THE FEASIBILITY STUDY OF USING LOW ENRICHED URANIUM FOR CONVERSION OF RUSSIAN PLUTONIUM PRODUCTION REACTORS

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ABSTRACT

In the report the main results of feasibility study of modernization of the Russian industrial reactors, producing Plutonium and delivering an electrical power and heat, using low-enriched fuel (LEU), containing about of 20% of U-235, are presented. The purpose of modernization stop Plutonium production.
On the basis of results of work the following main conclusions was made.

- Conversion of the ADE-type reactor cores to LEU fuel is feasible.
- A critical milestone for successful LEU conversion is the beginning of the LEU lifetime fuel and absorber tests in two channels in March, 1999.

The work was carried out by the Russian experts group under the assignment of MINATOM and DOE at ANL financial support.

STATUS OF REACTORS CORE CONVERSION

Plutonium Disposition Includes Stopping Production

The United States is working cooperatively with the Russian Federation to manage and dispose of plutonium and other nuclear weapons material. A principal source of weapons-grade plutonium is from plutonium production reactors still operating in Russia. Russia has already shut down 10 reactors that previously produced weapons-grade plutonium as part of its nuclear weapons program. Three remaining reactors designed for plutonium production are still operating, providing heat and power for the regions in which they are located. The Government of the Russian Federation has sought U.S. cooperation to enable these reactors to meet heating needs without producing unneeded plutonium, which is the foundation of the Core Conversion Project. Converting the cores of these reactors to use a different fuel composition eliminates plutonium production while still providing required heat generation.

The fundamental events on paths to core conversion are introduced in a fig.1.

Critical Event	Date
Request U.S. assistance to examine possibility of stopping plutonium production **Minister of Atomic Energy (Minatom), Gosatomnadzor (GAN)**	**August 1992**
Agree to investigate options to cease plutonium production **Presidents Clinton and Yeltsin**	**January 1994**
Sign protocol to cease plutonium production **Energy Secretary O'Leary and Minister Mikhailov**	**March 1994**
Support recommendation of Feasibility Study and agree to proceed with design and analyses **Vice President Gore and Prime Minister Chernomyrdin**	**January 1996**
Design, analyses, testing and regulatory phase of project begins	**October 1996**
Sign the government-to-government agreement "About cooperating concerning plutonium production reactors" **Vice President Gore and Prime Minister Chernomyrdin**	**September 1997**

Figure 1. Critical Events on the Path to Core Conversion

Russian Plutonium Production Reactors

The three reactors designed for plutonium production are graphite-moderated, light-water cooled with 2600 fuel channels and pressurized primary cooling systems. The lifetime of the reactors is limited by graphite growth due to neutron irradiation.

Two of the operating production reactors are located at Seversk, a location also known formerly as Tomsk-7, and the third is at Zheieznogorsk, previously Krasnoyarsk-26. ADE-4, the oldest of the operating reactors at Seversk on the Tom River in Siberia, was started up in 1964, and is projected to be shut down in 2007. The other reactor at Seversk, ADE-5, was started up in 1965 and is projected to be shut down in 2008. The ADE-2 reactor is sited within a mountain near the city of Zheieznogorsk on the Yenisey River. It was started up in 1964, with projected shutdown in 2007.

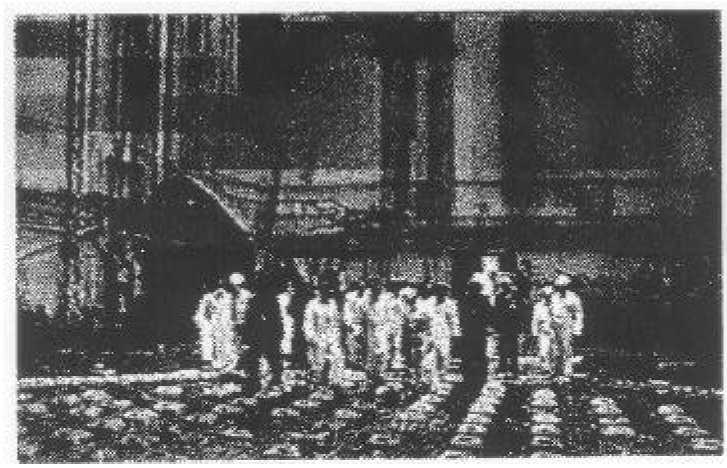


Figure 2. U.S. technical inspectors on the operating deck of the underground plutonium production reactor, ADE-2, at Zheieznogorsk during full-power conditions

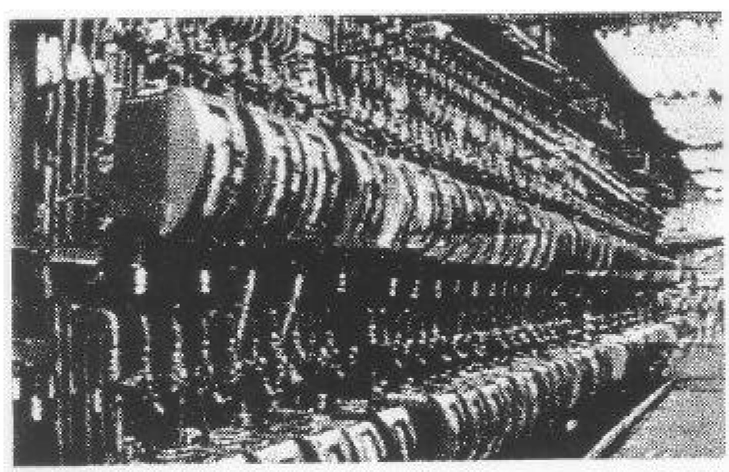


Figure 3. Flow meters for each of the reactor cooling channels at the underground ADE-2 reactor in Zheieznogorsk

Figure 4. Location of Seversk and Zheieznogorsk Sites in Russia

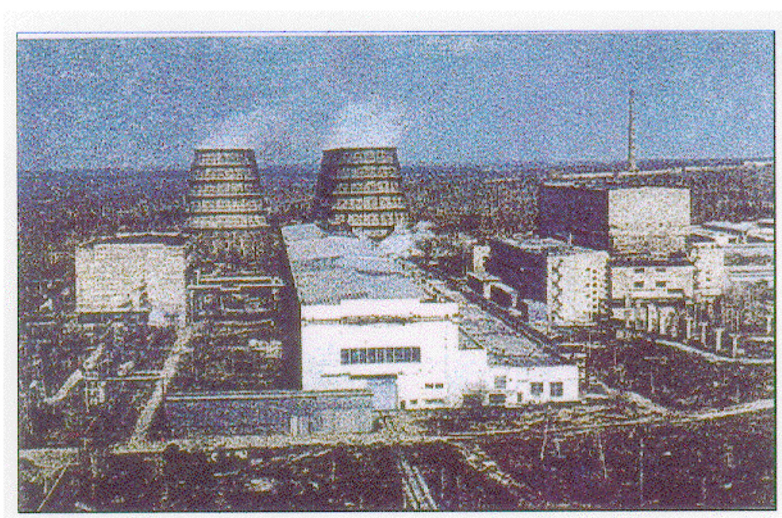


Figure 5. ADE-4 and ADE-5 near Seversk

Figure 6. Entrance ADE-2 (underground) near Zheieznogorsk

While the Russians no longer need to produce additional plutonium for use in nuclear weapons, they must continue to operate these plans to provide regional heat and electricity. The reactors also constitute the primary economic base in these regions.

Feasibility of Core Conversion to Stop Plutonium Production

The United States and Russia have jointly evaluated the option of converting the cores of the existing reactors to an alternate fuel design, and have determined it to be a feasibile approach to eliminating plutonium production in Russia by 2000. With the understanding that Russia plans to continue operation of the reactors through 2007, the joint U.S.-Russian feasibility study found:

- fuel core conversion is viable
- it can be accomplished in about four years
- conversion will enhance reactor safety, by modernization of primary coolant control, instrumentation, and emergency response systems.

In addition, from the U.S. perspective, conversion represents the quickest way to achieve the U.S. policy goal-stopping production of plutonium by the year 2000-at the least expense. As an added advantage, once converted, the reactor fuel cores will consume approximately 6 metric tons of Russian highly enriched uranium (HEU).

Based on the jointly concluded feasibility study, the United States and Russia have undertaken the joint U.S./Russian Core Conversion Project. Objectives of the project are as follows:

- complete core design, analysis, and testing by September 2000
- obtain regulatory approval for reconstruction of ADE-5, ADE-2, ADE-4 in February 2000
- complete installation preparations by spring of 2000
- convert core of one reactor at October 2000
- convert cores in remaining two reactors in July 2001

Current Operating Conditions

The fuel of Russian plutonium production reactors consists mainly of natural uranium, with a small amount of highly enriched uranium in a graphite core. These reactors, used until now to produce fissile material for nuclear weapons manufacture, have not received approval by the Russian regulatory agency, Gasotomnadzor (GAN) for their current safety level, nor have licenses been issued for any of the three reactors. They generate much greater quantities of spent fuel that requires reprocessing or storage than non-production reactor designs. During their operation in support of the Russian nuclear military mission, the weapons-grade material generated in the reactors was reprocessed in onsite facilities.

Operating Conditions Following Core Conversion

In the process of converting the reactor cores, low burnup natural uranium fuel is replaced by enriched (90 or 20% U^{235}) uranium, which alloys the fuel to reach high burnup. Irradiation of the new fuel does not produce weapons-grade plutonium. The reactors will consume approximately 6 metric tons per year of enriched uranium that is material used in nuclear weapons.

Having converted the operation of the reactors from a defense mission to a purely civilian power production mission will make the reactors subject to independent licensing by the civilian nuclear regulatory body, GAN.

Core conversion will require joint development of solutions to technical issues that arise. For example, the alternate fuel will incorporate boron and gadolinium absorbers that capture excess neutrons formerly used to produced plutonium. Nonburnable boron carbide and burnable gadolinium absorbers interspersed among the fuel segments compensate for the added neutrons produced by the enriched uranium and eliminate the need for more control rods and their drive mechanisms to adjust reactivity, which would be very costly and complicate core safety upgrades.

The participants of the Russian-American project of core conversion and communications between them are introduced in a Fig.7.

Progress

The United States and Russia have been taking steps together to ensure that the Core Conversion Project is launched and completed sucessfully. Specifically:

- All scheduled design and safety analyses have been initiated.
- Design requirements were prepared and submitted to GAN in May 1998.
- Life-time irradiation tests of two channel in ADE-4 was started in August 1998.
- Polycell reactor irradiation tests will be started in November 1998.
- Preparation for critical assembly testing is in progress.
- Probabilistic risk assessment, severe accident, and deterministic analyses have been initiated.

Safety improvements

Although the primary reason for completing the Core Conversion Project is to provide the technological means to stop production of plutonium without sacrificing the heat capacity available from operations of these reactors, the project will also make it possible to improve the safety of the reactors for the time that the Russians plan to continue their operation. Examples of the factors that will make this possible are given below.

Independent oversight by GAN

The Russian production reactors, once converted, will be subject to GAN regulatory approval of nuclear safety level and operational licensing.

Reactor plant modernization

The primary coolant system will be reconfigured into two independent loops to maintain core cooling in the event of a major pipe break. A separate emergency core cooling system will be added to the reactors to prevent fuel melting in the event of a loss of coolant accident.

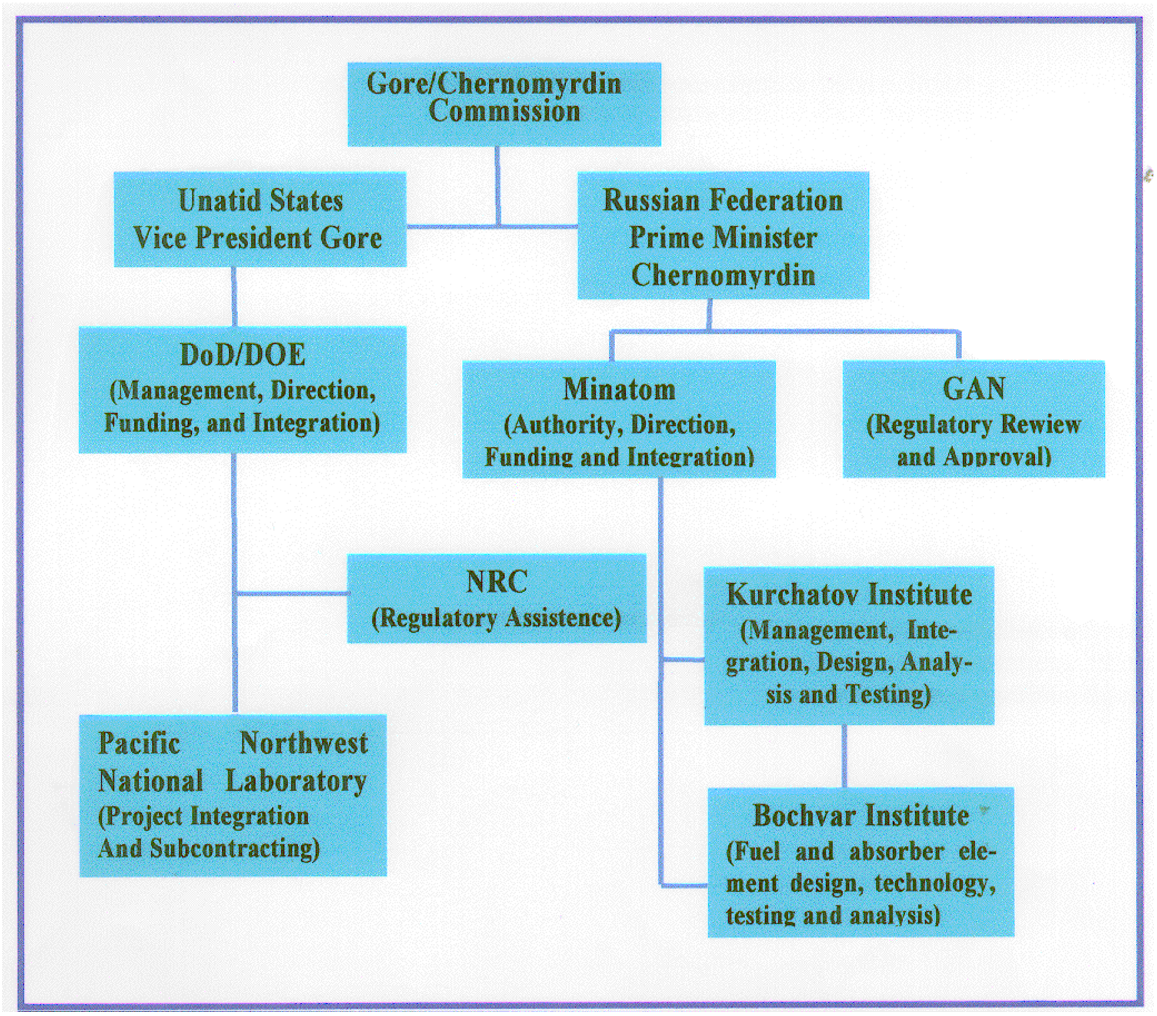


Figure 7. U.S./Russian Core Conversion Project Participants

The cold shutdown reactivity margin will be increased from 1% to 3%, to provide further assurance that the reactors can be maintained in safe shutdown condition.

Spent fuel storage pool facilities will be modernized to meet requirements for criticality safety with the enriched uranium fuel used for core conversion, and to improve control of water chemistry for long-term integrity of spent fuel cladding.

Core conversion modifications

Some changes unique to core conversion will also contribute to improved safety for these reactors, For example, the new design for the fuel and absorber compositions and configurations for core conversion should provide an inherent negative void coefficient for the water coolant, at all times in the burnup cycle, when the reactors are operating at more than 30% of their rated power, enhancing stable operations.

FEASIBILITY STUDY TO CONVERTING THE RUSSIAN PLUTONIUM PRODUCTION REACTORS TO THE USE OF LEU FUEL

The basic variant of conversion is the concept of high-enriched (90%) uranium usage. As prototype the dispersion fuel element of DAV-type was chosen. DAV elements are used now as spark-elements for the purposes of regulation of energy distribution in cores of ADE reactors.

The American side requested a study to assess the feasibility of performing the conversions using low-enriched fuel (LEU), containing about of 20% of U-235, in order to exclude the usage of high-enriched uranium (HEU) in commercial sector. Use of HEU fuel can result in significant risk of unauthorized distribution of uranium suitable for manufacturing of nuclear weapons. The use of LEU, as well as HEU, eliminates production of weapon grade plutonium.

For this work the expert study group was formed from representatives following Russian organizations: Bochvar Institute (Moscow), Kurchatov Institute (Moscow), the Siberian Chemical Combine (Tomsk), MINATOM. The work was carried out under the assignment of Minatom and DOE, under ANL funding.

The experts group has prepared the report, in which one the following fundamental questions were reviewed.

1. Preliminary results of the reactor-physics calculations for a reactor core of the ADE type with LEU fuel
2. Feasibility of manufacturing LEU fuel elements at existing production facilities.
3. Reprocessing of the spent fuel.
4. Comparative cost assessment of fuel cycles with HEU and LEU fuels, based on currently available information
5. The major elements of a time schedule for the LEU reactor conversion.

The report was debated with the American experts at a seminar, which one has take place on July 20-24 in Argonne National Laboratory.

As a result of study materials of the report and discussion the Russian and American experts came to following fundamental conclusions.

1. Conversion of the ADE-type reactor cores to LEU fuel is feasible. Use of LEU fuel instead of HEU fuel would require no changes in the reactor design other than the composition of the fuel, and would cause only minor changes of the neutron characterisitcs of the core.
2. LEU conversion of ADE reactors which have already been converted to HEU fuel would require additional analysis. No significant problems are anticipated, but the group has not studied this case.
3. Application of LEU fuel will not result in any significant changes in the fuel fabrication process. Two processes must be adjusted to handle the change in the uranium dioxide content in the fuel element from ~2.5 vol% to ~12vol%, and the scrap recovery process.
4. Currently, Russian experts are developing options for handling the spent fuel, involving either spent fuel storage or reprocessing.
5. The preliminary cost assessment has not revealed any significant difference in the fuel-cycle cost of conversion with either LEU or HEU fuels if storage is chosen for spent fuel disposal. There is a considerable uncertainty about the comparative costs of spent fuel reprocessing. More information on this topic will become available around the end of 1998.
6. A critical milestone for sucessful LEU conversion is the beginning of the LEU lifetime fuel and absorber tests in two channels (show Fig.8). The operational schedule of the ADE-4 reactor at Tomsk indicates that the optimal time for the beginning of such tests is March, 1999.

7. Normally, GAN approval to begin fabrication of fuel and absorber elements for the first core loading is obtained only after successful completion of the lifetime tests on fuel and absorber elements. Under such a scenario, beginning of LEU operations in the first ADE reactor could occur in December 2002.
8. Beginning of LEU operations can occur earlier if the fabrication of the LEU fuel and absorber elements begins before the end of the life-time tests on the fuel and absorber elements, as it is planned for the HEU fuel. However, in this case the manufacturers of fuel and absorber elements could suffer a financial loss if the reactor tests were not successful. If the manufacturers are protected against such a financial risk and a GAN/MINATOM decision is made to start fuel manufacturing earlier, the beginning of LEU operations in the first ADE reactor would occur in March 2002.
9. Pursuing LEU conversion would result in additional costs for reactor core calculations, design documentation, testing, and licensing. This cost would be significantly less than the equivalent cost allocated to produce the same documentation for the HEU conversion. Depending on how the LEU conversion is implemented,

- Some risk of a financial loss might be incurred if fabrication of an LEU core loading is begun before receiving the GAN operating license; and
- Some additional costs might be incurred if an option is chosen that requires LEU and HEU cores loading to be available simultaneously for the same reactor.

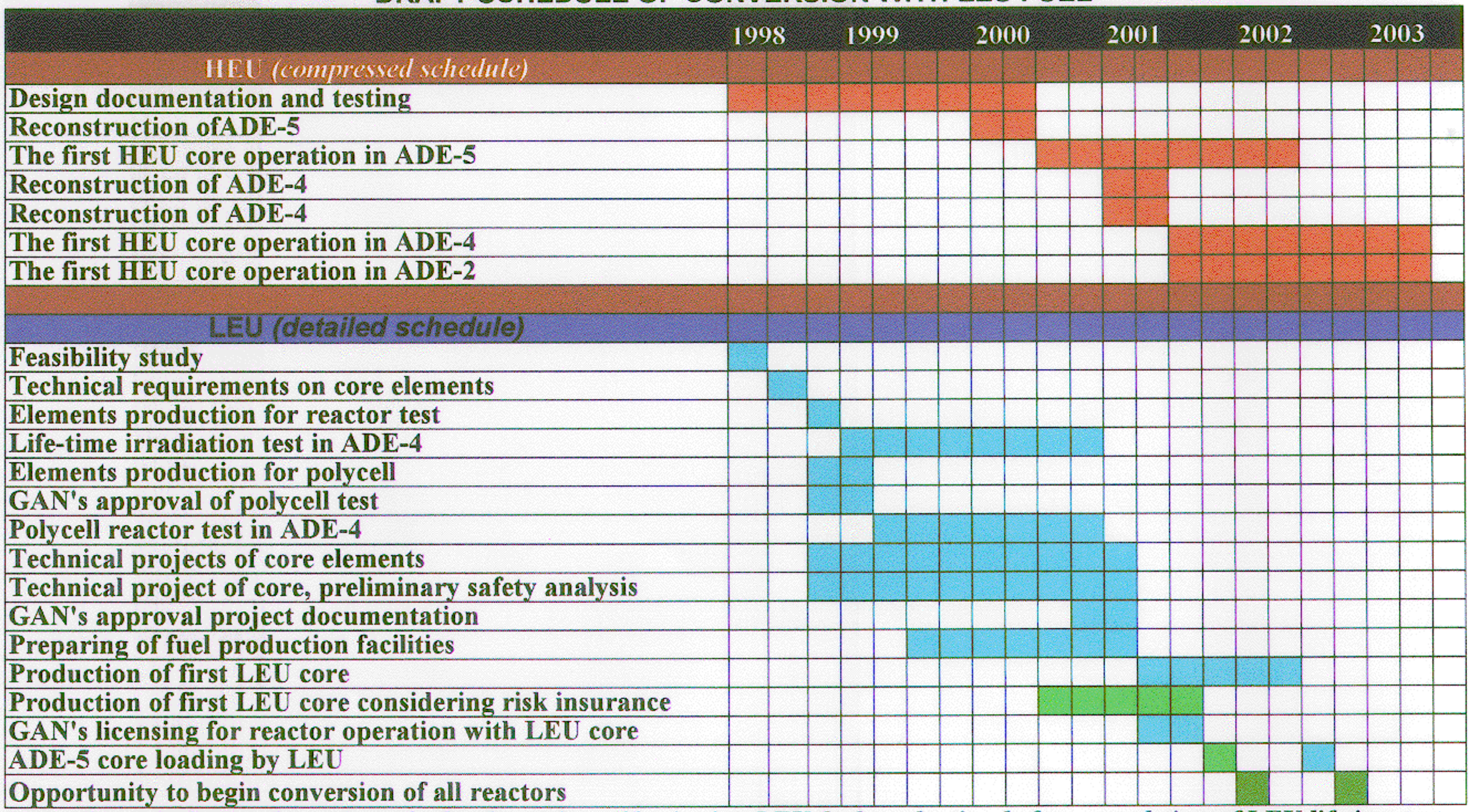
Conclusion

Successful conversion of the fuel cores of the three plutonium production reactors still operating in Russia by the joint U.S./Russian Core Conversion Project will stop weapons-grade plutonium production, will burn enriched uranium that is weapons-grade material, and will significantly improve safety at the reactors.

Use of fuel with enrichment no more than 20% will allow not only to solve a problem of cessation of plutonium production, but also it is essential to decline risk of unauthorized distribution of high enriched uranium, suitable for fabrication of nuclear weapons.

The cooperative efforts of the U.S. and Russian teams on this project are producing results that enhance international security and provide for the needs of the local populace.

DRAFT SCHEDULE OF CONVERSION WITH LEU FUEL



Note: Green indicates the main tasks for the option of beginning LEU fuel production before completion of LEU lifetime tests. Other secondary tasks would also need to be adjusted if this option is chosen.