes. This new building would incorporate the following:

- A facility for filling 24-liter containers with 19% LEU;
- A facility to volatilize the 19% LEU and extract it from the 24-liter containers;
- A facility for long-term storage of 24-liter containers. The total facility size will depend on expected storage period planned for the 19% LEU;
- A facility for blending 19% LEU with blendstock and producing LEU at less than 5%;
- A brine refrigerating plant and associated piping;
- Auxiliary installations and systems, including ventilation and weighing rooms, service rooms, mass spectrometry, and radiochemical laboratories.

SCENARIO B11: SINGLE-STAGE HEU BLEND-DOWN TO 4.4% LEU (ASTM C996-96)

Scenario B11 is equivalent to Scenario A13, but at a higher blend-down rate, and similar to the current operations under the HEU Purchase Agreement (Figure 9).

FIGURE 9: SCHEMATIC OF SCENARIO B11



Highly Enriched U_3O_8 Production

To produce sufficient highly enriched U_3O_8 for this scenario it is necessary to use all of the available capacities at PA Mayak and at SCC's chemical metallurgical plant (CMP).

The CMP has insufficient capacity to refine the highly enriched U_3O_8, thus the capacity of the ammonium polyuranate calcination section would need to be increased. This would entail installing one additional continuous sedimentation and calcination plant at the CMP that includes:

- Operators' zone;
- Sedimentation and calcination units with associated vacuum pump rooms;
- Premises for interim storage of highly enriched U_3O_8.

It would be necessary to decommission and dispose of the equipment that is currently installed in the designated areas.

To make full use of its available capacities, PA Mayak would require the following additional equipment:

- 100 containers for storage and transport of metal chips and highly enriched U_3O_8 between facilities on the site;
- Two muffle furnaces for ammonium polyuranate calcination complete with auxiliary capacitance equipment;
- 150 TUK-90 containers to transport the refined highly enriched U_3O_8 to SCC.

Highly Enriched UF_6 Production

To produce 12.5 metric tons HEU per year of highly enriched UF_6, the available capacities at SCC's fluorination plant (2.2 metric tons HEU per year) would be used together with a new fluorination module at SCC, which would have a capacity of 12 metric tons HEU per year. There would be no need to access the available capacities at ECP, thus minimizing intersite transportation requirements.

The new fluorination module would require the following:

- Erecting a new building to house a fluorination line for highly enriched uranium with all ancillary systems and storage facilities. This would have a capacity of 12 metric tons HEU per year;
- Providing additional rooms for interim storage of finished product containers, feed materials, and reusable containers;
- Reconstructing the washing section and installing new equipment;
- Constructing a new rail-spur and rail-bay for loading and unloading railway cars with feed materials and highly enriched UF_6;
- Extending the analytical laboratory and providing new equipment;
- Fabricating an additional 350 6-liter containers.

Blendstock Production

The scenario would require 369 metric tons per year of 1.5% blendstock prepared from tails, which, in turn, would require an additional 1,464 kSWU per year of uranium enrichment capacity.

Taking into account the available enrichment capacity of 187 kSWU per year, SCC would have to expand the ISP uranium enrichment capacity by 1,277 kSWU per year.

LEU Production

Taking into account the available capacities at ECP and UECC, the ISP at SCC would require additional capacities for interim storage of highly enriched UF_6 (10.3 metric tons per year) and for blending HEU with 1.5% LEU (1.2 metric tons per year).

These new capacities would require:

- A new blending plant that can volatilize and collect HEU from 6-liter containers, similar to one already operating in the isotope separation plant. This new plant would require all main and auxiliary systems, such as power supply, process monitoring, emergency protection, ventilation, cooling, radiation control, etc.;
- A new storage facility for containers of highly enriched UF_6;
- A new collector for the LEU blendstock taken from 2.5 m^3 containers, and new facility to condense the 4.4% LEU into 0.8 m^3 interim containers;
- A double-pipe system for feeding two UF_6 gas flows.

To be able the use of the full available LEU cylinder filling capacities at UECC and ECP, the following facility improvements will be necessary:

UECC

- Extending the areas for interim storage of filled 30B containers, including ventilation and physical protection systems, dosimetry control station, and emergency and fire signal systems;
- Fabricating additional reusable 0.8 m^3 containers for liquid phase LEU.

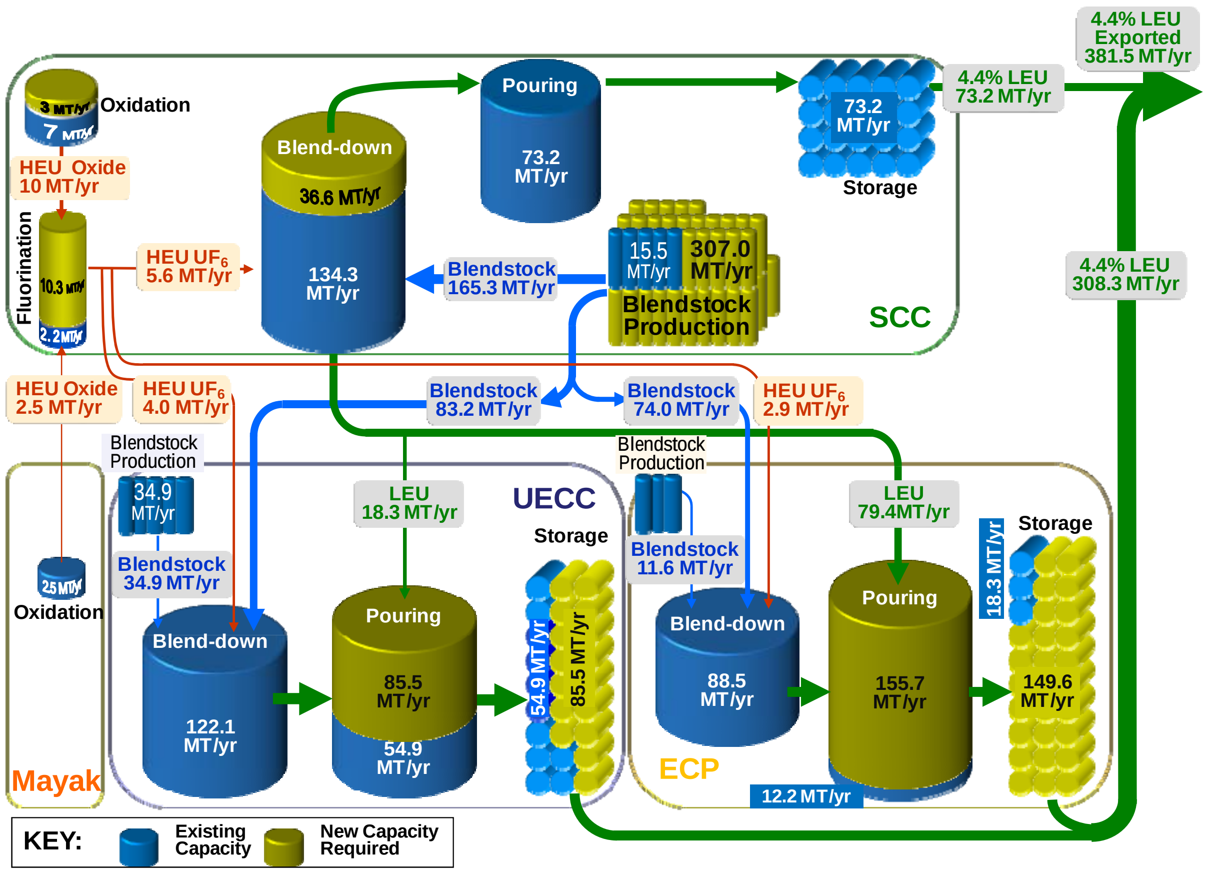
ECP

- Extending the facility that prepares 30B containers for filling and installing of new equipment. Because of the lack of space in the current building, it would be necessary to erect a new building with a floor area of about 250 m^2;
- Expanding by 180 m^2 of the areas for interim storage of 30B containers by elongating the building and erecting a new annex, and adding the necessary systems for ventilation and physical protection, dosimetry control station, and emergency and fire signal systems;
- Fabricating additional reusable 1 m^3 containers for liquid phase LEU.

SCENARIO B12: SINGLE-STAGE HEU BLEND-DOWN TO 4.4% LEU (ASTM C996-96)

Scenario B12 (Figure 10) is similar to B11 except that U.S. tails with a higher enrichment level are used in place of Russian tails. This reduces the amount of new uranium enrichment effort required to 927 kSWU per year, which is 27% less than for Scenario B11.

FIGURE 10: SCHEMATIC OF SCENARIO B12

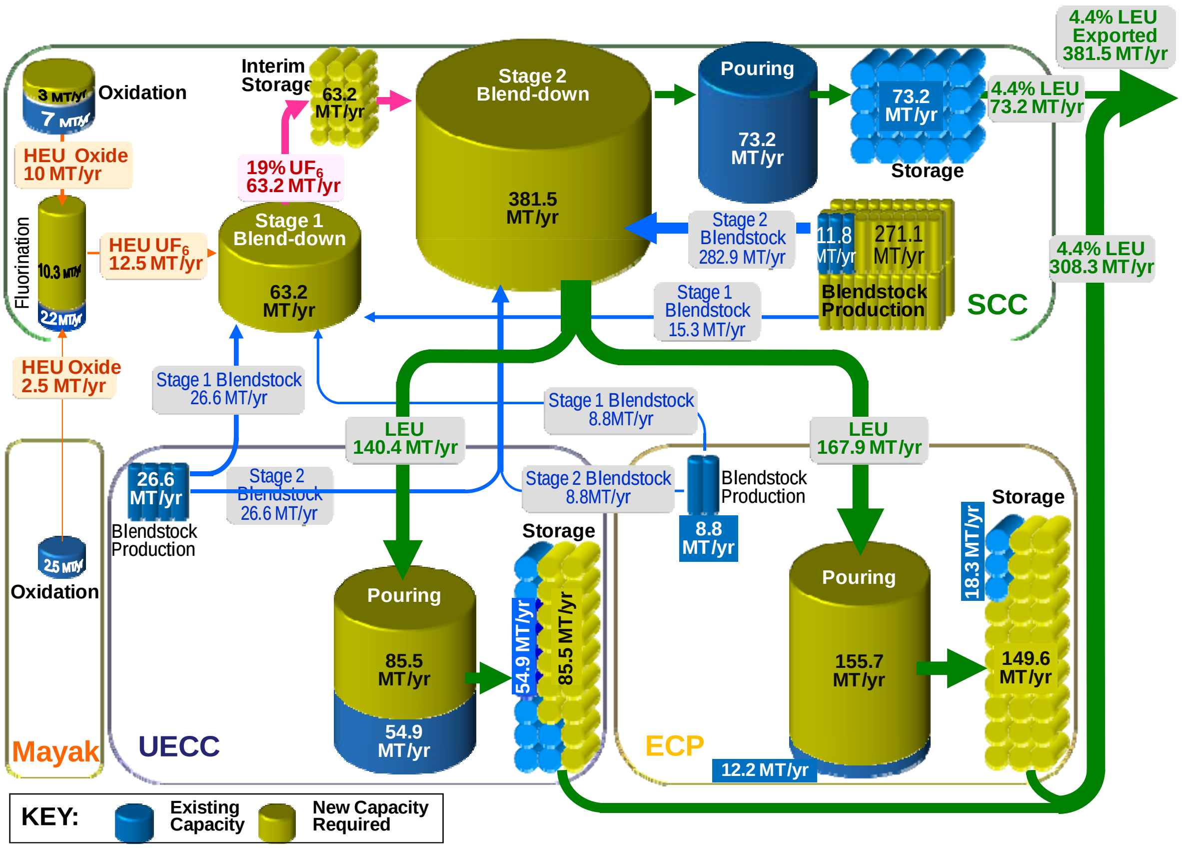


All issues for other production stages are the same as for Scenario B11.

SCENARIO B13: TWO-STAGE HEU BLEND-DOWN TO 4.4% LEU

This scenario is similar to A14, differing only in the rate of HEU blend-down (Figure 11).

FIGURE 11: SCHEMATIC OF SCENARIO B13



Highly Enriched U_3O_8 and UF_6 Production

The required actions and equipment to enhance capacities at SCC are the same as for Scenario B11.

Blendstock Production

The Stage 1 blend-down to 19% LEU in this scenario would require 50.7 metric tons per year of 1.5% blendstock and 201 kSWU per year. The Stage 2 blend-down of 19% LEU to 4.4% LEU would require 318 metric tons per year of blendstock and 1,263 kSWU per year. Taking into account the available enrichment capacity, 13.9 kSWU per year of additional uranium enrichment capacity would be required for the Stage 1 blend-down and 1,061 kSWU per year for Stage 2.

LEU Production

The Stage 1 blend-down and intermediate storage activities would require SCC to add enough storage capacity to the ISP to accommodate 8.1 metric tons per year of highly enriched UF_6, as well as new capacities to produce and store 63.2 metric tons per year of 19% LEU.

A new evaporator facility would be required to feed blendstock from 2.5 m^3 containers to the Stage 1 mixing, with a transfer pipeline to deliver blendstock gas also to the new Stage 2 blending plant.

The Stage 2 blend-down would require additional capacities at the ISP for blend-down of 63.2 metric tons per year of 19% LEU to 4.4% LEU. As noted in the discussion for Scenario A14, it would be necessary to construct a new blending and storage facility for 19% LEU near the ISP HEU blending control system. This new building would include:

- A facility for filling 24-liter containers with 19% LEU from the Stage 1 blend-down;
- A facility for volatilizing 19% LEU from 24-liter containers to feed into the Stage 2 blend-down;
- An interim storage facility for 24-liter containers, with racks and all necessary ancillary systems;
- A brine refrigerating plant;
- Pipework to connect the new evaporation plant with the new blending plant;
- Ventilation and weighing rooms, staff accommodation rooms, and other ancillary installations and systems to meet regulatory requirements;
- A new mass-spectrometry and radiochemical laboratory for the SEP.

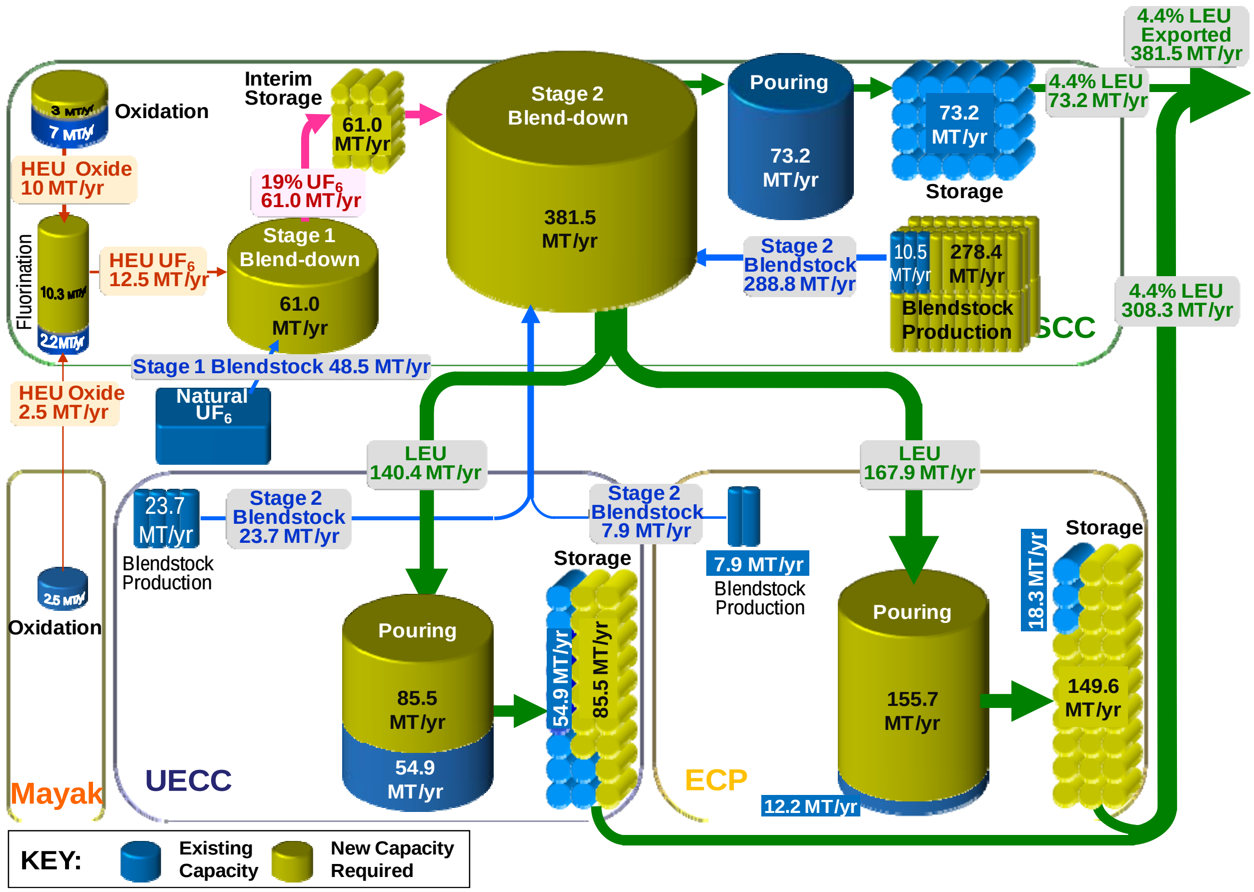
For the Stage 2 blend-down, it would be necessary to build a new facility and associated transfer piping to fill 0.8 m^3 intermediate containers with 4.4% LEU.

Accessing the full available capacities of the cylinder filling plants at UECC and ECP as well as storing the final LEU would require the same enhancements discussed under Scenario B11.

SCENARIO B14: TWO-STAGE BLEND-DOWN TO 4.4% LEU (ASTM C996-96)

In scenario B14 (Figure 12), HEU is blended directly with natural uranium to produce 19% LEU in the Stage 1 blend-down. The Stage 1 blend-down uses a 1.62% enriched blendstock produced from Russian tails, to produce a commercial grade 4.4% LEU that meets ASTM C996-96.

FIGURE 12: SCHEMATIC OF SCENARIO B14



Highly Enriched U_3O_8 and UF_6 Production

The requirements for increased highly enriched U_3O_8 and UF_6 production capacities at SCC are as described in Scenario B11.

Blendstock Production

The HEU is blended down to 19% LEU without a need for uranium enrichment effort because natural uranium is used directly as the first stage blendstock.

The second-stage blend-down would require a uranium enrichment capacity of 1476 kSWU per year to produce a 1.62% enriched blendstock from Russian tails. This higher specification blendstock is needed to produce a commercial grade 4.4% LEU product that meets ASTM C996-96 specifications. This means that 1289 kSWU per year of new uranium enrichment capacity would be required, after taking into account the available capacity of slightly more than 187 kSWU per year.

LEU Production

The requirement for additional capacities and equipment for LEU production are as described for Scenario B13.

APPENDIX 2: TRANSPORT OUTSIDE OF RUSSIA

As assessment was made of the costs, schedule, risks, and issues associated with transporting low-enriched UF_6 with an enrichment of either 10% or <5% from St. Petersburg, Russia, to the United States, and for the transportation of depleted uranium tails from the United States to St. Petersburg. In all cases it was assumed that the uranium would be transported in the form of UF_6.

SHIPPING UF_6

Transporting UF_6 is well established. The material is shipped as a solid inside cylinders of various sizes. Natural or depleted UF_6 is usually shipped in type 48Y cylinders although the type 48G cylinder may be used under certain circumstances. UF_6 enriched <5% U-235 is shipped in type 30B cylinders, and UF_6 containing 19% U-235 is shipped in type 5B cylinders.

The analysis assumed that the 48Y/48G cylinders would be fitted with thermal protection devices during transportation, as is required by current regulations. Although the requirement to use these devices may be changed in the future, it is not known whether, or when, this may occur.

Cylinders containing enriched UF_6 must be transported inside Outer Protective Packages (OPP), sometimes referred to as Protective Shipping Packages (PSP). The OPP model for 30B cylinders is the UX-30. For the 5B cylinder, the OPP is a double-high 55-gallon drum.

All of these cylinders and OPPs are in general use and available for lease or purchase, except the 5B and its OPP. There has been little need to transport material requiring 5B cylinders in recent years, so these items are not readily available. This issue is discussed further in Transporting 19% UF_6.

UF_6 is routinely shipped between the United States and Russia both as natural uranium, which is the same as depleted uranium from a transportation perspective, and as LEU with an enrichment level of <5% U-235. Consequently, all of the associated packaging and regulatory matters are routine. NTI is unaware of any transportation of 19% UF_6 between Russia and the United States. The occasional shipment, however, of HEU metal between Russia and the EU is informative for certain transportation issues.

TRANSPORTING DEPLETED URANIUM

Depleted uranium would be transported from the United States to Russia at a rate of 1,992 metric tons per year. A 48Y cylinder contains approximately 8.2 metric tons of uranium, so this represents a total of 243 cylinders per year.

The most cost effective approach would be to transport 80 cylinders at a time using a charter ocean vessel. Accordingly, the data presented in Table 8 is based on the following assumptions:

- Anticipated shipment size approximately 80 48Y cylinders containing approximately 656 MTU;

- Cylinders to be shipped from Paducah, Kentucky, to SCC, using rail to the U.S. port, a charter vessel to St. Petersburg, and rail from St. Petersburg to SCC;
- All cylinders are provided free of charge;
- The data in the table exclude insurance costs, which would be based on the declared cargo value.

TABLE 8: TRANSPORTATION COSTS

Item	Price	Units
Installation of thermal protection	$150	per cylinder
Transport by rail from USEC facility to export port (TBD)	$1500	per cylinder
Loading of vessel	$100	per cylinder
Export formalities at port	$10	per cylinder
Ocean freight-estimated charter cost includes	$400,000	80 cylinders
Bunker at current rates and all port charges	$5000	per cylinder
Customs clearance in St. Petersburg	$100	per cylinder
Transport from St. Petersburg to SCC		
1-3 cylinders per railcar	$11,200 $3733	per car or per cylinder
One caboose per train	$11,200.00 $150	per train or per cylinder
Total direct shipping costs	**$10,743**	per cylinder
Total for 80 cylinders	**$859,440**	per shipment

TRANSPORTING UF_6 ENRICHED TO <5%

Shipping low-enriched UF_6 from SCC to the United States would require using 30B cylinders, each containing 1.5 metric tons of uranium, fitted with UX-30 OPPs. Because the cylinders are likely to be in long-term storage, they will not be reused; however, the OPPs can be reused for several shipments per year. The purchase prices of cylinders and OPPs are covered in Equipment, below. For the HEU blend-down scenarios, it would be necessary to transport between 70 and 254 cylinders per year. The standard method of carriage would be used, with four OPPs secured to a 20-foot ocean flat rack container (TEU) and shipped using liner service. Even at the maximum expanded blend-down rate in the scenarios, only about five TEUs would be shipped each month. This would be a good shipment size and with preplanning, would minimize the cost of internal Russian rail.

The shipping costs for a consignment of twenty 30B cylinders are shown in Table 9. The data in the table assume rail transport from SCC to St. Petersburg with five TEUs (20 cylinders), traveling together.

Table 10 shows the variation in transport costs if a shipment was to originate from ECP or UECC rather than SCC. All costs and assumptions remain the same except for internal Russian rail charges: ECP is approximately 15% more than SCC and UECC is approximately 10% less than SCC.

TABLE 9: CASE A: SHIPPING 30B CYLINDERS FROM SCC TO THE UNITED STATES EAST COAST FABRICATOR

ITEM	COST	UNITS
4 cylinders/one TEU per railcar	$11,200 $2800	per car or per cylinder
One caboose per train	$11,200 $560	per train or per cylinder
Export formalities at St. Petersburg	$100	per cylinder
Ocean freight on Atlantic RO/RO: St. Petersburg to Baltimore	$2600	per cylinder
Customs clearance in the port	$50	per cylinder
Trucking from Baltimore to Columbia, Wilmington, or Lynchburg	$400	per cylinder
Return of empty OPPs via road to Baltimore	$250	each
Export formalities	$50	each
Ocean freight on Atlantic RO/RO from Baltimore to St. Petersburg	$1000	each
Customs clearance in St. Petersburg	$100	each
Rail transport of OPPs from St. Petersburg to SCC	$2000	each
Total for 20 cylinders (approximately 30 metric tons of LEU of less than 5% enrichment)	**$198,200**	

TABLE 10: CASE B: SHIPPING 30B CYLINDERS FROM ECP OR UECC TO UNITED STATES EAST COAST FABRICATOR

Item	Cost	Units
Direct shipping costs from ECP	$11,400	per cylinder
Total for 20 cylinders	**$228,000**	
Direct shipping costs from UECC	$8920	per cylinder
Total for 20 cylinders	**$178,400**	

TRANSPORTING 19% UF_6

The transportation of 19% enriched LEU presents significant additional issues although the actual total cost of transportation would be less due to the lesser volume.

The two key issues are the procurement of the necessary cylinders and OPPs and the additional security that would be required due to the security category of the material. According to the

U.S. Nuclear Regulatory Commission security regulations in 10CFR73, 19% enriched LEU is deemed to be of "moderate strategic significance."

Shipments of large quantities of 19% enriched uranium, however, may require further security measures at the discretion of the competent authorities at the time of transportation. This may include the need to provide the charter vessel with armed escorts, thus raising the costs of transoceanic transportation to $1 million per shipment or even more.

Although air shipment of the 19% enriched material appears advantageous, the current International Atomic Energy Agency (IAEA) regulations do not allow the type 5B packages to be transported by commercial air carriers. Accordingly, this analysis assumes that surface transportation would be assumed. As each 5B cylinder only carries 16 kilograms uranium, it would be necessary to transport many of cylinders each year. Twenty metric tons of 19% LEU is equivalent to 1,250 5B cylinders. In the larger case of 63 metric tons 19% LEU, the requirement for 5B cylinders would be in excess of 3,900 cylinders per year.

The transportation costs per TEU for internal Russian rail transport, for ocean shipment, and for internal U.S. truck transport to either Lynchburg (BWXT) or Erwin (NFS) are similar to those for the 30B shipments provided that additional security measures are not required. The issue is the amount of 19% LEU that can be included in one TEU. Physically, it is possible to load about 48 double-high 5B OPPs in each TEU. It is also possible to ship multiple TEUs together. It would require between 26 and 80 TEUs to ship all of the 19% LEU each year, depending on the blend-down scenario under consideration.

If appropriate containers are identified or designed, air charter might be used to transport the 19% enriched LEU to an U.S. east coast airport close to the destination facility, such as Washington Dulles (for Lynchburg, Virginia), Knoxville (for Oak Ridge, Tennessee) or Atlanta (for Erwin, Tennessee). The cost of air charter would depend on market conditions at the time, and would cost approximately $350,000 for a large commercial aircraft, such as a Boeing 757, at the time of writing this report. Delivery by road from the airport to destination facility would cost approximately $3,000 per vehicle, with the number of vehicles dependant on the amount of packages involved. Substantial cost savings on air charters are possible if the delivery schedule is flexible.

TIMING OF SHIPMENTS

Transportation of the depleted UF_6 from Paducah, Kentucky, to SCC would take approximately 35–38 days, as shown in Table 11.

TABLE 11: TIME TO TRANSPORT TAILS FROM PADUCAH, KENTUCKY, TO SCC

Activity	Time Taken (Days)	Comment
Loading time	3	
Internal U.S. transport	2 5	truck or by rail
Staging and loading at U.S. port	3	
Ocean transport	18	assuming charter
Customs clearance in Russia	2	
Transport to SCC by rail	7	(estimated)
Total	**35–38**	

Surface transportation of the enriched UF_6 from SCC to a U.S. fabricator facility would take approximately 32 days, as shown in Table 12.

TABLE 12: TIME TO TRANSPORT LEU FROM SCC TO U.S. FABRICATOR FACILITY

Activity	Time Taken (Days)	Comment
Loading time	3	
Transport to St. Petersburg by rail	7	(estimated)
Export formalities and loading	3	
Ocean transport to Baltimore	15	assuming charter
Customs clearance in Baltimore	2	
Truck transport to fabricator	2	(estimated)
Total	**32**	

Return of the OPPs from the U.S. fabricator to SCC would take approximately thirty days, as shown in Table 13.

TABLE 13: TIME TO TRANSPORT OF OPPS FROM U.S. FABRICATOR TO SCC

Activity	Time Taken (Days)	Comment
Loading time	1	
Truck transport to Baltimore	2	
Staging and loading at port	3	
Ocean transport to St. Petersburg	15	
Import formalities in Russia	2	
Rail transport to SCC	7	(estimated)
Total	**30**	

The timescales for shipments to and from ECP or UECC would be comparable to those for SCC, varying only by one or two days.

REGULATORY REQUIREMENTS

The shipments in question would be subject to both U.S. and Russian regulatory requirements. These include import/export licensing requirements, packaging regulations, transport regulations, and security regulations.

Within the United States, the appropriate agencies are the Nuclear Regulatory Commission (NRC) and the U.S. Department of Transportation (DOT). The Department of Homeland Security (DHS) is also involved through the Coast Guard but this applies more to the ocean operator and does not directly affect the shipping organization.

Licensing of the tails material for export would normally fall under the auspices of the NRC. In the absence of a nuclear cooperation agreement between the United States and Russia, however, this responsibility is not defined and would have to be determined by the respective governments.

The NRC export licensing procedures are set out in the U.S. Code of Federal Regulations at 10CFR110. For material of this type going to an approved country for an approved purpose, issuing an export license is routine, and subject to the relatively small fee of $8,100. A routine license can be obtained in 60 days if the recipient country responds quickly to the request for safeguards assurances, which are part of the licensing process. A bulk license covering the export of material for several years, however, can be obtained for a single charge.

If the bilateral agreement is not approved at the time of export, the only way to make the shipment is via a specific “government-to-government” agreement. This is the method currently used to return the Russian uranium to Russia under the HEU Purchase Agreement, and would act as a precedent case.

The Russian import requirements are generally managed through the import license of TENEX, which is the usual contracting party in Russia for all fuel contracts. TENEX has existing licenses that could cover the importation of U.S. tails for expanded HEU blend-down, but could also obtain new licenses within approximately three months.

Export sales of LEU are managed by TENEX, which also acts as the Russian agent for the HEU Purchase Agreement. Hence, the export of the enriched UF_6 from Russia would also be managed through a TENEX export license, either existing or newly obtained. TENEX currently has licenses that cover exporting material with an enrichment of up to 19.75% U-235.

Importing enriched uranium into the United States is also covered in 10CFR110.27, which states that any person may import material that he/she is authorized to possess. Because the U.S. fabricators who might agree to the storage of the Russian LEU are authorized to possess the material, it would be unnecessary to obtain a specific import license because the material could be imported under the recipient's possession license.

All the packages involved in the shipment are standard cylinders and outer packages and are already in use throughout the industry. They have all necessary approvals for general usage under IAEA and national requirements. There are no impediments to their continued usage. In the United States, for purposes of import/export, these approvals are given by DOT. In Russia, these approvals are overseen by the Russian nuclear regulator, Rostechnadzor.

Transport regulations are also under the jurisdiction of DOT in the United States. Most of the requirements are imposed on the carriers for safety issues after the material has been packaged by the shipper. In this case, the shipper would be DOE/USEC in Paducah, Kentucky, because they would be certifying that the material was packaged correctly. The carriers must maintain distance controls for the materials in question and provide approved drivers. The situation is the same in Russia with Rostechnadzor responsible for transport safety approvals. Security regulations are governed by NRC and Rostechnadzor respectively. For the depleted and low-enriched materials, the requirements are minimal and amount to predetermination of route and schedule. The recipient should be aware of date of arrival and acknowledge receipt promptly. Tracking devices are not needed, although they are frequently used as an added precaution. Information about the shipment is restricted to only those with a need to know. However, there is widespread use of specific data on shipping documents as required for safety purposes.

For the 19% LEU, the security would be at a higher level, although the exact levels of security have yet to be determined. NRC would wish to review the transport plan. Based on the quantity to be shipped, the security would be adjusted according to an order by the NRC rather than by regulatory change. This means that the 10CFR73 requirements can only be used as a base. Security for nuclear material transportation Russia is already high, with escorts required for all shipments, thus no significant changes would be expected.

DHS requirements govern all transport workers with access to ports and hazardous goods as well as U.S. Customs and Border Protection and U.S. Coast Guard matters. The intent is to "keep the borders safe" and to protect hazardous materials from becoming the focus of attacks. All carriers to be used must screen their workers and provide the appropriate cleared and badged employees. DHS is more concerned with the importation of uranium, and so would have little interest in the export of uranium tails. Shipments of LEU transported on commercial liner vessels would be subject to inspection upon arrival in order to ensure material integrity. Consequently, many ocean carriers are refusing to carry such cargos because of the delays that they may cause to their operations.

INSURANCE

There are two categories of insurance that are applicable to the shipments in question: Loss and Damage Insurance and Nuclear Liability Insurance.

Loss and Damage Insurance

During the course of transport, it is possible that either the shipping packages or the contents could be damaged or even lost. The range of possible accidents includes truck or rail accidents to the sinking of a vessel on the high seas. The former would most likely result in damage to the cylinders/OPPs but no loss of material. The latter could result in the total loss of the LEU. This is an issue that all shippers of merchandise face when making shipments domestically or internationally.

The shipping carriers have responsibility for their actions, but they do not carry the burden for total loss of the uranium. It is thus necessary to determine if the owner of the material wishes to insure against loss. This insurance is easily obtained and the cost can be established by applying to an insurance agent and putting a “reporting policy” in effect for shipments. The shipper would then specify the value of the material (presumably for replacement purposes) and the negotiated rates would apply. Typical rates are in the range of 12–15 U.S. cents per $100 of declared value. The actual rates would also be based on factors such as the chosen deductibles, war risk, quantities (risk) per vessel, and the experience rating of the specific carriers to be used.

Nuclear Liability Insurance

Standard liability insurance policies, whether for commercial or residential use, exclude coverage due to “nuclear events.” In the United States, all nuclear facilities are required to have coverage either through specific “nuclear liability pool” insurance or through the U.S. government Price-Anderson Act coverage or both. These policies /Acts also cover shipments to and from these facilities within the United States. Russia has a similar nuclear liability indemnification for transportation of nuclear materials within the territory of Russia.

The “nuclear incident” covered by the U.S. and Russian policies and indemnifications is a defined term, and is an incident that includes a nuclear criticality. Such a criticality cannot occur during the transportation of empty containers or depleted uranium because the material is insufficiently reactive. A nuclear incident would only be possible with the shipment of enriched uranium.

Although it is not required by law or regulation, it is possible to purchase a “shippers and transporters” nuclear liability policy in amounts up to $30 million U.S. dollars, with the possibility of higher coverage amounts following a specific request. The policy is usually written through a commercial liability carrier, such as Lloyds of London, with a specific rider for nuclear liability coverage. The actual decision on coverage would be best discussed with a knowledgeable agent. Nuclear transportation companies typically carry such a policy as a precaution to defend against lawsuits in the very rare event that a shipment is involved in an accident.

SHIPPING SAMPLES

It is customary for the receiver to witness the weighing of the cylinders and to obtain samples taken from the UF_6 at the time that it is loaded into the cylinders to determine the actual quantity and assay. The project manager would need to engage a local agent at each of the UF_6 plants to witness the cylinder filling. This is important before receipt of the material in order to determine what is being purchased. It is even more important in the case of expanded HEU blend-down, because cylinders could be put into storage for long periods of time without any other check of their contents.

Contracts for the LEU from expanded HEU blend-down should include the right to observe the weighing and sampling of the cylinders and specify the method to be used for sample receipt and analysis. A standard process has been agreed with Russia for materials received under the HEU Purchase Agreement and this should be acceptable to all parties for expanded HEU blend-down.

The samples are usually shipped by air in advance of receipt of cylinders. Batches of samples, small tubes with a few grams of material, can be shipped for $1,000–$1,500 to the appropriate laboratories. Sometimes the samples accompany the cylinders during surface transportation. The actual transportation method is determined based on the payment terms under the contract.

STORING MATERIAL IN THE UNITED STATES

It is proposed that the enriched uranium that is returned to the United States would be stored pending use in the U.S. fuel cycle at storage facilities that are licensed by the NRC.

There are a limited number of U.S. facilities currently able to store 19% LEU, including Nuclear Fuel Services (NFS), Erwin, Tennessee; BWXT, Lynchburg, Virginia; and USEC, Piketon, Ohio. The Y-12 facility in Oak Ridge, Tennessee, could also be considered for storage of 19% LEU material, although it might be judged to be under the control of the U.S. government and thus not independent. The NFS or BWXT would be preferred because the further blend-down of the material could be done at one of those two facilities.

For the <5% LEU, the list would include, in addition to the above three facilities, any of the fuel fabricators in the United States: Westinghouse, Columbia, SC; Global Nuclear Fuels (GNF), Wilmington, North Carolina; and AREVA NP, Lynchburg, Virginia, or Richland, Washington. It could also be possible, however, to negotiate with a nuclear utility to store the material at an existing reactor site. As of December 2010, there are no independent storage sites.

Typically, the fabricators are willing to store inventory at their facilities but prefer that it remain there for eventual use by that fabricator. This may not fit well with the project goal, which is to have material available for use at any fabricator, although establishing storage at all of them would probably be redundant and unnecessary.

Storing <5% LEU at a utility reactor site would provide the flexibility to subsequently move the material to whichever fabrication facility is required. Reactor sites already have site licenses for material <5% and this could be expanded to include material for storage. The existing facility security would certainly meet the needs of the NRC for storage, and all of the U.S. reactor sites are covered by the Price-Anderson Act nuclear liability indemnification.

Another option would be to store LEU at the Savannah River Site (SRS). This would require agreement with U.S. Department of Energy (DOE) to use some portion of the site for LEU storage, either in an existing building or in a new facility. SRS is a federal site, therefore the storage proposal would be subject to an environmental impact evaluation.

EQUIPMENT

It will be necessary to purchase a significant amount of equipment to effectively manage the material transportation, as shown in Table 14. This includes purchasing 30B or 5B cylinders as appropriate, together with their OPPs, the TEUs required to ship 30B cylinders, and the thermal protection devices required to transport 48Y cylinders.

It may not be necessary to purchase 48Y cylinders, depending on the condition and availability of the cylinders in which the depleted uranium is stored. However, a price for so doing is included in the table for reference purposes.

Table 14 shows the estimated 2008 prices for UF_6 cylinders manufactured by Westerman Companies in Bremen, Ohio, and OPPs manufactured by Columbiana HiTech in Greensboro, North Carolina. Quantity discounts can normally be negotiated based on needs. The purchase of refurbished TEUs for use in shipping UX-30 containers is the recommended approach. There are many companies that refurbish and sell these units, and it is possible to solicit competitive bids at the appropriate time.

TABLE 14: PRICES OF UF_6 CONTAINERS, OPPS, AND TEUS

CYLINDER	PRICE	PER
30B	$6,500	each
48Y	$10,850	Each, based on an order for 500
5B	$15,000	Each (estimated—none have been fabricated recently)
UX-30 packages	$25,000	each
5B package	N/A	N/A
Hard-type thermal protection devices	$6,500	each
Blanket type thermal protection devices	$3,500	each
Refurbished TEU	$4,500	each

ADMINISTRATION

Coordination and administration of the transportation logistics and equipment procurement would require the equivalent of one full-time employee's year of effort per year from a professional traffic management company that is familiar with the international transport of nuclear material. Typically, such firms charge an annual fee plus a cost per shipment for monitoring and administration. It would also be an advantage to employ people at the Russian facilities to witness the weighing and sampling of the cylinders. These people can be employed by the hour as subcontractors to the manager. The annual cost of management and administration is estimated to be $250,000 per year.

ANALYZING RISK OF TRANSPORTING LOW-ENRICHED UF_6 AND TAILS

Even if the U.S. and Russian governments conclude a government-to-government agreement covering the expanded blend-down of HEU, the transportation activities would still carry a moderate risk component, based on previous experience. This section identifies the risks associated with this project that involves the transportation of 0.4% tails from a storage site in the United States through St. Petersburg and ultimately to SCC, and the transportation of 19% and <5% LEU from SCC via St. Petersburg to the United States.

The risk factors include:

1. Timely availability of transport equipment and modes of transportation;
2. Government action:
   - Rulings enacted that specifically affect the transportation of this material;
   - Changes in regulations/laws that govern transportation of nuclear material in general;
   - Individuals of political influence speaking against this project and/or the transportation;
3. Local political/civil resistance or opposition to the transportation, including legal challenges;

4. Obtaining the necessary permits/licenses or approvals from the local and federal governments;
5. The terrorist risk;
6. Weather;
7. The effect that changes in technology may have on the transportation;
8. Changes in currency exchange rates;
9. The availability of funding for this project;
10. Potential for a transportation accident and its consequences;
11. Negotiating an agreement (the business contract) with Russia.

A general observation on the transportation risk management is that time is likely not a critical factor for the materials transported under an expanded HEU blend-down program. Although there will be important milestones to be achieved and schedules to be met, a delay will not jeopardize the long-term goals of this project. The decreased importance of the time factor results in a corresponding decrease in the consequences of these risks as well as the actions and therefore the costs necessary to mitigate those risks.

Availability of Transport Equipment and Modes of Transportation

As described earlier, shipping depleted uranium or the tails requires either a 48Y or 48G cylinders; shipping 5% UF_6 requires a 30B cylinder with a corresponding UX-30 OPP; and the 19% UF_6 requires a 5B cylinder with a double 55-gallon drum OPP. The 30B and 48Y cylinders and their OPPs are readily available for lease or purchase. The transportation scenarios assume that the 48Y cylinders will be leased but they can be readily purchased if needed. This is less true of the 5B cylinder and its OPP because there is minimal material being shipped in the 19% U-235 enrichment range. The 5B cylinders and their corresponding OPPs, however, can be purchased because their design is defined, they can be readily fabricated, and they have been licensed for this use.

The risk that there will not be timely availability of transport equipment, which includes the shipping cylinders and their OPPs, is low, provided that sufficient lead-time is given to fabricate the 5B cylinders and their OPPs.

The risk associated with the timely availability of the transport mode, whether it is truck, rail or ocean vessel is minimal. Significant quantities of depleted uranium and enriched uranium have been shipped between the United States and Russia for many years and it represents an important source of revenue for those carriers. The greatest challenge is to schedule the shipping arrangements with a reasonable amount of advanced notice, which places a focus on the appropriate exchange of information, as is typically the case in the movement of these materials.

Government Action

Rulings Enacted That Specifically Affect the Transportation of This Material

This risk factor involves both the U.S. and Russian governments. There is considerable support for this program in both countries and it is unlikely that either country would enact legislation or pass rules that specifically target transporting this material.

Nuclear material has been moved between these two countries for many years under the HEU Purchase Agreement and this project has similar objectives. This risk is, therefore, low.

Changes in Regulations/Laws That Govern Transportation of Nuclear Material in General

The regulations and laws that govern transporting nuclear materials are known and are not overly restrictive in both the United States and Russia. There has been a movement to tighten security and there is the possibility that there could be additional requirements placed on shipments of nuclear materials.

Those restrictions, if enacted and made effective, may not be applicable to the tails material considering their very enrichment level. In any event, the possibility does exist that over the duration of this project there could be additional security requirements placed on transporting the nuclear materials involved. However, the cost of implementing the as-yet-unknown additional security requirements is not likely to be large.

Individuals of Political Influence Speaking Against This Project and/or the Transportation

Similar to the analysis above, the political downside for speaking out against this important nonproliferation project makes it unlikely that a politician or local leader would do so. Therefore, the risk of this occurring is low.

Local Political/Civil Resistance or Opposition to the Transportation, Including Legal Challenges

This risk factor includes the possibility of some type of local resistance or opposition to moving these nuclear materials through a given city or town, or on a certain highway. This risk of this occurring is low because the routes over which these materials travel have been used for this purpose for many years under different projects.

Under typical conditions the transport route information is only known to those needing that information and in the past when local resistance has occurred it was managed by the local authorities and the effect was short lived. This risk of this occurring is low and the effect, should it occur, would also be low.

Obtaining the Necessary Permits/Licenses or Approvals from the Local and Federal Governments

An export license would have to be obtained from the NRC to export the tails to Russia. This is a straight-forward procedure as set out in 10CFR110, provided that either a nuclear cooperation agreement or a specific intergovernmental agreement to cover the expanded HEU blend-down program is in place between the United States and Russia.

Delays in obtaining the necessary intergovernmental agreements would prevent shipping depleted tails from the United States to Russia, with both cost and schedule effects.

Russia would import the uranium tails under the existing TENEX license. If a new Russian import license became necessary as a consequence of restructuring of nuclear activities in Russia, it is expected that this could be obtained in about three months based on prior experience.

TENEX is also licensed to export the LEU, which covers LEU with an enrichment level of up to 19.75% U-235. A license to import the enriched UF_6 into the United States would have to be obtained by the entity that will store the material. That license is obtained from the NRC and is straightforward provided that adjustments to import quotas are included in the inter-governmental agreement.

All shipping packages involve standard cylinders and outer packs and can be used without restrictions in both the United States and Russia. The shipment of the 19% U-235 material is not of the typical enrichment and would likely require some specific attention to its security in the transport plan. This would have to be addressed with the NRC staff and the conditions would likely be set by an Order of the NRC Commission. This would not be a difficult negotiation with the NRC staff but it would have to be completed in a timely fashion to allow for the import and movement of the 19% U-235 material in the United States.

Obtaining the necessary permits/licenses or approvals from the local and federal governments is a low risk factor but appropriate attention should be given to the 19% U-235 material.

The Terrorist Risk

In today's environment, possible acts of terrorism must be considered in all operations concerning nuclear materials. All material transported for expanded HEU blend-down program will comply with the security requirements and guidelines of the United States, Russia, and the IAEA, with additional security measures, such as armed escorts and tracking devices, if appropriate. The 19% LEU provides a more attractive target and may justify correspondingly greater security precautions.

Weather

The risk of weather negatively affecting the transportation of the material under this project is low. The risks are routinely controlled by the professional transportation organizations.

Effect of Changes in Technology on Transportation

The transportation of the nuclear materials under this project involves tried and proven technologies, which include the standard design of the shipping cylinders and their respective outer packs. Although it is possible that a new regulatory environment could require technological changes, there would have to be a compelling reason to change from what has been successfully used for decades. The risk of this occurring is low.

APPENDIX 3: ASSESSING STAGE 2 BLEND-DOWN IN THE UNITED STATES

BACKGROUND

To complement the joint analysis discussed above, NTI performed an independent technical, cost, and risk assessment for the blend-down in the U.S of 19% intermediate LEU imported from Russia to 4.95% LEU appropriate for sale to U.S. customers. This assessment was based on a preliminary engineering assessment of capital and operating costs.

The two existing commercial U.S. HEU blend-down sites deploy classical uranium solution chemistry to blend the HEU to lower enrichments using a natural, depleted, or slightly enriched uranium blendstock. Between 1999 and 2006, USEC processed more than 50 metric tons of HEU, mostly metal and oxide, through solution blend-down to produce LEU suitable for fabrication of commercial nuclear reactor fuel. The final LEU product had an average enrichment of 4.0% U-235.

Another major program, the TVA Blended Low Enriched Uranium (BLEU) Project, established by a DOE/NNSA/TVA Interagency Agreement, covers the blend-down of 40 metric tons HEU to a LEU product with an average enrichment of 4.95% U-235 to fuel TVA's Browns Ferry Nuclear Units 2 and 3. The LEU from the BLEU program complies with ASTM specifications for commercial LEU with the exception of elevated levels of the U-234 and U-236 isotopes.

The 40 metric tons HEU in the BLEU project is composed of approximately 23 metric tons blended by NFS in its BLEU Prep Facility (BPF) to low-enriched uranyl nitrate (LEUN) solution and the LEUN converted to reactor-grade uranium oxide powder by AREVA-NP in its BLEU Complex; both facilities are located in Erwin, Tennessee. The balance of the HEU, 17 metric tons, is being processed at the Savannah River Site prior to transfer to AREVA's BLEU Complex.

SCENARIOS

The scenarios evaluated in this assessment were as follows:

U.S. Scenario 1: Conversion of 19% UF_6 to an oxide followed by blend-down of this oxide using an existing aqueous-based system to provide a LEUN solution with an enrichment of 4.95% U-235. The blendstock would be natural uranium oxide. This scenario would require constructing a facility for the UF_6 to oxide conversion. The resulting LEUN solution would then be provided to a U.S. fuel fabricator for finishing to UO_2 fuel.

U.S. Scenario 2: Direct blend-down of the 19% LEU to 4.95% UF_6 using natural uranium hexafluoride as the blendstock. This system is similar to that deployed by the Russian sites under the HEU Purchase Agreement. This scenario would require constructing a gaseous blending facility to perform the blend-down because there is no such facility in the United States presently. The resulting low-enriched UF_6 would be transferred to nuclear fuel fabricators for fabrication of fuel in the normal manner.

ABILITY TO MEET ASTM C996-04 SPECIFICATION FOR URANIUM ISOTOPES

Parameters

The first step in the scenario evaluation is to confirm that the LEU product would comply with the ASTM C996-04 specification, if natural or depleted uranium is used as blendstock. The Russian HEU is assumed to have isotopic composition of 90% U-235, 1.001% U-234, and 8.999% U-238. This estimate of the HEU isotopic content was calculated by assuming that the HEU was prepared from natural uranium, using a 0.3% tails assay, and crosschecked assuming a 0.35% tails assay. The higher tails assay would result in a greater content of U-234 in the HEU, and therefore is a more conservative assumption. The depleted uranium blendstock was assumed to have an assay of 0.2% U-235, resulting from enriching natural uranium to 3% U-235. In every case, the final product was assumed to be 4.95% U-235.

Because U-236 is not found in appreciable quantities in natural uranium, it was assumed that this isotope will not be an issue in the HEU generated from natural uranium, and therefore, will meet the ASTM specification in regard of this isotope. In the event that the HEU used for blend-down was derived from reprocessed uranium, a revised analysis of blendstock isotopic requirements would be required.

A small amount of U-234 is present in natural uranium. Because U-234 is a lighter uranium isotope than U-235, it is concentrated at a higher rate than U-235 during the enrichment process. This causes the U-234/U-235 ratio of HEU to be significantly greater than that for natural uranium or LEU derived from natural uranium. This high U-234/U-235 ratio is a cause for concern when planning the blend-down of HEU for commercial fuel use. Uranium available in the United States usually has a U-234 content of 54 µg/g. The uranium available from other sources, including some sources in the Former Soviet Union, can have higher concentrations of U-234. The ASTM specification for natural uranium, ASTM C787-03, covers U-234 concentrations of up to 62 µg/g.

The limit on U-234 for LEU is specified in ASTM C996-04 as 11.0 x 10^3 µg/g U-235[8] as compared to 10 x 10^3 µg/g U-235 for the earlier ASTM C996-96.

Results

With the assumptions above, and using typical U.S. natural uranium with a U-234 content of 54 µg/g, the blend-down of HEU with natural uranium blendstock would produce 4.95% LEU with a U-234 concentration of 10.6 x 10^3 µg/g U-235. This result is within the ASTM C996-04 isotopic limit, but outside the ASTM C996-96 limit.

Based on the HEU isotopic purity assumed in the Parameters section, above, the ASTM C996-04 specification could be met using U.S. natural uranium as blendstock, without the need for enriching the blendstock prior to use. If the 19% intermediate LEU were to be produced using

[8] Noting that for U-234 levels greater than 10.0 x 10^3 µg/g U-235 ASTM C996-04 requires agreement in advance from the customer.

an enriched blendstock prepared from tails or natural uranium, the U-234/U-235 ratio of the 4.95% blend-downed product can be lowered to meet the ASTM C996-96 specification limits.

Discussions with commercial nuclear fuel fabricators indicated that a slightly increased level of U-234 content should not significantly affect the market value or acceptability of this material. The flexibility possessed by fuel fabrication facilities permits blending of different uranium feed material to achieve a fully compliant feed that achieves the most conservative ASTM specifications.

DESIGN BASIS ASSUMPTIONS

The following assumptions were used for the analysis:

- A modular facility design with each module able to process 20 metric tons per year of 19% LEU. Capacity can be increased in multiples of 20 metric tons/year;
- The 19% LEU will be received as UF_6 in standard 5A and/or 5B cylinders;
- The 19% LEU meets ASTM chemical purity specifications and will not require further purification;
- The final LEU product will have an enrichment level of 4.95% U-235;
- UF_6 blendstock will be provided in 48X cylinders;
- Depleted uranium blendstock is available at no cost, and natural uranium blendstock is available at current market price;
- LEU product supplied as UF_6 would be packaged in 30B cylinders;
- Facility operations will be 48 weeks/year, 5 days/week, with 3 shifts/day, with an operating efficiency of 85%;
- Liquid wastes will be processed in existing waste water treatment facilities;
- For 19% enriched material, 6-inch diameter columns are a favorable geometry for process equipment.

U.S. SCENARIO 1: SOLUTION BLEND-DOWN OF 19% LEU AT AN EXISTING FACILITY

The first process considered was the dry conversion of 19% UF_6 to U_3O_8 for dissolution and blend-down at an existing U.S. facility. In this process, the 19% UF_6 feed cylinders are first leak checked by confirming that the cylinder is at negative pressure. Once the cylinder passes its leak check, it is then emptied in the evacuation station. Cylinder evacuation is achieved by blowing hot air across the outside of the cylinder causing the heated UF_6 to sublime directly from solid to gas.

The forced hot air heating allows the use of a lower temperature, and thus lower cylinder pressure; this provides a greater margin of safety during the heating cycle. For added safety, the cylinder pressure and temperature are maintained below the UF_6 triple point, ensuring that no liquid UF_6 is formed. After the cylinders are thoroughly emptied they are returned for reuse.

The sublimed UF_6 is carried by an inert gas (nitrogen or argon) and introduced, along with steam, into a reaction chamber. Inside the chamber the UF_6 and steam are heated and react to form solid UO_2F_2 according to Reaction 1 below.

$$UF_6(g) + 2H_2O(g) \rightarrow UO_2F_2(s) + 4HF(g)$$ **Reaction 1**

The UO_2F_2 settles to the bottom of the reactor and is collected and conveyed into a rotary calciner. Steam is injected into the calciner to react with the UO_2F_2 to form U_3O_8 according to Reaction 2 below.

$$3UO_2F_2(s) + 3H_2O(g) \rightarrow U_3O_8(s) + 6HF(g) + \tfrac{1}{2}O_2(g)$$ **Reaction 2**

The U_3O_8 is continuously monitored for moisture content as it leaves the calciner. The U_3O_8 must be confirmed dry before transfer to the storage and packaging area.

The dry uranium oxide is conveyed from the rotary calciner to a storage hopper in the storage and packaging area. This area is a moderator exclusion area to allow for greater flexibility in U_3O_8 handling, with larger volumes of material, larger containers, and closer spacing. Uranium oxide from the storage hopper is dispensed into the oxide packaging glove box where it is packaged as an intermediate product for transfer to an existing facility for dissolution and blend-down. The packaging container size and type will be determined by transportation requirements as well as requirements of the blend-down facility. For the purposes of this analysis, it is assumed that the uranium oxide will be packaged into 2-liter polyethylene bottles.

The existing blend-down facility will receive the 19% enriched U_3O_8 and dissolve it in nitric acid to produce a uranyl nitrate, $UO_2(NO_3)_2$, solution. The 19% enriched uranyl nitrate will then be mixed with an uranyl nitrate blendstock solution to form a 4.95% enriched blended product solution. This LEUN solution can be transported directly to a fuel fabricator, where it will be converted to a reactor-grade uranium oxide final product.

The cost of conversion to uranium oxide is not included here; this work would be performed by the fuel fabricator. Using natural uranium as blendstock, 20 metric tons/year of 19% intermediate LEU will result in 86 metric tons/year of 4.95% LEU product.

For each mole of UF_6 processed, six moles of hydrogen fluoride (HF) are formed, as shown by Reactions 1 and 2 above. The HF produced is condensed as hydrofluoric acid. The recovered acid is concentrated, collected, analyzed for uranium and other impurities, and potentially sold as a product. (A similar dry conversion process at commercial LEU processing facility consistently makes HF solution that is sold to a commercial HF user.)

This overall processing scenario is shown schematically in Figure 13 and Figure 14.

FIGURE 13: PROCESS FLOW DIAGRAM FOR CASE 1—OXIDE PRODUCTION

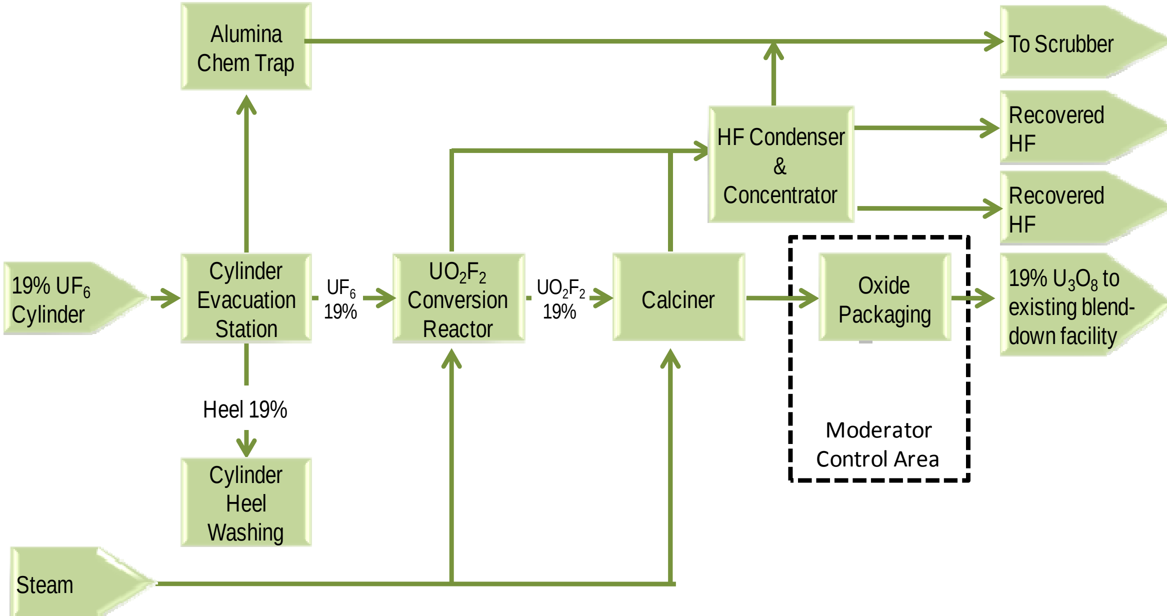
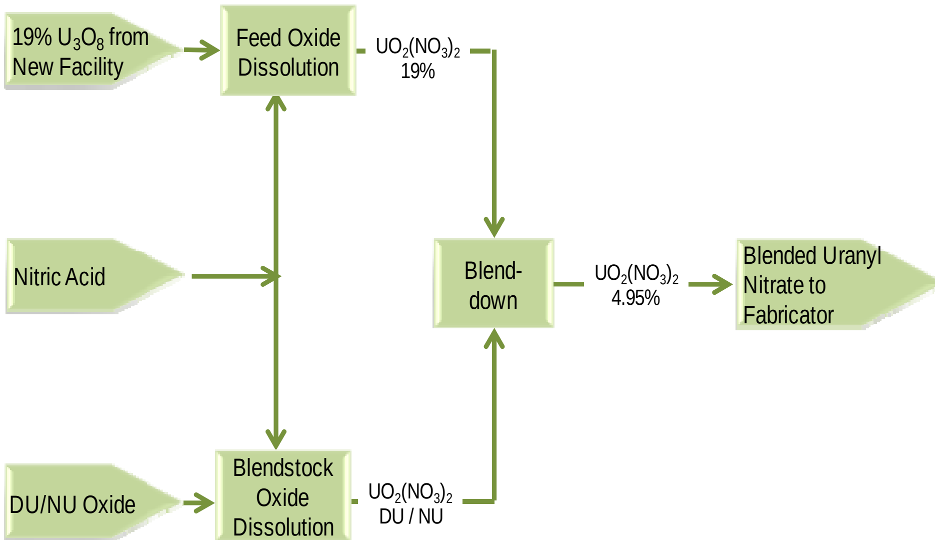


FIGURE 14: PROCESS FLOW DIAGRAM FOR CASE 1—BLEND-DOWN AT EXISTING FACILITY



U.S. SCENARIO 2: BLEND-DOWN AS GASEOUS UF_6

The second process considered was blend-down as UF_6 without chemical conversion. In this process, the 19% enriched UF_6 feed cylinders are first leak checked and evacuated in the same manner as U.S. Scenario 1.

Blendstock UF_6 cylinders are heated in similar manner to the 19% LEU cylinders. Because of their large size, the blendstock cylinders would require steam preheating, with forced hot air used to maintain temperature.

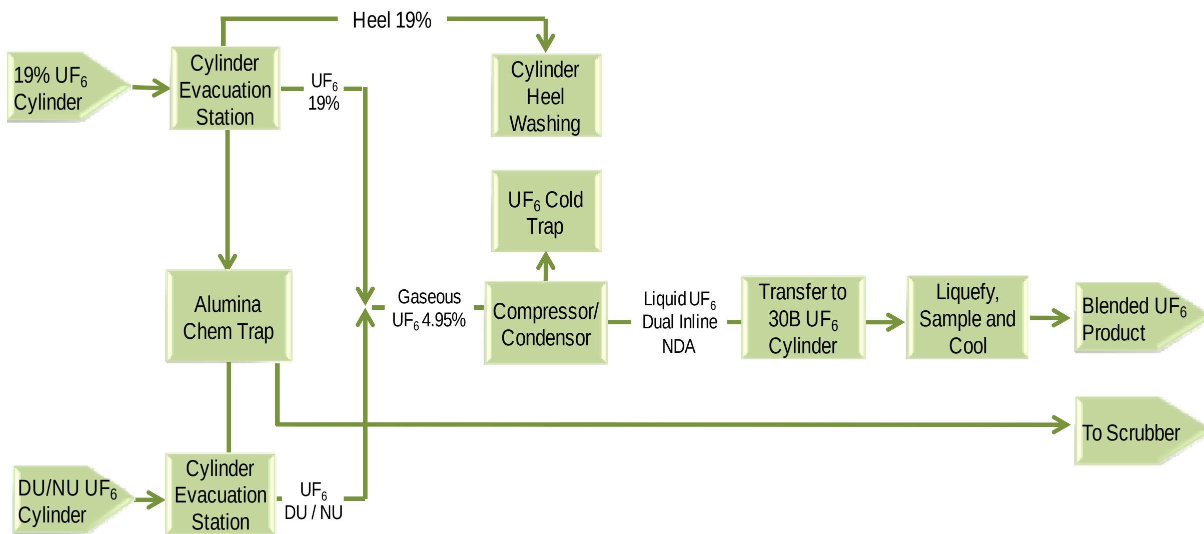
The 19% UF_6 and the blendstock UF_6 are combined in a blending tee. The input rates of both gases are carefully controlled to produce the 4.95% LEU product by blending of the gases. The gaseous UF_6 product is then compressed to greater than 22 psia and condensed as liquid UF_6, which can be poured into the 30B UF_6 product cylinder.

When a 30B cylinder is filled, the product UF_6 is diverted to a second 30B filling station. The filled 30B cylinder is then heated to completely liquefy the UF_6, and after adequate time to ensure homogeneity, a sample of the liquid UF_6 is taken. The filled cylinder is then cooled to re-solidify the UF_6 prior to handling.

As in U.S. Scenario 1, using natural uranium as blendstock, 20 metric tons per year of 19% intermediate LEU would result in 86 metric tons/year of 4.95% LEU product.

This process is shown schematically in Figure 15.

FIGURE 15: PROCESS FLOW DIAGRAM FOR CASE 2



RISKS AND RISK MITIGATION—COMPARISON AND DISCUSSION

The primary technical risk for either case is regulatory authority licensing and facility location. The large mass of UF_6 to be handled in U.S. Scenario 2, and the fact that much of this UF_6 is in liquid form, could pose significant hurdles to public acceptance and licensing. This type of facility could be located at sites that are already accustomed to handling large quantities of UF_6. The dry conversion process of U.S. Scenario 1 also involves handling of UF_6, but the quantity is much smaller, and the UF_6 is not allowed to become liquid. This type of facility may have less difficulty obtaining a license, and the number of suitable locations should be significantly greater. Also, the blend-down portion of U.S. Scenario 1 exists in the United States, is licensed, and is currently operating.

Both U.S. Scenario 1 and U.S. Scenario 2 carry safety risks that must be managed, primarily that of the release of UF_6. In U.S. Scenario 1, a maximum of 100 kg UF_6 is heated and is only handled in solid and gas phases. In comparison, U.S. Scenario 2 requires heating several tons of UF_6, much of which is handled in the liquid phase. Liquid UF_6 is more difficult to control than solid or gaseous UF_6, and is more problematic in the event of release. Consequently, U.S. Scenario 2 has greater potential for off-site damage than U.S. Scenario 1.

An additional safety risk is the potential for spilling HF. In U.S. Scenario 1, about 120 gallons of 35% HF solution are produced weekly. Although controls would be implemented to reduce the possibility of an HF spill, the risk cannot be entirely eliminated. The U.S. Scenario 2 process does not produce HF, and thus does not possess this risk. Spilled HF is more readily contained than a release of UF_6.

COST AND SCHEDULE

Cost

The costs of blend-down were estimated by reference to an existing uranium processing facility of similar-scale. The reference facility processes LEU in similar quantities and with similar technical complexity to the process being studied. The reference facility was used to calculate nonprocessing area requirements, facility capital costs in $/ft2, and facility Decontamination and Decommissioning (D&D) costs in $/ft2. The basis facility was also used to estimate personnel requirements, security costs, and miscellaneous operating costs. Using this reference facility as a guide, estimated costs are projected to have an uncertainty range of -10% to +30%. These costs are summarized in Table 15.

TABLE 15: U.S. SCENARIOS COST SUMMARY ($ 2007)

Categories	U.S. Scenario 1: Solution Blend-down	U.S. Scenario 2: Gaseous UF_6 Blend-down
New facility area	5,800 ft^2	5,824 ft^2
Enriched feed (19%)	20 metric tons/yr	20 metric tons/yr
LEU product (4.95%)	87 metric tons/yr	87 metric tons/yr
Facility capital	$18.4M to $26.4M	$17.9M to 25.4M
Storage capital	$0.9M	$0.9M
Operating cost[a]	$26.3M/yr	$9.8M/yr
Natural uranium blendstock cost[b]	$14.6M/yr	$14.6M/yr
Decontamination and decommissioning cost	$9.9M	$10.2M

[a] Does not include natural uranium blendstock costs.

[b] Assumes $220/kg uranium.

The capital costs for 19% LEU and blendstock storage and the costs of the blendstock are independent of the scenario chosen. The estimated capital and D&D costs of U.S. Scenarios 1 and 2 are very similar and well within the uncertainty of the estimates.

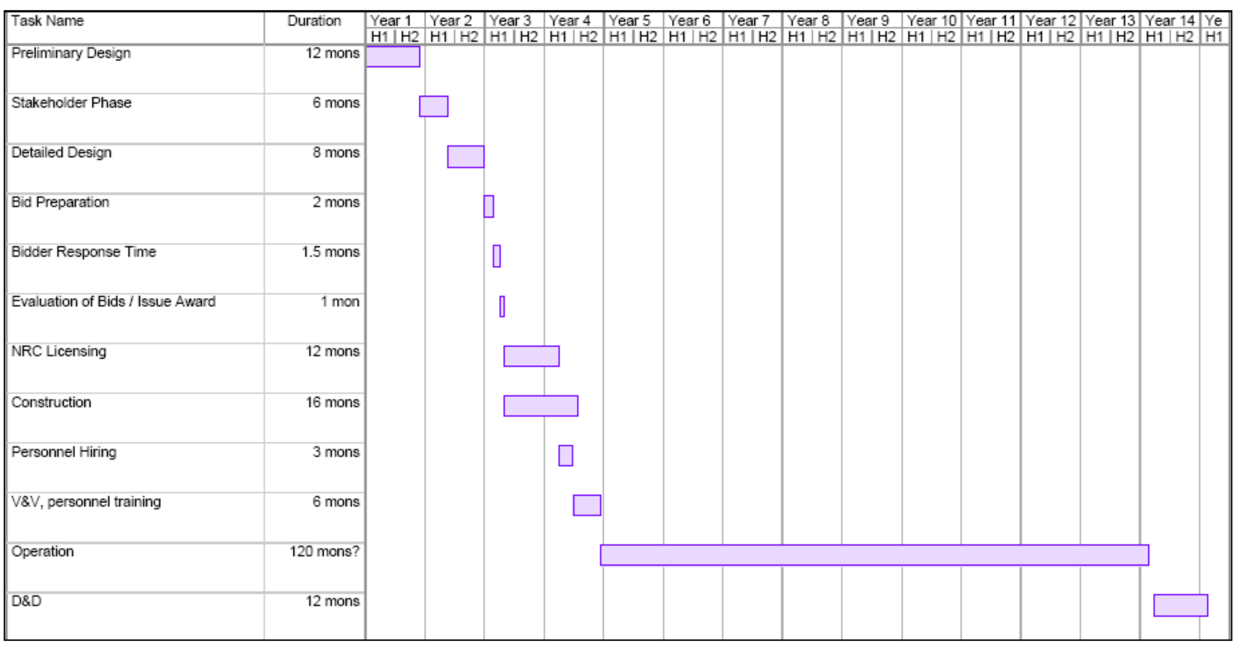
The operating costs of the two scenarios are significantly different, with the estimated operating cost of U.S. Scenario 1 being significantly greater than those for U.S. Scenario 2. The source of this difference is the number of additional steps involved to convert the LEU gas to a solid, then to a solution; convert the blendstock solids to solution; combine the two solutions and then prepare the LEU product. The cost of procurement of blendstock for blend-down is the dominant cost associated with operations.

Additional storage capacity may be required for up to 60 metric tons of 19% UF_6 to accommodate either larger Russian blend-down rates or to address the backlog of incoming material at the lower generation rate prior to startup of U.S. facilities. In either case, capital storage costs would need to be increased to address additional incoming material for storage.

Schedule

The schedules for implementation of the blend-down regimes are similar for both cases. Figure 16 provides a representative schedule for the two cases. Blend-down operations are expected to start four years after start of project design. This assumes that licensing of the blend-down facility can be achieved in a twelve-month period, based on recent experience in licensing Category I facilities. Nonetheless, with increasing regulatory scrutiny of new nuclear facilities, the time to license the facility could be extended beyond the estimated twelve months.

FIGURE 16: SCHEDULE FOR IMPLEMENTATION OF BLEND-DOWN



Alternative Blend-Down Approaches

Two other methods of converting UF_6 to oxide were not evaluated in this scope, but are potentially applicable. These are briefly mentioned here as potential future scenarios for investigation.

The first alternate method for converting UF_6 to oxide is the well-proved ammonium di-uranate (ADU) "wet" conversion process. In this process, UF_6 is vaporized and mixed with liquid water to form UO_2F_2 and HF. The UO_2F_2 solution is then mixed with excess ammonia solution to precipitate ADU. The ADU is filtered, and the resulting solids are calcined to produce uranium dioxide that is suitable for fuel fabrication. The large volume of filtrate solution (ammonium hydroxide and ammonium fluoride) is treated with lime to remove the fluorides for disposal as calcium fluoride precipitate, CaF_2. The disadvantages of this process are the large volume of ammonia required and the large volumes of liquid and solid waste generated. In the past, most UF_6 was processed in this manner. However, most fuel fabricators have shifted to more efficient and environmentally benign dry process. Therefore, even though the wet process is proven and is compatible with the existing blend-down facility, it is not recommended for further consideration.

The second alternative method is blend-down as a solid. In this process, 19% LEU oxide would be prepared in U.S. Scenario 1 above, and then transferred to a new solids blend-down facility. The blendstock would be natural or depleted uranium, also in oxide form. Both oxide streams would be dried in a rotary calciner and then treated to reduce the particle size to less than 100 microns. The oxides then would be measured by mass and blended to the target enrichment. The blended oxide would then be subjected to a high energy milling to fuse the particles to prevent settling or separation. Similar operations have been demonstrated at small scale. However, large scale dry oxide blending of HEU with lower enrichments to achieve a useable product of consistent enrichment has not yet been demonstrated. Solids blending avoids handling a more chemically hazardous material, such as HF, and reduces the likelihood of a significant spill. Working with uranium oxides only also allows for greater flexibility in equipment sizing because water and other moderators are excluded from the processing area and much larger batches can be handled safely.

Historically, the solids blending process has not been favored from a materials control and accounting (MC&A) perspective because of concern about reseparation of the mixed enrichments. A variant of this approach has been used at the ULBA facility in Kazakhstan. At the ULBA facility after the blend-down of uranium oxide in solid form, the blended oxide is then dissolved to produce uranyl nitrate. The dissolution of the blended oxide results in a homogeneous liquid mixture. By dissolving the oxide, MC&A concerns of nonhomogeneity are eliminated.

For the basis case of 20 metric tons/year, the existing liquid blend-down facility should be considered first. If, however, the desired rate of processing is increased beyond the existing liquid blending capacity, the solids blending scenario could be considered.

Storing 19% and <5% LEU at U.S. Facilities

The scenarios for the blend-down of Russian 19% LEU in the United States requires that the blend-down site must have capacity for storage of both the 19% LEU and the <5% LEU product. The 19% LEU material contained in the 5A/5B cylinders would be stored until it can be input to the blend-down process. Once 30B cylinders are filled with <5% enriched product, they would be moved from the process area to a storage area to await shipment to the fuel fabricator. The reference blend-down site considered in this study is one of two such facilities in the United States with an NRC license and associated infrastructure to possess and process all enrichments of uranium. The site license could be amended to include new storage and processing facilities for handling the UF_6 streams of interest in this report.

The baseline assumptions made for estimating storage costs are as follows:

- Accepting 19% LEU for storage is predicated on demonstrating a final disposition;
- The 19% LEU will comprise 20 metric tons/year in the form of UF_6;
- The required storage capacity for 19% LEU is 20 metric tons in 5A/5B cylinders, equivalent to one year of material receipts;
- The outgoing product would be approximately 87 metric tons/year of <5% enriched UF_6;
- The storage capacity for product UF_6 in 30B containers should be 87 metric tons, equivalent to one year of processing;
- Operating manpower will be required to support the UF_6 storage facilities;
- UF_6 storage areas should be enclosed, regardless of enrichment level;
- The 19% LEU and the <5% LEU will have separate storage facilities.

The following sections present estimates of capital and operating costs for the designated UF_6 streams. Estimated costs presented below are projected to be within a range of -10% to +30%.

Storage Costs for 19% Enriched UF_6

Estimated Capital Costs

To store 20 metric tons of 19% enriched UF_6, a storage facility of about 8,400 ft^2 would be required. At a cost of $105/$ft^2$, this storage building would cost about $880,000. This cost is unrelated to either particular process and is not included in the total estimated capital costs for the U.S. scenarios.

Table 16 summarizes the total estimated capital cost of a storage facility, which is about $941,000.

TABLE 16: ESTIMATED CAPITAL COSTS FOR 19% LEU STORAGE

Item	Capital Cost
Building 8,392 ft^2 @ $105/$ft^2$	$ 881,160
Drum handling equipment	$ 10,000
Criticality detection	$ 50,000
Total Capital Cost	**$ 941,160**

Operating Costs

It is assumed that the 20 metric tons of 19% LEU would be stored in 5A or 5B cylinders with overpacks. The total mass of 19% LEU to be stored is less than a quarter of the mass of the LEU product to be stored in the 30B cylinder as discussed below. However, because 19% LEU must be packed into smaller containers, this amount of material requires 20 times the number of containers, and thus, 20 times the number of handling operations, compared to the LEU product storage. Therefore, the personnel and operating costs of storing the 19% LEU are greater than those for storing the <5% LEU product.

The manpower estimate for surveillance and maintenance of this facility is summarized in Table 17.

TABLE 17: YEARLY MANPOWER ESTIMATE FOR 5A/5B STORAGE

Personnel	Required	$/hr each	$/yr each	$/yr total
Operators	2	40	83,200	166,400
Rad. technician	0.5	62	128,960	64,480
Clerk	0.5	40	83,200	41,600
Total				**272,480**

The total operating cost is estimated to be $356,000/year, as summarized in Table18.

TABLE 18: OPERATING COST SUMMARY FOR 5A/5B STORAGE

	Unit	$/Unit	Quantity	$/Total
Personnel	Total	272,480	1	272,000
Materials (PPE, maintenance, etc.)	Operator	23,920	2	48,000
Waste burial	Total	24,000	1	24,000
Other / miscellaneous	Total	12,134	1	12,000
Total				**356,000**

Storage Costs for <5% Enriched UF_6

Estimated Capital Costs

The current practice at U.S. fuel fabrication facilities is to store 30B cylinders outdoors on a concrete slab. It is probable, however, based on recent discussions with regulatory agencies, that storing UF_6 cylinders at a new processing facility would require an enclosed space. Therefore, storage is assumed to be in a warehouse.

The 87 metric tons of <5% LEU would require about 66 30B cylinders. Allowing for ample space to maneuver cylinders indicates a storage area of about 3,300 ft^2. The unit capital cost of this warehouse is estimated at \$105/ft^2 plus the cost of a bridge crane and a criticality detection system, giving a total capital cost of about \$456,500 as shown in Table 19.

TABLE 19: ESTIMATED CAPITAL COSTS FOR <5% LEU STORAGE

Item	Capital Cost
Building 3,300 ft^2 @ \$105/ft^2	\$ 346,500
Bridge crane	\$ 60,000
Criticality detection	\$ 50,000
Total capital cost	**\$ 456,500**

Operating Costs

Operating this storage facility will require additional personnel utilization, as summarized in Table 20, at an estimated cost of \$95,000/year. In addition to the personnel costs, the facility will require operating supplies, waste disposal, and other miscellaneous costs. The total of all operating costs is estimated to be \$127,000/year, as summarized in Table 21. It is assumed that adding a storage warehouse will not increase the annual security cost or other operating costs of the parent facility.

TABLE 20: YEARLY MANPOWER ESTIMATE FOR 30B STORAGE

Personnel	Required	$/hr each	$/yr each	$/yr total
Operators	0.5	40	83,200	41,600
Rad. technician	0.25	62	128,960	32,240
Clerk	0.25	40	83,200	20,800
Total				**94,640**

TABLE 21: ANNUAL OPERATING COST SUMMARY FOR 30B STORAGE

	Unit	$/Unit	Quantity	Total
Personnel	Total	94,640	1	95,000
Materials (PPE, maintenance, etc.)	Operator	23,920	0.5	12,000
Waste burial	Total	12,000	1	12,000
Other / miscellaneous	Total	8,090	1	8,000
Total				**127,000**

Alternative Storage Scenarios and Costs

This study provides that storage capacity should be provided for one-year's worth of 19% LEU and for <5% LEU product. However, it is conceivable that multiple years' worth of storage of either the incoming 19% LEU and/or the <5% LEU product may be required. For example the Russian blend-down facilities may produce 20 metric tons/year of 19% LEU for several years before the U.S. blend-down facilities' construction is complete. In such a case, the estimated storage costs would be modified to account for the larger volumes and requisite manpower required to handle the increased material.

Capital and Direct Costs by Scenario

Table 22 shows a summary of the capital and direct costs for the three scenarios for which blend-down is performed in the United States.

TABLE 22: ESTIMATED COST STAGE 2 BLEND-DOWN IN UNITED STATES—U.S. SCENARIO 2: GASEOUS UF_6 BLEND-DOWN

Scenario	Capital Cost ($M)	Direct Cost ($M/yr)
	4.0 MT HEU/yr Scenario	
A14-U.S.	20.9	10.5
	12.5 MT HEU/yr Scenario	
B13-U.S.	61.8	30.6
B14-U.S.	61.8	30.6

Note: The capital cost includes the blending facility and associated storage facilities. The direct cost includes the blending facility and associated storage facilities direct cost per year. The capital cost and direct cost estimates for the 12.5 metric tons scenario are determined by scaling up the 20 metric ton per year blending facility estimate given in the 4.0 metric ton HEU scenario by a factor of 3X and the associated storage facilities by a factor of 2.4X

CONCLUSIONS

Although some capital amendments to current U.S. HEU blend-down processes will be required, the Russian 19% LEU can be blended with U.S. natural uranium to produce 4.95% LEU that meets the 2004 ASTM UF_6 specification, and with good marketability within the commercial nuclear fuel industry of the final product. Re-enriching depleted tails as a blendstock would not be necessary unless the U-234 content of the 19% LEU is significantly worse than the assumptions for this analysis.

The U.S. blend-down scenarios discussed in this chapter are well understood and have been demonstrated at processing scale. Only the liquid blend-down system of U.S. Scenario 1 is currently licensed and operating in the United States. U.S. Scenario 1 offers the advantages of an existing blend-down facility, less UF_6 susceptible to release, and less likelihood of experiencing significant hurdles to licensing. U.S. Scenario 2 offers the advantages of reduced operating cost, no HF byproduct, and fewer total processing/conversion steps.

Category I nuclear facilities with their broad special nuclear materials licenses for storing and processing all enrichments of uranium are prime candidates for receiving, storing, and processing the 19% LEU. Such facilities may require amendments of their licenses for handling and processing UF_6 streams. Based on recent discussions with regulators, it appears that enclosed facilities for storing UF_6 will be required for new storage and processing facilities.

APPENDIX 4: INCENTIVES

This appendix is adapted from the paper below, available on the website of the Belfer Center for Science and International Affairs at Harvard University (www.belfercenter.ksg.harvard.edu):

> Bunn, Matthew. "Expanded and Accelerated HEU Downblending: Designing Options to Serve the Interests of All Parties." Paper presented at the Institute for Nuclear Materials Management 49th Annual Meeting, Nashville, TN, July 17, 2008.

INTRODUCTION

Russia is likely to have hundreds of tons of HEU not needed for plausible military purposes after the current 500-ton HEU Purchase Agreement is completed in 2013. Accelerating and expanding the blend-down of this excess HEU would have significant security benefits. Russia has made clear, however, that it will not extend the HEU Purchase Agreement on its current terms. What set of incentives might convince Russia that it was in its national interest to blend hundreds of tons of additional HEU to LEU, while protecting the interests of other key stakeholders?

Currently, Russia produces 1.5% enriched blendstock for the HEU deal by stripping tails, using almost as many separative work units (SWU) each year as are contained in the LEU delivered to the United States. Because Russia must also carry out several other processes to transform HEU weapons components to deliverable LEU, it costs Russia more to make LEU by blending HEU using this approach than it would to produce new LEU from scratch. Moreover, with Russia limited to selling only through USEC (formerly the U.S. Enrichment Corporation), USEC succeeded in negotiating below-market prices, so Russia receives less revenue than it would for commercial sales as well. Hence Russia has no incentive to continue the existing deal beyond the 500 tons already agreed.

But the current deal provides nearly half of the LEU required in the U.S. market. To partly replace this supply when the HEU deal ends in 2013, Russia and the United States have agreed on an amendment to the U.S.-Russian suspension agreement that would, in effect, allow Russia to compete for 20% of the U.S. market from 2014 to 2020, with all restraints removed thereafter. This agreement is designed to provide adequate supply while making it possible for the firms planning investments in new enrichment plants in the United States—now including Louisiana Energy Services, USEC, Areva, and GE-Hitachi—to plan and raise funds. Recent U.S. court decisions that determined that enrichment is a service, not a good—and hence not subject to U.S. anti-dumping laws—could open the U.S. market to unrestricted Russian exports, if not reversed by the U.S. Supreme Court or by further legislation.9

Clearly, the possibility of large additional supplies of LEU from HEU could have a major affect on uranium and SWU markets. Unexpectedly releasing large quantities of LEU from HEU could crash prices and disrupt much-needed investments in uranium mining and enrichment capacity.

[9] Most Russian SWU are sold as enriched uranium product, which contains uranium that would still be subject to anti-dumping laws and agreements, but this could change over the longer term.

But uranium mine output is still far below annual consumption and there are long time lines to expand production to meet demand. Utilities would love to purchase more SWU than are currently available to save on expensive uranium by driving down tails assays. In short, if handled appropriately, LEU from large additional quantities of HEU could play a key role in fueling nuclear growth while mining and enrichment capacity expand—without unduly competing with existing suppliers.

THE INTEREST OF KEY PARTIES

No agreement to expand and accelerate the blend-down of Russian or U.S. excess HEU will succeed unless it is structured in a way that serves the interests of all sides. What are the key interests that must be addressed?

The Russian nuclear industry today is growing and well-financed, not desperate for cash as it was in 1992 when the HEU Purchase Agreement was first agreed. Moreover, the amount of HEU remaining is smaller and U.S.-Russian strategic relations are worse than was the case in 1992. Today, Russia's top priorities related to considering options for expanded and accelerated blend-down of HEU are (1) maintaining sufficient stocks of HEU for remaining military needs; (2) ensuring sufficient fuel for Russia's strategic initiatives to expand nuclear reactor construction at home and abroad; (3) establishing a major international presence as a reactor and fuel vendor, including maximizing the international competitiveness of Russian nuclear reactor exports and fuel leasing services; (4) gaining equal footing in international fuel markets, including expanded and stable access to U.S., European, and Asian enrichment and uranium markets on profitable terms; (5) maximizing the potential value available from HEU; (6) building long-term U.S.-Russian partnership in nuclear energy development; (7) maintaining employment for key nuclear workers and facilities; and (8) avoiding domestic political confrontations over selling off "Russia's patrimony." Reducing the proliferation dangers and arms reduction obstacles posed by large HEU stockpiles and the costs of storing these stockpiles are presumably also objectives Russia shares, although they have not been strongly articulated in Russia's HEU policymaking. Of these interests, supporting Russia's major strategic initiatives in nuclear energy is likely to be more important to Russia's approach to HEU blend-down than modest quantities of additional profit to be made.

Russia sees its HEU stockpile as a national patrimony, bought at the price of years of blood and toil. The default Russian view is likely to be to say "nyet" to large-scale additional HEU blend-down beyond the 500 tons covered by the original HEU purchase agreement. The key, therefore, is to explore whether there exists a set of circumstances under which expanding and accelerating the blend-down of HEU could be so strongly in Russia's national interests that the Russian political establishment is convinced that it should go this route. What set of incentives could turn "nyet" into "da"?

U.S. government interests related to expanding and accelerating the blend-down of Russian HEU include (1) achieving the nonproliferation and arms reduction benefits of reducing HEU stockpiles as quickly as possible; (2) maintaining a viable domestic enrichment industry (an objective mandated by U.S. law); (3) ensuring an adequate and reliable fuel supply for a growing U.S. nuclear energy enterprise, including avoiding undue dependence on only one source and avoiding price crashes that would undermine needed investments; (4) minimizing cost to the U.S. government; and (5) to the extent consistent with the above objectives, reducing fuel costs to U.S. nuclear utilities. Of course, the United States, like Russia, seeks to maintain enough of its own HEU for both nuclear weapons and naval fuel.

U.S. industry interests are to some extent split between fuel consumers and producers, although all have a strong interest in stable, predictable markets. U.S. utilities want assured supplies of fuel in both the near term and the long term, at reasonable and stable prices. But with multibillion dollar investments in nuclear reactors, making sure the fuel will be there is more important than its price. Release of additional material blended from Russian HEU would be strongly in the interests of U.S. nuclear utilities—especially if handled in a way that avoided scaring off the investments needed to provide long-term uranium, enrichment, and conversion supply. U.S. uranium producers, enrichers, and converters want stable and high prices for their products and services, and predictable limits on the entry of additional foreign material into the U.S. market, which represents a threat to their market share and may drive down prices. Predictability—so that investors can make decisions with confidence on projects that may not pay off for a decade or more—is more important than absolute price, although perceptions of price trends (in particular, not creating perceptions that prices were likely to fall substantially) are important for maintaining the investment needed to bring annual production into balance with annual demand.

Although there are many specific variations from one country to another, in general, the interests of European and Asian governments and their nuclear industries are similar to those for the U.S. government and industry, described above.

With appropriate mechanisms for making the release of LEU from HEU predictable and limiting any market damage it might otherwise cause, it should be possible to structure an approach that protects the interests of all parties. Approaches that could be considered include relying on existing economic incentives for Russia to make commercial use of its HEU; providing additional positive incentives for Russia to blend more HEU; threatening negative consequences (such as constraints on market access) if Russia does not blend more HEU; launching new partnership-based initiatives that include blending more HEU; and combinations of these approaches. Important criteria to consider for each option include (1) probability of Russian acceptance; (2) degree to which U.S. and other industry interests are protected; (3) the scale and pace of HEU blend-down that might be achieved; and (4) cost to the U.S. government or other governments of encouraging Russia to blend additional HEU to LEU.

EXISTING INCENTIVES WITH A DIFFERENT APPROACH

From the point of view of international security, once HEU has been blended to LEU, it does not matter if that LEU is shipped to the United States or elsewhere, used in Russia, or simply stored. If, rather than shipping the LEU blended from HEU for sale and fabrication in the United States, Russia fabricated fuel from this LEU at its own fabrication facilities to fuel Russian reactors or Russian-exported reactors, it would not have to meet ASTM specifications, and it could blend the HEU with natural uranium or even with tails—saving more than 5 million SWU for every 30 tons of HEU blended.

If blended with 0.2% U-235 tails, a ton of 90% enriched HEU would produce 21 tons of 4.5% enriched LEU. Blending 300 tons of HEU in this manner would be the equivalent of both a virtual uranium mine producing 6,400 tons per year for ten years and a virtual enrichment plant producing 3.9 million SWU per year for ten years.[10] Of course, there is no requirement that the blending to LEU and commercial release on the market have to occur at the same rates: it might well turn out to serve Russia's interests better to meter the material onto the market more slowly, even if the blending occurred rapidly. (It might serve U.S. and international interests to give Russia incentives to blend the HEU to LEU rapidly, but to carefully regulate the release of the blended LEU onto the commercial market.)

This amount of material would be enough to provide key support for Russia's strategic initiatives for growing domestic nuclear construction and nuclear exports. Russia is clearly concerned over getting sufficient uranium supplies to fuel its plants, and has been actively negotiating uranium deals not only with former Soviet countries but with major suppliers such as Australia and Canada as well. LEU blended from HEU could take the pressure off; combined with new production, there would be enough material to ensure that there were no uranium or SWU constraints on Russian nuclear energy growth or nuclear export growth for decades to come. (Indeed, as discussed below, there may be an opportunity for a joint U.S.-Russian initiative on nuclear energy and disarmament, focused on providing LEU from HEU for the initial cores of all U.S.-built or Russian-built reactors.)

Moreover, Russia could generate immense revenues from this material. Every ton of LEU blended from HEU used to fuel Russian-designed reactors would free up an additional ton of new-production LEU for export. If that freed-up LEU were sold at current long-term market prices of around $230 per kilogram of uranium and $150 per SWU, the LEU made from each ton of HEU would be worth more than $72 million. Blending 300 tons of HEU in this way would produce LEU worth some $22 billion.[11] The only thing Russia would need from other countries is enough market access to sell this uranium and SWU at market prices; this will require careful planning and market mitigation measures to avoid undermining the predictable prices necessary for investments in sustainable production capacity. Reactor operators will certainly be eager to buy such additional amounts of uranium and SWU in the 2013–2030 timeframe, and it should be possible to work out arrangements that make this possible without undermining the commercial prospects of Western producers.

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[10] This assumes 0.3% U-235 tails. At 0.2% U-235 tails, closer to the economic optimum at high uranium prices, the equivalent would be closer to 5,000 metric tons of uranium and 4.8 million SWU per year.

[11] Estimates of long-term contract prices provided by International Nuclear Enterprise Group. This is a gross revenue figure, not a profit figure. The other analyses of blending costs sponsored by the Nuclear Threat Initiative, however, suggest that the cost of blending this HEU to LEU would be a small fraction of the $22 billion in revenue, leaving room for many billions of dollars in profit to Russia.

LEU blended from HEU could support Russia's strategic objectives as a nuclear reactor and fuel exporter in other ways as well. In seeking export sales of reactors, Russia could offer a guarantee of lifetime fuel supply, with the assurance made especially credible by being backed up by a large LEU reserve made from blended HEU. This increased fuel assurance, plus the disarmament aspect of using up HEU, could make these reactors more attractive in relation to their competitors. Making LEU from HEU might be a particularly attractive approach for reactors that use LEU fuel with enrichment in the 8–19% range, where making material from HEU would greatly reduce enrichment costs; these include South Africa's planned pebble-bed reactors, future Russian floating reactors, the gas-turbine modular helium reactor (GT-MHR) being jointly developed by the United States and Russia, future small "nuclear battery" reactors, and others. LEU from HEU could supplement the fuel reserve at the Angarsk International Enrichment Center and could make participation in the Center more attractive for some countries, because of the link to disarmament; offering LEU from HEU could have a similar effect for Russia's hoped-for fuel leasing business.

Overall, there appear already to be significant incentives for Russia to blend down additional HEU. If Russia came to perceive additional blend-down of HEU as an important means to support its strategic objective in nuclear energy, it might well choose to pursue such expanded blending. Approaches focused on using this material for initial cores of new reactors and metering it into existing long-term contracts at a predictable pace could reduce undesirable market effects and protect the interests of foreign nuclear industries. Because Russia has not yet indicated any intention to blend down large additional quantities of HEU to LEU, additional incentives may be necessary to achieve such large-scale blend-down—especially if the security objectives of blend-down are to be achieved at a pace faster than Russia might require the material for its commercial purposes.

PROVIDING NEW INCENTIVES FOR EXPANDED BLEND-DOWN

A wide variety of options exist for the United States or other governments to offer additional incentives to help convince Russia to blend additional HEU to LEU. Incentives that could be offered include additional market access; payments of cash premiums for purchases of LEU made from HEU; paying Russia's costs to blend HEU to a 19% intermediate level, as a security investment; offering to transfer rich tails to Russia so that it could strip to produce additional LEU (or to reduce the blendstock costs of blending HEU for export to the United States); and agreeing to engage in new joint nuclear energy initiatives with Russia. Existing HEU transparency arrangements could be used to confirm that Russia had done whatever additional blending was agreed to.

Expanded Market Access

The recently amended Suspension Agreement effectively allows Russia to compete for 20% of the U.S. LEU market from 2014–2020 and 100% thereafter, without any linkage to additional blending of HEU. Russia is likely to resist any effort that would reduce the market access already agreed, reducing the options related to market access that are now available. Nevertheless, plausible market-access options include:

Access beyond the suspension agreement. Congress could consider passing legislation that would offer Russia expanded access to the U.S. market if Russia agreed to blend additional HEU. Senator Pete Domenici (R-NM), for example, has proposed legislation (discussed in more detail below) that would allow Russia to compete for 25%, rather than 20%, of the U.S. market if Russia continued to blend 30 tons a year of HEU after the existing HEU Purchase Agreement was complete (and would allow the LEU to be used in Russia rather than shipped to the United States, opening the opportunities for support for Russian strategic initiatives and large revenues discussed above). At this writing, this legislation has been attached to the Senate version of the supplemental appropriations bill. Discussions surrounding the Domenici legislation, however, suggest that those investing in new enrichment plants in the United States will strongly resist offering Russia the opportunity to compete for more than 25% of the U.S. market.

Access for SWU used to go to lower tails assays. The United States could allow Russia to sell additional SWU in the U.S. market, linked to additional blend-down of HEU, if those SWU were used to produce the same amount of LEU with lower tails assays. (Going from 0.3% tails to 0.2% tails can increase SWU requirements by 23%, potentially adding more than 2 million SWU per year to U.S. market demand.) This would not injure other SWU suppliers, and would modestly improve the uranium shortage situation.

Access for additional SWU sold to the firms establishing U.S. enrichment plants. The firms establishing new enrichment plants in the United States may suffer delays in building these facilities (as many past plants have); having access to SWU under their control that could allow them to limit their financial risk by fulfilling their enrichment contracts even if the plants do not begin operating on time could serve their financial interests. The United States could agree to allow Russia to sell SWU going beyond the levels in the suspension agreement if Russia blended additional HEU to LEU and if the additional SWU coming into the United States were sold to any of these firms, allowing them to build up reserve stocks. Because there are several such companies (USEC, LES, Areva, and GE-Hitachi), they would compete with each other for whatever SWU Russia wanted to sell and they wanted to buy, helping to ensure that Russia would get a fair price.

European and Asian governments could also consider linking expanded access to their markets to Russian agreement to expand HEU blend-down—such as by counting LEU blended from HEU as a separate supply that did not count against the limit on supply from any one supplier.

A Premium on SWU Purchases

Another approach would be for the U.S. government (or another government) to pay Russia a premium over the market SWU price for additional blend-down, saying, in effect, "for every SWU that you can demonstrate comes from HEU or is matched by a SWU in LEU that comes from HEU, we will pay you an additional $10 on top of the commercial price." At a blending rate of 30 tons per year, that would bring Russia $40–$50 million/year (depending on blending strategy), which would increase proportionally at a 42.5 tons/year blending rate. An obvious problem with this approach is that payments big enough to be a substantial incentive to Russia may be big enough to be difficult to get governments to appropriate.

Payment for Blending to 19%

Another option would be for the United States (or another government) to pay Russia a fee for blending an agreed amount of HEU to an intermediate level of 19% enriched LEU, which could then be stored until market conditions were right for Russia to use it (the timing and rate of commercial release possibly being limited by an agreement). Once HEU had been blended to 19%, Russia could draw on this stock for further blending to commercial levels as needed to meet its LEU contracts, thereby producing each kilogram of LEU with far fewer SWU and less uranium than would be required to produce it by enriching natural uranium. Indeed, the initial blending to 19% could be done with natural uranium (at the cost of needing 1.62% enriched blendstock for the final blending, if the LEU was to be sold in a way that required meeting ASTM C996-96 specifications); this would eliminate the need for enrichment for the initial blending, by far the most expensive and time-consuming element of the accelerated blend-down scenarios.[12] The size of the payment would, of course, be a matter for negotiation; it might well cover the full cost of blending to 19%, plus some profit for Russia (although, with the initial processing paid for, Russia would in any case make more profit from each kilogram of commercial LEU produced than it would if it had to cover the full cost of processing and blending, as it would in the existing incentives options above). Alternatively, once the material had been blended to 19%, it could be shipped to the United States for final blending and sale.

Providing Rich Tails for Blending or Stripping

The United States could agree to send a small portion of its comparatively "rich" depleted uranium tails to Russia if Russia agreed to blend down a specified additional amount of HEU. As discussed in other publications, making blendstock for deliveries that must meet ASTM specifications by stripping tails with 0.3% U-235 would require far fewer SWU than producing blendstock from 0.18% U-235 tails. Although many parties would like access to the uranium contained in these tails for direct enrichment to LEU, allocating some portion of the rich U.S. tails specifically to HEU blend-down would provide an additional nonproliferation benefit. Blending the 150 remaining tons under the existing HEU Purchase Agreement in this way would require less than 39,000 tons of the roughly 500,000 tons of tails in the U.S. stockpile (of which approximately one-third has a U-235 content of 0.3% or higher), and would free up more than a $1 billion worth of SWU, a higher value-added use for the material than any available in the United States (even without considering the national security benefits of blending additional HEU).[13]

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[12] This would be true if the concentrations of undesirable isotopes in the material to be blended were similar to those in the material blended so far. If material beyond the 500 tons covered by the existing HEU Purchase Agreement had higher concentrations of undesirable isotopes, different blending approaches might be required.

[13] It would take approximately 8.5 million fewer SWU (valued here at $150/SWU) to produce the needed 4,275 tons of 1.5% enriched blendstock by stripping 0.3% U-235 tails to 0.15% than by stripping 0.18% U-235 to 0.15%. For a discussion of the value-added of other options for these tails, see U.S. Congress, Government Accountability Office, *Nuclear Material: DOE Has Several Potential Options for Dealing with Depleted Uranium Tails, Each of Which Could Benefit the Government* (Washington, DC: March 31, 2008).

NEW U.S.-RUSSIAN INITIATIVES INCLUDING EXPANDED HEU BLEND-DOWN

Several options are available that would make expanded HEU blend-down one part of new joint U.S.-Russian initiatives on nuclear energy and nuclear arms reductions.

Linking to an Expanded U.S.-Russian Nuclear Energy Partnership

The United States and Russia are pursuing a range of cooperation on civilian nuclear energy. But there are several more ambitious types of U.S.-Russian nuclear energy partnership that could be pursued. The United States could seek to tie certain aspects of such a partnership to Russian agreement to blend substantial additional amounts of HEU.

In the early 1990s, in fact, then-Minister of Atomic Energy Victor Mikhailov proposed that the way HEU blend-down should be managed was with a U.S.-Russian joint venture that would market the resulting LEU and share in the profit. Such an arrangement may be less attractive to Russia today, now that Russia's nuclear infrastructure is on a sound economic footing and already has access to world markets without U.S. help. But there are a variety of potential advantages that might be gained from a broader partnership in which U.S. and Russian firms would jointly develop and market reactors, fuel, or both. For example, Rosatom and U.S.-based firms might agree to approaches that would blend the best U.S. technologies (such as advanced reactor control systems) and the best Russian technologies into next-generation reactors for export. Such reactors might be fueled with fuel blended from HEU, under fuel-leasing arrangements in which portions of the fuel would be made in the United States and portions in Russia, and the spent fuel shipped to Russia (if the United States proved politically unable to accept spent fuel returns). The United States and Russia might agree to use LEU blended from HEU to fuel advanced reactor types that the two sides might jointly develop (such as the GT-MHR, under joint development now, and small encapsulated reactors, as discussed above). As in purely Russian systems, use of blended HEU could make such systems more attractive to potential purchasers.

New U.S.-Russian Nuclear Energy-Disarmament Initiative

A major possible step would be a new U.S.-Russian joint initiative on nuclear energy and disarmament. Under this initiative, the United States and Russia would each pledge that they would make available LEU blended from HEU (beyond the 500 tons and 174 tons the two countries declared excess in the 1990s) to fuel the initial cores and the first reloads of each new reactor built in either of their countries, or that either of their companies exported, for a specified period (possibly the next two decades), or up to a particular number of reactors.

Such an initiative would provide assured initial fuel supply for all reactors purchased from the United States or Russia; would link growth of nuclear energy to continuing nuclear disarmament (with each reactor built representing the destruction of something like 100 nuclear bombs); would avoid adding the demand "spike" from startup of each of these new reactors to a nuclear fuel market struggling to meet demand; and would not take away existing markets from existing suppliers.

Making LEU for the initial core for each 1000-GWe plant would require roughly 1.5–2.5 tons of 90% enriched HEU, depending on how the material was blended (and larger quantities if the HEU was less enriched). Fueling each such reactor would then require roughly 0.75–1 tons of HEU per year after that (again depending on the details of blending). Hence, if (1) Russia and the United States each committed to following this approach for all reactors they built domestically or exported for the next 15 years; (2) Russia succeeded in building 40 reactors during that time (more or less in line with current plans); and (3) Russia committed to provide both the initial core and the first three years of fuel for each of these facilities from blended HEU, that would result in blending an additional 180–270 tons of HEU. U.S. reactor construction rates are likely to be somewhat lower, at least at the beginning of the period, but this approach would also result in a substantial amount of additional blending of U.S. HEU.

NEGATIVE INCENTIVES IF RUSSIA DOES NOT BLEND ADDITIONAL HEU

Another class of approaches would focus on threatening to take some particular negative action unless Russia agreed to blend down specified quantities of HEU at a specified pace. The most commonly discussed approaches involve restricting or cutting off access to the U.S. or other nuclear fuel markets.

For example, early in 2008, some proposals considered in Congress (greatly modified later) called for limiting imports from Russia to 5% of the U.S. enrichment market (a 75% reduction from the level permitted in the suspension agreement amendment) unless Russia agreed to blend large amounts of additional HEU to LEU.

In the current political and market environment, such approaches may not work very well. Russia's government today is self-confident and flush with oil revenue, strategic relations with the United States have gotten worse, and in today's tight uranium and SWU markets, Russia's nuclear industry is likely to be confident that it can find markets for its products. Russia would likely see legislative imposition of drastic cuts in already negotiated market access unless Russia met new U.S. demands on HEU blend-down as bad faith on the U.S. part. The political fallout could be substantial. If Russia could negotiate adequate market access, it might well choose to sell its SWU in Europe and Asia instead. If that occurred, the market damage could be substantial (including skyrocketing U.S. fuel prices, at least for a period), although arrangements could eventually be made to export the displaced SWU to the United States.

COMBINATIONS OF APPROACHES

Of course, policymakers could combine multiple approaches incentives from the menu presented above. Senator Pete Domenici (R-NM), for example, has proposed legislation that would combine positive and negative incentives to try to convince Russia to blend an additional 300 tons of HEU. In the version passed by the Senate in its version of the supplemental appropriations bill, Russia would have been limited to 17% of the U.S. fuel market (as opposed to 20% specified in the amended suspension agreement) unless it agreed to continue blending HEU beyond the 500 tons covered by the existing agreement; the fraction of the market Russia could compete for would increase as Russia blended more HEU, up to a cap of 25% of the U.S.

market at a blending rate of 30 tons per year. Although the 20% limit in the amended suspension agreement would expire in 2020, under the Senate bill, the cap would not expire until an additional 300 tons of HEU had been blended. This provision was heavily criticized by Rosatom Chief Sergei Kirienko as unilaterally rewriting a trade deal already agreed to, and was not included in the final appropriations act. Sen. Domenici has since floated a revised version that would give Russia access to 20% of the U.S. market, and would expire in 2020, as with the suspension agreement, but would allow Russia to compete for up to 25% of the U.S. market if it blends additional HEU. Domenici has made the point that this additional 5% of the U.S. market would mean as much as $1 billion in additional sales for Russia during the period between expiration of the current HEU deal and 2020.[14] Whether some provision of this kind will be passed into law this year remains uncertain.

U.S. RECIPROCITY

In the original negotiation of the HEU Purchase Agreement, reciprocity, in the sense of the United States also blending large stockpiles of HEU to LEU, was only a minor issue. At that time, with its nuclear industry in desperate financial condition, Russia was primarily interested in the revenue from the LEU to be produced; Russian officials may have seen U.S. blending as introducing more material in the market that would compete with their own.

In today's context, however, for Russian officials to make the case domestically for blending large additional quantities of HEU may require the United States taking similar action. Because the two sides have HEU stockpiles of quite different size (and probably somewhat different HEU requirements for weapons and naval fuel), exact equality—a kilogram of U.S. HEU blended for every kilogram of Russian HEU blended—is not likely to be a sensible goal. Rather, the two countries should consider, as they agree on lower numbers of nuclear weapons, agreeing to reduce their HEU stockpiles in parallel to the minimum required to support those remaining warhead stockpiles (plus a modest additional stock for naval fuel).[15]

CONCLUSIONS AND RECOMMENDATIONS

Blending hundreds of tons of HEU beyond the 500 tons covered by the existing HEU Purchase Agreement to LEU, and accelerating the pace of blend-down, could contribute substantially to U.S. and international security. Technology is available that could make it possible to accelerate the blend-down. Russia has made it clear that it does not plan to continue the existing arrangements beyond the 500 tons already agreed. But a variety of other arrangements could be designed under which Russia would have far greater economic and strategic incentives to expand and accelerate the blend-down of its HEU.

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[14] See "Politics on Supplemental Leave Domenici Amendment Behind," *UX Weekly,* June 23, 2008, and "Domenici Steps Up Promotion of Uranium Enrichment Plan in FY2009 Supplemental Spending Bill," press release, June 11, 2008.

[15] See discussion in Bunn, M. and A. Diakov, "Disposition of Excess Highly Enriched Uranium," in International Panel on Fissile Materials, *Global Fissile Materials Report 2007.*

Drawing on the menu of options provided in this report, the United States should begin negotiations with Russia with the goal of gaining agreement on an expanded and accelerated HEU blend-down approach, going well beyond the 500 tons covered in the existing HEU Purchase Agreement.

Other interested governments should also seek to give Russia incentives to blend down additional HEU, including offering additional market access for LEU blended from HEU, or matched by LEU blended from HEU.

The United States should be prepared to agree to expand and accelerate its own blend-down of excess HEU.

The United States and Russia should agree to reduce their nuclear weapon stockpiles to low levels, and to reduce their HEU stockpiles to the minimum required to support those low levels of nuclear weapons plus a modest additional stock for naval fuel.

GLOSSARY

Term	Description
0.3% tails	Depleted uranium enrichment tails with a U-235 content of 0.3%
CEP	Condensation/evaporation plant for UF_6 sublimation from containers for transfer to process installations and its desublimation from process installations into containers
CFL	Central Factory Laboratory
CMP	Chemical Metallurgical Plant
Costs of decommissioning	Money required for shutdown, preservation, or restoration to Greenfield status of a facility with an expired service life
D&D	Decontamination and Decommissioning
Desublimation	Phase transition of a substance from gaseous to solid state
Economic analog	Facility with characteristics similar to a new facility
ECP	Production Association "Electrochemical Plant," Zelenogorsk
EPS	Emergency Protection System
HEU	Highly enriched uranium
HEU Blend-down	Blending of HEU with a blendstock to produce an LEU product
HEU components	Metal articles from HEU extracted from nuclear weapons
HEU Purchase Agreement	Agreement between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted From Nuclear Weapons of 1993, http://www.nuclear.energy.gov/pdfFiles/heuPurchaseAgreement.pdf
ISP	Isotope Separation Plant
kSWU	Thousand separative work units, a measure of uranium enrichment effort
LEU	Low-enriched uranium
LEU blendstock	low-enriched uranium - blendstock
LEU product	low-enriched uranium product
LEUN	Low-enriched uranyl nitrate
MC&A	Materials control and accounting
MP	Mixing plant

NPP	Nuclear Power Plant
PA Mayak	Production Association “Mayak,” Ozersk
Pouring	The de-sublimation and liquid-phase transfer of UF_6 to cylinders
PS	Pouring section
Refinement	Product purification
SCC	Siberian Chemical Combine
SNiP	Rules and standards used in capital construction in Russia (approved by the RF Federal Construction Agency)
SP	Sublimate Plant
SPS	sample packing section
Sublimation	Phase transition of a substance from solid to gaseous state
SWU	Separative Work Unit, a measure of uranium enrichment effort
Tails	Depleted UF_6 produced during source material enrichment in separation production, U-235 content lower than one in natural uranium
Tails Assay	The U-235 content of the depleted uranium discharged from a uranium enrichment facility, expressed as weight percent U-235
U_3O_8	Uranium mixed oxide (UMO)
UECC	Urals Electrochemical Combine, Yekaterinburg
UF_6	Uranium hexafluoride (UHF)
USEC	Formerly the U.S. Enrichment Corporation, operator of U.S. enrichment facilities