PROPOSAL 3

Replace HEU Fuel in Soviet-Built Research and Test Reactors with LEU Fuel

Soviet-Built Research Reactors

The Soviet Union built large numbers of research and test reactors and critical assem blies[42] in Russia, in other Soviet republics, in Eastern Europe, and elsewhere. They were installed at reactor development institutes, military research and production centers, academic research institutes, universities, and non-nuclear research and industrial facilities. Most of them used fuels containing HEU. Today, Russia has approximately 40 operational HEU fueled research and test reactors and critical assemblies (not including reactors used for defense-related activities).[43] There are three operational research reactors in former Soviet republics and several others in operation elsewhere (see Table 1).[44] Unused or slightly irradiated fuel at these facilities represents an attractive target to terrorists or nations seeking to obtain HEU for nuclear weapons. Spent HEU fuel is less attractive because fission products make it radioactive and, therefore, difficult to handle. However, spent fuel or materials extracted from it can still be used to make a nuclear weapon. Research facilities can be eliminated as targets for proliferants if they convert their reactors from HEU fuel to LEU fuel and if all remaining HEU-based fresh and spent fuels at those sites are moved to larger, more secure facilities within Russia.

The facilities of most concern are reactors with continuous power levels above one megawatt (MW). Lower-power reactors, critical assemblies, and pulse reactors typically have fuel cores that last for the lifetime of the reactor and do not need to be replaced. While the fuel is inside of the reactor, it is much less of a security risk. However, reactors with a continuous power level of more than one MW have much higher uranium requirements and may need frequent HEU fuel reloading and replacement. For example, a 5-10 MW IRT- or VVR research reactor may require up to 10 kg of 90-percent HEU per year for reloading. The 100-MW, SM-3 reactor at the Institute of Atomic Reactors in Dimitrovgrad (NIIAR) consumes an estimated 70 kg of HEU per year (see Table 1).

The relative openness of research reactors, especially those located in universities or academic research institutes, to a large number of people makes it more difficult to assure stringent security and control of fissile materials.

There is also a sizable industrial infrastructure within Russia to support the research reactor program. Movement of HEU fuel through this infrastructure provides additional opportunities for diversion, which could be eliminated if all HEU-fueled reactors were to convert to LEU fuels.

Why Fuel Conversion?

Research reactors in Russia and other former Soviet republics are now facing considerable difficulties. Approximately one-third of all facilities are over 30 years old. The reactors are aging

This section is based on a draft of a paper by Oleg Bukharin of Princeton University, titled "US-Russian Reduced Enrichment and Test Reactor (RERTR) Cooperation."

TABLE 1. **Soviet-Built Research Reactors Over One MW Power**[45]

OPERATOR	FACILITY	POWER (MW)	ENRICHMENT (%)	UTILIZATION (MWd/yr)	MAXIMUM BURNUP (%)	ANNUAL U-235 REQUIREMENT (kg/yr)
RUSSIA						
Kurchatov Institute/Moscow	IR-8	8	90	300	60	0.5
IPPE/Obninsk	BR-10 fast reactor	10	90 or Pu	1,500	8	20
NIIAR/ Dimitrovgrad	SM-3 MIR-M1 BOR-60 RBT-10/1 RBT-10/2 RBT-6 Prima	100 100 60 10 10 6 100	90 90 90 or Pu 63 63 63 na	30,000 28,000 20,000* 2,800 2,800 1,680 Under Development	43 60 50* 45 45 45	70 47 42 RBT reactors use spent fuel from SM reactors.
NIKIET-Yekaterinburg	IVV-2M	15	90	2,600	75	3.5
Institute of Nuclear Physics, TPI/Tomsk	IRT-T	6	90	1,000*	50	2.1
MIFI/ Moscow	IRT-MIFI	2.5	90	450	50	1
NIFKhI-Obninsk/ Obninsk	VVR-TS	15	30	2,400	50	4.8
PNPI/Gatchina, St.Petersburg	VVR-M PIK	18 100	90 90*	2,600 Under Construction	70 40	3.7
FORMER SOVIET UNION						
Tashkent, Uzbekistan	VVR-CM	10	Was 90, converted to 36	2,000	70	3
Institute of Nuclear Physics/Almaty, Kazakhstan	VVR-K	10	36	1,000	50*	2.1
Institute of Nuclear Physics (Kiev, Ukraine)	VVR-M	10	36	2,000	60	3.5
EASTERN EUROPE AND OTHER COUNTRIES						
Czech Republic	LWR-15	15	80	1,700	45	4
Serbia	R-A	6.5	80	†	†	3.0
Poland	MARIA	30	Was 80, converted to 36	2,800	40	7.4
Bulgaria	IRT-2000	2	36	85	50*	0.2
Hungary	VVR-SZM	10	36	875	55	1.6
Romania	VVR-S	2	36	400*	50*	0.8
North Korea	IRT-DPRK	8	36	640	50*	1.3
Libya	IVV-7	10	80	270	40	.7
Vietnam	DRR	0.5‡	36	30	0.5*	0.06

† Information not available.

* There is some uncertainty about these figures. They were estimated based on available information when there were insufficient data to provide exact figures.

‡ Although the Vietnam reactor operates at less than one MW, it is still significant from a non-proliferation standpoint.

physically and obsolete in design. For many there is inadequate funding either to continue their operation or to decommission them. In addition, there is a considerable attrition of research and technical staff due to aging and losses to commercial jobs. Funding problems make it difficult for facilities to provide adequate security for their HEU fuels.

The relative openness of research reactors, especially those located in universities or academic research institutes, to a large number of people (including scientists, technicians, and the general public) makes it more difficult to assure stringent security and control of fissile materials. Certain security measures and equipment such as armed guards, multi-layered access restrictions, and sophisticated intrusion detection systems, which are routinely employed at nuclear defense and fuel cycle facilities, are often not accepted in a research reactor setting because of political and public safety reasons. During Russia's financial meltdown in August 1998, small research facilities found themselves in particularly dire straights. Many were not able to pay for electricity to power safeguards and security systems or to support even the most basic operations of their guard forces.

There have been some particularly troubling incidents at research reactor sites. For example, in 1997, the Institute of Nuclear Physics at the Tomsk Polytechnical Institute in Russia could not account for a fresh fuel assembly, which contained 145 grams of 90-percent enriched HEU, which was intended for its IRT-T reactor.[46] This is considerably less than the 25 kilograms considered by the International Atomic Energy Agency as a "significant quantity" for the production of a nuclear weapon, but its disappearance is troublesome nonetheless.

Many Soviet-built research reactors have become permanently non-operational. Expanding the MCC Project can facilitate the task of removing HEU from those facilities, as could a revitalized program to return spent research reactor fuel to Russia as discussed below. Other facilities may be persuaded to shut down their reactors and give up their HEU if provided sufficient incentive to do so. However, some facilities will continue to do research that requires a reactor or critical assembly. Converting research reactors at those facilities from HEU to LEU fuel would eliminate the risk of HEU diversion. Such a conversion would have a number of other important nonproliferation benefits as well. It would:

- Reduce (or eliminate) the proliferation risks associated with fabrication, storage, transportation, and disposition of research reactor fuel;
- Facilitate consolidation and disposition of inventories of fresh HEU fuel that exist at some research reactor locations;
- Allow the Russian government, other host governments, and the international community to save millions of dollars needed to upgrade and maintain security at research reactor facilities; and
- Support US efforts to get Western-built research reactors to convert from HEU to LEU fuel.

US-Russian Cooperation to Reduce Enrichment of Research Reactor Fuel

The United States has been supporting reactor fuel conversion for over 20 years. The Department of Energy launched the Reduced Enrichment Research and Test Reactor Program (RERTR) in 1978. The program, which the Argonne National Laboratory (ANL) coordinates, works to develop higher-density LEU fuels and seeks to make them broadly available to research reactors. Higher densities allow the uranium to be diluted to low enrichment without increasing the physical size of the fuel elements. Approximately 40 research reactors of over one MW in the United States and abroad have begun or completed the transition to LEU fuel since the beginning of the program; this is more than half of the HEU fueled reactors in the US and other Western nations. As a result, US HEU exports declined from almost 700 kg per year in the mid-1970s to zero in 1993. Furthermore, with the exception of the FRM-II research reactor nearing completion in Germany, no HEU-fueled research reactor has been built in the Western world since the RERTR program began.

In 1978, the Soviet Union launched its own effort to reduce the enrichment level of research reactor fuels. During the next ten years, they were able to develop higher density "cermet fuel"[47] with uranium enriched to 36-percent U-235; this meant an increase in uranium density from 1.5

to 2.5 gU/cm^3 (grams of uranium per cubic centimeter). This new higher density fuel was able to be loaded into IRT- and VVR-type reactors without changes in core configuration, but it did result in some loss of neutron flux.[48] This reduction in flux was problematic, because neutron production is the main task that research reactors are designed to carry out. During the 1980s, the Soviet Union largely stopped exporting 90-percent HEU fuel to Soviet-built research reactors in other countries and started supplying them with 36-percent HEU instead. The Soviet reduced enrichment program, however, ground to a halt in the late 1980s due to insufficient funding.

Revitalizing the Russian fuel conversion effort has become an important priority of the US RERTR Program. In December 1993, the United States and Russia signed an agreement to design and manufacture fuel enriched to 19.75-percent U-235 for Soviet-designed research reactors.[49] Under this agreement, the US RERTR Program contracts with Russian research institutes to perform RERTR-related studies. It also supports the Russian effort by providing US expertise in fuel development and design and help in analyzing how well Russian reactors would perform with new LEU fuels. In addition, the program assists reactor operators with actual conversion.

Development of LEU fuel

In the joint program's first years, the Russian institutes insisted on working on the development of higher-density (3.85 gU/cm^3), uranium-oxide cermet fuels, with which they had considerable experience, instead of US-proposed silicide fuels. In 1997, test fuel assemblies for MR-, VVR-, and IRT-type reactors were irradiated in the reactors at the Institute of Atomic Reactors in Dimitrovgrad (NIIAR), the Institute of Nuclear Physics in St. Petersburg (PNPI), and the Kurchatov Institute in Moscow, respectively. The NIIAR and Kurchatov fuel assemblies failed tests,[50] delaying the project's overall progress. However, PNPI successfully completed tests of fuel elements in 2001, which put the program in a position to convert the fuel in VVR-type reactors, such as the research reactor in Budapest. Some uncertainty remains, however, regarding the ability of Russian fuel fabricators to mass-produce new, higher-density uranium oxide fuel at a reasonable cost.

In 2000–2001, the fuel development effort took a new turn, which may make the work on uranium-oxide fuels obsolete. The Bochvar Institute in Moscow, in cooperation with the Electrostal fuel fabrication facility near Moscow, proposed using a uranium-molybdenum alloy fuel dispersed in an aluminum matrix (U-Mo fuel).[51] The U-Mo fuel is easier to manufacture and experts believe they can achieve densities of 6–7 gU/cm^3 with it. This should allow all Soviet-designed reactors outside of Russia and most reactors in Russia to convert to LEU fuel. The US RERTR Program funds the development work, which draws on both Russia's research intoU-Mo fuels and technical data from US and French efforts.[52] Irradiation of test fuel elements is scheduled to begin in mid 2002. Other Russian institutes are also working on uranium-molybdenum fuel.

Reactor conversion

So far, the joint US-Russian program has had only limited success in facilitating conversion to LEU fuel. Some elements of the Russian nuclear establishment continue to view all nuclear operations as sensitive and oppose cooperation and information sharing with the United States. In addition, Russian specialists, having observed the dissatisfaction of some reactor operators in Western Europe with RERTR arrangements and seeing the DOE's refusal to convert some of its own reactors to LEU fuel, might believe that the use of LEU fuel would entail a financial burden and a decline in the quality of reactor performance. Some are concerned that since LEU fuel has a higher neutron-absorbing U-238 content, it might produce a less intense neutron flow than its HEU counterpart. This reduced intensity would be problematic, because, as mentioned above, neutron production is the *raison d'être* for most research reactors. This fear can be conclusively alleviated only by demonstrating adequate performance in the first reactors to adopt the new fuels.

Because of the opposition from Russian operators, the RERTR Program is focusing its initial conversion work on Eastern Europe and former Soviet republics other than Russia. The initial conversions are still several years away. Assuming full cooperation of the reactor operators and availability of the new U-Mo fuel, conversion of the reactor in Tashkent, Uzbekistan, which program officials consider a pilot project, could happen as early as 2005. The program has targeted reactors in Kazakhstan, Ukraine, the Czech republic, Hungary, Poland, and Bulgaria for conversion between 2006 and 2009. The actual schedule will depend on many factors. For example, the MARIA reactor in Poland has recently made a transition to 36-percent enriched fuel and has a fresh fuel supply that will last until 2009. The reactor does not plan to convert to LEU before then.

In the meantime, the US and Russian partners are working to characterize the remaining Soviet-built research reactors, and to define procedures for management and disposition of spent high-density fuel. For example, the Kurchatov Institute has begun to study the feasibility of converting its IR-8 reactor to high density LEU fuel.[53] We hope that reactor conversion experiences in Eastern Europe and former Soviet republics will demonstrate the benefits of the new LEU fuel to reactor operators in Russia.

Moving Forward

Conversion of research reactors from HEU to LEU fuel is not possible unless there is a source of high-density LEU fuel, which is of high-quality and reasonable price, and unless the reactor

BOX 2. Russian Take-Back of HEU Fuels

For many years, it has been official Russian policy to take back spent research reactor fuel, but Russia has not followed that policy consistently. Spent HEU fuel has some value if it is reprocessed, blended, and sold, but the cost of transporting, storing, and processing the spent HEU fuel exceeds the value of the product. Russia has been unwilling to bear that cost. Since late 1999, the United States has been working with Russia and the International Atomic Energy Agency to repatriate Soviet-supplied HEU fuels from 16 nations. Most of those nations are eager to send back their spent fuel to eliminate the storage and security costs and reduce the risk of accidents or theft of the HEU fuel.

Negotiations are well under way for a program under which the United States will pay Russia to take back Soviet-supplied fuel. This effort is closely tied to efforts to convert research reactors from HEU to LEU fuels. According to a US source cited in *NuclearFuel*, "the US funding is tied to a commitment to convert to LEU."[54] If reactor operators agree to convert, the US would pay some or all of the costs of fabricating and transporting new LEU fuel in addition to assisting with Russia's cost to transport and manage the HEU fuel. Under this program, Russia would also take back unused fresh HEU fuel from reactors that convert and would take all HEU fuels from reactors that are no longer operating.

According to DOE's 2003 Budget request, the US and Russia have reached "preliminary agreement" on spent fuel management costs and a pilot shipment site for return of Soviet-supplied HEU fuels to Russia. DOE hopes to complete the agreement this year. According to the Budget, in 2003 DOE plans to "initiate repatriation to Russia of 500 fresh and spent nuclear fuel assembles and participate in two fact-finding missions to evaluate fuel inventory and conditions at six potential sites".

The first test bed for the program is likely to be the Tashkent reactor in Uzbekistan, which is currently using 36 percent-enriched HEU fuel. However, according to the *"NuclearFuel"* article cited above, the Tashkent reactor reportedly has both fresh and spent fuel of 80 to 90 percent enrichment in storage, the removal of which should be a high priority. Another high priority for the United States is removal of about 50 kg of fresh, 80 percent-enriched, HEU fuel and additional amounts of spent and lightly irradiated fuel from an inoperable reactor at the Vinca Institute of Nuclear Sciences, near Belgrade, Serbia.

Russian takeback of Soviet-supplied HEU fuel can have a significant impact on reducing the proliferation danger of HEU stockpiles. It should receive the strongest possible support from the United States, including sufficient funding and attention from high-level policy officials.

operators are willing to make the transition. The recent change of RERTR's focus from uranium-oxide to U-Mo LEU fuel will hopefully put the program on track towards solving the fuel availability problem. However, conversion of the SM-3 reactor in Dimitrovgrad and some other high-power reactors in Russia may require additional efforts to change structural materials in their fuel and possibly develop even denser fuel.[55]

Convincing all reactor operators to convert to LEU fuel will remain a challenging task and will require focused and sustained efforts on the part of Russia and the United States.

Incentives for reactor operators

Most reactor operators are likely to make the transition to LEU fuel if that are provided with a package of incentives, including:

- Provision of a guaranteed supply of free LEU fuel for a reasonable period of time;
- Assistance in removing the backlog of spent fuel to another location; and
- Payment for and disposition of any un-irradiated HEU fuel.

The first incentive would likely involve payment by the United States to a fuel fabricator (presumably in Russia) for at least the first LEU fuel core. The United States might also cover fuel qualification and other conversion-related expenses. The second and third elements of the package would involve negotiating with and paying Minatom a reasonable price for packaging and moving fuel to Russia, and for subsequent fuel storage and disposition in Russia. (See Box 2).

While conversion to less than 20-percent enriched LEU is the ultimate goal, the US should provide incentives to research reactors to move to 36-percent enriched fuel, as a first step, if no suitable LEU fuel is available. The VVR-CM reactor in Tashkent has made such a transition, thereby greatly reducing the overall risk of nuclear proliferation from Uzbekistan. The reflected critical mass[56] of 36-percent enriched uranium is about 150 kg—six times that of 90-percent enriched HEU. That means about six times as much material is needed to make a nuclear weapon from the lower enriched HEU. For comparison, the reflected critical mass of 19.9-percent enriched LEU is over 400 kg.

Strengthening the US RERTR Program

In recent years, the RERTR Program has received little support from DOE's top management. The program is under-funded at $5 million per year. In addition, DOE has not drawn on the potential for synergy between the RERTR Program, the MCC Project, and efforts to encourage Russian take-back of Soviet-supplied HEU fuels. Conversion of research reactors to LEU fuel would help eliminate or reduce the resistance of some institutes to giving up their HEU stocks out of fear that they would be unable to continue nuclear research.

The level of funding for reactor conversion has been grossly insufficient. Since 1996, much of the RERTR work in Russia has been financed though a one-time $1.5 million grant from the US Department of State's Nonproliferation and Disarmament Fund. These resources are insufficient and, as a result, potentially valuable work is going unfunded. In principle, the DOE could use funds from the RERTR program to support work in Russia, but the RERTR Program's budget has been declining, and it is not sufficient to fund both the US and Russian development efforts.[57]

A broad effort to convert Russian-origin research reactors, which goes beyond current research, development, and demonstration projects, would require additional funding. Ballpark estimates suggest a cost of $1 million per reactor to convert to the new fuels, including the cost of the first LEU core, but not including the cost of other incentives. An increase over current appropriations of less than $20 million per year, for the next few years, would be sufficient to fund the conversion of nearly all Soviet-built, HEU-fueled reactors and the return of all HEU fuels to Russia within by 2010. No funding for these purposes is likely to be available from Russia or other former Soviet countries. It is up to the United States to fund these programs, in order to significantly reduce the potential for diversion of HEU.