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Options for Creating a Nuclear Fuel Stockpile for Assured Nuclear Fuel Supply

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ABSTRACT

Rising world demand for fossil fuels, in conjunction with their decreasing availability, continues to drive a steady increase in the relative price of fossil energy. This increasing price of fossil fuels, compounded by environmental concerns about the release of carbon dioxide, is causing a surge of interest in nuclear power as an economic and dependable source of clean energy. Complete indigenous nuclear fuel cycles, however, are not attractive economic investments unless very large in scale; additionally, they pose substantial proliferation risks. In order to help persuade countries to develop nuclear power plants but to forgo development of indigenous nuclear fuel cycles, mechanisms to assure nuclear fuel supply must be developed. Assurances of nuclear fuel supply and spent fuel take-back can provide a means for States to confidently implement nuclear energy programs while insuring that an increased level of proliferation resistance is maintained.

This paper examines the economic and political implications of a scenario in which a stylized deal for the continued blend-down of Russian highly enriched uranium (HEU) is used to supply a low-enriched uranium (LEU) stockpile that is used as part of a system for fuel supply assurance. We present and offer exploratory analysis of a series of questions for both government and industry regarding the assurance of this nuclear fuel supply. Key questions, including the impact on the market of an LEU stockpile, are raised and considered.

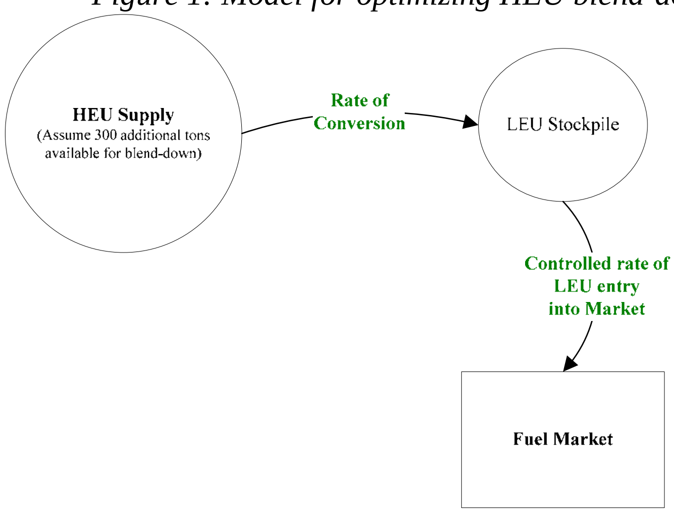
INTRODUCTION: THE NEED FOR FUEL SUPPLY ASSURANCE

As fossil fuels become scarcer, nuclear power is seen as an increasingly attractive and dependable source of clean energy. However, enrichment and reprocessing facilities do not provide attractive rates of return unless they are very large scale, in order to maximize economies of scale. Widely distributed ownership of these fuel cycle elements also poses substantial and probably unacceptable proliferation risks. The fuel market has functioned well to allocate fuel to existing reactors for decades. *Actual* disruptions in fuel supply have not historically constrained reactor operations even in politically sensitive cases. However, it can be plausibly argued that *potential* disruptions in fuel supply may deter new reactor construction, or may increase the probability that a State would attempt to develop a complete fuel cycle, particularly in cases where political isolation is a daunting factor for governments considering investment in nuclear power. Assurances of nuclear fuel supply (and, although not a focus of this paper, spent fuel take-back) can provide a means for States to confidently implement nuclear energy programs and ensure that adequate proliferation resistance is maintained. One of the effects of a fuel supply assurance program would be to underwrite some of the risk associated with a nuclear renaissance.

In addition to underwriting risk for legitimate new reactor customers, providing an assurance program under neutral international management removes an argument for indigenous enrichment programs. Enrichment plant economies of scale require roughly 3.0 million separative work units (SWU) to achieve competitiveness in the current industry; without enrichment demand significantly higher than is found in countries with new or emerging nuclear power programs, these countries should find it economically difficult to justify investment in an indigenous enrichment program (unless building enrichment capacity is not motivated by economics). In this context, a fuel assurance program clarifies the motivations of those states which choose indigenous enrichment for emergent nuclear programs. U.S. President Bush and IAEA Director General Mohamed El Baradei have both emphasized the need for controlling proliferation of enrichment and reprocessing technologies, which are listed as "sensitive technologies" by the Nuclear Suppliers Group because they provide the means for a country to produce weapons-useable fissile material. El Baradei also indicates that an integral step to bringing proliferation-sensitive parts of the fuel cycle under multinational control, thus lowering the risk of their diversion to weapons, is to create a mechanism ensuring a reliable supply of reactor fuel to bona fide users. Such a mechanism might include a fuel bank under control of the International Atomic Energy Agency.[1]

The political and economic implications of using and creating a stockpile for fuel supply assurance are examined in this paper through a scenario in which additional Russian ex-military highly enriched uranium (HEU) is down-blended to low enriched uranium (LEU) for the nuclear fuel stockpile. A conceptual model (see Figure 1) shows the interaction of the following critical factors: 1) Continuing and accelerating the U.S.-Russia HEU I agreement, 2) Introducing LEU from blended down HEU to the fuel market without impacting market stability, and 3) Creating an LEU nuclear fuel stockpile out of blended-down material considered excess to market demand.

Figure 1: Model for optimizing HEU blend-down through creating a Fuel stockpile



ACCELLERATED HEU BLEND-DOWN

The first U.S.-Russian HEU Purchase Agreement, signed in 1992, allows for the U.S. and Russia to collaborate in blending down over 500 metric tons of Russian highly enriched uranium (HEU) sourced from dismantled nuclear weapons. Under this agreement, 30 metric tons of HEU are blended down each year and shipped to the U.S., where they supply roughly 50% of U.S. nuclear power reactor fuel requirements. This agreement is due to expire in 2013, leaving a substantial amount of HEU surplus for weapons needs in Russia. A portion of this material, possibly in the range of 300 MT, might be available by Russia for additional blend-down under the right circumstances.[2]

There are significant nonproliferation benefits to reducing Russia's surplus HEU stockpile *at the fastest rate that is politically and economically feasible*. The benefits include reducing the amount of weapons-grade HEU available. Indirectly, an LEU stockpile to support assured fuel supply may deter more countries from developing enrichment and reprocessing plants and thus weapons useable material. Creating an HEU II agreement will be a significant challenge, and will undoubtedly require substantial negotiation between the U.S. and Russia to determine mutually agreeable terms and conditions.[3] For instance, despite the revenue generated for Russia and Rosatom, it has been widely publicized that Russia sees the HEU I deal as a subsidy for the United States Enrichment Corporation (USEC), as USEC receives an attractive margin for its handling and short-term financing services.[4,5] It is possible that Russia may prefer to use its excess uranium enrichment capacity (SWU), currently being used to produce diluent for blend down, to produce fuel which it could sell on the growing commercial market for a higher price. Other questions in establishing an HEU II blend-down agreement could include the cost and structure of blend down arrangements and LEU fuel delivery, U.S. quotas for Russian LEU, and the financing of new enrichment and other processing facilities to produce sufficient feed material enabling accelerated HEU blend down and LEU manufacturing.

Reducing the HEU available in Russia through accelerating HEU blend down is an important nonproliferation goal. However, it needs to be balanced against the economic cost of constructing new enrichment and processing facilities. There is limited capacity in Russia for blending down ex-military HEU. In order to conform to American Society for Testing and Material (ASTM) specifications, Russia enriches uranium tails to use as the diluent for the HEU blend down; Russia's lack of enrichment capacity for producing diluent is one of the limiting factor in accelerating blend down. Blend down currently occurs at the rate of 30 metric tons (MT) per year, although Russia has 1.6 MT of excess capacity that could be used to accelerate blend down to a maximum capacity (MC) of 31.6 MT per year. Accelerating blend down beyond of 31.6 MT per year would require capital investment and the construction of additional facilities for enrichment, chemical processing, and manufacturing.[6] Tables 1 and 2 provide estimates for the potential cost, construction time, and blend-down schedules for various HEU-I and HEU-II accelerated blend-down options.

Table 1. Cost and Schedule for Accelerated HEU I Blend-down Scenario[7]

	Base Blend down Rate	Maximum Capacity	Construction 5 MT New Capacity	Construction 10 MT New Capacity
Blend Down Rate Per Year	30 MT	31.6 MT	36.6 MT	41.6 MT
Capital Cost ($M) [8]	0	0	$162.7 M	$359.9 M
Construction Time (years)	0	0	3.5	5.0
Year HEU-I completed	2013	2013	2012	2012
Year +300 Ton complete	N/A	N/A	N/A	N/A

Table 2. Cost and Schedule for Accelerated HEU II Blend-down Scenario[9]

	Base Blend down Rate	Max Capacity	5 MT Capacity	10 MT Capacity	20 MT Capacity	30 MT Capacity	40 MT Capacity	50 MT Capacity
Blend Down Rate Per Year	30 MT	31.6 MT	36.6 MT	41.6 MT	51.6 MT	61.6 MT	71.6 MT	81.6 MT
Capital Cost ($M) [10]	0	0	$162.7	$359.9	$958.0	$1613.6	$2119.0	$2691.2
Construction Time (years)	0	0	3.5	5.0	8.0	10.0	10.0	12.0
Year HEU-I completed	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Year +300 Ton complete	2023	2022	2021	2020	2019	2019	2019	2020

Table 1 shows that there is little marginal benefit to building additional enrichment capacity if the sole purpose is to accelerate HEU I blend down. Even under optimistic circumstances, (i.e. assuming that negotiations for accelerated blend down of HEU I are completed in 2006, and construction of new capacity begins in 2007), new capacity would not be completed until shortly before the termination of the HEU I agreement. Adding new capacity would accelerate blend down approximately one year, at the cost of $156.9 million. However, building additional capacity could accelerate blend down under an HEU II agreement. Beginning construction of additional facilities *immediately following the successful negotiation of an HEU II agreement* would help ensure that additional capacity is available in time for the initiation of HEU II blend down.

The model represented in Table 2 assumes that an HEU II agreement is negotiated quickly (by the end of 2006), that there is a smooth transition from HEU-I to HEU-II, and that construction of any additional capacity to accelerated blend-down under HEU-II begins immediately (early 2007). From Table 2, it can be seen that HEU blend down can be accelerated through capital investment in new capacity. However, determining the optimal rate of accelerated blend down requires consideration of the projected time for establishing an HEU II agreement, as well as the amount of HEU to be blended down. Delays in reaching an agreement reduce the acceleration benefits gained from constructing new capacity, whereas blend down of larger amounts of HEU increases the benefits gained from constructing new capacity. The overall decision to invest in accelerated blend down will be impacted by these factors, as well as the nonproliferation value placed on accelerating the removal of HEU from Russia.

IMPACT OF BLEND DOWN ON FUEL MARKET AND LEU STOCKPILE

The HEU I agreement provided additional enriched uranium to the market, resulting in reduced need for uranium from other sources and commercial enrichment capacity. However, whether LEU from the HEU I agreement acted to depress fuel prices or inhibit investment in new enrichment capacity is unclear. One concern about an HEU II agreement is that the market will not be able to absorb the increased supply of LEU. If significant additional quantities of LEU are produced down without definite plans to deliver the material to a stockpile, and without *assurances to keep the material off the open market*, it could significantly depress the price of enrichment, jeopardizing the commercial enrichment industry. An influx of LEU on the market could also impact market structure, potentially pushing a marginal supplier of uranium or enrichment out of the market, discouraging an existing supplier from making a necessary investment to upgrade its capacity, or depressing investment in mining and other operations.[11] A structured blend-down agreement, including quotas or very specific conditions for the controlled release of blend down materials to the market, and provisions for excess blend-down material to be delivered to a stockpile, could mitigate industry concerns regarding the impact of HEU blend down on the market. Such a stockpile would be maintained under suitable management and used as part of a fuel supply assurance framework. Additional measures, including guidelines for releasing LEU from a stockpile, would most likely be needed to provide additional assurance to industry that LEU would not flood the market.

DETERMINING A CONTROLLED RATE OF LEU RELEASE

A LEU stockpile would grow proportionately with the rate of HEU blend down, and diminish as the material is released into the market. To estimate the rate at which new LEU is generated, and examine the growth of a LEU stockpile, we make several assumptions, including:

1) 300 MT HEU have been added in an HEU II agreement
2) The maximum capacity of 31.6 MT HEU in the current Russian blend-down complex is utilized beginning in 2007 and the complex maintains maximum utilization until the desired amount of HEU has been blended down. In this scenario, 500 MT material under HEU I, plus 300 MT under HEU II
3) The HEU II agreement accelerates blend down according to the MC+10 option. Construction of the additional capacity begins in 2007 and comes online in 2012.

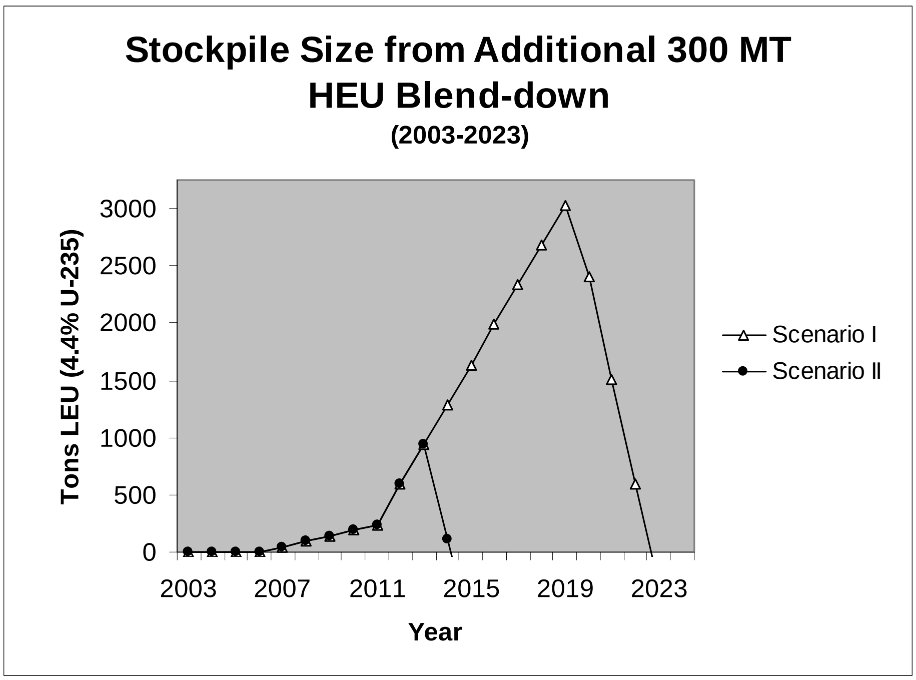
There has been significant discussion between industry and government regarding how much LEU can be introduced into the fuel market without causing a serious market disruption. A wide variety of variables, including the construction of new enrichment facilities, can impact the fuel market. Here, we describe two scenarios for the growth and depletion of a fuel stockpile which release LEU to the fuel market; the mechanisms for releasing LEU from the stockpile are chosen to minimize the industry impact of additional LEU on the market. For each scenario, we assume that if the need for a fuel supply stockpile does not continue beyond the time at which HEU II blend down is completed, excess material continues to be delivered to the market until the stockpile is consumed.

Scenario I: Baseline – Current USEC quotas applied to the HEU II agreement

Currently, annual quotas set by the USEC Privatization Act determine the rate of entry of the LEU component from the HEU deal into the U.S. market. W*e assume that the market will continue to be stable under these quotas.* As material is blended down under the HEU II agreement, LEU is released into the U.S. and international markets according to current USEC quotas.[12] After material is absorbed into the market according to USEC release quotas, the residual LEU created through accelerated blend-down is transferred to an LEU stockpile. (This assumes that the non-U.S. market does not plan to purchase additional LEU material beyond what is indicated in USEC quotas.) This scenario results in a maximum stockpile size, when the material under HEU II has been completely blended down, of approximately 3000 MT LEU in 2019. The stockpile could be maintained at this size as a mechanism for fuel supply assurance, or (as depicted here) sold on the market, according to quotas, until the stockpile has diminished, and is completely depleted by 2023.

Scenario II: Increase USEC quotas in proportion to demand growth
In Scenario II, USEC quotas are continued according to the current schedule until 2013, after which they are increased to accommodate all new global LEU demand. Demand forecasts for the U.S. and the World through 2025 are based on World Nuclear Association (WNA) projections.[13] This scenario creates a maximum stockpile size of nearly 1000 MT of LEU in 2013. LEU from the stockpile is used to fill all "new" world demand (i.e. any demand created following completion of the HEU I agreement) and is depleted by 2015.

Figure 3. Build-up and Utilization of Stockpile for HEU II Accelerated Blend Down



FINDINGS
Our modeling of the two scenarios defined above indicates that an LEU stockpile for purposes of fuel assurance would be a significant undertaking in terms of both the volume of material stored and the duration for which it must be held. The stockpile volume is defined by the differences in a blend-down rate which we wish to maximize (for non-proliferation reasons) and a release rate to the market (which must be constrained to avoid undue impacts on market function). The stockpile duration is governed by the long-term release rate, which is in turn a function of conditions for release and the industry growth rate.

Two different metrics for releasing LEU into the market were considered. Scenario I results in maximum stockpile sizes of approximately 3000 MT, and can be absorbed by the market with no demonstrable effects by approximately 2023. Scenario II, which allocates material from the stockpile to fill demand created by construction of new reactors, would reduce the stockpile size significantly faster. Hypothetically, this scenario would not impact the price of SWU, although it would most likely delay the time frame in which industry would choose to build additional capacity to fill new demand. Scenarios I and II illustrate theoretical maximum and minimum rates at which LEU could be introduced into the market. Further analysis, and input from industry, would be needed in order to determine an optimal rate of release.

POLICY QUESTIONS

Creating an LEU stockpile used to back a system of nuclear fuel supply assurances raises a variety of social, economic, and political questions that must be discussed before establishing a fuel stockpile. Key questions include: the organization, ownership, and management of a stockpile; options for storage, format, and location of a stockpile; and guidelines for allocating stockpile supplies to enforce nonproliferation regimes.

- **Stockpile Management and Fuel Ownership**: Who are the owners and managers of the fuel in the stockpile? The IAEA has indicated it would be willing to manage such a stockpile, a recent report by the WNA indicated that industry would support a fuel stockpile, with specific terms and conditions of use, under management by the IAEA.[14] What form should the stockpile take? Uranium Oxide? UF_6? Fabricated Fuel? Where should it be located? Is there one or more location? Should “flags” on the material be maintained?
- **Participation in Fuel Supply Assurance**: Which states would participate in a system of fuel supply assurance? Would participation be limited to those states that do not have full fuel cycle capability? Would states have to meet certain “nonproliferation criteria” (such as NPT membership) to participate?
- **Release of Fuel from the Stockpile**: What are the criteria for releasing fuel from the stockpile, and who determines those criteria? What is the role of the IAEA? What would be a reasonable cost for fuel supply? What terms would be used to supply the fuel? Would fuel be supplied for the lifetime of a reactor, or merely for a specified time frame, or in the form of core reloads?
- **Sale or Lease**: Is fuel supplied through direct sale, or a leasing mechanism? If the contract is structured as a sale, would there be guidelines for management of the spent fuel? If there is fuel take-back, by whom? What is the cost to the fuel suppler, and who pays for shipment? Where does it start/stop? China and Russia have expressed interest in spent fuel storage -- where is the material stored?
- **Long-Term Market Impacts**: Is there long-term impact of having assured fuel with respect to the commercial market? If spent fuel is stored at multiple facilities, and there are no flags, is U.S. (or other industry) fuel less competitive because it does have flags?

CONCLUSION

Creating an LEU stockpile could provide a useful mechanism for minimizing States’ interest in investing in domestic fuel cycle capabilities. Accelerating the blend-down rate of Russian HEU could both reduce proliferation concerns associated with the existence of large quantities of HEU as well as provide an initial means of supplying the stockpile. The overall decision to invest in additional capacity for accelerating blend down will be affected by several factors, including the nonproliferation value placed on removing excess Russian HEU. Similarly, a number of factors impact the optimum rate at which LEU resulting from HEU blend down can be released onto the market without a significant negative impact on industry. The creation of a stockpile raises critical policy questions which must be discussed in order to further protect the market, as well as create for benefit reactor owners concerned about security of supply. The clear and immediate nonproliferation benefits dictate further investigation of the options to accelerate HEU blend down and establish an LEU stockpile. Scenarios described in this paper can be used by governments, industry, and the IAEA to begin discussions on the most acceptable methods for stockpile supply, management, location, tolerable levels of release of material.

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[7] Assumes that an acceleration agreement for HEU I would be reached by early 2007, and existing excess capacity will be used beginning in 2007. Also assumes the successful negotiation of an HEU II agreement with a blend down schedule equivalent to, or accelerated from HEU I, and that construction for additional capacity will begin in 2007.

[8] Absolute value ($M) of capital investment, according to NTI

[9] Assumes that an acceleration agreement for HEU I would be reached by early 2007, and existing excess capacity will be used beginning in 2007. Also assumes the successful negotiation of an HEU II agreement with a blend down schedule equivalent to, or accelerated from HEU I, and that construction for additional capacity will begin in 2007.

[10] Absolute value ($M) of capital investment, according to NTI

[11] Since enrichment plant economies of scale require roughly 3.0 million SWUs to achieve competitiveness, it is unlikely that a new plant will be built unless there is sufficient demand for SWU to guarantee full capacity of plant operations, or unless there are other motivations for investing in enrichment capacity.

[12] Uranium Institute Trade Briefing, Issue 1, August 1999.

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