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**JOINT CONCEPTUAL ANALYSIS  
AND COST EVALUATION  
OF THE POSSIBILITY  
OF ACCELERATED DISPOSITION  
OF HIGHLY ENRICHED URANIUM  
NO LONGER NEEDED  
FOR DEFENSE PURPOSES**

Final Report

MOSCOW • 2005

**This Report  
has been prepared jointly  
by Russian and American specialists  
through a project of  
the NUCLEAR THREAT INITIATIVE,  
INC. (NTI)**

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## LIST OF TERMS AND ABBREVIATIONS USED

**Annual additional costs** – funds needed each year to cover the extra expenses of maintaining modifications to a facility

**Capital investment (costs)** – funds needed to implement conversion or construction of new industrial facility or modification of an existing industrial facility

**Commercial natural uranium** – uranium containing 0.711%  $^{235}\text{U}$  with concentrations of  $^{232}\text{U}$ ,  $^{234}\text{U}$  and  $^{236}\text{U}$  isotopes consistent with ASTM C 787-90 specifications

**Decommissioning (costs)** – funds needed to shut down, lay up or liquidate an industrial facility after the expiration of its service life

**Desublimation** – phase transition of a substance from a gaseous state into a solid state

**DIEEC** – Department of International and External Economic Cooperation

**ECP** – Electrochemical Plant Production Association

**FSUE** – federal state unitary enterprise

**HEU** – highly enriched uranium in which the weight percent of  $^{235}\text{U}$  is 20% or greater

**HEU components** – metal HEU components extracted from nuclear weapons

**kSWU** – thousand SWU

**LEU** – low enriched uranium in which the weight percent of  $^{235}\text{U}$  is less than 20%

**LEU products** – commercial or interim products in the form of low enriched uranium hexafluoride with different  $^{235}\text{U}$  content

**Mayak** – Mayak Production Association

**MSWU** – millions SWU

**MTU** – metric tons of Uranium

**Natural equivalent of uranium tails** – amount of recovered natural uranium that can be produced from uranium tails during enrichment

**NPP** – nuclear power plant

**PA** – production association

**Product stream** – enriched  $\text{UF}_6$  product

**Recovered natural uranium** – uranium of approximately natural enrichment (0.7%  $^{235}\text{U}$ ) produced during the enrichment of uranium tails

## LIST OF TERMS AND ABBREVIATIONS USED (CONTINUED)

- Refinement** – removal of impurities from uranium oxide to produce a more purified version of the oxide
- RF** – Russian Federation
- SCC** – Siberian Chemical Combine
- Separation cascade** – complex made up of multiple separation machines (gas centrifuges) designed to produce enriched uranium
- Separation cascade feed** – material in the form of  $UF_6$  fed to a separation cascade
- Separation work unit (SWU)** – measurement of the effort needed to separate  $^{235}U$  and  $^{238}U$
- SNM** – special nuclear material includes uranium enriched in the isotope  $^{235}U$
- Source material** – uranium of natural  $^{235}U$  concentration or less (uranium tails) used in diluent production
- Sublimation** – phase transition of a substance from a solid state into a gaseous state
- $U_3O_8$**  – a type of uranium oxide suitable for feeding to a fluorination facility
- UECC** – Urals Electrochemical Combine
- $UF_6$**  – uranium hexafluoride
- UHF** – uranium hexafluoride ( $UF_6$ )
- UMO** – a mixture of uranium oxides produced by the oxidation of uranium metal, primarily consisting of  $U_3O_8$
- Uranium tails** – depleted  $UF_6$  of lower than natural  $^{235}U$  concentration produced via source material enrichment in separation production
- Uranium tails assay** – degree of  $^{235}U$  content of uranium tails

# SUMMARY

## 1. Research Goals

The research that forms the basis for this conceptual analysis was carried out jointly by Russian and US specialists at the request of NTI. Its focus was an examination of the options for accelerating the downblending of Russian HEU no longer used for defense purposes (hereafter, excess HEU), to LEU for use in nuclear power plants (NPPs).

The Agreement between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted From Nuclear Weapons of 1993 (hereinafter referred to as the “HEU Purchase Agreement”), which is currently in force, envisages the processing of 500 metric tons of uranium (MTU) of Russian HEU into LEU by 2013 (30 MTU of HEU annually).

Since the HEU Purchase Agreement (Article 5, Item 3) envisaged accelerating uranium processing beyond the rates specified in Article 2 (Item 2) of the Agreement and the 1994 contract for the purchase of LEU derived from HEU, this research considered new options for HEU accelerating HEU processing, taking into account the possible conclusion of a new agreement in the future.

The twelve options analyzed (see Table P.1) included the following:

- additional processing of 5, 10, 20, or 30 MTU per year above the current level of 30 MTU per year and intermediate LEU products (12 and 19% enrichment);

Analyzed HEU accelerated blend-down options

Option	HEU processing increment	HEU processing volume	LEU product enrichment, %	LEU product delivery	Temporary LEU product storage	
					Russia	USA
1A1	5 MTU/year	35 MTU/year	4.4	immediate		
1A2			4.4	deferred	+	
1B3			12.0	deferred		+
2A1	10 MTU/year	40 MTU/year	4.4	immediate		
2C1			19.0	immediate		
3A1	20 MTU/year	50 MTU/year	4.4	immediate		
3A2			4.4	deferred	+	
3C2			19.0	deferred	+	
4A1	30 MTU/year	60 MTU/year	4.4	immediate		
4A3			4.4	deferred		+
4B2			12.0	deferred	+	
4C3			19.0	deferred		+

- direct transfer of LEU products to potential customers, as well as deferred transfer after temporary storage.

Various aspects associated with accelerated blend-down analyzed during the course of this research included: current production capacities, the feasibility of accelerated HEU processing, the time period needed to complete particular options, legal considerations, the influence of additional LEU on uranium markets, and the extra costs associated with accelerated HEU processing.

The research used current HEU-LEU processing indices as the basis for this analysis.

## 2. Current Production Reserves

Table P.2 provides an estimate of current basic processing capacities and possible reserves for enhancing the volume of processing HEU into LEU products.

**Production capacities and reserves (estimated) as regards the increase of HEU processing into LEU products, MTU/year**

Stage		Production capacity	Current process	Reserve of capacity
Production of highly enriched (HE) UMO		37	30	<b>7</b>
Production of HE UHF		34.0	30	<b>4</b>
Diluent production		31.6	30	<b>1.6</b>
Fabrication of LEU products	4.4% LEU	43.9	30	<b>13.9</b>
	12 and 19% LEU	None	–	<b>None</b>

As one can see from Table P.2, operating capacities make possible an increase of 1.6 MTU (maximum) per year in excess of the 30 MTU per year processed under the HEU Purchase Agreement. The reason for this limit is mainly due to a shortage of available separation capacities for the diluent production.

### **3. Possible Implementation of Accelerated HEU-LEU Blend-Down Options**

The projected capital upgrades for realizing the accelerated HEU blend-down options are given in Table P.3.

When options associated with processing an additional 5 MTU of HEU per year into 4.4% LEU are considered, existing capacities are sufficient only to meet increased highly enriched  $U_3O_8$  production targets. Increasing the volume of processing HEU into LEU by 10, 20, 30 MTU per year will require additional capacities at all processing stages. The implementation of options involving processing HEU into intermediate LEU products greatly reduces the need for additional separation capacities, which will be required only if the increment of HEU processing exceeds 10 MTU per year. However, those options will require the introduction of new HEU blend-down processes, because current operating processes are not intended for producing LEU with over 5% enrichment.

Table P.3

Conditions for fulfilling HEU accelerated blend-down options

Option	HEU increment	Production of highly enriched UMO MTU/year	Production of highly enriched UHF, MTU/year	Production of the diluent, MTU/year		Production of LEU, MTU/year	
				Additional separation capacities and equipment	Due to reserves	4.4% LEU	12 and 19% LEU
1A1 and 1A2	5 MTU/year	Due to reserves	New plant, additional storage facilities for NM	Additional separation capacities and equipment	Due to reserves	Additional storage facilities for NM and transport means	New production, new storage facilities for NM and transport means
1B3				Additional separation capacities and equipment		Additional storage facilities for NM and transport means	
2A1	10 MTU/year	New plants, new storage facilities for NM and transport means	New plants, additional storage facilities for NM and transport means	Additional separation capacities and equipment	Due to reserves	New plants, storage facilities for NM and transport means	New production, new storage facilities for NM and transport means
2C1				Additional separation capacities and equipment			
3A1, 3A2, and 3C2	20 MTU/year	New plants, new storage facilities for NM and transport means	New plants, additional storage facilities for NM and transport means	Additional separation capacities and equipment		New plants, new storage facilities for NM and transport means	New production, new storage facilities for NM and transport means
4A1, 4A3, 4B2, and 4C3	30 MTU/year	New plants, new storage facilities for NM and transport means	New plants, additional storage facilities for NM and transport means	Additional separation capacities and equipment		New plants, new storage facilities for NM and transport means	New production, new storage facilities for NM and transport means

Table P.4

**Summarized estimates of absolute/unit values of costs and periods  
of implementation of HEU accelerated blend-down options**

Estimate of costs and periods		HEU processing increment, MTU/year											
		5			10			20			30		
		1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Capital investment	Absolute value, mln \$	162.7	166.4	275.0	359.9	283.6	958.0	974.3	402.1	1,613.6	1,613.6	652.5	477.2
	Unit value, \$ thsd/kg HEU	32.5	33.3	55.0	36.0	28.4	47.9	48.7	20.1	53.8	53.8	21.8	15.9
Extra costs	Absolute value, \$ mln/year	1.53	3.04	19.51	3.79	23.13	13.41	17.21	34.69	20.71	20.71	44.56	35.34
	Unit value, \$ thsd/kg HEU	0.31	0.61	3.9	0.38	2.31	0.67	0.86	1.73	0.69	0.69	1.49	1.18
Period of HEU accelerated processing, year		3.5	3.5	2.3	5.0	2.6	8.0	8.0	2.8	10.0	10.0	3.0	4.0

## 4. Cost and Schedule as Regards the Implementation of HEU Accelerated Blend-Down

The estimates of capital investment in additional capacities, annual additional costs, and the schedule estimates for HEU accelerated blend-down options are given in Table P.4.

The estimates of capital investment in additional capacities, annual additional costs, and the time required to complete accelerated HEU blend-down ranges from \$157 million to \$1.6 billion, annual additional costs from \$1.5 to \$45 million, and the time period from 2.3 to 10 years.

In order to increase the volume of HEU processed each year by 5 MTU, those options yielding final LEU products (options **1A1** and **1A2**) would require about 1.7 times less capital investment and take 1.5 times less time than option **1B3**, down-blending to an intermediate 12% LEU product.

Accelerating HEU processing by **20** or **30** MTU per year (options **3A1**, **3A2**, **4A1**, and **4A3**) requires a large amount of investment—from **\$1** to **\$1.6 billion**—and a long period to introduce additional capacities (from **8** to **10 years**)

The large capital requirements and prolonged time are mainly due to the absence of reserves at Russian separation enterprises and the need for new uranium enrichment capacities.

To increase HEU blend-down by 10 MTU or higher per year, the capital investment required for options yielding intermediate LEU products is 1.25–3 times lower than for options resulting in final LEU products, while the time required to realize these options is 2–2.5 times less.

Options for turning HEU into intermediate LEU products also have the advantage of greatly reduced demand for additional separation capacities, which are the most capital-intensive in the HEU processing chain.

## 5. Impact of HEU Accelerated Down-Blending on Uranium and Separation Services Markets

The accelerated down-blend scenarios have the potential to significantly impact the uranium and/or enrichment markets, as well as cause possible overdependence of the US or Europe upon imported SWU. Thus, effective measures are needed to minimize market impact.

Sales of large amounts of uranium and enrichment services may distort the competitive structure of the nuclear fuel markets

Holding additional material off-market in an inventory would not by itself provide the required market protection because market participants will anticipate the release of material at the earliest feasible opportunity and adjust their buying patterns accordingly.

Therefore, additional market protection mechanisms are needed to provide price stability. These include, for example, managing the rate at which the inventories of LEU held off-market would be released into the market, restricting sales of the contained uranium and SWU to long-term contracts, avoiding sales at “market-related” prices, and selling the material via consortia of major industry players.

Another possible option for avoiding market damage would be for all or part of the LEU produced from the down-blended HEU to be purchased by the US government and retained as a strategic inventory. This could then be used to cover nuclear fuel supply disruptions that would threaten the stability and economy of the US nuclear electricity generating sector, in a manner analogous to the strategic oil reserve.

## **6. Legal Aspects of Accelerated HEU Blend-Down**

The HEU Purchase Agreement is the basic normative document to be considered in an examination of a possible acceleration of HEU blend-down, as it stipulates the possibility of such an acceleration.

Of all options under analysis, only those options associated with the temporary storage of LEU products on US territory present legal issues, which relate to the temporary storage of LEU products on US territory, civil liability for nuclear damage during LEU transport and storage, transfer of property rights, and liability for accidental loss of a product in storage. However, legal provisions dealing with these issues are commonly considered while negotiating sales/purchase contracts, and are mainly settled in conformity with current international trade law, bilateral agreements, and established business practice.

Accelerated HEU processing will require a new bilateral agreement and a new contract, where the above particulars could be taken into account.

## **7. Additional Issues Associated With Accelerated HEU Blend-Down**

**a.** The estimates of costs and implementation periods for various accelerated HEU processing options are based only on the analysis of

production capacities of enterprises directly engaged in HEU processing. However, the creation of additional capacities at these enterprises is closely connected with the capabilities of related enterprises from other industries delivering necessary materials and equipment. An increased demand for those materials and equipment will entail extra investment in production capacities, which will affect both economic indices and the period of implementation of accelerated HEU blend-down options.

In addition, the creation of new production capacities operating for a relatively small period will result in extra expenses associated with the hiring and firing of additional personnel. Further analysis of the impact of these issues would need to be considered in optimizing selected options.

**b.** Accelerated processing of HEU into LEU products will require a large amount of investment in extremely specialized production capacities established for a limited period of time. Decisions will later have to be made concerning their further use or decommissioning. Under these circumstances, it is extremely unlikely that investments will be recouped; hence, any project associated with accelerated HEU blend-down will be determined by both commercial and political decisions.

# INTRODUCTION

## **a. Project Description**

In compliance with the Agreement Between the Government of the United States and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted From Nuclear Weapons of February 18, 1993 (hereinafter referred to as the "HEU Purchase Agreement") and the January 14, 1994, Implementing Contract between the United States Enrichment Corporation (USEC) and TekSnabEksport (Tenex), as executive agents for the US and Russia, to implement the HEU Purchase Agreement, Russia has carried out the processing of HEU and the delivery of the LEU thus obtained to the US since 1995. Article 5 (Item 3) states that the parties to the HEU Purchase Agreement shall, whenever practicable, strive to accelerate the processing of HEU into LEU above the rates specified in the HEU Purchase Agreement (Article 2, Item 2).

The above documents specify the total amount of HEU subject to processing, which is equal to 500 MTU.

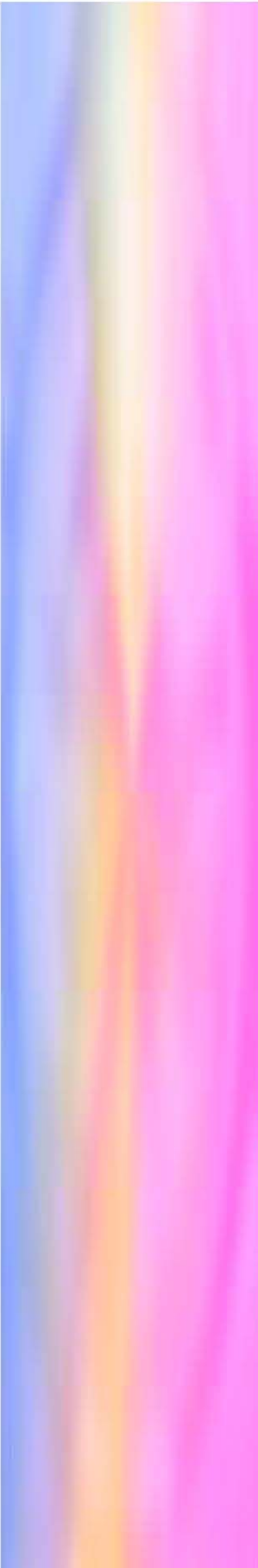
In 1995, 6 MTU of HEU were processed. In the years that followed, the rate of processing increased: 12 MTU in 1996, 18 MTU in 1997, and 24 MTU in 1998. Since 1999, 30 MTU have been processed each year. If this rate is maintained, the processing of 500 MTU of HEU will be completed by 2013.

The fulfillment of the HEU Purchase Agreement confirms the United States and Russia's commitment to the goals of the Nuclear Non-Proliferation Treaty.

## **b. Motivations for the Current Research**

The Nuclear Threat Initiative proposed that the prospects for accelerating HEU processing above the rates determined in the current contract (30 MTU/year) be analyzed. In addition, the organization suggested that accelerated processing might be achieved not only through increased HEU processing into final 4.4% product, but also through blending down HEU into intermediate LEU products of higher enrichment levels that do not exceed 20%.

## **c. Research Organization and Content**




In accordance with the NTI proposal and with the agreement of the leadership of the Russian Ministry of Atomic Energy (Minatom), now Rosatom, the parties came to an agreement reflected in the Memorandum of Understanding of October 23, 2002 between NTI and the Minatom Department of International and External Economic Cooperation (DIEEC), envisaging conceptual analysis and economic evaluation of accelerated excess HEU elimination (Attachment 1).

The above Memorandum specified the basic tasks of the research, including:

- ❑ a general description of the blend-down process (Task 2);
- ❑ an analysis of options for accelerating the blend-down of HEU into LEU (direct blend-down of HEU into LEU, as well as options involving the blend-down of HEU into an intermediate non-defense material) (Task 3);
- ❑ a determination of the type and content of diluents used in the process of accelerated HEU blend-down in order that the resulting LEU meet commercial specifications (Task 4);
- ❑ an analysis of the likely future of the commercial LEU market, given various accelerated HEU blend-down options (Task 5);
- ❑ an analysis and evaluation of the additional production capacities required to implement the accelerated HEU blend-down options, for all process stages (HEU oxidation, HEU fluorination, diluent manufacture, HEU blend-down, storage of blended material) (Task 6);
- ❑ economic estimates of the costs of implementing the HEU accelerated blend-down options (Task 7);
- ❑ an analysis of the legal aspects of implementing accelerated HEU blend-down (international standards and export procedures, property rights, legislative restrictions, etc.) (Task 8).

In order to coordinate the research, a Joint Coordination Group (JCG) was formed by Russian and US specialists. At the first JCG (October 25, 2002), the basic research parameters were adopted and recorded in a document entitled "Project Parameters" (Attachment 2).



The main participants involved in work on the Russian side were specialists from industrial enterprises engaged in HEU processing under the HEU Purchase Agreement, including SCC (Siberian Chemical Combine), Mayak, and ECP (Electrochemical Plant), as well as leading Rosatom research organizations (the Research and Design Institute of Energy Technology, Atominform, the Research Institute of Chemical Technology, the Bochvar Institute for Inorganic Materials, etc.). Scientific supervision and integration on the Russian part was carried out by the Atominform Institute.

The research carried out by Russians was governed by a contract concluded by NTI and Atominform, and included an Independent Contractor Agreement and Statements of Work (SW) for the aforementioned tasks (except for Task 5).

The US participants conducted research under Task 5 in conformity with a separate SW.

The research results are set forth in reports [1–7].


The current report summarizes the results of the research under the Project as a whole.

**This Report includes the Summary, this Introduction, Six Sections, and Conclusions**

The **Summary** gives a short description of the research goals and overall results.

**Section One** provides a general description of the current HEU blenddown process (including an HEU processing flow sheet, interaction of Rosatom enterprises engaged in the HEU Purchase Agreement, information on production flows, and an estimate of the level to which HEU processing can be increased using existing production capacities).

**Section Two** considers options for accelerating HEU blend-down into LEU and the results of the feasibility analysis (factors analyzed, the choice of options and their characteristics, the results of an analysis of the type and composition of the diluent to be used for accelerated HEU blenddown, as well as an estimate of the additional capacities needed to realize various accelerated HEU blend-down options given existing capacities).



**Section Three** analyzes the feasibility of the options for accelerated processing of HEU into LEU products (technical measures required for the realization of each option, implementation periods).

**Section Four** provides cost estimates for the various HEU processing options under consideration. The basic factors influencing these economic estimates are explained, and the capital investment and annual additional costs each option involves are summarized.

**Section Five** analyzes the world uranium and enrichment services markets, evaluates the market impact of accelerated Russian HEU downblending, and considers possible measures to mitigate this impact.

**Section Six** presents the legal aspects of accelerated HEU blend-down (Russian and international legislation and agreements, the HEU Purchase Agreement now in force, international principles of nuclear nonproliferation, nuclear counterterrorism, property rights, civil liability for and insurance against nuclear damage, state safety regulations, protection of intellectual property rights, and legal norms regulating the handling of nuclear material).

The main **conclusions** are given at the end of the Report.

**1.**

**Basic  
HEU-LEU processing  
indices, prospects  
of enhancing HEU  
processing volume  
on current production  
capacities**

## 1.1. General flow sheet of HEU processing into LEU

Figure 1.1 [1] provides a general flow sheet of HEU processing.

The HEU-LEU process includes the following four technological processes:

- production of 90%  $U_3O_8$  (uranium mixed oxide) from weapon grade HEU components;
- production of 90%  $UF_6$  (uranium hexafluoride);
- production of the diluent (1.5%  $UF_6$ );
- production of LEU (4.4%  $UF_6$ ).

### Production of 90% $U_3O_8$

Metal uranium from weapon-grade HEU components is taken from temporary storage facilities and transferred from transport containers into containers used within the enterprise, and subsequently transferred to the mechanical treatment section to be cut into metal chips. The chips are then oxidized in gloveboxes. The resulting  $U_3O_8$  is further refined to eliminate radiogenic and chemical impurities.

### Production of 90% $UF_6$

Refined  $U_3O_8$  is transferred to the fluorination section and is converted into  $UF_6$  through the use of fluorine. The gas mixture that results from this fluorination is sent to the desublimation section. In desublimators, cooled  $UF_6$  is withdrawn from the gas flow and turned into a solid. The  $UF_6$  is desublimated into transport vessels, which are placed in temporary storage until delivery to the dilution section.

### Diluent Production (1.5% $UF_6$ )

In order to make the LEU conform to ASTM C 966-96 requirements, a 1.5%  $^{235}U$  diluent is fabricated from commercial natural uranium preliminarily depleted (of  $^{234}U$ ) in an enrichment plant. The first production of this type of diluent took place at the Urals Electrochemical Combine (UECC). The production of diluent of the required quality from various kinds of blendstock is thoroughly examined in Report 3. The main results are given below.

The resulting diluent is transferred to the desublimation section, condensed, and transferred to intermediate containers.

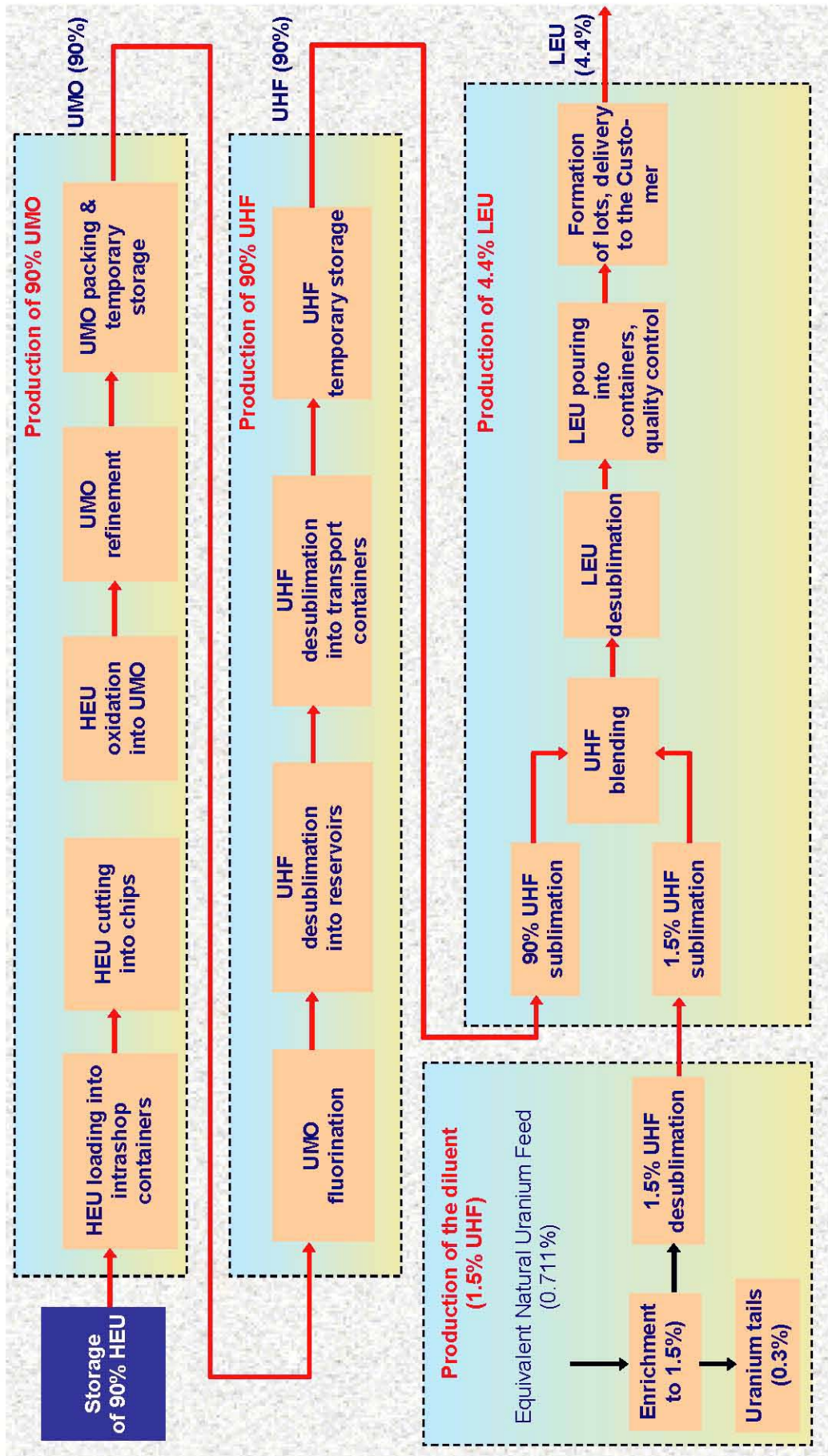


Fig. 1.1. General flow sheet of HEU processing into LEU  
 UMO –  $U_3O_8$  UHF –  $UF_6$

## Production of LEU (4.4% UF<sub>6</sub>)

The containers of HEU (90% UF<sub>6</sub>) and diluent (1.5% UF<sub>6</sub>) are transferred to the sublimation units and fed via mass flow rate dosing units and vacuum pipes to the blending section. The blended gas flow (LEU) is fed via a third pipe to the desublimation unit where it is condensed into intermediate containers. From these containers, LEU is transferred to transport containers; during this procedure the product quality is checked. Containers with LEU are placed into the temporary storage facility where LEU lots for delivery to the customer are formed.

The material balance flows for processing 30 MTU of HEU into LEU are given in Figure 1.2.

This data shows that 30 MTU of 90% HEU mixed with 1.5% diluent produces 915.5 MTU of 4.4% LEU, and consumes 885.5 MTU of diluent. The natural component in the LEU produced is 9,132.7 MTU, the uranium consumption for the diluent production being equivalent to 2,585.4 MTU natural uranium. The separative work for producing 915.5 MTU of 4.4% diluent from natural uranium makes up 5,528.3 kSWU, that for producing 885.5 MTU of the diluent, 3,513.7 kSWU.

### 1.2. Interaction of Rosatom Enterprises Engaged in Processing HEU into LEU, Balance of Material Flows

At present, HEU is processed into LEU at four Rosatom enterprises, as follows:

- Siberian Chemical Combine (SCC);
- Electrochemical Plant (ECP);
- Mayak Production Association;
- Urals Electrochemical Combine (UECC).

Only one enterprise, SCC, performs all stages of HEU processing. The other enterprises perform certain stages, namely: production of highly enriched U<sub>3</sub>O<sub>8</sub> (Mayak); production of highly enriched UF<sub>6</sub> (from U<sub>3</sub>O<sub>8</sub>), diluent, and LEU (ECP); production of diluent and LEU (UECC).

Figure 1.3 shows the interaction of enterprises and the flows of fissile materials while processing HEU into LEU. Table 1.1 presents estimated indices of LEU production at Rosatom enterprises.

As can be seen in Figure 1.3 and Table 1.1, highly enriched U<sub>3</sub>O<sub>8</sub> produced at Mayak (15 MTU) is delivered to two enterprises: ECP (8.2 MTU) and SCC (6.8 MTU) for further processing.

At SCC, highly enriched U<sub>3</sub>O<sub>8</sub> received from Mayak (6.8 MTU) together with U<sub>3</sub>O<sub>8</sub> produced at SCC (15 MTU) is processed into UF<sub>6</sub>.

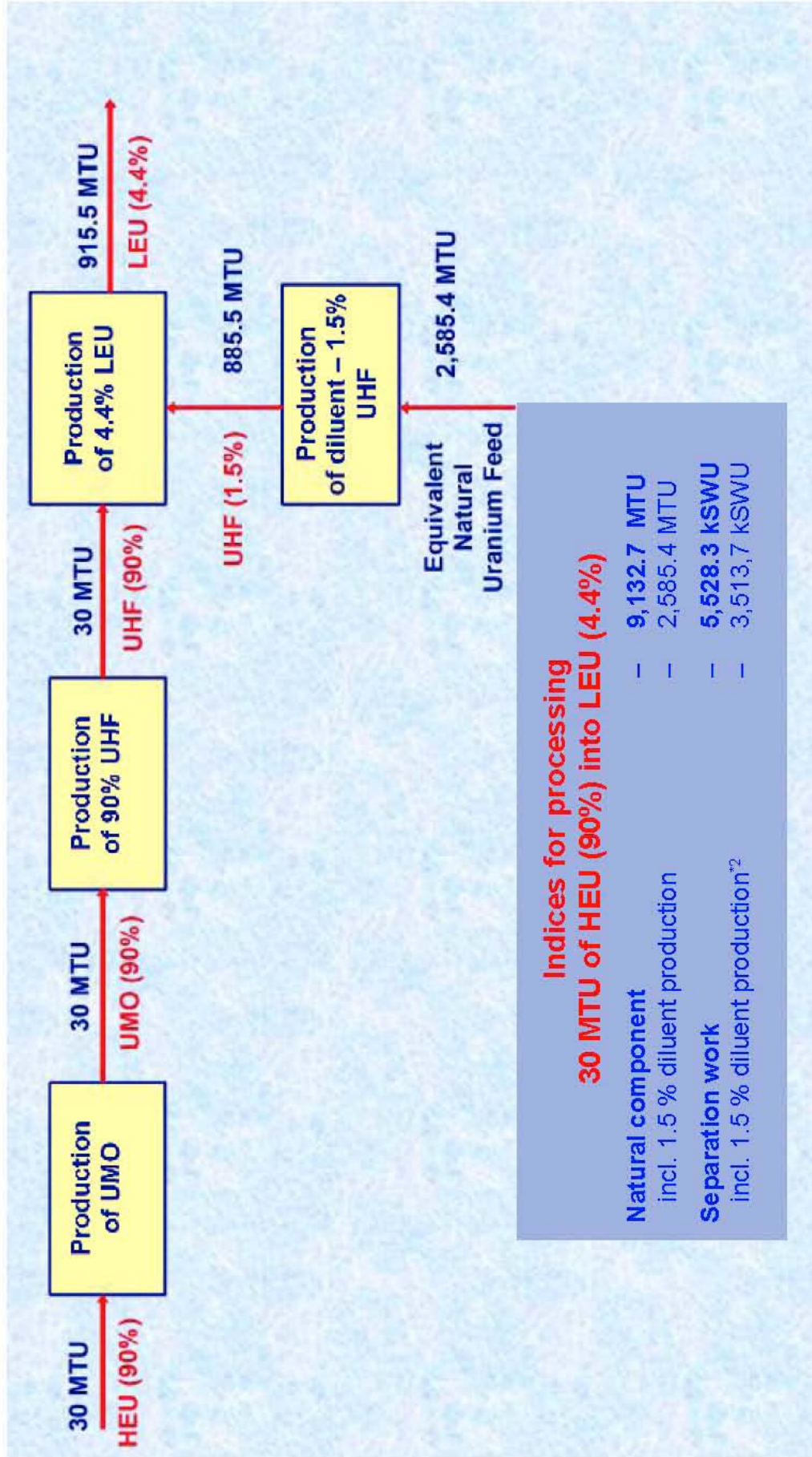


Fig. 1.2. Estimated material balance for processing HEU into LEU<sup>1</sup>  
<sup>1</sup> not accounting processing losses;

<sup>2</sup> with the account of SWU for raw purification from isotope <sup>234</sup>U

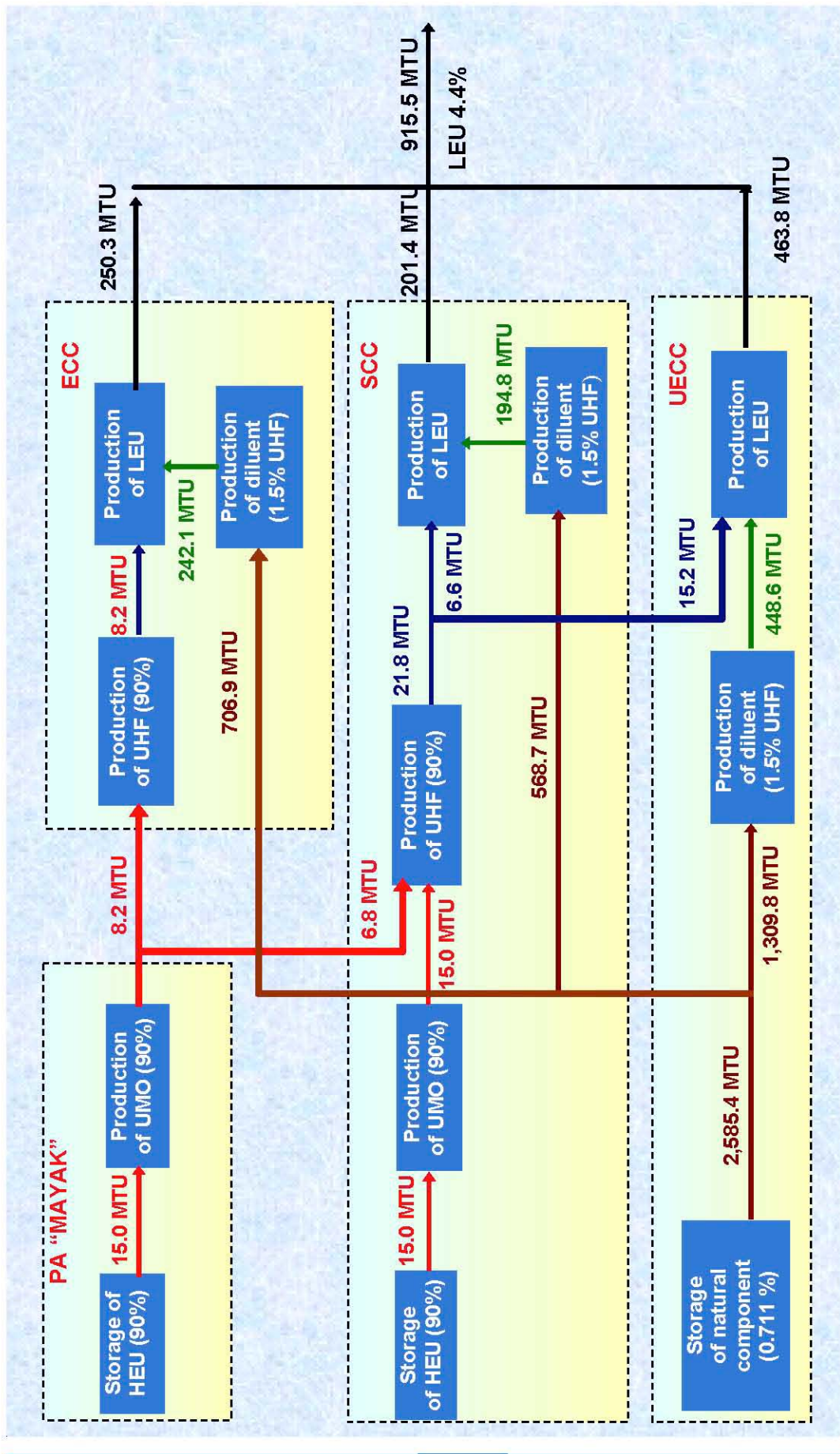


Fig. 1.3. Interaction of Rosatom enterprises while processing HEU into LEU under the contract in force

Table 1.1

**Estimated indices of LEU (4.4%) production from HEU (90%)  
at Rosatom enterprises, MTU (kSWU)**

Enterprise	Consumption of 90% HEU	Production of 90% UMO	Production of 90% UHF	Production of diluent (1.5% UHF)	Separation work	Production of LEU (4.4%)
SCC	15.0 (50%)	15.0 (50%)	21.8 (72.7%)	194.8 (22.0%)	773.0 (22.0%)	201.4 (22.0%)
ECP	–	–	8.2 (27.3%)	242.1 (27.3%)	960.7 (27.3%)	250.3 (27.3%)
UECC	–	–	–	448.6 (50.7%)	1,780.0 (50.7%)	463.8 (50.7%)
MAYAK	15.0 (50%)	15.0 (50%)	–	–	–	–
<b>Total</b>	<b>30.0</b> (100%)	<b>30.0</b> (100%)	<b>30.0</b> (100%)	<b>885.5</b> (100%)	<b>3,513.7</b> (100%)	<b>915.5</b> (100%)

**Notes.** 1. The actual distribution of products under the HEU-LEU program at the given enterprises may change proceeding from their capacities and corporate interests.

2. Separation works are measured in kSWU.

Part of the highly enriched  $UF_6$  (15.2 MTU) is sent to UECC, another part (6.6 MTU) is used in the production of LEU. At SCC, highly enriched  $UF_6$  is mixed with SCC diluent (194.8 MTU) thus yielding 201.4 MTU of 4.4% LEU. The separative work for producing 201.4 MTU of the diluent makes up 773.0 kSWU.

Highly enriched  $U_3O_8$ , delivered to ECP, is turned into highly enriched  $UF_6$  and mixed with its own diluent (242.1 MTU) thus yielding 250.3 MTU of LEU. The separative work for producing 242.1 MTU of the diluent at ECP makes up 960.7 kSWU.

Highly enriched  $U_3O_8$  (15.2 MTU) delivered to UECC from SCC is mixed with its own diluent (448.6 MTU). As a result, 463.8 MTU of 4.4% LEU are produced. The separative work for fabricating 448.6 MTU of the diluent makes up 1,780.0 kSWU.

A detailed description of the HEU processing method currently used at each participating enterprise is given in Report 1 [1].

### **1.3. Estimate of Reserves for Increasing HEU-LEU Processing Volume Based on Current Capacities of Enterprises Involved**

It should be noted that in addition to capacities specially created for the HEU-LEU process, operating capacities that became available owing to cuts in Russian defense programs are being used in the current program.

The analysis of the production capacities of Mayak, SCC, ECP, and UECC, the plants engaged in the HEU-LEU process, made it possible to estimate the amount of reserves available for enhancing the HEU blend-down volume [2, 5].

As seen in Figure 1.1, each HEU-LEU stage includes a number of processing divisions with different production capabilities. Therefore, the production capabilities of each stage were evaluated based on the lowest capabilities of its divisions [5].

The estimates of possible reserves for the basic processing stages are indicated in Table 1.2.

Table 1.2

**Estimated reserves for increasing the HEU processing volume at enterprises engaged in turning HEU into 4.4% LEU**

Stage		Total	MAYAK	SCC	ECP	UECC
1	Production of highly enriched (HE) UMO	<b>7.5 MTU</b> of HEU	<b>2.5 MTU</b> of HEU	<b>5.0 MTU</b> of HEU	–	–
2	Production of HE UHF	<b>2.4 MTU</b> of HEU	–	<b>2.0 MTU</b> of HEU	<b>0.4 MTU</b> of HEU	–
3	Production of LEU diluent (separation work)	<b>1.6 MTU</b> of HEU ( <b>47.2 MTU</b> of 1.5% LEU; <b>187.3</b> kSWU)	–	<b>0.4 MTU</b> of HEU ( <b>11.8 MTU</b> of 1.5% LEU; <b>46.8</b> kSWU)	<b>0.3 MTU</b> of HEU ( <b>8.8 MTU</b> of 1.5% LEU; <b>34.9</b> kSWU)	<b>0.9 MTU</b> of HEU ( <b>26.6 MTU</b> of 1.5% LEU; <b>105.6</b> kSWU)
4	Production of 4.4% UHF	<b>7.4 MTU</b> of HEU ( <b>225.8</b> MTU of 4.4% LEU)	–	<b>2.4 MTU</b> of HEU ( <b>73.2</b> MTU of 4.4% LEU)	<b>0.4 MTU</b> of HEU ( <b>12.2</b> MTU of 4.4% LEU)	<b>4.6</b> MTU of HEU ( <b>140.4</b> MTU of 4.4% LEU)
<b>In general</b>		<b>1.6 MTU</b> of HEU	<b>2.5 MTU</b> of HEU	<b>0.4 MTU</b> of HEU	<b>0.3 MTU</b> of HEU	<b>0.9 MTU</b> of HEU

- estimated reserves available for highly enriched  $U_3O_8$  production permit an annual increase in HEU processing of no more than 7.5 MTU.
- estimated reserves available for highly enriched  $UF_6$  production permit an annual increase in HEU processing of no more than 2.4 MTU.
- estimated reserves available for the production of 1.5% diluent do not exceed 47.2 MTU/year, which corresponds to separative

work equal to 187.3 kSWU. These reserves cannot ensure the growth of HEU processing volume by more than 1.6 MTU/year.

□ annual estimated reserves available for 4.4% LEU production (LEU mixed with diluent) would allow the production of up to 225.8 MTU of LEU, which corresponds to an annual increase of 7.4 MTU HEU that could be blended down to 4.4% LEU.

In general, taking into account the limits of Russia's separation capacity (item 3 in Table 1.2), the available reserves cannot provide for more than a 1.6 MTU/year increase of HEU processing into 4.4% LEU.

**2.**

**Options  
for HEU accelerated  
blend-down,  
feasibility analysis**

## 2.1. Factors Determining Possible Accelerated HEU Blend-Down Options

The factors that were analyzed in this study to determine what the options for accelerated HEU blend-down might be were specified in the Project Parameters, as follows:

- ❑ alternative levels of increased annual HEU processing, above the current level of 30 MTU/year **5, 10, 20**, and **30** MTU/year, i.e. the annual volume of HEU processed may be as large as **35, 40, 50**, and **60** MTU;
- ❑ alternative enrichments of LEU by  $^{235}\text{U}$ : **4.4%** (final LEU product); **12%** and **19%** (intermediate LEU products);
- ❑ alternative deliveries (sales) of LEU products: **immediate (prompt)** and **deferred deliveries**, after temporary storage of the finished LEU product;
- ❑ alternative storage points for LEU products in case of deferred delivery after a temporary storage period: **Russian** territory, **US** territory, or the territory of a **European** country.

The options corresponding to the above conditions of accelerated HEU processing (48 in total) are presented in Attachment 2.

In the course of their joint examination of these factors, the Russian and US specialists made a selection (screening) of accelerated HEU processing options for subsequent analysis.

The screening criteria were as follows:

- ❑ degree to which the accelerated HEU processing options reflected the range of particular features and alternatives specified in the Project Parameters;
- ❑ degree to which the options reflected the range of accounting technical, production, economic, legislative, marketing, and other factors related to accelerated HEU processing; and
- ❑ exclusion of options with insignificant differences.

As a result, 12 options were selected (see Table 2.1).

Table 2.1

## Analyzed options for HEU accelerated processing

No.	Option	HEU processing increment	HEU annual enrichment volume	LEU product enrichment	LEU product delivery	Temporary storage of LEU products	
						Russia	USA
1	1A1	5 MTU/year	35 MTU	4.4%	immediate		
2	1A2			4.4%	deferred	+	
3	1B3			12.0%	deferred		+
4	2A1	10 MTU/year	40 MTU	4.4%	immediate		
5	2C1			19.0%	immediate		
6	3A1	20 MTU/year	50 MTU	4.4%	immediate		
7	3A2			4.4%	deferred	+	
8	3C2			19.0%	deferred	+	
9	4A1	30 MTU/year	60 MTU	4.4%	immediate		
10	4A3			4.4%	deferred		+
11	4B2			12.0%	deferred	+	
12	4C3			19.0%	deferred		+

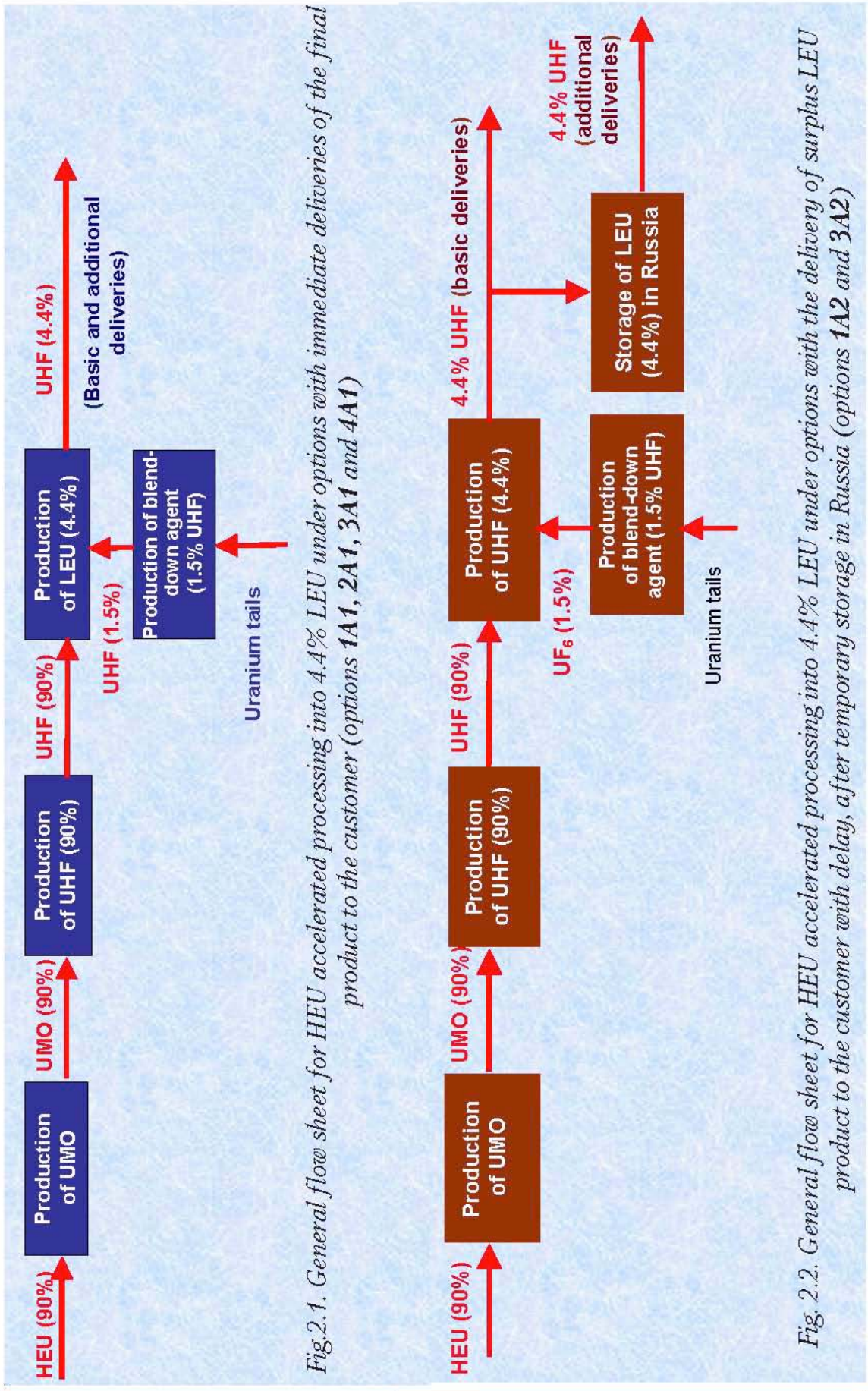


Fig.2.1. General flow sheet for HEU accelerated processing into 4.4% LEU under options with immediate deliveries of the final product to the customer (options 1A1, 2A1, 3A1 and 4A1)

Fig. 2.2. General flow sheet for HEU accelerated processing into 4.4% LEU under options with the delivery of surplus LEU product to the customer with delay, after temporary storage in Russia (options 1A2 and 3A2)



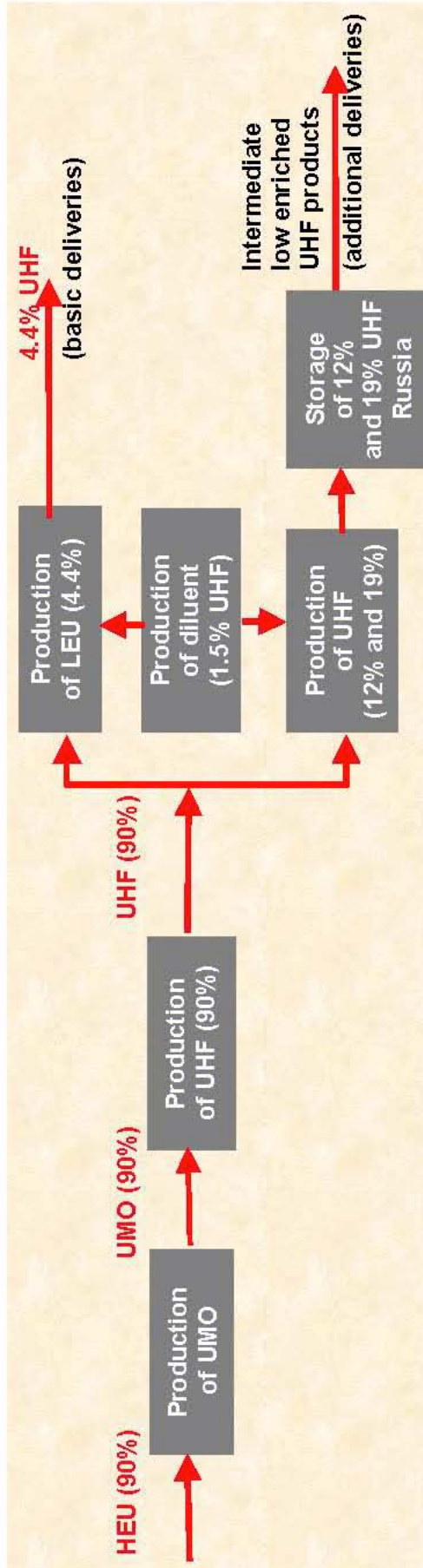


Fig. 2.5. General flow sheet for HEU accelerated processing into intermediate LEU products with the delivery of surplus LEU product to the Customer with delay, after preliminary storage (options 3C2 and 4B2)

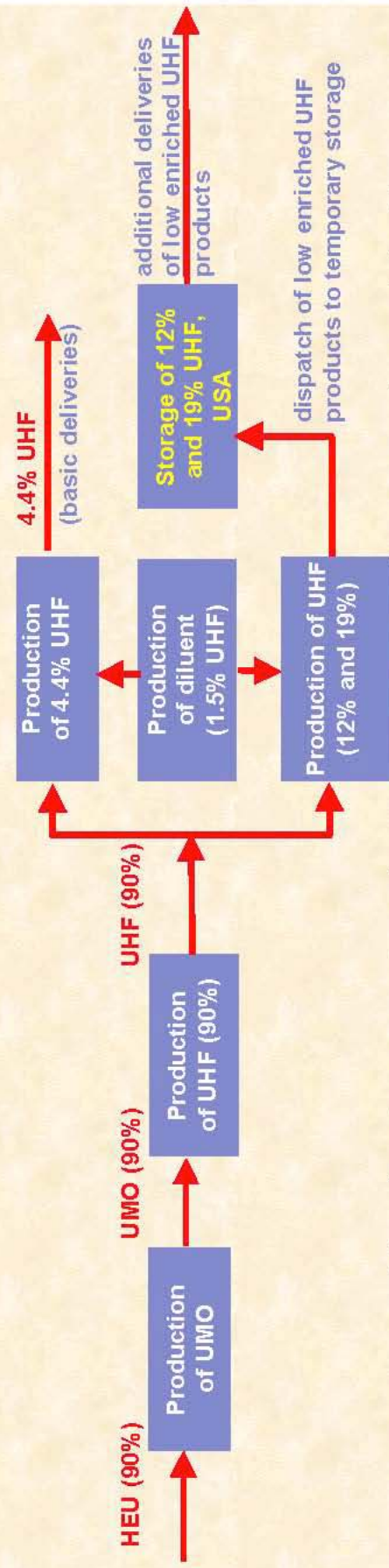


Fig. 2.6. General flow sheet for HEU accelerated processing into intermediate LEU products with the delivery of surplus LEU product to the Customer with delay, after temporary storage (options 1B3 and 4C3)

Seven of the selected options (1A1, 1A2, 2A1, 3A1, 3A2, 4A1, and 4A3) envisage processing HEU into final product – 4.4% LEU. In four of these options (1A1, 2A1, 3A1, and 4A1), the additional LEU is immediately delivered to the customer, while in options 1A2 and 3A2, the additional LEU deliveries are completed after temporary storage on Russia territory. Option 4A3 envisages temporary storage on US territory.

In the remaining five options, additional amounts of HEU are processed into intermediate LEU products with 12% (1B3 and 4B2) and 19% (2C1, 3C2, and 4C3) enrichment. It should be noted that in option 2C1, the additional LEU is delivered to the customer immediately, in options 3C2 and 4B2, after temporary storage on Russian territory, and in options 1B3 and 4C3, after temporary storage on US territory.

In options 1A1, 1A2, and 1A3, the annual amount of processed HEU totals 35 MTU, in options 2A1 and 2C1, 40 MTU, in options 3A1, 3A2, and 3C2, 50 MTU, in options 4A1, 4A3, 4B2, and 4C3, 60 MTU

Figures 2.1 thru 2.6 give general flow sheets for accelerated HEU processing into final and intermediate LEU products corresponding to the options given in Table 2.1.

## **2.2. Type and Composition of Diluent Applied during HEU Processing to Ensure that the Resulting LEU Meets Commercial Specifications**

### **2.2.1. Initial data and conditions**

When processing HEU into LEU, the quality of the LEU product must be ensured, such that its isotopic composition conforms to generally recognized specifications.

Since the quality of LEU product is for the most part determined by the characteristics of the diluent applied, the researchers considered various options for diluent production to ensure the quality of LEU product and minimize the volume of separative work.

The aforementioned Project Parameters set requirements for the quality of LEU product and the content of  $^{235}\text{U}$  in the diluent and blendstock for its fabrication, including the following:

- 4.4% LEU product complies with ASTM C 996-96 Specifications.  
(This research did not consider the influence of ASTM C 996-04

Table 2.2

### Isotopic composition of commercial natural uranium

Isotope	$\mu\text{g/gU}$	%
$^{232}\text{U}$	0.00001	$1 \cdot 10^{-9}$
$^{234}\text{U}$	58	0.0058
$^{236}\text{U}$	20	0.002

Table 2.3

### Standard content of uranium isotopes in commercial LEU

Uranium isotope	Maximum permissible content	
	$\mu\text{g/g uranium}$	
$^{232}\text{U}$	0.0001	$^{232}\text{U}$
$^{234}\text{U}$	10,000 / g of $^{235}\text{U}$	$^{234}\text{U}$
$^{236}\text{U}$	250	$^{236}\text{U}$

Specifications (as regards the content of  $^{234}\text{U}$  in LEU) in the source material and diluent characteristics);

- blendstock: 1.5%  $^{235}\text{U}$ ;
- blendstock source: commercial natural uranium and uranium tails;
- blendstock feed: 0.711%  $^{235}\text{U}$  (natural uranium), 0.25%  $^{235}\text{U}$ ; 0.3%  $^{235}\text{U}$ , and 0.35%  $^{235}\text{U}$  (uranium tails).

The isotopic composition of commercial natural uranium used in enrichment processes conforming to ASTM C 797-90 is summarized in Table 2.2.

According to the specifications, the content of  $^{235}\text{U}$  in commercial natural uranium shall be  $(0.711 \pm 0.004)$  g per 100 g of U, or 0.711%.

The requirements for  $^{234}\text{U}$  content in  $\text{UF}_6$  enriched to less than 5%  $^{235}\text{U}$  are specified by the ASTM C 996-96 standard and presented in Table 2.3.

The content of  $^{235}\text{U}$  in commercial LEU shall not exceed 5%.

The isotopic composition of the diluent depends both upon the isotopic content of the feed material from which it was derived as well as upon the enrichment of the uranium tails from which the diluent is produced. When commercial natural uranium is used as a feed, the isotopic composition of the resulting diluent will vary depending upon the final enrichment of the depleted uranium stream generated from enrichment. Furthermore, depleted uranium tails, even at the same uranium enrichment levels, will have differing isotopic compositions due to the differing final enrichments levels of various products. That is

why this analysis considered several diluent fabrication options using uranium tails with different isotopic compositions.

Given these facts, the following requirements were added to the preset parameters:

- ❑ when fabricating a diluent from commercial natural uranium, options involving uranium tails enriched to 0.3% and 0.15% must be evaluated;
- ❑ uranium tails with  $^{235}\text{U}$  content of 0.25%, 0.3% and 0.35% are processed through the enrichment of commercial natural uranium to 3.6%, 4.0% and 4.5%  $^{235}\text{U}$ ;
- ❑ in diluent fabrication from uranium tails, the secondary uranium tails content is taken as 0.15%;
- ❑ the estimated content of the most critical  $^{234}\text{U}$  isotope as part of 90% HEU was based on the assumption that the HEU is produced by enriching natural uranium (conforming to ASTM specifications) in separation processing with a uranium tails content of 0.3% and 0.35%.

As one can see from Table 2.3, of even-numbered uranium isotopes,  $^{234}\text{U}$  features the highest concentration of  $^{235}\text{U}$ . Therefore, meeting the ASTM requirements for the  $^{234}\text{U}$  content of LEU obtained during HEU blend-down will ensure the observance of requirements for other isotopes as well. Therefore, only the  $^{234}\text{U}$  content of products under consideration here was evaluated, since this is the most critical isotope determining the commercial specifications of those products.

### 2.2.2. Diluent production options

The aforementioned conditions specify the number of diluent production options, which vary according to the kinds of blendstock used, production conditions, and production methods.

The options are presented in Table 2.4.

The options were compared according to the following factors:

1. The diluent isotopic composition must ensure the 4.4% LEU meet quality requirements and comply with the ASTM C 996-96 specifications;
2. Minimal separative work volume and minimal blendstock consumption in diluent production;

Restrictions in the options analyzed were as follows:  $^{234}\text{U}$  content in HEU and its maximum permissible content in the final 4.4% LEU product.

Options of 1.5% diluent production from different kinds of blendstock

Option*	Kind of blendstock for diluent production	<sup>235</sup> U content in product which formed the blendstock, %	Uranium tails content in diluent production, %
1a1	Commercial natural uranium, 0.711%	–	0.3%
1a2	Commercial natural uranium, 0.711%	–	0.15%
1b1	Uranium tails, 0.25%	3.6%	0.15%
2b1	Uranium tails, 0.30%	3.6%	
3b1	Uranium tails, 0.35%	3.6%	
1b2	Uranium tails, 0.25%	4.0%	
2b2	Uranium tails, 0.30%	4.0%	
3b2	Uranium tails, 0.35%	4.0%	
1b3	Uranium tails, 0.25%	4.5%	
2b3	Uranium tails, 0.30%	4.5%	
3b3	Uranium tails, 0.35%	4.5%	

\* Diluent option numbers are not related to blend-down option numbers.

### 2.2.3. Analysis of diluent production options

The analysis was aimed at estimating the content of <sup>234</sup>U in 90% HEU obtained through the enrichment of natural uranium (with an isotope content conforming to ASTM Specs.), and at determining the maximal permissible content of that isotope in the 1.5% diluent while ensuring that the LEU product meets commercial specifications.

As a result, the following figures were obtained:

- <sup>234</sup>U content in 90% HEU: **1.001014%**;
- <sup>234</sup>U maximal permissible content in 1.5% diluent: **0.010854%**.

Diluent production from commercial natural uranium (options 1a1 and 1a2) was the first to be analyzed.

To this end, the researchers considered the production of a diluent from natural uranium with a uranium tails content equal to 0.15% and 0.3% <sup>235</sup>U. They also determined the maximal permissible content of <sup>234</sup>U in the blendstock for both options, such that the required content of that isotope in the diluent would be ensured. The results obtained were compared with the content of <sup>234</sup>U in commercial natural uranium.

The results (see Table 2.5) show that the content of <sup>234</sup>U in commercial natural uranium exceeds the maximal permissible level;

therefore, the above options (1a1 and 1a2) could not be used for processing HEU into LEU products.

Table 2.5

Content of  $^{234}\text{U}$  in natural and commercial uranium, %

Diluent production option	Maximal permissible content of $^{234}\text{U}$ in natural uranium, %	Content of $^{234}\text{U}$ in commercial natural uranium, %
1a1	0.003718	<b>0.005800</b>
1a2	0.004768	

The options for diluent production from uranium tails were analyzed next. To this end, the researchers determined the content of  $^{234}\text{U}$  in diluent fabricated from various kinds of blendstock. The results were compared with the maximal permissible content of that isotope in the diluent.

The results can be found in Table 2.6.

Table 2.6

Content of  $^{234}\text{U}$  in 1.5% diluent, consumption of uranium tails

Option	Specific uranium tails consumption for fabricating 1 kg of diluent, kg	Natural equivalent of uranium tails to produce 1 kg of diluent, kg	$^{234}\text{U}$ content in diluent, %
<b>1b1</b>	13.5	2.406	<b>0.008758</b>
<b>2b1</b>	9.0	2.406	<b>0.009360</b>
<b>3b1</b>	6.75	2.406	<b>0.009922</b>
1b2	13.5	2.406	0.008693
2b2	9.0	2.406	0.009299
3b2	6.75	2.406	0.009866
1b3	13.5	2.406	0.008626
2b3	9.0	2.406	0.009236
3b3	6.75	2.406	0.009809
<b>Maximal permissible content of U isotopes in 1.5% diluent</b>			<b>0.010854</b>

As can be seen in Table 2.6, the use of uranium tails (for all the options) as blendstock results in a  $^{234}\text{U}$  content in the diluent less than the maximum permissible value. Consequently, all of the types of uranium tails that were considered are suitable for diluent production, and ensure LEU conformity with ASTM C 996-96.

In addition, the Table 2.6 data on the consumption of blendstock in the production of diluent indicate that it is equal for all options.

Since all kinds of uranium tails are suitable for diluent production, the researchers chose to concentrate on those options with the highest  $^{235}\text{U}$  content in the diluent (**1b1**, **2b1**, and **3b1**), in order to reduce the number of options analyzed. These options cover the whole range of

uranium tails formed during natural uranium enrichment for nuclear fuel fabrication.

Next, these options were analyzed by the volume of separative work.

Table 2.7 presents an estimate of separative work per 1 kg of 1.5% diluent for each of the above options.

Table 2.7

**Separation work required for fabricating 1 kg of the diluent from uranium tails**

Option	<sup>235</sup> U content in uranium tails, %	Separation work volume, SWU
1b1	0.25	4.628
2b1	0.30	3.968
3b1	0.35	3.446

It follows from Table 2.7 that option **3b1**, with 0.35% <sup>235</sup>U content, is the best one for diluent fabrication as it involves the lowest volume of separative work.

However, the main variant chosen for further analysis was option **2b1**, which uses uranium tails with 0.3% <sup>235</sup>U content.

This option is close to option **3b1** in separative work volume but is superior to it because it uses the most common kind of uranium tails as blendstock and ensures the required quality of the final product resulting from HEU downblending.

Thus, the analysis of the diluent production options provides the following conclusions.

1. Using commercial natural uranium for this purpose is inadmissible, because that blendstock does not ensure the conformity of the final LEU product to ASTM C 996-96 Specifications.

2. Of the analyzed options for using uranium tails in diluent production, the most preferable (as concerns the minimal volume of separative work) is the one envisaging the use of 0.35% <sup>235</sup>U tails. However, since tails with 0.3% <sup>235</sup>U content are most numerous, they are considered to be the most suitable blendstock.

### **2.3. Additional Capacities Needed to Realize Proposed HEU Blend-Down Options Given Existing Capacities**

Calculating the material flows for each option provides estimated production outputs for all basic HEU-LEU stages [5]. The results are presented in Table 2.8.

Table 2.8

**Estimated production outputs for the main stages relative to the basic process and analyzed options for HEU accelerated processing into LEU products**

Options	Basic	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Processing of 90% HEU, MTU/year	30	35	35	35	40	40	50	50	50	60	60	60	60
Production of 90% UMO, MTU/year	30	35	35	35	40	40	50	50	50	60	60	60	60
Production of 90% UHF, MTU/year	30	35	35	35	40	40	50	50	50	60	60	60	60
<b>Total</b>	<b>885.5</b>	<b>1,033.1</b>	<b>1,033.1</b>	<b>922.6</b>	<b>1,180.7</b>	<b>926.1</b>	<b>1,475.9</b>	<b>1,475.9</b>	<b>966.7</b>	<b>1,771</b>	<b>1,771</b>	<b>1,108.4</b>	<b>1,007.3</b>
Production of 4.4% LEU	885.5	1,033.1	1,033.1	885.5	1,180.7	885.5	1,475.9	1,475.9	885.5	1,771	1,771	885.5	885.5
Production of 12% LEU	-	-	-	37.1	-	-	-	-	-	-	-	222.9	-
Production of 19% LEU	-	-	-	-	-	40.6	-	-	81.2	-	-	-	121.8
<b>Total</b>	<b>3,513.7</b>	<b>4,099.3</b>	<b>4,099.3</b>	<b>3,660.9</b>	<b>4,685.0</b>	<b>3,674.8</b>	<b>5,856.4</b>	<b>5,856.4</b>	<b>3,835.9</b>	<b>7,027.3</b>	<b>7,027.3</b>	<b>4,398.1</b>	<b>3,997.0</b>
Production of 4.4% LEU	3,513.7	4,099.3	4,099.3	3,513.6	4,685.0	3,513.6	5,856.4	5,856.4	3,513.6	7,027.3	7,027.3	3,513.6	3,513.6
Production of 12% LEU	-	-	-	147.3	-	-	-	-	-	-	-	884.5	-
production of 19% LEU	-	-	-	-	-	161.2	-	-	322.3	-	-	-	483.4
<b>Total</b>	<b>2,130.5</b>	<b>2,485.6</b>	<b>2,485.6</b>	<b>2,219.8</b>	<b>2,840.8</b>	<b>2,228.2</b>	<b>3,551.0</b>	<b>3,551.0</b>	<b>2,325.9</b>	<b>4,261.0</b>	<b>4,261.0</b>	<b>2,667.2</b>	<b>2,423.6</b>
Production of 4.4% LEU	2,130.5	2,485.6	2,485.6	2,130.9	2,840.8	2,130.9	3,551.0	3,551.0	2,130.9	4,261.0	4,261.0	2,130.9	2,130.9
Production of 12% LEU	-	-	-	88.9	-	-	-	-	-	-	-	536.3	-
Production of 19% LEU	-	-	-	-	-	97.3	-	-	195.0	-	-	-	292.7
<b>Production of LEU, MTU/year</b>	<b>915.5</b>	<b>1,068.1</b>	<b>1,068.1</b>	<b>915.5</b>	<b>1,220.7</b>	<b>915.5</b>	<b>1,525.9</b>	<b>1,525.9</b>	<b>915.5</b>	<b>1,831</b>	<b>1,831</b>	<b>915.5</b>	<b>915.5</b>
4.4%	-	-	-	42.1	-	-	-	-	-	-	-	252.9	-
12.0%	-	-	-	-	-	50.6	-	-	101.2	-	-	-	-
19.0%	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>Delivery of LEU-products</b>	<b>915.5</b>	<b>1,068.1</b>	<b>915.5</b>	<b>915.5</b>	<b>1,220.7</b>	<b>915.5</b>	<b>1,525.9</b>	<b>915.5</b>	<b>915.5</b>	<b>1,831</b>	<b>915.5</b>	<b>915.5</b>	<b>915.5</b>
4.4%	-	-	-	-	-	50.6	-	-	-	-	-	-	-
12.0%	-	-	-	-	-	-	-	-	-	-	-	-	-
19.0%	-	-	-	-	-	-	-	-	-	-	-	-	-
<b>LEU put in storage, MTU/year</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
4.4%	-	-	-	152.6	-	-	-	610.4	-	-	-	-	-
12.0%	-	-	-	-	-	-	-	-	-	-	915.5	-	-
19.0%	-	-	-	42.1	-	-	-	-	-	-	-	252.9	-
<b>LEU deferred deliveries, MTU/year</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
4.4%	-	-	-	-	-	-	-	-	-	-	-	-	-
12.0%	-	-	-	42.1	-	-	-	610.4	-	-	915.5	-	-
19.0%	-	-	-	-	-	-	-	-	101.2	-	-	-	151.8
<b>Total</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>	<b>-</b>
4.4%	-	-	-	-	-	-	-	-	-	-	-	-	-
12.0%	-	-	-	-	-	-	-	-	-	-	-	-	-
19.0%	-	-	-	-	-	-	-	-	-	-	-	-	-

Table 2.9 shows the necessary increase in separative work and blendstock consumed in the production of diluent at each processing stage for the various accelerated HEU blend-down options, as well as the current HEU blend-down process [5].

The comparison of these data with existing capacities (Table 1.2) allows one to calculate the amount of additional capacities needed to fulfill the accelerated HEU blend-down program. These estimates can be found in Table 2.10.

Table 2.10 shows that all accelerated HEU blend-down options require additional capacities. The required increase in capacities is different for different stages and is determined by the available reserve capacity.

In the production of highly enriched  $U_3O_8$ , additional capacities are not required if annual HEU processing is increased no more than 5 MTU (options 1A1, 1A2, and 1B3). Other options all require additional capacities: from 2.5 MTU (10 MTU annual increase) to 22.5 MTU (30 MTU annual increase).

The production of highly enriched  $UF_6$  requires additional capacities at all stages: from 2.6 MTU (5 MTU annual increase) to 27.6 MTU (30 MTU annual increase).

Diluent production requires additional capacities for all options of accelerated HEU processing into final LEU products (options 1A1, 1A2, 2A1, 3A1, 3C2, 4A1, and 4A3). The demand for extra separation capacities for those options ranges from 398.8 kSWU (for an annual HEU increase of 5 MTU) to 3,326.3 kSWU (HEU annual increase of 30 MTU). This volume of separation capacities is comparable to URENCO or the newly created US separation facilities.

HEU blend-down to intermediate LEU products will require a much lower increase in separation capacities. For instance, the implementation of options 1B3 and 2C1 (additional processing of 5 and 10 MTU of HEU into 12% and 19% LEU, respectively) would be possible with the use of available reserve capacities. Additional capacities will be required only to fulfill option 3C2 (additional processing of 20 MTU of HEU into 12% LEU) and options 4B2 and 4C3 (additional processing of 30 MTU of HEU into 12% and 19% LEU, respectively).

Table 2.9

## Production increment required for HEU accelerated blend-down options under analysis

Options	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Additional HEU processing volume, MTU/year	5.0			10.0			20.0			30.0		
Production of highly enriched UMO, MTU/year	5.0			10.0			20.0			30.0		
Production of highly enriched UHF, MTU/year	5.0			10.0			20.0			30.0		
Production of 1.5% diluent, MTU/year	147.6	147.6	37.1	295.2	40.6	590.4	590.4	81.2	885.5	885.5	222.9	121.9
Separation work, kSWU/year	585.6	585.6	147.2	1,171.3	161.1	2,342.7	2,342.7	322.2	3,513.6	3,513.6	884.4	483.3
Blendstock consumption, MTU/year	355.1	355.1	89.3	710.3	97.7	1,420.5	1,420.5	195.4	2,130.5	2,130.5	536.3	293.1
LEU product output, MTU/year	152.6	152.6	-	305.2	-	610.3	610.3	-	915.5	915.5	-	-
	12.0%	-	42.1	-	-	-	-	-	-	-	252.9	-
	19.0%	-	-	-	50.5	-	-	101.2	-	-	-	151.8
	4.4%	Russia	-	-	-	-	610.3	-	-	-	-	-
	USA	-	-	-	-	-	-	-	-	915.5	-	-
LEU product put in storage, MTU/year	12.0%	Russia	-	-	-	-	-	-	-	-	252.9	-
	USA	-	42.1	-	-	-	-	-	-	-	-	-
	19.0%	Russia	-	-	-	-	-	101.2	-	-	-	-
	USA	-	-	-	-	-	-	-	-	-	-	151.8

Table 2.10

Estimate of demands for additional capacities and their deficiency relative to the analyzed options for HEU accelerated blend-down

Options		1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3	
Additional HEU processing volume, MTU/year			5.0		10.0			20.0				30.0		
On the Whole	Capacity reserves, MTU/year	1.6												
	Demand for capacities for HEU accelerated blend-down, MTU/year		3.4		8.4			18.4				28.4		
For separate process stages	Production of highly enriched UMO, MTU/year	Additional production	5.0		10.0			20.0				30.0		
		Capacity reserves	7.5											
		Capacity deficiency	no			2.5			12.5				22.5	
	Production of highly enriched UHF, MTU/year	Additional production	5.0			10.0			20.0				30.0	
		Capacity reserves	2.4											
		Capacity deficiency	2.6			7.6			17.6				27.6	
	Production of 1.5% diluent, MTU/year	Additional production	147.6	147.6	37.1	295.2	40.6	590.4	590.4	81.2	885.5	885.5	222.9	121.9
		Capacity reserves	47.2											
		Capacity deficiency	100.4	100.4	no	248.0	no	543.2	543.2	34.0	838.3	838.3	175.7	74.7

Table 2.10, continued

Options		1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Separation work for the diluent, kSWU/year	Additional production	585.6	585.6	147.3	1,171.2	161.1	2,342.7	2,342.7	322.2	3,513.6	3,513.6	884.4	483.3
	Capacity reserves	<b>187.3</b>											
Surplus consumption of blendstock for the diluent, MTU/year	Capacity deficiency	398.3	398.3	no	983.9	no	2,155.4	2,155.4	134.9	3,326.3	3,326.3	697.1	296.0
	Additional production	355.1	355.1	89.3	710.3	97.7	1,420.5	1,420.5	195.4	2,130.5	2,130.5	536.3	293.1
Production of 4.4% LEU, MTU/year	Additional production	152.6	152.6	-	305.2	-	610.3	610.3	-	915.5	915.5	-	-
	Capacity reserves	<b>225.8</b>											
Production of 12% LEU, MTU/year	Capacity deficiency	no	no	no	79.4	no	384.5	384.5	no	689.7	689.7	no	no
	Additional production	-	-	42.1	-	-	-	-	-	-	-	252.9	-
Production of 19% LEU, MTU/year	Capacity reserves	<b>no</b>											
	Capacity deficiency	-	-	42.1	-	-	-	-	-	-	-	252.9	-
Production of 19% LEU, MTU/year	Additional production	-	-	-	-	50.5	-	-	101.1	-	-	-	-
	Capacity reserves	<b>no</b>											
Capacity deficiency	-	-	-	-	-	50.5	-	-	101.1	-	-	-	151.7

For separate process stages

The dilution of HEU to 4.4% LEU will require additional capacities only for those options where HEU processing is increased by more than 10 MTU per year (options 2A1, 3A1, 3A2, 4A1, and 4A3).

The downblending of HEU to intermediate LEU products (for all variants under consideration) will demand the production of new diluent, because the current HEU dilution process must produce LEU with a maximum enrichment level of 5%.

The estimates of extra capacities required at Mayak, SCC, ECP, and UECC to realize the HEU blend-down options under analysis are given in Attachment 3 (Tables P3.1 thru P3.4).

It should be noted that these estimates assume the distribution of similar products among the enterprises and their conformity to the current process. This research did not touch upon the optimization of the processing structure (taking into account the difference in capacity reserves at identical production sections or the distribution of additional capacities among the enterprises). Optimization of the production structure may reduce the cost of accelerated HEU blend-down and reduce the implementation period. However, this optimization can only occur at the project development stage, when a particular HEU blend-down option is being finalized.

The following facts also deserve mention:

This research envisaged the use of 1.5% diluent for producing both the final 4.4% product and the intermediate LEU products of 12% and 19% enrichment.

Some experts believe that it is possible to obtain intermediate LEU products from initial dilution with natural or depleted uranium. In their view, a final 4.4% product conforming to ASTM C 996-96 requirements can be obtained through the use of diluent for the second dilution process enriched above 1.5%. Such options were not considered in this research. If the research is continued, it would be reasonable to analyze these options.

**3.**

**Feasibility  
analysis of HEU  
accelerated  
blend-down options**

### **3.1. Detailed Analysis of the Technical Feasibility of HEU Blend-Down Options Facilitating the Acceleration of Processing HEU into 4.4% LEU**

To assess the feasibility of accelerated HEU blend-down options, the researchers analyzed the capabilities of each processing enterprise and estimated what new technical arrangements would be needed to introduce additional capacities at various processing stages [2, 5].

Table 3.1 gives estimates of technical arrangements needed to realize the various HEU-LEU options. A more detailed description of those arrangements at the main processing stages can be found in Attachment 4 (Tables P4.1 thru P4.4).

Table 3.1 shows that the existing capacities (without additional facilities) only allow for an annual increase of 5 MTU HEU processed into  $U_3O_8$ ; an annual increase of 10 MTU can only be achieved if diluent is fabricated to use in the production of intermediate LEU products (options 1B3 and 2C1). Realizing any of the other options under consideration require various other new arrangements, such as the purchase of new equipment, modernization or design of new plants, and construction of storage facilities or extension of existing storage areas. Those arrangements are different for various sections of particular enterprises and depend on the available reserves and additional production levels.

Let us consider the capabilities needed for the basic options under consideration.

### **3.2. Technical Arrangements Facilitating the Acceleration of Processing HEU into 4.4% LEU**

#### **5 MTU annual increment of HEU processing (options 1A1 and 1A2)**

##### **Production of highly enriched $U_3O_8$**

No additional capacities required.

##### **Production of highly enriched $UF_6$**

Required: new fluorination plant and new facility for temporary storage of highly enriched  $UF_6$  (SCC), and extension of storage facility for HEU components (ECP).

##### **Diluent production**

Required: additional separation capacities at SCC (82 kSWU), ECP (125 kSWU), and UECC (191.3 kSWU).

Table 3.1

## Estimated conditions for fulfilling HEU accelerated blend-down

Options	HEU increment, MTU	Annual output of highly enriched UMO, MTU	Annual output of highly enriched UHF, MTU	Annual output of the diluent, MTU	Annual output of LEU products, MTU	
					4.4% LEU	12% and 19% LEU
Potential	–	37	34.0	31.6	43.9	Not available
Current process	–	30	30	30	30	0
Reserves	–	7	4.0	1.6	13.9	Not available
1A1 1A2	5 MTU/year	Ensured due to reserves	R&D work, new storage facilities, new plants & equipment, increased staff	Additional separation capacities & equipment	Additional equipment, new storage facilities, increased staff, additional transport means	R&D work, new production, new storage facilities, increased staff
1B3				Ensured due to reserves		
2A1	10 MTU/year	R&D work, new plants, additional containers & reservoirs, new storage facilities, increased staff	R&D work, new storage facilities, new plants & equipment, additional transport means, increased staff	Additional separation capacities & equipment	New plants, new storage facilities, increased staff, additional transport means	R&D work, new production, new storage facilities, increased staff
2C1				Ensured due to reserves		
3A1 3A2 3C2	20 MTU/year	R&D work, new plants, additional containers & reservoirs, new storage facilities, increased staff	R&D work, new storage facilities, new plants & equipment, additional transport means, increased staff	Additional separation capacities & equipment	New plants, new storage facilities, increased staff, additional transport means	R&D work, new production, new storage facilities, increased staff
4A1 4A3 4B2 4C3	30 MTU/year	R&D work, new plants, additional containers & reservoirs, new storage facilities, increased staff	R&D work, new storage facilities, new process lines, new plants & equipment, increased staff	Additional separation capacities & equipment	New plants, new storage facilities, increased staff, additional transport means	R&D work, new production, new storage facilities, increased staff

Additional equipment will also be required at ECP's desublimation section.

### **Dilution of HEU**

Required: extra areas for intermediate storage of LEU products at UECC (option 1A2).

Additional transport means are also needed for external transportations of highly enriched  $UF_6$  (SCC) and LEU products (ECP and UECC).

### **10 MTU annual increase in HEU processing (option 2A1)**

#### **Production of highly enriched $U_3O_8$**

Mayak is in need of additional storage areas for HEU components, new plants & equipment at the sections for converting HEU components into metal chips and for extraction refinement, as well as additional transport and storage containers for nuclear material.

#### **Production of highly enriched $UF_6$**

Required: new fluorination plants (SCC and ECP), extension of storage facility for highly enriched  $U_3O_8$  (ECP), and a new storage facility for highly enriched  $UF_6$  (SCC). SCC is also in need of additional transport means for external transportation of highly enriched  $UF_6$ .

#### **Diluent production**

Required: additional separation capacities at SCC (210 kSWU), ECP (285 kSWU), and UECC (488.3 kSWU).

UECC and ECP will also require additional equipment at the desublimation section.

#### **HEU dilution**

Required: new plants & equipment at the mixing and liquid-phase transfer sections (ECP and UECC), as well as additional areas for temporary storage of LEU products (SCC and ECP).

UECC and ECP are also in need of additional transport means for external transportations of LEU products.

## **20 MTU annual increase in HEU processing (options 3A1 and 3A2)**

### **Production of highly enriched $U_3O_8$**

Mayak needs new storage facilities for HEU components and highly enriched  $U_3O_8$ , new plants & equipment at the sections for converting HEU components into metal chips, for extraction refinement, for certification of purified highly enriched  $U_3O_8$ , as well as additional transport and storage containers for nuclear material and transport means.

SCC is in need of a new plant for obtaining purified highly enriched  $U_3O_8$  and additional storage areas for highly enriched  $U_3O_8$ .

### **Production of highly enriched $UF_6$**

SCC and ECP are in need of new fluorination plants and analytical laboratories, as well as new facilities for temporary storage of highly enriched  $U_3O_8$  and  $UF_6$ . Besides, SCC will have to acquire transport means for external transportations of highly enriched  $UF_6$ .

### **Diluent production**

Required: additional separation capacities at SCC (468 kSWU), ECP (605 kSWU), and UECC (1,082 kSWU).

All of these enterprises will also require additional equipment at desublimation sections.

### **HEU dilution**

Required: new plants & equipment at the mixing and liquid-phase transfer sections (ECP and UECC), as well as at the liquid-phase transfer section of SCC. All of these enterprises will also require new facilities for temporary (option 3A1) or intermediate (option 3A2) storage of LEU products, as well as additional transport means for external transportations of LEU products.

### **30 MTU annual increase in HEU processing (options 4A1 and 4A3)**

#### **Production of highly enriched $U_3O_8$**

Mayak will require the same actions as for options 3A1 and 3A2. In addition, SCC will need new plants for production of highly enriched  $U_3O_8$ , production of purified highly enriched  $U_3O_8$  and its certification, as well as a new facility for temporary storage of highly enriched  $U_3O_8$  and additional transport means.

#### **Production of highly enriched $UF_6$**

SCC and ECP will required the same measures as envisaged for options 3A1 and 3A2.

#### **Diluent production**

Required: additional separation capacities at SCC (726 kSWU), ECP (924 kSWU) and UECC (1,676 kSWU). Besides, all of these enterprises will require additional equipment at desublimation sections.

#### **HEU dilution**

ECP, UECC, and SCC will require new plants & equipment at mixing and liquid-phase transfer sections, as well as new facilities for temporary storage of LEU products and additional transport means for external transportations of those products.

### **3.3. Technical Arrangements Facilitating the Acceleration of Processing HEU into Intermediate LEU Products**

#### **5 MTU annual increase in HEU processing into 12% LEU (option 1B3)**

#### **Production of highly enriched $U_3O_8$ and $UF_6$**

The required technical arrangements for these processes are similar to those envisaged for options 1A1 and 1A2.

#### **Diluent production**

If the present-day distribution of similar products among enterprises and the current processes in which they are used should remain unchanged, ECP will be in need of additional separation capacities

equal to 5.3 kSWU. If the reserve separation capacities of SCC and UECC are used, no additional separation capacities will be required.

### HEU dilution

SCC, ECP and UECC need to set up new HEU dilution productions, including:

- ❑ a new mixing plant incorporating the following equipment:
  - a collector for transferring highly enriched  $UF_6$  sublimation from 6-liter containers;
  - a collector for transferring  $UF_6$  diluent sublimation from 2.5 m<sup>3</sup> containers;
  - a unit for mixing highly enriched  $UF_6$  with 1.5% diluent;
  - a collector for transferring 12%  $UF_6$  desublimation into 40-liter containers;
- ❑ a new condensation/evaporation plant (CEP);
- ❑ a collector for transferring 12% LEU condensation into 40-liter reservoirs (20–30 reservoirs);
- ❑ a facility for temporary storage of 40-liter containers and TUK 8A packaging sets
- ❑ plants for transferring 12%  $UF_6$  from intermediate 40-liter reservoirs into TUK 8A, V=37 liters (to be designed and manufactured);
- ❑ piping for connecting CEP with the new mixing plant and for delivering the  $UF_6$  diluent;
- ❑ a new analytical laboratory;
- ❑ a new sample package section for liquid 12% LEU

In order to apply the HEU-LEU mixing control system, the new plant needs to be outfitted with additional equipment ensuring the stability of gas pressure in the pipeline for 12%  $UF_6$ .

Operations with 12% LEU will require the design of a new container, with a capacity of 40 liters, for  $UF_6$  desublimation, conversion into the liquid-phase, and transfer into 8A containers.

In addition, all enterprises will have to build facilities for temporary storage of TUK packaging sets with 8A containers.

**30 MTU annual increase in processing into 12% LEU  
(option 4B2)**

**Production of highly enriched  $U_3O_8$  and  $UF_6$**

The required technical arrangements for these processes are similar to those envisaged for options 4A1 and 4A3.

**Diluent production**

Required: additional separation capacities at SCC (148 kSWU), ECP (207 kSWU), and UECC (342.8 kSWU). ECP and UECC will also be in need of additional equipment at the desublimation section.

**HEU dilution**

SCC, ECP, and UECC will require the creation of new HEU dilution production facilities, similar to those described under option 1B3, taking into account the increased amount of LEU received.

**10 MTU annual increase in processing HEU into 19% LEU%  
(option 2C1)**

**Production of highly enriched  $U_3O_8$  and  $UF_6$**

The required technical arrangements for these processes are similar to those envisaged for options 4A1 and 4A3.

**Diluent production**

If the present-day distribution of similar products among enterprises and the current processes in which they are used should remain unchanged, ECP will be in need of additional separation capacities equal to 9.1 kSWU. If the reserve separation capacities of SCC and UECC are used, no additional separation capacities will be required.

**HEU dilution**

SCC, ECP and UECC need to set up new HEU dilution production facilities including:

- a new mixing plant incorporating the following equipment:
  - a unit for transferring highly enriched  $UF_6$  sublimation from 6-liter containers;
  - a unit for transferring  $UF_6$  diluent sublimation from 2.5 m<sup>3</sup> containers;

- a collector for transferring 19% UF<sub>6</sub> desublimation into 10-liter containers;
- a unit for mixing highly enriched UF<sub>6</sub> with 1.5% diluent;
- a new condensation/evaporation plant (CEP);
- a collector for transferring 19% UF<sub>6</sub> condensation into 10-liter reservoirs;
- a facility for temporary storage of 10-liter reservoirs and TUK 5A (5B) containers, V = 8 liters;
- plants for transferring liquid 19% UF<sub>6</sub> from 10-liter containers into containers of type 5A (5B);
- piping for connecting CEP with the new mixing plant and for delivering the UF<sub>6</sub> diluent;
- a new analytical laboratory;
- a new sample package section for liquid 19% LEU.

In order to apply the HEU-LEU mixing control system, the new plant needs to be outfitted with additional equipment ensuring the stability of gas pressure in the pipeline for 19% UF<sub>6</sub>.

Operations with 19% LEU will require the design of a new container, 10 liters in capacity, for UF<sub>6</sub> desublimation, conversion into the liquid-phase, and transfer into 5A (5B) containers, as well as auxiliary equipment.

In addition, all enterprises will have to build facilities for temporary storage of TUK packaging sets with type 5A (5B) containers.

### **20 MTU annual increase in HEU processing into 19% LEU (option 3C2)**

#### **Production of highly enriched U<sub>3</sub>O<sub>8</sub> and UF<sub>6</sub>**

The required technical arrangements for these processes are similar to those envisaged for option 2A1.

#### **Diluent production**

Required: additional separation capacities at SCC (24.1 kSWU), ECP (53.1 kSWU), and UECC (57.8 kSWU).

#### **HEU dilution**

SCC, ECP, and UECC will require new HEU dilution production facilities, similar to those intended for option 2C1, taking into account

the increased amount of LEU received. In addition, all of these enterprises will have to arrange new facilities for temporary storage of TUK 5A (5B) containers and 10-liter containers.

### **30 MTU annual increase in HEU processing into 19% LEU (option 4C3)**

#### **Production of highly enriched $U_3O_8$ and $UF_6$**

The required technical arrangements for these processes are similar to those envisaged for options 2A1 and 3C2.

#### **Diluent production**

Required: additional separation capacities at SCC (59.5 kSWU), ECP (97.0 kSWU), and UECC (139.4 kSWU).

#### **HEU dilution**

SCC, ECP, and UECC will require new HEU dilution production facilities, similar to those intended for options 2C1 and 3C2, taking into account the increased amount of LEU received. In addition, all of these enterprises will have to arrange new facilities for temporary storage of TUK 5A (5B) containers.

### **3.4. Estimated time period needed to realize HEU blend-down options**

The analysis of arrangements associated with the reconstruction and construction of new installations and facilities at Mayak, ECP, SCC, and UECC for promoting the accelerated processing of HEU into LEU products made it possible to estimate the time needed to implement the various options under consideration (see Table 3.2).

The estimate of the time needed to implement construction projects began with preliminary construction and used commissioning schedules in accordance with the current standards and methods used in Russian industrial designs [6].

Table 3.2

## Estimated periods of implementation of HEU accelerated blend-down options

Indicator	Option												
	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3	
Dates of capital investments employment in creation of additional capacities (exclusive of separation production),	<b>month</b>	27	27	28	27	31	33	33	34	35	35	34	35
	<b>(year)</b>	(2.3)	(2.3)	(2.3)	(2.3)	(2.6)	(2.8)	(2.8)	(2.8)	(2.9)	(2.9)	(2.8)	(2.9)
Commissioning dates for separation capacities,	<b>month</b>	42	42	15	60	18	96	96	27	120	120	36	48
	<b>(year)</b>	(3.5)	(3.5)	(1.3)	(5.0)	(1.5)	(8.0)	(8.0)	(2.3)	(10.0)	(10.0)	(3.0)	(4.0)
Implementation dates for HEU accelerated processing,	<b>month</b>	42	42	28	60	31	96	96	34	120	120	36	48
	<b>(year)</b>	(3.5)	(3.5)	(2.3)	(5.0)	(2.6)	(8.0)	(8.0)	(2.8)	(10.0)	(10.0)	(3.0)	(4.0)

It is clear from Table 3.2 that the period needed to realize the HEU-LEU options is largely determined by the introduction of new separation capacities.

For options involving the accelerated blend-down of HEU to final 4.4% LEU product and requiring a good deal of surplus separation capacities, the time needed varies from 3.5 years (5 MTU annual increase in HEU processing) to 10 years (30 MTU annual increase in HEU processing).

Options associated with processing HEU into intermediate LEU products demand a much lower increase in separation capacities. The time needed for these options is mainly determined by the commissioning of new production facilities and varies from 2.3 to 4 years, depending on the additional HEU processing volume.

**4.**

**Estimated  
costs relative  
to options for HEU  
accelerated  
processing  
into LEU products**

## 4.1. Basis of Economic Estimates

□ The cost estimates are based on data on the measures required to accelerate processing of HEU at the Mayak, SCC, ECP, and UECC enterprises and estimates of the volume of equipment and work needed. The latter estimates were made while performing Tasks 3, 4, and 6 [2, 3, 4] and are outlined in Section 3 of this report.

□ The costs were estimated for all of the stages involved in HEU downblending, including:

- turning metal HEU into highly enriched  $U_3O_8$ ;
- fluorination of highly enriched  $U_3O_8$ ;
- fabrication of diluent;
- HEU blend-down and formation of LEU products, including mixing plants, the filling of transport containers, the storage of nuclear material, and analytical laboratories.

When estimating costs, the specialists took into account the required expansion of existing, or arrangement of new, storage capacities for nuclear material, as well as the additional transport means needed for internal and external transportation of nuclear material.

□ The costs estimates of accelerated HEU blend-down options calculated the cost of additional capital investments needed to increase production output at all processing stages, as well as the amount of annual additional costs for new equipment and facilities.

The estimated capital investments included: costs of design work, expert examination of design documents, modernization of existing and construction of new plants and facilities, including construction equipment, and licensing costs, as well as costs associated with the decommissioning of plants and facilities constructed to accelerate the elimination of HEU. The additional costs related to the upkeep and maintenance of new equipment and new facilities was estimated in compliance with the RF Taxation Code and are as follows:

- Staff wages, assuming payment of Russia's unified social tax;
- Upkeep, operation, repair, and maintenance of capital assets;
- Staff labor safety
- General management and production expenses;
- Deductions to the decommissioning fund; and
- Compulsory deductions in compliance with current legislation (scheduled accumulations).

The first two cost items are direct costs immediately related to the maintenance of new facilities and are determined by direct estimates based on physical volumes. The latter four items are indirect costs and are usually determined as percentage of direct cost amounts.

□ The estimates of capital costs and additional expenses for various accelerated HEU blend-down options were made at current prices for building materials, equipment, labor and energy resources used in capital development and in compliance with regulatory and taxation standards valid in Russia at the time of the research.

□ Capital cost estimates were given in US dollars made by converting cost amounts in Rubles to US currency at the current rate of exchange. In 2004, the US dollar rate of exchange was 28 Rubles per dollar.

□ Where design studies for separate facilities scheduled for construction to implement a given accelerated HEU blend-down option were not available and cost indices and prices per unit under Russian conditions were thus non-existent, the relevant average world indices and prices were used. In particular, capital cost estimates in this report for providing additional enrichment capacity are based on experiences in Western countries, and adjusted for Russia, taking into account the use of existing infrastructure with an adjusted index used for some of the options derived from experts' assessment.

□ The summarized results of economic estimates are given both in absolute values and in unit indices per kg of extra HEU subject to processing.

□ The cost estimates were made in compliance with the following regulatory documents currently in force in Russia:

- Reference Book on Base Prices for Design & Survey Operations, which specified cost estimate procedures for design & survey, regulatory and licensing documents;
- Code of Cost Estimate Rules (SP 81-01-94) and Construction Products Cost Estimate Procedures on the RF Territory, which provides the basic principles and general structure of construction estimates as well as estimate requirements;
- Methodical Recommendations for Estimating the Efficiency of Investment Projects approved by the RF Ministry of Economics, RF Ministry of Finance, and RF State Construction Committee (Decree VK-477 of June 21, 1999);
- Tax Code of the Russian Federation.

In addition, the estimate of expenses to accelerate HEU blend-down used the cost estimate methods developed for weapon-grade plutonium disposition within the framework of US-Russian cooperation.

The methods used to estimate costs are related in detail in the Task 7 Report [6].

## **4.2. Consolidated Estimates of Capital Costs and Extra Annual Expenses of Maintaining New Capacities Introduced to Allow for the Accelerated Processing of HEU into LEU products**

The estimate of investment in accelerated HEU processing at SCC, Mayak, ECP, and UECC (see Task 7 Report) was the basis for estimating the amount of investment required for each option under consideration.

Table 4.1 and Figure 4.1 provide consolidated estimates of investments for each option under consideration and the distribution of costs among the main processing stages, with separate categories for the cost of additional transport means and storage facilities for nuclear material, as well as decommissioning costs. In addition, Table 4.1 gives costs per kg of surplus HEU subject to processing.

From the estimates, it is clear that the fulfillment of the accelerated HEU blend-down options will require a great amount of investment: from **\$163.0 million** to **\$1.6 billion**.

The amount of capital investment needed depends on the following factors:

- kind of LEU product: final or intermediate;
- annual increase in HEU processing; and
- terms of LEU product delivery to the customer: immediate or after temporary storage.

One can see from Table 4.1 and Figure 4.1 that at small increases of HEU processed (up to **5 MTU** per year), the processing of HEU into intermediate LEU products demands a large volume of investment because of the necessity of setting up new production facilities.

Table 4.1

**Estimate of the total volume of investment in additional capacities for implementing HEU accelerated blend-down options for the main process stages, mln \$**

Stage	Options											
	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Production of highly enriched UMO	–	–	–	0.6	0.6	3.4	3.4	3.4	8.4	8.4	8.4	8.4
Production of highly enriched UHF	12.2	12.7	12.7	13.1	13.1	31.6	31.6	31.6	32.4	32.4	32.5	32.5
Diluent production	135.1	135.1	1.8	333.2	3.1	872.5	872.5	45.6	1,409.8	1,409.8	235.9	100
HEU dilution	0.7	–	202.0	0.8	204.4	20.1	12.9	210.9	47.0	47.0	207.5	213.9
Storage facilities	3.1	6.6	4.8	3.5	7.5	4.7	19.7	28.7	7.8	7.8	59.2	18.5
Transport means	2.5	2.4	9.2	5	12.5	14.3	14.3	27.5	40.1	40.1	49	49
Decommissioning	3.3	3.5	44.5	3.7	42.4	11.3	12.8	54.4	19.8	19.8	60	54.9
<b>Costs total</b>	<b>156.9</b>	<b>160.2</b>	<b>275.0</b>	<b>359.9</b>	<b>283.6</b>	<b>958.0</b>	<b>967.2</b>	<b>402.1</b>	<b>1,565.3</b>	<b>1,565.3</b>	<b>652.5</b>	<b>477.2</b>
<b>Costs per unit, mln \$/kg of HEU</b>	<b>31.4</b>	<b>32.0</b>	<b>55.0</b>	<b>36.0</b>	<b>28.4</b>	<b>47.9</b>	<b>48.4</b>	<b>20.1</b>	<b>52.2</b>	<b>52.2</b>	<b>21.8</b>	<b>15.9</b>

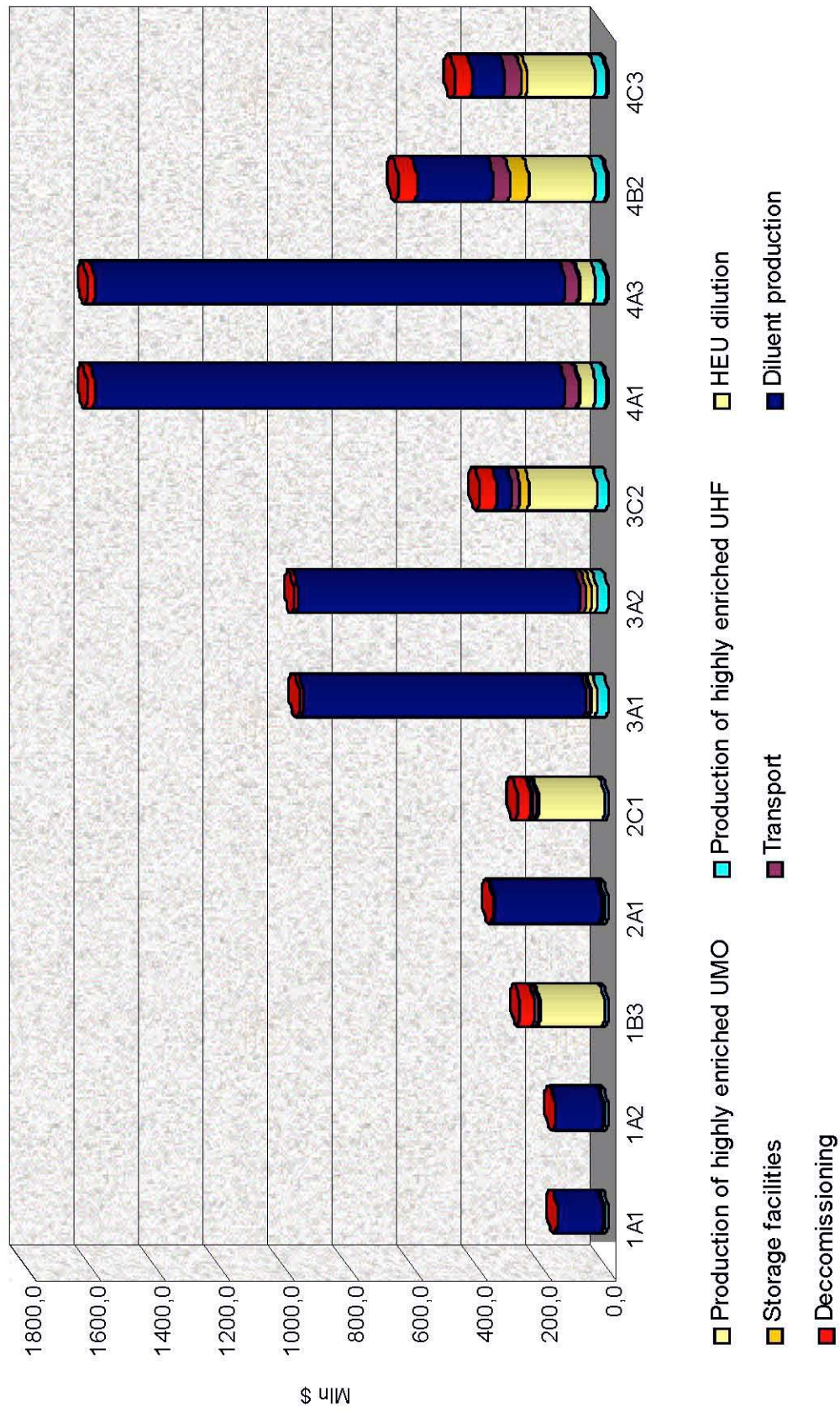


Fig. 4.1. Estimated distribution of investments for the main process stages

One can see from Table 4.1 and Figure 4.1 that at small increases of HEU processed (up to **5 MTU** per year), the processing of HEU into intermediate LEU products demands a large volume of investment because of the necessity of setting up new production facilities.

If HEU processing is increased by **10 MTU** per year or more, the volume of investment for options resulting in final LEU product is much higher than for options with intermediate LEU products, due to the higher increase in separation capacities required to process HEU into 4.4% LEU.

Increasing the volume of HEU to be processed increases the cost per unit of additionally processed HEU for options envisaging HEU processing into final LEU product, but unit cost decreases for options where HEU is processed into intermediate LEU products. These differences are associated with the cost of additional separation capacities, which make up from **88 to 92%** of the total expenses for processing HEU into final LEU product, and from **1 to 30%** for processing HEU into intermediate LEU products.

Separation production is the greatest cost in the main processing stages. In addition, a considerable portion of the expenses, especially for options involving the blend-down of HEU to intermediate products, are associated with HEU dilution, storage facilities, and transportation.

Table 4.2 and Figure 4.2 show the distribution of construction costs among enterprises (Mayak, SCC, ECP, and UECC). One can see that the share of each of the four enterprises in the total volume of costs depends on the kind of a product made and the increase in HEU processing volume.

In turning HEU into 4.4% LEU, Mayak's share in the total volume of costs is minimal (less than one percent), the share of SCC, from **21 to 28%**, the share of ECP, from **26 to 32%**, and the share of UECC, from **42 to 50%**. In processing HEU into intermediate LEU products, the greatest share is held by SCC (from **31 to 39%**).

Table 4.3 provides consolidated estimates of additional annual expenses associated with the repair and maintenance of newly introduced fixed assets. Because of the absence of data, these estimates do not contain the cost of maintaining additional separation capacities.

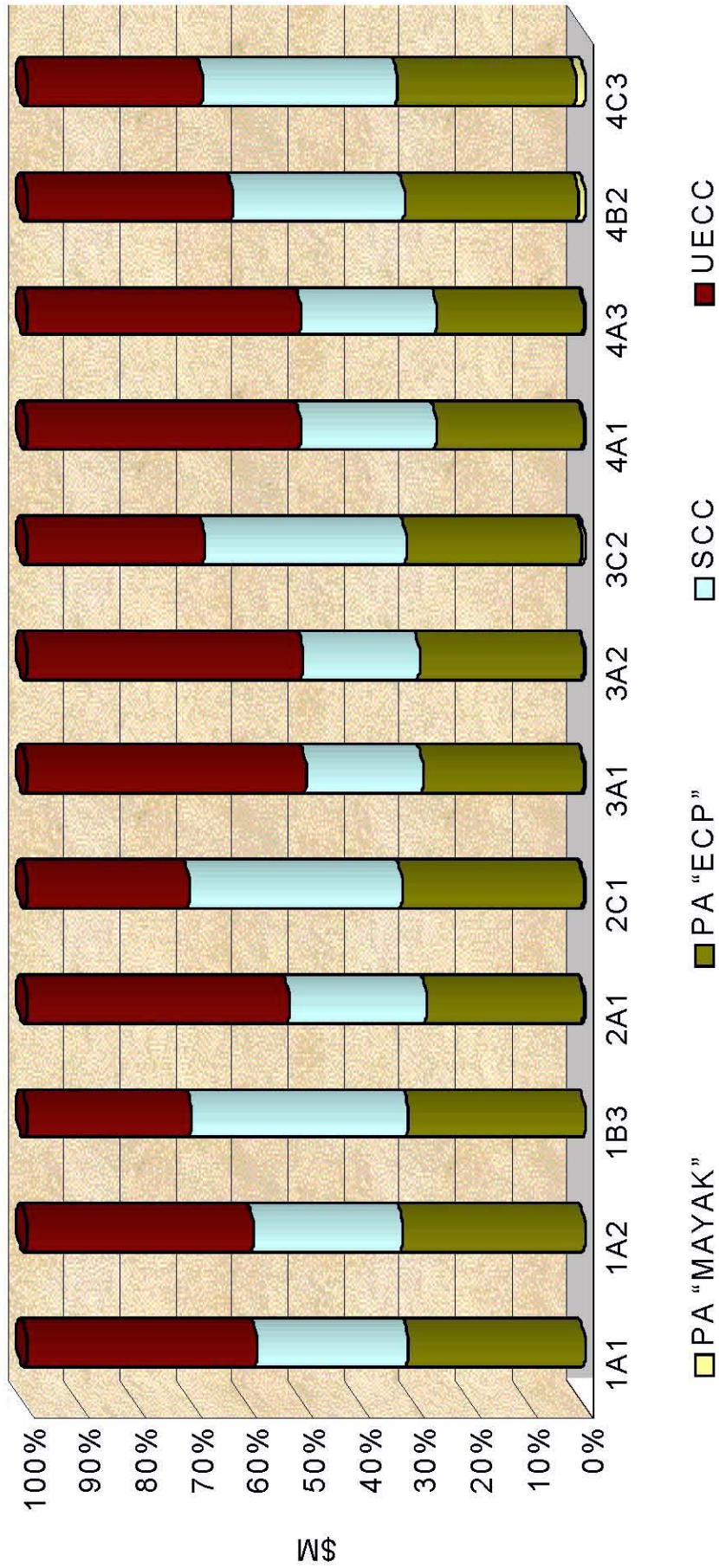


Fig. 4.2. Estimated investments in the introduction of capacities among the enterprises.

Table 4.2

Distribution of capital construction costs among the enterprises, %

Name of enterprise	Options											
	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
PA "MAYAK"	–	–	–	0.2	0.3	0.2	0.2	0.7	0.4	0.4	1.2	1.7
PA "ECP"	29.0	29.9	31.6	28.1	32.4	28.8	29.7	31.5	27.2	27.2	31.1	31.9
SCC	28.3	27.9	38.8	24.7	38.3	21.0	20.2	35.8	24.1	24.1	30.7	34.8
UECC	42.7	42.2	29.6	47.1	29.0	50.0	49.9	32.0	48.3	48.3	37.0	31.6
<b>Costs total</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>	<b>100.0</b>

Table 4.3

Estimated value of additional annual costs of additional HEU blend-down capacities for different participating enterprises, mln \$\*

Enterprises	Options											
	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
PA "MAYAK"	–	–	–	0.53	0.53	1.09	1.09	1.09	1.93	1.93	1.93	1.93
PA "ECP"	0.15	0.72	0.48	0.61	1.03	2.98	4.49	3.77	3.69	3.69	7.05	4.54
SCC	1.38	1.75	10.93	2.65	12.52	6.77	5.80	15.71	11.72	11.72	20.42	18.67
UECC	–	0.57	8.10	–	9.05	2.57	3.83	14.12	3.37	3.37	15.16	10.20
<b>Total</b>	<b>1.53</b>	<b>3.04</b>	<b>19.51</b>	<b>3.79</b>	<b>23.13</b>	<b>13.41</b>	<b>15.21</b>	<b>34.69</b>	<b>20.71</b>	<b>20.71</b>	<b>44.56</b>	<b>35.34</b>
<b>Costs per unit, thsd. \$/kg of HEU</b>	<b>0.31</b>	<b>0.61</b>	<b>3.9</b>	<b>0.38</b>	<b>2.31</b>	<b>0.67</b>	<b>0.76</b>	<b>1.73</b>	<b>0.69</b>	<b>0.69</b>	<b>1.49</b>	<b>1.18</b>

\* Costs of creating new separation capacities not accounted.

As can be seen in Table 4.3, a small increase in processing HEU into 4.4% LEU (**5 MTU** annual increase, option **1A1**) requires the least extra cost (about **\$1.5 million** per year). However, costs grow along with the increasing amount of HEU processed and reach \$21 million per year if HEU processing is increased by **30 MTU** per year.

**5.**

**Analysis of LEU  
Commercial Market and  
Impact of Accelerated HEU  
Processing**

## 5.1. Development of nuclear power and nuclear fuel markets

Nuclear-generated electricity is a fundamentally important component of the global energy mix and a cornerstone of the rapid economic growth in countries such as China and India. Even the Western economies are beginning to again re-evaluate nuclear power as they address politically challenging issues such as energy independence, competition for natural resources, and global warming.

According to the World Nuclear Association (WNA), the total capacity of nuclear power reactors is expected to grow from 365 GWe in 2004 to close to 440 GWe by 2025, and so to create growth in the demand for nuclear fuel over the same period, with particular implications for the uranium and enrichment services markets. These two markets have been dominated in recent years by the release of government stockpiles accumulated during the Cold War, which created the impression of a surfeit of material, and masked the underlying trend of increasing scarcity of supply.

Evaluating the prospects and the actual state of the raw base of commercial nuclear power industry, one may say that the industry foresees a uranium supply gap opening in the near term. In response, uranium market prices, which rose sharply during 2004 as mining companies scrambled to increase production and to find new uranium deposits, are expected to continue to climb in the years ahead.

In contrast to the prospects for uranium market, the supply of enrichment services (which are also referred to as separative work units or “SWU”), is expected to be just sufficient to meet market demand over the period to 2025. However, this expectation is based in part upon the construction of three major new enrichment facilities in the U.S. and Europe that will replace ageing and uneconomic existing enrichment capacities. The present day prices for enrichment services in the U.S. are higher than market forces alone would dictate. The sale of Russian SWU is restricted by trade policy in both the U.S. and Europe, and recent trade action brought by the United States Enrichment Corporation (USEC), against its European competitors resulted in duties being applied to European SWU sold in the US. However, competition between the three Western enrichers, USEC, Urenco and Eurodif, is expected to be muted over the next decade as they seek to develop new enrichment capacities. The SWU prices are therefore expected to remain fairly stable at today’s levels in the medium term.

A number of price projections for both uranium and enrichment are published by the nuclear industry, but these have a relatively short

term focus, and are not suitable for assessing the trends over a two decade period. Therefore, for the purposes of this report, a long-term model of the markets' dynamics was developed, using published forecasts and supported by additional analysis as appropriate. This model predicts that the uranium prices will continue to rise over the period to 2025 (Fig. 5.1) while enrichment prices will decline toward the end of the decade as the trade restrictions against Russian SWU are lessened or removed, and the new enrichment plants begin operation (Fig. 5.2).

The given price projections were used for assessing the potential impact upon the international nuclear fuel markets of the additional LEU derived from accelerated Russian HEU blend-down.



*Fig. 5.1. Uranium Price Forecast*



*Fig. 5.2. U.S. SWU Price Forecast*

## 5.2. Estimate of market impact of accelerated HEU blend-down

### Market Sensitivity to Additional LEU

It takes several years to commission a new uranium mine or even to significantly expand production at an existing uranium mine site, and this has two consequences for this analysis. Given the expected uranium supply shortage, the nuclear power industry is likely to welcome a new source of uranium supply in the medium term, including uranium derived from an accelerated Russian HEU blend-down program. However, it is also likely to require reassurance that its long-term supplies will not be jeopardized because needed investments in uranium mines are postponed in response to the release of large quantities of HEU-derived uranium.

Similarly, for the enrichment markets, it could be argued that the availability of new supplies of enrichment from an accelerated Russian HEU blend-down program would be helpful to cover any schedule risk with the construction of new enrichment facilities. However, the licensing and construction of these enrichment facilities requires substantial capital expenditure, in excess of \$1 billion for each of the commissioned facilities. The larger HEU blend-down options (up to 20–30 MTU annual increment) would have the potential to displace a sizeable fraction of the world enrichment markets and, therefore, to jeopardize the return on the investments presently being made for new enrichment capacities.

The history of the existing HEU Agreement and the USEC privatization of 1996 illustrate the potential market impacts and industry response that are likely to be encountered by the accelerated HEU blend-down proposals. Disagreements relating to trade protection regulations in the USA, and fierce resistance to the program from the U.S. domestic mining industry and its supporters in the U.S. Senate impeded the implementation of the HEU Agreement for almost six years. Successful execution of this important non-proliferation program eventually required U.S. government intervention to modify the U.S. trade restrictions on Russian nuclear fuel and to purchase uranium from the initial deliveries.

The liquidation of former U.S. Government uranium inventories following the privatization of USEC in 1996 collapsed the uranium market price from its 1996 high of over \$16/lb  $U_3O_8$  to around \$7/lb  $U_3O_8$  some five years later. This not only discouraged the worldwide new mine investment required for the long-term supply security, but also forced some existing mines to close, and caused deferment of essential

operational and prospecting investments. Thus it caused considerable structural harm to the U.S. uranium supply industry.

According to the U.S. Department of Energy, the uranium and enrichment from the HEU Agreement are now an essential component of commercial market supply, creating the potential for further market distress when the HEU Agreement ends in 2013, unless these supplies are replaced from other sources.

### Impact of HEU blend-down options on the market

The additional uranium and SWU that would result from the 12 analyzed options for accelerated HEU blend-down are shown in Table 5.1.

Table 5.1.

Uranium and SWU Content by Options

Option	LEU Enrichment, %	Annual LEU Produced (MTU U/yr)	Equivalent Annual U <sub>3</sub> O <sub>8</sub> (M lbs/yr)	Annual SWU Content (M SWU/yr)	Timing of Sale	Storage Location
<b>Option Group 1 (5 MTU HEU/yr)</b>						
1A1	4.4	153	3.97	0.9	Immediate	–
1A2	4.4	153	3.97	0.9	Delayed	Russia
1B3	12.0	42	3.11	0.9	Delayed	USA
<b>Option Group 2 (10 MTU HEU/yr)</b>						
2A1	4.4	305	7.94	1.8	Immediate	–
2C1	19.5	49	5.95	1.8	Delayed	Russia
<b>Option Group 3 (10 MTU HEU/yr)</b>						
3A1	4.4	610	15.82	3.7	Immediate	–
3A2	4.4	610	15.82	3.7	Delayed	Russia
3C2	19.5	49	11.90	3.7	Delayed	Russia
<b>Option Group 4 (20 MTU HEU/yr)</b>						
4A1	4.4	916	23.76	5.5	Immediate	–
4A3	4.4	916	23.76	5.5	Delayed	USA
4B2	12.0	253	18.73	5.4	Delayed	Russia
4C3	19.5	148	17.98	5.5	Delayed	USA

At the lower end of the market impact scale are the Group 1 options, each envisaging the blend-down of additional 5 MTU of HEU per year and capable of exerting only a modest impact upon the uranium and enrichment prices. The 153 MTU of LEU produced annually under

options 1A1 and 1A2 would produce some 4 million lbs  $U_3O_8$ , equivalent in quantity to a typical Central Asian or Australian ISL-based uranium mine. This is a relatively small increment on the global volume of uranium produced each year, and, for example, would be expected to weaken the underlying long-term uranium price by around \$ 0.50/lb $U_3O_8$  (Option 1A1, Fig. 5.3).

Likewise it is expected that the additional annual SWU volume of 0.9 MSWU would be absorbed into the international SWU marketplace without significant market perturbation. For example, Urenco has increased its European enrichment capacity by a similar quantity in each of the recent years, and this has not noticeably impacted the separation markets. The price impact is projected to be a reduction of around \$ 0.25/SWU (option 1A1, Fig. 5.4).



Fig. 5.3. Uranium Price Effects - Option Group 1  
 — option 1A1, — option 1A2, — option 1B3, — base option



Fig. 5.4. SWU Price Effects - Option Group 1:  
 — option 1A1, — option 1A2, — option 1B3, — base option

Since these options would not significantly alter the investment decisions of primary uranium producers or enrichers, there is unlikely to be any industry-wide harm. The minor impact on profitability of the suppliers to the industry would be offset by the lowered costs for the utilities that purchase the uranium and enrichment services.

There is a potential for greater impact when sale of the material is deferred. In two of the Group 1 options (1A2 and 1B3), an inventory equivalent to 32 million lbs  $U_3O_8$  and 8 MSWU would potentially be available for commercialization by 2014. This would cause a significant, though short-lived, disruption to both the uranium and SWU markets if all of the material were to be released to the market at that time.

The Group 4 options envisage the greatest increment of HEU blend-down (30 MTU per year). These options would create a new uranium supply of almost 24 million lbs  $U_3O_8$  per year, equivalent to one eighth of the world market demand, and 5.5 M SWU per year, equivalent to almost half of the U.S. market demand. These annual volumes are similar to those for the existing HEU Agreement.

The displacement of primary uranium production by LEU from Option 4A1 would be result in a major price depression estimated at some \$3.45 /lb  $U_3O_8$  compared to the Base Option analysis (Fig. 5.5).

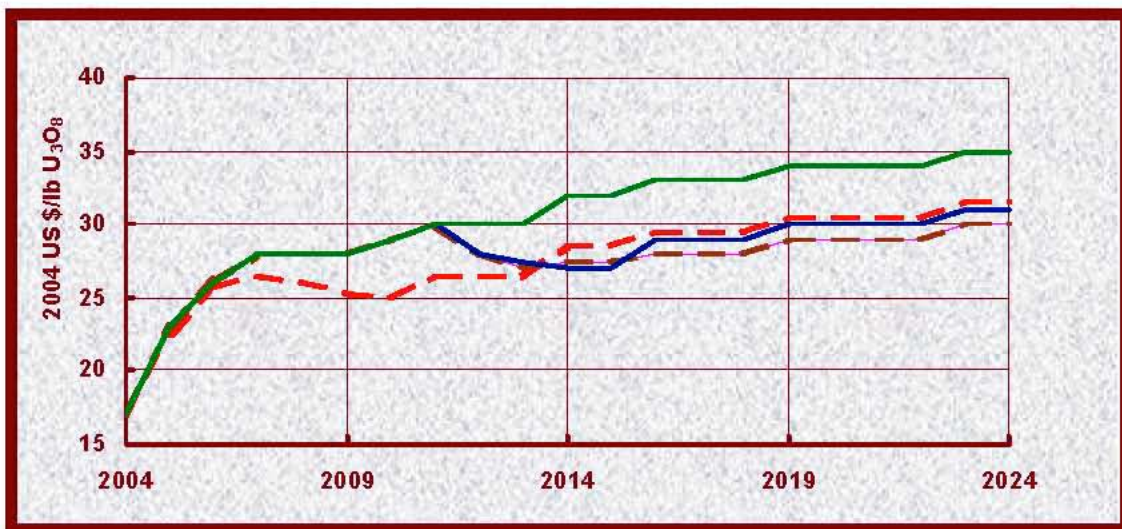


Fig. 5.5. Uranium Price Effects - Option Group 4:  
 - - - option 4A1, - - - option 4A3, — option 4B2, — option 4C3,  
 — base option

The estimates also show that the price for uranium enrichment under Option Group 4 may reduce by \$8/SWU by 2014 (Fig. 5.6).



Fig. 5.6. SWU Price Effects - Option Group 4:  
 - - - option 4A1, — option 4A3, — option 4B2,  
 - - - option 4C3, — base option

Under options 4A3, 4B2, and 4C3, holding the blend-down material off-market would create a very significant “overhang” of material with potentially devastating market implications should the material be released suddenly.

The projected uranium prices were based on the assumption that the inventoried materials from the above options would be released steadily over a ten year period.

The market impact of the Group 2 and Group 3 options lies between those of the Group 1 and Group 4 options discussed above.

### 5.3. Measures mitigating the impact of accelerated Russian HEU blend-down on the markets

The accelerated blend-down options have the potential to significantly impact the uranium and/or enrichment markets, as well as cause possible overdependence of the U.S. or Europe upon imported SWU. Thus, it is necessary to implement effective controls to minimize the market impact.

Sales of large amounts of uranium and enrichment services may distort the competitive structure of the nuclear fuel markets.

Holding additional material off-market in an inventory would not provide the required market protection because the market participants will anticipate the release of material at the earliest feasible opportunity and adjust their buying patterns accordingly.

Therefore, additional market protection mechanisms are needed to provide price stability. These include, for example, managing the rate at which the inventories of LEU held off-market would be released into the market, restricting sales of the contained uranium and SWU to long-

term contracts, avoiding sales at “market-related” prices, and selling the material via consortia of major industry players.

Another possible option for avoiding market damage would for all or part of the LEU produced from the blend-down HEU to be purchased by the U.S. government and retained as a strategic inventory. This could then be used to cover nuclear fuel supply disruptions that would threaten the stability and economy of the U.S. nuclear electricity generating sector, in a manner analogous to the strategic oil reserve.

**6.**

**Legal aspects  
of accelerated HEU  
processing  
into LEU products**

## 6.1. Relevant legislation

During the course of this research, international treaties and agreements, Russian regulations, and Russian civilian legislation as it relates to accelerated HEU blend-down were analyzed.

The analysis of international legal aspects took into account the following documents:

- The Nuclear Non-Proliferation Treaty and international principles of nuclear counterterrorism;
- Bilateral US-Russian agreements on using HEU extracted from nuclear weapons;
- Convention on the Physical Protection of Nuclear Material and Guidelines for Nuclear Transfers (the so-called London Guidelines);
- Voluntary IAEA measures to safeguard weapon-grade nuclear material withdrawn from the defense programs of the two countries;
- International trade & export limitations, EURATOM quotas for Russian nuclear material and US limitations on the use of Russian nuclear material;
- Legal acts introducing alterations to the rules for nuclear material transport and the impact of those acts on possible acceleration of uranium processing; and
- Legal norms regulating the physical protection of nuclear materials during fabrication, storage, and transport (e.g. INFCIRC/225/Rev. 4, INFCIRC/274/Rev. 4).

The analysis of Russian regulations relevant to the accelerated processing of HEU concentrated on the following aspects:

- Russian nuclear regulatory legislation relevant to accelerated HEU processing, including laws on the licensing and monitoring of nuclear, radiation, and environmental safety;
- Russian technical regulatory legislation on nuclear & radiation safety;
- Russian export control system and customs regulations;
- Physical protection measures and legislation regulating the state system of accounting and control of nuclear materials;
- Russian legal and normative acts regulating the fabrication, storage, and transport of nuclear material;
- Legal procedures for monitoring the movement of the natural uranium component involved in the production of LEU to be delivered to the US;

- ❑ Legislation introducing changes to the rules for nuclear material transport and the impact of these laws on the possible acceleration of uranium processing; and

- ❑ Licensing and the list of required licenses and permits.

The analysis of civil legislation affecting the accelerated processing of HEU included:

- ❑ Ownership laws in the nuclear sphere, principles of civil liability for nuclear damage and insurance against nuclear damage;

- ❑ Intellectual property laws in the field of nuclear power; and

- ❑ Licensing and the list of required licenses and permits.

A list of the relevant legislation used in the course of the analysis is given in the Task 8 Report [7].

## **6.2. Review and analysis of the legislation regulating the current HEU-LEU program**

The development and realization of the long-term Russian-US program to eliminate excess HEU resulting from a sharp reduction in the Russian nuclear stockpile (HEU Purchase Agreement), necessitated the elaboration of special legislation regulating all of the activities related to the HEU-LEU program, in addition to the existing international legal regime and Russian laws on handling nuclear materials both on the world market and in bilateral export/import operations.

To this end, Russia and the United States signed a set of agreements at the intergovernmental and inter-agency levels (between the Russian Ministry of Atomic Energy and various US federal agencies). In addition, Russia developed and adopted relevant national laws.

Figure P5.1 (in Attachment 5) reviews the main special legislation adopted to facilitate the HEU-LEU Program, and the hierarchy of these laws.

The analysis of this legislation showed that:

**a.** Russia has a sufficiently complete legal base providing for efficient legal management of the HEU-LEU Program. A good number of the legal norms do not depend on the rate of HEU processing into LEU. In particular, the Intergovernmental Agreement of February 18, 1993 (“HEU Purchase Agreement”) will continue to be the main legal basis for any efforts to accelerate the processing of HEU.

**b.** The current HEU Purchase Agreement envisages possible acceleration of HEU processing (Article 5, item 3).

**c.** Since the Agreement Suspending the Antidumping Investigation on Uranium from the Russian Federation, lifting limitations on Russian exports of LEU derived from HEU to the USA, expired on March 31, 2004, a new agreement must be prepared in the near future. If a decision on accelerated HEU processing should be taken, that decision must be reflected in the text of this or a future agreement.

**d.** After final decision is made on a particular accelerated HEU processing option, the main HEU Purchase Agreement contract may have to be revised, as might other contracts.

### **6.3. International nuclear non-proliferation legislation and accelerated HEU processing**

International treaties and agreements on the non-proliferation of nuclear weapons are the basis for all legislation regulating the HEULEU program.

The principal international treaties and agreements in this area are provided in Figure P5.2 (Attachment 5).

The analysis showed that accelerated HEU blend-down is in full compliance with these agreements, in particular, with Articles 1, 3 and 6 of the Non-Proliferation Treaty, as well as with the IAEA Statute.

### **6.4. International principles of nuclear counter-terrorism and accelerated processing of HEU**

In analyzing national nuclear counter-terror legislation, the researchers examined its effectiveness at preventing and containing nuclear terrorist acts and the illegal transfer of nuclear materials during the processing of HEU into LEU (at all stages, including nuclear material storage, processing, and transportation, as well as international transport). Figure P5.3 lists the international and Russian legislation related to nuclear counter-terrorism. The full list of legal documents analyzed is given in Report on Task 8.

The analysis of these documents has shown the following:

- the system of laws, by-laws, and departmental acts of the Russian Federation meet the requirements of the international nuclear counter-terror regime where accelerated processing of HEU is concerned;
- the state system for accounting and control of nuclear materials provides for constant state supervision of the reliability of records and reports on nuclear material, and creates the necessary conditions for the application of IAEA safeguards, and the monitoring of Russia's observance of its international obligations in the field of non-proliferation during accelerated processing of HEU; and
- the physical protection of nuclear material and nuclear facilities is in conformity with IAEA document INFCIRC/225/Rev.4 (corrected).

## **6.5. Russian safety regulations and accelerated processing of HEU**

The following areas of Russian safety regulations that relate to the accelerated processing of HEU were analyzed in this study:

- Technical regulatory regime;
- Licensing of activities in the field of nuclear power; and
- State supervision of nuclear, radiation, and environmental safety.

Figure P5.4 (in Attachment 5) shows the basic elements of the Russian regulatory system that provide for the safe operation of nuclear power facilities and other relevant legal and normative acts. The analysis of these regulatory measures has shown the following:

- The Russian system for regulating nuclear safety is based on generally accepted international regulations and standards;
- Russian legislation provides for the complete realization of all safety regulations while performing any kind of activity in the nuclear sphere, including accelerated processing of HEU.

## **6.6. Russian legislation regulating the handling of nuclear material (fabrication, storage, transport, and export)**

State policy on the management of nuclear material, radioactive substances, and radioactive waste is based on generally acknowledged principles, confirmed by international documents that have been ratified

by Russia, namely: the Convention on the Physical Protection of Nuclear Material (1980), the Convention on Early Notification of a Nuclear Accident (1986), the Convention on Assistance in the Case of a Nuclear Accident or Radiological Emergency (1986), the Convention on Nuclear Safety (1996), the Joint Convention on the Safety of Spent Fuel Management and the Safety of Radioactive Waste Management (1997).

The aims of Russia's policy in this field are specified in the federal law "On Atomic Energy."

The full list of Russian legislation regulating the management of nuclear material during its fabrication, storage, transport, and export/import is given in the Task 8 Report [7].

The analysis of Russian legislation regulating the management of nuclear material during its fabrication, storage, transport, and export/import (including if HEU processing is accelerated) has shown that Russian laws fully conform to international nonproliferation, nuclear counter-terror, and nuclear radiation and safety agreements.

## **6.7. Property rights, civil and legal liability for nuclear damage, insurance against nuclear damage during accelerated processing of HEU**

Property rights in the Russian Federation in the field of nuclear power are regulated by the RF Constitution (Articles 8, 71, 72, 114). Property rights regarding nuclear facilities, radiation sources, storage points, nuclear material, and radioactive substances are further specified in Article 5 of the federal law "On Atomic Energy" [7].

The analysis of the current system of civil liability for nuclear damage to third parties in different countries has shown that there are two approaches to nuclear damage recovery, namely:

- recovery of such damages in conformity with international conventions on civil liability for nuclear damage to third parties, as well as pursuant to national laws on civil liability for nuclear damage to third parties; and
- adherence to national tort legislation.

Since Russia has neither joined the relevant conventions nor adopted a national law on nuclear damage recovery, it acts within traditional tort law (Article 1079 of the RF Civil Code on liability for damage caused by hazardous activities, Articles 1080 and 1081 of that Code, etc.).

Within the framework of this legislation:

- not only can an operator be held liable for nuclear damage, but other persons as well (contractor, subcontractor, carrier etc.);
- there is no legal provision for the recovery of damages through the use of the funds of private insurance companies, or state budgetary and compensation funds;
- suits can be brought both in Russian courts and abroad; thus the legal determination of the causation of nuclear damages is unpredictable.

At present, the RF State Duma is considering the Vienna Convention of 1963 for its possible ratification, as well as a draft of the Federal law, “On Civil Liability for Nuclear Damage and the Financial Security Thereof” (the draft has passed the first reading).

The analysis of laws relating to civil liability for nuclear damage and insurance against nuclear damage indicates that Russian legislation in this area, as well as a system of liability insurance, are in the final stages of development.

## **6.8. Legal protection of intellectual property rights in Russia during accelerated processing of HEU**

The intellectual property rights analyzed in this study were classified as those related to industrial property, copyright, commercial secrets (including know how), and state secrets.

The main international agreement and Russian legislation protecting intellectual property relevant to the accelerated processing of HEU are given in Table P5.5 (in Attachment 5). The full list of normative and legal document analyzed is given in Report on Task 8 [7].

The analysis of these documents has shown that the RF legislation enables the use and protection of intellectual property in any field, including accelerated processing of HEU, on the international, national, and regional levels.

## **CONCLUSIONS**

- 1 The analysis of international nonproliferation and nuclear counter-terrorism legislation as well as, Russian national legislation in the nuclear field has shown that there are currently no legal restrictions on the accelerated processing of HEU.

- ② The HEU-LEU Program is supported by fairly complete legislation providing for effective control over all processes associated with the processing of HEU into LEU, with due account of international nonproliferation and nuclear counter-terror regimes, as well as international agreements on physical protection and nuclear materials accounting and control regimes (including its processing, transport, export/import etc.). The majority of the existing legislation does not depend on the rate of HEU processing into LEU. In particular, the HEU Purchase Agreement remains the basic document regulating legal questions related to accelerated HEU processing, since the possibility of accelerating the HEU-LEU program is mentioned in the document.
- ③ An analysis of all of the possible accelerated HEU blend down options discussed earlier in this report leads to the following conclusions:
- A. There will be no regulatory differences between the regulation of accelerated HEU blend-down options with either immediate or deferred delivery after temporary storage in Russia (options **1A1**, **1A2**, **2A1**, **2C1**, **3A1**, **3A2**, **3C2**, **4A1**, and **4B2**) and regulation of the current process.
- B. Where options involve temporary storage of LEU products in the USA (options **1B3**, **4A3**, and **4C3**), the following legislative differences come into play:
- civil liability for nuclear damage during LEU transport and storage;
  - transfer of property rights; and
  - liability for accidental loss of property in storage.

However, these differences are factors usually dealt with when concluding concrete sales and purchase agreements, the procedure for their settlement is largely determined by current

international trade legislation, bilateral agreements, and generally accepted practice.



**General  
conclusions**

**1 Conditions, cost estimates and estimated time needed to realize various accelerated HEU blend-down options**

**5 MTU annual increment of HEU processing volume**

**Option 1A1**

**(Processing of HEU into 4.4% LEU with immediate delivery to the USA)**

The realization of this option will require the following additional capacities:

- SCC: new fluorination plant, extension of storage facilities for HEU components and highly enriched  $UF_6$ , additional separation capacities and additional transport means for external transportations of highly enriched  $UF_6$ ;
- ECP: additional separation capacities and equipment for the desublimation and liquid-phase transfer section, extension of storage facilities for highly enriched  $U_3O_8$  and LEU product, additional transport means for external transportations of LEU products; and
- UECC: additional separation capacities and equipment for the desublimation section.

Required investment (preliminary estimate): **\$162.7 million** over **3.5** years, annual additional costs: **\$1.5 million**.

**Option 1A2**

**(Processing of HEU into 4.4% LEU, intermediate storage of the product in Russia prior to dispatching it to the USA)**

In addition to the new capacities just mentioned (see option **1A1**), the realization of this option will require an additional facility for intermediate storage of LEU products at UECC.

Required investment (preliminary estimate): **\$166.4 million** over **3.5** years, annual additional operating costs: **\$3.0 million**.

**Option 1A3**

**(Processing of HEU into intermediate 12% LEU with immediate delivery of the product to the USA)**

This option will require the following additional capacities:

- SCC: new fluorination plant, new production facility for HEU blend-down to 12% LEU, and new storage facilities for highly enriched  $UF_6$  and LEU product;
- ECP: new HEU blend-down production facility, extension of the storage facility for highly enriched  $U_3O_8$ , and new storage facility for LEU product;
- UECC: new HEU blend-down production facility and new storage facility for LEU products.

Required investment (preliminary estimate): **\$275.0** million over **2.3** years, annual additional costs: **\$19.5** million.

## 10 MTU annual increment of HEU processing volume

### Option 2A1

#### (Processing of HEU into 4.4% LEU with immediate delivery of the product to the USA)

This option will require the following additional capacities:

- Mayak: new plants for highly enriched  $U_3O_8$  production and a new storage facility for HEU components;
- SCC: new plants for highly enriched  $UF_6$  production, additional separation capacities, extension of existing and construction of new storage facilities for HEU components, highly-enriched  $UF_6$ , and LEU product;
- ECP: new plants for producing highly enriched  $UF_6$  and LEU, additional separation capacities, new storage facilities for highly-enriched  $UF_6$  and LEU product, and additional transport means for external transportation of LEU product; and
- UECC: additional separation capacities and equipment for the desublimation section, new plants for LEU production, new storage facility, and additional transport means for external transportation of LEU product.

Required investment (preliminary estimate): **\$360.0** million over **5** years, annual additional costs: **\$3.8** million.

### Option 2C1

#### **(Processing of HEU into intermediate 19% LEU with immediate delivery of the product to the USA)**

This option will require the following additional capacities:

- Mayak: new plants for highly enriched  $U_3O_8$  production and new storage facility for HEU components;
- SCC: new plants for highly enriched  $UF_6$  production, additional separation capacities, new production facility for HEU blend-down to 19% LEU product, and new storage facilities for highly-enriched  $UF_6$  and LEU product;
- ECP: new plants for highly enriched  $UF_6$  production, additional separation capacities, new production facility for HEU blend-down to 19% LEU product, and new storage facilities for highly-enriched  $U_3O_8$  and LEU product; and
- UECC: additional separation capacities, new production facility for HEU blend-down to 19% LEU, new storage facility for LEU product.

Required investment (preliminary estimate): **\$284** million over **2.6** years, annual additional costs: **\$23** million.

### **20 MTU annual increment of HEU processing volume**

### Option 3A1

#### **(Processing of HEU into 4.4% LEU with immediate delivery of the product to the USA)**

This option will require the following additional capacities:

- Mayak: new plants for highly enriched  $U_3O_8$  production, new storage facility for HEU components and highly enriched  $U_3O_8$ , additional transport means;
- SCC: new plants for productions of highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU, additional separation capacities and equipment for the desublimation section, new storage facilities for highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU, and additional transport means for external transportation of LEU product;
- ECP: new plants for production of highly enriched  $U_3O_8$  and LEU, additional separation capacities and equipment for the

- desublimation section, new storage facilities for highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU product, and additional transport means for external transportations of LEU product;
- UECC: additional separation capacities and equipment for the desublimation section, new plants for LEU production, new storage facility for LEU product, and additional transport means for external transportation of LEU product.

Required investment (preliminary estimate): **\$958.0** million over **8** years, annual additional costs: **\$13.4** millions.

### Option 3A2

#### **(Processing of HEU into 4.4% LEU, intermediate storage of the product in Russia prior to its dispatching to the USA)**

Besides the actions envisaged for option **3A2**, this option will require the construction of additional facilities at SCC, ECP, and UECC for intermediate storage of LEU products (instead of temporary storage areas).

Required investment (preliminary estimate): **\$974.3** million over **8** years, annual additional costs: **\$15.2** million.

### **30 MTU annual increment of HEU processing volume**

#### Options 4A1 and 4A3

#### **(Processing of HEU into 4.4% LEU with immediate delivery of the product to the USA, option 4A3 envisaging LEU storage in the USA)**

The realization of this option will require the following additional capacities:

- Mayak: new plants for highly enriched  $U_3O_8$  production, new storage facilities for HEU components and highly enriched  $U_3O_8$ , and additional transport means;
- SCC: new plants for production of highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU, additional separation capacities and equipment for the desublimation section, new storage facilities for highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU, additional transport means;
- ECP: new plants for production of highly enriched  $U_3O_8$  and LEU, additional separation capacities and equipment for the desublimation section, new storage facilities for highly enriched

U<sub>3</sub>O<sub>8</sub>, highly enriched UF<sub>6</sub>, and LEU product, additional transport means;

- UECC: additional separation capacities and equipment for the desublimation section, new plants for LEU production, new storage facility for LEU product, and additional transport means for external transportation of LEU product.

Required investment (preliminary estimate): **\$1,613.6** million over **10** years, annual additional costs: **\$20.7** million.

### **Option 4B2**

#### **(Processing of HEU into 12% LEU, intermediate storage of the product in Russia prior to its dispatching to the USA)**

This option will require the following additional capacities:

- Mayak: new plants for highly enriched U<sub>3</sub>O<sub>8</sub> production, new storage facilities for HEU components and highly enriched U<sub>3</sub>O<sub>8</sub>, additional transport means;
- SCC: new plants for the productions of highly enriched U<sub>3</sub>O<sub>8</sub> and highly enriched UF<sub>6</sub>, additional separation capacities, new production facility for HEU blend-down to 12% LEU, storage facilities for highly enriched UF<sub>6</sub> and intermediate storage of LEU, additional transport means;
- ECP: new plants for highly enriched UF<sub>6</sub> production, additional separation capacities and equipment for the desublimation section, new production facilities for HEU blend-down to 12% LEU, new storage facilities for highly enriched U<sub>3</sub>O<sub>8</sub>, highly enriched UF<sub>6</sub>, and LEU product, additional transport means;
- UECC: additional separation capacities and equipment for the desublimation section, new production facility for HEU blend-down to 12% LEU, new storage facilities for highly enriched U<sub>3</sub>O<sub>8</sub>, highly enriched UF<sub>6</sub>, and LEU product, additional transport means for external transportation of LEU product.

Required investment (preliminary estimate): **\$652.5** million over **3** years, annual additional costs: **\$44.5** million.

### **Option 4C3**

#### **(Processing of HEU into 19% LEU with immediate delivery of the product to the USA for subsequent temporary storage)**

This option will require the following additional capacities:

- Mayak: new plants for highly enriched  $U_3O_8$  production, new storage facilities for HEU components and highly enriched  $U_3O_8$ , additional transport means;
- SCC: new plants for the productions of highly enriched  $U_3O_8$  and highly enriched  $UF_6$ , additional separation capacities, new production facility for HEU blend-down to 19% LEU, storage facilities for highly enriched  $UF_6$  and intermediate storage of LEU product, additional transport means;
- ECP: new plants for highly enriched  $UF_6$  production, additional separation capacities and equipment for desublimation section, new production facility for HEU blend-down to 19% LEU, new storage facilities for highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU product, additional transport means; and
- UECC: additional separation capacities and equipment for the desublimation section, new facility for HEU blend-down to 19% LEU, new storage facilities for highly enriched  $U_3O_8$ , highly enriched  $UF_6$ , and LEU product, additional transport means for external transportation of LEU product.

Required investment (preliminary estimate): **\$477.2** million over **4** years, annual additional costs: **\$35.3** million.

According to these estimates, all of the accelerated HEU-processing options require a considerable volume of investment, ranging from **\$163.0** million to **\$1.6** billion, depending on the following factors:

- kind of LEU product: final or intermediate;
- annual increase in HEU processing volume; and
- terms of LEU delivery: immediate or deferred, after temporary storage.

At a small increase in HEU processing (up to **5 MTU** per year), HEU blend-down to intermediate LEU products demands a large volume of investment because of the need for new production facilities. In options increasing the volume of HEU processing by **10 MTU** per year and above, the investment required for options resulting in final LEU product is far higher than for options producing intermediate LEU products, since the former requires much greater separation capacities, which are very capital-intensive.

## **② Impact of HEU Accelerated Down-Blending on Uranium and Separation Services Markets**

The accelerated blend-down options have the potential to significantly impact the uranium and/or enrichment markets, as well as cause possible overdependence of the US or Europe upon imported SWU.

Sales of large amounts of uranium and enrichment services may distort the competitive structure of the nuclear fuel markets.

Holding additional material off-market in an inventory would not provide the required market protection because the market participants will anticipate the release of material at the earliest feasible opportunity and adjust their buying patterns accordingly.

Therefore, additional market protection mechanisms are needed to provide price stability. These include, for example, managing the rate at which the inventories of LEU held off-market would be released into the market, restricting sales of the contained uranium and SWU to long-term contracts, avoiding sales at “market-related” prices, and selling the material via consortia of major industry players.

Another possibility for avoiding market damage would be for all or part of the LEU produced from the down-blended HEU to be purchased by the US government and retained as a strategic inventory. This could then be used to cover nuclear fuel supply disruptions that would threaten the stability and economy of the US nuclear electricity generating sector, in a manner analogous to the strategic oil reserve.

## **③ Legal aspects of accelerated fulfillment of HEU-LEU program**

The analysis of the international nonproliferation and nuclear counterterrorism regimes and Russian national legislation in the field of nuclear power indicates that there are no legal restrictions to the accelerated processing of HEU. The HEU Purchase Agreement now in force will remain the basic legal document regulating accelerated processing of HEU since it includes a provision for the possible acceleration of the HEU-LEU process.

The only legislative difference between the existing HEU-LEU process and accelerated processing options comes into play if LEU products are to be stored on US territory (options 1B3, 4A3, and 4C3). In this case, new provisions will be required for civil liability for nuclear

damage during LEU transport and storage, transfer of the property rights, and liability for the accidental loss of a product in storage.

However, such provisions are usually made when concrete sales and purchase contracts are concluded, and the procedure for their settlement is largely determined by current international trade law, bilateral agreements, and generally accepted practice.

#### **4 Additional issues that may arise during accelerated processing of HEU**

As was indicated above, the implementation of all HEU blend-down options under consideration will entail significant capital costs. In addition, one should recognize that much of this investment will be for the construction of special facilities that will only be used for a limited period of time and then shut down. This makes recouping these investments nearly impossible; any attempt to recover these expenses will inevitably result in increased production costs, and require the revision of manufacturer's prices.

The realization of options involving the blending down of HEU to intermediate LEU products, while associated with fewer capital costs than those options entailing downblending HEU to the final product, may give rise to the following problems:

**First**, technical issues related to the production of higher enriched LEU (12% and 19%), its packaging and transportation;

**Second**, economic issues related to the financing of the cost of producing and storing the intermediate LEU products until their delivery (sale) to the Customer; and

**Third**, altering the terms and conditions of existing contracts, to allow for the delivery of 12% and 19% LEU, taking into account the legal principles mentioned above.

One should keep in mind that the estimates of costs and time periods to implement accelerated HEU blend-down were based purely on an analysis of capacities of processing enterprises. However, the creation of additional capacities at these enterprises is closely tied to the capabilities of enterprises in related industries that provide inputs of necessary materials and equipment. An increased demand for those materials and equipment will entail extra costs to build new production capacities, and affect the time needed to implement the accelerated HEU blend-down options.

Furthermore, the creation of production facilities operating for a relatively small period of time will increase personnel expenses associated with the hiring of new personnel and their downsizing upon termination of the HEU accelerated blend-down program.

# Attachments

**MEMORANDUM OF UNDERSTANDING**  
**on Cooperation**  
**between the Department of International and External Economic Cooperation**  
**of the Ministry of the Russian Federation for Atomic Energy**  
**And the United States Charitable Organization, The Nuclear Threat Initiative, Inc.,**  
**on the Joint Conceptual Analysis and Cost Study of**  
**Accelerating the Blend-Down of Russian Highly Enriched Uranium**  
**No Longer Needed for Defense Purposes**

The Department of International and External Economic Cooperation of the Ministry of the Russian Federation for Atomic Energy (hereinafter "DIEEC of MinAtom of Russia") and the Nuclear Threat Initiative, Inc., a United States charitable organization (hereinafter "NTI"), hereafter referred to as "the Parties",

Seeking to facilitate the studying of possibilities of reducing the amount of weapons usable uranium in excess of the commitments specified in the existing agreements and in light of the arrangements of the Presidents of Russia and the United States proclaimed in May 2002,

Affirming the central role the Agreement Between the Government of the United States of America and the Government of the Russian Federation Concerning the Disposition of Highly Enriched Uranium Extracted from Nuclear Weapons ("HEU Purchase Agreement") of 1993 has played in achieving nonproliferation goals,

Have agreed as follows:

ARTICLE I.

1. The Parties shall cooperate with the aim of carrying out the Joint Conceptual Analysis and Cost Study (hereinafter "the Project") of a possibility to accelerate the rate of disposition of highly enriched uranium no longer required for defense purposes in addition to the amounts specified in the 1993 HEU Purchase Agreement. This Project shall include the tasks outlined in the Exhibit to this Memorandum, which shall constitute an inseparable part thereof. The tasks shall be updated and added upon mutual consent of the Parties.
2. The studies under this Memorandum shall be analytical and calculated in nature and shall not envisage any experimental, design and development activities.
3. NTI shall provide up to two million US dollars for executing the Project specified in Article I, paragraph 1.
4. The DIEEC of MinAtom of Russia and NTI shall arrange for executing the Project.

5. Upon the completion of the Project, a report describing its outcome shall be presented to U.S. and Russian Federation Government officials responsible for the implementation of the 1993 HEU Purchase Agreement.
6. Results of the Project may be made publicly available, in part or in whole, upon agreement of the Parties.
7. The cooperation contemplated in this Memorandum shall at no time impact the implementation of the 1993 HEU Purchase Agreement.

#### ARTICLE 2.

1. In order to coordinate and monitor the implementation of this Memorandum, the Parties hereto shall establish a Joint Coordinating Group (JCG). Each Party shall nominate its JCG members in an exchange of letters.
2. The JCG shall act as a supreme body with regard to all issues related to the implementation of this Memorandum. The decisions of the JCG shall be binding upon all entities participating in the execution of the Project in accordance with this Memorandum.
3. The JCG shall pursue the following tasks:
  - Review and approval of the General Work Plan within the framework of this Memorandum and funds for execution of individual tasks listed in the Exhibit to this Memorandum and their milestones.
  - Determining work priorities within the tasks listed in the Exhibit to this Memorandum, coordination of their execution, review and approval of reports regarding the contracts.
  - Resolution of any differences that may arise as a result of execution of work under this Memorandum.
  - Review of any other issues as agreed by the Parties.

#### ARTICLE 3.

1. To execute the Project described in Article 1, paragraph 1 of this Memorandum, the Parties shall agree that the Federal State Unitary Enterprise *TsNIIAtominform* (hereinafter "FSUE *TsNIIAP*") acts as the general contractor and enters into financial interactions with NTI as related to execution of work by organizations and specialists of MinAtom of Russia.
2. All tasks listed in the Exhibit and performed within the framework of this Memorandum shall be based on individual contracts and grant agreements.

3. Contracts and grants to execute the Project within the funding specified in Article 1, paragraph 3 shall be in accordance with the decisions made by the JCG.
4. The cooperation between the Parties shall be based on the national laws of the Parties.

#### ARTICLE 4.

1. In order to assist in the implementation of this Memorandum, the monetary funds, materials, equipment and services provided by NTI, shall constitute free technical assistance and shall be free from taxes or customs duties, pursuant to applicable Russian Federation laws.

#### ARTICLE 5.

1. NTI intends to engage in audits and inspections in order to determine that the funds provided by NTI are expended according to their intended purpose, pursuant to Article 1, paragraph 3 of this Memorandum. The audit and inspection procedure shall be set forth in contracts in accordance with applicable laws of the Russian Federation.
2. The distribution of rights for the intellectual property transferred or created in the framework of work executed under contracts with FSUE *TsNIIAI* shall be determined in the contracts thereof.
3. Applicable civil liability provisions shall be set forth in the contracts between NTI and FSUE *TsNIIAI*.
4. Exchange of information under this Memorandum shall not include State or commercial secrets. Information gained by either Party as a result of implementing this Memorandum shall not be disclosed to any third party without the prior approval of the other Party.

#### ARTICLE 6.

1. This Memorandum shall enter into force on the date of signature, and shall remain in force for eighteen months. The Memorandum may be extended for successive six-month periods with the written consent of both Parties. The Memorandum may be amended by written agreement of the Parties.
2. This Memorandum may be terminated by either Party by sending written notice of its intent to terminate the Memorandum, in which case the Memorandum shall terminate three months from the date of the notification.

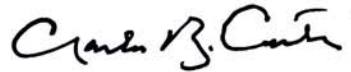
3. If the Memorandum is terminated, the Parties shall engage in consultations for the purposes of completing the contracts initiated when the Memorandum was still in force.

Executed in Moscow on October 23, 2002 in duplicate, in the Russian and English languages, both versions being equally legally valid and binding.

For the DIEEC of the Ministry of the  
Russian Federation for Atomic Energy



For the Charitable Organization  
Nuclear Threat Initiative, Inc., USA



**EXHIBIT**  
to the  
**MEMORANDUM OF UNDERSTANDING**  
on Cooperation  
between the Department of International and External Economic Cooperation  
of the Ministry of the Russian Federation for Atomic Energy  
And the United States Charitable Organization, The Nuclear Threat Initiative, Inc.,  
on the Joint Conceptual Analysis and Cost Study of  
Accelerating the Blend-Down of Russian Highly Enriched Uranium  
No Longer Needed for Defense Purposes

**LIST of Tasks**  
Pursuant To Article 1, Paragraph 1 of the Memorandum

1. Establishment of initial parameters for the Project.
2. General description of the blend-down process.
3. Analysis of options for accelerated blend-down HEU into LEU (direct blend-down of HEU into LEU, as well as options involving the blend-down of HEU into an intermediate non-defense material).
4. Determination of the type and content of diluents used in the process of accelerated HEU blend-down in order to provide the commercial specifications of the resultant LEU.
5. Analysis of existing projections of the commercial LEU market, for various accelerated HEU blend-down options.
6. Analysis and evaluation of the additional production capacities required to implement the accelerated HEU blend-down options, for all process stages (HEU oxidation, HEU fluorination, diluent manufacture, HEU blend-down, storage of blended material).
7. Economic estimations of costs for implementation of the HEU accelerated blend-down options.
8. Analysis of legal aspects of implementing the accelerated HEU blend-down (international standards and export procedures, property rights, legislative restrictions, etc.).
9. Preparation, review and approval of the final report of the Project.

Table P2.1

**Basic options for HEU accelerated processing in compliance  
with the Project Parameters**

No.	Option	HEU processing increment	LEU product enrichment, %	LEU product delivery	Temporary storage of LEU products			
					Russia	USA	Europe	
1	1A1	5 MTU/year	4.4	immediate				
2	1A2			deferred	+			
3	1A3			deferred		+		
4	1A4			deferred			+	
5	1B1		12.0	12.0	immediate			
6	1B2				deferred	+		
7	1B3				deferred		+	
8	1B4				deferred			+
9	1C1		19.0	19.0	immediate			
10	1C2				deferred	+		
11	1C3				deferred		+	
12	1C4				deferred			+
13	2A1	10 MTU/year	4.4	immediate				
14	2A2			deferred	+			
15	2A3			deferred		+		
16	2A4			deferred			+	
17	2B1		12.0	12.0	immediate			
18	2B2				deferred	+		
19	2B3				deferred		+	
20	2B4				deferred			+
21	2C1		19.0	19.0	immediate			
22	2C2				deferred	+		
23	2C3				deferred		+	
24	2C4				deferred			+
25	3A1	20 MTU/year	4.4	immediate				
26	3A2			deferred	+			
27	3A3			deferred		+		
28	3A4			deferred			+	
29	3B1		12.0	12.0	immediate			
30	3B2				deferred	+		
31	3B3				deferred		+	
32	3B4				deferred			+
33	3C1		19.0	19.0	immediate			
34	3C2				deferred	+		
35	3C3				deferred		+	
36	3C4				deferred			+
37	4A1	30 MTU/year	4.4	immediate				
38	4A2			deferred	+			
39	4A3			deferred		+		
40	4A4			deferred			+	
41	4B1		12.0	12.0	immediate			
42	4B2				deferred	+		
43	4B3				deferred		+	
44	4B4				deferred			+
45	4C1		19.0	19.0	immediate			
46	4C2				deferred	+		
47	4C3				deferred		+	
48	4C4				deferred			+

*Table P3.1*

**Estimated demands for additional capacities and their deficiency relative to the analyzed options for HEU accelerated blend-down at PA “MAYAK”**

Options		1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Processing of 90% HEU, MTU/year		5			10		20			30			
Production of 90% UMO, MTU/year	Additional production	2.5			5.0		10.0			15.0			
	Capacity reserve	2.5											
	Capacity shortage	no			2.5		7.5			12.5			

Table P3.2

Estimated demands for additional capacities and their deficiency relative to the analyzed options for HEU accelerated blend-down at SCC

Options	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Additional HEU processing volume, MTU/year	5.0	5.0		10.0		20.0		30.0				
Additional production	2.5	2.5		5.0		10.0		15.0				
Capacity reserve	5.0											
Capacity shortage	no	no	no	no	no	5		10				
Additional production	3.6	3.6		7.3		14.5		21.8				
Capacity reserve	2.0											
Capacity shortage	1.6	1.6		5.3		12.5		19.8				
Additional production	32.5	32.5	8.2	64.9	8.9	129.9	129.9	17.9	194.8	194.8	49.0	26.8
Capacity reserve	11.8											
Capacity shortage	20.7	20.7	no	53.1	no	118.1	118.1	6.1	183	183	37.2	15
Additional expense	128.8	128.8	32.4	257.7	35.4	515.4	515.4	70.9	773.0	773.0	194.6	106.3
Capacity reserve	46.8											
Capacity shortage	82.0	82.0	no	210.9	no	468.6	468.6	24.1	726.2	726.2	147.8	59.5

Table P3.2 continued

Options	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Surplus consumption of blendstock for the diluent, MTU/year	78.1	78.1	19.6	156.3	21.5	312.5	312.5	43.0	468.7	468.7	118.0	64.5
Additional production	33.6	33.6	–	67.1	–	134.3	134.3	–	201.4	201.4	–	–
Production of 4.4% LEU, MTU/year	73.2											
Capacity reserve	no	no	no	no	no	61.0	61.0	no	128.2	128.2	no	no
Capacity shortage	–	–	9.3	–	–	–	–	–	–	–	55.6	–
Additional production	–	–	–	–	–	–	–	–	–	–	–	–
Production of 12% LEU, MTU/year	no											
Capacity reserve	–	–	9.3	–	–	–	–	–	–	–	55.6	–
Capacity shortage	–	–	–	–	11.1	–	–	22.2	–	–	–	33.4
Additional production	–	–	–	–	–	–	–	–	–	–	–	–
Production of 19% LEU, MTU/year	no											
Capacity reserve	–	–	–	–	11.1	–	–	22.2	–	–	–	33.4
Capacity shortage	–	–	–	–	–	–	–	–	–	–	–	–

Table P3.3

**Estimated demands for additional capacities and their deficiency relative to the analyzed options  
for HEU accelerated blend-down at ECP**

Options	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Additional HEU processing volume, MTU/year	5.0			10.0			20.0			30.0		
<b>Production of highly enriched (HE) UHF with due account of HE UMO stored, MTU/year</b>												
Additional production	1.4			2.7			5.5			8.2		
Capacity reserves							0.4					
Capacity shortage	1.0			2.3			5.1			7.8		
<b>Production of 1.5% diluent, MTU/year</b>												
Additional production	40.3	40.3	10.1	80.6	11.1	161.2	161.2	22.2	241.7	241.7	60.9	33.3
Capacity reserves							8.8					
Capacity shortage	31.5	31.5	1.3	71.8	2.3	152.4	152.4	13.4	232.9	232.9	52.1	24.5
<b>Separation work for the diluent, kSWU/year</b>												
Additional expense	159.9	159.9	40.2	319.8	44.0	639.6	639.6	88.0	959.2	959.2	241.5	131.9
Capacity reserves							34.9					
Capacity shortage	125.0	125.0	5.3	284.9	9.1	604.7	604.7	53.1	924.3	924.3	206.6	97.0

Table P3.3 continued

Options		1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Surplus consumption of blendstock, MTU/year		96.9	96.9	24.4	193.9	26.7	387.8	387.8	53.3	581.6	581.6	146.4	80.0
Additional production		41.7	41.7	-	83.3	-	166.6	166.6	-	249.9	249.9	-	-
Production of 4.4% LEU, MTU/year		12.2											
Capacity reserves		no											
Capacity shortage		29.5	29.5	no	71.1	no	154.5	154.4	no	237.7	237.7	no	no
Additional production		-	-	11.8	-	-	-	-	-	-	-	69.0	-
Production of 12% LEU, MTU/year		no											
Capacity reserves		no											
Capacity shortage		-	-	11.8	-	-	-	-	-	-	-	69.0	-
Additional production		-	-	-	-	13.6	-	-	27.8	-	-	-	41.4
Production of 19% LEU, MTU/year		no											
Capacity reserves		no											
Capacity shortage		-	-	-	-	13.6	-	-	27.8	-	-	-	41.4

Table P3.4

**Estimated demands for additional capacities and their deficiency relative to the analyzed options for HEU accelerated blend-down at UECC**

Options	1A1	1A2	1B3	2A1	2C1	3A1	3A2	3C2	4A1	4A3	4B2	4C3
Additional HEU processing volume, MTU/year	2.6			5.0			10.2			15.3		
Additional production	74.8	74.8	18.8	149.7	20.6	299.3	299.3	41.2	448.9	448.9	113.0	61.8
<b>Capacity reserves</b>	<b>26.6</b>											
Capacity deficiency	48.2	48.2	no	123.1	no	272.7	272.7	14.6	422.3	422.3	86.4	35.2
Additional production	296.9	296.9	74.6	593.9	81.7	1187.8	1187.8	163.4	1781.4	1781.4	448.4	245.0
<b>Capacity reserves</b>	<b>105.6</b>											
Capacity deficiency	191.3	191.3	no	488.3	no	1082.2	1082.2	57.8	1675.8	1675.8	342.8	139.4
Surplus consumption of blendstock, MTU/year	180.0	180.0	45.3	360.1	49.5	720.2	720.2	99.1	1080.2	1080.2	271.9	148.6
Additional production	77.4	77.4	–	154.8	–	309.4	309.4	–	464.2	464.2	–	–
<b>Capacity reserves</b>	<b>140.4</b>											
Capacity deficiency	no	no	no	14.4	no	169.0	169.0	no	323.8	323.8	no	no
Additional production	–	–	21.0	–	–	–	–	–	–	–	128.1	–
<b>Capacity reserves</b>	<b>no</b>											
Capacity deficiency	–	–	21.0	–	–	–	–	–	–	–	128.1	–
Additional production	–	–	–	–	25.8	–	–	51.1	–	–	–	76.9
<b>Capacity reserves</b>	<b>no</b>											
Capacity deficiency	–	–	–	–	25.8	–	–	51.1	–	–	–	76.9

Table P4.1

**Technical arrangements facilitating the acceleration of HEU processing in the production of highly enriched UMO**

HEU processing increment	5 MTU (options 1A1, 1A2, and 1B3)	10 MTU (options 2A1, 2C1)	20 MTU (options 3A1, 3A2, and 3C2)	30 MTU (options 4A1, 4A3, 4B3, and 4C3)
<b>PA "MAYAK"</b>				
<b>Additional capacities</b>	<b>Not required</b>	<b>2.5 MTU/year</b>	<b>7.5 MTU/year</b>	<b>12.5 MTU/year</b>
Temporary storage of HEU components	Due to reserves	Extra areas	New storage facility	New storage facility
Production of highly enriched (HE) UMO	Due to reserves	Containers & equipment	Storage facility, new plants & equipment	Storage facility, new plants & equipment
Extraction refinement of HE UMO	Due to reserves	New plants	New plants	New plants
Production of refined HE UMO	Due to reserves	New plants & containers	Storage facility, new plants & containers	Storage facility, new plants & containers
Certification of refined HE UMO	Due to reserves	Additional containers	Analytical equipment & containers	Analytical equipment & containers
Temporary storage of refined HE UMO and its transport	Due to reserves	Additional containers & TUK sets	Extra areas, equipment, containers, TUK sets, transport means	Extra areas, equipment, containers, TUK sets, transport means
<b>SCC</b>				
<b>Additional capacities</b>	<b>2.5 MTU/year</b>	<b>5.0 MTU/year</b>	<b>10.0 MTU/year</b>	<b>15.0 MTU/year</b>
Production of highly enriched (HE) UMO	Due to reserves	Due to reserves	Due to reserves	New plant
HE UMO extraction refinement	Due to reserves	Due to reserves	Due to reserves	Due to reserves
Production of refined HE UMO	Due to reserves	Due to reserves	New plant	New plant
Certification of refined HE UMO	Due to reserves	Due to reserves	Due to reserves	New equipment
Temporary storage of refined HE UMO and its transport	Due to reserves	Due to reserves	Due to reserves	New storage

**Technical arrangements facilitating the acceleration of HEU processing  
in the production of highly enriched UHF**

HEU processing increment	<b>5 MTU</b> (options 1A1, 1A2, and 1B3)	<b>10 MTU</b> (options 2A1 and 2C1)	<b>20 MTU</b> (options 3A1, 3A2, 3C2)	<b>30 MTU</b> (options 4A1, 4A3, 4B3, and 4C3)
<b>SCC</b>				
<b>Additional capacities</b>	<b>3.6 MTU/year</b>	<b>7.3 MTU/year</b>	<b>14.5 MTU/year</b>	<b>21.8 MTU/year</b>
Temporary storage of HE UMO (CMP)	On available areas	On available areas	New storage	New storage
Production of HE UHF	New plant in new building	New plant in new building	New plant in new building	New plant in new building
Certification of HE UHF	New laboratory	New laboratory	New laboratory	New laboratory
Temporary storage of HE UHF (SP), transport to ISP (SCC and UECC)	New storage, transport means	New storage, transport means	New storage, transport means	New storages, transport means
<b>ECP</b>				
<b>Additional capacities</b>	<b>1.0 MTU/year</b>	<b>2.3 MTU/year</b>	<b>5.1 MTU/year</b>	<b>7.8 MTU/year</b>
Temporary storage of HE UMO	Storage extension	Storage extension	New storage	New storage
Production of HE UHF	Due to reserves	New plant & equipment	New plants in new building	New plants in new building
Certification of HE UHF	Due to reserves	Due to reserves	New plant	New plant
Temporary storage of HE UHF	On available areas	On available areas	New storage	New storage

CMP = chemical metallurgical plant

SP = sublimate plant

ISP = isotope separation plant

**Technical arrangements facilitating the acceleration of HEU processing  
at the stage of diluent production**

Options	SCC		ECP		UECC	
	Increment of separation capacities, kSWU	Desublimation section	Increment of separation capacities, kSWU	Desublimation section	Increment of separation capacities, kSWU	Desublimation section
1A1 and 1A2	82.0	Due to reserves	125	Additional equipment	191.3	Due to reserves
1B3	Due to reserves	Due to reserves	5.3	Due to reserves	Due to reserves	Due to reserves
2A1	210.9	Due to reserves	285	Additional equipment	488.3	Additional equipment
2C1	Due to reserves	Due to reserves	9.1	Due to reserves	Due to reserves	Due to reserves
3A1 and 3A2	468.6	Additional equipment	604.7	Additional equipment	1,082.2	Additional equipment
3C2	24.1	Due to reserves	53.1	Due to reserves	57.8	Due to reserves
4A1 and 4A3	726.2	Additional equipment	924.3	Additional equipment	1,675.8	Additional equipment
4B2	147.8	Due to reserves	206.6	Additional equipment	342.8	Additional equipment
4C3	59.5	Due to reserves	97.0	Due to reserves	139.4	Due to reserves

Table P4.4

**Technical arrangements facilitating the acceleration of HEU processing at the HEU dilution stage**

Option	SCC			ECP			UECC		
	Mixing plant	Liquid-phase pouring	Temporary storage of LEU products	Mixing plant	Liquid-phase pouring	Temporary storage of LEU products	Mixing plant	Liquid-phase pouring	Temporary storage of LEU products
1A1 and 1A2	Due to reserves	Due to reserves	On existing areas (new storage)	Due to reserves	Extra equipment and areas	On existing areas (new storage)	Due to reserves	Due to reserves	On existing areas (new storage)
1B3	New mixing plant in new building	New pouring plant	On existing areas (not required)	New mixing plant in new building	New pouring plant	On existing areas (not required)	New mixing plant in new building	New pouring plant	New storage (not required)
2A1	Due to reserves	Due to reserves	New storage (not required)	Additional equipment	Extra equipment and areas	New storage (not required)	New mixing plant	New pouring plant	On existing areas (not required)
2C1	New mixing plant in new building	New pouring plant	On existing areas (not required)	New mixing plant in new building	New pouring plant	New storage (not required)	New mixing plant in new building	New pouring plant	New storage (not required)
3A1	Due to reserves	Additional equipment	New storage (not required)	New mixing plant in new building	Extra equipment and areas	New storage (not required)	New mixing plant	New pouring plant	New storage (not required)
3A2	Due to reserves	Additional equipment	On existing areas (new storage)	New mixing plant in new building	Extra equipment and areas	New storage (new storage)	New mixing plant	New pouring plant	New storage (new storage)
3C2	New mixing plant in new building	New pouring plant	New storage (new storage)	New mixing plant in new building	New pouring plant	New storage (new storage)	New mixing plant in new building	New pouring plant	New storage (new storage)
4A1 and 4A3	New mixing plant in new building	Additional equipment	New storage (not required)	New mixing plant in new building	New pouring plant	New storage (not required)	New mixing plant	New pouring plant	New storage (not required)
4B2	New mixing plant in new building	New pouring plant	New storage (new storage)	New mixing plant in new building	New pouring plant	New storage (new storage)	New mixing plant in new building	New pouring plant	New storage (new storage)
4C3	New mixing plant in new building	New pouring plant	New storage (not required)	New mixing plant in new building	New pouring plant	New storage (not required)	New mixing plant in new building	New pouring plant	New storage (not required)

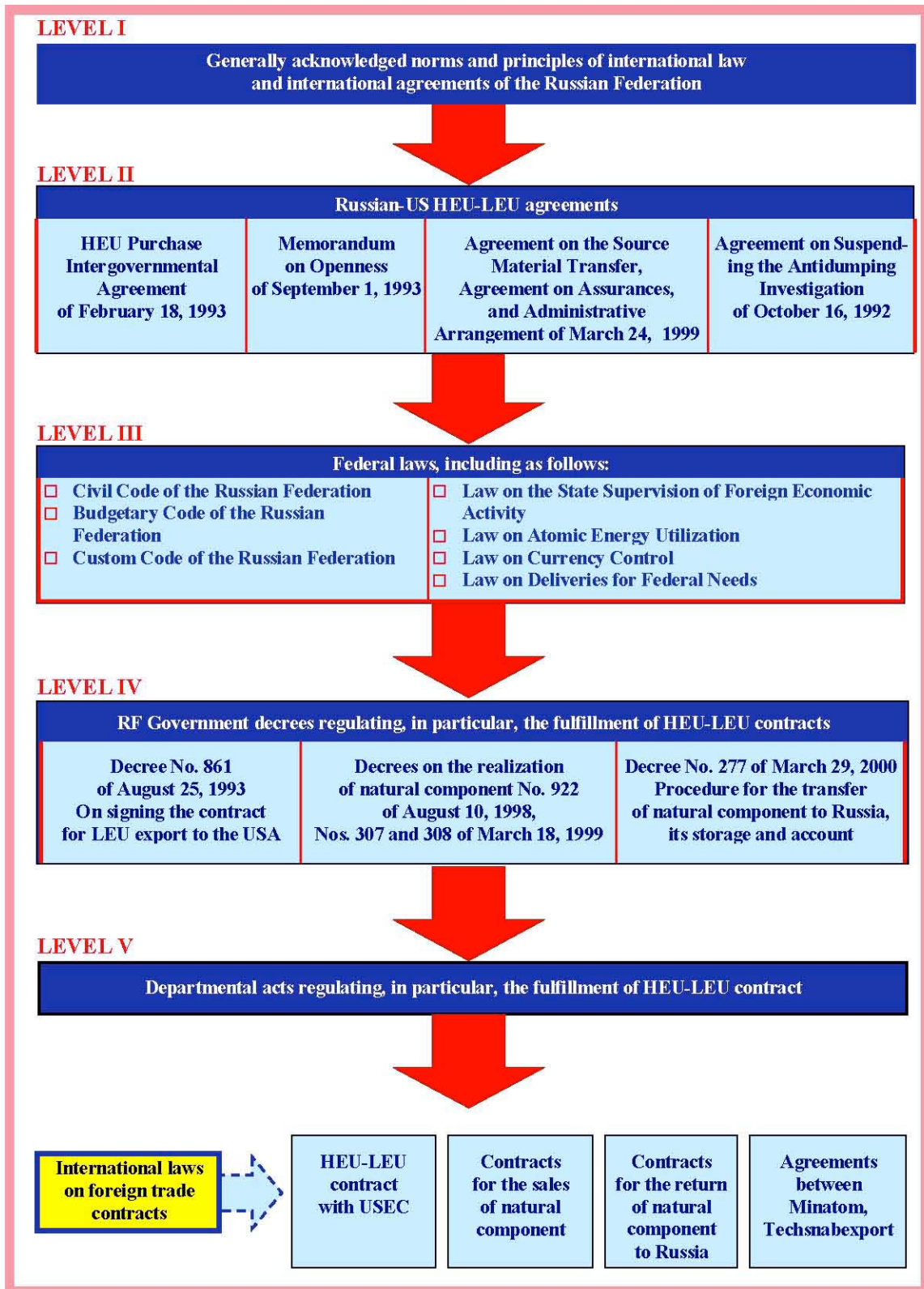


Fig. P5.1. The hierarchy of legal norms regulating the HEU-LEU Program

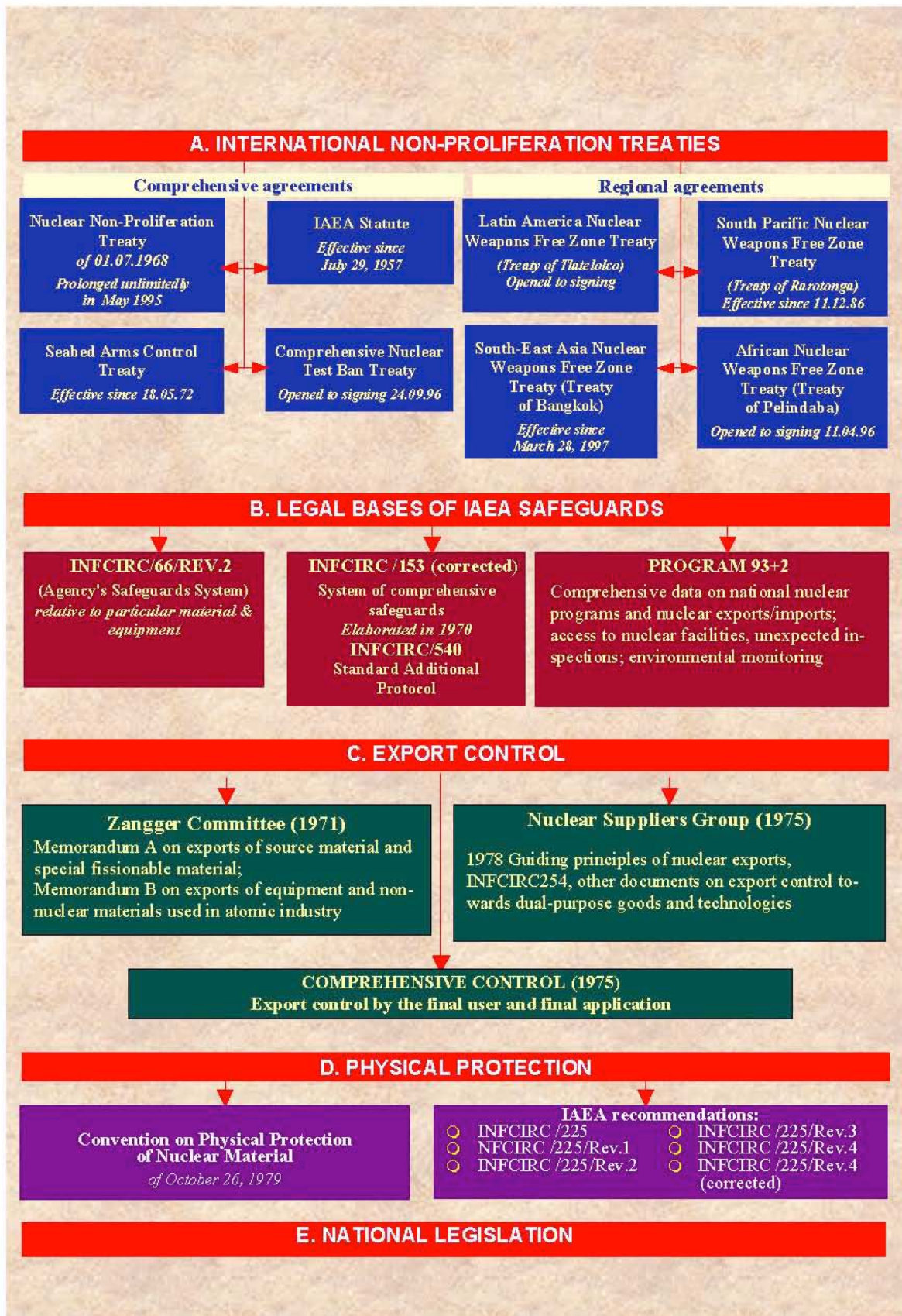
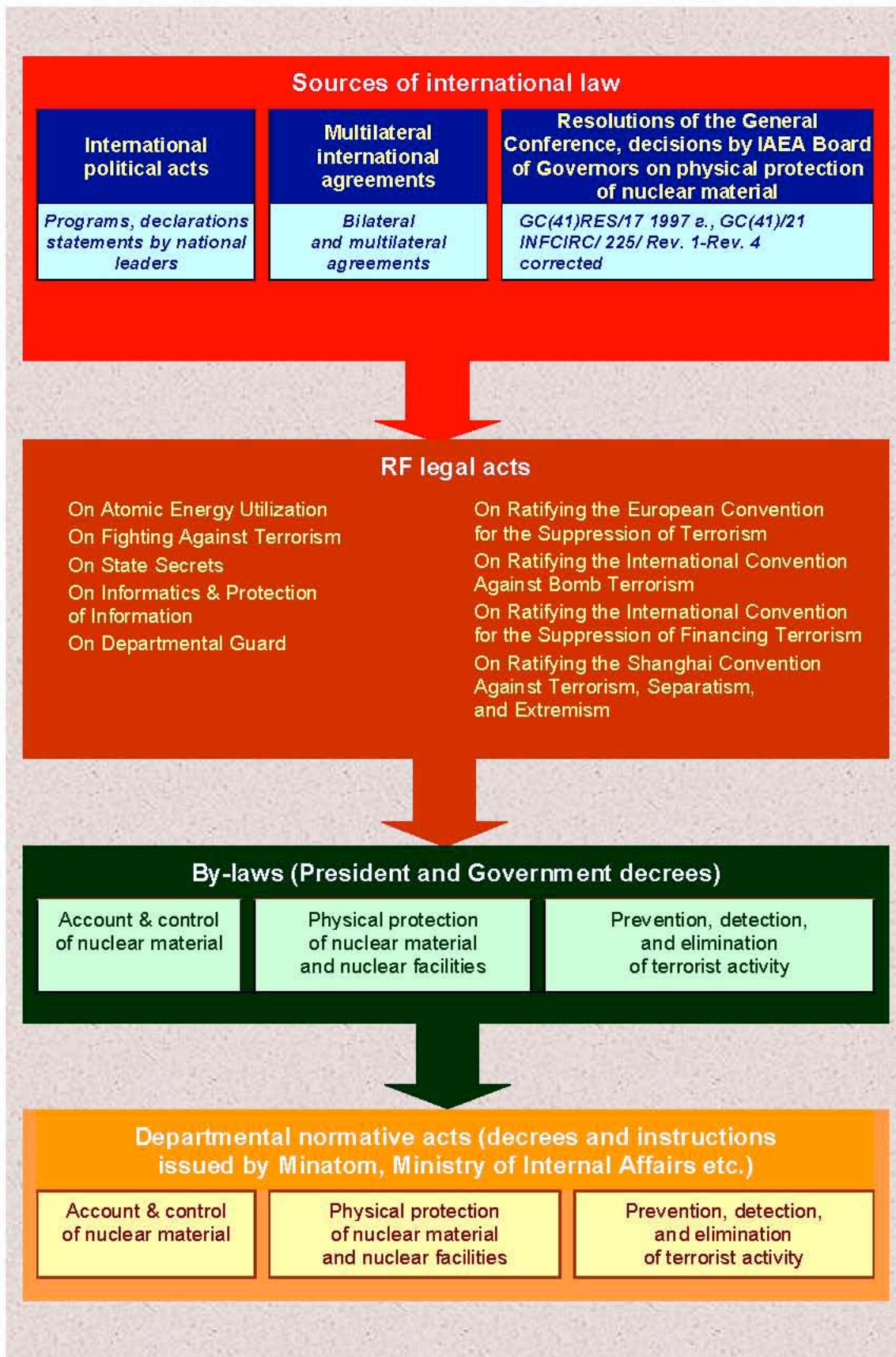
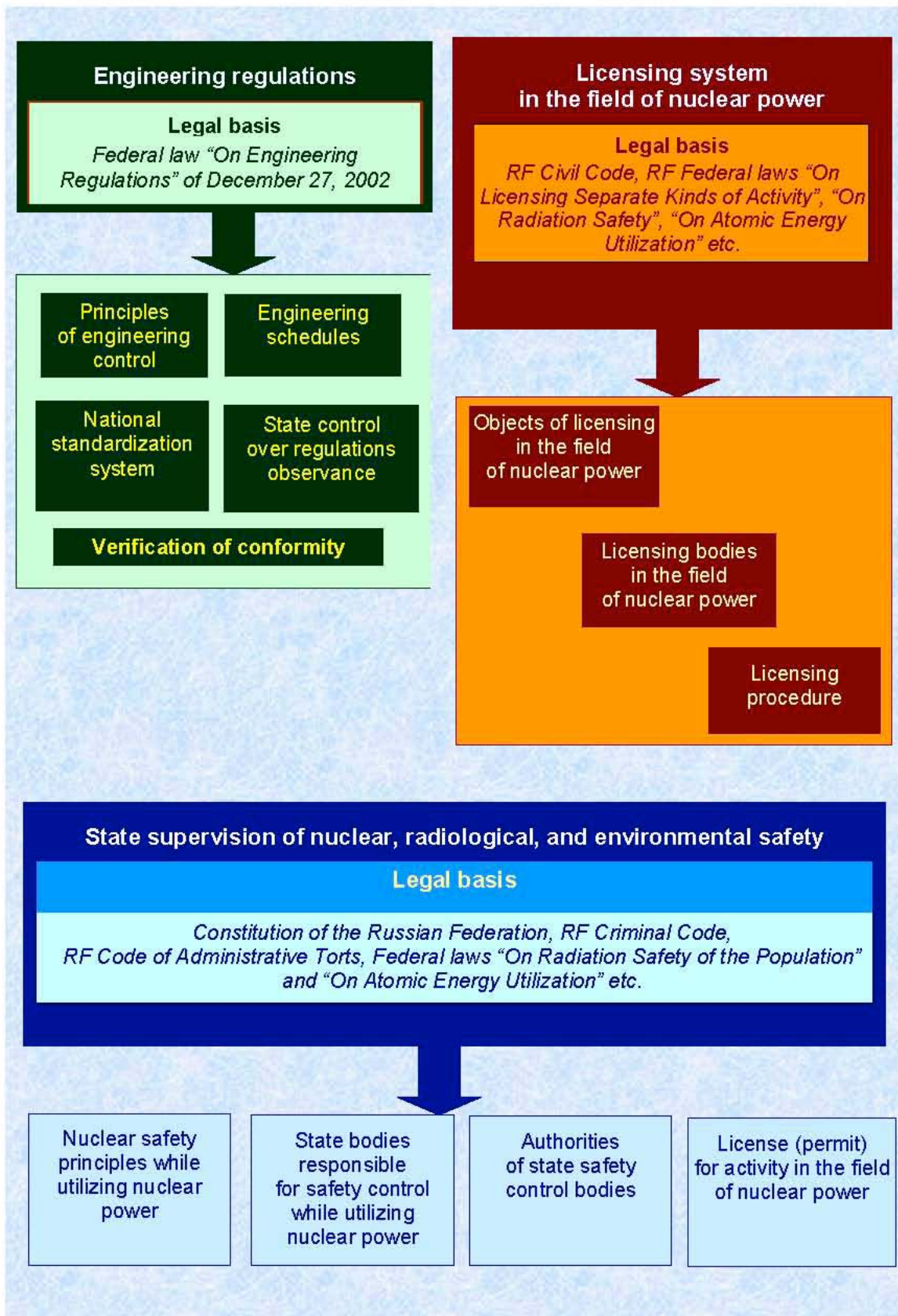


Fig. P5.2. International legal norms specifying the principles of non-proliferation relative to accelerated processing of HEU



*Fig. P5.3. International counteraction to nuclear terrorism during accelerated processing of HEU*



*Fig. P5.4. Mechanisms of state guarantees of safety during accelerated processing of HEU*

**Legal protection of intellectual property during accelerated reprocessing of HEU in compliance with the RF legislation**

**A. Intellectual property** is determined in Article 2 of the Convention establishing the **World Intellectual Property Organization – WIPO** (signed on July 14, 1967 at Stockholm, and altered on October 2, 1979)

The objects of intellectual property as regards accelerated processing of HEU can be related to **industrial property, copyright, commercial secrets (know how inclusive), and state secrets.**

**B. International and regional (CIS) levels of legal protection of intellectual property**

<b>B1. Industrial property</b>	<b>B2. Copyright</b>
The Paris Convention on the Protection of Industrial Property of March 20, 1883	World Convention on Copyright of September 6, 1952 as revised on July 24, 1971
The Patent Law Treaty, Regulations to this Treaty, and Agreed Statements by the Diplomatic Conference	Agreement on Cooperation on Copyright and Allied Rights (Moscow, September 24, 1993).
The Patent Cooperation Treaty (signed at Washington on June 19, 1970) in the wording of February 3, 1984	WIPO Agreement on Copyright of December 20, 1996
Eurasian Patent Convention (Moscow, August 9, 1994). Bilateral agreements with CIS member-states on the protection of industrial property	

**C. National level of legal protection**

<b>C1. Industrial property</b>	<b>C2. Copyright</b>	<b>C3. Protection of commercial secrets (know how inclusive)</b>	<b>C4. Protection of state secrets</b>
RF Patent law (with alterations and amendments) No. 22-FZ of February 7, 2003 RF Government Decree No. 793 of August 12, 1993, approving the Regulations on duties imposed in connection with the patenting of inventions, utility models, industrial designs; registration of trademarks etc. (in the wording of July 4, 2003, No. 403) RF Government Decree No. 822 “On applying on the RF territory some provisions of the USSR legislation on inventions and industrial prototypes” of August 14, 1993	RF Law No. 5351-1 “On copyright and allied rights” of July 9, 1993 (with alterations and amendments No. 110-FZ of July 19, 1995) RF President Decree No. 556/98 “On legal protection of results of R&D work of defense, special, and dual application” RF Government Decree No. 413 “On improving the activity of federal power bodies in the field of copyright” of April 12, 1999	RF Civil Code (Article 139) RF President Decree No. 188 “On approving a List of confidential data” of March 6, 1997 RF Government Decree No. 35 “On the List of data that cannot be treated as commercial secrets” of December 5, 1991 RF Criminal Code, No. 63-FZ of June 13, 1996 (Article 183). The draft of a Federal law “On the commercial secret” has passed the first reading (May 23, 2003)	RF Law No. 5485-I “On the state secret” of July 21, 1993 Federal law No. 24-FZ “On informatics and protection of information” of February 20, 1995 RF Criminal Code No. 63-FZ of June 13, 1996, Articles 275, 276, 283, and 284 RF President Decree No. 1203 of November 30, 1995, approving the List of data referred to state secrets (with alterations and amendments of January 24, 1998) RF Government Decree No. 326 of April 11, 2000 “On licensing separate kinds of activity (with alterations and amendments of November 17, 2000)

*Fig. P5.5. Main elements of the legal protection of intellectual property during accelerated processing of HEU in conformity with the RF legislation*

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