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Market for Uranium Enrichment Services

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Market for Uranium Enrichment Services

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January 15, 2003

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1. Introduction

Nuclear power presently supplies approximately 20% of electricity requirements in the United States (U.S.). Uranium enrichment is an integral step in the production of nuclear fuel for U.S. nuclear power plants. At the present time, less than one half of U.S. enrichment requirements are being produced by enrichment plants that are located in the U.S.[1] "In interagency discussions, led by the National Security Council, concerning the domestic uranium enrichment industry, there was a clear determination that the United States should maintain a viable, competitive, domestic uranium enrichment industry for the foreseeable future...Maintaining a reliable and economical U.S. uranium enrichment industry is an important U.S. energy security objective."[2] During 2002, two companies that offer uranium enrichment services worldwide announced plans to license and build new centrifuge based uranium enrichment plants in the U.S.[3]

This report presents an analysis of the market for uranium enrichment services during the period 2003 through 2020. It considers several scenarios associated with and without the proposed introduction of new uranium enrichment capacity in the U.S. In the context of this analysis, it is important to recognize that the market for uranium enrichment services is international in nature. The owners and operators of commercial uranium enrichment facilities that are located in seven countries sell uranium enrichment services worldwide. In addition, entities in several other countries enrich uranium to supply indigenous commercial requirements. Requirements for uranium enrichment services, which are associated with the operation of commercial nuclear power plants, presently exist in 28 countries. Market related changes that occur in one part of the world impact the supply and requirements situation throughout the world. Accordingly, in order to understand the behavior of the market for uranium enrichment services in the U.S., it is necessary to examine the world market

Section 2 provides a forecast of installed nuclear power generating capacity during this period. A forecast of world requirements for uranium enrichment services that corresponds to the forecast of installed nuclear power generating capacity is provided in Section 3.

Section 4 discusses current and potential future sources of uranium enrichment services throughout the world and an analysis of market supply and requirements under alternative scenarios is presented in Section 5.

Section 6 discusses the various commercial considerations and other implications of associated with each scenario. ERI's conclusions are presented in Section 7.

2. Forecast of Installed Nuclear Power Generating Capacity

ERI has prepared forecasts of installed nuclear power generating capacity by country and categorized them into the following five world regions: (i) U.S., (ii) Western Europe, (iii) Commonwealth of Independent States (C.I.S.) and Eastern Europe, (iv) East Asia, and (v) remaining countries are grouped as Other.

Eastern Europe consists of the following emerging market economy countries that were in the past classified as Communist Bloc countries and are operating nuclear power plants: Bulgaria, the Czech Republic, Slovakia, Hungary, Lithuania, and Romania. Of the 12 C.I.S. countries that were part of the former Soviet Union (F.S.U.), the three with nuclear power plants still operating are Russia, Ukraine and Armenia.

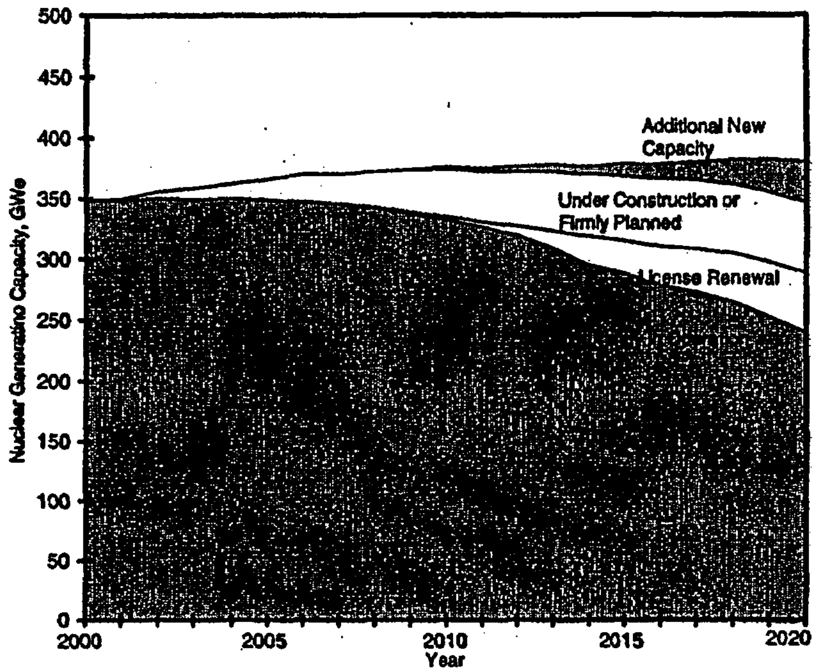
East Asia includes Japan, the Republic of Korea (South Korea), Taiwan, the People's Republic of China (P.R.C.) and North Korea. It is the only region forecast to increase nuclear power capacity significantly from current levels.

This forecast was based on ERI's country-by-country and unit-by-unit review of current nuclear power programs and plans for the future. The resulting ERI projections of future world nuclear generation capacity are dependent on the following factors:

- Nuclear generating units currently in operation and retirements among these units that occur during the forecast period;
- Capacity that is created by extending the operating lifetimes of units currently in operation beyond initial expectations through license renewal;
- Units under construction, already ordered, or firmly planned with likely near-term site approval; and
- Additional new capacity that will require site approval and will be ordered in the future.

ERI believes that world nuclear capacity will be dominated by plants currently in operation over the forecast period of this report, accounting for 82% of the total in 2015 and 75% in 2020. A small but significant contribution of 7% in 2015 and 13% in 2020 is obtained through license renewal. Units currently under construction, firmly planned or proposed will account for 14% in 2015 and 15% in 2020, while additional new capacity will account for 3% in 2015 and 9% in 2020. Cumulative retirements over the same period will amount to 10% of total operable capacity in the year 2015 and 17% in 2020, offsetting the amount of capacity currently under construction or firmly planned with site approval. Figure 1 presents ERI's forecast and composition of world nuclear generation capacity in these four categories:

Figure 1. Forecast and Composition of World Nuclear Generation Capacity



In the U.S., it is expected that a significant portion of existing units with operating licenses scheduled to expire by 2020 will find license renewal to be technically, economically and politically feasible. In fact, the U.S. Nuclear Regulatory Commission (NRC) granted the first license extension in the U.S. to the two unit Calvert Cliffs Nuclear Station in March 2000. By the end of 2002 a total of 10 units had been granted license extensions in the U.S. Applications for the renewal of operating licenses for 16 additional units have been submitted to the NRC for review, and the NRC has been notified of operator plans to submit applications for an additional 24 units during the next six years[4,5]. This accounts for approximately 50% of the installed nuclear generating capacity in the U.S. As of March 2002, the NRC expected "that virtually the entire operating fleet will ultimately apply" to renew their operating licenses.[6] The transition to a competitive electric generation market has not led to the early retirement of additional U.S. operating capacity, but instead has resulted in further plant investment in the form of plant power uprates. These have included more than 40 power uprates, representing approximately 1.7 Gigawatt electric (GWe) that have been approved by the NRC during the last three years (2000 through 2002), seven applications for power uprates that are currently under review by the NRC, and an additional 49 applications for power uprates that are expected by the NRC.[7]

ERI's forecast of installed nuclear power generating capacity is summarized in Table 1.

Table 1. Summary of World Nuclear Power Installed Capacity Forecast (GWe)

Year	U.S.	Western Europe	C.I.S. & E. Europe	East Asia	Other	World
2002	96.5	126.9	45.9	66.5	19.8	355.6
2005	97.8	124.8	47.6	74.6	21.4	366.2
2010	96.1	119.7	45.9	88.8	26.0	376.5
2015	92.3	113.5	46.0	101.2	25.8	378.8
2020	92.0	106.6	45.0	110.7	26.5	380.8

As shown in Figures 2 and 3 for the U.S. and world, respectively, these ERI forecasts are consistent with the most recently published forecasts of installed nuclear generation capacity prepared by the U.S. Department of Energy/Energy Information Administration (EIA)[8,9] and the World Nuclear Association (WNA)[10].

Figure 2. Comparison of Forecasts of U.S. Nuclear Generation Capacity

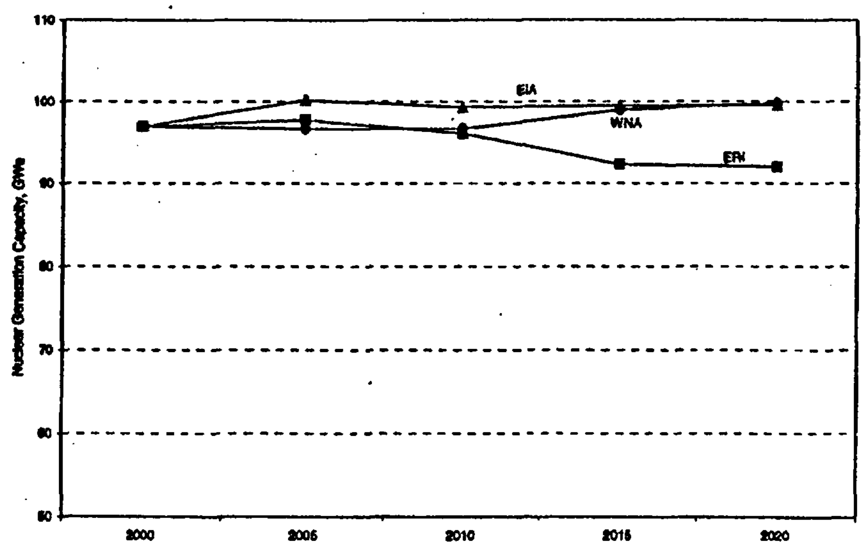


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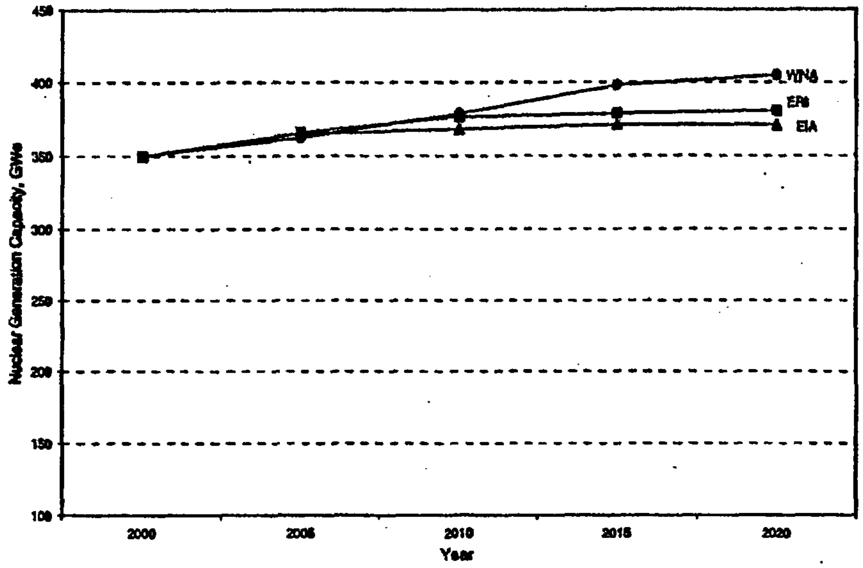
Figure 3. Comparison of Forecasts of World Nuclear Generation Capacity



On a world basis, ERI's forecast is consistent with an average annual nuclear power installed capacity growth rate of 0.8% through 2010, and a very low annual rate of growth, 0.1%, thereafter, as the effects of plant retirements begin to offset the introduction of new plants. World installed nuclear power capacity is forecast to rise a total of 5.9% from a present value of 355.6 GWe, which is estimated for the end of 2002 to 376.5 GWe by 2010, and to rise an additional 1.1% to 380.8 GWe by 2020. The corresponding annual average rate of change in installed nuclear power capacity by world region is presented in Table 2.

Table 2. Forecast of Annual Average Rate of Change in Installed Nuclear Power Capacity

World Region	Annual Rate of Change 2002 to 2010	Annual Rate of Change 2010 to 2020
United States	0.0%	-0.4%
Western Europe	-0.6%	-1.2%
East Asia	3.9%	2.2%
C.I.S./Eastern Europe	0.2%	-0.2%
Other	3.4%	0.2%
World	0.8%	0.1%

The period through 2010 generally reflects ongoing construction and some firmly planned additions, minus early retirements. The post 2010 period is governed by the retirement of existing capacity, as mitigated by license renewal, and additional new capacity that may not yet be firmly planned. Nuclear capacity in Western Europe is forecast to decline at a rate that increases noticeably after the year 2010, as the terms of existing operating licenses are reached and no new capacity additions are made. Nuclear capacity in the U.S. is forecast to decline slightly, even though several new nuclear power plants are forecast by ERI to become operational during the 2016 to 2020 period. A small increase for nuclear power is forecast for the C.I.S. and Eastern Europe through 2010, as many nuclear units using first generation Soviet technology are not retired as quickly as some in Western Europe initially anticipated would be the situation. However, retirements do result in a small decline after 2015. East Asia is forecast to show strong growth through 2010 and beyond, as nuclear continues to expand to fill a portion of growing energy needs in this part of the world. Countries in the Other region undergo modest growth through 2010 as ongoing construction projects are completed and some units placed on extended standby return to service, but little net growth is forecast thereafter.

3. Uranium Enrichment Requirements Forecast

A forecast of uranium enrichment services requirement was prepared by ERI consistent with its nuclear power generation capacity forecasts, which were presented in Section 2. A summary of the nuclear fuel design and management parameters that were used in developing the forecast of uranium enrichment requirements is as follows:

- Country-by-country average capacity factors rising with time from a world average of 80% in 2001 to 84% by 2010. The average capacity factor for the U.S. in 2001 was 90% and a capacity factor of 88% was assumed for the long-term;

- Individual plant enriched product assays based on plant design, energy production, design burnup, and fuel type (note that Russian designed fuel has a 0.30 weight percent (w/o) uranium isotope 235 (U-235) margin when compared to Western fuel design, while typical Japanese practice includes a 0.20 w/o U-235 margin);

- Enrichment tails assays of 0.30 w/o U-235, except for the U.S. where the assay has increased to 0.32 w/o; Japan (0.28 w/o); France (0.27 w/o); and the C.I.S. and Eastern Europe where tails assays of 0.20 w/o are assumed;

- Current plant specific fuel discharge burnup rates for the U.S., and country and reactor type-specific fuel burnup rates elsewhere, generally increasing in the future;

- Country (for some non-U.S. countries) and plant specific fuel cycle lengths (for the U.S. and other countries), collectively averaging approximately 20 months in the case of the U.S., and 16 months for all light water reactors (includes U.S. reactors);

- Equivalent uranium enrichment requirement savings resulting from plutonium recycle in some Western European countries (France, Germany, Belgium, Switzerland, and possibly Sweden) and Japan. The projections assume that the previously planned Japanese implementation of recycle will continue to be delayed and that the rate of implementation will also be slowed initially; and

- Equivalent enrichment requirements savings resulting from the recycle of excess weapons plutonium in the U.S. and Russia are also included. Total equivalent enrichment services requirements savings associated with recycling of commercial and military plutonium are in the range of 3% and 5% over the long term.

Table 3 provides a forecast of average annual enrichment services requirements by world region that must be supplied from world sources of uranium enrichment services. These requirements reflect adjustment for the use of recycled plutonium in mixed oxide (MOX) fuel. It should be recognized that on a year to year basis, there is both upward and downward annual fluctuations that reflect the various combinations of nominal 12 month, 18 month and 24 month operating/refueling cycles that occur at nuclear power plants throughout the world. Therefore, interval averages are provided in this table.

Table 3. World Average Annual Uranium Enrichment Requirements Forecast After Adjustment for Plutonium Recycle in MOX Fuel(Million SWU)

Period	U.S.	Western Europe	C.I.S. & E. Europe	East Asia	Other	World
2002	11.7	11.1	6.4	7.3	0.7	37.2
2003-2005	11.1	11.6	6.2	8.0	0.6	37.5
2006-2010	11.1	11.6	6.1	8.7	0.9	38.4
2011-2015	10.2	11.0	5.8	10.2	0.9	38.1
2016-2020	10.1	10.4	5.7	11.1	0.9	38.2

As shown in this figure, during the 2003 to 2005 period, world annual enrichment services requirements are forecast to be 37.5 million separative work units (SWU), which is only a 0.8% increase over the estimated 2002 value of 37.2 million SWU. ERI forecasts that annual enrichment services requirements will rise very gradually with the average annual requirements during the 2006 to 2010 period reaching 38.4 million SWU, an increase of 3.2% over 2002. Annual requirements for enrichment services are forecast to be virtually flat thereafter, averaging 38.1 to 38.2 million SWU per year throughout the period 2011 through 2020.

These ERI forecasts of uranium enrichment requirements in the U.S. and world are generally consistent with the most recently published forecasts by both the EIA and WNA. Figures 4 and 5 provide comparisons of the ERI forecasts with those published by these two organizations for U.S. and world requirements.[11,12,13] Since both EIA and WNA present their uranium enrichment requirements forecasts prior to adjustment for the use of recycled plutonium in MOX fuel, ERI has presented its forecasts in the same manner.

Figure 4. Comparison of Forecasts of U.S. Average Annual Uranium Enrichment Requirements Forecasts, Unadjusted for Plutonium Recycle in MOX Fuel

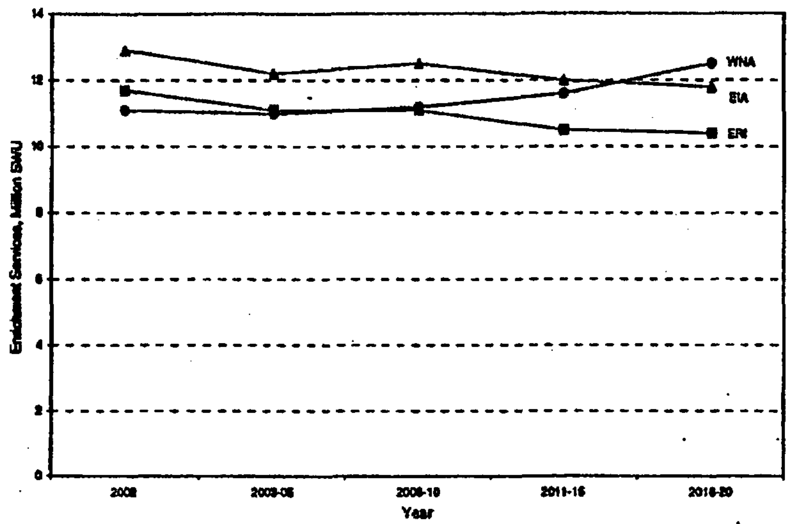
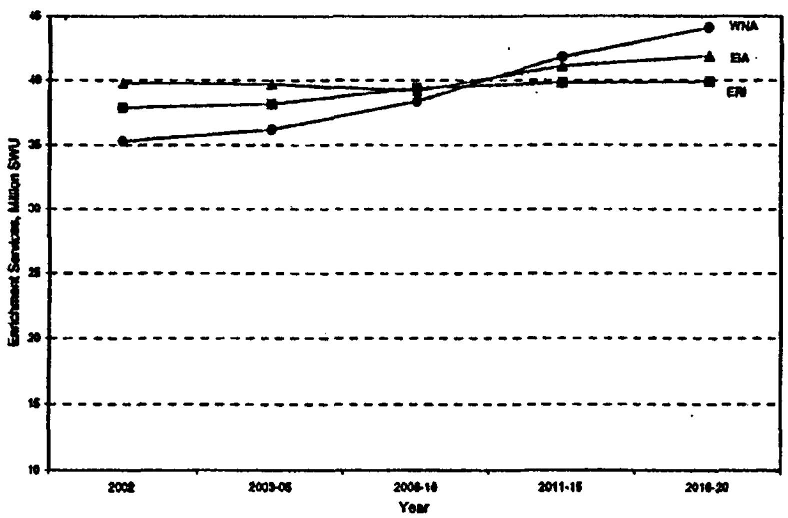


Figure 5. Comparison of Forecasts of World Average Annual Uranium Enrichment Requirements Forecasts, Unadjusted for Plutonium Recycle in MOX Fuel



Since the EIA does not publish a forecast of plutonium recycle in MOX fuel, ERI has compared its forecast of plutonium recycle in MOX fuel, which is developed based in part on published information[14], against that of WNA[15] and finds the forecasts to be in general agreement. ERI's assumptions, as reflected in Table 3, for the adjustment to uranium enrichment requirements associated with the utilization of plutonium recycle in MOX fuel are summarized in Table 4.

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Table 4. ERI Forecast of Adjustment for Plutonium Recycle in MOX Fuel to Uranium Enrichment Services (Million SWU)

Period	U.S.	World
2002	0.0	0.7
2003-2005	0.0	0.7
2006-2010	0.0	1.0
2011-2015	0.3	1.7
2016-2020	0.3	1.7

In the context of the analysis that is presented in subsequent sections of this report, it may be useful to note that ERI's uranium enrichment requirements forecasts, which are presented in Table 3, suggest U.S. requirements for uranium enrichment services (Figure 4) that are between 11% and 15% lower than the average of the EIA and WNA forecasts during the period 2011 through 2020 and between 4% and 8% worldwide (Figure 5) during this same period. If the slightly higher EIA or WNA forecasts for uranium enrichment requirements were used by ERI in the subsequent analysis that is present in this report, then an even greater need would be forecast for newly constructed uranium enrichment capability.

4. Current and Potential Future Sources of Uranium Enrichment Services

Table 5 summarizes current and potential future sources and quantities of uranium enrichment services. These sources include existing inventories of low enriched uranium (LEU), production from existing uranium enrichment plants, enrichment services obtained by blending down Russian weapons grade highly enriched uranium (HEU), as well as new enrichment plants and expansions in existing facilities, together with enrichment services that might be obtained by blending down U.S. HEU. The distinction is made in this table between current annual "physical capability" and current annual[16] "economically competitive and physically usable capability", both of which may be less that the facility's "nameplate rating". In the case of facilities that are in the process of expanding their capability, the annual production that is available to fill customer requirements during the year is listed, not the end of year capability.

The nameplate rating is characterized as the annual enrichment capability of the enrichment cascades if all auxiliary systems were physically capable of supporting that level of facility operation, which is not always the situation in an older facility. The physical capability is characterized as the annual enrichment capability of the entire facility, taking into account whatever limits may be imposed by auxiliary systems, but independent of the economics associated with operation at that level of production. The economically competitive and physically usable capability refers to that portion, which may be all or part, of the physical capability that is capable of producing enrichment services that can be competitively priced. For instance, the cost of firm power during Summer can be several times higher than the cost of non-firm power that may be purchased under contract during the remainder of the year. In practice this limits the annual enrichment capability of electricity intensive gaseous diffusion enrichment plants. In addition, physically usable requires that the enriched uranium product that can be obtained from the enrichment plant that is not subject to international trade restrictions and will meet appropriate material specifications for its use in commercial nuclear power plants that operate in countries outside the C.I.S. and Eastern Europe.

Current total world annual supply capability from all available sources, independent of physical suitability of material or economics is presently estimated by ERI to be approximately 49 million SWU, as shown in Table 5. However, the total world annual supply capability of enrichment services that are used to meet C.I.S. and Eastern European requirements, plus those which are economically competitive and meet material specifications for use by Western customers, and are not constrained by international trade restrictions amounts to only 37.8 million SWU, as also shown in Table 5. This is only 0.4 million SWU greater than the estimated 2002 requirements of 37.2 million SWU, which was presented in Table 3. These conclusions are consistent with other recently published analyses of the market for uranium enrichment services.[17,18,19,20]

Table 5. Current and Potential Future Sources of Uranium Enrichment Services

Ref.	Source	Technology	Current Annual Physical Capability Millions SWU	Annual Economically Competitive and Usable Capability Million SWU 2002	2016	Comments Regarding Potential Future Action
1	Inventories	inventory	0.85	0.85	0.5	0.5 in 2005 onward. Includes existing LEU inventories, most of which will be used internally.
2	Urenco (existing)	centrifuge	5.4	5.4	3.5	Three European sites, declines as oldest units are retired.
3	Eurodif (existing)	diffusion	10.8	8.0	0.0	Scheduled to ramp down beginning in 2007 as replacement centrifuge plant begins operation.
4	USEC (existing)	diffusion	8.0	6.5	0.0	Scheduled to ramp down beginning in 2010 as replacement centrifuge plant begins operation.
5	Russian/Tenex	centrifuge	9.0	9.0	9.0	Approx. 6.3 is used to meet C.I.S. and Eastern European requirements, approx. 2.7 is exported to Western countries; exports could increase by 0.5.
6	Other (existing)	both	1.9	1.9	1.05	Primarily Japan & P.R.C. for internal use; expected to decline to approx. 1.25 by 2009.
7	Russian HEU-derived (includes 4.2 from blendstock)	inventory, down blending required	5.5	5.5	5.5	U.S.-Russian Agreement ends in 2013; may/may not be extended.
8	USEC – DOE HEU-derived	inventory, down blending required	0.6	0.6	0.0	Present supply is expected to be exhausted by 2006.
9	DOE HEU-derived (potential source)	inventory, down blending required	0.0	0.0	0.25	0.25 expected beginning in 2005, ramping up to 0.66 between 2009 and 2012, then back to 0.25.
10	Urenco (potential expansion and replacement)	centrifuge	0.0	0.0	3.5	Scheduled to ramp up at rate to achieve and maintain 7.0 in Europe by 2007.
11	Eurodif (new)	centrifuge	0.0	0.0	7.5	Scheduled to ramp up beginning in 2007, while ramping down existing diffusion capacity to achieve and maintain total capacity of 7.5 by 2016.
12	LES (new)	centrifuge	0.0	0.0	3.0	Scheduled to ramp up beginning in 2007, to achieve and maintain total capacity of 3.0 by 2012.
13	USEC (new)	centrifuge	0.0	0.0	3.5	Expected to ramp up beginning in 2010 to achieve and maintain total capacity of 3.5 by 2013.
14	Other (potential expansion)	centrifuge	0.0	0.0	0.6	Primarily P.R.C. capacity for internal use; expected to increase to match internal requirements.
15	Russian (constrained)	centrifuge	1.5	0.0	0.7	Expected to ramp down to achieve and maintain total of 0.7 by 2007 as exports increase.
16	Russian (tails enrichment)	centrifuge	1.6	0.0	0.0	Also constrained by Western trade policies.
17	Russian (outside of specifications for use in Western reactors)	centrifuge	3.7	0.0	0.0	Excess to internal needs and unsuitable for export; used to enrich tails to create uranium for internal use.
	Total		48.8	37.8	38.6	

The **Inventories** (Table 5, Ref. 1) refer to existing inventories of LEU that are held primarily by owners and operators of nuclear power plants in Europe and East Asia, those that are present in Kazakhstan, and to a limited extent elsewhere. ERI expects that most such inventories will be used internally at an average rate of just under one million SWU per year through 2004, and then at a rate of 0.5 million SWU beginning in 2005.

The **existing Urenco centrifuge enrichment capability** (Table 5, Ref. 2) refers to capability from existing machines that are presently in operation or in the process of being installed at Urenco's three European enrichment plants, which are located in Gronau, Germany, Almelo, Netherlands and Capenhurst, United Kingdom. These plants had a combined production capability of 5.25 million SWU at the end of 2001[21] and 5.85 million SWU per year as of end of 2002. Urenco is expected to produce 5.4 million SWU of enrichment services during 2002. Urenco machines that are presently being built and installed are expected to result in an average annual capability of 5.9 million SWU during the period 2002 through 2005. As the older units of enrichment capacity are retired, ERI expects the Urenco capability that is presently in operation will decline over time, reaching 3.5 million SWU per year in 2016.

The **existing Eurodif enrichment capability** (Table 5, Ref. 3) refers to capability from the 10.8 million SWU per year (nameplate rating) Georges Besse gaseous diffusion plant (GDP) [22]that is located near Pierrelatte, France. It should be noted that about 2.8 million SWU per year of the physically available Eurodif enrichment capability is not economically competitive due to very high electric power costs at that higher operating range.[23] According to the schedule that was announced by Areva (which is the holding company for Cogema - the majority owner of Eurodif and the company responsible for marketing its enrichment services), it is expected that the 8 (=10.8-2.8) million SWU per year in GDP enrichment capability may be split between customer deliveries and pre-production beginning in 2007, as the new replacement centrifuge plant begins operations. This will enable Eurodif to build up a surplus of enrichment services that it can use to supplement centrifuge production following the planned shut down of the Georges Besse GDP in 2012.[24] Accordingly, during the period 2005 through 2010 Eurodif is forecast to be able to supply to the market 7.1 million SWU on an average annual basis from the Georges Besse GDP, with the balance used to create the previously mentioned stockpile. Eurodif's ability to supply the market from this plant will drop to an average annual capability of 3 million SWU during the period 2011 through 2015, based on ERI forecasts for the Georges Besse GDP's last two years of operation.

The **existing USEC enrichment capability** (Table 5, Ref. 4) refers to capability from the 8 million SWU per year GDP, which is located in Paducah, Kentucky.[25] The annual nameplate capability of 11.3 million is not physically attainable without capital upgrades to the plant, which are not expected. ERI estimates that approximately 1.5 million SWU per year of the 8 million SWU capability is not economically competitive due to very high electric power costs in that operating range.[26] This is similar to the situation described previously for the Eurodif GDP. The commercial centrifuge plant construction schedule that was announced by USEC calls for the first increment of production from its new commercial centrifuge enrichment plant in 2010, followed by a rapid ramp up to full production by 2013. To optimize economic operation of its plants, ERI assumes that USEC would operate the Paducah GDP at the full 6.5 million SWU per year during 2010, and then shut down at the end of that year.[27,28] In so doing, it is assumed that USEC would be able to supply up to 3.9 million SWU to the market during 2010 from the Paducah GDP, stockpiling the balance to be used to supplement centrifuge plant production as it is being ramped up to full production capability.

Of the Russian 20 million SWU in total annual uranium enrichment plant capability[29,30] (Table 5, Refs. 5, 15, 16 and 17), Of this total amount, approximately 10 million SWU of its annual uranium enrichment capability is available for use in Western nuclear power plants.[31,32] However, current U.S. and European trade policies[33,34,35] effectively limit the quantity of Russian enrichment services that can be sold directly to Western customers to approximately 3 million SWU annually, of which 2.7 million SWU is the estimated level of Western exports for 2002. Approximately 4.2 million SWU per year of the remaining 7.3 (=10.0-2.7) million SWU per year of enrichment services that are constrained by trade policy are used to create highly enriched uranium (HEU) blendstock. This is estimated by ERI based on enriching 0.3 w/o U-235 tails material as feed up to 1.5 w/o U-235 product to be used as blendstock, at a tails assay of 0.11 w/o U-235, in the amount required to blend 30 MT of Russian HEU annually. Approximately 1.6 million SWU per year of it is used to recycle tails material (i.e., enrich tails to natural uranium assay or higher) for Urenco and Eurodif.[36,37] This is estimated by ERI based on enriching 0.3 w/o tails to produce 2,000 MT of uranium at a natural enrichment equivalent assay of 0.711 w/o U-235 at an operating tails of 0.2 w/o U-235. This leaves approximately 1.5 (=7.3-4.2-1.6) million SWU per year of trade policy constrained, but otherwise available, Russian enrichment capacity available for potential export. This capacity may be used to recycle Russia's own tails material to create the equivalent of natural uranium feed for export

Russia has an additional 10 million SWU of annual uranium enrichment capacity that does not meet material specifications for use in Western nuclear power plants. Approximately 3.7 million SWU of this additional annual Russian capacity is excess to the approximately 6.3 million SWU per year in C.I.S. and Eastern European requirements, but due to its material properties it cannot be exported to the Western world. This excess annual capacity is instead utilized by Russia for a combination of recycling of Russian tails material and to operate those plants at lower tails assays. Given the complexity of the Russian situation, Table 6 provides a summary of the sources and uses of Russian enrichment services as described above.

Table 6. Summary of Current Russian Sources and Uses of Enrichment Services

Source/Use	Current Annual Physical Capability Million SWU	Cross Reference to Table 5
Material Meeting Western Specifications		
• Exported to Western Countries	2.7	(5)
• Used for HEU blendstock	4.2	(7)
• Used to enrich tails for European enrichers	1.6	(16)
• Constrained material excess	1.5	(15)
Material Not Meeting Western Specifications		
• Used in C.I.S. and Eastern European Nuclear power plants	6.3	(5)
• Used internally to process tails	3.7	(17)
Total	20.0	
Russian HEU-derived SWU in excess of blendstock	1.3	(7)

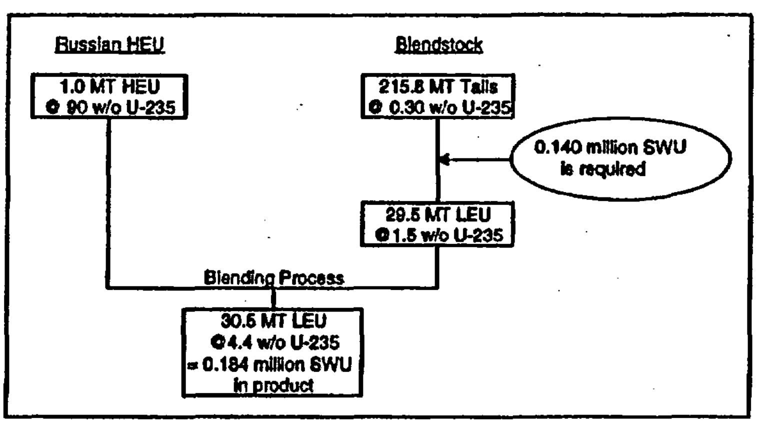
The **Other existing capability** (Table 5, Ref. 6) is dominated by approximately 1 million SWU of annual centrifuge and diffusion enrichment capability in the Peoples Republic of China (P.R.C.), 0.9 million SWU of annual Japanese centrifuge enrichment capability, and 0.1 million SWU of annual capability from other countries. The majority of this capability is used internally, although the P.R.C. exports small amounts from time to time. The P.R.C. is gradually replacing its small diffusion enrichment capability with centrifuge capability that is imported from Russia. The Japanese capability is expected to gradually decline, reaching zero by about 2009, due to high failure rates that have limited centrifuge operating lifetimes. Brazil has recently announced its plans to begin operation of a small uranium enrichment facility, which will be gradually ramped up to meet its internal requirements.[38,39,40,41,42,43,44,45]

The **Russian HEU-derived LEU** (Table 5, Ref. 7) while expected to average just over 6 million SWU per year during 2003 through 2005 to allow for catch up on previous deliveries, is expected to return to an annual level of 30 MT HEU or approximately 5.5 million SWU through 2013, when the term of the current U.S.-Russian agreement for 500 MT HEU concludes.[46] Ongoing discussions continue between the U.S. and Russia regarding additional quantities of Russian HEU-derived LEU for the post 2013 time period.[47] While recognizing a very high level of uncertainty, one might postulate that this arrangement may continue beyond the term of the present agreement, and possibly at the current level of 5.5 million SWU per year. It is important to note, as explained below, that in order to create and utilize the 5.5 million SWU contained in the LEU that is derived from the Russian HEU, 4.2 million SWU contained in blendstock is required. Therefore, the net addition to world supply is only 1.3 (=5.5-4.2) million SWU per year.

By way of background it should be understood that the HEU recovered from nuclear weapons, which is reported to have a U-235 assay of approximately 90 w/o, can be converted to LEU that is usable in commercial nuclear power plants by blending it with slightly enriched uranium; for example, 1.5 w/o U-235 uranium blendstock. Since the mass difference enrichment technologies, which are gaseous diffusion and gas centrifugation, enrich the undesirable light isotope U-234 at a higher rate than they enrich U-235, the 0.0054 w/o trace concentration of U-234 in natural uranium (which might otherwise serve as the feed material to create the 1.5 w/o blendstock) is amplified to on the order of 1.25 w/o in 90 w/o U-235 HEU. Fortunately, the reverse is also true and the U-234 isotope is depleted at a greater rate than U-235 in the enrichment plant tails streams; for example, down to 0.0014 w/o in 0.30 w/o U-235 tails. Because of this, enrichment plant tails provide a good starting point for the production of slightly enriched uranium blendstock (e.g., 1.5 w/o U-235) and are therefore used for blending down the 90 w/o Russian HEU.[48] In short, the two-step process, the enriching of tails to produce 1.5 w/o LEU blendstock (assuming a tails assay of 0.11 w/o U-235) and the actual blending of the HEU with this LEU blendstock results in the dilution of U-234 to a level that conforms with the industry's nuclear fuel material specifications.

Figure 6 illustrates this process and presents HEU to LEU conversion relationships that highlight the contribution of the enrichment services that are associated with creating the blendstock relative to the enrichment services that may be associated with the resulting product, which is available for use in commercial nuclear power plants.

Figure 6. Relationship Among HEU, Blendstock, Product



As illustrated in Figure 6, 76% (=0.140/0.184) of the SWU that is available in the product must have been expended to produce the blendstock. Therefore, assuming that 30 MT HEU is processed each year to yield LEU that contains the equivalent of 5.5 million SWU, then 4.2 million SWU (=.76*5.5) of this amount is expended in producing the blendstock. The net amount of additional SWU resulting from the down blending of 30 MT HEU is only 1.3 million SWU (=.24*5.5). The SWU-to-product ratios and uranium feed-to-

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product ratios are calculated using standard equations for separative work and material balance.[49]

USEC is presently utilizing the balance of the U.S. Department of Energy (**DOE**) **HEU-derived LEU** (originally 50 metric tons of HEU, later reduced to 48 metric tons[50]) that was transferred to it at privatization (Table 5, Ref. 8) at an annual rate of approximately 0.6 million SWU. At the present rate of utilization, it is expected to be exhausted by 2006.

There is also **DOE HEU** (Table 5, Ref. 9) that includes the 33 metric tons of HEU (MT HEU) (approximately 3.5 million SWU equivalent) that is being used by the Tennessee Valley Authority (TVA)[51] and 10 MT HEU[52] (approximately 1.5 million SWU equivalent) that is expected to become available beginning in 2009. The TVA material is expected to be utilized at a rate of 0.25 million SWU per year over a fourteen year period of 2005 through 2018. The 10 MT HEU is forecast to be used over a four year period, allowing DOE HEU-derived SWU to ramp up to 0.66 million SWU per year between 2009 and 2012, before dropping back to 0.25 million SWU per year. Approximately 50 additional metric tons of HEU has been declared excess, but no formal disposition plan has been established and thus it may not be commercialized.

In addition, the U.S. defense establishment is reported to hold approximately 490 MT HEU in various forms (e.g.., weapons, naval reactor fuel, reserves)[53]. However, there has been no indication if some or all of this material may be made available for commercial use, and if so on what schedule. Any forecast that includes use of the enrichment services that may be associated with this material must be recognized as being highly speculative. Therefore, ERI does not consider it to be prudent to include it in this market analysis. Furthermore, to the extent that some or all of the equivalent uranium enrichment services associated with this material were assumed to become available, it is important to remember that blendstock must be prepared, as previously discussed in the context of the Russian HEU.

Based on the down blending analysis of the Russian HEU that was summarized in Figure 6, it appears that 0.76 million SWU is required to create the blendstock in order to obtain each 1 million SWU in LEU product, which could be made available for commercial use in nuclear power plants. This means that the net increase in enrichment services that could be obtained from any additional DOE HEU-derived LEU would be only 24% of the SWU contained in the LEU. Therefore even if it were assumed that all 490 MT HEU were made available, at the present conversion rate of 0.184 million SWU per MT HEU, multiplied by 24%, then only an additional 22 million SWU could become available. This is equivalent to about two years of U.S. total requirements for enrichment services. If this were spread out over 20 years, it would add a net 1.1 million SWU per year or less than 3% (=1.1/37.8) to the available world supply. Furthermore, it would require virtually USEC's entire 3.5 million SWU of planned new commercial centrifuge enrichment capability to create the blendstock that would be required to down blend this material (=490*0.184*.76/20).

Urenco expansion plans for its European production capability (Table 5, Ref. 10), when taken together with its present installed enrichment capability, suggest that Urenco is likely to reach a total annual production level of 7 million SWU by 2007[54,55,56], where ERI expects that it will be maintained into the future.

Eurodif plans for a new centrifuge enrichment plant have been announced (Table 5, Ref. 11). It plans to replace its existing gaseous diffusion plant with a new 7.5 million SWU per year enrichment plant that utilizes Urenco centrifuge technology. It expects to bring the new plant into operation beginning in 2007 and achieve full capability operation of 7.5 million SWU per year by 2016. Achieving the announced schedule is dependent upon Urenco and Areva reaching a detailed agreement regarding the structure of a joint venture to manufacture centrifuges.[57]

The Louisiana Energy Services (LES) partnership has announced its plan to build a new 3 million SWU per year enrichment plant in Hartsville, Tennessee, using Urenco centrifuge technology (Table 5, Ref. 12). It expects to bring the new plant into operation beginning in 2007 and to achieve full capability of 3 million SWU per year by 2012.[58]

USEC has also announced plans to replace the Paducah GDP with a new 3.5 million SWU per year centrifuge enrichment plant (Table 5, Ref. 13). It plans to begin enrichment operations at the new plant in 2010, with full capability by 2013.[59,60]

The potential expansion in Other,(Table 5, Ref. 14) is primarily due to the expected increase in P.R.C. capability. It is expected to grow at a rate that allows it to supply its own requirements, reaching approximately 1.05 million SWU per year by 2010 and 1.35 million SWU per year by 2015. With the exception of Japan, the supply capability in other countries is expected to double during the next several years from its present level of 0.1 million SWU per year to 0.2 million SWU per year, and then remain at approximately 0.2 million SWU per year into the future.[61,62,63]

It is useful to note the geographical distribution of these current and potential future sources of enrichment services, as identified in Table 7, and the concentration of sources of enrichment services among individual companies, as identified in Table 8, to better appreciate the market considerations that will be discussed in subsequent sections of this report.

Table 7. Current and Potential Future Sources of Uranium Enrichment Services Arranged According to Geographical Location

Table 5 Ref.	Source	Geographical Location	Current Annual Physical Capability Million SWU	Annual Economically Competitive and Usable Capability Million SWU	
				2002	2016
4	USEC (existing)	U.S.	8.0	6.5	0.0
8	USEC - DOE HEU-derived	U.S.	0.6	0.6	0.0
9	DOE HEU-derived (potential source)	U.S.	0.0	0.0	0.25
12	LES (new)	U.S.	0.0	0.0	3.0
13	USEC (new)	U.S.	0.0	0.0	3.5
	Subtotal U.S.		**8.6**	**7.1**	**6.75**
2	Urenco (existing)	Europe	5.4	5.4	3.5
3	Eurodif (existing)	Europe	10.8	8.0	0.0
10	Urenco (potential expansion and replacement)	Europe	0.0	0.0	3.5
11	Eurodif (new)	Europe	0.0	0.0	7.5
	Subtotal Europe		**16.2**	**13.4**	**14.5**
5	Russian/Tenex	Russia	9.0	9.0	9.0
7	Russian HEU-derived (includes 4.2 from blendstock)	Russia	5.5	5.5	5.5
15	Russian (constrained)	Russia	1.5	0.0	0.7
16	Russian (tails enrichment)	Russia	1.6	0.0	0.0
17	Russian (outside of specifications for use in Western reactors)	Russia	3.7	0.0	0.0
	Subtotal Russia		**21.3**	**14.5**	**15.2**
6	Other (existing)	East Asia (primarily)	1.9	1.9	1.05
14	Other (potential expansion)	East Asia (primarily)	0.0	0.0	0.6
	Subtotal East Asia		**1.9**	**1.9**	**1.65**
1	Inventories	Dispersed	0.85	0.85	0.5

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Table 8. Current and Potential Future Sources of Uranium Enrichment Services Arranged According to Commercial Ownership or Control

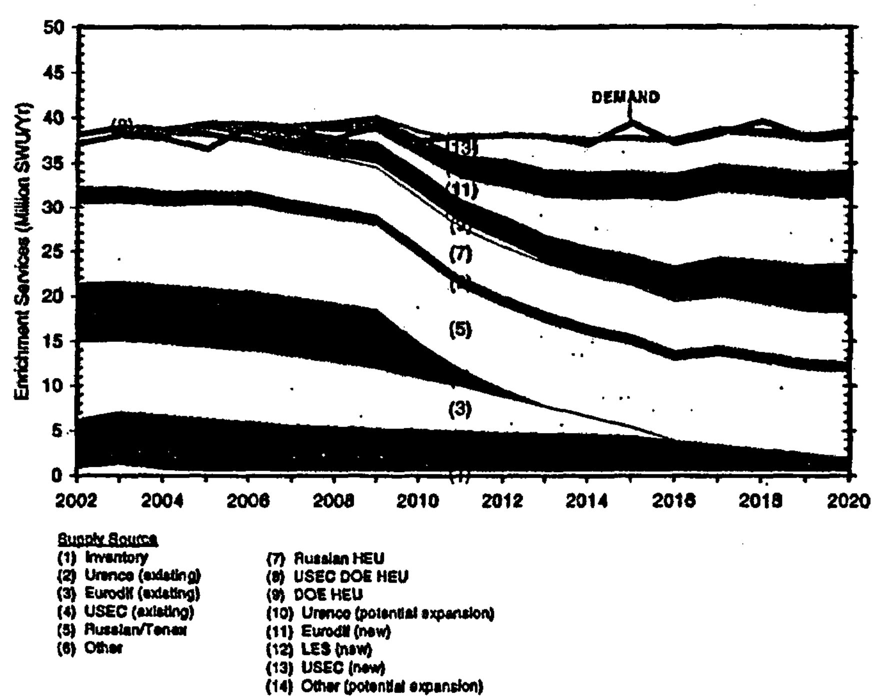
Table 5 Ref.	Source	Commercial Ownership or Control	Current Annual Physical Capability Million SWU	Annual Economically Competitive and Usable Capability Million SWU	
				2002	2016
4	USEC (existing)	USEC	8.0	6.5	0.0
8	USEC – DOE HEU-derived	USEC	0.6	0.6	0.0
13	USEC (new)	USEC	0.0	0.0	3.5
7	Russian HEU-derived (includes 4.2 from blendstock)	USEC	5.5	5.5	5.5
	Subtotal USEC		**14.1**	**12.6**	**9.0**
9	DOE HEU-derived (potential source)	DOE	0.0	0.0	0.25
	Subtotal DOE		**0.0**	**0.0**	**0.25**
12	LES (new)	LES	0.0	0.0	3.0
	Subtotal LES		**0.0**	**0.0**	**3.0**
2	Urenco (existing)	Urenco	5.4	5.4	3.5
10	Urenco (potential expansion and replacement)	Urenco	0.0	0.0	3.5
	Subtotal Urenco		**5.4**	**5.4**	**7.0**
3	Eurodif (existing)	Eurodif	10.8	8.0	0.0
11	Eurodif (new)	Eurodif	0.0	0.0	7.5
	Subtotal Eurodif		**10.8**	**8.0**	**7.5**
5	Russian/Tenex	Russia	9.0	9.0	9.0
15	Russian (constrained)	Russia	1.5	0.0	0.7
16	Russian (tails enrichment)	Russia	1.6	0.0	0.0
17	Russian (outside of specifications for use in Western reactors)	Russia	3.7	0.0	0.0
	Subtotal Russia		**15.8**	**9.0**	**9.7**
6	Other (existing)	P.R.C./Japan (primarily)	1.9	1.9	1.05
14	Other (potential expansion)	P.R.C./Japan (primarily)	0.0	0.0	0.6
	Subtotal Other PRC/Japan (primarily)		**1.9**	**1.9**	**1.65**
1	Inventories	Dispersed	0.85	0.85	0.5

5. Market Analysis of Supply and Requirements

5.1 Scenario A – LES and USEC Centrifuge Plants Are Built in the U.S.

Scenario A represents the scenario that is being actively pursued by both LES and USEC, consistent with schedules that have been announced by each company. Figure 7 presents ERI's forecast of uranium enrichment supply and requirements through 2020, consistent with this scenario. The shaded areas are keyed by reference number to Tables 5 through 8 and are described above.

Figure 7. Illustration of Supply and Requirements for Scenario A



During the period 2003 through 2005, the average annual economically competitive and physically usable production capacity that is not constrained by international trade agreements, together with the SWU derived from Russian HEU and other sources reflected in the tables previously provided, is forecast to be 39.3 million SWU, assuming that Urenco adds an additional one million SWU of new capacity by then. However, this is just 1.8 million SWU (4.8%) more than average annual forecast requirements during this same period of 37.5 million SWU.

Moving forward in time to the period 2006 through 2010, during which it is assumed by ERI that: Urenco has reached 7 million SWU per year of capacity in Europe; LES has 2 million

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SWU per year of capability in operation; Eurodif has the first 1.75 million SWU per year of centrifuge capability in operation and is supplementing this with 5.75 million SWU per year of its older more expensive GDP production to achieve a total capability of 7.5 million SWU per year, and has pre-produced and stockpiled the balance of 2.25 (=8.0–5.75) million SWU for use in subsequent years to optimize the transition; USEC will have brought the first 0.5 million SWU per year increment of centrifuge enrichment capability into operation, and will prepare to shutdown the older and more expensive GDP production after having pre-produced and stockpiled the balance of 2.6 (=6.5-3.9) million SWU for use in subsequent years to optimize the transition during 2011 and 2012; Russia sells 9.75 million SWU per year into the world market (i.e., includes supply to Russian designed nuclear power plants in the C.I.S. and Eastern Europe, and exports to Western nuclear power plants, but excludes blendstock and enrichment of tails for other enrichers); the Russian HEU-derived LEU continues to provide enrichment services into the market at a rate of 5.5 million SWU per year and USEC has exhausted its DOE HEU-derived SWU; and DOE HEU-derived SWU continues to enter the market at a rate of between 0.25 and 0.66 million SWU per year. Under this scenario, the average annual economically competitive and unconstrained production capacity during the 2006 through 2010 period of 39.5 million SWU is only 1.1 million SWU (2.9%) more than average annual forecast requirements during this same period of 38.4 million SWU.

Continuing with this scenario to 2011 through 2015 period, by the end of this period it is assumed that Urenco continues to maintain a capability of 7 million SWU per year of capacity in Europe; LES has reached 3 million SWU per year of capability in operation; Eurodif has completed 6.5 million SWU per year of centrifuge capability in operation, has shut down its older more expensive GDP production, and is using 1 million SWU of pre-produced SWU to achieve a total annual capability of 7.5 million SWU; USEC will have brought the entire 3.5 million SWU per year of enrichment capability into operation and like Eurodif, will have shut down its older more expensive GDP production; Russia sells 9.75 million SWU per year into the world market; the Russian HEU-derived LEU continues to provide enrichment services into the market at a rate of 5.5 million SWU per year; USEC has exhausted its DOE HEU-derived SWU; and DOE HEU-derived SWU continues to enter the market at a rate of 0.25 to 0.66 million SWU per year. During the period 2011 through 2015, the average annual economically competitive and unconstrained production capacity, together with the SWU derived from Russian HEU and other elements of the tables previously provided, is forecast to be 38.1 million SWU which is equal to the average annual forecast requirements during this same period of 38.1 million SWU.

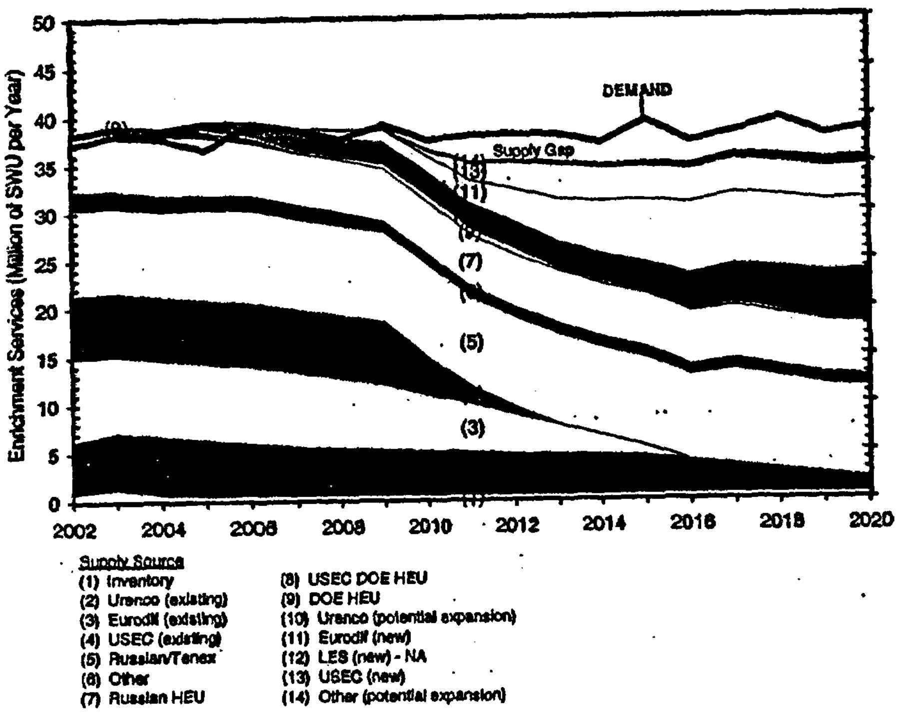
During the 2016 to 2020 period, the final increment of capacity is assumed to have been implemented for the new Eurodif centrifuge facility. Minor perturbations to supply continue to take place. Accordingly, during the period 2016 through 2020, the average annual economically competitive and unconstrained production capacity, together with the SWU derived from Russian HEU and other elements of the tables previously provided, is forecast to be 38.5 million SWU which is only 0.3 million SWU (0.8%) in excess of the average annual forecast requirements during this same period of 38.2 million SWU.

Supply and requirements are in very close balance after 2010, emphasizing the need for all supply sources, including the proposed LES and USEC centrifuge enrichment plants in the U.S.

Commercial considerations and other implications associated with Scenario A are presented in Section 6.1.

The following sections present alternatives to Scenario A wherein it is postulated that LES does not proceed with the construction and operation of its proposed gas centrifuge enrichment facility in Hartsville, Tennessee. To provide perspective for these scenarios, Figure 8 illustrates the forecast uranium enrichment supply and requirements situation for Scenario A without the 3 million SWU per year LES centrifuge enrichment plant.

Figure 8. Illustration of Supply and Requirements for Scenario A Without the Proposed LES Facility



5.2 Scenario B – No LES; USEC Deploys Centrifuge Plant and Continues to Operate Paducah GDP

An alternative scenario is that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. Since an initial motivating factor for building this plant was to increase the amount of indigenous uranium enrichment capacity in the U.S., the first alternative considered is one that also provides for additional enrichment capacity located in the U.S. Under this scenario, it is postulated that USEC continues with its current plans to build and operate a 3.5 million SWU per year commercial uranium enrichment plant. However, instead of shutting down the Paducah GDP upon completion of the new centrifuge enrichment plant, USEC continues to operate the Paducah GDP. This would result in the availability of excess supply that is equal to about 10% of annual requirements.

Commercial considerations and other implications associated with Scenario B are presented in Section 6.2.

5.3 Scenario C – No LES; USEC Deploys Centrifuge Plant and Increases Centrifuge Plant Capability

This alternative scenario also assumes that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. It also provides for additional enrichment capacity located in the U.S. Under Scenario C, it is postulated that USEC continues with its current plans to build and operate a 3.5 million SWU per year commercial uranium enrichment plant and also continues to operate the Paducah GDP on a temporary basis to compensate for the absence of the LES plant, while its commercial centrifuge plant is being gradually brought into operation. However, instead of stopping at 3.5 million SWU, USEC continues to add centrifuge enrichment capability to its new commercial centrifuge enrichment plant in order to compensate for the 3 million SWU per year of enrichment services that would have been provided by LES under Scenario A. Under Scenario C, USEC would need to operate the Paducah GDP for an additional two or three years in order to meet the enrichment services requirements that would have been supplied by LES and also to pre-produce inventories that would be needed to supplement centrifuge production during the expansion of the new plant.

Commercial considerations and other implications associated with Scenario C are presented in Section 6.3.

5.4 Scenario D – No LES; USEC Does Not Deploy Centrifuge Plant and Continues to Operate Paducah GDP

This alternative scenario assumes that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. Under this scenario, it is postulated that USEC does not succeed with its current plans to build and operate a 3.5 million SWU per year commercial uranium enrichment plant. Instead, it assumed that USEC continues to operate the Paducah GDP on a long term basis at 6.5 million SWU per year to compensate for the absence of the 3 million SWU per year LES plant and the 3.5 million SWU per year USEC centrifuge plant.

Commercial considerations and other implications associated with Scenario D are presented in Section 6.4.

5.5 Scenario E – No LES; Urenco Expands Centrifuge Capability in Europe

This alternative scenario also assumes that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. However, it does not provide for additional enrichment capacity located in the U.S. Under this scenario, it is postulated that Urenco expands its existing European plants to compensate for the 3 million SWU per year of enrichment services that would have been provided by LES under Scenario A.

Commercial considerations and other implications associated with Scenario E are presented in Section 6.5.

5.6 Scenario F – No LES; Russia Increases Sales of the HEU-Derived SWU Under the U.S.-Russian Agreement

This alternative scenario assumes that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. However, it does not provide for additional enrichment capacity located in the U.S. Under this scenario, it is postulated that Russia increases sales of the HEU-derived SWU to USEC under the U.S.-Russia Agreement to compensate for the 3 million SWU per year of enrichment services that would have been provided by LES under the Scenario A.

Commercial considerations and other implications associated with Scenario A are presented in Section 6.6.

5.7 Scenario G – No LES; Russia Is Allowed to Increase Sales Into the U.S. and Europe

This alternative scenario also assumes that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. However, it does not provide for additional enrichment capacity located in the U.S. Under this scenario, it is postulated that it is allowed to increase its sales of commercial enrichment services into the U.S. and Europe to compensate for the 3 million SWU per year of enrichment services that would have been provided by LES under Scenario A.

Commercial considerations and other implications associated with Scenario G are presented in Section 6.7.

5.8 Scenario H – No LES; U.S. HEU-Derived LEU is Made Available to the Commercial Market

This alternative scenario assumes that the 3 million SWU per year LES centrifuge uranium enrichment plant is not built in the U.S. Under this scenario, it is postulated that the U.S. government makes available additional HEU-derived LEU to the U.S. commercial market. However, as previously discussed in Section 4, it is not apparent that there is sufficient net equivalent enrichment services to compensate on a long term basis for the 3 million SWU per year of enrichment services that would have been provided by LES under Scenario A.

Commercial considerations and other implications associated with Scenario H are presented in Section 6.8.

The scenarios described above do not represent the only long term possibilities for U.S and world enrichment supply. These scenarios do represent the most likely alternatives apparent at the present time based upon known and planned sources of supply. When examining the alternatives available if LES does not build a uranium enrichment plant in the U.S., only one alternative source of supply is considered in each alternative scenario. It is of course possible that several alternative supply sources could combine to fill the supply gap that is anticipated if the LES facility is not built. However, the approach taken allows the implications of each potential alternative source of supply to be examined individually. Nonetheless, the implications that are presented in Section 6 for each individual alternative scenario would still be relevant even if the alternatives are postulated to be used in combination.

6. Commercial Considerations and Other Implications of Each Scenario

As background for the discussion that follows, it is important to recognize that the owners and operators of nuclear power plants have two primary objectives in purchasing nuclear fuel, including uranium enrichment services.[64,65] The first objective is security of supply – that is the ability of the purchaser to rely on their suppliers to deliver nuclear fuel materials and services on schedule and within technical specifications, according to the terms of the contract, for the contract's entire term. The second objective is to ensure a competitive procurement process – that is the ability of the purchaser to select from among multiple suppliers through a process that is conducive to fostering reasonable prices for the nuclear fuel materials and services that are purchased.

While one can postulate alternative supply scenarios, a number of which are presented in Section 5, there are commercial considerations and other implications associated with each such scenario, many of which can have a significant impact on the purchasers' ability to achieve the two primary purchasing objectives just presented.

Nuclear power plants are a significant component of the U.S. electric power supply system, providing almost 20% of the electricity that is consumed in the U.S. each year. The current U.S. market for uranium enrichment services is characterized by annual requirements of approximately 11.7 million SWU. During the eight year period 2003 through 2010 these requirements are forecast to average 11.1 million SWU per year and during the ten year period 2011 through 2020 they are forecast to average between 10.1 and 10.2 million SWU per year.

Indigenous supply from the single, aging, high cost, and electric power intensive Paducah GDP, which is operated by USEC, could potentially supply up to 6.5 million SWU of these requirements (55%), as was previously discussed in Section 5. However, USEC has obligated much of the ongoing production from the Paducah GDP to meet the contractual requirements of some of its Far East customers. As a result, a significant amount of USEC's obligations to U.S. customers are being met with the Russian HEU-derived SWU that USEC purchases from Techsnabexport (Tenex) under its contract as executive agent for the U.S. government. Recognizing the numerous problems associated with long term dependence on the Paducah GDP, USEC has established plans to build a 3.5 million SWU per year commercial uranium enrichment plant within ten years, using an upgraded version of DOE centrifuge technology, and shut down the Paducah GDP. The balance of U.S. requirements for uranium enrichment services are under contract to Urenco and Eurodif, whose facilities are located in Europe.[66]

Operators of many nuclear power plants in the U.S., who are also the end users of uranium enrichment services in the U.S., view the present supply situation with concern. They see a world supply and requirements situation for economical uranium enrichment services that is presently in balance, exhibiting a potential for significant shortfall if plans that have been announced by two of the primary enrichers are not executed (i.e., Scenario A - both USEC and LES proceed with their respective plans to build new commercial centrifuge uranium enrichment plants in the U.S. and USEC ceases to operate the Paducah GDP). These U.S. purchasers find that as a result of recent trade actions and substantial duties imposed on Eurodif[67,68] that one source of competitive enrichment services for U.S. consumption has been significantly restricted for the foreseeable future. They view themselves as being largely dependent on a single enricher, USEC, whose only operating enrichment plant is the Paducah GDP, which has very high operating costs that impact the financial situation of USEC itself. These purchasers are concerned that the primary source of enrichment services that USEC delivers for use in their nuclear power plants is obtained from Russia and could be vulnerable to either internal or international political unrest in the future. [69,70] Also, there is concern that neither the performance nor economics of the updated version of the DOE centrifuge technology that USEC is planning to use have been successfully demonstrated. This is not to say that the technology would not be successful, but there is still much to be done, while the schedule announced by USEC is very aggressive and the economics remain unproven.

With this background the commercial considerations and other implications associated with each of the scenarios identified in Section 5 will be briefly addressed.

6.1 Scenario A – LES and USEC Centrifuge Plants Are Built in the U.S.

This scenario effectively replaces the 6.5 million SWU per year of enrichment services from the Paducah GDP, with a combination of 3.5 million SWU per year of enrichment services from a new USEC commercial centrifuge enrichment plant and 3 million SWU per year of enrichment services from a new LES centrifuge enrichment plant, leaving the total capability of indigenous U.S. primary supply effectively unchanged, but secure for the long term. See Table 6, Geographical Location – U.S. As shown in Figure 1, economic world supply capability is in approximate balance with long term world requirements for this scenario. Given the effective balance between the forecasts of world long term supply and requirements for uranium enrichment services, the poor economics and limited lifetime of the Paducah GDP, and the potential uncertainty surrounding the announced schedule and ultimate success of USEC's centrifuge program, there is a need for new U.S. enrichment capability that utilizes proven technology on an achievable schedule, as is provided for in Scenario A.

This scenario would result in the establishment of two long term sources of energy efficient, low cost, reliable uranium enrichment services in the U.S., which is positive with respect to the security of supply objective. In addition, the presence of two indigenous enrichment facilities in the U.S. should serve to foster competition and result in more predictable long term sources of uranium enrichment services, which would help meet the objective of ensuring a competitive procurement process for U.S. purchasers of these services.

6.2 Scenario B – No LES; USEC Deploys Centrifuge Plant and Continues to Operate Paducah GDP

Under this scenario, it is postulated that LES does not build a uranium enrichment plant in the U.S. Accordingly, there is a 3 million SWU per year supply deficit for which other sources of supply must compensate. This scenario further assumes that this supply capability is made up by USEC, which continues to operate the Paducah GDP. However, USEC would also be operating a 3.5 million SWU per year centrifuge enrichment plant and would be expected to continue with its obligations under the executive agent agreement to purchase 5.5 million SWU per year of Russian HEU-derived SWU. Given its existing customer base, it is expected that USEC would have to operate the Paducah GDP at 3 million SWU per year or less.

The negative financial impact of operating the Paducah GDP at low production levels[71] could threaten USEC's ability to fund its planned centrifuge plant, as well as create financial instability for the corporation.

While providing for indigenous U.S. supply, the resulting concerns associated with the age of the Paducah GDP, its significant requirements for electric power, the low level at which it would have to be operated, the resulting impact on USEC overall financial situation, and the lack of multiple competitive sources of indigenous U.S. supply, would not alleviate concerns among U.S. purchasers of enrichment services regarding either long term security of supply or ensuring a competitive procurement process for U.S. purchasers of these services. Scenario B is not viewed by ERI as an attractive long term solution.

6.3 Scenario C – No LES; USEC Deploys Centrifuge Plant and Increases Centrifuge Plant Capability

Under this scenario, it is postulated that LES does not build a uranium enrichment plant in the U.S. Accordingly, there is a 3 million SWU per year supply deficit for which other sources of supply must compensate. This scenario further assumes that this supply capability is made up by USEC, which would proceed to build and operate a 3.5 million SWU per year centrifuge enrichment plant, continue to operate the Paducah GDP on an interim basis longer than currently planned, and then rapidly increase its centrifuge enrichment plant capability to 6.5 million SWU per year. USEC would also be expected to continue with its obligations under the executive agent agreement to purchase 5.5 million SWU per year of Russian HEU-derived SWU. The immediate expansion of the just completed centrifuge enrichment plant would be expected to be quite difficult for USEC from a financial perspective. However, with financial participation from external sources, it may be achievable. At the present time, USEC can provide no assurance that it will be able to fund its previously announced 3.5 million SWU per year commercial centrifuge enrichment plant. To assume funding sources for a near doubling of the plant capability would be highly speculative at this time, particularly without its having demonstrated yet that the centrifuge technology will perform as anticipated.

Scenario C, should it come to fruition, provides for indigenous U.S. supply , but only from a single USEC-owned enrichment plant. The remaining concerns are that neither the performance nor economics of the updated version of the DOE centrifuge technology that USEC is planning to use have been successfully demonstrated and the outcome will not be known for a number of years. There would remain an ongoing absence of multiple competitive sources of indigenous U.S. supply. Accordingly, this may not alleviate concerns among U.S. purchasers of enrichment services regarding either long term security of supply or ensuring a competitive procurement process for U.S. purchasers of these services. Given its dependence on a yet to be proven technology and a single indigenous U.S. enricher, Scenario C is not viewed by ERI as the most advantageous long term solution.

6.4 Scenario D – No LES; USEC Does Not Deploy Centrifuge Plant and Continues to Operate Paducah GDP

Under this scenario, it is postulated that neither LES nor USEC build uranium enrichment plants in the U.S. Accordingly, there is a 6.5 million SWU per year supply deficit for which other sources of supply must compensate. This scenario further assumes that this missing supply capability is made up by USEC, which continues to operate the Paducah GDP at 6.5 million SWU per year. Given the unfavorable economics of continued GDP operation, this would be viewed as having a high economic cost associated with it. Obviously, USEC views continued operation of the Paducah GDP as being unacceptable or undesirable, as evidenced by its announcement to build a commercial centrifuge enrichment plant and shut down the Paducah GDP.[72,73]

At some point in time, it is reasonable to assume that the Paducah GDP must ultimately be replaced. Accordingly, Scenario D does not represent a permanent solution, but only a postponement of the time when new uranium enrichment capacity must be constructed in the U.S. The cost of such a postponement is likely to be quite high and the risk of supply disruption in the U.S. would increase as the Paducah GDP continues to get older.

While providing for indigenous U.S. supply, the concerns associated with the age of the Paducah GDP, its significant electric power requirements, the resulting impact on USEC's overall financial situation, and the lack of multiple competitive sources of indigenous U.S. supply, would not alleviate concerns among U.S. purchasers of enrichment services regarding either long term security of supply or ensuring a competitive procurement process for U.S. purchasers of these services. Scenario D is not viewed by ERI as a viable long term solution.

6.5 Scenario E – No LES; Urenco Expands Centrifuge Capability in Europe

Under this scenario, it is postulated that LES does not build a uranium enrichment plant in the U.S. Instead it is postulated that Urenco expands its centrifuge capability in Europe to offset the loss of 3 million SWU per year of enrichment capability in the U.S. While this may be physically possible, from a commercial perspective this may be unacceptable to Urenco for a number of reasons. For example, there are a variety of risks associated with such factors as uncertain level of sales that might be achieved for Urenco in the U.S. market, significant concentration of its enrichment business in a single market, unpredictable changes in currency exchange rates, transatlantic shipping, and unknown future trade actions that could be undertaken by a protective U.S. government on behalf of its indigenous enricher. When these factors are considered collectively, it is quite likely that Urenco would view the risk of building an additional 3 million SWU per year of enrichment capability in Europe specifically to serve the U.S. market as commercially unacceptable. Furthermore, its decision to enter the LES partnership indicates that Urenco does not perceive expanding its centrifuge enrichment capability in Europe (Scenario E) as being an attractive alternative to building new centrifuge capability in the U.S. Of course, if enrichment prices were high enough and contract terms long enough, then the above mentioned commercial risks could potentially be overcome from the enricher's perspective. However, such a situation would not be viewed as favorable by U.S. purchasers.

Scenario E would not alleviate the desire on the part of U.S. purchasers for either additional indigenous uranium enrichment capability in the U.S. or provide for a second source of supply competition located in the U.S. Consequently, neither the security of supply objective nor the objective of ensuring a competitive procurement process for U.S. purchasers of these services could be assured.

6.6 Scenario F – No LES; Russia Increases Sales of the HEU-Derived SWU Under the U.S.-Russian Agreement

Under this scenario, it is postulated that LES does not build a 3 million SWU per year uranium enrichment plant in the U.S. Instead it is postulated that Russia increases its sales of the HEU-derived SWU to USEC under the U.S.-Russian Agreement. Given that uranium enrichment services from the Paducah GDP are preferentially used by USEC to meet contract obligations to its non-U.S. customers, this scenario implies that USEC could potentially be meeting more than 80% ([5.5+3]/10.2) of U.S. post 2010 annual requirements for uranium enrichment services with Russian HEU-derived SWU. This would appear to introduce security of supply risks on a national level.[74]

While Scenario F may be physically possible, it should be recognized that the net addition of 3 million SWU per year derived from blending down the Russian HEU would require an additional 2.3 million SWU per year in enrichment capacity to prepare blend stock. Incidently, this is equivalent to the combination of the 1.6 million SWU per year that is being used to enrich tails for the European enrichers, as shown in Table 5, and the 0.7 million SWU per year of Russian capability that is shown as being constrained (Table 6, Ref. 15). Furthermore, accelerating the use of the Russian HEU by approximately 55% (=3.0/5.5) would result in its being exhausted much earlier than previously anticipated, quite likely before 2020, based upon present estimates of available Russian HEU.[75] Thus the issue of replacement capacity for LES would not have been solved, only postponed.

Scenario F would not alleviate the desire on the part of U.S. purchasers for either additional indigenous uranium enrichment capability in the U.S. or provide for a second source of supply competition located in the U.S. Consequently, neither the security of supply objective nor the objective of ensuring a competitive procurement process for U.S. purchasers of these services could be assured.

6.7 Scenario G – No LES; Russia Is Allowed to Increases Sales Into the U.S. and Europe

Under this scenario, it is postulated that LES does not build a uranium enrichment plant in the U.S. Instead it is postulated that Russia increases its sales of commercial SWU to Western countries, including the U.S. While 3 million SWU per year of additional supply would be required to compensate for the lack of the proposed LES facility, Russia presently has only 2.3 million SWU per year in available and physically acceptable enrichment capacity. This includes the combination of the 1.6 million SWU per year that is presently used to enrich tails for the European enrichers, as shown in Table 5, Ref. 16, and the 0.7 million SWU of Russian capability that is shown as being constrained in the future (Table 5, Ref. 15). Some reports have suggested that Russia might be able to expand its capability by 25%[76], which would be equivalent to 2.5 million SWU per year in exportable enrichment services, by replacing its older less efficient centrifuges with its higher capacity generation of centrifuges. However, this is not certain. Russian commercial enrichment sales in the U.S. have been subject to trade restrictions for the past ten years. When the current suspension agreement ends in 2004, the original antidumping investigation could resume. USEC and its labor unions have given no indication that they would cease their opposition to new imports of Russian commercial enrichment services into the U.S. Additionally, the agreement between USEC and DOE that was executed in 2002[77] would allow USEC to cease operation of the Paducah GDP without penalty under this scenario.

Scenario G would not alleviate the desire on the part of U.S. purchasers for either additional indigenous uranium enrichment capability in the U.S. or provide for a second source of supply competition located in the U.S. Consequently, neither the security of supply objective nor the objective of ensuring a competitive procurement process for U.S. purchasers of these services could be assured.

6.8 Scenario H – No LES; U.S. HEU-Derived LEU is Made Available to the Commercial Market

Under this scenario, it is postulated that LES does not build a uranium enrichment plant in the U.S. Instead it is postulated that U.S. HEU-derived LEU is made available to the commercial market. As discussed in Section 4, the U.S. defense establishment is reported to hold approximately 490 MTHEU in various forms that have not been declared surplus to U.S. government needs. However, there has been no indication if some or all of this material may be made available for commercial use, and if so on what schedule. Any forecast that includes use of the enrichment services that may be associated with this material must recognized as being highly speculative. Therefore, ERI does not consider it to be prudent to include it in this market analysis. Furthermore, to the extent that some or all of the equivalent uranium enrichment services associated with this material were assumed to become available, it is important to remember that blendstock must be prepared.

Based on the discussion presented in Section 4, the net increase in enrichment services that could be obtained from any additional DOE HEU-derived LEU would be only 24% of the SWU contained in the LEU. Therefore even if it were assumed that all 490 MTHEU were made available, at the present conversion rate of 0.183 million SWU per MTHEU, multiplied by 24%, the net increase in supply would be only 22 (=490x0.183x.24) million SWU. This is about two years of U.S. total requirements for enrichment services. If this were spread out over 20 years, it would add a net 1.1 million SWU per year, or less than 3% to the available world supply. This still leaves a deficit of almost 2 million SWU per year during the postulated 20 years over which this material would be used.

The issue of replacement capacity for LES would not have been solved under Scenario H. Consequently, neither the security of supply objective nor the objective of ensuring a competitive procurement process for U.S. purchasers of these services could be assured.

7. Conclusion

Including the scenario that is being actively pursued at the present time, Scenario A, a total of eight alternative supply scenarios have been identified and summarized in Section 5 with respect to their ability to meet future long term nuclear power plant operating requirements for uranium enrichment services. In addition, a number of commercial considerations and other implications for each scenario have been identified in Section 6.

When the critical nuclear fuel procurement objectives, security of supply and ensuring a competitive procurement process for U.S. purchasers of these services are considered, it becomes apparent that for long term planning purposes those alternatives that rely upon either additional Russian or U.S. HEU-derived SWU (Scenarios F and H) or additional use of Russian commercial enrichment services (Scenario G) are inadequate. While further expansion of Urenco enrichment facilities in Europe to meet what would be potentially unfilled U.S. requirements (Scenario E) might on the surface be viewed as a satisfactory approach, it does not contribute substantially to meeting the objective of improved security of supply through the construction of additional indigenous U.S. supply capability. In addition, as a result of factors that are largely outside the control of either U.S. purchasers or Urenco, as identified in Section 6.5, this approach may not contribute to meeting the objective of ensuring a competitive procurement process for U.S. purchasers of these services. In addition, the commercial risks, as also discussed in Section 6.5, may be unacceptable to Urenco.

This leaves Scenarios A through D, which provide for the use of either existing or new indigenous uranium enrichment capacity in the U.S. for further consideration. Among these alternatives, Scenarios A and C involve the long term use of centrifuge technology for uranium enrichment. In Scenario A, LES deploys and operates 3 million SWU per year of centrifuge enrichment capability while USEC deploys and operates 3.5 million SWU per year of centrifuge enrichment capability. In Scenario C, USEC ultimately deploys 6.5 million SWU per year of centrifuge enrichment capability and LES does not proceed.

In contrast, Scenarios B and D rely either in part or entirely upon the long term use of the Paducah GDP. In Scenario B, USEC deploys and operates 3.5 million SWU per year of centrifuge enrichment capability, which it supplements by the continued operation of the Paducah GDP at a level of 3 million SWU per year, while LES does not proceed. In Scenario D, neither LES nor USEC deploy new centrifuge enrichment capability, and USEC continues to operate the Paducah GDP at 6.5 million SWU per year. ERI believes that the approach that best serves the U.S. owners and operators of nuclear power plants and ultimately the consumers of electricity in the U.S. would be Scenario A. This approach, which is being actively pursued at the present time, provides for the construction and operation of two new uranium enrichment plants in the U.S., using centrifuge technology that would significantly improve security of supply, with ongoing competition from both USEC and LES, as well as Urenco and eventually Cogema (on behalf of Areva/Eurodif) ensure a competitive procurement process for U.S. purchasers of these services.

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