PRELIMINARY COST ASSESSMENT FOR THE DISPOSITION OF WEAPON-GRADE PLUTONIUM WITHDRAWN FROM RUSSIA'S NUCLEAR MILITARY PROGRAMS

Report of the
Joint U.S.-Russian Working Group
On Cost Analysis and Economics
in Plutonium Disposition

April 2000

Honorable Ernest J. Moniz
Under Secretary
U.S. Department of Energy
U.S. Co-Chair
Joint U.S.-Russian Steering Committee
on Plutonium Management

Honorable Valentin B. Ivanov
First Deputy Minister
Ministry of the Russian Federation for Atomic Energy
Russian Co-Chair
Joint U.S.-Russian Steering Committee
on Plutonium Management

Dear Honorable Co-Chairs:

At its meeting in Washington, DC on 18-19 October 1999, the Joint U.S.-Russian Steering Committee on Plutonium Management directed the Joint U.S.-Russian Working Group on Cost Analysis and Economics in Plutonium Disposition to prepare, by early 2000, a macro-level analysis of the expected costs of disposing of thirty-four metric tons (34MTs) of Russian weapon-grade plutonium over the course of approximately the next twenty-five years.

We are pleased to submit the working group's preliminary report. The report is the result of several months of detailed analysis by U.S. and Russian experts, and embodies their best technical judgments on the basis of information available at this time.

Although the cost analysis is based on an agreed "base case scenario" for plutonium disposition in Russia, it should be kept in mind that international agreements and arrangements for the Russian program and its funding are still to be completed. Nothing in our use of a specific disposition scenario for purposes of cost analysis should be taken to imply commitments on the part of either of the governments concerned beyond commitments that have been officially agreed.

Although the report is very much a collaborative effort of U.S. and Russian experts, it is not a formal or official document of the governments, ministries or institutions whose experts have participated in its preparation. The report contains only unclassified information, and does not, in our view, contain proprietary or other business-sensitive information.

Respectfully submitted,

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Office of Fissile Materials Disposition
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5 April 2000

FOREWORD

The Joint U.S.-Russian Steering Committee on Plutonium Management was established in the Agreement Between the Government of the United States of America and the Government of the Russian Federation on Scientific and Technical Cooperation in the Management of Plutonium That Has Been Withdrawn From Nuclear Military Programs, signed in Moscow on 24 July 1998.

The Steering Committee is co-chaired by Dr. Ernest J. Moniz, Under Secretary, U.S. Department of Energy (DOE), and Dr. Valentin B. Ivanov, First Deputy Minister, Ministry of the Russian Federation for Atomic Energy (MINATOM). Its role is to coordinate and agree upon scientific and technical work undertaken under the July 1998 Agreement.

The Joint U.S.-Russian Working Group on Cost Analysis and Economics in Plutonium Disposition was established as a permanent working group of the Steering Committee in October 1999. The working group is co-chaired by James L. Lacy, Director, International Policy and Programs, Office of Fissile Materials Disposition, DOE, and Vladimir V. Shidlovsky, Head of the Department of the Nuclear Fuel Cycle, MINATOM.

As an initial task, the Steering Committee asked the working group to develop by early 2000 "a credible and comprehensive macro-level analysis of expected total costs of the Russian plutonium disposition program." The Steering Committee added that "this analysis ... [should] take into consideration as many uncertainties as possible relating to costs and economic factors of the Russian program in order to inform the dialogue of the international community's discussions about financing the Russian program."

This report responds to that request. The analysis has been conducted jointly by U.S. and Russian technical and cost experts. Participating in the analysis have been experts from DOE, the U.S. State Department, Bechtel National Inc., International Nuclear Consultants, Inc., Oak Ridge National Laboratory, MINATOM, the Institute of Physics and Power Engineering (IPPE), the All-Russia Design and Scientific Research Institute for Complex Power Technology (VNIPIET), Bochvar All-Russia Research Institute of Organic Materials (VNIINM), Research Institute of Atomic Reactors (NIIAR), MAYAK Production Association (PA), RRC "Kurchatov Institute," State Specialized Design Institute (GSPI), All-Russia Institute for Operations of Nuclear Power Plants (VNIIAES), Rosenergoatom Concern, and RF Gosatomnadzor (GAN)

The report has been reviewed and approved by the working group co-chairs for submission to the Co-Chairs of the Steering Committee. The English and Russian texts have been judged to have substantially the same meaning.

SUMMARY

This report addresses the additional costs of disposing of 34 MTs of Russian weapon-grade plutonium. "Additional costs" are costs directly related to the disposition of this plutonium that are above-and-beyond the routine costs of generating nuclear energy in Russia through the use of uranium fuel. They include the costs of new and/or modified and upgraded facilities, associated infrastructure, and operations that will be needed for the disposition of weapon-grade plutonium, and the added costs of licensing and regulating these activities.

A "base case scenario" for the disposition of the 34 MTs has been employed as the framework for the cost assessment. It assumes that most (33 MTs) of the 34 MTs of Russian weapon-grade plutonium will be disposed of by irradiation in existing Russian reactors as mixed oxide (MOX) fuel; approximately 1 MT will be immobilized for eventual deep geological disposal. The scenario identifies specific facilities and operations that would be involved in the Russian program, including a timetable of projected annual rates for the disposition of the plutonium through 2025.

The base case scenario is neither a prediction nor a conclusion about the details of the Russian program. Rather, it reflects a plausible, technically developed, technically feasible, and comparatively economical approach to implementing the Russian program, and provides a single and consistent framework for analyzing and estimating costs across the breadth of the program, and over time. Variations on, alternatives to, and excursions from the base case are technically and programmatically possible. Indeed, depending upon technical, licensing and economic developments that cannot be predicted with confidence at this time, some such variations and excursions may become necessary in the future in any case, with attendant cost implications for the Russian program.

For purposes of current discussions of international funding, our examination of the base case suggests an overall "starting" cost of 1.7 billion in current (year 2000) U.S. dollars, or $1.9 billion if Russian value-added taxes are included (Table). These are starting costs only. Several categories of costs have had to be excluded from the current assessment because either: (1) not enough, or not precise enough, information is available regarding these categories to permit assessment of the macro-level cost implications at this time; or (2) no intergovernmental discussions, understandings or agreements have yet taken place concerning whether and/or how to take these categories into account. The reader should keep in mind that—when subsequently computed and when and if agreed—these costs would be in addition to the costs assessed in the report.

The costs presented here are "starting" costs in another respect as well. The reader should bear in mind the preliminary nature of the cost assessment itself. It is customary in early, order-of-magnitude cost analyses such as this to assign a margin-of-error factor or percentage to the reported costs, in order that the level of analytical confidence in the costs as assessed may be properly appreciated. We do not do so here, in part because we do not have a solid enough analytical basis at present to quantify the scope and range of possible error. There should be no question, however, that there are significant uncertainties concerning some of the Russian program's technical elements and associated costs. Much still needs to be known—and in some cases thoroughly tested—before more confident levels of cost projection can be assigned.

Summary of Projected "Starting" Costs
(Current US $1000s)

Cost Element	Research, Development and Pre-Capital Costs	Design and Construction of Facilities and Equipment Costs	Operating Costs	Total
Plutonium Conversion	12,600	97,390	175,300	285,290
MOX Fuel Fabrication	101,725	207,700	378,800	688,225
Reactor Modifications and Operations	22,600	193,900	104,400	320,900
Transportation	3,900	28,100	84,450	116,450
Spent Fuel Storage for BN-600	1,900	18,300	87,500	107,700
Immobilization	29,000	64,900	106,100	200,000
SUBTOTAL	171,725	610,290	936,550	1,718,565
Value-Added Tax			170,540	170,540
TOTAL	171,725	610,290	1,107,540	1,889,105

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1. BACKGROUND

In the period since Presidents Clinton and Yeltsin signed in September 1998 a "Joint Statement of Principles for Management and Disposition of Plutonium Designated As No Longer Required for Defense Purposes," the governments of the United States and Russia have been engaged in negotiations on the mutual and reciprocal disposition of weapon-grade plutonium to be withdrawn from their nuclear military programs. The intended outcome is an agreement by which each side will dispose of thirty-four metric tons (34 MTs) of this plutonium, according to roughly parallel timetables, over a period of approximately twenty-five years.

A key understanding is that the costs of disposing of Russian weapon-grade plutonium in the manner envisioned by the two governments will be funded largely by non-Russian sources, with the Russian Federation contributing to the effort according to arrangements still to be negotiated. The United States has pledged to contribute financial support. The United States, Russia and other countries have also been engaged in consultations about international funding to support the Russian disposition effort.

A central interest for all concerned is the expected cost of the intended Russian program. Up to now, this has been uncertain. Estimates have varied widely, from less than 1 billion to more than 3 billion U.S. dollars. Some estimates have focused only on portions of the Russian program and portions of the costs involved. There also has been little consistency among estimates in terms of assumptions about the Russian program's expected throughputs, the technologies to be employed, or the siting of facilities.

2. THIS REPORT

This report was commissioned by the Joint U.S.-Russian Steering Committee on Plutonium Management in order to bring greater clarity, comprehensiveness and precision to understandings of the costs involved. The report addresses the additional costs of disposing of the 34 MTs of Russian weapon-grade plutonium. "Additional costs" are costs directly related to the disposition of weapon-grade plutonium that are above-and-beyond the routine costs of generating nuclear energy in Russia through the use of uranium fuel. They include the costs of new and/or modified and upgraded facilities, associated infrastructure, and operations that will be needed for the disposition of weapon-grade plutonium, and the added costs of licensing and regulating these activities.

2.1 Purpose

The purpose of the report is to provide an analytically-based, macro-level assessment of these additional costs—one that takes into account as many uncertainties as possible relating to the technical, cost and economic factors in the Russian program—in order to inform the international community's discussions about providing funding assistance. The report is concerned only with the costs involved in the plutonium disposition program in Russia. It does not address questions of funding, or costs that might be associated with the organization and management of external funding support or the integration of program activities.

2.2 Disposition of Russian Plutonium

Past analyses of the costs of Russian plutonium disposition often have been unilluminating because the programmatic and technical assumptions on which they are based have not been set

forth clearly and completely, or adequately explained. In this report, we document the assumptions that underlie the cost analysis. Taken together, these assumptions form a "base case scenario" for the disposition of the 34 MTs of Russian weapon-grade plutonium.

The scenario has been approved by MINATOM to serve as the basis for Russian cost estimates of plutonium disposition. It has been adopted by the co-chairs of the Joint U.S.-Russian Working Group on Cost Analysis and Economics in Plutonium Disposition to serve as the "base case" framework for this preliminary joint assessment. The base case assumes a program designed, built and operated to dispose of weapon-grade plutonium at an average of two MTs/year in existing Russian nuclear reactors.[1] It identifies specific facilities and operations that would be involved in the Russian program, including a timetable of projected annual rates for the disposition of the plutonium through 2025.

The base case scenario is described in section 3. The scenario is neither a prediction nor a conclusion about the details of the Russian program. Rather, it reflects a plausible, technically developed, technically feasible, and comparatively economical approach to implementing the Russian program, and provides a single and consistent framework for analyzing and estimating costs across the breadth of the program, and over time.

In viewing the base case, the reader should keep in mind several things:

- The scenario has been developed and employed solely for purposes of cost analysis and projection. It does not imply policy, programmatic or technical decisions concerning the elements covered in the scenario.

- Variations on, alternatives to, and excursions from the base case are technically and programmatically possible. Indeed, depending upon technical, licensing and economic developments that cannot be predicted with confidence at this time, some such variations and excursions may, in any case, become necessary in the future, with resulting cost implications for the Russian program.

- International agreements and arrangements for the Russian program and its funding are still to be completed. Nothing in our use of a specific disposition scenario for the purposes of cost assessment should be taken to imply commitments on the part of either of the governments concerned beyond commitments that have been formally and officially agreed upon.

2.3 Source Data and Past Analyses

In assessing and projecting costs, we have built upon previous Russian and joint U.S.-Russian work on various components of the Russian program, and also on separate Russian and American analyses, a number of them done specifically for the purposes of this report. In most cases, the source data are Russian, adjusted, refined and recalculated as needed by agreement of the U.S. and Russian experts in the course of the joint analysis. Where, in a few cases, such as the cost of

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[1] The United States and the Russian Federation intend to undertake a study in the time ahead to determine whether and how the annual disposition rate in Russia might at least be doubled—possibly by employing reactors outside Russia for irradiation of Russian MOX fuel. The additional costs in facility design, construction and operation for the larger throughput would be calculated as part of that study.

licensing, we have employed source data from other countries' experiences, we have adjusted the data according to agreed formulas to reflect Russian requirements and circumstances.

2.4 Scope of Analysis

Although based on detailed assessments of the costs of various program components, the report deals with these costs at a macro-level of analysis. The assessment covers costs from the present through approximately 2025, and takes account of the additional pre-capital, capital, and operating expenditures associated with the disposition of 34 MTs of Russian weapon-grade plutonium.[2] All costs are presented in current (year 2000) U.S. dollars.

The cost assessment is predicated on the expectation that most (33 MTs) of the 34 MTs of Russian weapon-grade plutonium will be disposed of by irradiation in existing Russian reactors as mixed oxide (MOX) fuel; approximately 1 MT will be immobilized for eventual deep geological disposal.[3] The items of relevant cost include:

- Design, construction and operation of a conversion facility in Russia to produce plutonium dioxide or mixed plutonium-uranium oxide suitable for manufacture as MOX fuel for Russian reactors.[4]
- Design, construction, and operation of MOX fuel fabrication facilities in Russia.
- Modification, safety upgrades and portions of service life extensions of existing Russian nuclear reactors and associated site infrastructure to irradiate this MOX fuel;[5]
- Associated transportation, interim storage and waste management;
- Preparation for and immobilization of approximately 1 MT of the 34 MTs of impure weapon-grade plutonium;
- Attendant licensing and regulatory activities.[6]

The process flow for the disposition of weapon-grade plutonium as MOX fuel, and the scope of the cost assessment, are illustrated in Figure 1.

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2 The assessment takes account of expectations that a small quantity (~1.2 MT) of MOX fuel would be produced by pyroelectrochemical conversion and vibropac technology for the BOR-60 and BN-600 reactors in the early stages of the program.

3 These expectations are derived from U.S.-Russian negotiations, and reflect areas of general agreement as of late January 2000. Any subsequent changes in these areas would require a reassessment of the cost implications.

4 The conversion facility would be designed, constructed and operated so as to facilitate the blending of a quantity of non-weapon grade plutonium with the weapon-grade plutonium in order to conceal the isotopic assay of the latter.

5 The principal reactor modifications would consist of: (1) for VVER-1000 reactors, instrumentation and additional new MOX fuel storage and spent fuel storage; (2) for the BN-600, reactor head configuration, control rod drive assemblies, instrumentation, shielding, and additional new MOX fuel storage and spent fuel storage.

6 The possible employment of high-temperature gas reactors (HTGR) in the disposition of Russian weapon-grade plutonium has not been taken into account in this preliminary assessment. Research and development work on possible HTGR utilization for these purposes is at too early a stage to permit confident cost estimates at this point in time.

2.5 Exclusions

Several categories of costs have been excluded from the preliminary assessment. These are identified in section 4.1. The reasons for exclusion from the assessment are essentially two:

- Not enough, or not precise enough, information is available regarding these categories to permit assessment of costs at this time.

- No inter-governmental discussions, understandings or agreements have yet taken place concerning whether and/or how to take these categories into account in assessing the costs of the Russian program.

The reader should bear in mind that—when computed and when and if agreed—these costs will be in addition to the costs addressed in this preliminary report.

2.6 Organization of the Report

In preparing this report, we have been mindful of the wider audience of U.S., Russian, and international decision-makers who may be interested in the analysis. We have sought to organize and present the analysis, and supporting and explanatory materials, with this wider, non-technical, audience in mind.

In section 3 we sketch the principal elements and features of the Russian effort, including the detailed base case scenario that serves as the basis for the preliminary cost estimates. In section 4 we briefly examine the considerations and guideposts that have shaped the scope and character of the preliminary cost assessment. We present the results of the preliminary cost analysis in section 5. We express and discuss the estimated costs in composite, summary form; according to principal program elements; by stages of program development; and across time, from the present to approximately 2025.

3. DISPOSITION OF RUSSIAN WEAPON-GRADE PLUTONIUM

Like the U.S. counterpart program to which it would be linked by intergovernmental agreement, the Russian effort would focus exclusively on weapon-grade plutonium that has been withdrawn from nuclear military programs.[7] A monitoring and inspections regime, yet to be negotiated, would cover most aspects of both countries' programs for the full life of the programs. At each of the facilities in the programs, verification would be based on international standards.

The pace of disposition in both programs will be dependent on, among other things, sustained and uninterrupted funding support. Because the programs will be linked in an agreement of mutual and reciprocal obligations, delays in either country's disposition schedule would most likely result in concomitant hold-ups in the other's.

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[7] Although MINATOM would have a central role in the design and implementation of the Russian program, the Russian endeavor would require and entail the active participation of a number of Russian agencies and entities throughout its 25-year duration.

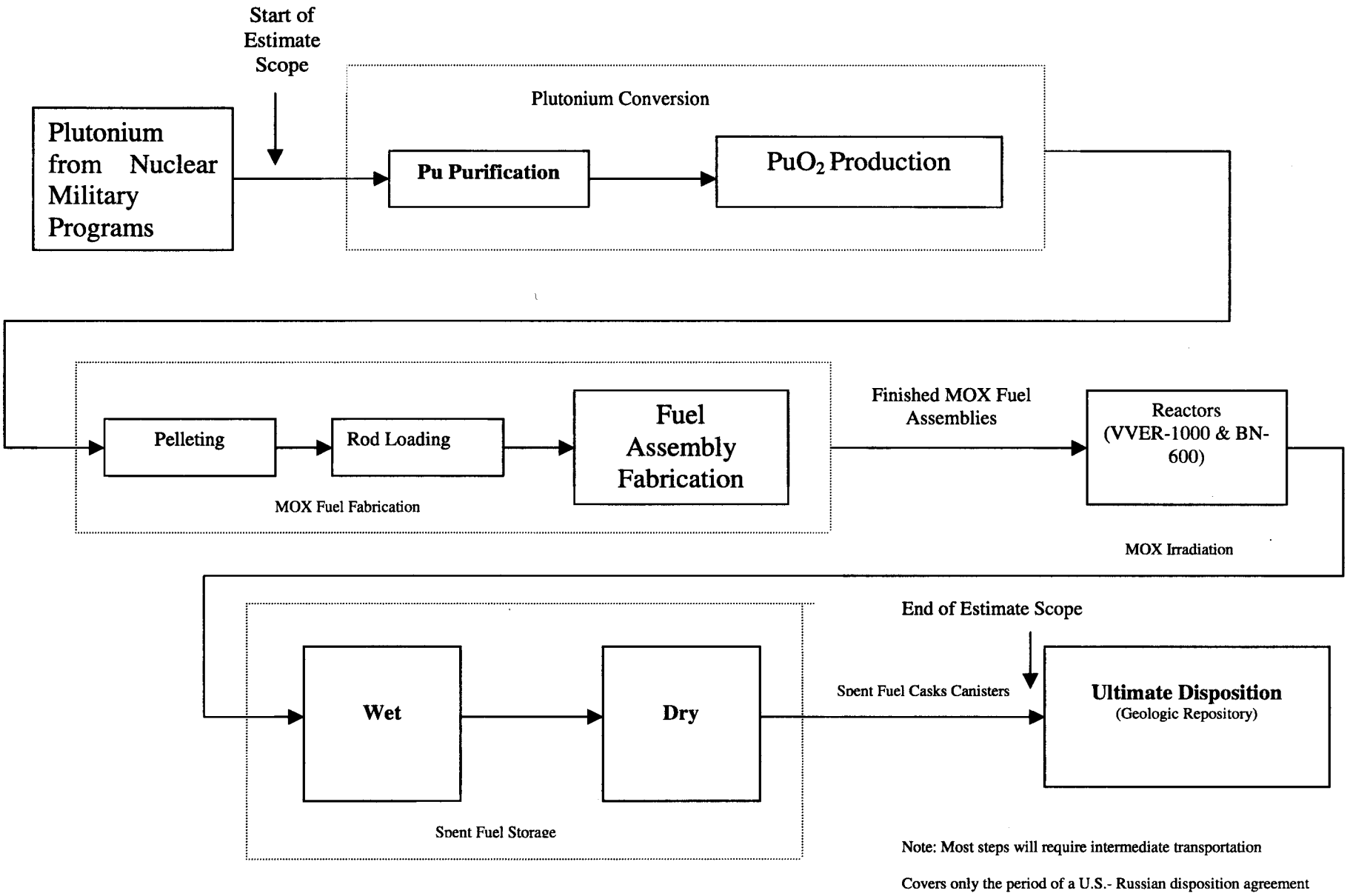

Figure 1:
Process Flow for
Russian Plutonium Disposition

3.1 Overview

The 34 MTs of Russian plutonium are expected to consist, variously, of plutonium clean metal (25 MTs), oxide (8 MTs) and impure oxide (1 MT). Most (33 MTs) of this plutonium would be fabricated into MOX fuel and dispositioned by irradiation in a combination of VVER-1000 light water reactors, the experimental BOR-60 reactor, and following modification the BN-600 fast reactor; the 1 MT of impure oxide would be immobilized for eventual deep geological disposal (Table 1).[8]

Table 1. Forms, Quantities and Methods of Disposition

Form	Quantity	Method of Disposition
Clean Metal	25 MTs	MOX/Irradiation
Oxide	8 MTs	MOX/Irradiation
Impure Oxide	1 MT	Immobilization

Although some quantities of this plutonium could begin to be dispositioned by irradiation as early as 2001, and nearly 3 MTs could be fully dispositioned in the BOR-60 and BN-600 reactors by the end of 2008 (see Table 2), the Russian program would not commence operating on a full industrial scale until about 2009. Between now and late 2007, the principal activities would consist of designing, constructing, modifying, and licensing the requisite industrial-scale facilities.[9] From 2009 through 2025, the disposition rate for weapon-grade plutonium would average 2 MTs/year. The last MOX fuel assemblies would be discharged in about 2029.

The conversion and fuel fabrication facilities would be specially designed and constructed for these purposes. The reactors used to irradiate the fuel will need not only to be modified and upgraded to handle MOX fuel; most will also require service life extensions to allow their availability for the full course of the disposition effort.

3.2 Base Case Scenario

These general features have been translated into a detailed set of program and planning assumptions for purposes of estimating the costs of the Russian program over the course of its approximately 25-year duration. The principal features of this base case scenario are illustrated in Figure 2. Fuel production and disposition rates are charted in detail in Table 2.

Of particular note are the following propositions concerning the siting and operation of facilities, and associated transportation and licensing requirements:

- All new and dedicated facilities would be located at existing nuclear sites in Russia.
- The plutonium conversion facility would be located at MAYAK.

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[8] Because blend stock, up to 12 percent, would be added to the plutonium volume to be dispositioned in order to mask the military characteristics of the source plutonium, the actual volume of plutonium dispositioned through irradiation will be nearly 37 MTs.

[9] Construction of industrial-scale conversion and fuel fabrication facilities in Russia would begin in mid-2003, and be completed by late 2007.

- MOX fuel would be fabricated at three facilities: NIIAR (near Dimitrovgrad), Mayak (Ozersk), and Krasnoyarsk.

- The disposition of weapon-grade plutonium in Russia would be carried out within three operations areas: the Balakovo Nuclear Power Plant (NPP), the Beloyarsk NPP, and the BOR-60 reactor at the Research Institute of Atomic Reactors (NIIAR) near Dimitrovgrad. Of Russia's seven available VVER-1000 reactors, only the four units at Balakovo NPP would be modified, upgraded and have their operational lifetimes extended for irradiation of MOX fuel.[10]

- The storage of spent MOX fuel would be carried out in two steps: "wet" on-site power plant storage, and long-term "dry" storage in the storage facilities of the Krasnoyarsk Integrated Mining-and-Chemical Industrial Combine.

- The immobilization of weapon-grade plutonium would be carried out within two operations areas: at MAYAK PA and at the Krasnoyarsk Integrated Mining-and-Chemical Industrial Combine. Each site would store its own low-level waste and transuranic waste until final disposal.

- Transportation of materials would be required between: lead assembly fuel fabrication facilities and reactor units, the conversion facility and the fuel fabrication facility, the fuel fabrication facility and reactor units, and on-site spent fuel storage at the reactor units and Krasnoyarsk after about six years.[11]

- Licenses will be required to construct (or modify) the following facilities: plutonium conversion facility, MOX fuel fabrication facility, BN-600 reactor, VVER-1000 reactors,[12] pilot fuel fabrication facilities, spent fuel storage facility, storage facilities for intermediate products, waste storage facilities, and cask and transport vehicle design. Licenses also will be required for the movement of material between sites.

4. FACTORS IN THE PRELIMINARY COST ASSESSMENT

Before turning to the anticipated costs of the base case, it is important to be clear about the boundaries and "counting rules" of the preliminary cost assessment. Not all additional costs of the Russian program are (or can be) taken into account in the preliminary assessment. Some program costs are (and need to be) separately identified, and analyzed differently from others, at this time. Although we present a macro-level quantification of the program's costs that should be greatly informative for current discussions about funding the Russian effort, many of the underlying details (such as work hours and material and equipment costs) will require further assessment in the time ahead in order to adjust—and strengthen the levels of confidence that may be assigned to the overall cost projections. We briefly discuss these "bounding" considerations in the subsections below.

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[10] This assumes achievement over time of approximately a 40 percent MOX core loading for the reactors involved.

[11] Transportation of plutonium would meet international standards. Transport containers for new MOX fuel will have to be licensed and manufactured, and new transportation vehicles for security of new MOX fuel will be required. A new type of shipping cask also will be needed for the transportation of spent fuel.

[12] Service life extensions also would be required for the four VVER-1000 units and the BN-600.

4.1 Excluded Items

Noted in Section 2.5, several categories of cost have been excluded from the preliminary cost assessment because either: (1) not enough, or not precise enough, information is available at this time; or (2) no intergovernmental understandings or agreements have yet taken place concerning whether and/or how to take these categories into account.

Excluded from the preliminary cost assessment—on one or both of these grounds—are costs associated with the following:

- Monitoring and inspection of the Russian disposition program to ensure compliance with intergovernmental agreements.
- Provisions for material protection, control and accounting (MPC&A) in accordance with international standards.
- Decontamination and decommissioning of the structures and facilities involved.
- The permanent burial of wastes.
- Downtime of Russian nuclear power plants that may result from the plutonium disposition effort.
- Compensation for the possible losses of Russian enterprises that fabricate uranium fuel.
- Contributions to the social structure and programs of Russian communities affected or impacted by the plutonium disposition effort.
- Possible additional costs, directly related to the plutonium disposition program, in the service life extension of Russian reactors.
- Provisions for insurance or escrow funds for various contingencies (e.g., delays or interruptions in future funding support, unanticipated delays or downtimes in Russian reactor performance).
- Activities concerned with public information about, and awareness of, the disposition program within Russia.
- The international and Russian management of the program.
- Possible licensing fees and royalties associated with the utilization or transfer of technologies, processes and systems developed and/or owned by non-Russian commercial and other entities.
- The reader should keep in mind that—when subsequently computed and when and if agreed—these costs would be in addition to the costs assessed in Section 5 of this report.

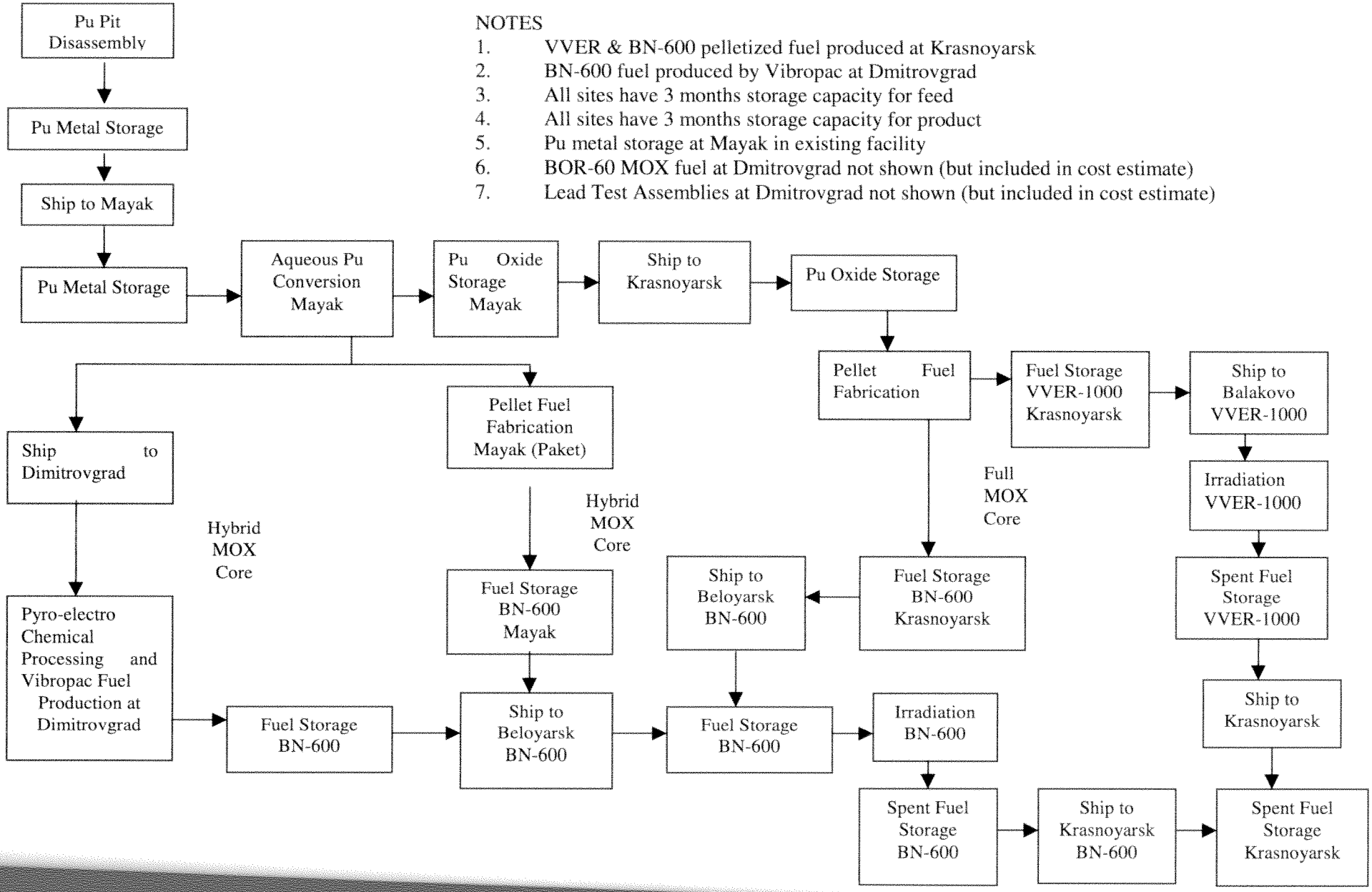
NOTES
1. VVER & BN-600 pelletized fuel produced at Krasnoyarsk
2. BN-600 fuel produced by Vibropac at Dmitrovgrad
3. All sites have 3 months storage capacity for feed
4. All sites have 3 months storage capacity for product
5. Pu metal storage at Mayak in existing facility
6. BOR-60 MOX fuel at Dmitrovgrad not shown (but included in cost estimate)
7. Lead Test Assemblies at Dmitrovgrad not shown (but included in cost estimate)
Pu Pit Disassembly
Pu Metal Storage
Ship to Mayak
Pu Metal Storage
Aqueous Pu Conversion Mayak
Pu Oxide Storage Mayak
Ship to Krasnoyarsk
Pu Oxide Storage
Pellet Fuel Fabrication
Fuel Storage VVER-1000 Krasnoyarsk
Ship to Balakovo VVER-1000
Irradiation VVER-1000
Spent Fuel Storage VVER-1000
Ship to Krasnoyarsk
Spent Fuel Storage Krasnoyarsk
Ship to Dimitrovgrad
Pellet Fuel Fabrication Mayak (Paket)
Hybrid MOX Core
Hybrid MOX Core
Full MOX Core
Pyro-electro Chemical Processing and Vibropac Fuel Production at Dimitrovgrad
Fuel Storage BN-600
Fuel Storage BN-600 Mayak
Ship to Beloyarsk BN-600
Fuel Storage BN-600 Krasnoyarsk
Ship to Beloyarsk BN-600
Fuel Storage BN-600
Irradiation BN-600
Spent Fuel Storage BN-600
Ship to Krasnoyarsk BN-600

Table 2 – Base Case Scenario

Year	Conversion at Mayak		MOX at Dimitrovgrad						MOX at Mayak		MOX at Krasnoyarsk			
	MT Pu/yr		Fuel Assemblies (FA)			MT Pu/yr			FA	MT Pu/yr	FA		MT Pu/yr	
	Demo	Industrial	BOR-60	BN-600	VVER-1000	BOR-60	BN-600	VVER-1000	BN-600	BN-600	BN-600	VVER-1000	BN-600	VVER-1000
2000			50			0.030								
2001			50			0.030								
2002			50	7		0.030	0.042							
2003	0.40		50	11	3	0.030	0.066	0.046						
2004	0.40		50	25		0.030	0.150		25	0.150				
2005	0.40		50	25		0.030	0.150		25	0.150				
2006	0.40		50	25		0.030	0.150		25	0.150				
2007		2.36	50	25		0.030	0.150		25	0.150			0.313	
2008		2.75	50	25		0.030	0.150		25	0.150	74		0.625	0.916
2009		2.75	50			0.030					147	18	1.250	1.500
2010		2.75	50			0.030					293	72	1.250	1.500
2011		2.75	50			0.030					293	72	1.250	1.500
2012		2.75	50			0.030					293	72	1.250	1.500
2013		2.75	50			0.030					293	72	1.250	1.500
2014		2.75	50			0.030					293	84	1.250	1.500
2015		2.75									293	84	1.250	1.500
2016		2.75									293	84	1.250	1.500
2017		2.75									293	120	1.250	1.500
2018		2.75									293	120	1.250	1.500
2019		2.75									293	120		1.500
2020												120		1.500
2021												120		1.500
2022												120		1.000
2023												120		
Total	1.60	35.36	750	143	3	0.450	0.858	0.046	125	0.750	3151	1398	13.44	21.416

Table 2 Continued

Year	Annual consumption of Pu. MT/yr								Spent MOX Fuel Storage		
	BOR–60	BN–600	Balakovo NPP					Total per year	Krasnoyarsk		RIAR
			B–1	B–2	B–3	B–4	Total VVER		BN–600	VVER–1000	BOR–60
2000								0.000			
2001	0.030							0.030			
2002	0.030	0.042						0.072			
2003	0.030	0.066						0.096			
2004	0.030	0.140				0.046	0.046	0.216			
2005	0.030	0.140						0.170			50
2006	0.030	0.280						0.310			50
2007	0.030	0.280						0.310			50
2008	0.030	0.453						0.483	50		50
2009	0.030	0.938				0.279	0.279	1.247	50		50
2010	0.030	1.250	0.279	0.279	0.279	0.279	1.116	2.396	50	3	50
2011	0.030	1.250	0.279	0.279	0.279	0.279	1.116	2.396	50		50
2012	0.030	1.250	0.279	0.279	0.279	0.279	1.116	2.396	74		50
2013	0.030	1.250	0.279	0.279	0.279	0.279	1.116	2.396	147		50
2014	0.030	1.250	0.279	0.279	0.279	0.465	1.302	2.582	293		50
2015	0.030	1.250	0.279	0.279	0.279	0.465	1.302	2.582	293	18	50
2016		1.250	0.279	0.279	0.279	0.465	1.302	2.552	293	72	50
2017		1.250	0.465	0.465	0.465	0.465	1.860	3.110	293	72	50
2018		1.250	0.465	0.465	0.465	0.465	1.860	3.110	293	72	50
2019		1.250	0.465	0.465	0.465	0.465	1.860	3.110	293	72	50
2020			0.465	0.465	0.465	0.465	1.860	1.860	293	84	
2021			0.465	0.465	0.465	0.465	1.860	1.860	293	84	
2022			0.465	0.465	0.465	0.465	1.860	1.860	293	84	
2023				0.420	0.465	0.465	1.815	1.815	293	120	
Total	0.45	14.84	4.743	5.163	5.208	6.091	21.670	36.960	3351	1401*	750

**Sum is presented. The last spent MOX–fuel assemblies from VVER–1000 will be discharged in 2029.*

4.2 Taxes, Custom Fees, Profits, and Accumulations

In the routine planning for facilities and programs in Russia, taxes, custom fees, profits, and accumulations are normally taken into account in the assessment and projection of costs. By the same token, where there is international funding for facilities and programs in Russia, it is common that, in the international agreements providing for such funding, some or all of these types of costs are waived or otherwise not charged against the program's external funding.

We have not excluded these costs in the preliminary cost assessment. Instead, we have sought, where possible, to separately calculate and separately identify value-added (VAT) and similar taxes, import/export duties, fees and charges, and profits and accumulations—in order that these costs might be viewed and appreciated separately from other projected costs.[13]

4.3 Licensing and Regulation

Russian licensing standards for the disposition of weapon-grade plutonium have not been fully developed at this early point in the definition of the Russian program. In order to gain some appreciation of what the costs of Russian licensing might plausibly be, we agreed to employ variations of U.S. licensing criteria as a surrogate guide.[14]

4.4 Other Items

In the normal course of Russian planning and cost estimation for industrial programs, depreciation of capital costs and amortization of other costs are factored into operating costs and routine operating expenditures. In the case at hand, with capital costs presumably funded by the international community, depreciation and amortization are appropriately excluded from assessments of the additional costs of operating the plutonium disposition program.

The exclusion has been agreed in principle, and is reflected where possible in the assessments presented in Section 5. However, greater analytical attention will be required in the coming period in order to ensure that depreciation and amortization charges have been fully and effectively removed in fact from the source data and analyses underlying the macro-level quantifications.

4.5 Limitations on Analysis

It is customary in preliminary, order-of-magnitude, assessments of overall program costs (such as this) to assign a margin-of-error factor or percentage to the reported costs, in order that the level of analytical confidence in the costs as assessed may be appropriately appreciated. We do not do so here, in part because we do not have a solid enough analytical basis at present to quantify the scope and range of possible error.

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[13] Because of the nature of the source data and analyses underlying the preliminary macro-level assessment, it is not possible at this time to isolate and separately identify all of these various taxes and fees.

[14] We have assumed that a Safety Analysis Report (SAR) would need to be generated by the responsible Russian design entity and approved by RF Gosatomnadzor (GAN). Costs for the U.S. MOX facilities at the Savannah River Site have been used as a basis for the assessment of the probable Russian costs involved, with labor costs converted to current (year 2000) Russian wage rates.

It certainly is possible that, when details of the intended Russian program are more closely examined in the time ahead—e.g., specific labor rates, job-hours, material costs, and equipment costs—projections of the macro-level costs of the program will need to be adjusted, either upward or downward. It may also be the case that the overall costs of the program might not change significantly, but that the costs of specific program elements might.

5. PROJECTED COSTS

The results of the preliminary assessment are summarized in the text and the tables that follow. In the aggregate, the "starting" costs of the Russian program should be in the range of $1.7 billion to $1.9 billion, depending on whether Russian value-added-taxes are taken into account in the cost projection (Table 3). A little more than 40 percent of the expenditures would support research and development, the design and construction of facilities, and the procurement of equipment. The rest are operating costs over the life of the program.[15]

Most of the expected costs are associated with the irradiation of weapon-grade plutonium as MOX fuel in Russian reactors.[16] Approximately $200 million would go for the immobilization of the plutonium that is not consumed in reactors.

Table 3 – Summary of "Starting" Projected Costs
(Current US $1000s)

Cost Element	Research, Development and Pre-Capital Costs	Design and Construction of Facilities and Equipment Costs	Operating Costs	Total
Plutonium Conversion	12,600	97,390	175,300	285,290
MOX Fuel Fabrication	101,725	207,700	378,800	688,225
Reactor Modifications and Operations	22,600	193,900	104,400	320,900
Transportation	3,900	28,100	84,450	116,450
Spent Fuel Storage for BN-600*(1)*	1,900	18,300	87,500	107,700
Immobilization*(2)*	29,000	64,900	106,100	200,000
SUBTOTAL	171,725	610,290	936,550	1,718,565
Value-Added Tax			170,540	170,540
TOTAL	171,725	610,290	1,107,540	1,889,105

(1) For 40 years of operation.
(2) Includes facilities at Mayak and Krasnoyarsk

[15] With a limited exception, licensing costs are included in the amounts presented in Table 3. The costs for Rosenergoatom activities associated with licensing existing Russian reactors for utilization of MOX fuel have not yet been estimated, and are not included in the current cost assessment. Also, the data in Table 3 include allowances for new fuel storage—"just-in-time" delivery of new fuel was ruled out as part of the cost assessment---on the assumption that MOX fuel will require additional shielding and security.

[16] Costs associated with the mixing, handling and burning of blend stock are included in the figures presented in Table 3.

5.1 Program Elements

Expected program costs may be more clearly seen when disaggregated according to principal program elements. The conversion of weapon-grade plutonium to an oxide suitable for the fabrication of MOX fuel would begin with a demonstration plant, with an expected plutonium throughput of approximately 1.6 MTs, followed by an industrial plant for the bulk of the program with an overall throughput of approximately 34.8 MTs. The projected costs of each—and both—are presented in Table 4.[17]

Table 4 - Plutonium Conversion
(Current US $1000s)

Cost Element	Research, Development and Pre-Capital Costs	Design and Construction of Facilities and Equipment Costs	Operating Costs	Total
Demonstration Plant				
R&D and Process Selection	8,200			8,200
Licensing	300	200	700	1,200
Construction		13,000		13,000
PuO Production *(1)*			10,900	10,900
Industrial Plant				
R&D and Process Selection	3,000			3,000
Licensing	1,100	700	3,600	5,400
Construction		83,490 *(2)*		83,490
PuO Production *(3)*			160,100	160,100
TOTAL	12,600	97,390	175,300	285,290

(1) Production of blended plutonium oxide is estimated at present at $6800/kg pu.
(2) Includes blending of plutonium feed stocks at an added cost of ~10% due to higher radiation.
(3) Production of blended plutonium oxide is estimated at present at $4600/kg pu.

The fabrication of fuel for the BN-600 reactor would be done as follows: for a hybrid core, at NIIAR (vibropac fuel production) and at the PAKET facility of the MAYAK Production Association (pelletized fuel); for full core loading, at the Krasnoyarsk Integrated Mining-and-Chemical Industrial Compound (pelletized fuel). The fabrication of lead test assemblies for the VVER-1000 reactors would be carried out as follows: plutonium dioxide at the conversion demonstration facility of the MAYAK PA; pellets and fuel elements at NIIAR; and fuel assemblies at the Novosibirsk Chemical Concentrate Combine.

[17] Notably, industrial-scale conversion would take place at one Russian site—Mayak—employing an aqueous process to produce plutonium oxide for MOX fuel for the BN-600 and the VVER-1000 reactors.

Table 5 - MOX Fuel Fabrication
(Current US $1000s)

Cost Element	Research, Development and Pre-Capital Costs	Design and Construction of Facilities and Equipment Costs	Operating Costs	Total
Fabrication of Pellet Fuel for VVER-1000 and BN-600 at Krasnoyarsk				
Fuel Research and Development	90,425			90,425
Licensing	1,600	1,100	1,900	4,600
Construction of Facility	1,000	164,000		165,000
Production of MOX Fuel			318,000	318,000
Waste Processing and Storage		11,500	10,000	21,500
Fabrication of Pellet Fuel at PO Mayak				
Fuel Research and Development	2,900			2,900
Licensing				
Construction of Facility		25,300		25,300
Production of MOX Fuel			29,000	29,000
Waste Processing and Storage				
Fabrication of Vibropac Fuel at Dimitrovgrad				
Fuel Research and Development	4,500			4,500
Licensing	800	500	1,000	2,300
Construction of Facility	500	5,300		5,800
Production of MOX Fuel			18,900	18,900
Waste Processing and Storage				
TOTAL	101,725	207,700	378,800	688,225

In all, six Russian reactors would be employed to irradiate MOX fuel: BOR-60 (disposition of 0.45 MTs of weapon-grade plutonium); BN-600 (15.048 MTs to be dispositioned), and four VVER-1000 units at Balakovo (21.446 MTs).

Transportation of materials and fuel will be required between the following locations: lead assembly fuel fabrication facilities to reactor units; conversion facility to fuel fabrication facilities; fuel fabrication facilities to reactor units; and onsite storage at the reactor units to Krasnoyarsk.

Table 6 - Reactor Modifications and Operations
(Current US $1000s)

Cost Element	Research, Development and Pre-Capital Costs	Design and Construction of Facilities and Equipment Costs	Operating Costs	Total
VVER-1000				
Fuel Qualification	18,100			18,100
Licensing *(1)*	1,000	500	3,000	4,500
Reactor Modifications		52,000		52,000
New Fuel Storage	2,000	25,000		27,000
Reactor Operations			63,000	63,000
BN-600				
Fuel Qualification	500			500
Licensing *(1)*	800	300	2,600	3,700
Reactor Modifications		73,600		73,600
New Fuel Storage	100	42,400		42,500
Reactor Operations			26,800	26,800
BOR-60				
Reactor Modifications and Operations	100	100	9,000	9,200
TOTAL	22,600	193,900	104,400	320,900

(1) Costs for Rosenergoatom activities associated with licensing have not been included.

Table 7 - Transportation
(Current US $1000s)

Cost Element	Research, Development and Pre-Capital Costs	Design and Construction of Facilities and Equipment Costs	Operating Costs	Total
PuO Transport Equipment	50	4,550	12,590	17,190
New Fuel Transport Equipment	400	17,050	16,930	34,380
Spent Fuel Transport Equipment	3,450	6,500	47,430	57,380
Licensing for Transport Operations			7,500	7,500
TOTAL *(1)*	3,900	28,100	84,450	116,450

(1) Does not include costs of transportation of plutonium and other materials to the conversion facility.

5.2 Costs Across Time

Given the ambitious design and construction schedule for the Russian program, nearly one-third of the costs would be incurred between 2001 and 2006 (Table 8). Annual operating costs from 2007 to 2019 would average approximately $90 million.

Table 8- Costs in Time Profile
(Current US $Millions)

Year	Annual	Cumulative	Year	Annual	Cumulative
2001	48	48	2014	99	1,318
2002	78	126	2015	99	1,417
2003	107	232	2016	98	1,515
2004	118	351	2017	78	1,594
2005	118	469	2018	78	1,672
2006	114	584	2019	78	1,750
2007	81	665	2020	28	1,778
2008	88	753	2021	28	1,806
2009	72	825	2022	28	1,834
2010	99	924	2023	25	1,860
2011	99	1,022	2024	20	1,880
2012	99	1,121	2025	6	1,886
2013	99	1,220	2026	3	1,889

6. NEXT STEPS

In the time ahead, the Joint U.S.-Russian Working Group on Cost Analysis and Economics in Plutonium Disposition will further develop, extend and deepen the analysis of the costs of the Russian program, and also examine a number of the cost categories that have been excluded from this report.