Joint U.S./Russian Study on the Development of a Preliminary Cost Estimate of the SAFSTOR Decommissioning Alternative for the Leningrad Nuclear Power Plant Unit #1

September 1998

Prepared by
Joint U.S./Russian Study Team
Pacific Northwest National Laboratory
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for the
United States Department of Energy and the
Russian Federation Ministry of Atomic Energy

Printed in the United States of America

**Available to DOE and DOE contractors from the
Office of Scientific and Technical Information,
P.O. Box 62, Oak Ridge, TN 37831**

Prices available from (615) 576-8401.

**Available to the public from the
National Technical Information Service
U.S. Department of Commerce
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Nuclear Power Plant Unit #1**

September 1998

Prepared for
U.S. Department of Energy
Office of Nuclear Energy, Science and Technology

Pacific Northwest National Laboratory
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Executive Summary

The objectives of the two joint Russian/U.S. Leningrad Nuclear Power Plant (NPP) Unit #1 studies were the development of a safe, technically feasible, economically acceptable decommissioning strategy, and the preliminary cost evaluation of the developed strategy. The first study, resulting in the decommissioning strategy, was performed in 1996 and 1997. The preliminary cost estimation study, described in this report, was performed in 1997 and 1998.

The decommissioning strategy study included the analyses of three basic RBMK decommissioning alternatives, refined for the Leningrad NPP Unit #1. The analyses included analysis of the requirements for the planning and preparation as well as the decommissioning phases. The types of data and technical information collected and evaluated include the following:

- The legislative and regulatory requirements for decommissioning in both Russia and the U.S., including an evaluation of the level of preparedness of the decommissioning related legislature and regulations.
- The technical, technological and timing requirements for the removal of the spent nuclear fuel.
- The capability to, and requirements for, reprocessing, storing and/or burying NPP operational and decommissioning radioactive wastes.
- The technical requirements for NPP decommissioning experience from past maintenance, reconstruction and decommissioning, and the state-of-the-art of dismantling, decontamination and dismantling technologies.
- The safety requirements, including ecological safety.
- The technical preparedness of the nuclear power sector and the socio-economic condition of Russia.

The resulting recommended decommissioning alternative for the Leningrad NPP Unit #1 was a SAFSTOR alternative for the reactor and associated structures and the reuse of the remainder of the Unit #1 facilities for radioactive waste storage and reprocessing. Five phases were defined for the SAFSTOR strategy:

- Planning for decommissioning
- Preparation for decommissioning
- Preparation for SAFSTOR
- SAFSTOR
- Final dismantling of the reactor and associated structures.

Preliminary cost estimates of the SAFSTOR alternative were developed in the second joint Leningrad NPP study, as described in this report. For comparison, costs estimates were developed for decommissioning the RBMK unit for both the U.S. and Russia conditions. The U.S. and Russian "conditions" are based on the methodologies used in each country and the current socio-economic conditions (e.g., it was assumed Russian wages are one tenth those in the U.S.).

The cost study was performed as follows:

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- The NRC's BWR Cost Estimating Computer Program (CECP) was selected for estimating the cost of decommissioning an RBMK because of the many similar systems between the BWR and the RBMK.
 - The CECP inputs were modified to accept metric unit data and RBMK system information.
 - Factors were selected from joint parallel nuclear power alternatives study (JPNAS) for converting U.S. decommissioning costs to the Russian conditions.
 - A "spreadsheet" methodology was developed for calculating costs related to the RBMK reactor and its associated structures.
 - Data were collected and entered into the CECP and the spreadsheet.

The estimated cost for the SAFSTOR alternative for the Leningrad NPP Unit #1 is approximately \$825M for the U.S. conditions and \$175M plus the cost of waste disposal for the Russian conditions. That is, the cost to decommission the Leningrad NPP Unit #1 under U.S. conditions is approximately three times that of decommissioning the same reactor unit under Russian conditions. The primary causes of the difference in cost are the inclusion of final disposal costs under the U.S. conditions, and the difference in wages and productivity. It should be noted that the Russian condition estimate does not include waste processing or storage. Also, the Russian condition cost estimate does not contain the final disposal costs. The storage and processing costs were not included because these costs are not usually considered decommissioning costs and are not estimated by the CECP. The final disposal costs were also not included because Russia currently has no centralized (regional or national) disposal sites for NPP radioactive waste.

The SAFSTOR alternative for the Leningrad NPP Unit #1 provides an opportunity for minimal initial decommissioning costs. For relatively small up-front costs, the Leningrad NPP Unit #1 could be put into a long-term safe storage with approximately 75% of the total decommissioning costs to be realized in the out years. Given the economic conditions within Russia, it is desirable to decrease the up-front costs.

The recommendations resulting from the decommissioning strategy study are included in the final document for that study. The recommendations from the cost estimation study are:

- The computer model used for the cost estimation study should be modified to capture RBMK reactor components and structures; and to estimate decommissioning radiation dose rates. The result would be an RBMK decommissioning cost and dose rate model.
- An insurance system should be developed for NPP decommissioning in Russia.
- The recently defined national radioactive waste disposal concept should be implemented to satisfy future NPP decommissioning requirements.

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1.0 Introduction

The U.S. Department of Energy (DOE), through the International Nuclear Safety Program, has been involved in the decommissioning planning for Soviet Union designed, first-generation RBMK-1000 reactors. As part of the Program, the DOE previously funded a joint U.S./Russian study to analyze decommissioning strategies for the Leningrad Nuclear Power Plant (NPP) Unit #1, a representative RBMK-1000 reactor. The previous study analyzed three alternative decommissioning strategies: unit decommissioning with immediate dismantling of reactor structures, unit decommissioning with deferred dismantling of reactor structures, and unit entombment. Unit decommissioning with deferred dismantling of reactor structures was recommended based on the results of the analyses that considered technical and financial feasibility and the current conditions within Russia.

The current DOE-funded, joint U.S./Russian project is to provide a first-order cost estimate for the Leningrad NPP Unit #1 decommissioning strategy recommended in the earlier study. The Pacific Northwest National Laboratory was chosen to lead the Leningrad NPP Unit #1 Decommissioning Cost Study. Kurchatov Institute coordinated the study for the Russian side. Among the Russian participants were experts from many organizations under the Russian Nuclear Power Sector: Leningrad NPP; the Research and Development Institute of Power Engineering (NIKIET, Moscow), the designer of the RBMK reactor; the All-Russian Design and Research Institute of Power Technology (VNIPIET, St. Petersburg), the designer of the Leningrad NPP; the Research and Design Institute of Installation Technology (NIKIMT, Moscow); Atom Ergo Proyekt (AEP, Moscow), the designer of nuclear power plants with VVER and RBMK reactors; and the Volgodonsk branch of All-Russian Research Institute of Nuclear Power Engineering (VNIIAM, Volgodonsk). The results of the Leningrad NPP Unit #1 Decommissioning Cost Study, the method used, and the assumptions made are described in this report.

1.1 Background

The initial Leningrad decommissioning study was initiated by the U.S. DOE based on a recommendation from the earlier Joint Parallel Nuclear Power Alternatives Study (JPNAS) that there be joint development of a decommissioning program for a specific Russian first-generation reactor. A team of Pacific Northwest National Laboratory and Brookhaven National Laboratory personnel were selected to coordinate with Russians to organize the study, select the representative first-generation unit, and conduct the research. Minatom supported the study and recommended the Leningrad NPP Unit #1 as the representative RBMK-1000 for the study. Experts from the Kurchatov Institute coordinated the study on the Russian side, which included participants from many organizations under the Russian Nuclear Power Sector.

The initial Leningrad Decommissioning Strategy Study included a survey and analysis of Russian and U.S. laws and regulations affecting decommissioning, a survey and analysis of Russian and U.S. experience relevant to decommissioning, and the analysis of three decommissioning alternatives to find a safe, technically feasible, cost-effective decommissioning strategy for Leningrad NPP Unit #1.

Three decommissioning alternatives for Leningrad NPP Unit #1 were evaluated as part of the initial Leningrad decommissioning study:

- Immediate dismantling of the reactor core and the decommissioning of the unit's associated facilities.

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- Immediate dismantling of non-core equipment, isolation of the core, storage of the core for 70 years, and the delayed final decommissioning of the core at the end of the 70-year storage period.
 - Burial of the unit in place.

The delayed decommissioning alternative was recommended. The immediate dismantling alternative was not chosen because the current Russian economic condition makes the alternative infeasible. The burial in place alternative was not recommended because NPP sites in Russia are set aside for nuclear use and the unit site would be reclaimed at some future time so that another reactor could be built on the site (basically matching the delayed decommissioning alternative).

The study also looked at the final end state for the Leningrad NPP Unit #1 and recommended the unit rooms be used for waste processing and storage for an indefinite period of time. Such an end state reduces total cost (no construction of new facilities for waste management and no dismantling of the current unit facilities) and satisfies the requirement for handling and storing waste on the Leningrad NPP site.

The next phase of the decommissioning planning for the Leningrad NPP Unit #1 was to obtain a rough order cost estimate to perform the work associated with the recommended decommissioning alternative. The current study provides that rough order cost estimate. The resulting cost estimate is an improvement of the earlier JPNAS generic cost estimate for RBMK-1000s in that it is the cost associated with the specific actions recommended to be taken at the Leningrad NPP Unit #1.

1.2 Methodology and General Assumptions

The joint study team reviewed several cost models to find one that was at the correct level of detail for the current level of decommissioning planning for the Leningrad NPP Unit #1 and was accepted by the industry. The NRC model, the BWR (boiling water reactor) Cost Estimating Computer Program (CECP), was selected as the model to be used for this study.

The model was used to cost planning and preparation, decommissioning of RBMK systems and equipment similar to BWR systems and equipment, safe storage, and indirect costs. Costs were computed off-line in a spreadsheet for construction, and decommissioning of the reactor core and its associated metal structures. Some D&D activities, described later in this report, were not costed because they were not included in the original BWR CECP and were beyond the scope of this project. However, the costs of the uncoded activities would be a small percentage of the total costs and within the error of the cost estimate. Other costs that are not related to decontamination and decommissioning but would be incurred in Russia due to the decommissioning, were also not costed. These include such costs as the socio-economic costs and the operations and maintenance of the waste storage facility. Final disposal of the decommissioning waste was also not costed, because there is no central waste disposal site in Russia. Waste is stored on site and will continue to be stored until a national plan is developed.

1.3 Report Structure

In this study, the three decommissioning alternatives investigated in the previous study are revisited and analyzed. The analysis and results are described in Section 2. The cost methodology and assumptions are described in Section 3, the resulting cost estimate and conclusions are detailed in Section 4, and recommendations are provided in Section 5.

2.0 Analysis of Decommissioning Alternatives

The goal of the previous U.S./Russian joint study on Leningrad NPP decommissioning strategies was to define a safe, technically and economically feasible decommissioning strategy for the first-generation RBMK-1000 Unit #1 at the Leningrad NPP. The decommissioning strategy for the Leningrad Unit #1 was developed and recommended. This strategy is based on the SAFSTOR decommissioning alternative characterized by deferred dismantling of reactor structures after their long-term safe storage.

This decommissioning alternative was chosen on the basis of the preliminary analysis of socio-economic and other factors influencing the choice and implementation of the alternative.

A goal of this current project was a more comprehensive analysis and comparison of decommissioning alternatives for an RBMK unit including the DECON alternative, characterized by immediate dismantling of reactor structures, and ENTOMB, characterized by entombment of the reactor structures. The results of this comprehensive analysis provide higher credibility and qualification for selecting the SAFSTOR decommissioning alternative with deferred reactor structure dismantling, which was recommended previously for Leningrad Unit #1.

A method based on qualitative and system analysis and comparison was chosen for the comparison of the decommissioning alternatives for the Leningrad NPP Unit #1. The results of the analysis and comparison of the stages and main decommissioning procedures associated with SAFSTOR are presented below.

2.1 Decommissioning Alternatives

The decommissioning of an NPP unit is the final stage of the NPP life cycle and must be performed under radioactive conditions. It is a consequence of the radioactivity that developed in the nuclear facility's equipment and structures while it was in operation. Radiation imposes substantial limitations not only on the choice of technologies and on aspects of technical policy for decommissioning, but also on the choice of the decommissioning alternative.

When an NPP unit decommissioning is planned, radiation conditions make it necessary to find the decommissioning alternative that is advantageous in terms of complex criteria combining economic acceptability, minimum personnel dose rates, and amounts of radioactive wastes formed.

Technical literature now recognizes the following basic decommissioning alternatives depending on the time required and work methods, the techniques used, and expected final conditions of the nuclear facility:

- unit entombment
- unit decommissioning with immediate dismantling of reactor structures
- unit decommissioning with deferred dismantling of reactor structures.

Specialized Western literature uses the terms ENTOMB, DECON, and SAFSTOR to denote these decommissioning alternatives.

In practice, various combinations of these decommissioning options may be used. This presumes different combinations of methods, work schedules, and the final conditions of the units being decommissioned and of their sites. The final end state may be governed both by the

condition of the NPP unit shut down for decommissioning, by plans for subsequent use of the NPP site, or by other factors.

Preparation for unit decommissioning phase (3 to 5 years) is necessary for each of the decommissioning alternatives. At this phase, independent of the decommissioning option chosen, the following activities should be performed:

- standard unit shutdown and cooldown
- nuclear fuel holdup in the reactor core or cooling ponds
- removal of nuclear fuel from unit
- drainage of multiple forced circulation circuit and other process circuits and their decontamination
- comprehensive inspection of unit and other work to the extent necessary to develop a unit decommissioning project
- development of required organizational, technical, and design documentation
- handling of operational radioactive wastes
- operation and servicing of unit systems and equipment remaining in operation
- preparations for the next decommissioning phase.

The following is a brief description of the decommissioning alternatives with an analysis of their advantages for decommissioning RBMK-1000 units.

2.1.1 Immediate Dismantling Alternative

Unit decommissioning with immediate dismantling of reactor structures (DECON) is a decommissioning alternative in which reactor structures, systems, equipment, and other unit structures are dismantled, and the radioactive wastes are removed. These decommissioning activities are performed almost immediately after final shutdown and the removal of spent nuclear fuel from the unit. The site is restored after the unit is dismantled. This option has the following basic phases: preparation for dismantling of reactor structures; dismantling and demolition of the reactor and other unit structures.

2.1.1.1 Preparation for Dismantling of Reactor Structures

This phase includes decontamination of the unit's equipment, systems, and other structures. In this phase clean, slightly contaminated and low-radioactivity equipment and systems are dismantled and removed, after which the clean equipment is recycled, and the radioactive waste is processed, packaged, and stored in an organized fashion at the unit site.

2.1.1.2 Dismantling and Demolition of the Reactor and Other Unit Structures

This phase includes complete dismantling and removal of highly radioactive reactor structures to sites specially prepared for their long-term storage or burial; demolition of other unit structures not used; and, if necessary, specific procedures to restore the unit site.

The lengths of these phases are defined in the unit decommissioning project. On the basis of current estimates, one may assume that with this RBMK-1000 Unit decommissioning alternative it will take three to five years to prepare for and five to seven years to complete dismantling and demolition. Table 2.1 presents a list of basic decommissioning activities for the DECON alternative.

Table 2.1. List of Decommissioning Activities for Unit Decommissioning with Immediate Dismantling of the Reactor Structures

A. Preparation for dismantling of reactor structures

1. Decontamination of the systems and equipment not required in decommissioning
2. Inspection of the unit's equipment and systems required in decommissioning
3. Decontamination of the unit's rooms and equipment to ensure radiological safety
4. Dismantling of systems and equipment in a control room
5. Handling of operational radioactive waste
6. Servicing of the systems and equipment remaining in operation
7. Preparation of the personnel for works at the next stage.

B. Dismantling and demolition of the reactor and other unit structures

1. Dismantling of the reactor and other structures
2. Handling of radioactive waste formed in dismantling of the structures
3. Radiation monitoring, sorting and storage of wastes reusable with or without restrictions
4. Decontamination or cleaning of reactor concrete cavity
5. Servicing of the systems and equipment remaining in operation
6. Dismantling and removal of other unit structures not used
7. Decontamination and dismantling of technological equipment used for dismantling
8. Bringing the remaining unit structures and site up to the radiation and sanitary requirements
9. Final survey of the unit and its site.

The main advantages of this decommissioning alternative are no need for long-term surveillance, technical inspection, maintenance, or radiological inspections; the opportunity to recruit operational personnel to do the decommissioning; and rather rapid clearing of the site for construction of replacement power capacities.

The main disadvantages are rather high personnel dose rates; large amounts of high-level radioactive wastes; high one-time initial costs; and the requirement of appropriate storage facilities for radioactive wastes created during unit decommissioning.

2.1.2 Entombment Alternative

Entombment is a decommissioning alternative in which the highly radioactive equipment, systems, and structures of the unit are localized in place. Under this decommissioning alternative, the localized equipment, systems, and reactor structures are entombed for a long time, and the entombment zone and environment near this zone are monitored.

The entombment option has the following basic phases: preparation for the entombment, including the localization of high-radioactivity structures and the reactor, and entombment of localized high-radioactivity structures and the reactor.

2.1.2.1 Preparation for the Entombment

This phase includes dismantling and removing clean and low-radioactive equipment and systems, partial dismantling, and, if necessary, storing in reactor rooms high-radiation elements and equipment for subsequent localization and entombment. Before the entombment, the zones of

highly radioactive equipment, systems, and reactor structures are localized, and, if necessary, the load-bearing metal structures of the reactor reinforced.

The entombment zones are localized by erecting additional protective barriers around the highly radioactive systems, equipment, and the reactor to prevent unauthorized access and the spread of radioactivity into the environment, and to protect against natural disasters and other external forces.

2.1.2.2 Entombment of the Localized Structures

This phase includes the entombment of the localized highly radioactive systems, equipment, and the reactor by filling and/or spreading buffer materials (sand, clay, earth, etc). The systems, equipment, and structures outside of the localization and entombment zones are dismantled and removed as their radioactivity decreases, and the entombment zones are monitored. This monitoring is minimal and mainly of the environment near the entombment zones.

The required time for completing each of these phases is defined in the NPP unit decommissioning project. However, on the basis of existing estimates, one might roughly assume that RBMK unit entombment may take six to ten years for the preparation phase and 100 years or more for the entombment phase (depends on decay time of long-lived radionuclides within the entombed reactor and other structures). Table 2.2 presents a list of basic decommissioning activities for the entombment alternative.

Table 2.2. List of Decommissioning Activities for Entombment Alternative

A. Entombment preparation phase <ol style="list-style-type: none">1. Decontamination of the systems and equipment not required in decommissioning2. Required reinforcement of the reactor and other localized structures3. Localization of the high-radioactive unit elements and the reactor in place4. Total localization of the unit construction5. Erection of additional protective barriers around localized highly radioactive structures6. Handling of operational radioactive waste7. Servicing of the systems and equipment remaining in operation.
B. Entombment phase (100 years or more) <ol style="list-style-type: none">1. Entombment of the localized highly radioactive unit elements and the reactor2. Decontamination of the unit's rooms and equipment out of the entombment zones to ensure safety3. Dismantling of the systems and equipment out of the entombment zones4. Handling of the radioactive waste formed in dismantling of the systems and equipment out of the entombment zones5. Radiation monitoring and handling of wastes reusable with or without restrictions6. Bringing the remaining unit structures and site up to the radiation and sanitary requirements7. Servicing of the systems and equipment remaining in operation8. External monitoring of the entombment zones and the environment.

2.1.3 Safe Storage Decommissioning Alternative

Unit decommissioning with deferred dismantling of reactor structures involves phased dismantling and removal of the high-radioactivity reactor structures, systems, equipment, and other unit structures, and use of certain procedures to restore the unit site. The feature of this decommissioning alternative is that the highly radioactive structures are dismantled and removed after long-term safe storage to decrease their radioactivity as a result of natural radionuclide decay and to enhance dismantling safety. This option has the following main phases: preparation for safe storage; long-term safe storage; and final dismantling of the reactor and other unit structures.

2.1.3.1 Preparation for Safe Storage

This phase includes localization of highly radioactive equipment, systems, and the reactor in place; decontamination (usually standard) and conservation of unit equipment, systems, and civil structures used in the following phases.

In this phase the operability of the unit's radiological inspection system should be ensured and the system should be optimized for the specific work to be done and the conditions of the reactor and its structures. Unit equipment and systems supporting reactor structure long-term safe storage and subsequent decommissioning should remain operable.

Clean, slightly contaminated, and low-radioactivity equipment and systems may be dismantled and removed, after which the equipment may be recycled and the radioactive waste processed, packaged, and stored on the unit site.

2.1.3.2 Long-Term Safe Storage

This phase includes surveillance and maintenance of the localized and conserved unit equipment, systems, and other unit structures. The period of this phase depends on many factors such as the service life of the unit structures housing the localized reactor equipment and systems, the decline in the radioactivity of the structures and equipment as a result of natural radionuclide decay, the dismantling equipment required, and others.

2.1.3.3 Dismantling and Demolition of the Reactor and Other Unit Structures

This phase includes dismantling of the localized highly radioactive equipment, systems, and reactor structures; demolition of other unit structures not used; processing, packaging, and storage of resulting radioactive waste on site; and specific procedures to restore the unit site.

The times required for completing each of these phases are defined in the unit decommissioning project. On the basis of current estimates it may take three to five years to prepare for safe storage, 30 to 70 years for long-term safe storage, and five to seven years for demolition of the reactor and other unit structures. Table 2.3 presents a list of basic decommissioning activities for the SAFSTOR unit decommissioning alternative.

2.2 Qualitative Analysis of the Decommissioning Alternatives

The choice of a unit decommissioning alternative and unit end state depends on the technical approaches available for decommissioning on the current Russian socioeconomic conditions and on other factors. Design and technical features of RBMK-1000 NPP units also influence the

Table 2.3. List of Decommissioning Activities for the Safe Storage Alternative

<p>A. Preparation for safe storage</p> <ol style="list-style-type: none">1. Decontamination of systems and equipment not required in decommissioning2. Inspection of the unit's equipment and systems required in decommissioning3. Isolation of the highly radioactive unit elements and the reactor in place4. Bringing the unit's rooms up to the radiation and sanitary requirements to allow for servicing the systems and equipment located in these rooms5. Handling of operational radioactive waste7. Servicing of the unit systems and equipment remaining in operation8. Preparation for the next decommissioning phase, including the training of unit personnel
<p>B. Long-term safe storage</p> <ol style="list-style-type: none">1. Preparation of places for storage of radioactive waste and other wastes2. Dismantling of equipment out of the localized zones3. Conditioning, transportation, and storage of radioactive wastes4. Servicing of the unit systems and equipment remaining in operation5. Preparation for the next decommissioning phase
<p>C. Dismantling and demolition of the reactor and other unit structures</p> <ol style="list-style-type: none">1. Disconservation and inspection of the equipment and systems to be used2. Dismantling of localized reactor and other highly radioactive structures3. Handling of radioactive waste formed in dismantling4. Radiation monitoring, sorting and storage of wastes reusable with or without restrictions5. Decontamination or cleaning of reactor concrete cavity (if necessary)6. Servicing of the unit systems and equipment remaining in operation7. Dismantling and removal of unit structures not used8. Conditioning, transportation, and storage of radioactive wastes9. Decontamination and dismantling of the equipment used in dismantling10. Bringing the remaining unit structures up to the radiation and sanitary requirements11. Final survey of the unit and its site

choice and implementation of a decommissioning alternative for an NPP unit with this type of reactor. The influence of these factors on the choice and implementation of various decommissioning alternatives for an RBMK-1000 NPP unit is estimated in the following sections.

2.2.1 Immediate Dismantlement

According to expert estimates, preparation to dismantle the reactor and other highly radioactive structures of a unit with an RBMK-1000 reactor may take eight to ten years after final reactor shutdown.

Special remote process equipment is required to dismantle the highly radioactive reactor structures and the graphite stack of an RBMK-1000. This equipment should include multifunctional remote-controlled systems. Currently, Russia does not have this specialized equipment, but conceptual experimental design studies are being done.

In addition, appropriate disposal or storage facilities are needed for various categories of large volumes of radioactive waste that will result from dismantlement. Russia does not have centralized radioactive waste disposal or storage facilities and does not plan to build them in the near future. Moreover, the concept for environmentally safe handling of irradiated graphite from an RBMK-1000 has not been developed. The graphite is a potential hazard because tritium and long-lived, genetically significant C-14 radionuclides are accumulated in it. No complete dismantling of reactor structures has been done in Russia. Regulatory and methodological bases for planning and performing such kind of work in high-radioactivity conditions have not been developed in Russia either.

One may therefore conclude that preparations for decommissioning an RBMK-1000 unit by immediate dismantling of the reactor and other unit structures are inadequate and that it cannot be done as a near-term option in Russia.

2.2.2 Entombment

Note that the provisions of the NPP unit decommissioning concept used in Russia call for clearing existing nuclear power plant sites and using them to build new (replacement) NPP units. According to this concept, the decommissioning alternative chosen must provide for possible subsequent elimination of entombment zones and for specific procedures to restore the NPP unit site.

From this point of view, the main goal of the entombment alternative should be to lower the radioactivity of the reactor structures through natural decay of radioactive elements to a level permitting the dismantling of the structures and the handling of the resulting radioactive wastes without specialized technologies or restrictions on personnel doing the work. Therefore, highly radioactive reactor structures would be localized by engineering structures (protective barriers) to isolate them from the environment and ensure safe entombment for the required period. In this case, the service life and long-term reliability of the engineering structures would govern the choice of the length of the entombment phase. Thus, the entombment decommissioning alternative may be suitable for nuclear facilities if the radioactivity can be lowered to a level permitting personnel to work without restriction within the service life of the engineering structures used to localize the highly radioactive reactor structures.

According to estimates of a previous study, when an RBMK-1000 reactor has been operated for its design service life (30 years), a large amount of long-lived radionuclides (such as Ni-59, Ni-63, Zr-93, Nb-94, C-14, and others), most of which have half-lives in excess of 1,000 years, are formed in the reactor's metal structures and graphite stack as a result of activation by neutrons. To bring reactor structures to a radiologically safe condition, the reactor should be entombed for thousands of years, which is far longer than the expected service life of any engineering structures (primarily concrete).

On the basis of experience, one might assume that the performance characteristics of reinforced concrete structures for RBMK-1000 units will be maintained for a maximum of 100–150 years. This is clearly insufficient for the required decline in the level of reactor structure radioactivity if the entombment decommissioning alternative is used.

One may therefore conclude that the entombment option is inadequate for an RBMK unit because no protective barriers can be erected to assure no release of long-lived radionuclides in the environment for the time required for their decay. However, this decommissioning

alternative should not be completely excluded from consideration for decommissioning an RBMK unit if the following conditions exist:

- performance characteristics of the protective barriers are guaranteed for the entombment period
- the protective barriers are dismantled and the localized and other remaining structures are dismantled and removed after completing the entombment phase.

In this case, the entombment decommissioning alternative is similar in many ways to the long-term safe storage decommissioning alternative. The entombment alternative differs from the long-term safe storage alternative by the following:

- more work involved in localizing the reactor and other unit structures during the entombment preparation phase
- longer period entombment compared with long-term safe storage
- less inspection of the entombed reactor and other highly radioactive structures.

No experience exists in the world on large-scale localization of the reactor and other highly radioactive structures for periods considerably exceeding NPP operational lifetime. Therefore, environmental safety cannot be provided for the required time of entombment, because such requirements were not provided in design of these units. The entombment option, therefore, cannot be considered for an RBMK unit prepared to the necessary extent.

2.2.3 Safe Storage

Analysis of the change in the radioactivity of RBMK-1000 reactor structures as a function of safe storage time after final reactor shutdown, done in the previous joint study, shows that from the standpoint of unit radiological parameters (total reactor radioactivity and gamma dose rate), a unit should be held for 50 to 100 years prior to the start of reactor dismantling. The calculations show that 50 years is the point after which reactor structures begin to exhibit a slight reduction in their radioactivity. One-hundred years is the time required for the main dose-forming radionuclide, Co-60, to decay to an acceptable level. In this case, the gamma dose rate near the reactor structures during dismantling would be 1–5 mrem/hr—about 10^{-6} times the initial radioactivity of the cobalt. Obviously, this exterior gamma radiation dose rate near reactor structures will permit them to be dismantled without specialized equipment. After these structures are dismantled, they may even be classified as moderately radioactive waste in terms of specific β -radioactivity. The decommissioning alternative with deferred reactor dismantling, therefore, is appropriate for an RBMK unit.

Analysis also showed the following additional advantages of selecting safe storage as a near-term option. First, there is time for the development of regulations, including the development of national standards for reusable materials, for required research and development, and for construction of the required disposal or storage facilities for radioactive waste. Second, the amount of radioactive waste formed and the dose rates to personnel decrease considerably as a result of partial decay of radionuclides. Third, the financial problem can be simplified because no large initial financing is required, and the continuous accumulation and spending of funding are also possible. Thus, the qualitative analysis and comparison of the decommissioning alternatives resulted in conclusion that the decommissioning alternative with deferred reactor dismantling

(SAFSTOR) is the most preferable for decommissioning an RBMK unit under the socio-economic conditions of Russia.

2.3 Systems Analysis of the Decommissioning Alternatives

SAFSTOR was recommended for Leningrad NPP Unit #1 based on a qualitative analysis. To additionally substantiate the recommendation, a system analysis was performed of the three decommissioning alternatives considered for an RBMK-1000 unit.

2.3.1 Methodology

The system analysis of the decommissioning alternatives is based on selecting independent criteria and on expert's ranking the alternatives by the criteria with a specified ranking system. To make the system analysis more realistic, the criteria were chosen and the alternatives ranked according to the feasibility of various technical decisions and the current Russian socioeconomic conditions.

The criteria were chosen and analyzed to classify the criteria by functional groups. The weighting factors were assigned by the experts for the criteria and their groups. The weighting factors indicate the significance of the criteria for the implementation of various decommissioning alternatives. Thus, the decommissioning alternatives were analyzed step-by-step with gradual development of the analysis based on

- ranking by quantitative and qualitative criteria
- ranking after the criteria are additionally classified by groups and the weighting factors were assigned to the groups
- ranking after the criteria and the groups were both assigned weighting factors.

The methodological approach and the results of the system analysis are described in the following sections.

2.3.2 System Analysis Based on Ranking by Quantitative and Qualitative Criteria

The decommissioning alternatives were analyzed using the criteria that were chosen by determining quantitative and qualitative features of practical implementation of the alternatives. Depending on whether the implementation features are quantitative or qualitative, the criteria found were assigned to "quantitative" or "qualitative" categories.

The criteria were chosen considering the current Russian conditions. Therefore, the system of quantitative and qualitative criteria were supplemented with criteria from a third category to estimate the technical feasibility of the decommissioning alternatives for an RBMK unit.

The decommissioning alternatives were analyzed and compared, with the following ranking system for each criterion:

- 5 – very good
- 4 – good
- 3 – not clear
- 2 – bad
- 1 – very bad.

Groups of experts were interviewed independently and the results were averaged to rank each decommissioning alternative by the chosen criteria. As a result of this system analysis, a final mark was found for each decommissioning alternative:

$$\sum_i \sum_j b_{ij}$$

where i = criterion category; j = criterion; and b = ranking of criteria j for category i .

The preferred decommissioning alternative for an RBMK unit is the decommissioning alternative with a maximum sum. The chosen criteria for three categories and averaged results for expert's ranking of the decommissioning alternatives are listed in Tables 2.4, 2.5, and 2.6.

Table 2.4. Analysis of the Alternatives by Quantitative Criteria

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Minimization of decommissioning time	5	2	1
2. Minimization of manpower	2	4	3
3. Minimization of personnel dose rates	2	4	3
4. Minimization of energy consumption	2	3	4
5. Minimization of construction and mounting works	5	4	2
6. Minimization of radioactivity of radioactive wastes	1	3	4
7. Minimization of expenses for radioactive waste handling	1	3	4
8. Rate of recycling materials return	5	4	3
9. One-time initial costs	1	4	3
TOTAL	24	31	27

Table 2.5. Analysis of the Alternatives by Qualitative Criteria

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Minimization of risk from inner source of accidents	2	4	3
2. Minimization of risk from outer source of accidents	4	2	3
3. Continuity of personnel work	5	3	2
4. Social factor for unit personnel	4	3	2
5. Necessity to use unique equipment	1	3	4
6. Minimization of ecological risk for the environment	2	4	3
7. Opportunity of the fastest use of the unit site	5	3	1
TOTAL	23	22	18

Table 2.6. Analysis of the Alternatives by the Criteria for Technical Feasibility for an RBMK Unit

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Readiness of legislative and regulatory environment	2	3	3
2. Readiness of regional burial or storage facilities	1	3	4
3. Readiness of special equipment	2	4	3
4. Availability of required funds	1	4	3
5. Readiness for handling of irradiated RBMK graphite	1	3	4
6. Necessity to provide a long-term integrity of protective barriers and reactor structures	5	3	1
TOTAL	12	20	19

2.3.3 System Analysis with Weighting Factors for Groups

The system analysis approach described above is a rough evaluation of the alternatives, because the quantitative and qualitative criteria are not fully independent. Also, the criteria are not complete enough to reflect the current understanding of priorities related to decommissioning activities. To eliminate these deficiencies and to increase the value of the results obtained by the system analysis, some modifications were introduced in the used method.

The criteria were reclassified into the following categories chosen according to current requirements for decommissioning activities and readiness of the Russian nuclear power sector for these activities:

- Category 1 – technical feasibility criteria
- Category 2 – safety criteria
- Category 3 – economic efficiency criteria
- Category 4 – social criteria and other factors.

A weighting factor was defined for each category, χ_i (where: i = category). The weighting factors were defined by averaging the rankings of independent experts. The weights were then normalized, i.e., $\sum \chi_i = 1$. The following “weighted” sums were calculated for each decommissioning alternative:

$$\sum_i \chi_i \sum_j b_{ij}$$

where i = category; j = criteria; b = ranking of criteria j in category i ; and χ = weighting factor for category i .

As in the previous method, the decommissioning alternative with a maximum sum of marks was chosen as the preferred decommissioning alternative. The weighting factors, by category, are shown in Table 2.7.

The criteria, their classification by category, and the results for the experts’ ranking of the decommissioning alternatives are listed in Tables 2.8, 2.9, 2.10, and 2.11.

Table 2.7. Weighting Factors by Category

Category	χ_i
1. Technical feasibility criteria	0.28
2. Safety criteria	0.20
3. Economic efficiency criteria	0.41
4. Social criteria and other factors	0.11

Table 2.8. Analysis of the Alternatives by the Technical Feasibility Criteria

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Readiness of legislative and regulatory environment	2	3	3
2. Readiness of regional burial or storage facilities for radioactive waste	1	3	4
3. Readiness of special technologies	2	4	3
4. Readiness of technologies for handling of radioactive graphite	1	4	4
5. Necessity to use unique equipment	1	3	4
6. Necessity to provide long-term integrity of protective barriers and reactor structures	5	3	1
TOTAL	12	20	19

Table 2.9. Analysis of the Alternatives by the Safety Criteria

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Personnel safety (minimization of personnel dose rates)	2	4	3
2. Safety of population and the environment	4	3	2
3. Minimization of risk from inner source of accidents	2	4	3
4. Minimization of risk from outer source of accidents	4	2	3
5. Safety of handling of formed radioactive waste	2	3	3
TOTAL	14	16	14

2.3.4 System Analysis Based on Categorization of the Criteria with Weighting Factors for Categories and Criteria

As a final stage of system analysis for comparing the decommissioning alternatives, weighting factors were used not only for each category of criteria but also for each criterion. The experts' ranking of the criteria, the categories, and the category weighting factors for this analysis are the same as in the previous analysis.

Table 2.10. Analysis of the Alternatives by the Economic Efficiency Criteria

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Costs of dismantling activities	3	3	3
2. Costs of operational activities	3	3	3
3. Costs of energy consumption	2	3	4
4. Costs of special equipment and expendables	1	3	4
5. Costs of radioactive waste handling	1	3	4
6. Costs of construction and mounting work	5	4	2
7. One-time initial costs	1	4	3
8. Costs of personnel training	4	3	3
9. Rate of recycling materials return	5	4	3
TOTAL	25	30	29

Table 2.11. Analysis of the Alternatives by the Social Criteria and Other Factors

Criteria	DECON b_{ij}	SAFSTOR b_{ij}	ENTOMB b_{ij}
1. Opportunity of the fastest use of the unit site	4	3	2
2. Continuity of personnel work	5	3	2
3. Social factor for unit personnel	4	3	2
4. Minimization of decommissioning time	5	2	1
TOTAL	18	11	7

The criteria weighting factor values, ω_{ij} , (where i = index of a group of criteria and j = index of a criterion in the group), were found by independently interviewing experts. The values of the criteria weighting factors were found by averaging the results of the independent experts' ranking and are shown in Tables 2.12, 2.13, 2.14, and 2.15. The values were normalized within each category, i.e., $\sum \omega_j = 1$.

The following were calculated for each decommissioning alternative:

$$\sum_i \chi_i \sum_j \omega_{ij} \cdot b_{ij}$$

As in the previous method, the alternative with a maximum sum was chosen for RBMK unit decommissioning.

2.3.5 Results of the System Analyses

The results of the system analysis of the decommissioning alternatives based on quantitative and qualitative criteria with no weighting factors are given in Table 2.16.

Table 2.12. Weighting Factors for the Technical Feasibility Criteria

Criteria	ω_{ij}
1. Readiness of legislative and regulatory environment	0.08
2. Readiness of regional burial and storage facilities	0.38
3. Readiness of special technologies	0.09
4. Readiness for handling radioactive graphite	0.16
5. Necessity to use unique equipment	0.14
6. Necessity to provide long-term integrity of protective barriers and reactor structures	0.15

Table 2.13. Weighting Factors for the Safety Criteria

Criteria	ω_{ij}
1. Personnel safety	0.22
2. Population and environmental safety	0.32
3. Minimization of risk from inner source of accidents	0.14
4. Minimization of risk from outer source of accidents	0.10
5. Safety of handling of formed radioactive wastes	0.22

Table 2.14. Weighting Factors for the Economic Efficiency Criteria

Criteria	ω_{ij}
1. Costs of dismantling activities	0.12
2. Costs of operational activities	0.08
3. Costs of energy consumption	0.10
4. Costs of special equipment and expendables	0.11
5. Costs of radioactive waste handling	0.15
6. Costs of required construction and mounting work	0.15
7. One-time initial costs	0.13
8. Costs of personnel training	0.06
9. Rate of recycling materials return	0.10

Table 2.15. Weighting Factors for the Social Criteria and Other Factors

Criteria	ω_{ij}
1. Opportunity of the fastest use of the unit site	0.13
2. Continuity of personnel work	0.27
3. Social factor for unit personnel	0.31
4. Minimization of decommissioning time	0.29

Table 2.16. Results of the Analysis Using Quantitative and Qualitative Criteria with No Weighting Factors

Category	DECON	SAFSTOR	ENTOMB
1. Quantitative criteria	24	31	27
2. Qualitative criteria	23	22	18
3. Technical feasibility criteria	12	20	19
TOTAL	59	73	64

The results show that, according to the totals, the deferred reactor dismantling (SAFSTOR) is preferable for decommissioning an RBMK unit. This alternative has significant advantages over the DECON alternative for the quantitative and technical feasibility criteria, and the DECON alternative insignificantly (by one point) exceeds the SAFSTOR alternative for the qualitative criteria.

A similar comparison with the entombment decommissioning alternative (ENTOMB) does not show such significant advantages of the SAFSTOR alternative. The SAFSTOR decommissioning alternative exceeds the ENTOMB decommissioning alternative for the quantitative and qualitative criteria, but it is only one point higher for the technical feasibility criteria.

The results of the system analysis weighting factors for the categories are given in Table 2.17. The results of this analysis show that the decommissioning alternative with deferred reactor dismantling is again preferable for decommissioning an RBMK unit. The SAFSTOR alternative has significant advantages over the DECON alternative for the technical feasibility criteria and the safety and economic efficiency criteria. But the DECON alternative exceeds the SAFSTOR alternative for the social and other criteria. A comparison of the SAFSTOR decommissioning alternative with the ENTOMB decommissioning alternative again shows insignificant advantages of the SAFSTOR alternative.

Table 2.17. Results of the Analysis Using Category Weighting Factors

Category	DECON	SAFSTOR	ENTOMB
1. Technical feasibility criteria	3.36	5.60	5.32
2. Safety criteria	2.80	3.20	2.80
3. Economic efficiency criteria	10.25	12.30	11.89
4. Social and other criteria	1.98	1.21	0.77
TOTAL	18.39	22.31	20.78

The results of the last analysis that used weighting factors for both criteria and categories are given in Table 2.18.

The results of Table 2.18 show that in this case, deferred reactor dismantling is again preferable for decommissioning an RBMK unit. The SAFSTOR decommissioning alternative, as in previous analyses, ranks below the DECON decommissioning alternative for social and other criteria but exceeds it in comparison with other categories of criteria.

Table 2.18. Results of the Analysis Using Weighting Factors for Criteria and Categories

Category	DECON	SAFSTOR	ENTOMB
1. Technical feasibility criteria	0.44	0.92	0.98
2. Safety criteria	0.57	0.65	0.54
3. Economic efficiency criteria	0.86	1.08	1.03
4. Social and other criteria	0.50	0.30	0.19
TOTAL	2.37	2.95	2.73

However, the SAFSTOR decommissioning alternative exceeds the ENTOMB decommissioning alternative in all categories except for being insignificantly lower for the technical feasibility criteria. This result is a consequence of the subjective choice of the criteria for this category (Table 2.7) and weighting factors for the criteria in this category (Table 2.11) in particular, for the criterion of providing long-term integrity of protective barriers and reactor structures.

Sensitivities of the results to the weighting factors was analyzed for this category. This analysis showed that increasing the weight of the protective barrier criterion led to eliminating the higher rank of the ENTOMB decommissioning alternatives over the SAFSTOR alternative.

As result of the system analysis performed, the following can be concluded:

- The system analysis was performed by three different approaches. The results of these analyses confirmed the recommendation to use deferred reactor dismantling (SAFSTOR) for decommissioning an RBMK unit.
- It can be also concluded that changes in socioeconomic conditions or technical policy in nuclear power or its readiness for conducting decommissioning of NPP units could result in another choice of both the system of criteria and the weighting factors. In this case, naturally, results of the analysis could be changed in favor of another decommissioning alternative.

2.4 The Preferred Decommissioning Alternative and the Recommended End State

Analysis of the factors delaying the development of full-scale decommissioning of shutdown Russian NPP units shows that in the economic situation in Russia the SAFSTOR decommissioning alternative with deferred reactor dismantling is more preferable for decommissioning RBMK-1000 NPP units. Since Leningrad NPP was RBMK-1000 reactors, the recommendation for the SAFSTOR decommissioning alternative applies to Leningrad NPP Unit #1. The results of the system analyses presented above also show that the SAFSTOR decommissioning alternative with deferred reactor dismantling is the most preferable for decommissioning Leningrad NPP Unit #1.

A major problem in decommissioning an NPP unit is the handling of the radioactive waste formed during dismantling, including processing, transportation, storage, and/or burial. The pace of the dismantling and the economic parameters of the decommissioning work will, to a considerable extent, depend on the readiness and timeliness of solving the waste handling problem and the associated cost.

Russia has no storage facilities or repositories for radioactive waste, and their construction is not planned in the near future. The lack of such facilities will delay full-scale dismantling when Leningrad Unit #1 is decommissioned. Thus, the processing and removal of radioactive waste formed when Leningrad Unit #1 is decommissioned is a major problem.

One possible way to solve the radioactive waste problem in Russia is to build radioactive waste processing and long-term storage facilities right on the NPP sites. There are two alternatives for selecting such a site: to locate the facility in a special separate building at the site or in the rooms and structures of NPP units being decommissioned. The analysis of which siting alternative is optimal should be the subject of a separate study, but, according to some preliminary estimates, the location of this facility within the rooms and structures of the units that are decommissioned seems economically preferable. Therefore, a decommissioning alternative with construction of radioactive waste processing and storage facilities within unit rooms is proposed for Leningrad NPP Unit #1.

2.4.1 Description of the Recommended Unit End State

It's known that accurate definition of the final condition of the facility after decommissioning helps to increase the efficiency and economic acceptability of the chosen decommissioning alternative. Therefore, choosing an optimal final NPP unit condition when it is decommissioned is a part of planning the decommissioning work.

As noted above, this study proposes the SAFSTOR decommissioning alternative with construction of a facility for radioactive waste processing and long-term storage in unit rooms as an end state of the Leningrad NPP Unit #1. During SAFSTOR, when Leningrad NPP Unit #1 is decommissioned, the following procedures should be carried out to achieve its final condition:

- partial dismantling of turbine hall equipment to make room for the radioactive waste processing facility
- isolation of the reactor structures in a concrete cavity
- conversion of the unit's main building rooms into storage for processed radioactive waste (operational and decommissioning radioactive waste)
- dismantling of the remaining turbine hall equipment to make room for storing processed radioactive waste and operable equipment (this equipment can be used at other Leningrad NPP units or sold it to other NPPs with RBMK-1000 reactors for partial compensation of decommissioning costs).

It would be economically more acceptable if the radioactive waste processing and storage facilities have the capacity to handle the wastes formed in decommissioning of not only Unit #1, but either Phase I units or all Leningrad NPP units.

The Unit #1 rooms and structures can be used later as a training base for developing RBMK-1000 unit decommissioning practices and to give personnel the required skills.

2.4.2 The SAFSTOR Stages for Leningrad NPP Unit #1

Current practice is that the planning and preparation of Leningrad NPP Unit #1 decommissioning should be started before final shutdown of the unit. This period of work is known as the pre-shutdown stage.

During the pre-shutdown stage, the decommissioning alternative chosen for Leningrad NPP Unit #1 should be qualified, and a series of organizational and technical procedures should be developed: a program for comprehensive engineering and radiation inspection, decommissioning program, and technical specifications for development of the decommissioning project. The purchase of special equipment as well as the work on preparing the reactor cooling ponds and in-site nuclear spent fuel storage facilities should also be started at this stage.

The preparation for decommissioning must be completed after final shutdown of the Leningrad NPP Unit #1. As noted in Section 2, the major goal of this stage is to receive the Unit #1 decommissioning license, which requires that the following procedures be performed: standard unit shutdown and cooldown; nuclear fuel holdup in the reactor core or cooling ponds; removal of nuclear fuel from the unit; decontamination and drainage of the multiple forced circulation circuit and other process circuits; comprehensive engineering and radiation inspection of the unit (to the extent necessary for development of a unit decommissioning project); and development of the required organizational, technical, and design documentation.

The SAFSTOR decommissioning alternative recommended for Leningrad NPP Unit #1, will also include these stages:

- pre-shutdown
- preparation for decommissioning
- preparation for long-term safe storage
- long-term safe storage
- dismantling and demolition of reactor structures.

The list of the main activities for the last three stages will mainly correspond to the procedures described in Section 2 for SAFSTOR. However, because the radioactive waste processing and storage facilities are to be built in the Unit #1 rooms, the list of activities for these stages is supplemented by other organizational and technical procedures to develop and operate the radioactive waste facilities.

Table 2.19 lists the main activities to be done during the Leningrad NPP Unit #1 decommissioning by stage and provides estimates of the time required for each activity. The list of activities was developed on the basis of available experience and understanding of the activities. Nevertheless, the list of activities should not be considered as final, because some activities at any stage could require additional analysis and qualification in the future.

For instance, during preparation for long-term safe storage, special consideration should be given to the problem of extracting and removing technological channels from the reactor graphite stack. The experience on extracting and removing technological channels was gained during reconstruction of the Leningrad NPP units. This experience as well as estimates of the time history of their radioactivity show that extracting and removing technological channels from the reactor graphite stack are expedient at this stage. However, analysis of this problem in view of other conditions, for instance, the availability of repositories for burying technological channels, may show that it is not expedient to extract and remove the channels during preparation for safe storage. The activities listed in Table 2.19 should therefore be developed in more detail when the decommissioning plan for the Leningrad NPP Unit #1 is elaborated.

Table 2.19. Stages and Main Activities for the SAFSTOR Decommissioning Alternative Recommended for Leningrad NPP Unit #1

Stages and List of Activities	Work schedule, years before (-) or after shutdown	
	Start	End
A. Pre-Shutdown Stage	-5	0
1. Conduct an optimizational analysis on the option chosen for decommissioning the unit		
2. Develop organizational and technical documentation		
2.1. Develop an overall concept for decommissioning the Phase I units		
2.2. Develop a program for a comprehensive survey of the unit		
2.3. Develop unit decommissioning plan		
2.4. Develop specification for development of a unit decommissioning project		
2.5. Create a database of information for unit decommissioning		
3. Start the purchase of special equipment		
4. Start preparing cooling pond and spent nuclear fuel storage facilities		
B. Preparation for Unit Decommissioning Stage	0	5
1. Standard unit shutdown and cooldown	0	1
2. Nuclear fuel storage cooling in the reactor core	0	1
3. Handling of spent nuclear fuel	2	5
3.1. Standard removal of nuclear fuel from the reactor to the cooling ponds		
3.2. Removal of nuclear fuel from unit		
4. Removal of other nuclear materials from equipment and areas (if necessary)	0	5
5. Comprehensive survey of unit and experimental design work to develop a unit decommissioning project	1	3
6. Development and approval of required organizational, technical, and design documentation	1	5
6.1. Approval of a procedure for servicing the unit after removal of nuclear fuel		
6.2. Development and approval of the decommissioning project		
6.3. Official registration of decommissioning license		
6.4. Development of specification and distribution of orders for manufacturing required dismantling equipment		
6.5. Development of other documentation		
7. Handling of operational radioactive waste	2	5
7.1. Construction of facilities to process radioactive waste (if necessary)		
7.2. Operational radioactive waste processing		
8. Operation and maintenance	0	5
8.1. Operation of systems and equipment of shutdown unit		
8.2. Operation of the spent nuclear fuel storage facility		
8.3. Operation of radioactive waste storage facility		
9. Preparation for the next stage	4.5	5

Table 2.19. (contd.)

Stages and List of Activities	Work schedule, years before (-) or after shutdown	
	Start	End
C. Unit Preparation for Safe Storage Stage	5	10
1. Decontamination work	5	6
1.1. Inspection and required reconstruction of equipment and systems for decontamination		
1.2. Standard decontamination and drainage of multiple forced circulation circuit		
1.3. Decontamination and drainage of other process circuits and the nuclear fuel cooling ponds		
2. Deactivation of systems and equipment not required for decommissioning	5	5.5
3. Inspection of equipment and systems required for safe storage	5	6
3.1. Rebuild standard heating and ventilation, power supply, sewage, fire and radiation safety, and other necessary systems		
3.2. Upgrade or install (if necessary) dosimetry and radiological inspection systems		
3.3. Reserve equipment and systems that may be used for decommissioning		
4. Isolation of the reactor in place to prevent radionuclides from escaping	6	8
4.1. Dismantle reactor system elements and structures obstructing reactor isolation		
4.1.1. Dismantling of technological channels and channels of control and protection system		
4.1.2. Dismantling of equipment, pipes, and structures above top load-bearing structure		
4.1.3. Dismantling of equipment, pipes, and structures below bottom load-bearing structure		
4.2. Isolate the other reactor structures		
4.2.1. Installation of plugs in circuits of the top load-bearing structure		
4.2.2. Installation of plugs in circuits of the bottom load-bearing structure		
4.2.3. Installation of protective floor above the reactor		
4.3. Seal ventilation, cable, and pipe runs from the reactor cavity		
4.4. Total isolation of the reactor construction space		
5. Bringing unit rooms into compliance with radiological and health requirements so that they can be used as temporary processed radioactive waste storage facilities	5	6
5.1. Decontaminate reactor section equipment and rooms		
5.2. Organize temporary storage for dismantled equipment in the turbine hall		
5.3. Remove thermal insulation from equipment, piping and structure		
5.4. Dismantle and transport equipment and systems from rooms designated for radioactive waste storage to sites of temporary storage		
6. Construction of the radioactive waste storage and processing complex	5	10
6.1. Prepare and refurbish rooms to store processed radioactive waste		
6.2. Partially dismantle turbine hall equipment to make room for the radioactive waste processing complex		
7. Handling of operational radioactive waste	5	10
7.1. Process operational radioactive waste		
7.2. Transport radioactive waste to temporary storage		
8. Operations and maintenance	5	10

Table 2.19. (contd.)

Stages and List of Activities	Work schedule, years before (-) or after shutdown	
	Start	End
8.1. Regularly inspect, repair, and operate required equipment and systems		
8.2. Operate the spent nuclear fuel storage facility		
8.3. Operate the radioactive waste storage facility		
9. Preparation of systems and equipment necessary for the next stage (including necessary experiment and design work)	9	10
D. Long-Term Safe Storage Stage	10	80
1. Preparation of warehousing and temporary storage of wastes permitted for restricted and unrestricted use	10	15
2. Construction and installation of the radioactive waste processing complex	10	15
3. Dismantling of equipment and systems outside the reactor isolation area	10	20
3.1. Completely dismantle turbine hall equipment		
3.2. Dismantle reactor section equipment and systems (as radioactivity declines)		
4. Conditioning, transportation and disposition of radioactive waste for storage	15	20
5. Operations and maintenance	10	80
5.1. Regularly inspect, repair, and operate required equipment and systems		
5.2. Operate the spent nuclear fuel storage facility		
5.3. Operate the radioactive waste processing and storage complex		
6. Preparation of systems and equipment necessary for the next stage (including necessary experimental and design work)	78	80
E. Dismantling and Demolition of Reactor Structures	80	85
1. Removal from storage and inspection of equipment, systems, and structures	80	81
2. Training of unit personnel		
3. Dismantling of reactor structures	82	84
3.1. Install required equipment, power supply, and dust suppression and gas purification systems		
3.2. Install equipment to dismantle reactor structures		
3.3. Open protective engineering barriers and remove structures obstructing access to reactor		
3.4. Dismantle reactor structure elements		
4. Handling of radioactive waste created during dismantling	82	85
4.1. Dismantle and complete radiological inspection and sorting of reactor units, reactor metal structure fragments, and graphite		
4.2. Package and remove reactor structure elements		
4.3. Process radioactive waste		
4.4. Transport processed radioactive waste to rooms prepared for radioactive waste storage		
5. Radiological inspection and sorting and temporary storage of waste accepted for restricted and unrestricted use	83	85
6. Cleaning or decontamination of the surface of the concrete reactor cavity (if necessary)	84	85
7. Operations and maintenance	80	85
7.1. Regularly inspect, repair, and operate required equipment and systems		
7.2. Operate the spent nuclear fuel storage facility		
7.3. Operate the radioactive waste processing and storage complex		

Table 2.19. (contd.)

Stages and List of Activities	Work schedule, years before (-) or after shutdown	
	Start	End
8. Demolition and deconstruction of unused unit structures	83	85
9. Putting remaining unit structures into compliance with radiological and health requirements	83	85
10. Decontamination and dismantling of equipment used in dismantling	84	85
11. Final survey of unit structures and site	84	85

3.0 Cost Estimating for Leningrad NPP Unit #1 Decommissioning

A United States cost model for BWR decommissioning was selected for cost estimating the decommissioning alternative recommended for Leningrad NPP Unit #1 with an RBMK-1000 reactor. The model used is the CECP (Cost Estimating Computer Program) which was developed by the Pacific Northwest National Laboratory (PNNL) for the U.S. Nuclear Regulatory Commission (NRC). However, the BWR CECP is not fully correct for estimating RBMK decommissioning because design features of the BWR and RBMK are different, as are economic conditions in the U.S. and Russia. Therefore, in this study the cost methodology used integrates the CECP code calculations and Russian estimates of labor costs for dismantling of RBMK reactor structures. This methodology also allowed the transformation of the results from American economic conditions to Russian conditions. More details of the methodology used for cost estimating, the American cost methodology and Russian method for estimating labor costs as well as the list of costed activities, and the input data used in calculations, are presented below.

3.1 Features of Methodology and American CECP

The U.S. BWR CECP was chosen for cost estimating because of the similarity of the single-circuit coolant circulation schemes for NPP units with RBMK and BWR reactors. It allowed for the use of some of the data in the available BWR database of the CECP for an RBMK unit. However, the use of the U.S. BWR CECP for calculating decommissioning cost estimates for an RBMK-1000 unit, as well as the input data, are associated with the following key features due to differences between designs of equipment and systems.

3.1.1 Equipment and Systems of a Reactor Section

Design and technical features of equipment and systems of BWR reactor section are significantly different from the same equipment and systems of RBMK reactor section. The major difference between the two units is that the BWR is a vessel type and the RBMK is a channel type. The compact core of a BWR reactor is contained in a rather small steel pressure vessel; an RBMK core is of considerable size and contains more than 2000 channels, a 2000-tonne graphite block stack, and metal structures with complex configurations for hermetically sealing the reactor space, core support, and radiation protection.

Designs of the coolant circulation systems and a number of other systems of the BWR and RBMK units are also significantly different. However, the coolant circulation circuits and systems have many similar elements. Examples include pipelines; reactor pumps; a number of auxiliary, supplying and protective systems (systems for chemical water preparation; gas cleaning; monitoring integrity of fuel rods; control and protection system; systems for ventilation and heating, cable system), etc. One type of RBMK system added to the CECP data is the drum separator (2 per unit).

The significant design and technical differences necessitate large-scale modifications of the CECP for cost estimating the decommissioning of an RBMK reactor. However, modification of the CECP was not funded or analyzed in this study. Instead, costs were estimated for dismantling equipment and systems of the RBMK reactor section based on the U.S. cost methodology and the labor costs estimated by Russian experts. The Russian estimates were based on state regulations for labor costs of construction and dismantling of various structural elements, equipment, and systems of NPP units as well as their correcting factors for radiation and other conditions of performing this work.

3.1.2 Turbine Hall

Structures of equipment and systems of single-circuit NPPs with BWR and RBMK were analyzed. This analysis showed the identical organization of heat-to-electricity transformation based on a steam turbine operating with dry saturated steam. The steam turbine circuits of the BWR and RBMK include similar elements such as a steam turbine, generator, separator-superheater, condenser, regenerative heaters, condensate pumps, steam ejectors, hydrogen recombiners, valves, and pipelines. The analysis showed that the differences in the systems and equipment for the BWR and RBMK turbine halls are primarily their numbers, masses and dimensions. Two systems were added to the CECP data: bubblers (2 per unit) and deaerators (4 per unit).

Thus, the cost of dismantling the systems and equipment for the RBMK turbine hall was estimated based on the design of BWR equipment and systems but corrected to account for the differences in numbers (e.g., turbines, condensers, pipelines and valves, cables, electric facilities, etc.) as well as in their size and shape.

3.1.3 Auxiliary Systems and Other Equipment

Currently, there is no database of required data on auxiliary systems and other equipment for an RBMK-1000 unit. It was not possible to develop such a database during this study. Our analysis showed that the design of RBMK systems such as the emergency core cooling systems, the system for cooling and cleaning the cooling pools water, the system for collecting and processing low-level radioactive and drainage water, the systems for cleaning chemical water and condensate, the system for bleed-off and checking steam leaks, ventilation system, heating system, electric equipment components (excluding electrical gears of reactor pumps and feedwater pumps), and other systems and auxiliary equipment are similar to corresponding BWR systems. Because of the design similarities of the BWR and RBMK auxiliary systems and other equipment, cost estimating for their dismantling was performed based on the BWR experience.

3.1.4 Differences in U.S. and Russian Economic Conditions

Economic conditions in the U.S. and Russia are characterized by differences in labor cost, labor productivity, cost of equipment, costs of construction and structural materials, and so on. Therefore, several special conversion factors were used to convert the cost calculations from the "U.S. conditions" to the "Russian conditions" for decommissioning an RBMK. The conversion factors take into account the economic differences and transform the results from one economic condition to the other.

The conversion factors developed and used for the Joint Parallel Nuclear Alternative Study (JPNAS) were used in this study to convert the cost estimates from U.S. to Russian economic conditions. The JPNAS analysis dealt only with global parameters affecting cost. They deal with plant equipment, commodities, and elements determining power plant installation cost. The elements comprising installation cost include the rate of pay for construction craft labor, their productivity, and indirect construction cost variances arising from construction methods or social structures.

The results obtained by the JPNAS analysis are based on intuitive judgement and the following assumptions:

1. The factors for equipment and materials (other than concrete and structural steel) assume that the Russian economy will continue to change in the direction of market-based pricing and will eventually be as competitive and the world market.

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2. Concrete and structural steel are assumed to cost more in Russia due to infrastructure and housing construction.
 3. The construction labor cost comparison assumes that the relationship between average labor cost and cost of construction labor will remain the same as in the past (construction 30% higher).
 4. Direct and indirect labor productivities are based on a direct comparison of actual total project man-hours for the construction of a Russian NPP (Kalinin NPP units) and U.S. data for a similar project.
 5. Social costs normally provided in Russia, such as housing, medical care, schooling, etc., are not reflected in any comparisons of cost.

In developing the factor adjusting U.S. equipment cost to Russian, it was assumed that Russian equipment manufacturers will be at least as competitive as the world market for similar type and quality. Recent experience with lump-sum bidding by international suppliers indicates that U.S. domestic pricing is, on average, about 30% higher than average quotes received from international competition.

The factors for commodities, other than concrete, assumed the same pricing scenario as described for equipment pricing. The cost of concrete, one of the more significant materials required for power plant construction, is comparable to U.S. cost. Combining this fact with the generally accepted fact that there is an urgent need to upgrade the infrastructure and construct more housing, leads one to the assumption that concrete cost will be equal to U.S. pricing, and the cost of structural steel, another material that will be in demand, will cause steel to be at the higher end of world pricing. This resulted in a multiplier of 0.55 for structural steel, assuming that the cost of turbine-building structural steel is representative of all such steel.

The development of a factor to adjust U.S. construction labor productivity to conditions and methods in Russia was based on a comparison of the actual manpower loading data experienced on Kalinin NPP Units 1 and 2 and U.S. manhours adjusted for a two unit plant of a similar project. The resulting global manhour multiplier of manhours from U.S. construction labor productivity to conditions and methods in Russia was 2.5.

Data based on the national average rates of pay in Russia, taking into account the rate of escalation, were used to develop an adjustment factor for construction wage rates. The various sources and methods, adjusted for a January 1994 base, resulted in a range of factors varying from 0.03 to 0.07 of the construction wage rate in U.S. conditions. The comparison did not include the cost of housing, health care, education, day care, and other labor subsidies provided by industry or government. In order to be conservative, and due to the speculative results, a factor of 0.10 was used in the JPNAS.

A comparison of the rates of pay of engineers in the manufacturing sector of the Russian economy indicated that the rate of pay for engineers is 0.15 of a comparable "unloaded" rate in U.S. conditions. It was assumed that this sector of the labor market would most readily adapt to a more independent employment approach and be less dependent on government support.

The JPNAS resulting factors used for converting U.S. based cost estimates to a Russian Federation basis are summarized below.

Equipment	0.70
Commodities:	
- concrete	1.00
- steel (structural)	0.55
- other	0.70
Productivity of Direct & Indirect Labor	2.5
Construction Labor	0.10
Professional Services	0.15

3.2 Methodology and Assumptions

The BWR CECP software developed and used by the NRC was the basis of the Leningrad NPP Unit #1 decommissioning cost estimating process. The model provides a cost calculating methodology used by the NRC. The CECP, designed to be used on a personal computer, provides estimates for the cost of decommissioning BWR units to the point of license termination. Such cost estimates include costs for component, piping, and equipment removal; packaging; decontamination; transportation; burial; and manpower.

Though U.S. licensees are not required to use this computer program to plan their decommissioning activities and estimate their projected decommissioning costs, the program is useful to obtain information on NRC's basis for cost estimates. Likewise, it may be used to validate some independent studies.

Using equipment and consumable costs and inventory data supplied by the user, the CECP calculates unit cost factors and then combines these factors with transportation and burial cost algorithms to produce a complete report of decommissioning costs. For this purpose the CECP uses a special database that includes: 1) labor rates, burial costs, constants; 2) unit cost factors for decontamination; 3) unit cost factors for contaminated systems; 4) decommissioning schedules; 5) site information; 6) special equipment costs; 7) building decontamination costs; 8) contaminated system costs; 9) nuclear steam supply system costs; 10) staffing costs; and 11) undistributed costs.

The CECP calculates the decommissioning schedules and shutdown dose rates as a baseline for dose rates prevailing at the times the activities are performed. Radiation dose rates are based solely on cobalt-60. It is assumed that this radionuclide is by far the most significant source of occupational radiation exposure. Thus, the CECP calculates burial volumes, person-hours, crew-hours, and exposure person-hours associated with decommissioning. However, the exposure calculations were not used for this study.

The BWR CECP is explained in detail in NUREG/CR-6270, *Estimating Boiling Water Reactor Decommissioning Costs, A User's Manual for the BWR Cost Estimating Computer Program Software, Final Report*. The baseline BWR analysis that was used for default inputs and cost estimates in this study is explained in detail in NUREG/CR-6174, *Revised Analyses of Decommissioning for the Reference Boiling Water Reactor Power Station, Effects of Current Regulatory and Other Considerations on the Financial Assurance Requirements of the Decommissioning Rule and on Estimates of Occupational Radiation Exposure, Main Report Final Report*.

There are two versions of the CECP software: the BWR version and the pressurized water reactor (PWR) version. The BWR CECP version was used on this project, but the code was

updated as part of this study to make it useful for estimating projected costs of decommissioning RBMK-1000 nuclear power stations.

The code was modified to accept data in metric units; cost factors were updated to 1997 dollars assuming an annual inflation rate of 3%; and, for the U.S. conditions, burial costs were updated to better reflect current burial charges. When possible, the Leningrad RBMK systems and equipment were mapped to similar BWR systems and costs by the CECF code. In this case, input data were updated to reflect the RBMK case. The RBMK data used for the CECF are presented in Appendix A.

Where equipment or systems are present in a BWR reactor but not in an RBMK, no costs were computed. Where no information was available or incomplete for the RBMK (e.g., breakout of people types for non-direct charges), the BWR data presented in NUREG/CR-6270 were used as default. Where there was no similar BWR system or situation as compared to the RBMK (e.g., the reactor core dismantlement and construction of the waste processing and storage facilities), a separate spreadsheet was used to estimate the cost. The costs from CECF output and the spreadsheet were combined for the final cost estimate. The cost estimate was then converted to Russian conditions using cost factors explained in Section 3.1.

3.2.1 Russian Condition

The Russian condition reflects changes from the U.S. condition. It reflects the costs associated with decommissioning an RBMK in Russia and the infrastructure and economics in place in Russia.

The following cost factors from the JPNAS, described in Section 3.1.4 were used to convert U.S. condition costs and factors to the Russian condition:

- A productivity factor of 2.5 was used to convert U.S. work durations to Russian durations.
- A cost factor of 0.1 was used to convert U.S. salaries to Russian salaries.
- A procurement factor of 0.7 was used to convert U.S. equipment procurement costs to Russian procurement costs.

The Russian condition provides cost for five phases. All time lengths for the phases are based on Russian estimates. The five phases are

- Phase 1, Decommissioning Planning, is five years long and is performed prior to shutdown. This phase reflects half the work of what is called Phase 1 under the U.S. condition
- Phase 2, Decommissioning Preparation, is five years long. This phase again reflects half the work of what is called Phase 1 under the U.S. condition
- Phase 3, Preparation for Storage, was costed for five years
- Phase 4, Safe Storage, is assumed to be 70 years long
- Phase 5, Final Dismantlement, is assumed five years long.

The other major difference between the Russian condition and the U.S. condition is that there is no centralized waste disposal site in Russia. Waste must be processed and stored onsite for an undetermined period of time. The Russian condition reflects the construction necessary to modify the LNPP Unit #1 facilities for waste storage and processing.

3.2.2 U.S. Condition

The U.S. condition serves as the reference case. It reflects the costs associated with decommissioning an RBMK as if it were in the United States and reflects the infrastructure and economics in place in the United States.

The U.S. condition provides cost for five phases, which is typical in the United States. Russian estimated time lengths were adjusted to reflect the U.S. condition. The phases costed are

- Phase 1, Planning and Preparation, is 2.5 years long and is performed prior to shutdown. 2.5 years is believed to be representative for the United States and is from the BWR data
- Phase 2, Preparation for Decommissioning, is 2.0 years long and was added to reflect the time for spent fuel removal.
- Phase 3, Preparation for Storage, was costed for two years. The two years reflect a Russian estimate of five years for the same phase divided by the assumed productivity factor of 2.5. It assumes that if you can do the work 2.5 times faster, then you can do the work in $1/2.5$ of the time.
- Phase 4, Safe Storage, is assumed to be 70 years long
- Phase 5, Final Dismantlement, is assumed to be two years long. The same reasoning as applied to Phase 2 was used. The BWR input data were for 1.7 years. Since the RBMK is probably more difficult to dismantle, two years was used.

The other big difference for the U.S. condition is the handling of waste. For the U.S. Condition, it is assumed all waste would be sent to a low-level waste (LLW) disposal site. No waste would be processed and stored on site.

3.2.3 Assumptions

Several assumptions, in addition to those mentioned above, were made for the Leningrad NPP Unit #1 decommissioning cost estimate. Some of the assumptions relate only to the U.S. or Russian condition, while others relate to both conditions. All assumptions, even those mentioned above, are listed here.

3.2.3.1 Assumptions Related to Both Conditions

Indirect labor costs, including insurance and regulatory costs as well as indirect personnel, are based on the previous BWR analysis. The one exception to this assumption is the indirect personnel cost associated with Phase 4 for the Russian condition. The Russians estimate a staff of approximately 40 people for maintenance during safe storage for an RBMK, while approximately 17 people are used to maintain facilities for a BWR. The difference in the estimates is the need to maintain a round the clock staff for the RBMK due to the weather conditions in northern Russia. Therefore, the BWR indirect, non-security personnel estimate for Phase 4 was multiplied by 4 for a total staff of 37 people for the Russian condition. For the other phases, the BWR indirect personnel estimates, which were used for the cost estimate, were higher than or equal to those estimated for the RBMK.

Non-decommissioning costs are not included. In Russia, the total cost to decommission LNPP Unit #1 includes socioeconomic costs, spent-fuel storage, and operation and maintenance of the waste processing and storage facility. These costs are not included in the costs estimated by this study.

All costs are assumed in 1997 dollars. A 3% annual inflation rate was assumed to convert the original 1994 CECF costs to 1997 dollars. The code was modified to generate a 1997-dollar estimate. The "seavan," a maritime container that is 2.4 m x 2.4 m x 6.1 m, was assumed as the standard container for moving waste.

The decommissioning costs of the following RBMK systems and equipment were estimated using the equivalent BWR equipment: HVAC equipment (not ducting); cranes, cables and cable trays; structural beams and supports; and floor drains. That is, though some information may have been received for the listed equipment, either the information was insufficient to generate an RBMK specific cost estimate or the CECF was unable to accommodate the new information.

Although the RBMK reactor isolation and final reactor dismantlement costs were computed using a spreadsheet, it was assumed that the crew make up would be similar to those of the BWR for similar activities. That is, although the person-hours needed to dismantle an RBMK may be very different than those needed for dismantling a BWR, the same types of people were assumed.

3.2.3.2 Assumptions Related to the Russian Condition

In the Russian condition, the LNPP Unit #1 is decommissioning in Russia. Therefore, Russian personnel (productivity and wages), and onsite waste processing and storage are assumed. Factors from JPNAS were used to convert the U.S. condition to the Russian condition. Equipment costs were multiplied by 0.7, durations were multiplied by 2.5, and personnel wages were multiplied by 0.1.

There are five phases for the Russian condition. The time length for each phase was estimated by Russian experts. Construction costs were based on Means, and modified using the cost and productivity factors for the Russian condition.

3.2.3.3 Assumptions Related to the U.S. Condition

The U.S. condition assumes the LNPP Unit #1 is decommissioning in the United States. Therefore, U.S. personnel (productivity and wages), and centralized burial are assumed. It was assumed there is no construction for the U.S. condition because burial sites are available.

There are five phases for the U.S. condition. The duration of each phase was assumed to be the same as for the BWR, assumed to be the same as estimated by the Russians, or assumed to be 1/2.5 times the Russian estimate. Phases whose time length depends on productivity are assumed 1/2.5 times the Russian estimate, unless the time length assumed for the BWR analysis is greater and then the BWR analysis time length was used. Phase 1 was assumed the same as that for the BWR analysis, Phases 2 and 4 were assumed 1/2.5 times the Russian estimate, and Phase 3 was assumed the same as the Russian estimate because it is not dependent on productivity.

3.3 Russian Method for Estimating Labor Hours

A method widely used by Russian design organizations was a basis for labor hour estimating of dismantling activities. This method is used in Russia for construction labor hour estimating for new NPP construction, repairs, and reconstruction. This method is based on the norms used in the Russian nuclear power sector and a number of factors correcting the norms to account for dismantling differences.

The Russian norms are published in special reference books and give specific labor in man-hours per tonne of corresponding equipment or structures being mounted. In this work the norms for

specific RBMK equipment and structure labor hours were used. These data are given in "Costs of NPP Equipment Construction" (VSN-42-85) and "Rules for Applying Costs of Construction Equipment" (SNiP IV-6-82).

The following factors were used to correct the norms and convert labor hour estimates from construction to dismantling:

- dismantling factor K_{dem} (as a rule, $K_{dem} \leq 1$) sets ratio of dismantling-to-construction labor hours
- factor K_{rad} (as a rule, $K_{rad} \geq 1$) takes into account that work is done under radiation conditions
- factor K_{cond} (as a rule, $K_{cond} \geq 1$) takes into account difficulty of the work under special conditions (for example, while extracting serpentinite or sand fillings from cavity of the structures).

Depending on the type of structures or equipment to be dismantled and on the conditions of their further treatment, the K_{dem} factor can have the following values:

- 0.3 - where equipment and structures are dismantled for scrap
- 0.4 - when complex equipment, such as, heat exchangers, is dismantled and fragmented as well as when equipment is dismantled to be further used without any conservation and packing
- 0.5 - when equipment is to be further used and requires packaging in boxes, lubricating with a corrosion-preventive composition, and preparation of packaging specifications
- 0.6 - when metal structures are dismantled.

The K_{rad} factor is used in the Russian nuclear sector to account for difficulty of work under radiation. This factor can have the values of 1.0 up to 1.25 and, in some cases, up to 2.0–3.0. The K_{rad} factor is the product of the following five specific correction factors, $K_1 \times K_2 \times K_3 \times K_4 \times K_5$, among which are:

- K_1 - a preparation time factor
- K_2 - a radiation inspection time factor
- K_3 - a construction and training time factor
- K_4 - a factor to extend the time to suppress dust, and to decontaminate the equipment, structures, tools and working places
- K_5 - a factor to account for time to change personnel.

The K_{cond} factor accounts for difficulty of the work under special conditions and it is usually equal to 1.25.

The value of the total (resulting) correcting factor, K_{tot} , is used to convert construction to dismantling labor hours and is determined as the product of the correcting factors mentioned above, namely, $K_{tot} = K_{dem} \times K_{rad} \times K_{cond}$. Note that, depending on work conditions, the total correcting factor, K_{tot} , accounts for all or only some of the correcting factors.

The right values for the correcting factors are important in determining labor hours and were calculated for each type of dismantled equipment or structure. Russian experts studied the data on radiation conditions and possible arrangements for each type of RBMK equipment or structure. The analysis resulted in the correcting factors used for this study.

Table 3.1 presents the values of the construction norms used for calculating dismantling labor hours, a list of equipment and reactor structures to be dismantled, and the values for the correcting factors K_{tot} , K_{dem} , and K_{over} (where: $K_{over} = K_{rad} \times K_{cond}$). Note that the values of the total correcting factor, K_{tot} , given in Table 3.1 correspond to manual and mechanized methods of dismantling work but without the use of special remote-control facilities.

According to the Russian method of estimating labor hours based on construction norms, the final result includes the total labor hours—direct labor hours of construction itself, indirect labor hours to provide auxiliary means, and materials and subsidiary personnel for main production process. The indirect labor hours are also taken into account in the CECF code, and to avoid double account for these hours, the results of Russian estimates of the total labor hours were corrected by multiplying them by factor of 0.6. This value was specified expertly.

Thus, only direct labor hours were estimated by Russian experts. All indirect labor costs (for instance, costs of energy supply, taxes, insurance, security, other auxiliary and service personnel, etc.) that will occur when an RBMK is decommissioned were calculated according to the American cost methodology with the use of the CECF.

3.3.1 Labor Hour Estimating for Dismantling Work when the Reactor is Isolated

Labor hours were estimated for the reactor structure dismantling necessary for isolating the reactor and preparing it for safe storage. The work was divided into the following activities:

- development of design documentation for isolation of the reactor structures
- development of project for organization of dismantling work and technological processes
- development of design documentation for technical equipment
- manufacturing of the required set of technical equipment
- dismantling work.

Labor hours to dismantle the reactor equipment and structures were estimated using available norms on labor rates and cost of construction for the specific RBMK equipment. Table 3.1 contains the results of Russian direct labor hour estimates for reactor equipment and reactor structure dismantling. Labor hours for design work were estimated using current norms on labor rates and salary conditions in Russia.

In January 1998 rubles, the cost of developing the design documentation was estimated at about 1.2 million rubles, 0.8 million rubles for design documentation for isolation of the reactor structures, 2.8 million rubles for design documentation for technical equipment (about 100 equipment units).

The average salary of designers and engineers was estimated as 2000 rubles a month at the beginning of 1998. The salary is assumed to be 25% of the total cost of the design work. With these assumptions, the direct labor hour estimates for design work are

- $1,200,000 \times 0.25/2,000 = 150$ man-month to develop design for organization of dismantling work and technological processes
- $800,000 \times 0.25/2,000 = 100$ man-month to develop design documentation for isolation of the reactor structures
- $2,800,000 \times 0.25/2,000 = 350$ man-month to develop design documentation for technical equipment.

Table 3.1. Labor Hours and Correcting Factors on Dismantling of Equipment and Systems of Reactor Section of RBMK-1000 Unit

Equipment and Systems	Weight, t	Const., person -hr/t	K _{dem}	K _{over}	K _{tot}	Dismantling, person-hr
1. REACTOR	12,258	-	-	-	-	931,000
1.1. Protective Coating under reactor	460	55	1.0	1.2	1.20	19,800
1.2. Graphite Stack (Columns/ Blocks)	1,760	114	0.7	1.2	0.84	95,550
1.3. Channels	559	450	0.8	1.4	1.12	169,040
1.4. Bottom Tracks (cutting parts)	155	944	0.5	2.0	1.00	152,930
1.5. Top Tracks (cutting parts)	130	1,200	0.6	1.4	0.84	79,530
1.6. Cross Support Structure	110	111	0.4	1.0	0.40	2,930
1.7. Bottom Load-Bearing Structure	570	443	0.5	1.2	0.60	90,900
1.8. Top Load-Bearing Structure	600	400	0.5	1.2	0.60	86,400
1.9. Cylindrical Liner	70	774	0.5	1.4	0.70	21,130
1.10. Circular Biological Shield	567	197	0.4	1.2	0.48	31,770
1.11. Chircular Biological Shield	222	206	0.4	1.2	0.48	13,050
1.12. "A" Scheme	170	55	0.5	1.0	0.50	2,800
1.13. Top Plate Floor	1,400	98	0.4	1.0	0.40	32,000
1.14. Roller Supports	22.1	55	0.5	1.2	0.60	2,540
1.15. Tracks Parts in Reactor Spase	532.5	230	0.7	1.2	0.84	61,320
1.16. Filling of Load-Bearing Structures	1,630	15	1.5	1.0	1.50	23,310
1.17. Sand Filling	3,300	15	1.0	1.0	1.00	46,000
2. CENTRAL HALL	486.2	-	-	-	-	17,710
2.1. Refueling machine (RM)	448	84	0.5	1.2	0.60	13,550
2.2. Ventilation equipment (HVAC Ducts)	3.2	1,240	0.8	1.4	1.12	2,660
2.3. Protective Coating (above top plate floor)	35	55	1.0	1.2	1.20	1,500
3. EQUIPMENT OF MFCC AND ADDED SYSTEMS	3,600	-	-	-	-	533,750
3.1. Steam-water Pipelines + Hangers	303 + 93	1,200	0.6	1.4	0.84	238,600
3.2. Reactor Bottom Water Pipelines + Hangers	163 + 29	897	0.5	2.0	1.00	124,000
3.3. Drum-Separators + Hangers	901 + 212	51	1.0	1.2	1.20	31,670
3.4. Suction and Pressure Headers + Hangers	218 + 25	179	0.8	1.4	1.12	29,230
3.5. Downcomers Pipelines + Hangers	207 + 20	462	0.5	1.4	0.70	34,350
3.6. Distribution Group Headers with Valves and Flowmeters	128	197	0.8	1.4	1.12	17,470
3.7. Multiple Forced Coolant Circuit (MFCC) Pipelines	342	268	0.5	1.4	0.70	38,500
3.8. MFCC Pumps & Motors	848	72	0.4	1.2	0.50	7,430
3.9. MFCC Valves	111	268	0.5	1.4	0.70	12,500
4. AUXILIARY SYSTEMS	275	-	-	-	-	84,390
4.1. Pipelines of Control Rod Cooling Channels (above reactor) + Hangers	9.2 + 2.3	2,510	0.8	1.4	1.12	4,220
4.2. Pipelines for Control Rod Cooling Channels (under reactor) + Hangers	8.2	2,510	0.5	1.8	0.90	4,070
4.3. Pipelines, Valves + Equipment in Conrol Rod System rooms	3.5 + 4.4	620	0.8	1.4	1.12	23,540
4.4. Pipelines of FCICS	18.2	2,740	0.5	1.4	0.70	8,170

Table 3.1. (contd.)

Equipment and Systems	Weight, t	Const., person -hr/t	K_{dem}	K_{over}	K_{tot}	Dismantling, person-hr
4.5. Equipment in Rooms of Fuel Channel Integrity Control System (FCICS) (outside reactor cavity)	34.8	1,250	0.8	1.4	1.12	6,890
4.6. Equipment of System for Control of Fuel Rods Integrity	23 + 100	120	0.5	1.2	0.60	5,310
4.7. Pipelines of the Cooling Circuit of Water Biological Shielding (circular biological shields)	4.7	520	0.7	1.4	0.98	2,120
4.8. Gas and Steam-Gas Pipelines (reactor top)	13.3	520	0.7	1.4	0.98	6,000
4.9. Gas and Steam-Gas Pipelines (reactor bottom)	14.8	520	0.8	1.4	1.12	6,660
4.10. Emergency Cooling Pipelines	28.4	750	0.5	1.0	0.50	12,780
4.11. Pipelines of Long-time Cooling System	8.5	750	0.5	1.0	0.50	3,830
4.12. Pipelines of Prompt Safety System	1.7	750	0.5	1.0	0.50	800

Note that these Russian estimates for development of design documentation were not accounted for in the cost estimate provided in this study. The corresponding costs as well as the costs of manufacturing of the required set of technical equipment in the current cost estimate were calculated using the CECF and U.S. experience for a BWR.

3.3.2 Labor Hour Estimating for Isolation of the Reactor Structures

The Russian labor hours for isolating the reactor structures were estimated for the following activities:

- manufacturing and mounting of individual and group plugs for top load-bearing structure tracts (the total mass of about 10 tons)
- manufacturing and mounting of individual and group plugs for bottom load-bearing structure tracts (the mass of about 10 tons)
- manufacturing and mounting of a carrying ceiling above the reactor, designed to bear falls of heavy things (the mass is 150 tons)
- manufacturing and mounting of metal structures to seal the drums of the system for monitoring the integrity of technological channels in the concrete cavity (the mass is about 5 tons)
- manufacturing and mounting of metal structures to seal the drums of the control and protection system in the concrete cavity (the mass is about 5 tons)
- sealing of other process bypasses (the total mass of the structures is up to 10 tons).

The total Russian costs of manufacturing and mounting these sealing structures (total mass of about 200 tons) were estimated using the norm cost for mounting one tonne of the corresponding structures equal to 2,600 rubles per tonne (January 1998 costs). With the total correcting factor specified by Russian experts as 2 to account for work under radiation and cramped conditions, the total cost of these activities is $200 \times 2,600 \times 2 = 1,040,000$ rubles (January 1998 costs).

Then, with an average salary of a construction worker equal to 3,000 rubles a month, the direct labor hours for manufacturing and mounting these sealing structures with the mass of 200 tons will be $1,040,000,000 \times 0.25/3,000 = 90$ man-month.

3.3.3 Labor Hour Estimate for Final Dismantling of the Reactor Structures

The Russian labor hours for final dismantling of the reactor structures were estimated for the following activities:

- development of the project for activities and technological process
- development of the design documentation for technological and dismantling equipment
- manufacturing of technological equipment
- opening of protection barriers, engineering inspection and manufacturing of preparational activities for dismantling
- final dismantling of the reactor structures.

The direct labor for the reactor structure dismantling were estimated according to the described method. Some reactor structures have a rather large mass of about 600 tons and with their serpentine filling—more than 1000 tons. Therefore, it was supposed that dismantling these structures includes cutting them into separate fragments at the site and their further removal. The corresponding correcting factors and Russian direct labor estimates for dismantling the remaining reactor structures are given in Table 3.1.

Besides dismantling of the reactor structures, Russian estimates also include labor for design work (300 man-month) and the inspection and preparational work (960 man-month) required when the barriers are removed. According to the Russian estimates, manufacturing of technological equipment required for dismantling will require an additional 3.5 million rubles (January 1998 costs).

Note again, that the Russian labor estimates for opening the barriers, inspection, and preparatory activities for dismantling as well as design work were not used in the cost estimate. The corresponding costs were accounted for using the CECF according to the U.S. experience in such activities.

3.3.4 Operational Labor Estimates

The Russian estimates of operational labor include operation of a facility for radioactive waste processing during safe storage and reactor dismantling and maintenance of the unit systems and equipment remaining in operation. The estimates for operation of a radioactive waste processing facility assumes the facility will be in operation for 12 years during safe storage (10 to 22 years after reactor shutdown). During this time all radioactive waste from partial dismantling of the reactor structures and turbine hall equipment must be processed. Then the facility is conserved up to the stage when the reactor structures are finally dismantled. At this stage the facility will be in operation for about five years. During this period all radioactive waste from the final dismantling of the reactor structures must be processed. Only the safe storage operational personnel were costed using the CECF.

3.4 Description of Spreadsheet Calculations

Four major calculations not covered by the CECF were performed in a spreadsheet: reactor dismantling, reactor localization, construction of the radioactive waste processing and storage

complex, and final demolition and site restoration. The reactor calculations were not preformed using the CECF because of the lack of similarity between the BWR and the RBMK reactors. The construction costs were not covered by the CECF because construction of radioactive waste facilities is not considered a decommissioning activity in the U.S.

The reactor dismantling and localization labor costs were estimated using Russian estimates of man-hours and a typical crew, as defined in the CECF. The wages and crew mix of personnel used in the spreadsheet were identical to those used in the CECF. Waste packaging (both U.S. and Russian Conditions), and shipping and burial (U.S. Conditions only) costs associated with reactor dismantling and localization were estimated using factors developed from the baseline BWR cost estimate developed for the NRC using the CECF.

Construction costs of the radioactive waste processing and storage facilities were based on Russian estimates of man-hours for conversion of Unit #1 rooms and on assumed other associated facilities (i.e., power plant and warehouse) to be constructed. Again, the typical decommissioning crew and crew wages used in the CECF were used to convert man-hours to labor costs for the radioactive waste facility construction. Standard U.S. construction factors were used to develop cost estimates for an assumed 1000-m² warehouse and a 1000 m² power plant.

The final demolition and site restoration costs were estimated using the demolition and site restoration costs of the reference BWR costs estimated using the CECF. Costs for BWR site areas not found at an RBMK site (e.g., cooling towers) were deleted from the original costs using the spreadsheet.

For all the above costs, Russian condition costs were estimated using the same factors used to convert the CECF cost estimates.

A detailed description of the spreadsheet calculations are provided in Appendix C.

3.5 List of Activities Accounted For in the Preliminary Cost Estimate

The cost for the Leningrad NPP Unit #1 decommissioning was estimated for the stages and for the list of main procedures given in Table 2.18. However, several activities listed in Table 2.18 were not accounted for in the cost estimate:

- The cost of non-decommissioning activities. The cost of these activities should be included in the operational costs. These activities include the unit shutdown and cooling, spent nuclear fuel handling, handling of operational radioactive waste, and operation of site storage for spent nuclear fuel and operational radioactive waste.
- The activities whose costs are difficult to estimate. The research and analysis needed were not covered by this study. Activities in this category include preparation of the cooling ponds and the site storages for spent nuclear fuel, revision and reconstruction of the unit systems and equipment required and the final disposition of radioactive waste for these activities, radiation monitoring, sorting and storage of radioactive waste for limited and unlimited use, personnel training, and other activities.
- The activities whose costs can be estimated only after the decommissioning project and other required design and working documentation are developed. These activities include development of regulations for activities, dismantling of structures not used, and others.
- The cost of equipment necessary for constructing a facility for processing and storage of processed radioactive waste. The cost estimates are only approximate; they do not include

the cost of the radioactive waste facilities dismantling after decommissioning, the cost of graphite handling after the reactor structures are dismantled, and the cost of final removal of spent nuclear fuel and processed radioactive waste from the NPP site.

A list of activities accounted for in the cost estimate for the decommissioning alternative recommended for the Leningrad NPP Unit #1, is given in Table 3.2. The activities listed in Table 3.2 include all the main activities to be done for the decommissioning alternative and can be costed using the CECP, for the most part.

Because of the differences in RBMK and BWR designs, the CECP was not used to estimate cost for a number of tasks. Russian experts estimated labor hours for the following decommissioning procedures: development of the unit decommissioning project with the end state chosen, i.e., with construction of a facility for radioactive waste reprocessing and storage in certain rooms of the unit; construction and mounting work to prepare the unit rooms for building this facility, and total dismantling of the reactor structures after the safe storage stage. The labor costs of the RBMK unit preparation for its safe storage were calculated for dismantling of parts of the reactor structures and systems; isolation of the remaining reactor structures; sealing of process, vent, and other tracts; isolation of the area in which the reactor structures remain.

To prepare the reactor structures for safe storage, it was supposed necessary to dismantle the process and CPS channels, equipment, pipelines and other elements located above the metal structures of the top load-bearing structure; equipment, pipelines and other elements located below the metal structures of the bottom load-bearing structure; and to dismantle some of the structure located out of the concrete cavity.

It was assumed that before dismantling, preparation would be needed. This includes mounting of required transport means, layout of electric and gas supply, local vent exhausters, as well as mounting and tuning of the dismantling equipment, including lines for fragmentation of solid radioactive waste. Also, to dismantle the reactor systems and equipment during preparation for safe storage, as well as to segment the equipment and pipelines, it will be necessary to develop and manufacture a set of the corresponding technical equipment. At this stage, the experts defined only the main types of dismantling equipment required: equipment for mechanical, thermal and explosive cutting of the pipelines and tracks; equipment for cutting off the technological and other channels; equipment for cutting upper and lower coolant channels; a set of automatic and half-automatic weight catchers; special reusable containers for transportation of solid radioactive wastes to the processing area; a local line with a shearing press; and other special equipment and tools.

Based on current experience in repairing and reconstructing RBMK units, it was estimated that development of more than 100 items of equipment and tools could be required to dismantle the reactor structures. For comparison, about 360 special equipment and tools were developed for RBMK reconstruction and repairs.

The remaining reactor structures should be completely dismantled, segmented, and removed after safe storage. The decommissioning labor hours were estimated assuming the current level of dismantling equipment and technologies. These activities will be performed 50–70 years after reactor shutdown, and it is difficult to predict the level of the technical progress for that time.

Table 3.2. List of Activities Costed for the SAFSTOR Decommissioning Alternative
Recommended for Leningrad NPP Unit #1^(a)

Stage and Activities	Work schedule, yr	
	Start	End
A. Pre-Shutdown Stage	-5	0
1. <i>Not taken into account for cost estimations</i>	-	-
2. Develop organizational and technical documentation:		
2.1. Develop an overall concept for decommissioning Phase I units		
2.2. Develop a program for a comprehensive survey of the unit		
2.3. Develop unit decommissioning plan		
2.4. Develop specification for development of a unit decommissioning project		
2.5. Create a database of information for unit decommissioning		
3. Start the purchase of special equipment		
4. <i>Not taken into account for cost estimations</i>	-	-
B. Preparation for Unit Decommissioning Stage	0	5
1. <i>Not taken into account for cost estimations</i>	-	-
2. <i>Not taken into account for cost estimations</i>	-	-
3. <i>Not taken into account for cost estimations</i>	-	-
4. <i>Not taken into account for cost estimations</i>	-	-
5. Comprehensive inspection of unit and experimental design work to develop a unit decommissioning project	1	3
6. Development and approval of required organizational, technical, and design documentation:	1	5
6.1. <i>Not taken into account for cost estimations</i>	-	-
6.2. Development and approval of the unit decommissioning project		
6.3. Official registration of decommissioning license		
6.4. Development of specification and distribution of orders for manufacturing of required dismantling equipment		
6.5. <i>Not taken into account for cost estimations</i>	-	-
7. <i>Not taken into account for cost estimations</i>	-	-
8. <i>Not taken into account for cost estimations</i>	-	-
9. <i>Not taken into account for cost estimations</i>	-	-
C. Preparation for Safe Storage Stage	5	10
1. Decontamination work:	5	6
1.1. <i>Not taken into account for cost estimations</i>		
1.2. Standard decontamination and drainage of multiple forced circulation circuit		
1.3. Decontamination and drainage of other process circuits and the nuclear fuel cooling ponds		
2. Deactivation of systems and equipment not required for decommissioning	5	5
3. <i>Not taken into account for cost estimations</i>	-	-
4. Isolation of the reactor in place to prevent radionuclides from escaping	6	8
4.1. Dismantle reactor system elements and structures obstructing reactor isolation		
4.1.1. Dismantling of technological channels and channels of control and protection system		
4.1.2. Dismantling of equipment, pipes, and structures above top load-bearing structure		
4.1.3. Dismantling of equipment, pipes, and structures below bottom load-bearing structure		
4.2. Isolate the other reactor structures		
4.2.1. Installation of plugs in circuits of the top load-bearing structure		
4.2.2. Installation of plugs in circuits of the bottom load-bearing structure		
4.2.3. Installation of protective floor above the reactor		
4.3. Seal ventilation, cable, and pipe runs from the reactor cavity		
4.4. Total isolation of the reactor construction space		

Table 3.2. (contd.)

Stage and Activities	Work schedule, yr	
	Start	End
5. Bringing unit rooms into compliance with radiological and health requirements so that they can be used as temporary processed radioactive waste storage facilities	5	6
5.1. Decontaminate reactor section equipment and rooms		
5.2. Organize temporary storage for dismantled equipment in the turbine hall		
5.3. Remove thermal insulation from equipment, piping, and structures		
5.4. Dismantle and transport equipment and systems from unit rooms designated for radioactive waste storage to sites of temporary storage		
6. Construction of the radioactive waste storage and processing complex:	5	10
6.1. Prepare and refurbish unit rooms to store conditioned radioactive waste		
6.2. Partially dismantle turbine hall equipment to make room for the radioactive waste processing complex		
7. <i>Not taken into account for cost estimations</i>	-	-
8. Operations and maintenance:	5	10
8.1. Regularly inspect, repair and operate required equipment and systems of unit		
8.2. <i>Not taken into account for cost estimation</i>		
8.3. <i>Not taken into account for cost estimation</i>	-	-
9. <i>Not taken into account for cost estimations</i>	-	-
D. Long-Term Safe Storage Stage	10	80
1. Preparation of warehousing and temporary storage of wastes permitted for restricted and unrestricted use.	10	15
2. Construction and installation of the radioactive waste processing complex	10	15
3. Dismantling of equipment and systems outside the reactor isolation area	10	20
3.1. Completely dismantle turbine hall equipment		
3.2. Dismantle reactor section equipment and systems (as radioactivity declines)		
4. Conditioning, transportation and disposition of radioactive wastes for their storage	15	20
5. Operations and maintenance:	10	80
5.1. Regularly inspect, repair and operate required equipment and systems		
5.2. <i>Not taken into account for cost estimation</i>		
5.3. <i>Not taken into account for cost estimation</i>		
6. <i>Not taken into account for cost estimations</i>	-	-
E. Dismantling and Demolition of Reactor Structures Stage	80	85
1. Removal from storage and inspection of equipment, systems and structures	80	81
2. <i>Not taken into account for cost estimations</i>	-	-
3. Dismantling of reactor structures	82	84
3.1. Install required equipment, power-supply, and dust suppression and gas purification systems		
3.2. Install equipment to dismantle reactor structures		
3.3. Open protective engineering barriers and remove structures obstructing access to reactor		
3.4. Dismantle reactor structure elements		
4. Handling of radioactive waste created during dismantling	82	85
4.1. Dismantle, complete radiological inspection and sort reactor units, reactor metal structure fragments and graphite		
4.2. Package and remove reactor structure elements		
4.3. Process radioactive waste		
4.4. Transport processed radioactive waste to rooms prepared for radioactive waste storage		
5. <i>Not taken into account for cost estimations</i>	-	-
6. Cleaning or decontamination of the concrete surface of the reactor cavity (if necessary)	84	85
7. Operations and maintenance	80	85
7.1. Regularly inspect, repair and operate required equipment and systems		
7.2. <i>Not taken into account for cost estimation</i>		
7.3. <i>Not taken into account for cost estimation</i>		

Table 3.2. (contd.)

Stage and Activities	Work schedule, yr	
	Start	End
8. <i>Not taken into account for cost estimations</i>	-	-
9. <i>Not taken into account for cost estimations</i>	-	-
10. Decontamination and dismantling of equipment used in dismantling	84	85
11. Final survey of unit structures and site	84	85

(a) A full list of main decommissioning procedures is presented in Table 2.18.

According to the recommended decommissioning alternative no expensive remote-controlled robots are supposed to be created to dismantle the structures, because the estimates show that due to decrease in the radioactive level after safe storage the personnel can dismantle these structures without any limits.

The mass of the main reactor structures, including a serpentinite mixture filling, is rather large (the mass of some structures is more than 1,000 tons). Therefore, the dismantling and removal technologies should include cutting the structure into segments in place prior to removal.

The final dismantling of the reactor structures should begin with the dismantling of the top load-bearing structure, then the graphite stack blocks should be disassembled with the remaining parts of the upper and lower tracts. After this, the metal structures of the cylindrical liner and water protection tanks would be dismantled. Dismantling of the bottom load-bearing structure and the cross support completes the dismantling of the reactor structures.

It was supposed that the reactor structures could be cut with technologies, such as oxygen cutting, plasma cutting, or arc cutting. Explosive charges could be used to cut tubes of the top or bottom load-bearing structures. It was estimated that the total mass of the structures to be dismantled could be about 7,000 tons, while the mass of the serpentine and sand fillings to be removed—up to 5,000 tons.

The blocks of the reactor graphite stack could be dismantled and removed in several ways: for example, slice-by-slice, by columns of several blocks or by combination of these ways. When the graphite stack is dismantled, the reactor space could be filled with water to suppress dust production and to improve the radiation conditions.

Before dismantling, a number of preparational operations should be done. These operations relate to opening engineering barriers, revising and preparing equipment, transportation, and other means, mounting of special ventilation, etc. The corresponding technologies for dismantling of the reactor structures should be prepared, and the project plan and destruction or reconstruction of the remaining buildings of the unit should be developed.

In conclusion, the list of the main procedures described in this report should not be considered as complete and final. The final list of activities will be determined only after the unit decommissioning project is developed. It can also be supposed that this project will provide details for the decommissioning activities to be done within next 10–15 years.

Changes in the legislative and regulatory environment, development of new techniques and technologies, and possible changes in Russian economic conditions could cause a change in the concept and strategy for decommissioning NPP units in Russia. In this connection, this study was

not aimed to provide a detailed list and sequence of main procedures required for the decommissioning alternative recommended for the Leningrad NPP Unit #1. The list of main procedures presented in this report was prepared to provide a basis for cost estimating complete enough for the recommended decommissioning alternative.

3.6 Input Data Used for Cost Estimating

Two types of input data were required for cost estimating: inputs for the CECF code and inputs for calculations done in a spreadsheet using the U.S. Cost methodology and Russian labor hour estimates. As already noted, costs that cannot be estimated using the CECF require direct labor input. Table 3.3 contains direct labor hour estimates for the reactor structure dismantling and decontamination of areas required for packing and storage of processed radioactive wastes.

The labor hour estimates required for the cost calculations are given for specific activities and operations at the corresponding stages of the chosen decommissioning alternative. These labor costs were estimated by the Russian methodology described above for the necessary decommissioning activities on partial dismantling of the reactor structures while the reactor is prepared for localization, on localization of the reactor structures at their site, and on final dismantling of the reactor structures.

This table also contains Russian labor cost estimates for design work and for operation of the radioactive waste processing facility as well as the unit systems and equipment necessary at the stage of unit safe storage. The labor costs of operation of the unit systems and equipment were estimated taken into account the experience on operation and maintenance of the Leningrad NPP units as well as the existing U.S. experience.

Data on mass and dimensional parameters of the structures, equipment and systems of an RBMK unit that significantly differ from those for a BWR unit were required as input data for the CECF code calculations. Necessary data on mass and dimensional parameters of the equipment and systems of an RBMK unit are presented in Table 3.4. Note that this table contains the mass and dimensional parameters related only to the main equipment and systems typical for an RBMK unit.

The data presented in Table 3.4 were summarized by several sections of the table related to main equipment and systems of the reactor section ("A" Block), equipment and system of the turbine hall ("G" Block), auxiliary systems ("D" and "V" Blocks), thermal insulation materials (reactor section), cables (without supporting structures), and some other unit auxiliary systems (in particular, vent systems).

A study of the WNP-2 BWR plant in Richland, Washington suggested that the following formula could be used as a very rough estimate for the weight of a single hanger:

$$W = 388D + 23.7$$

where W is the hanger weight in kilograms, and D is the diameter of the pipe in meters.

The data that are provided in Table 3.4 give the weight of the hangers used on piping of a certain diameter. To get the number of hangers, a needed input, D was used to get W and then W was divided into the total weight of the hangers for pipes of the same diameter.

Table 3.3. Labor Hours and Input Data Used for Cost Estimating of Leningrad NPP Unit #1 Decommissioning

Components of Cost Estimations (stages and activities of Table 2.18)	Input data, pers-hr or m ^{2(a)}	Notes
A. Planning Activities for Unit Decommissioning	636,000 pers-hr	Russian estimation of pers-hr for Items: 1,2, and 4
1. Comprehensive survey of unit and experimental design necessary to develop a unit decommissioning project (Stage 2: Item 6)	+	
2. Development and approval of the unit decommissioning project (Stage 2: Item 7.2)	+	
3. Official registration of decommissioning license (Stage 2: Item 7.3)	+	CECP estimation
4. Development of specification and distribution of orders for manufacturing of required dismantling equipment (Stage 2: Item 7.4)	+	
B. Preparation for Unit Decommissioning		
1. Standard decontamination and drainage of MFC circuit (Stage 2: Item 5.2)	12,000 m ²	summary surface of MFCC
2. Decontamination and drainage of the process circuits and nuclear fuel cooling ponds (Stage 2: Item 5.3)	19,500 ^(b) +1,200 m ²	surface of process circuits and nuclear fuel cooling ponds
C. Preparation for Long-Term Safe Storage	2,103,200 pers-hr	Russian estimation of pers-hr for Items: 4,5,6,7,8,9,10, and 11
1. Deactivation of systems and equipment not required for decommissioning (Stage 3: Item 1)	+	3,500 pers-hr
2. Rebuild standard heating and ventilation, power supply, sewage, fire and radiation safety, and other necessary systems (Stage 3: Item 2.1)	-	1,400 pers-hr
3. Upgrade or installation of dosimetry and radiological inspection systems (Stage 3: Item 2.2)	-	53,000 pers-hr
4. Dismantling of technological channels and channels of control and protection system (Stage 3: Item 3.1.1)	+	
5. Dismantling of equipment, pipes, and structures above the top load-bearing structure (Stage 3: Item 3.1.2)	+	
6. Dismantling of equipment, pipes, and structures below bottom load-bearing structure (Stage 3: Item 3.1.3)	+	
7. Installation of plugs in circuits of the top load-bearing structure (Stage 3: Item 3.2.1)	+	
8. Installation of plugs in circuits of the bottom load- bearing structure (Stage 3: Item 3.2.2)	+	
9. Installation of protective floor above the reactor (Stage 3: Item 3.2.3)	+	
10. Seal ventilation, cable, and pipe runs from the reactor cavity (Stage 3: Item 3.3)	+	
11. Total isolation of the reactor construction space (Stage 3: Item 3.4)	+	
D. Dismantling of Reactor Structures	531,000 pers-hr	Russian estimation of pers-hr for Items: 2,3,4, and 5
1. Training of unit personnel (Stage 5: Item 2)	-	35,000 pers-hr
2. Install required equipment, power-supply, and dust sup- pression and gas purification systems (Stage 5: Item 3.1)	+	

Table 3.3. (contd.)

Components of Cost Estimations (stages and activities of Table 2.18)	Input data, pers-hr or m ^{2(a)}	Notes
3. Install equipment to dismantle reactor structures (Stage 5: Item 3.2)	+ ^(b)	equipment cost was accounted for using CECP methodology
4. Open protective engineering barriers and remove structures obstructing access to reactor (Stage 5: Item 3.3)	+	
5. Dismantle reactor structure elements (Stage 5: Item 3.4)	+	
E. Operations		
1. Regularly inspect, repair, and operate required equipment and systems of unit:		
- during the preparation stage for unit decommissioning (Stage 3: Item 7.1)	255,000 pers-hr/yr	Russian estimation ^(b)
- during the stage of unit safe storage (Stage 4: Item 5.1)	255,000 pers-hr/yr	Russian estimation ^(b)
- during the stage of reactor structure dismantling (Stage 5: Item 7.1)	255,000 pers-hr/yr	Russian estimation ^(b)
2. Operate the spent nuclear fuel storage facility		
- during the preparation stage for unit decommissioning (Stage 3: Item 7.2)	-	
- during the unit safe storage stage (Stage 4: Item 5.2)	-	
- during the reactor structure dismantling stage (Stage 5: Item 7.2)	pers-hr = 0	nuclear spent fuel handling is absent
3. Operate the radioactive waste processing and storage complex		
- during the preparation stage for unit decommissioning (Stage 3: Item 7.3)	-	
- during the stage of unit safe storage (Stage 4: Item 5.3)	-	1,200,000 pers-hr
- during the reactor structure dismantling (Stage 5: Item 7.3)	-	280,000 pers-hr
F. Construction of Radioactive Waste Processing and Storage Complex	173,790+79,815 +656,000 pers-hr	Russian estimation of pers-hr for Items: 1+2, 5+6, and 8
1. Decontaminate reactor section equipment and rooms (Stage 3: Item 4.1)	+	
2. Organize temporary storage for dismantled equipment in the turbine hall (Stage 3: Item 4.2)	+	
3. Remove thermal insulation from equipment, piping and structure (Stage 3: Item 4.3)	- ^(b)	318,500 pers-hr
4. Dismantle and transport equipment and systems from unit rooms designated for radioactive waste storage to sites of temporary storage (Stage 3: Item 4.4)	+	Calculated by CECP
5. Prepare and refurbish unit rooms to store processed radioactive waste (Stage 3: Item 5.1)	+	
6. Partially dismantle turbine hall equipment to make room for the radioactive waste processing complex (Stage 3: Item 5.2)	+	according to Russian estimations, it is equal to 40% of total cost of turbine hall dismantling
7. Preparation of warehousing and temporary storage of wastes permitted for restricted and unrestricted use (Stage 4: Item 1)	2,000 m ²	cost estimation for construction of covered place outside unit
8. Construction and installation of the radioactive waste processing complex (Stage 4: Item 2)	+	equipment cost accounted for according to American methodology

(a) "+" or "-" - it is accounted for or not accounted for in cost estimating.

(b) It is accounted for using the BWR defaults instead of Russian estimates.

4.0 Results

Table 4.1 shows the results for the Leningrad NPP Unit #1 decommissioning cost estimate. As explained in this document, the U.S. condition estimates represent the cost of decommissioning the Leningrad NPP Unit #1 if it were in the United States, given U.S. economic conditions and waste management capabilities. The Russian condition estimates represent the cost of decommissioning the Leningrad NPP Unit #1 in Russia, given the Russian economic conditions and waste management capabilities. The estimates represent the costs associated only with decommissioning activities. That is, the costs associated with operating the NPP after shutdown (prior to decommissioning), socioeconomic impacts, and the operating of the waste processing and storage facility are not included in the estimates.

Table 4.1. Leningrad NPP Unit #1 Decommissioning Cost Estimates

Phase	U.S. Conditions	Russian Conditions
Decommissioning Planning	\$13.4M	\$5.9M
Decommissioning Preparation	\$6.8M	\$2.6M
Preparation for Safe Storage	\$116.1M	\$39.4M
Safe Storage	\$250.2M	\$86.9M
Final Decommissioning	\$114.6M	\$39.8M
Waste Disposal (final decommissioning)	\$322.1M	Unknown
Total	\$823.1M	\$174.7M + Waste Disposal

Table 4.1 shows that the Decommissioning Planning and Preparation Phases, Russian Conditions, would be approximately \$8.5M compared with \$20.2M for the same phases in the United States. The decommissioning planning and preparation phases under the Russian conditions would take a total of ten years. Therefore, planning and preparation for decommissioning would cost approximately \$1M per year over a ten-year period.

The results also show that the Russian Preparation for Safe Storage phase would cost approximately \$39.4M. The total cost would be spread over a five-year period and would cost approximately \$8M per year. This compares with \$116.1M over two years for the same reactor in the United States, or approximately \$60M per year.

Beyond the preparation phases the Russian estimates have less meaning because it is expected and hoped that the Russian economic situation will continue to improve. As the economy improves, one could expect the out-year costs shown under the Russian conditions would increase and become more similar to the U.S. conditions.

It should also be noted that the costs of processing, storing and final disposal of the waste have not been costed under the Russian conditions. Also, the waste processing and storage costs are operational costs associated with the waste storage facility and are therefore not included. The final waste disposal has not been costed because the final disposition of the waste is unknown at this time. Russia currently has no centralized waste disposal facility, and it is unknown if, when or where such a facility might be built or what costs would be associated with using such a facility. If the U.S. conditions are an indicator, the Russian costs associated with waste disposal would be at least as much as the final decommissioning costs.

Table 4.2 shows the percentage breakout of costs by phase for both the U.S. Condition and for the Russian Condition. It should be noted that for both the U.S. and Russian Conditions, seventy to seventy-five percent of the total costs are in the last two phases, Safe Storage and Final Decommissioning.

Table 4.3 shows the breakout of costs and the percentage breakout by activity. Note the cost estimates are without the 25% contingency included in Table 4.1. For the U.S. Conditions, approximately 50% of the total decommissioning cost estimate is due to removal of equipment and structures, and utility staff labor. The percent contribution of utility staff labor cost for the Russian conditions is similar to that under the U.S. conditions. However, the removal of equipment and systems cost percentage is much less because only the packaging cost is included in the Russian condition estimate while transportation and burial are included in the U.S. conditions estimate.

The detailed cost estimate results are presented in Appendix B.

Table 4.2. Percentage of Total Decommissioning Cost by Phase

Decommissioning Phase	U.S. Conditions	Russian Conditions
1. Decommissioning Planning	1.6	3.4
2. Decommissioning Preparation	0.8	1.5
3. Preparation for Safe Storage	14.4	22.5
4. Safe Storage	56.5	49.7
5. Final Decommissioning	26.8	22.8
Total, %	100	100

Table 4.3. Costs and Percentages by Activity

Decommissioning Activity Costs	U.S. Conditions		Russian Conditions	
	U.S. \$ (M)	%	U.S. \$ (M)	%
1. Reactor Localization	36.2	5.5	9.0	6.4
2. Removal of Reactor Structures	71.7	10.9	4.6	3.3
3. Removal of Equipment and Systems	218.8	33.2	11.3	8.1
4. Demolition & Site Restoration	40.3	6.1	10.1	7.2
5. Radioactive Waste Facility Construction	0	0	6.9	4.9
6. Decontamination	17.2	2.6	2.5	1.8
7. Dry Active Waste (Packaging + Shipping + Burial)	8.5	1.3	0.6	0.4
8. Utility Staff	134.4	20.4	28.3	20.3
9. DOC Staff (including overheads)	31.4	4.8	10.1	7.2
10. Nuclear Liability Insurance	56.2	8.5	13.4	9.6
11. Environmental Monitoring	4.1	0.6	4.4	3.1
12. Plant Power Usage	5.1	0.8	1.1	0.8
13. Special Tools and Equipment	3.9	0.6	2.7	1.9
14. Site Termination Survey	1.2	0.2	0.3	0.2
15. Surveillance and Maintenance during Safe Storage	1.4	0.2	1.0	0.7
16. Other Costs (Regulatory, Experts, Laundry Services, etc.)	28.2	4.3	33.5	24.0
Total (without contingency)	658.4	100	139.7	100

5.0 Conclusions and Recommendations

5.1 Conclusions

The cost associated with getting the Leningrad NPP Unit #1 into a safe storage condition is relatively inexpensive: approximately \$48M over 15 years, or less than \$1M per year for ten years followed by \$8M per year for five years. Once in a safe storage configuration, the reactor would be unusable without large expenditures and would be in a safe configuration until final decommissioning was performed. Safe storage also delays the outlay of large expenditures (\$87M for safe storage and \$40M for final decommissioning) and delays the generation of large quantities of waste that would only incur further costs as they would have to be processed and stored until final disposal could be arranged. Given the economic conditions in Russia and the fact that final disposition options have yet to be defined, keeping initial costs low and minimizing the waste to be generated while ensuring safety are the logical choice.

The safe storage alternative was selected in the first Leningrad NPP Unit #1 decommissioning study based on technical, technological, safety and economic feasibility. The current study results show the safe storage alternative is beneficial for the current Russian economic conditions.

The work performed during the two Leningrad NPP Unit #1 decommissioning studies should serve as a basis for all future decommissioning work in Russia and could be used for other Former Soviet Union RBMK sites.

5.2 Recommendations

There are many recommendations that were made in the final report for the decommissioning strategy study that was performed for the Leningrad NPP Unit #1. Those recommendations are not repeated here.

The recommendations that resulted from the decommissioning cost estimating study reported in this report are as follow:

- The BWR CECP should be modified to: provide cost estimates for the RBMK reactor systems and structures, and provide dose rate estimates for decommissioning activities. The resulting model would be an RBMK decommissioning cost and dose rate model.
- An insurance system needs to be developed for NPP decommissioning in Russia.
- The Russian radioactive waste disposal concept that has been defined should be implemented to satisfy future NPP decommissioning requirements.

Appendix A

Data Input

Table A.1.

MENU F INPUTS --	
1 RPV: Height (meters)	13.081
2 RPV: Diameter (meters)	4.826
3 RPV: Height adjustment (%)	0.000
4 RPV: Respiratory protection adjust. (%)	20.000
5 RPV: Rad/ALARA activities (min)	25.000
6 RPV: Plasma-arc torch change-out factor (%)	46.000
7 RPV: Suit-up and unsuit time (min)	120.000
8 RPV: Work break time (min)	30.000
9 RPV: Number of laborers	4.000
10 RPV: Number of crafts	3.000
11 RPV: Number of crew leaders	1.000
12 RPV: Number of rad monitors	1.000
13 RPV: Dose rate, for removing int. (milliSv/hr)	0.100
14 RPV: Dose rate, for cutting vessel (milliSv/hr)	0.300
15 RCS Pipe (< .45): Total Length of piping (m) (This is the sum of the lengths of Table 6, items 1.3.1, 1.3.2, 1.3.5, and 1.3.6)	79705.400
16 RCS Pipe (< .45): Total Weight of piping (kg) (This is the sum of the weights of Table 6, items 1.3.1, 1.3.2, 1.3.5, and 1.3.6)	801000.000
17 RCS Pipe (< .45): Total Volume of piping (m ³)	583.000
18 RCS Pipe (< .45): Removal time (min)	50.000
19 RCS Pipe (< .45): Height adjustment (%)	10.000
20 RCS Pipe (< .45): Respiratory protection adjust. (%)	20.000
21 RCS Pipe (< .45): Rad/ALARA activities (min)	25.000
22 RCS Pipe (< .45): Suit-up and unsuit time (min)	120.000
23 RCS Pipe (< .45): Work break time (min)	30.000
24 RCS Pipe (< .45): Number of laborers	3.000
25 RCS Pipe (< .45): Number of crafts	1.500
26 RCS Pipe (< .45): Number of crew leaders	0.500
27 RCS Pipe (< .45): Number of rad monitors	0.500
28 RCS Pipe (< .45): Absorbent material (m ²)	0.000
29 RCS Pipe (< .45): Plastic (m ²)	0.000
30 RCS Pipe (< .45): Gases (hours)	0.000
31 RCS Pipe (< .45): Dose rate (milliSv/hr)	0.000
32 RCS Pipe (.45-.60): Total Length of piping (m)	0.000
33 RCS Pipe (.45-.60): Total Weight of piping (kg)	0.000
34 RCS Pipe (.45-.60): Total Volume of piping (m ³)	0.000
35 RCS Pipe (.45-.60): Removal time (min)	0.000
36 RCS Pipe (.45-.60): Height adjustment (%)	0.000
37 RCS Pipe (.45-.60): Respiratory protection adjust. (%)	0.000
38 RCS Pipe (.45-.60): Rad/ALARA activities (min)	0.000
39 RCS Pipe (.45-.60): Suit-up and unsuit time (min)	0.000
40 RCS Pipe (.45-.60): Work break time (min)	0.000
41 RCS Pipe (.45-.60): Number of laborers	0.000
42 RCS Pipe (.45-.60): Number of crafts	0.000
43 RCS Pipe (.45-.60): Number of crew leaders	0.000
44 RCS Pipe (.45-.60): Number of rad monitors	0.000
45 RCS Pipe (.45-.60): Absorbent material (m ²)	0.000
46 RCS Pipe (.45-.60): Plastic (m ²)	0.000
47 RCS Pipe (.45-.60): Gases (hours)	0.000
48 RCS Pipe (.45-.60): Dose rate (milliSv/hr)	0.000
49 RCS Pipe (.60-.76): Total Length of piping (m)	0.000
50 RCS Pipe (.60-.76): Total Weight of piping (kg)	0.000

Table A.1. (contd.)

MENU F INPUTS --	
51 RCS Pipe (.60-.76): Total Volume of piping (m ³)	0.000
52 RCS Pipe (.60-.76): Removal time (min)	0.000
53 RCS Pipe (.60-.76): Height adjustment (%)	0.000
54 RCS Pipe (.60-.76): Respiratory protection adjust. (%)	0.000
55 RCS Pipe (.60-.76): Rad/ALARA activities (min)	0.000
56 RCS Pipe (.60-.76): Suit-up and unsuit time (min)	0.000
57 RCS Pipe (.60-.76): Work break time (min)	0.000
58 RCS Pipe (.60-.76): Number of laborers	0.000
59 RCS Pipe (.60-.76): Number of crafts	0.000
60 RCS Pipe (.60-.76): Number of crew leaders	0.000
61 RCS Pipe (.60-.76): Number of rad monitors	0.000
62 RCS Pipe (.60-.76): Absorbent material (m ²)	0.000
63 RCS Pipe (.60-.76): Plastic (m ²)	0.000
64 RCS Pipe (.60-.76): Gases (hours)	0.000
65 RCS Pipe (.60-.76): Dose rate (milliSv/hr)	0.000
66 RCS Pipe (> .76): Total Length of piping (m) (This is the sum of the lengths of Table 6, items 1.3.4 and 1.3.7)	341.000
67 RCS Pipe (> .76): Total Weight of piping (kg) (This is the sum of the weights of Table 6, items 1.3.4 and 1.3.7)	60000.000
68 RCS Pipe (> .76): Total Volume of piping (m ³)	124.000
69 RCS Pipe (> .76): Removal time (min)	220.000
70 RCS Pipe (> .76): Height adjustment (%)	10.000
71 RCS Pipe (> .76): Respiratory protection adjust. (%)	20.000
72 RCS Pipe (> .76): Rad/ALARA activities (min)	25.000
73 RCS Pipe (> .76): Suit-up and unsuit time (min)	120.000
74 RCS Pipe (> .76): Work break time (min)	30.000
75 RCS Pipe (> .76): Number of laborers	3.000
76 RCS Pipe (> .76): Number of crafts	1.500
77 RCS Pipe (> .76): Number of crew leaders	0.500
78 RCS Pipe (> .76): Number of rad monitors	0.500
79 RCS Pipe (> .76): Absorbent material (m ²)	1.858
80 RCS Pipe (> .76): Plastic (m ²)	4.645
81 RCS Pipe (> .76): Gases (hours)	0.330
82 RCS Pipe (> .76): Dose rate (milliSv/hr)	0.700
83 RCS Insulation Volume (m ³)	244.500
84 RCS Insulation Weight (kg)	1450.000
85 Structural: Weight (kg)	539463.000
86 Structural: Weight of cable & cable trays (kg)	23535.000
87 Structural: Number of cuts required	772.000
88 Structural: Linear meters of cuts	737.600
89 Structural: Height adjustment (%)	0.000
90 Structural: Respiratory protection adj. (%)	0.000
91 Structural: Rad/ALARA activities (min)	25.000
92 Structural: Suit-up and unsuit time (min)	120.000
93 Structural: Work break time (min)	30.000
94 Structural: Dose rate (milliSv/hr)	0.010
95 Eq Removal Crew: Height adjustment (%)	10.000
96 Eq Removal Crew: Respiratory protection adjust. (%)	20.000
97 Eq Removal Crew: Rad/ALARA activities (min)	25.000
98 Eq Removal Crew: Suit-up and unsuit time (min)	120.000
99 Eq Removal Crew: Work break time (min)	30.000
100 Eq Removal Crew: Number of laborers	3.000

Table A.1. (contd.)

MENU F INPUTS --	
101 Eq Removal Crew: Number of crafts	1.500
102 Eq Removal Crew: Number of crew leaders	0.500
103 Eq Removal Crew: Number of rad monitors	0.500
104 Surf Wash Crew: Suit-up time (minutes)	120.000
105 Surf Wash Crew: Breaks (minutes)	30.000
106 Surf Wash Crew: ALARA (minutes)	25.000
107 Warm-up Wash Crew: Warm-up (minutes)	15.000
108 Surf Wash Crew: Cleanup (minutes)	50.000
109 Surf Wash Crew: Number of laborers	2.000
110 Surf Wash Crew: Number of crafts	1.000
111 Surf Wash Crew: Number of crew leaders	0.500
112 Surf Wash Crew: Number of rad monitors	0.500
113 Surf Wash Crew: Crew dose rate (milliSv/hr)	0.030
114 Surf Wash Crew: Cleansing rate (m ² /min)	0.743
115 Surf Wash Crew: Vacuum hose replacement (\$)	933.000
116 Surf Wash Crew: HEPA filter replacement (\$)	237.000
117 Surf Wash Crew: Misc. parts (\$)	1582.000
118 Surf Wash Crew: Waste water process. (\$/m ³)	299.000
119 Recirc Pumps: Number of pumps	8.000
120 Recirc Pumps: Weight of one pump (kg)	106000.000
121 Recirc Pumps: Volume of one pump (m ³)	57.000
122 Recirc Pumps: Removal. time (1 pump, minutes)	480.000
123 Recirc Pumps: Height adjustment (%)	10.000
124 Recirc Pumps: Respiratory protection adj. (%)	20.000
125 Recirc Pumps: Rad/ALARA activities (min)	25.000
126 Recirc Pumps: Suit-up and unsuit time (min)	120.000
127 Recirc Pumps: Work break time (min)	30.000
128 Recirc Pumps: Absorbent material (m ²)	18.580
129 Recirc Pumps: Plastic (m ²)	46.450
130 Recirc Pumps: Gases (hours)	0.330
131 Recirc Pumps: Dose rate (milliSv/hr)	3.000
132 Recirc Pumps: Shipping cradle cost (\$)	3955.000
133 Recirc Pumps: Shipping cradle weight (kg)	907.000
134 Turbine: Number of turbines	2.000
135 Turbine: Weight (kg)	1788000.000
136 Turbine: Cutting Time (hours/cut)	6.500
137 Turbine: Dose rate (milliSv/hr)	0.010
138 Condenser: Number of condensers	8.000
139 Condenser: Weight (kg)	282000.000
140 Condenser: Cutting Time (hours/cut)	6.500
141 Condenser: Shell & tube bundle area (m ²)	490.000
142 Condenser: Tube bundle cross section (m ²)	4.400
143 Condenser: Cost of material sawed (\$/m ²)	2767.000
144 Condenser: 3 X 3 X 7.6 container cost (\$)	4350.000
145 Condenser: 3 X 3 X 7.6 container weight (kg)	2268.000
146 Condenser: Dose rate (milliSv/hr)	0.010
147 SDS: Number of drum separators	4.000
148 SDS: Weight of each drum separator	278000.000
149 SDS: Number of cuts	80.000
150 SDS: Cutting time (hours/cut)	6.500
151 SDS: Area to be washed (m ²)	360.000
152 SDS: Work difficulty factor	1.200

Table A.1. (contd.)

MENU F INPUTS --	
153 SDS: Dose rate (milliSv/hr)	0.010
154 Deaerators: Number of deaerators	4.000
155 Deaerators: Weight of each deaerator (kg)	73000.000
156 Deaerators: Number of cuts	50.000
157 Deaerators: Cutting time (hours/cut)	6.500
158 Deaerators: Area to be washed (m ²)	234.000
159 Deaerators: Work difficulty factor	1.200
160 Deaerators: Dose rate (milliSv/hr)	0.010
161 Bubblers: Number of Bubblers	2.000
162 Bubblers: Weight of each deaerator (kg)	91000.000
163 Bubblers: Number of cuts	50.000
164 Bubblers: Cutting time (hours/cut)	6.500
165 Bubblers: Area to be washed (m ²)	243.000
166 Bubblers: Work difficulty factor	1.200
167 Bubblers: Dose rate (milliSv/hr)	0.010
168 Feed Pump: Number of pumps	5.000
169 Feed Pump: Weight of each pump (kg)	29600.000
170 Feed Pump: Dose rate (milliSv/hr)	0.010
171 FW Heaters: Number of heaters	12.000
172 FW Heaters: Weight of each heater (kg)	56300.000
173 FW Heaters: Dose rate (milliSv/hr)	0.010
174 MSRs: Number of MSRs	8.000
175 MSRs: Weight of each MSR (kg)	119000.000
176 MSRs: Number of cuts	27.000
177 MSRs: Cutting time (hours/cut)	6.500
178 MSRs: Area to be washed (m ²)	146.000
179 MSRs: Work difficulty factor	1.200
180 MSRs: Dose rate (milliSv/hr)	0.010
181 Fuel Racks: Weight of all fuel racks (kg)	276125.000
182 Fuel Racks: Large plastic bags, each (\$)	872.000
183 Fuel Racks: Removal contract (\$)	93437.000
184 Fuel Racks: Dose rate (milliSv/hr)	0.010
185 Sac Shield: Subcontractor costs (\$)	84750.000
186 Sac Shield: Person-hours	3600.000
187 Sac Shield: Estimated dose (person-Sv)	0.457
188 Chem Decon: Subcontractor costs (\$)	1497250.000
189 Chem Decon: Energy costs (\$)	26894.000
190 Chem Decon: Person-hours	12960.000
191 Chem Decon: Estimated dose (person-Sv)	0.457
192 Chem Decon: Number of HICs required for chem decon	18.000
193 Chem Decon: Number of HICs required for spent IX resin	5.000
194 DS & RFC: Total wall area (m ²)	722.000
195 DS & RFC: Total floor area (m ²)	206.000
196 DS & RFC: Dose Rate (milliSv/hr)	0.010
197 SF Pool: Total wall area (m ²)	641.000
198 SF Pool: Total floor area (m ²)	127.000
199 SF Pool: Volume (m ³)	1540.000
200 SF Pool: Dose Rate (milliSv/hr)	0.010

Table A.2. Menu Item E: Contaminated Systems Costs

Component Description	Category	Disposal	Quantity	Vol (m ³)	Wt (kg)	Dia (m)	L (m)	mSv/hr	Table
System Name: Auxiliary Systems (Primarily Piping)									
1 Pipes to Ctrl Rod Cool Channels & Hangers (a)	Sm Pipe	Sea-Van	8100	0.00053	1.42	0.026	N/A	0	6-1.4.1
2 Pipes to Ctrl Rod Cool Channels & Hangers (b1)	Sm Pipe	Sea-Van	2500	0.000616	1.28	0.028	N/A	0	6-1.4.2
3 Pipes to Ctrl Rod Cool Channels & Hangers (b2)	Lg Pipe	Sea-Van	45	0.0777	110	0.325	N/A	0	6-1.4.2
4 Pipelines, Eq, Valves in CRS rooms (1)	Sm Pipe	Sea-Van	3400	0.000615	1.03	0.028	N/A	0	6-1.4.3
5 Pipelines, Eq, Valves in CRS rooms (2)	Lg Pipe	Sea-Van	20	0.0375	220	0.219	N/A	0	6-1.4.3
6 Pipelines of FCICS	Sm Pipe	Sea-Van	30000	0.000154	0.61	0.014	N/A	0	6-1.4.4
7 FCICS equipment	Lg Misc.	Sea-Van	100	0.174	348	N/A	N/A	0	6-1.4.5
8 Fuel rod integrity control system equipment	Lg Pipe	Sea-Van	460	0.178	267.39	1	N/A	0	6-1.4.6
9 Bio shield cooling circuit pipelines	Sm Pipe	Sea-Van	590	0.00454	7.97	0.038	N/A	0	6-1.4.7
10 Gas and steam/gas pipelines (rx top 1)	Sm Pipe	Sea-Van	660	0.003167	4.871291	0.0635	N/A	0	6-1.4.8
11 Gas and steam/gas pipelines (rx top 2)	Lg Pipe	Sea-Van	46	0.142531	219.238	0.426	N/A	0	6-1.4.8
12 Gas and steam/gas pipelines (rx bottom 1)	Lg Pipe	Sea-Van	660	0.001134	2.297747	0.038	N/A	0	6-1.4.9
13 Gas and steam/gas pipelines (rx bottom 2)	Lg Pipe	Sea-Van	46	0.142531	288.7715	0.426	N/A	0	6-1.4.9
14 Emergency cooling pipelines (1)	Lg Pipe	Sea-Van	124	0.0806	65.64	0.325	N/A	0	6-1.4.10
15 Emergency cooling pipelines (2)	Sm Pipe	Sea-Van	1320	0.0045	15.35	0.076	N/A	0	6-1.4.10
16 Long time cooling system pipelines (1)	Lg Pipe	Sea-Van	145	0.0179	29.83	0.152	N/A	0	6-1.4.11
17 Long time cooling system pipelines (2)	Sm Pipe	Sea-Van	280	0.00454	14.91	0.076	N/A	0	6-1.4.11
18 Prompt safety system pipelines	Lg Pipe	Sea-Van	270	0.0139	6.3	0.133	N/A	0	6-1.4.12
19 FCC Valves	Lg Valve	Sea-Van	32	3	3470	0.8	4	0	6-1.3.9
20 Pipelines in Auxiliary Transformer Rooms	Lg Pipe	Sea-Van	457	0.0806	65.64	0.325	N/A	0	7-2
21 Miscellaneous Equipment (qty. unknown)	Lg Misc.	Sea-Van	50	0.28	420	N/A	N/A	0	7-2
22 Pumps (control rods system room)	Lg Pump	Sea-Van	20	4	5975	1.63	1.63	0	7-2
23 Hxs (control rods system room)	Lg HX	Sea-Van	4	9.7	14560	1.35	6.76	0	7-2
24 Pipes (control rods system room)	Lg Pipe	Sea-Van	367	0.0806	65.64	0.325	N/A	0	7-2
25 Steam-water hangers	Sm Hngr.	Sea-Van	1780	N/A	N/A	0.076	N/A	0	6-1.3.1
26 Reactor bottom water-piping hangers	Sm Hngr.	Sea-Van	650	N/A	N/A	0.057	N/A	0	6-1.3.2
27 Suction and pressure headers, hangers for	Lg Hngr.	Sea-Van	59	N/A	N/A	1.04	N/A	0	6-1.3.4
28 Downcomer pipeline hangers	Lg Hngr.	Sea-Van	135	N/A	N/A	0.325	N/A	0	6-1.3-5
System Name: Turbine Hall Equipment									
1 Condensate pump	Lg Pump	Sea-Van	6	2.5	22400	1	2.5	0	6-2.1.6
2 Condensate booster pump	Lg Pump	Sea-Van	6	2	21000	1	2	0	6-2.1.5
3 Injector system	Lg Misc.	Sea-Van	1	11.5	46000	N/A	N/A	0	6-2.1.8
4 Small feedwater pump	Lg Pump	Sea-Van	2	2	6700	1	2	0	6-2.1.10
5 Technological condensers	Lg Misc.	Sea-Van	4	17	12000	N/A	N/A	0	6-2.1.11
6 Evaporators	Lg Misc.	Sea-Van	4	46	33500	N/A	N/A	0	6-2.1.12
7 Steam Collectors	Lg Misc.	Sea-Van	2	174	126500	N/A	N/A	0	6-2.1.13
8 Fast-operated relief condenser valves	Lg Valve	Sea-Van	4	2	2600	1	2	0	6-2.1-17
9 Fast-operated relief deaerator valves	Lg Valve	Sea-Van	3	0.5	400	0.5	1	0	6-2.1-17

Table A.2. (contd.)

Component Description	Category	Disposal	Quantity	Vol (m ³)	Wt (kg)	Dia (m)	L (m)	mSv/hr	Table
10 Fast-operated relief bubbler valves	Lg Valve	Sea-Van	1	2	1800	1	2	0	6-2.1-17
11 Main stop and control valve	Lg Valve	Sea-Van	8	0.7	550	0.8	1.1	0	6-2.1-18
12 Main relief valve	Lg Valve	Sea-Van	8	0.43	250	0.3	1.3	0	6-2.1-19
13 Demineralizer filters	Tank	Sea-Van	22	N/A	30000	3	4.1	0	6-2.1-20
14 Demineralizer filters	Tank	Sea-Van	3	N/A	1000	2	6.5	0	6-2.1-20
15 Heat exchangers for district heating	Lg HX	Sea-Van	4	9.61	17000	1.2	8.5	0	6-2.1-21
16 Drain coolers	Lg Misc.	Sea-Van	6	6	19000	N/A	N/A	0	6-2.1-22
17 Oil coolers	Lg HX	Sea-Van	10	3.3	4600	1	4.2	0	6-2.1-23
18 Hydrogen recombiners	tank	Sea-Van	4	N/A	2730	1.5	2.8	0	6-2.1-24
System Name: Main Stream									
1 Main Steam Lines - 1	Lg Misc.	Sea-Van	10	16	23996	N/A	N/A	0	6-2.4.1
2 Main Steam Lines - 2	Lg Misc.	Sea-Van	100	15	22599	N/A	N/A	0	6-2.4.1
3 Main Steam Lines - 3	Lg Misc.	Sea-Van	10	60	91470	N/A	N/A	0	6-2.4.1
4 Main Steam Lines - 4	Lg Misc.	Sea-Van	10	20	29340	N/A	N/A	0	6-2.4.2
5 Main Steam Lines - 5	Lg Misc.	Sea-Van	100	32	47915	N/A	N/A	0	6-2.4.2
6 Main Steam Lines - 6	Lg Misc.	Sea-Van	10	44	66612	N/A	N/A	0	6-2.4.2
7 Stainless Valves (dia < 0.08)	Sm Valve	Sea-Van	4963	0.03	23	0.08	0.35	0	6-2.4.3
8 Stainless Valves (0.08 < dia < 0.4)	Lg Valve	Sea-Van	2406	0.08	90	0.3	0.84	0	6-2.4.3
9 Stainless Valves (0.4 < dia < 0.7)	Lg Valve	Sea-Van	226	0.4	466	0.6	1.5	0	6-2.4.3
10 Stainless Valves (dia > 0.7)	Lg Valve	Sea-Van	52	2	1004	0.76	2.3	0	6-2.4.3
11 Steel Valves (dia < 0.08)	Sm Valve	Sea-Van	5133	0.03	16	0.08	0.35	0	6-2.4.4
12 Steel Valves (0.08 < dia < 0.4)	Lg Valve	Sea-Van	1945	0.08	189	0.3	0.84	0	6-2.4.4
13 Steel Valves (0.4 < dia < 0.7)	Lg Valve	Sea-Van	397	0.4	495	0.6	1.5	0	6-2.4.4
14 Steel Valves (dia > 0.7)	Lg Valve	Sea-Van	108	2	461	0.76	2.3	0	6-2.4.4
15 Hangers (dia < 0.08)	Sm Hngr.	Sea-Van	1350	N/A	N/A	0.08	N/A	0	6-2.4.5
16 Hangers (0.08 < dia < 0.4)	Lg Hngr.	Sea-Van	1630	N/A	N/A	0.3	N/A	0	6-2.4.5
17 Hangers (0.4 < dia < 0.7)	Lg Hngr.	Sea-Van	1110	N/A	N/A	0.6	N/A	0	6-2.4.5
18 Hangers (dia > 0.7)	Lg Hngr.	Sea-Van	550	N/A	N/A	0.76	N/A	0	6-2.4.5
System Name: Other System Components									
1 HX: Cooler of deaerator vapors	Lg HX	Sea-Van	4	3.61	6000	1	4.6	0	6-2.2.1.1
2 HX: Cooler of deaerator drainage	Lg HX	Sea-Van	1	3.57	5450	0.8	7.1	0	6-2.2.1.2
3 HX: Boiler of SG intermediate circuit	Lg HX	Sea-Van	2	6.56	11000	1.2	5.8	0	6-2.2.1.3
4 HX: Boiler of heating sys inter circuit -1	Lg HX	Sea-Van	4	12.9	22400	1.4	8.4	0	6-2.2.1.4
5 HX: Boiler of heating sys inter circuit -2	Lg HX	Sea-Van	4	9.05	1700	1.2	8	0	6-2.2.1.4
6 Oil tank	Tank	Sea-Van	2	N/A	21400	4.18	9.1	0	6-2.2.2.1
7 Pressure oil tank	Tank	Sea-Van	4	N/A	4250	2.18	4.5	0	6-2.2.2.2
8 Heating system pressurizer	Tank	Sea-Van	2	N/A	24000	3	8.7	0	6-2.2.2.3
9 SG intermediate circuit pressurizer	Tank	Sea-Van	1	N/A	4500	1.4	5	0	6-2.2.2.4
10 Heating System deaerator cylinder -1	Tank	Sea-Van	1	N/A	3860	2	6.2	0	6-2.2.2.5
11 Heating System deaerator column -1	Tank	Sea-Van	1	N/A	90	0.8	0.9	0	6-2.2.2.5

Table A.2. (contd.)

Component Description	Category	Disposal	Quantity	Vol (m ³)	Wt (kg)	Dia (m)	L (m)	mSv/hr	Table
12 Heating System deaerator cylinder -2	Tank	Sea-Van	1	N/A	1444	1.2	4.5	0	6-2.2.2.5
13 Heating System deaerator column -2	Tank	Sea-Van	1	N/A	56	0.6	0.7	0	6-2.2.2.5
14 Gas cooler pressure pump	Lg Pump	Sea-Van	4	14.4	6500	2.25	3.6	0	6-2.2.3.1
15 Emerg. pumps for technological condensers	Lg Pump	Sea-Van	6	6.6	3000	1.67	3	0	6-2.2.3.2
16 Miscellaneous equipment	Lg Misc.	Sea-Van	80	1.17	1750	N/A	N/A	0	6-2.3.1
17 Other tanks	Tank	Sea-Van	73	N/A	1006	0.66	1.97	0	6-2.3.2
18 Other heat exchangers	Lg HX	Sea-Van	58	2.02	3030	0.95	2.85	0	6-2.3.3
19 Other pumps	Lg Pump	Sea-Van	73	0.91	1372	0.73	2.19	0	6-2.3.4

Appendix B
Decommissioning Cost by Phase

Table B.1. Phase #1: Decommissioning Planning

Decommissioning Activities	U.S. Conditions				Russian Conditions			
	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total	Dec+Rem+ Pac+Ship	Bury	Undistrib	Total
Undistributed Costs:	-	-	10.689	10.689	-	-	4.758	4.758
- Utility Staff	-	-	0.962	0.962	-	-	0.152	0.152
- DOC Staff	-	-	5.455	5.455	-	-	1.091	1.091
- Regulatory Costs	-	-	0.404	0.404	-	-	0.808	0.808
- Special Tools and Equipment	-	-	3.868	3.868	-	-	2.707	2.707
TOTAL	-	-	10.689	10.689	-	-	4.758	4.758

Table B.2. Phase #2: Decommissioning Preparation

Decommissioning Activities	U.S. Conditions				Russian Conditions			
	Dec+Rem+ Pack+Ship	Bur y	Undistrib	Total	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total
Undistributed Costs:	-	-	5.457	5.457	-	-	2.051	2.051
- Utility Staff	-	-	0.770	0.770	-	-	0.152	0.152
- DOC Staff	-	-	4.364	4.364	-	-	1.091	1.091
- Regulatory Costs	-	-	0.323	0.323	-	-	0.808	0.808
TOTAL	-	-	5.457	5.457	-	-	2.051	2.051

Table B.3. Phase #3: Preparation for Safe Storage

Decommissioning Activities	U.S. Conditions				Russian Conditions			
	Dec+Rem+ Pack+ Ship	Bury	Undistrib	Total	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total
Decontamination Costs:	15.148	1.473	-	16.621	1.705	-	-	1.705
- Chemical Decontamination	14.973	1.399	-	16.372	1.497	-	-	1.497
- RFC & D/S Pool Decon Costs	0.007	-	-	0.007	0.002	-	-	0.002
- Unit Rooms	0.034	-	-	0.034	0.012	-	-	0.012
- Waste Water Solidification Costs	0.134	0.074	-	0.208	0.194	-	-	0.194
Reactor Localization	-	-	36.151	36.151	-	-	9.038	9.038
Dry Active Waste Costs	0.004	0.151	-	0.155	0.004	-	-	0.004
RW Facility Costs:	-	-	-	-	-	-	6.907	6.907
- Preparatory Work	-	-	-	-	-	-	3.909	3.909
- RW Plant Construction	-	-	-	-	-	-	2.850	2.850
- RW Warehouse Construction	-	-	-	-	-	-	0.148	0.148
Undistributed Costs:	-	-	41.615	41.615	-	-	25.773	25.773
- Utility Staff	-	-	31.377	31.377	-	-	7.843	7.843
- DOC Staff	-	-	-	-	-	-	-	-
- Regulatory Costs	-	-	0.812	0.812	-	-	2.030	2.030
- Environmental Monitoring Costs	-	-	0.110	0.110	-	-	0.275	0.275
- Laundry Services	-	-	0.858	0.858	-	-	0.028	0.028
- Chemical Decon Energy	-	-	0.269	0.269	-	-	0.027	0.027
- Plant Power Usage	-	-	2.172	2.172	-	-	0.526	0.526
- Nuclear Liability Insurance	-	-	6.017	6.017	-	-	15.044	15.044
TOTAL	15.152	1.624	77.766	94.542	1.709	-	41.718	43.427

Table B.4. Phase #4: Safe Storage

Decommissioning Activities	U.S. Conditions				Russian Conditions			
	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total
Removal of Equipment and Systems:	29.250	171.066	-	200.316	10.371	-	-	10.371
- Recirculation Pumps	0.078	2.343	-	2.421	0.039	-	-	0.039
- RCS Pipelines	6.940	6.694	-	13.635	1.919	-	-	1.919
- RCS Pipelines Insulation	0.027	1.256	-	1.284	0.018	-	-	0.018
- Str. Beams, Plates & Cable Trays	0.677	2.591	-	3.267	0.170	-	-	0.170
- SF Racks	1.028	2.184	-	3.212	0.157	-	-	0.157
- Primarily Piping	5.816	5.700	-	11.517	1.611	-	-	1.611
- Main Steam	8.812	76.598	-	85.410	3.824	-	-	3.824
- Main Turbine	1.548	22.012	-	23.559	0.808	-	-	0.808
- Main Turbine Condenser	1.26	23.873	-	25.132	0.665	-	-	0.665
- Drum-Separators	0.593	2.126	-	2.719	0.185	-	-	0.185
- Feed Water Heaters	0.067	3.107	-	3.174	0.012	-	-	0.012
- Feed Water Pumps	0.027	1.018	-	1.045	0.006	-	-	0.006
- Deaerators	0.350	0.625	-	0.976	0.095	-	-	0.096
- Moisture Separator Reheaters	0.427	1.000	-	1.427	0.116	-	-	0.116
- Turbine Hall Equipment	0.799	13.070	-	13.869	0.440	-	-	0.440
- Bubblers	0.196	0.750	-	0.946	0.061	-	-	0.061
- Other System Components	0.605	6.119	-	6.724	0.245	-	-	0.245
Decontamination Costs:	0.505	0.122	-	0.627	0.784	-	-	0.784
- Spent Fuel Pool Decon	0.006	-	-	0.006	0.003	-	-	0.003
- Spent Fuel Pool Water Treatment	0.499	0.122	-	0.621	0.781	-	-	0.781
Dry Active Waste Costs	0.001	0.032	-	0.033	0.205	-	-	0.205
Undistributed Costs:	-	-	170.686	170.686	-	-	96.738	96.738
- Utility Staff	-	-	92.881	92.881	-	-	18.064	18.064
- DOC Staff	-	-	2.182	2.182	-	-	0.873	0.873
- Regulatory Costs	-	-	20.870	20.870	-	-	20.870	20.870
- Environmental Monitoring Costs	-	-	3.844	3.844	-	-	3.844	3.844
- Laundry Services	-	-	0.872	0.872	-	-	4.477	4.477
- Plant Power Usage	-	-	0.716	0.716	-	-	0.069	0.069
- Maintenance Allowance	-	-	1.375	1.375	-	-	0.962	0.962
- Nuclear Liability Insurance	-	-	47.460	47.460	-	-	47.460	47.460
- Small Tools and Minor Equip.	-	-	0.485	0.485	-	-	0.119	0.119
TOTAL	29.756	171.220	170.686	371.662	11.360	-	96.738	108.098

Table B.5. Phase #5: Final Decommissioning

Decommissioning Activities	U.S. Conditions				Russian Conditions			
	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total
Removal of Equipment:	2.734	15.796	71.535	90.065	0.898	-	4.629	5.527
- Reactor Structures	-	-	71.535	71.535	-	-	4.629	4.629
- HVAC Ducts	1.896	11.423	-	13.319	0.573	-	-	0.573
- HVAC Equipment	0.151	3.416	-	3.567	0.057	-	-	0.057
- Building Cranes	0.244	0.665	-	0.909	0.054	-	-	0.054
- Floor Drains	0.443	0.292	-	0.735	0.214	-	-	0.214
Dry Active Waste Costs	0.247	8.078	-	8.325	0.339	-	-	0.339
Site Termination Survey Costs	-	-	1.196	1.196	-	-	8.372	8.372
Demolition & Site Restoration Costs	-	-	40.313	40.313	-	-	10.078	10.078
Undistributed Costs:	-	-	36.104	36.104	-	-	21.076	21.076
- Utility Staff	-	-	8.389	8.389	-	-	2.097	2.097
- DOC Staff	-	-	16.373	16.373	-	-	4.093	4.093
- DOC Mobiliz./Demobiliz. Costs	-	-	2.983	2.983	-	-	2.983	2.983
- Consultant/Other Staff	-	-	0.547	0.547	-	-	0.137	0.137
- Regulatory Costs	-	-	0.812	0.812	-	-	2.030	2.030
- Environmental Monitoring Costs	-	-	0.110	0.110	-	-	0.275	0.275
- Laundry Services	-	-	2.009	2.009	-	-	2.163	2.163
- Plant Power Usage	-	-	2.172	2.172	-	-	0.526	0.526
- Nuclear Liability Insurance	-	-	2.709	2.709	-	-	6.772	6.772
TOTAL	2.981	23.874	149.148	176.003	1.237	-	44.155	45.392

Table B.6. Grand Total Costs for Decommissioning Phases

Decommissioning Phases	U.S. Conditions				Russian Conditions			
	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total	Dec+Rem+ Pack+Ship	Bury	Undistrib	Total
Without contingency:								
1. Decommissioning Planning	-	-	10.689	10.689	-	-	4.758	4.758
2. Decommissioning Preparation	-	-	5.457	5.457	-	-	2.051	2.051
3. Preparation for Safe Storage	15.152	1.624	77.766	94.542	1.709	-	41.718	43.427
4. Safe Storage	29.756	171.220	170.686	371.662	11.360	-	96.738	108.098
5. Final Decommissioning	2.981	23.874	149.148	176.003	1.237	-	44.155	45.392
GRAND TOTALS for Phases	47.889	196.718	413.746	658.353	14.306	-	189.420	203.726
With 25% contingency:								
1. Decommissioning Planning	-	-	13.361	13.361	-	-	5.948	5.948
2. Decommissioning Preparation	-	-	6.821	6.821	-	-	2.564	2.564
3. Preparation for Safe Storage	18.940	2.030	97.208	118.178	2.136	-	52.148	54.284
4. Safe Storage	37.195	214.025	213.358	464.578	14.200	-	120.922	135.122
5. Final Decommissioning	3.726	29.843	186.435	220.004	1.546	-	55.194	56.740
GRAND TOTALS for Phases	59.861	245.898	517.183	822.942	17.883	-	236.775	254.658

Appendix C
Details of Spreadsheet Approach
(Only in Russian Version)