DIFFICULT LEGACY: SPENT FUEL FROM SOVIET REACTORS

by

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Introduction

The purpose of this report is to examine the status and management of spent fuel produced in Soviet-designed nuclear power plants in nine countries: four countries of the former Eastern Bloc (Bulgaria, Hungary, and the Czech and Slovak Republics); four Newly Independent States (NIS) (Armenia, Lithuania, Russia, and Ukraine); and Finland. In each case we provide:

(1) an overview of the status of the country's nuclear sector and its Nuclear Power Plants (NPPs) (both operating and under construction);

(2) a description of current discharges and management of spent fuel; and

(3) an outlook for the future management of spent fuel in light of current and potential reprocessing agreements with Russia.

This analysis is the first of its type to examine the status of spent fuel in several countries operating Soviet-designed reactors. NRDC believes this analysis is critical to future decision-making on spent fuel storage and reprocessing and on the transport of nuclear waste. There are concerns in a number of countries regarding the safety of existing provisions for spent fuel storage and nuclear waste transport. Plans for large-scale reprocessing of spent fuel in Russia--involving the recovery of separated plutonium--raise serious concerns about risks associated with nuclear proliferation.

Overview

Soviet-Designed Reactors and Their Spent Fuel

The Soviet Union and its Eastern bloc allies relied almost entirely on Soviet-designed reactors for their nuclear energy.[1] Soviet-designed reactors now operate in nine countries throughout Eastern Europe and the former Soviet Union. There are presently 68 such reactors in operation and approximately 22 reactors in various stages of construction.[2] With the exception of five small older graphite-moderated water-cooled reactors and two liquid metal fast breeder reactors (LMFBRs), Soviet-designed power reactors fall into two main reactor types: the graphite-moderated water-cooled RBMK reactors and the pressurized water-moderated and cooled VVER reactors. The locations of these reactors by type are given in Tables 1-3.

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[1] An exception is the Krsko plant in Slovenia, a Western model nuclear reactor built by Westinghouse.

[2] Energy Information Administration, *World Nuclear Outlook 1994* (Washington, DC: Department of Energy, December 1994), pp. 83-101. There are also plans to complete two such reactors at Cienfuegos, Cuba. In addition, Russia's Ministry of Atomic Energy (Minatom) and the Iranian government signed a contract in January 1995 for the construction of at least one Soviet-designed power plant at Bushehr, Iran. Construction began at the end of 1995.

Table 1
RBMK Reactors

COUNTRY/LOC.	REACTOR	START-UP	CF(%)[1] 1994	SF(t)[2] 1994
RUSSIA				
Kurchatov, Kursk	Kursk 1	12/76	19	11.1
	Kursk 2	1/79	54	31.5
	Kursk 3	10/83	64	37.4
	Kursk 4	12/85	66	38.5
Sosnovyy Bor,	Leningrad 1	12/73	69	40.3
St. Petersburg	Leningrad 2	7/75	2	1.2
	Leningrad 3	12/79	83	48.5
	Leningrad 4	2/81	77	45.0
Desnogrosk, Smolensk	Smolensk 1	12/82	53	31.0
	Smolensk 2	5/85	63	36.8
	Smolensk 3	1/90	67	39.1
subtotal	***11 operating reactors/1 pipeline reactor[3]***		***56***	***360.4***
UKRAINE				
Pripyat, Kiev	Chernobyl 1	9/77	54	31.5
	Chernobyl 3	12/78	64	37.4
subtotal	***2 operating reactors***		***59***	***68.9***
LITHUANIA				
Sneickus	Ignalina 1	12/83	60[4]	52.6
	Ignalina 2	8/87	60	52.6
subtotal	***2 operating reactors***		***60***	***105.2***
TOTAL	**15 operating reactors**		**57**	**534.5**
	1 pipeline reactor		**60**	**52.6**
	16 operating/pipeline reactors		**57**	**587.1**

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[1] Average operating capacity factor for 1994. "Nuclear Electricity Generation for December 1994," *Nucleonics Week*, 9 February 1995, pp. 18-22.

[2] Estimated spent fuel output, based on capacity factors for 1994. Assumes fuel burnup = 20,000 MWd/t and thermal output = 3200 MWt for RBMKs in Russia and Ukraine; and 20,000 MWd/t and 4800 MWt for Ignalina Units 1 & 2 in Lithuania.

[3] One RBMK is under construction at the Kursk NPP.

[4] The actual 1994 capacity factor for the Ignalina reactors is not known. However, evidence suggests that the reactors are operating below 70 percent. *World Nuclear Outlook*, p. 88.

Table 2
VVER-440 Reactors

COUNTRY/LOC.	REACTOR	MODEL	START-UP	CF(%)[1] 1994	SF(t)[2] 1994
BULGARIA					
Kozloduy, Vratsa	Kozloduy 1	230	7/74	68	11.9
	Kozloduy 2	230	10/75	44	7.7
	Kozloduy 3	230	12/80	33	5.8
	Kozloduy 4	230	5/82	25	4.4
subtotal	***4 operating reactors***			***43***	***29.8***
CZECH REPUBLIC					
Trebic, Jihomarovsky	Dukovany 1	213	2/85	70[3]	12.3
	Dukovany 2	213	1/86	70	12.3
	Dukovany 3	213	11/86	70	12.3
	Dukovany 4	213	6/87	70	12.3
subtotal	***4 operating reactors***			***70***	***49.2***
HUNGARY					
Paks, Tolna	Paks 1	213	12/82	91	16.0
	Paks 2	213	9/84	91	16.0
	Paks 3	213	9/86	89	15.6
	Paks 4	213	8/87	78	13.7
subtotal	***4 operating reactors***			***87***	***61.3***
FINLAND					
Loviisa, Uusimaa	Loviisa 1	213	2/77	90	15.8
	Loviisa 2	213	11/80	81	14.2
subtotal	***2 operating reactors***			***86***	***30***
SLOVAK REPUBLIC					
Trnava, Zapadoslovensky	Bohunice 1	230	12/78	70[4]	12.3
	Bohunice 2	230	3/80	70	12.3
	Bohunice 3	213	8/84	70	12.3
	Bohunice 4	213	8/85	70	12.3
subtotal	***4 operating reactors/4 pipeline reactors[5]***			***70/70***	***49.2/49.2***

[1] Average operating capacity factor for 1994. *Nucleonics Week*, 9 February 1995, pp. 18-22.

[2] Estimated spent fuel output for 1994.

[3] Official 1994 capacity factor for the Czech Republic is not known. Figures have been calculated at 70 percent.

[4] Official 1994 capacity factor for the Slovak Republic is not known. Figures have been calculated at 70 percent.

[5] There are four VVER-440/213 reactors in the construction pipeline at the Mochovce NPP.

Table 2 (cont.)

RUSSIA					
Polyarnyye Zori,	Kola 1	230	6/73	56	9.8
Murmansk	Kola 2	230	12/74	11	1.9
	Kola 3	213	3/81	68	11.9
	Kola 4	213	10/84	58	10.2
Novovoronezhskiy,	Novovoronezh 3	230	12/71	56	9.8
Voronezh	Novovoronezh 4	230	12/72	50	8.8
subtotal	***6 operating reactors***			***50***	***52.4***
UKRAINE					
Kuznetsovsk, Rovno	Rovno 1	213	12/80	74	13.0
	Rovno 2	213	12/81	77	13.5
subtotal	***2 operating reactors***			***76***	***26***
ARMENIA					
subtotal	***2 pipeline reactors[4]***			***70***	***24***
TOTAL	**26 operating reactors**			**69**	**298.0**
	6 pipeline reactors			**70**	**74.0**
	32 operating/pipeline reactors			**70**	**372.0**

[4] Two VVER-440/230 reactors at Armenia's Metsamor Nuclear Power Plant, located in an area of high seismic activity, were closed in 1989 after the devastating 1988 earthquake in that country. In October 1995, despite heavy opposition from the West, Armenia restarted Metsamor 2. Metsamor 1 could also be brought back on-line in the near future.

Table 3
VVER-1000 Reactors

COUNTRY/LOC.	REACTOR	START-UP	CF(%)[1] 1994	SF(t)[2] 1994
RUSSIA				
Balakovo, Saratov	Balakovo 1	12/85	28	7.7
	Balakovo 2	10/87	53	14.5
	Balakovo 3	12/88	45	12.3
	Balakovo 4	4/93	41	11.2
Udomlya, Tver	Kalinin 1	5/84	54	14.8
	Kalinin 2	12/86	54	14.8
Novovoronezhskiy, Vomonezh	Novovoronezh 5	5/80	28	7.7
subtotal	***7 operating reactors/5 pipeline reactors[3]***		***43/70***	***83/96***
UKRAINE				
Kuznetsov, Rovno	Rovno 3	12/86	68	18.6
Konstantinovka, Nikolaev	South Ukraine 1	12/82	62	17.0
	South Ukraine 2	1/85	48	13.1
	South Ukraine 3	9/89	67	18.3
Energodar, Zaporozhe	Zaporozhe 1	12/84	46	12.6
	Zaporozhe 2	7/85	50	13.7
	Zaporozhe 3	12/86	57	15.6
	Zaporozhe 4	12/87	71	19.4
	Zaporozhe 5	8/84	53	14.5
Neteshin, Khmelnitski	Khmelnitski 1	12/87	76	20.8
subtotal	***10 operating reactors/5 pipeline reactors[4]***		***60/70***	***164/96***
BULGARIA				
Kozloduy, Vratsa	Kozloduy 5	11/87	28	7.7
	Kozloduy 6	8/91	59	16.2
subtotal	***2 operating reactors***		***44***	***23.9***
CZECH REPUBLIC				
subtotal	***2 pipeline reactors[5]***		***70***	***38.4***
TOTAL	**19 operating rectors**		**49**	**270.0**
	12 pipeline reactors		**70**	**229.6**
	31 operating/pipeline reactors		**56**	**499.6**

[1] Average operating capacity factor for 1994. *Nucleonics Week*, 9 February 1995, pp. 18-22.

[2] Estimated spent fuel output for 1994.

[3] There are five VVER-1000 reactors in the construction pipeline: two at Balakovo, one at Kalinin, and two at Rostov.

[4] In 1994, there were five VVER-1000 reactors in the construction pipeline in Ukraine: Khmelnitski 2, 3, and 4; Rovno 4; and Zaporozhe 6.

[5] There are two VVER-1000 reactors currently in the construction pipeline in the Czech Republic at the Temelin nuclear power plant.

In the following section we have estimated spent fuel discharges for the RBMK and VVER type reactors. For a given reactor size and type, average annual spent fuel discharge is a function of both the "fuel burnup"--the amount of fuel that is fissioned before it is removed--and the ratio of the energy output during the year to the amount of energy that would be produced if the reactor operated at full power for 100 percent of the time. The latter is referred to as the capacity factor (CF) and is often expressed as a percent. To minimize the unit cost of electricity, reactors should operate at the highest possible capacity factor. Due, however, to safety outages and shutdowns for refueling and maintenance, the average capacity factor worldwide over the past decade has been in the 65-70 percent range. Where we do not know the capacity factor for estimating spent-fuel discharges, we have used a nominal value of 70 percent, or the average value reported for other similar reactors.

Table 4 provides the characteristics of the RBMK and VVER type reactors, including the fuel burnup. The last column of Tables 1, 2, and 3 provides the estimated 1994 spent-fuel discharge (or fresh fuel requirement) for individual reactors.

Table 4
Reactor Operating Data

Reactor Type	Thermal Power (MWt)	Electric Power gross/net (MWe)	LEU Fuel Enrichment (% U-235)	Avg. Fuel Burnup (MWd/kgHM)	Spent Fuel Discharge @ CF = 70% (tHM/y)
RBMK-1000	3200	1000/960;1000/925	2.4	20	45.4
RBMK-1500	4800	1500/1450; 1500/1380	2.4	20	68.1
VVER-440	1375	440/410;408/376	3.6	28.6	12.3
VVER-1000	3000	1000/950	4.4	36-40	19.2-21.3

As seen from Table 4, when operating at 70 percent capacity factor, an RBMK-1000 reactor discharges about 45.4 tonnes of heavy metal (tHM) of spent fuel per year; an RBMK-1500 discharges about 68.1 tHM per year; a VVER-440 discharges about 12.3 tHM per year; and a VVER-1000 discharges about 19-21 tHM per year. Since the average annual spent fuel discharge is proportional to the capacity factor, the spent fuel discharges for other capacity factor values can be found easily by multiplying the values in Table 4 by the factor CF/70. Each tonne of RBMK spent fuel contains approximately 5 kilograms (kg) of plutonium, and each tonne of VVER spent fuel contains approximately 9 kg of plutonium.

Russian Reprocessing Facilities

Russia's spent fuel management program consists of both permanent disposal and chemical separation of plutonium and uranium from military and commercial irradiated fuel. The Mayak Chemical Combine (otherwise known as Chelyabinsk-65), originally built as a military chemical separation plant, now processes both civilian and naval reactor spent fuel, as well as spent fuel from tritium and plutonium production reactors. Two additional military chemical separation plants are located at Tomsk-7 and Krasnoyarsk-26 in Siberia.

Spent fuel from VVER-440 reactors is chemically separated at the RT-1 reprocessing plant at Chelyabinsk-65. Spent fuel from VVER-1000 reactors is presently being shipped to the incomplete RT-2 reprocessing plant at Krasnoyarsk-26. Pending completion of the RT-2 plant, VVER-1000 spent fuel is being stored in a temporary storage facility there. Russia has thus far been unable to obtain adequate funds to finance the RT-2 plant, and its completion remains uncertain.

Current Russian Laws that Govern Spent-Fuel Reprocessing

Historically, the Soviet Union provided fuel for all Soviet-designed reactors in Eastern Europe and retrieved the spent fuel for reprocessing. Since the break-up of the Soviet Union, Russia has signed reprocessing contracts with several countries in this region (Bulgaria, Finland, Hungary, and Ukraine), and continues to actively pursue additional contracts with other countries in the region.

In 1995 the Russian government issued three decrees to provide for the licensed import of spent fuel for reprocessing. Presidential Decree Number 72 of January 25 allowed one of Russia's military plutonium production complexes, Krasnoyarsk-26, "to accept, for temporary storage with the goal of subsequent reprocessing, spent nuclear fuel from foreign atomic power stations . . ." Presidential Decree Number 389 of April 20 removed the provision for temporary storage, and called for the return of products of separation to the country of origin. On July 29, the Russian Government approved Decree Number 773, which affirms the procedure for accepting spent nuclear fuel from abroad. The procedure mandates the "return to the supplier-country of radioactive waste formed during reprocessing and not intended for further use in the Russian Federation." (See Appendix A for an English translation of the procedure.) The procedure specifically mentions the return of only solid radioactive waste to the country of origin, and therefore leaves open the question of how liquid radioactive waste will be handled.

The issue has arisen as to whether the decrees conflict with the Russian Law on Environmental Protection, adopted in December 1991, which prohibits transport across Russian borders of "radioactive waste or materials from other states with the purpose of storage and disposal." The Russian Ministry of Atomic Energy (Minatom) contends that spent fuel is not radioactive waste. Minatom is attempting to avoid sanctions on storage and disposal by promising to return waste by-products of reprocessing to the country of origin.

These government decrees cannot technically supersede the Law on Environmental Protection; in practice, however, there have been many cases where presidential and governmental decrees have contradicted laws already on the books. The Russian Constitutional Court has yet to issue any guidelines on how to handle this situation. Observers hope that the passage of the Law on Radioactive Waste Handling, which has been under discussion in the State Duma (legislature) for two years, will clarify Russian government policy on this issue and, at the very least, provide clear legal grounds for an appeal in court. This law has been held up in part by debates over whether spent fuel should be defined as radioactive waste. The only attempt to resolve this murky situation through the judicial system occurred in January 1995, when the Duma tried to sue President Yeltsin in the Constitutional Court over the constitutionality of Presidential Decree Number 72. The Constitutional Court refused to hear the case, contending that it was not a constitutional issue.

Armenia

The Reactors

Before October 1995, no nuclear reactors had been in operation in Armenia since 1989. The country's two VVER-440 reactors--Metsamor 1 and 2, located in a region of high seismicity --were decommissioned after the disastrous 1988 earthquake in Armenia.[6] The United States and other G-7 nations have been vehemently opposed to the restart of the Metsamor reactors due to safety concerns. Both units were listed in the Department of Energy's 1995 report on the most dangerous nuclear reactors.[7] Despite Western opposition, however, Unit 2 at Metsamor was restarted in October, and ultimately Unit 1 may be brought back on-line. Although Armenia requested financial assistance to restart these reactors, none was granted by the G-7 countries. In March 1994, however, Russia agreed to provide financial and technical assistance to restart Metsamor 2.

Armenia's motivation for restarting the Metsamor reactors is to obtain desperately needed electricity. The bloody conflict over Nagorno-Karabakh, a small province in Azerbaijan claimed by both Armenia and Azerbaijan, has cut Armenia off from Russian fuel supplies and left the country with virtually no energy sources. Azerbaijan's economic blockade against Armenia has also contributed to this energy crisis. In 1994, Armenians were receiving roughly two hours of electricity per day.[8]

Spent Fuel

Ultimately, the two reactors at Metsamor would discharge approximately 24 tHM of spent fuel per year. From this, approximately 212 kg of plutonium could be extracted through reprocessing.

Little information is available regarding Armenia's management of spent fuel. Armenia and Russia have signed an agreement, however, through which Russia will supply fresh fuel to the reactors and accept spent fuel for reprocessing. While the agreement fails to state whether or not by-products will be returned to Armenia, it confirms that all activities concerning the materials will be carried out in accordance with the law of both countries.

Outlook

The safety of the operating reactor at Metsamor presents very serious concerns in the short term. The Metsamor reactors are first-generation VVER-440 series reactors which lack

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[6] *Post-Soviet Nuclear & Defense Monitor*, 3 March 1995, p. 14.

[7] Department of Energy Office of Energy Intelligence, *Most Dangerous Reactors* (Washington, DC: Department of Energy, May 1995).

[8] *Post-Soviet Nuclear & Defense Monitor*, 28 February 1994, p. 11.

fundamental safety features such as proper containment, adequate redundancy and separation of safety equipment, an efficient cooling capacity, and adequate fire protection mechanisms. In addition, as discussed above, the reactors are located in a region of high seismicity. Some limited safety upgrades were completed before the restart of Unit 2. For instance, corroded pipes and equipment that were stolen during the extended shutdown period were replaced, and adjustments were made to reinforce the reactor against severe earthquakes. Due to the urgency of restart, however, Armenia did not replace the reactor's obsolete control system. Moreover, the instability of the political and economic situation in Armenia could adversely affect the operational safety of the plant.

In the spring of 1995, Russia awarded Armenia a 110 billion ruble credit to restart these reactors.[9] Russia's willingness to provide such funds--especially when the Russian nuclear industry faces substantial economic uncertainty--as well as its preliminary reprocessing agreement with Armenia, indicates significant interest on Russia's part in acquiring reprocessing contracts from Armenia. Unfortunately, Russia has shown little concern for the long-term impacts of these contracts or for the serious safety hazards that accompany Metsamor's recommissioning.

[9] *Post-Soviet Nuclear & Defense Monitor*, 14 March 1995, p. 14.

Bulgaria

The Reactors

In Bulgaria, there are six VVER-type reactors presently in operation at Kozloduy, 300 kilometers (km) northeast of Sofia: four VVER-440 reactors and two VVER-1000 reactors. The Kozloduy reactors were built by Russia's Atomenergoexport, with the first reactor coming on line in 1974. Units 2 through 6 followed in 1975, 1980, 1982, 1987, and 1991 respectively.[10] There are currently no reactors under construction in Bulgaria.

Kozloduy Unit 1, considered to be the most unsafe of the VVER-440 units, was just recommissioned in October 1995 after being shut down in February for safety testing. The Bulgarian government, facing yet another winter of severe energy shortages, announced its intention to restart Unit 1 and to run it until the spring of 1996. Under the present Bulgarian plan, Unit 1 would be closed again in April 1996 for further testing and safety improvements.

Units 1 and 2 were initially shutdown in 1991 after an International Atomic Energy Agency (IAEA) Operational Safety Assessment Review Team concluded that the units were unsafe and should be closed immediately.[11] After some improvements in plant safety procedures and management, they were reopened a year later. Major safety upgrades were not undertaken at that time, however, and consequently international pressure brought on the second closure of Unit 1 in early 1995. The Department of Energy's Office of Energy Intelligence identified Kozloduy Units 1 and 2 as being among the most dangerous reactors in the world.[12]

Spent Fuel

In 1994, the four VVER-440 and two VVER-1000 reactors operated at an average of 43 percent capacity.[13] Operating at this low capacity factor, together the four Kozloduy VVER-440 reactors would discharge approximately 30 tHM of spent fuel per year, and the two VVER-1000 reactors approximately 24 tHM per year. Therefore, it is estimated that Bulgaria's 1994 spent fuel output contained roughly 486 kg of plutonium. If the average capacity factor of the reactors could be increased to a nominal 70 percent, the VVER-440s would discharge a total of about 50 tHM per year and the two VVER-1000 reactors approximately 40 tHM per year, containing a total of roughly 810 kg of plutonium.

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[10] *World Nuclear Outlook*, p. 83.

[11] DOE, *Most Dangerous Reactors*.

[12] Ibid.

[13] *Nucleonics Week*, 9 February 1995, p. 18.

Under the Soviet regime, Bulgaria had an agreement with the Soviet Union under which Kozloduy fuel was reprocessed in Russia free of charge.[14] In 1990, this agreement expired, leaving Bulgaria to handle its own nuclear spent fuel. Fuel is being stored temporarily in water pools at the Kozloduy NPP. In 1989, an Away From Reactor (AFR) storage facility was completed. An additional 600 tHM AFR storage pool is currently under construction.[15]

Outlook

Bulgaria's storage pools are nearing capacity, and the country has approached Russia about taking Bulgarian spent fuel. The Bulgarian Energy Committee stated in March 1995 that Russia had agreed to reprocess spent fuel from the Kozloduy VVER-440 reactors at the RT-1 reprocessing facility.[16]

The resolution of Bulgaria's VVER-1000 spent fuel problem, however, remains uncertain, as the Russian RT-2 reprocessing plant for VVER-1000 fuel has not yet been completed. However, the Kozloduy interim storage facility has proven unsuitable for storing VVER-1000 spent fuel.[17] Bulgaria signed a protocol with Russia on nuclear cooperation in June 1994,[18] which established a framework through which Russia will take back spent fuel from VVER-1000 reactors. As already noted, VVER-1000 fuel accepted by Russia would presently be stored at the RT-2 site pending completion of the reprocessing plant.

[14] "Russia to Reprocess Bulgaria's Nuclear Spent Fuel," Reuters, Sofia, 17 March 1995.

[15] *The World Nuclear Industry Handbook* (Nuclear Engineering International, 1994), p. 132.

[16] Reuters, Sofia, 17 March 1995.

[17] "Global Waste Management," *Nukem Market Report*, February 1995, p. 19.

[18] Ibid.

The Czech Republic

The Reactors

There are presently four VVER-440 reactors operating in the Czech Republic. Located in South Moravia, Dukovany, the reactors produce approximately 23 percent of the Czech Republic's electricity.[19] The first nuclear reactor was commissioned in 1985, with two following in 1986 and the fourth reactor coming on-line in 1987.[20] The reactors were supplied by SKODA Nuclear Power Plant Works, and are operated by the Czech power company, Ceske Energeticke Zovody (CEZ).

In addition to the four operating reactors, there are two VVER-1000 reactors under construction at the Temelin NPP. The reactors are slated for completion in 1997 and 1998. Due to controversy over their design and difficulties in securing funds to back-fit the Temelin reactors to Western safety levels, the completion of the reactors will likely be delayed.

Spent Fuel

The four reactors operating at Dukovany discharge approximately 50 tHM of spent fuel per year. If the Temelin reactors come on-line, this will increase by an additional 40 tHM spent fuel per year, giving a total of approximately 90 tHM per year for the Czech Republic.[21] From this, approximately 810 kg of plutonium per year could be extracted through reprocessing. Over the anticipated thirty-year lifetime of the Dukovany and Temelin reactors, approximately 2,850 tHM of spent fuel is projected to be discharged.

Like other former Eastern bloc countries, the former Czechoslovakia returned spent fuel to the Soviet Union according to official "take back" agreements.[22] Spent fuel from Dukovany, however, was not sent to Russia. Dukovany spent fuel was sent to the Bohunice NPP, located in the present day Slovak Republic, where it replaced Bohunice fuel that had been shipped to RT-1 in Russia.[23] With the collapse of the Soviet Union and the subsequent breakup of Czechoslovakia, the Czech and Slovak governments agreed that all Czech fuel currently stored at Bohunice NPP, approximately 16 tHM, must be returned to the Czech Republic as soon as proper storage facilities are available. The transfer of fuel is to be completed by 1997.

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[19] "Czech Nuclear Plant to Open on Time, Operator Says," Reuters, Prague, 24 March 1995.

[20] *World Nuclear Outlook*, p. 85.

[21] Reuters, Prague, 24 March 1995.

[22] David Albright et al., *World Inventory of Plutonium and Highly Enriched Uranium 1992* (New York: Oxford University Press, 1993), p. 88.

[23] "Global Waste Management," *Nukem Market Report*, February 1995, p. 19.

Irradiated fuel assemblies from Dukovany reactors are stored in high density storage racks in water pools. Each reactor has its own wet storage facility with a capacity of seven full fuel reloads, or 98 tHM.[24] The spent fuel ponds at Dukovany were re-racked in 1994, increasing their capacity by 90 percent.[25] The ponds will only be able to accept fuel until 1997. The proposed Temelin reactors will also have such pools.

An additional dry storage facility is currently under construction at Dukovany and will hold approximately 600 tHM. The facility, which uses CASTOR VVER-440 casks for storage, should reach full capacity by 2005. A Central Spent Nuclear Fuel Storage (CMVJP) facility, which can hold up to 3000 tHM, has been proposed. Preliminary designs are underway, and site selection for this facility should be decided by 1997. The CMVJP should provide sufficient storage capacity until such time as a permanent underground repository can be completed. The Czech Republic is conducting studies leading to the construction of a permanent underground repository, in hopes that such a facility could be operable by 2030.

Outlook

In December 1992, the Czech Republic announced that it had "decided not to pursue the reprocessing option on economic grounds."[26] However, on 4 December 1994, the Czech Republic signed an agreement with Russia which established the framework for reprocessing Czech spent fuel in Russia. The agreement, which contradicts CEZ's statements that reprocessing is not a viable option for the Czech Republic, stipulates that all by-products of reprocessing would be returned to the Czech Republic. In defense of the agreement, an official said that it is a "general framework agreement only; it has no commercial aspect."[27] Nonetheless, this agreement indicates that the Czech Republic views reprocessing as a potentially viable option for future management of spent fuel.

[24] Assumes a fuel core is 42 tHM, and a reload is one-third core, or 14 tHM.

[25] "Global Waste Management," *Nukem Market Report*, February 1994, p. 37.

[26] *Nuclear Fuel*, 2 January 1995, p. 15.

[27] Ibid.

Finland[28]

The Reactors

Four civilian nuclear reactors currently operate in Finland. Unlike the other countries discussed so far, the reactors in Finland were supplied by two different countries. Sweden's ASEA-Atom supplied two boiling water reactors in 1978 and 1980, while the Soviet Union's Atomenergoexport supplied Finland with two VVER-440 reactors in 1977 and 1980. Imatran Voima Oy (IVO) operates the two Soviet Reactors, located at the Loviisa Nuclear Power Plant on Hastholmen Island. The Swedish reactors, located in Olkiluoto, are operated by Teollisuude Voima Oy (TVO). All four reactors produce approximately 32.4 percent of Finland's aggregate electricity output per year. There are presently no reactors under construction in Finland.

Spent Fuel

Finland's spent fuel management program reflects the fact that two separate groups operate Finland's nuclear power plants. For the purposes of this paper, only spent fuel from the VVER-440 reactors will be discussed.

At the close of 1994, the reactors were operating at close to 90 percent capacity, and thus it is a valid assumption that together, the Loviisa reactors produce roughly 30 tHM of spent fuel per year. This amount of spent fuel contains roughly 270 kg of plutonium.

Over its forty-year lifetime, the Loviisa NPP will discharge approximately 1000 tHM of spent fuel. Spent fuel is first stored in the on-site storage pools, which collectively have a capacity of about 270 tHM. As of late 1994, they contained approximately 141 tHM of spent fuel. There are two additional facilities at the Loviisa site, both built partially underground: one in which fuel is stored in baskets, and one new rack storage facility. Nevertheless, additional space will be necessary by the year 2002.

In the 1970s, Finland passed legislation which mandated that all nuclear waste be exported out of the country. The government maintained that since fresh fuel was supplied by the Soviet Union, spent fuel should be taken back by Russia. A preliminary agreement with the Soviet regime became a contract for reprocessing of Loviisa spent reactor fuel. The fuel was exported directly to RT-1 at the Mayak Chemical Combine. The agreement did not stipulate that any by-products of reprocessing be returned to Finland. The contract, which has been renegotiated every five years since its inception, was picked up by Russia when the USSR dissolved in 1991, and continues to be in effect to date.

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[28] All material, unless otherwise noted, taken from: Finnish Center for Radiation and Nuclear Safety, *Radioactive Waste Management in Finland*, 2 February 1994.

In the early 1990s, the shipping of nuclear spent fuel to Russia evoked heated public protests by those asserting that Finland should not export its nuclear wastes. In 1994, the Finnish government amended the Nuclear Energy Act, making the import *and export* of nuclear waste materials illegal. The only temporary exceptions to this new law were the Loviisa spent fuel shipments to Russia, and the shipment of research-reactor fuel to the United States. Prior to 1995, thirteen shipments of spent fuel had been sent to Russia since 1981, bringing the total of spent fuel exported to Russia to 280 tHM.

Outlook

The Finnish agreement with Russia to reprocess spent nuclear fuel was due to expire in 1996; after the November 1996 shipment, Loviisa fuel would no longer be exported. In October 1995, however, the head of the Nuclear Safety Department of Finland's radiation protection authority announced that, due to safety concerns, it was possible that spent fuel would not be sent to Russia this year or next.[29] Despite this announcement, the 1995 shipment went forward with the provision that Russia retain the waste after reprocessing.

It is not yet clear what spent fuel management alternatives to reprocessing Finland will choose once shipments to Russia stop. Loviisa's interim storage pool will reach capacity by 2002, and Finland eventually will have to construct a long-term dry-storage facility to handle spent fuel from Loviisa.

A Finnish company, Posiva, has recently been jointly established by TVO and IVO to manage spent fuel from both the Soviet- and Swedish-designed reactors.[30] This company is presumably an attempt to unify TVO and IVO's approaches to spent fuel management in anticipation of halting export of Loviisa spent fuel to Russia. TVO and IVO had announced in May 1995 that they agreed to cooperate on plans for final disposal and construction of an underground facility for use by both utilities. In contrast to IVO, TVO has thus far avoided the reprocessing option, and has been conducting joint projects with Sweden to test technology for direct disposal of spent nuclear fuel. Since 1987, an interim storage facility called KPA Store has been storing the spent fuel from the Olkiluoto reactors. This facility has a capacity of 1200 tHM, and as of 1993, held 595 tHM from the Olkiluoto NPP. Posiva is currently evaluating a number of sites for a permanent geological repository, including Olkiluoto, Kivetty, and Romuvaara. Posiva hopes to select a location by 2000, with construction beginning by 2010.

[29] "Last Train Carrying Spent Nuclear Fuel from Finland?" *Helsinki Pohjoismaiset Uutiset Database*, 30 October 1995.

[30] "Finland: New Company Set Up to Manage Spent Fuel," *NucNet*, 19 October 1995.

Hungary

The Reactors

Four VVER-440 power reactors are currently operating at Hungary's Paks Nuclear Power Plant. The plant, located in Paks, Tolna, generates approximately 43.3 percent of Hungary's total electricity output.[31] The first reactor came on-line in December 1982. The three other units followed in 1984, 1986, and 1987, respectively. All reactors were supplied by Atomenergoexport and are operated by Hungarian Electricity Works, Ltd. (MVMT).

Hungary has two VVER-1000 reactors currently under construction. Construction of these reactors, which will be located at the Paks NPP, should be completed in 1997 and 1998, respectively.[32]

Spent Fuel

In 1994, the Paks Units 1-4 operated at capacity factors ranging from 78 percent to 91 percent, discharging approximately 61 tHM of spent fuel. Approximately 549 kg of plutonium could be separated from this amount of spent fuel through reprocessing.[33]

During the Soviet period, Hungary shipped fuel back to the Soviet Union under a "take back" agreement, which originated from a 1966 Soviet-Hungary nuclear cooperation agreement. With the fall of the Soviet Union, Hungary began preparing for in-country means of spent fuel storage. The Hungarian National Atomic Energy Commission (OAB), however, would prefer that all spent fuel of Russian origin be returned to Russia, as Hungary presently does not have sufficient storage capacity. Its spent fuel storage pool was said to be dangerously close to capacity in 1994.[34]

In 1993, Russia, Ukraine, and Hungary signed an agreement on the transport of spent nuclear fuel. Russia also signed a fresh-fuel supply agreement with Hungary that same year. Then, in April 1994, Russia and Hungary--represented by Russian Federation Prime Minister Viktor Chernomyrdin, Minatom's Director Viktor Mikhailov, and Hungarian Minister of Industry and Trade Janos Latorcai--signed a joint protocol supporting export of spent nuclear fuel to

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[31] *World Nuclear Outlook*, p. 14.

[32] Haruo Fujii and A. Morishima, eds., *Directory of Nuclear Power Plants in the World* (Tokyo: Japan Nuclear Energy Information Center Co., Ltd., 1994), p. 393.

[33] *Nucleonics Week*, 9 February 1995, p. 19.

[34] *Nuclear Fuel*, 13 February 1995, p. 12.

Russia.[35] This agreement led to the contract signed in August 1994 which established the necessary conditions for Hungary to export its spent fuel to Russia for reprocessing.[36]

The shipment of Hungarian spent fuel has already taken place under this contract. The first load of spent fuel, approximately 110 tHM, traveled by special rail-car through Ukraine to the RT-1 in Russia on 17 January 1995.[37] The contract allows for the burial of reprocessing waste products at the Mayak complex, although burial of waste is illegal under Russian law.

On 4 February 1995, the OAB issued a license to MVMT permitting the construction of a Modular Dry Vault Storage (MDVS) system which will hold spent fuel for 50 years.[38] If construction remains on schedule, the facility could be operable in 1996.[39]

Outlook

Hungary likely will continue to send its spent fuel to Russia in the near future, at least until its own dry storage facility is ready to accept waste. In spite of opposition to reprocessing from the Russian public and legislative branch, Russia probably will continue to accept spent fuel shipments from Hungary, at least in the near term. Maintaining good political relations with Hungary is in Russia's best interests. Moreover, Russia receives $10 million for each shipment of spent fuel from Hungary--currency which Russia's nuclear industry desperately needs.[40]

Because of opposition to reprocessing within Russia, however, Hungary continues to move forward with its construction of a dry storage system in case Russia should decide not to accept Hungary's spent fuel in the future.

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[35] *Nuclear Fuel*, 9 May 1994, p. 9.

[36] *Nuclear Fuel*, 30 January 1995, p. 10.

[37] Ibid.

[38] Ibid.

[39] "Global Waste Management," *Nukem Market Report*, February 1995, p. .

[40] *Nuclear Fuel*, 30 January 1995, p. 10.

Lithuania

The Reactors

There are presently two RBMK-1500 reactors operating in Lithuania. Located at the Ignalina NPP, the reactors produce about 87 percent of Lithuania's electricity.[41] The two reactors were supplied by the Soviet Union in December 1983 and August 1987.[42] There are presently no reactors under construction in Lithuania.

The operation of these two RMBK-1500 reactors is, at present, quite controversial. Both units were included in the Department of Energy's 1995 report *Most Dangerous Reactors.*[43] Although some post-Chernobyl safety upgrades have been made on these two units, the safety systems are generally considered to be inadequate, with insufficient redundancy, diversity, and separation of safety equipment. In addition, these units are operating at a higher power than other RBMK's. Demand-side pressure and Lithuania's overwhelming dependence on nuclear electricity, however, make it unlikely that the units will be shut down in the near future. Recently, an agreement between Lithuania and Russia was signed which will provide for fresh nuclear fuel from Russia in return for electricity.

Spent Fuel

The two RBMK-1500's located at Ignalina could discharge roughly 105 tHM of spent fuel, containing about 525 kg of plutonium annually. Lithuania had a "take back" agreement with the Soviet Union prior to 1991. Despite this agreement, no Lithuanian fuel was ever shipped to Russia since RBMK fuel is not being reprocessed.[44] When Ignalina's on-site storage facility reached capacity by the end of 1994, the plant began to utilize spent fuel storage casks.

Outlook

As Lithuania has no plans to complete additional reactors, its spent fuel management program may be adequate in the short term. The Ignalina NPP is working with SKB, a Swedish waste management company, to develop more efficient waste disposal strategies for low and medium level waste.[45] Of greatest concern to Lithuania at present are safety problems with the Ignalina reactors, but the country will also have to confront its long-term spent fuel management problems eventually.

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[41] *World Nuclear Outlook*, p. 14.

[42] Ibid., p. 88.

[43] DOE, *Most Dangerous Reactors*.

[44] "Global Waste Management," *Nukem Market Report*, February 1994, p. 40.

[45] Ibid.

Russia

The Reactors

There are currently twenty-nine civil nuclear power reactors in Russia: 11 RBMK, six VVER-440, seven VVER-1000, one liquid-metal fast breeder, and four small graphite-moderated, water-cooled reactors. Distributed among nine nuclear power plants, the reactors produced 12.5 percent of Russia's electricity output in 1994.[46] The majority of these reactors are operated by the consortium Rosenergoatom.

Russia's Kola NPP, listed in the DOE report *Most Dangerous Reactors*, continues to have the highest number of reported incidents in Russia.[47] In 1993, the Kola plant was responsible for 25 percent of all incidents at Russian power plants.[48] Poor safety culture at the plant (i.e., weak regulation, poor employee morale, and severe funding shortages) is generally considered to be responsible for the unusually high number of incidents at this VVER-440 plant. Other plants with unusually high incident rates are the Novovoronezhskaya and Balakovo NPP's.

There are presently seven reactors in various stages of construction. Russia proposes to complete six VVER-1000 units (Balakova 5 and 6, Kalinin 3, and Rostov 1, 2, and 3) as well as one RBMK (Kursk 5).[49]

Spent Fuel

In 1994, the reactors' operating capacity ranged from 2.3 percent to 82.9 percent.[50] From Russia's 11 RBMK reactors, an estimated 360 tHM of spent fuel containing 1,800 kg of plutonium was discharged. Operating at 70 percent capacity, Russia's VVER reactors could produce approximately 208 tHM per year. In 1994, the VVER reactors produced approximately 135 tHM of spent fuel containing approximately 1,215 kg of plutonium.

The 1994 report of the Russian State Nuclear Inspectorate (Gosatomnadzor, or GAN) revealed the dire status of Russian spent fuel storage and disposal.[51] Spent fuel is not being removed from RBMK's, as their fuel will not be subject to reprocessing or evacuation in the foreseeable future. According to GAN's report on nuclear safety during the first half of 1995, this fuel build-up has become a critical problem, particularly at the Smolenskaya NPP, where

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[46] *World Nuclear Outlook*, p. 14.

[47] Gosatomnadzor (GAN), *One Step Forward, Two Steps Back: Gosatomnadzor on the State of Nuclear Safety in the Country in the First Half of 1995*, 17 October 1995.

[48] DOE, *Most Dangerous Reactors*.

[49] *World Nuclear Outlook*, p. 99.

[50] *Nucleonics Week*, 9 February 1995, p. 20.

[51] GAN, *The State of Nuclear and Radiation Safety in the Russian Federation in 1994*.

storage pool capacity will last another six months at best.[52] In order to deal with the growing quantity of spent nuclear fuel at both RBMK and VVER plants, fuel is being "reracked," or packed more densely into already overfull storage facilities.

Safety regulations require that a sufficient amount of space be left in cooling ponds to allow for the unloading of the reactor core in the event of an emergency. At some storage sites, overfilling of cooling ponds has led to the inability to perform emergency core unloading. By the end of 1994, emergency core unloading had become impossible at the following plants: all units of Leningradskaya and Kurskaya NPP's, Smolenskaya 1 and 2, and Novovoronezhskaya 3 and 4.[53] Reracking provides, at best, only a temporary solution to the storage problem. At the Smolenskaya NPP, for example, despite reracking of its facilities, the plant still had to resort to unsanctioned transport of spent fuel from Unit 1 to 3 in order to allow for continuing operation of Unit 1.

Most of the storage sites are accumulating damaged fuel assemblies which cannot be accepted for reprocessing. In addition, at the Beloyarskaya NPP, which has been shut down for decommissioning, fuel assemblies have been stored in cooling ponds in containers intended for dry storage. A number of these containers have become unsealed, thus allowing for direct contact between the uranium and cooling water, and increasing the water's activity. The integrity of the steel lining of the ponds is uncertain, and in the event of a leak of radioactive cooling water, no additional containment or barriers are provided.

GAN does not have official permission to examine Russian military sites, and therefore it has incomplete information about the status of military spent fuel management. Moreover, in July 1995 a Presidential Order transferred responsibility for oversight of nuclear and radiation safety associated with nuclear weapons and military power plants from GAN to the Russian Defense Ministry. The available information, however, indicates that storage facilities at Navy sites for the North and Pacific Fleets are virtually full and do not meet existing safety standards.

The Mayak reprocessing facility is presently storing fuel on-site before it is reprocessed. Storage facilities at Mayak are currently 50-70% full. In addition, the RT-2 reprocessing site has been accepting VVER-1000 fuel, even though construction of the reprocessing facility has not been completed. Storage at this facility is already at least 20% full.

Outlook

Russia continues to actively seek reprocessing contracts with other countries, despite the present hazardous state of its own spent fuel management. Although there has been opposition

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[52] GAN, *One Step Forward, Two Steps Back: Gosatomnadzor on the State of Nuclear Safety in the Country in the First Half of 1995.*

[53] Information in the rest of this section is taken from the GAN report *The State of Nuclear and Radiation Safety in the Russian Federation in 1994.*

on safety grounds to reprocessing agreements with other countries from within Russia, the lack of reliable information on the state of Russian spent fuel management has thus far been a significant hindrance to opponents of reprocessing.

As noted previously, Minatom has addressed such criticism by providing for the return of by-products of reprocessed fuel to the country of origin. By formulating reprocessing contracts in such a way that by-products of chemical separation, including wastes, are returned to the country of spent-fuel origin, Minatom hopes to present a somewhat more persuasive argument to critics by arguing that waste products will not affect Russia's environment. However, the transport and handling of spent fuel, as well as the reprocessing process itself, pose serious dangers to the environment even if Russia is not the final destination of the by-products of reprocessing.

The Slovak Republic

The Reactors

There are presently four VVER-440 reactors operating at the Bohunice Nuclear Power Plant in Trnava, Zapadoslovensky. The first reactor came on-line at Bohunice NPP in 1978.[54] The other reactors followed in 1980, 1984, and 1985, respectively.[55] Bohunice 1 and 2, listed in DOE's *Most Dangerous Reactors*,[56] were supplied by Atomenergoexport, while Bohunice 3 and 4 were supplied by SKODA Concern Nuclear Power Plant Works (SKODA). The reactors, operated by Slovenske Elektrarne,[57] provide about 53 percent of the Slovak Republic's total electric power.[58]

Four VVER-440 reactors are also slated for completion at Mochovce. The project faces intense opposition, however, from those who fear potential accidents from these early model Soviet reactors, and from those who believe that completion of Mochovce is not the least-cost solution to the Slovak Republic's energy needs. Despite the Slovak Republic's failure to obtain Western financing for the project, the country appears determined to obtain the necessary funding. Prime Minister Meciar recently met with Russian Prime Minister Chernomyrdin to sign an agreement for funds towards completion of Mochovce 1 and 2. The agreement provides for $80 million in total assistance--$50 million as a direct loan, and $30 million which must be used to pay for Russian technological support and services. The agreement clearly favors Russia, as it requires the Slovak Republic to purchase fresh fuel from Russia for the duration of the plants' lifetimes in return for the aid. While the Russian aid will only cover a small portion of the total debt of the Mochovce project, this agreement shows the Slovak Republic's determination to go forward with the project.

Spent Fuel

The Bohunice reactors could discharge approximately 50 tHM of spent fuel per year from which about 450 kg of plutonium could be separated through reprocessing. When and if the Mochovce VVER-440 reactors come on-line, another 40 tHM of spent fuel could be produced, giving the Slovak Republic a spent fuel output of roughly 90 tHM per year.

As discussed in the section on the Czech Republic, the former Czechoslovakia had an agreement with the Soviet Union through which spent fuel was returned to Russia. This agreement ended in 1989 with the break-up of Czechoslovakia.

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[54] *World Nuclear Outlook*, p. 88.

[55] Ibid.

[56] DOE, *Most Dangerous Reactors*.

[57] Reuters, Bratislava, 28 April 1995.

[58] *World Nuclear Outlook*, p. 14.

At the Bohunice Nuclear Power Plant, a storage facility with a capacity of 600 tHM holds spent fuel from the Bohunice reactors and from the Czech Dukovany reactors. The facility can hold up to 5,000 spent VVER-440 fuel rods.[59] Even with the return of Dukovany spent fuel rods to the Czech Republic, the Bohunice interim storage facility will probably only last into 1996. Slovenske Elektrarne continues to seek ways to expand its spent fuel storage capacity, and studies have begun to determine a site for a permanent geological repository.

The planned storage rack at Mochovce would hold up to three years worth of spent fuel. A new design has been proposed, however, which would increase the rack's capacity to 5.5 years.[60] It should be noted that beyond interim storage, no final plans have been made for Mochovce's spent fuel.

Outlook

The Slovak Republic's storage capacity will likely be reached soon. Although there is currently no reprocessing contract with Russia, if the Mochovce reactors were completed, it is possible that their spent fuel would be sent to RT-1 in Russia for reprocessing. The two countries have signed a letter of intent that provides for the reprocessing of Mochovce spent fuel at the Russian RT-1 plant, which could lead to a reprocessing contract with Russia in the future--particularly if the current atmosphere of cooperation between the two countries on the completion of the plant continues.

[59] "Global Waste Management," *Nukem Market Report*, February 1995, p. 19.

[60] Slovenske Elektrarne and Electricite de France, *Public Participation Programme Project Documentation*, December 1994, p. 43.

Ukraine

The Reactors

There are currently fourteen nuclear reactors operating at five nuclear power plants in Ukraine. Of these reactors, there are ten VVER-1000 reactors, two VVER-440 reactors, and two RBMK reactors. All reactors were supplied by the Soviet Union and are operated by Ukraine's Ministry for the Protection of the Environment and Nuclear Safety.[61] Throughout 1994, the reactors operated at capacity factors between 43.6 and 76.3 percent.[62] In 1994, the overall electricity share produced by Ukraine's nuclear power plants was around 34.2 percent.[63]

The most controversial of these nuclear reactors are, of course, the two RBMK-1000 units still operating at Chernobyl, identified in DOE's *Most Dangerous Reactors* as the "worst of the worst."[64] Dire economic problems in Ukraine and the country's dependence on Chernobyl have thus far rendered international efforts to close these reactors--considered in many ways to be even more unsafe than at the time of the disastrous accident at Unit 4 in 1986--largely unsuccessful. On 20 December 1995, however, the G-7 nations signed a Memorandum of Understanding with Ukraine which reaffirmed the commitment to close the reactors by the year 2000. The Memorandum provides for $2.3 billion in Western assistance for alternative power and decommissioning.

Four VVER-1000 reactors are in various stages of construction in Ukraine: Khmelnitski 2, 3, and 4, and Rovno 4. The Memorandum of Understanding between the G-7 and Ukraine proposes the completion of two of these unfinished reactors--Khmelnitski 2 and Rovno 4--in return for Chernobyl shutdown, provided that these reactors can be proven to be part of a least-cost plan for Ukraine's energy sector.

Fuel

The Ukrainian nuclear industry faces several problems in continuing operation during the current period of economic and political instability. As Russia has continually raised fuel prices, Ukraine has been less and less able to purchase the quantity of fuel it needs. There is an agreement between Russia and Ukraine in which Ukraine receives fresh fuel in exchange for weaponry it returns to Russia.[65] However, the poor quality of the imported fuel has caused a

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[61] *Post-Soviet Nuclear & Defense Monitor*, 31 January 1995, p. 6.

[62] *Nucleonics Week*, 9 February 1995, p. 21.

[63] *Post-Soviet Nuclear & Defense Monitor*, 14 March 1995, p. 10.

[64] DOE, *Most Dangerous Reactors*.

[65] *Post-Soviet Nuclear & Defense Monitor*, 15 January 1995, p. 3.

drop in production, and the amounts of fuel stipulated in the agreement do not meet Ukraine's fuel needs.[66]

In the first six months of 1994, Ukraine was able to purchase only two loads of fuel.[67] In order to maintain full operation, Ukraine needs ten of these loads. Ukraine has since expressed its desire to build its own fuel production facilities,[68] but has been unable thus far to obtain the foreign investment necessary to complete the proposed facility.[69]

Spent Fuel

In addition to acquisition of fresh fuel, the management of spent nuclear fuel poses another pressing problem for Ukraine's nuclear industry. Ukraine's reactors could discharge more than 250 tHM per year. The Chernobyl reactors produced roughly 69 tHM of spent fuel containing about 345 kg of plutonium in 1994. The VVER-440 reactors discharged approximately 26 tHM of spent fuel, while the VVER-1000s discharged approximately 164 tHM. From this 190 tHM VVER spent fuel, approximately 1710 kg, or 1.71 t, of plutonium could be separated by reprocessing. Although overall nuclear activity declined in 1994, in December of that year some of Ukraine's reactors were operating at close to 100 percent capacity factor (Khmelnitski 1 and Zaporozhe 5, for instance).

There is a considerable lack of storage capacity at Ukraine's nuclear power plants. The spent fuel from RBMK reactors was never considered for reprocessing as it does not contain enough plutonium to justify the cost of the process. Instead, each nuclear power plant with RBMK type reactors stores the fuel in a 2000 tHM storage facility, constructed wherever these reactors were built.[70] To date, the spent fuel from Ukraine's RBMK reactors is stored on-site at the reactor.

Storing VVER spent fuel has posed a significant problem in Ukraine. Most on-site storage facilities are nearing capacity. Prior to 1992, Ukraine shipped VVER spent fuel to Russian storage facilities. In fact, the majority of the spent fuel stored at Krasnoyarsk-26 came from Ukraine. All Ukrainian fuel shipments to Russia were halted in 1992 due to the Russian Environmental Protection Law (discussed earlier). In 1994, after the issuance of presidential decrees allowing for the transport of spent fuel across Russian borders, the Rovno VVER-440 plant, prompted by severe saturation of its spent fuel storage facilities, signed a government-

[66] *Nuclear Fuel*, 2 February 1995, p. 12.

[67] *Post-Soviet Nuclear & Defense Monitor*, 24 October 1994, p. 6.

[68] *Nuclear Fuel*, 2 March 1995, p. 12.

[69] *Post-Soviet Nuclear & Defense Monitor*, 14 March 1995, p. 11.

[70] *Directory of Nuclear Power Plants in the World*, p. 225.

backed contract with Russia for reprocessing.[71] Due to Ukraine's economic problems, however, it is unlikely that this will prove to be a lucrative contract for Russia.

The urgency of the situation has prompted three plants to seek alternative arrangements by contracting foreign companies to build dry cask storage facilities. In December 1993, Zaporozhe NPP signed a contract with the U.S. firm Duke Engineering Services for fourteen dry storage casks.[72] After a warning from the Ukrainian government that without new storage facilities within the next year the NPP would have to shut down, the U.S. Department of Energy agreed to pay for the "construction, delivery and installation of three complete ventilated casks" for the Zaporozhe NPP.[73] The U.S. hopes to provide Ukraine with the technology to build such storage facilities itself.

Both the Chernobyl Nuclear Power Plant and the Rovno Nuclear Power Plant have ordered dry storage containers from Ontario Hydro.[74] The storage containers would hold RBMK fuel at Chernobyl and VVER-440 fuel at Rovno.

Outlook

Given Ukraine's severe spent fuel crisis, the reprocessing option may appear to provide a welcome, albeit temporary, solution for Ukraine. Spent fuel could be taken off their hands by Russia for at least ten years. In the meantime, Ukraine would need to develop a system of final disposal. Whether Ukraine opts for the "once through" spent fuel management option or for reprocessing, the question remains: in Ukraine's present dire economic straits, can the country afford to pay for either of these methods of spent fuel management?

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[71] Oleg Bukharin, *Future of the Reprocessing Business at the RT-1 Plant*, 10 September 1995, p. 4.

[72] *Post-Soviet Nuclear & Defense Monitor*, 5 December 1994, p. 1.

[73] Ibid.

[74] "Global Waste Management," *Nukem Market Report*, February 1995, p. 28.

Appendix A

CONFIRMED

by Decree of the Government of the Russian Federation from July 29, 1995 No. 773

PROCEDURE

of accepting spent nuclear fuel of foreign nuclear power stations for further reprocessing at Russian enterprises and returning radioactive wastes and materials formed during reprocessing

I. General Provisions

The procedure of accepting spent nuclear fuel from foreign nuclear power stations for further reprocessing at Russian enterprises and returning radioactive wastes and materials formed during reprocessing has been developed in execution of decrees of the President of the Russian Federation from April 21, 1993 No. 472 "On the Russian Federation's fulfillment of intergovernmental agreements on cooperation in equipping nuclear power stations abroad" and from April 20, 1995 No. 389 "On additional measures for strengthening control over execution of requirements of environmental safety during reprocessing of spent nuclear fuel."

This Procedure is intended to cover spent nuclear fuel from nuclear power stations erected abroad before 1991 with the technical assistance of the USSR; those newly built abroad according to designs of the Russian Federation; and also spent nuclear fuel of nuclear power stations built according to designs of other countries, accepted for reprocessing at the Mining-Chemical Combine in Zheleznogorsk, Krasnoyarsk Krai [Krasnoyarsk-26].

The import of spent nuclear fuel from foreign nuclear power stations for further reprocessing at Russian enterprises is implemented with the goal of separating valuable components (plutonium and uranium) for further use and for solidifying radioactive products of separation. A condition of accepting spent nuclear fuel is the return to the supplier-country of radioactive waste formed during reprocessing and not intended for further use in the Russian Federation.

The return of uranium and plutonium to any government which does not possess nuclear weapons can be implemented only under the condition of the placement of all nuclear activity of that government under the guarantee of the International Atomic Energy Agency (IAEA).

The import of spent nuclear fuel of foreign nuclear power stations for reprocessing and the export of radioactive waste and products of reprocessing is implemented according to licenses issued by the Ministry of Foreign Economic Relations of the Russian Federation on the basis of applications in an established format, which are preliminarily agreed upon with the Ministry of the Russian

Federation on Atomic Energy, and with the permission of the Federal Oversight of Russia on Nuclear and Radiation Safety to the reprocessing enterprises and applying organizations to conduct the according types of activity.

II. Preparation and Realization of Agreements

A basis for accepting spent nuclear fuel of foreign nuclear power stations for reprocessing are both inter-governmental agreements concluded by the USSR before 1991 and protocols to them, which are an integral part of according inter-governmental agreements, and current and newly concluded international treaties of the Russian Federation.

For foreign nuclear power stations erected before 1991 under technical assistance of the USSR, and also for nuclear power stations, which will be built according to designs of the Russian Federation, the obligations of the Russian Federation to accept spent nuclear fuel should be part of inter-governmental agreements on construction and operation of these nuclear power stations.

The acceptance of spent nuclear fuel from foreign nuclear power stations built according to designs of other countries can be implemented in accordance with inter-governmental agreements. Drafts of agreements are prepared by the Ministry of the Russian Federation on Atomic Energy and are agreed with interested federal organs of the executive branch.

During preparation of inter-governmental agreements on issues of accepting spent nuclear fuel for further reprocessing, it is necessary to proceed from the condition that solid radioactive waste and products of reprocessing not intended for use in the Russian Federation will be returned to the country which supplied the spent nuclear fuel to the Russian Federation.

Products of reprocessing (uranium and plutonium) not intended for use in the Russian Federation are returned to the country which supplied the spent nuclear fuel in a mutually agreed upon form under the condition of confirmation of guarantees by the IAEA and in accordance with international obligations on non-proliferation of nuclear weapons. The country which supplies spent nuclear fuel should guarantee that it has the administrative and technical capacity and the regulatory structure for handling and removing radioactive waste in observance of international norms of safety. It should also ensure the opportunity for regulatory organs of the Russian Federation to determine that the stated requirements are being observed before transboundary transfer of solid radioactive waste.

A basis for the practical realization of corresponding inter-governmental agreements on accepting spent nuclear fuel from foreign nuclear power stations for reprocessing and subsequent return of solid radioactive waste and products of reprocessing are contracts concluded by specially authorized organizations at the authorization of the Ministry of the Russian Federation on Atomic Energy with foreign companies and organizations on a commercial basis. The contracts should take into account requirements of international treaties of member countries of the IAEA, including agreements on IAEA guarantees, and also international and national standards and rules of safety, including those for transboundary transfer of radioactive waste.

III. Organization of Transportation of Spent Nuclear Fuel

The technical characteristics of spent nuclear fuel of foreign nuclear power stations which will be accepted [for reprocessing] should correspond to requirements of Russian Federation regulations.

The transportation of spent nuclear fuel is implemented in a direct railway connection under conditions of ''exclusive use'' in special transport containers for which certificates of permission are issued for construction and transportation of fuel. The certificates are issued in an established order and confirm that the given container and transportation correspond to the requirements of national regulations.

The acceptance of spent nuclear fuel by enterprises of the Ministry of the Russian Federation on Atomic Energy which will transport the spent nuclear fuel will occur on the state boundary of the Russian Federation.

Enterprises of the Ministry of the Russian Federation on Atomic Energy which conduct transportation of spent nuclear fuel will ensure a financial guarantee in case of compensating damage from the effects of radiation and for environmental safety during transportation on the territory of member countries of the Commonwealth of Independent States and the Russian Federation. They are also responsible for eliminating the consequences of a radiation accident.

During preparation of inter-governmental agreements, it is necessary to proceed from the assumption that outside of the territories of member countries of the Commonwealth of Independent States, the country which supplies spent nuclear fuel carries the financial guarantee in case of compensating damage from the effects of radiation and responsibility for eliminating the consequences of a radiation accident. Physical protection of the spent nuclear fuel is provided by the country on whose territory transportation is occurring, in accordance with that country's legislation.

Points at which responsibility for physical protection is transferred from one government to another should be determined by inter-governmental agreements.

IV. Organization of the Acceptance of Spent Nuclear Fuel for Reprocessing and the Return of Radioactive Waste and Products of Separation

The specific amount of spent nuclear waste which is accepted for reprocessing is determined by the Ministry of the Russian Federation on Atomic Energy, proceeding from the yearly applications of organizations and companies which operate nuclear power stations abroad; the conditions determined by the Federal Oversight of Russia on Nuclear and Radiation Safety for corresponding types of activity; the productivity of enterprises for reprocessing radioactive waste; and taking into account the environmental condition in the region where reprocessing enterprises are located. This amount is agreed upon with federal environmental protection bodies, bodies of the executive branch of Russian Federation territories, and local self-governing bodies.

The Ministry of the Russian Federation on Atomic Energy yearly announces the applications for the current year for importing spent nuclear fuel, planned negotiations with foreign companies and organizations, and also the specific amounts of spent nuclear fuel for reprocessing planned to be accepted that year. Announcements are made to the Ministry of Environmental Protection and Natural Resources of the Russian Federation, the Ministry of Foreign Relations of the Russian Federation, the Ministry of Foreign Economic Relations of the Russian Federation, the Ministry of the Russian Federation on Cooperation with Member Countries of the Commonwealth of Independent States, the Federal Oversight of Russia on Nuclear and Radiation Safety, and the Federal Directorate of Medical-Biological and Extreme Problems under the Ministry of Health and Medical Industry of the Russian Federation, as well as bodies of the executive branch of Russian Federation territories on which facilities for reprocessing spent nuclear fuel are located.

The total composition of radionuclides (activity) in solid radioactive waste returned to the country which supplied the spent nuclear fuel is determined according to a mutually agreed upon method, which takes into account the time of entry of the fuel and the time of cooling of solid waste. The cooling time for solid radioactive waste is established specifically for each contract, but no more than 20 years, and is determined by the necessity to reduce radiation and heat emanation to levels which ensure safe transportation of solid waste to the country which supplied the spent nuclear fuel.

Enterprises of the Ministry of the Russian Federation on Atomic Energy which reprocess spent nuclear fuel ensure the environmentally safe temporary cooling of spent nuclear fuel (before reprocessing); of solid radioactive waste generated during reprocessing of plutonium and uranium; and also safe conditions for returning solid radioactive waste and products of reprocessing not intended for use in the Russian Federation.

State inspection for nuclear and radiation safety at all stages of handling spent nuclear fuel and radioactive waste formed during its reprocessing is carried out by the Federal Oversight of Russia on Nuclear and Radiation Safety, the Ministry of Environmental Protection and Natural Resources of the Russian Federation, and the Ministry of Health and Medical Industry of the Russian Federation.

This Procedure is obligatory for all inter-governmental agreements on accepting spent nuclear fuel from foreign nuclear power stations for reprocessing at Russian enterprises.

Goes into force as of September 1, 1995

Translated by Diahanna Lynch