Background Paper BP-357E

NUCLEAR POWER IN EASTERN AND CENTRAL EUROPE

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November 1993

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NUCLEAR POWER IN EASTERN AND CENTRAL EUROPE

INTRODUCTION

The breakup of the former Soviet Union and other political changes in eastern and central Europe have opened up the area to closer scrutiny than was previously possible. Because of the accident at Chernobyl, nuclear power is one of the subjects that western nations have had a great deal of interest in exploring. The former Soviet Union designed and/or helped build more than 60 civilian reactors in the region. Most of these reactors follow one of two distinctly different designs: the VVER, or pressurized water reactor series; and the RBMK, which is a graphite-moderated, multi-channel reactor (the so-called Chernobyl type). In addition, there are two fast-breeder reactors and four graphite-moderated boiling water reactors for combined heat and power in operation in Russia. These last two designs are not widely distributed and so are not discussed in detail in this report.

As noted above, the safety of Soviet-designed reactors has been of great concern around the world since the catastrophic events at Chernobyl in 1986. This paper will briefly describe the technology involved. It will also examine the main safety concerns, both technical and organizational, associated with each reactor type. In addition, the paper will review the nuclear power programs in the new countries emerging from the former Soviet Union and its satellites and discuss the international efforts underway to address the most pressing problems.

THE TECHNOLOGY(1)

A. RBMK Reactors

A loose translation of the acronym RBMK is "very large, tube type reactor." This design originated from the early Soviet military reactors used to produce plutonium for weapons.

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(1) Information for this section provided by Government Corporate Relations, Atomic Energy of Canada Limited, November 1993.

The first generation of reactors, designed for plutonium production only, used graphite as the neutron moderator, with the fuel cooled by ordinary water. In the second generation, the fuel was enclosed in zirconium alloy pressure tubes, allowing the water to operate at high pressure and high temperature.

In this Soviet design, the coolant water itself is allowed to boil, and the resulting steam is fed directly to the steam turbines, which then power generators, producing electricity. The success of the early 100 and 200 MW military reactors led the Soviets to develop a 1,000 MW "commercial" RBMK reactor. The first two units, built near Leningrad, came on-line in 1973 and 1975.

The RBMK reactor consists of a large cylindrical array of graphite blocks which act as the neutron moderator and through which 1600 zirconium alloy pressure tubes pass vertically. The nuclear fuel, which is enriched uranium dioxide, is contained in the pressure tubes and the ordinary water, which acts as the coolant, is pumped upwards through them. The water absorbs heat from the nuclear reaction and, as a result, some of it boils, forming steam. The steam and water mixture then passes into the steam drums where it is separated, with the steam being channelled off to the turbines, which then drive the generators.

The reactor is controlled by a large number of control rods, which alter the rate of the nuclear reaction that takes place. As more rods are inserted into the reactor, the rate of fission slows down. The rods are the main safety feature of the RBMK, being used to shut down the reactor completely if necessary. However, in some circumstances, the shutdown rate is not adequate. The inappropriate operation of the reactor at Chernobyl during a scientific experiment created just such a situation. The safety system could not react fast enough to prevent the reactor from going out of control, with disastrous consequences. Subsequent modifications, including speeding up the shutdown system, redesigning the fuel and adding fixed neutron absorbers appear to have largely overcome this particular fault.

Unlike most western-designed nuclear reactors, the RBMK design does not include a concrete containment structure which would act to prevent the dispersion of radioactivity following an accident. The size and the layout of the existing RBMK plants precludes retrofitting such structures and so this problem remains.

B. VVER Reactors

The second type of soviet-designed reactor is the VVER type. This acronym stands for "water-water reactor," since ordinary water acts as both the neutron absorber (as opposed to graphite in the RBMK type) and as the fuel coolant. This reactor type is very similar to the PWRs (pressurized water reactors) used in many western countries. It has the same origin as well, having first been developed for use in nuclear-powered submarines.

The prototype land-based VVERs had power outputs of 210 MW and 365 MW. Subsequently, the design was standardized at a rated output of 440 MW. The first VVER reactors, model 230, were built in the 1960s; after 1970 they were superseded by the second generation, Model 213. A third generation of "small" (440 MW) reactors followed, as did the 1000 MW VVER 320 series. Each subsequent series added improved safety features, but, as discussed elsewhere in this report, concerns remain.

As was noted above, the VVER reactor is very similar to the pressurized water reactors common in western countries other than Canada. The reactor consists of a large, very thick-walled pressure vessel which contains the reactor fuel and ordinary water. The fuel used in the VVER reactor is enriched to about four times the natural level of uranium-235. The water acts as both a neutron moderator, which sustains the nuclear reaction, and as the coolant, which removes the heat of the reaction from the vessel. The hot water, which is also under pressure in the vessel, leaves the vessel and passes through heat exchangers. The heat is used to boil water, producing the steam to drive the steam turbines and subsequently the generators. The cooled water is then recirculated through the pressure vessel to continue the cycle.

SAFETY ISSUES

Various technical and organizational problems associated with the nuclear power program in the former Soviet Union (FSU) and its satellites have given rise to serious concerns about the safety of the reactors operating in that part of the world. Since the break-up of the FSU, experts from both within Eastern Europe and from the west have had the opportunity to work closely with Soviet scientists to assess the basic safety deficiencies and to identify possible remedial action. Western input has been on both a bi-lateral and a multinational basis, with the International Atomic Energy Agency playing a leading role in many studies. The results of these numerous investigations give a fairly clear picture of the situation.

One joint German-Russian study outlined the root causes of the safety deficiencies very succinctly.[2] According to this report, four main factors have contributed to the safety problems in Soviet-designed nuclear reactors. The first factor is the Soviet authorities' belief in the strength of their technology. In designing their reactors, the Soviets took into account only the most likely accidents and included safety systems to address only these. In western technology, even accidents with a very remote chance of happening are analyzed and safety systems for handling them are incorporated in the design.

A second difficulty arises from the strong reliance of Soviet technology on the human element. Western systems are more fully automated, recognizing the possibility of human error in the operation of such complex technology. In the Soviet design, personnel on duty in the control room are able to intervene in most aspects of reactor operation. For example, as happened at Chernobyl, control-room personnel can easily disconnect the main safety control system. This is not the case with western-designed reactors.

The "technological delay" in the Soviet economy has also led to a number of safety-related problems. This is particularly true in the areas of instrumentation and control, electronics and computing. Shortcomings in these areas, for example, made it difficult for the Soviets to include advanced automation concepts in their reactors. This led to even more reliance on human intervention in the operation of reactors and made it impossible for the Soviets to build sophisticated training simulators that would have improved the technical training of operators and given them the chance to perfect accident response procedures.[3]

The fourth problem identified, and echoed in other reports, was the lack of "corrective criticism." Within the Soviet government structure, one agency or department had responsibility for all aspects of nuclear power development; there was no independent organization to verify the safety of Soviet-designed reactors. In the newly emerging countries of Eastern Europe a great deal of effort is being made to ensure that the necessary regulatory framework for the safe operation of nuclear power stations is put into place.

A number of very detailed technical reports on the safety of Soviet-designed reactors have been prepared in recent years. The International Energy Agency has been the coordinating

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(2) A. Birkhofer, "Root Causes of Safety Deficiencies," Paper No. 4, Special Session on Nuclear Power in Eastern Europe and the CIS - An International Challenge?" World Energy Conference, Madrid, Spain, September 1992.

(3) *Ibid*.

agency for many of these efforts, having initiated a program in 1990 designed to help the countries of eastern Europe and the FSU assess the safety of the first generation VVER 230 reactors. The objectives of the program were: to identify major design and operational issues; to establish an international consensus on priorities for safety improvement; and finally, to provide assistance in their implementation.[(4)]

The international community focused first on the VVER 230 series, despite the grave concerns about the safety of RBMK technology that arose in the wake of the Chernobyl accident. Most experts felt that the RBMKs were so inherently unsafe that their use should and would quickly be phased out. Only the most urgent safety improvements were foreseen, to keep them operating until they could be replaced. Attention was focused on the VVER-230, which, though also considered unsafe, was likely to be in operation longer and therefore perhaps more worth upgrading. As subsequent sections of this paper point out, however, economic circumstances mean that RBMK reactors will continue in operation longer than once anticipated. The search for means of ensuring their longer-term safety has therefore come to the fore more recently. In fact, in 1992, the IAEA program was extended to cover the safety of RBMK reactors as well.[(5)]

The IAEA report on the safety of the VVER-230 is very detailed and technical. Only the highlights will be given here as illustrative of the problems faced. Appendix 1 provides a more detailed list of the generic safety concerns for these reactors. As already noted, of the three generations of VVERs, this model is seen as having the most safety problems and therefore requiring the most urgent changes.

One of the major concerns related to the VVER-230 is the lack a containment structure, such as the familiar concrete dome that encloses the CANDU and other western reactors, which would limit the spread of radioactive contaminants in the event of an accident. A second shortcoming is the insufficient level of "redundancy" (back-up) in the safety systems. In addition, there is no provision for response to common cause failure of the electrical system supplying the safety equipment or the reactor itself. The limited core cooling capacity, insufficient on-site fire

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(4) International Atomic Energy Agency (IAEA), "Safety Assessment of Proposed Improvements to RBMK Nuclear Power Plants," Report of the IAEA Extra-Budgetary Programme on the Safety of RBMK Nuclear Power Plants, Vienna, March 1993, Foreword.

(5) *Ibid.*

protection and an inadequate instrumentation and control system were also identified as problems needing urgent attention.(6)

In addition to the technical safety concerns, a number of major operational shortcomings were also identified in the IAEA report. For example, experts felt that there was not an effective management structure for identifying and correcting safety issues at the nuclear power stations. Furthermore, they identified problems with the equipment at the plants. It was not always maintained in an appropriate manner. Operating procedures were not always well or completely documented, or their use was inadequately enforced. The lack of proper training, especially in the absence of simulators, was also noted as a concern, as were inadequate inspection and regulatory enforcement.(7)

A number of experts have stated that the cost of improving the safety of VVER-230 reactors for long-term operation is too high.(8) They recommend retrofitting instead, with a view to keeping these plants in operation only as long as is absolutely required for energy needs.(9) As in the case of the RBMK reactors, however, the energy demands and the economic conditions in the countries using this reactor design may mean that the Model 230s stay in use longer than western experts would like.

The IAEA assessment of second generation VVERs, model 213, shows that they include significantly more safety features than the older model and so are of less immediate concern. Nonetheless, a number of measures need to be implemented to allow them to operate safely for their planned lifetimes. The list of urgent measures includes installation of western instrumentation and control to partially replace existing technology; installation of a residual heat removal system; upgrading of the emergency power supply; improved fire protection measures; personnel training; completion of operation, maintenance and inspection manuals and more

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(6) International Atomic Energy Agency, "The Safety of Nuclear Power Plants in Central and Eastern Europe," An Overview and Major Findings of the IAEA Project on the Safety of VVER Model 230 Nuclear Power Plants, Vienna, 1993, p. 1.

(7) *Ibid*., p. 11.

(8) Adolf Huttl, "Nuclear Power in Eastern Europe and the CIS - An International Challenge," Special Session #6, World Energy Conference, Madrid, Spain, September 1992, p. 3.

(9) Birkhofer (1992), p. 3.

complete accident analyses.(10) A number of medium-term measures are also identified that would add still more sophisticated safety features.

By all accounts, the VVER 1000, which is the newest, most advanced Soviet design, includes many of the safety features found in western pressurized water reactors. As a result, no major improvements are seen as necessary, although a number of retrofit measures are suggested. For example, the basic design of the VVER 1000 makes it very important to maintain careful minute-by-minute control of operating conditions. To ensure that operators are fully aware of what is happening in the reactor core, it is recommended that modern western instrumentation and control systems be installed. Other recommendations deal more with non-technical details such as improvements to operator training and to manuals dealing with operation, maintenance and control.(11)

As already noted, the safety of RBMK reactors is still of concern, as the estimated length of time during which they will remain operational appears to be increasing. It should be noted, however, that since the accident at Chernobyl, a significant number of changes have already be made in the operating RBMKs and in fact a number of new RBMKs have come into operation. These new reactors incorporate the safety improvements that have been backfitted on to the older units and so should be safer than their predecessors. The RBMK design has evolved over the years, even before Chernobyl, and so not all units will present the same problems. Concerns relate primarily to the six oldest RBMKs: two units at each of three sites, Kursk and Smolensk in Russia, and Ignalina in Lithuania.

The IAEA study on RBMK safety, which was published in March 1993, reviews the safety improvements already made to the RBMKs, and assesses their success. It also looks at the additional measures still required to further improve the safety of these units. In general terms, most of the changes already implemented address the major design and operational problems of the RBMK that contributed to the accident at Chernobyl. These included the large, inadequately monitored power fluxes within the reactor core; the slow, and again inadequate, response of the safety shutdown equipment; and the part played by human error.

Human error cannot be eliminated, but with new administrative and operating procedures in place, the chances of such error have been reduced. Also, there have been some

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(10) Huttyl (1992), p. 3.

(11) *Ibid*., p. 4.

technical changes that make the safety system less prone to human error. For example, in the original RBMK design, the operator could manually stop the reactor by pushing a button and keeping it depressed until the reactor was completely shut down. The button has been replaced by one that simply needs to be hit once and will stay activated until shutdown.

New equipment that monitors reactor core conditions every five rather than fifteen minutes has been added and there have been improvements to the equipment controlling the core physics. To address the shutdown problem, the control rods, which are inserted into the reactor to slow and finally stop the chain reaction, have been significantly altered. A new fast scram system (FSS), which includes 21 to 24 fast acting control rods with a response time of just 2.5 seconds, has been added. Also, there are now more control rods inserted from the bottom, as well as the top of the reactor, and their response time has gone from 19 seconds down to 12 seconds.

Additional changes have improved the reliability of electrical power supply to the safety systems; improved the outside water supply for emergency use in the upgraded emergency core cooling system; upgraded the fire protection systems; improved the seismic resistance of the facilities; and added on-site, automated radiation monitoring.(12) In at least one case, the Leningrad 1 unit, all 1,693 fuel channels have been replaced to bring them back to original design standards.(13)

Despite these significant changes to the RBMK reactors, western experts remain concerned about their safety. The IAEA report acknowledged the efforts made to date, but also listed measures that are still necessary. A number of these relate to the necessity for better data-handling equipment to ensure that operators can keep up with the rapid changes occurring while the reactor is in operation. Existing computer systems are characterized as being "overloaded," resulting in an inadequate data-processing capability. Experts still feel that the plant safety is toodependent on operator actions, and recommend further automation efforts. The replacement of existing instrumentation and control systems is recommended as well. Those responsible for the safety assessment of the RBMKs also note that they require more detailed information from authorities in the countries concerned to complete their assessment and make final recommendations.(14)

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(12) IAEA (1993), p. 10-11.

(13) E.O. Adamov *et al.*, "Making the Most of the Remaining RBMKs: First-Stage Upgrade Completed at Leningrad-1," *Nuclear Engineering International*, September 1992, p. 18.

(14) *Ibid.*, p. 19-20.

SOVIET-DESIGNED NUCLEAR POWER STATIONS IN CENTRAL AND EASTERN EUROPE

Table 1 provides details of the location, size and model of Soviet designed reactors that are in operation, or operable in eastern and central Europe. The situation in each country, with regard to the current and future role of nuclear power and to the nature of the problems being faced is different, and so will be reviewed briefly.

A. Russia

In Russia, there are currently 28 nuclear power reactors at nine separate sites, with a total installed capacity of some 19 342 MWe (megawatts electric). The 28 reactors include 11 of the RBMK type, with four each at Kursk and Leningrad and three more at Smolensk. Twelve reactors are of the VVER, or pressurized water, design and there is one fast breeder reactor at Beloyarsk. The final four reactors are a unique design, being small graphite-moderated boiling water reactors used for combined heat and power production, a technology not used anywhere else in the former Soviet Union.(15)

For the country as a whole, nuclear power accounts for about 11% of electricity generation; however, on a regional basis its importance is considerably greater. For example, in the St. Petersburgh area nuclear power provides 33% of all electricity, and in the Moscow area it provides 22%. This regional dependency means that western concerns about safety will not soon result in any nuclear power plant closures. The country simply has no short-term options. In fact, rather than contemplating shutting down any reactors, there are five additional VVER 1000 reactors under construction in Russia, along with the two heat-only reactors being installed in Voronezh. These six reactors could be on-line by the year 2000. Plans are also in place for two more fast-breeder reactors in the South Urals, but their construction status is uncertain at this time.(16)

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(15) "Datafile: Ex-USSR," *Nuclear Engineering International*, August 1992, p. 37.

(16) *Ibid*., p. 38.

Table 1
Soviet-Designed Power Reactors in Operation or Operable: 1992

Country	MWe	Type[1]	Model
Ex-USSR			
Russia			
Balakovo 1	1,000	PWR	V-320[2]
Balakovo 2	1,000	PWR	V-320
Balakovo 3	1,000	PWR	V-320
Kalinin 1	1,000	PWR	V-338
Kalinin 2	1,000	PWR	V-338
Kola 1	440	PWR	V-230
Kola 2	440	PWR	V-230
Kola 3	440	PWR	V-213
Kola 4	440	PWR	V-213
Novovoronezh 3	417	PWR	V-179
Novovoronezh 4	417	PWR	V-179
Novovoronezh 5	1,000	PWR	V-187
Kursk 1	700[3]	LWGR	RBMK-1000
Kursk 2	700[3]	LWGR	RBMK-1000
Kursk 3	1,000	LWGR	RBMK-1000
Kursk 4	1,000	LWGR	RBMK-1000
Leningrad 1	1,000	LWGR	RBMK-1000
Leningrad 2	700[3]	LWGR	RBMK-1000
Leningrad 3	1,000	LWGR	RBMK-1000
Leningrad 4	1,000	LWGR	RBMK-1000
Smolensk 1	1,000	LWGR	RBMK-1000
Smolensk 2	1,000	LWGR	RBMK-1000
Smolensk 3	1,000	LWGR	RBMK-1000
Beloyarsk 3	600	FBR	BN-600
Bilibino 1[4]	12	GBWR	EGP-6
Bilibino 2[4]	12	GBWR	EGP-6
Bilibino 3[4]	12	GBWR	EGP-6
Bilibino 4[4]	12	GBWR	EGP-6
Ukraine			
Chernobyl 1	700[3]	LWGR	RBMK-1000
Chernobyl 3	1,000	LWGR	RBMK-1000
Khmelnitsky 1	1,000	PWR	V-320
Rovno 1	392	PWR	V-213
Rovno 2	416	PWR	V-213
Rovno 3	1,000	PWR	V-320
South Ukraine 1	1,000	PWR	V-302
South Ukraine 2	1,000	PWR	V-302
South Ukraine 3	1,000	PWR	V-320

Table 1 (cont'd)

Country	MWe	Type	Model
Zaporozhe 1	1,000	PWR	V-320
Zaporozhe 2	1,000	PWR	V-320
Zaporozhe 3	1,000	PWR	V-320
Zaporozhe 4	1,000	PWR	V-320
Zaporozhe 5	1,000	PWR	V-320
Lithuania			
Ignalina 1	1,250[2]	LWGR	RBMK-1500
Ignalina 2	1,250[2]	LWGR	RBMK-1500
Armenia			
Armenia 1[5]	408	PWR	V-270
Armenia 2[5]	408	PWR	V-270
Kazakhstan			
Shevchenko[6]	150	FBR	BN-350
Others[7]			
Bulgaria			
Kozloduy 1	440	PWR	V-230
Kozloduy 2	440	PWR	V-230
Kozloduy 3	440	PWR	V-230
Kozloduy 4	440	PWR	V-230
Kozloduy 5	1,000	PWR	V-320
Kozloduy 6	1,000	PWR	V-320
Czech and Slovak Republics			
Bohunice 1	440	PWR	V-230
Bohunice 2	440	PWR	V-230
Bohunice 3	440	PWR	V-213
Bohunice 4	440	PWR	V-213
Dukovny 1	440	PWR	V-213
Dukovny 2	440	PWR	V-213
Dukovny 3	440	PWR	V-213
Dukovny 4	440	PWR	V-213
Hungary			
Paks 1	440	PWR	V-213
Paks 2	440	PWR	V-213
Paks 3	440	PWR	V-213
Paks 4	440	PWR	V-213
Finland			
Loviisa 1	440	PWR	V-213
Loviisa 2	440	PWR	V-213

Table 1 (cont'd)

[1] PWR = pressurized water reactor
LWGR = light water graphite-moderated reactor
FBR = fast breeder reactor
GBWR = graphite-moderated boiling water reactor

[2] VVER models V-179, V-230 and V-270 are first generation designs; model V-213 is second generation; and models V-187, V-338 and V-302 are third generation "small series" and V-320 third generation "large series."

[3] Output reduced by regulator for safety reasons.

[4] Graphite-moderated boiling water reactor for combined heat and power.

[5] These reactors were shut down in 1989, but the Armenian government recently decided to investigate recommissioning.

[6] Also desalinates 80,000 m^3 of water per day.

[7] Four V-230 units were built at Greifswald in former East Germany, but they have been shut down since reunification, due to safety concerns.

Source: 1. "Datefile: Ex-USSR," *Nuclear Engineering International*, August 1992, p. 37;

2. Morris Rosen, "International Nuclear Safety Assistance to Eastern Europe," *Special Session, Nuclear Power in Eastern Europe and CIS - An International Challenge?* World Energy Conference, Madrid, Spain, September 1992, p. 10-12.

Local authorities have already approved construction of additional reactors, as replacement for older units, at the Kola, Novovoronezh and Leningrad nuclear complexes. The 1992 state investment program for the Russian Federation included plans for three or four new nuclear power plants - anticipated to be at Kostroma, Karelia, the Far-East and probably Rostov.(17)

Given the experiences of the former Soviet Union with nuclear accidents, most notably at Chernobyl and the more recent explosion at Tomsk, one may wonder why any of the republics of the FSU still have such ambitious nuclear construction plans. The answer is simply that they need the energy. Russia now generates 80% of its electricity in aging oil-fired power plants and the production of oil in Russia has been dropping at the alarming rate of 15% annually in recent years. Add to this the fact that more and more of Russia's oil is being sold in the export market for hard currency, and the fact that the domestic price of oil has increased 300% in the past year, and the attraction of nuclear-generated electricity becomes clearer. All the republics of the FSU face similar problems and so for them also nuclear power will continue to be a necessary part of the energy supply for the foreseeable future.(18)

B. Ukraine

When it became an independent country, the Ukraine took on the burden of looking after the Chernobyl plant, site of the world's worst nuclear power plant accident. The government of the Ukraine took over control of this and four other nuclear power complexes from the former Soviet Ministry of Nuclear Power and Industry in November 1991. As shown in Table 1, the Ukraine now has 14 power reactors in operation. They have an installed capacity of 12,802 MWe and provide 25% of the Ukraine's electricity.

The two units still operating at Chernobyl, units 1 and 3, were scheduled to be shut down at the end of 1993. However, like Russia, the Ukraine desperately needs the energy they can produce. The country imports about 50% of its primary energy needs, with 90% of those imports coming from Russia. Russia now demands hard currency in payment for oil and gas, which Ukraine, with its economy in virtual collapse, cannot provide. This dilemma led the Parliament to reverse its decision to shut down the remaining Chernobyl reactors, and to begin repairs to a third

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(17) Andrei Gagarinski, "Great Expectations," *Nuclear Engineering International*, November 1992, p. 51.

(18) Judith Perera, "Why Russia Still Wants Nuclear Power," *New Scientist*, 8 May 1993, p. 29-30.

unit which had been out of service for two years following a fire.[19] The Ukraine is so desperate for electrical power that it has gone even further and lifted the moratorium on new nuclear plant construction which had been imposed following the Chernobyl disaster.[20] As a result of this policy change, three 1,000 MWe VVER reactors which are nearly complete (one each at the Khmelnytsky, Rovno and Zaporozhye sites) could be finished and come on line between 1993 and 1995, if the necessary money can be found. It has been suggested by some that it may be in the interests of the international community to provide loans to complete these reactors, since they would have much higher safety standards than the Chernobyl units that they could replace.[21]

With the dissolution of the Soviet Union, the Ukraine was left to develop its own bureaucracy for regulating and managing nuclear power. At the management level, the power stations have been formed into a consortium, which, in turn, has entered into contractual arrangements with agencies in Russia to secure the services needed to keep the plants operating. There has been some difficulty over Russian acceptance of spent fuel from Ukrainian reactors. This issue is still unresolved but discussions are underway to set up joint ventures to handle the problem.[22]

With regard to the Chernobyl site, Moscow withdrew all financial support at the end of 1991. To fund ongoing clean-up efforts, the people of the Ukraine are paying a big price - a 12% tax on all citizens (no information is available as to whether it is a consumption tax or an income tax, etc). Even this hefty tax, however, falls short of raising the amount needed to clean up the aftermath of the accident. In the last two years new agencies have evolved to oversee the clean up work. The Ministry of Affairs of Population Protection from the Results of Chernobyl (known as MinChernobyl) and the State Committee for Nuclear Power are in the process of sorting out who has responsibility for which aspects of the clean up; the latter feels it should have responsibility for the remains of unit 4 and its sarcophagus and MinChernobyl should look after only the cleaning up of the 43,000 square kilometre contaminated zone. No matter what the outcome of this bureaucratic

(19) B. Maddox, "Damage Limitation in a Death Zone," *U.K. Financial Times*, 17 November 1993, p. 6.

(20) "Economic Meltdown Leads Ukraine to Resume Building Nuclear Plants," *The Ottawa Citizen*, 22 October 1993, p. A-7.

(21) "Those Reactors at Chernobyl," *The Washington Post*, 30 October 1993, p. A20.

(22) *Ibid*.

battle, MinChernobyl has developed an action program to the year 2000, and has begun work on it.(23)

The program has three main aspects: radiation protection, which deals with the relocation of people in the contaminated zone; social security, which addresses the health-related problems of those affected by radiation or the fear of radiation contamination; and finally the long-term program, which includes decontamination, waste management, protecting water from contamination, and (at the moment) work on the sarcophagus and unit 4. Clearly, the clean up and management of the damaged reactor will be both costly and lengthy. Yet despite this bitter legacy the Ukraine has no choice but to continue to rely on nuclear technology for a significant proportion of its electricity production.

C. Lithuania

Lithuania operates two reactors of the RBMK, or Chernobyl type, each of which is rated at 1,500 MWe. All other RBMKs are only 1000 MW units. A third unit is partially completed but construction has been halted for some time, and recently the government announced its decision not to complete the unit. The station authorities have been given permission to sell off the equipment that is no longer needed.(24)

The safety of the two operating units is of great concern, especially to Sweden, on whose doorstep they are located. As a safety precaution, the units have been derated to 1,250 MWe each. Even so, they supply the majority of the country's electricity and earn valuable foreign currency as 42% of Lithuania's electricity (from all sources) is exported to Belarus. In fact, in early 1993 the percentage of Lithuanian power supplied by nuclear power topped all countries in the world at 88%. This percentage has grown gradually over the last few years as electricity demand in the country has fallen and fossil fuel plants have been shut down, in favour of operating the nuclear power stations at full capacity. Lithuania has no indigenous energy resources and the rising cost of importing oil, coal and gas from Russia is an important factor in this situation.

As is the case in the region's other newly autonomous republics, Lithuania was dependent on Russian operators at its nuclear power plants. Since independence, however, the majority of operators have become Lithuanian citizens and so the country has the necessary

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(23) Janet Wood, "Ukraine Takes on the Burden," *Nuclear Engineering International*, August 1993.

(24) "News Briefing," The Uranium Institute, 17-23 November 1993, p. 1.

technically trained people to keep the stations running efficiently. In addition, the power station operators have negotiated arrangements with Russia to ensure that a supply of nuclear fuel, spare parts and maintenance services remains available to them.(25) The government has also given approval for the construction of a spent fuel storage facility at Ignalina.

With such a large dependence on nuclear power, it is not likely that the two Ignalina units will soon be decommissioned and they have therefore received international attention aimed at upgrading their safety features. As outlined elsewhere in this paper, Sweden has established a bilateral program with Lithuania which has already seen about $7 million (U.S.) invested in safety-enhancing changes to the reactors.(26)

D. Armenia

There are two first-generation VVER reactors in Armenia, but neither has been in operation since 1989, when they were damaged by massive earthquakes. The closure of the nuclear power plants, which used to supply 25% of the country's electricity, has contributed to the severe energy shortages in Armenia, to the point that electricity use is rationed to just a few hours per day.

The continuing war with Azerbaijan has resulted in the cutting of oil and gas pipelines between the CIS and Armenia, which worsens the already desperate energy situation. In an attempt to address the staggering shortages of energy, the Armenian government has approached Russia for aid in re-commissioning the two damaged reactors, and experts from France are analyzing the safety improvements which can be made before re-starting one or both reactors. Plans have also been put forward for the construction of a further 2,000 MW of nuclear capacity by the year 2005. Neither of these options seems likely to be implemented, however, as long as the war goes on. Russia would not want to antagonize Azerbaijan, and in any case probably does not have the financial capability to be of much help.(27)

The international community does not want to see these reactors re-started, and since January 1992 the U.S. has been supplying aid, much of it in the form of fuel, to help Armenia

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(25) Wood (1993), p. 40.

(26) "Eastern Europe's Nuclear Power," *The Economist*, 24 July 1993, p. 20.

(27) Wood (1993), p. 40.

through its energy crisis. However, the fuel must be trucked in from a post in neighbouring Georgia, where the civil war often results in disruption of even these supplies.[(28)]

E. Bulgaria

Nuclear power provides more than 30% of the electricity generated in Bulgaria. A number of factors, including the poor state of the country's fossil-fuelled plants, the low quality and reduced production from domestic coal mines, and the unreliability of electricity imports from Russia and the Ukraine, dictate that nuclear power will continue to play a leading role in the energy scene.[(29)]

All six of the country's reactors are located at Kozloduy, on the Danube River about 220 km north of Sofia. The complex includes four 440 MWe first generation VVER 230 reactors and two, more modern 1,000 MWe VVER 320s. The oldest two units began operation in 1974-75, the next two in 1981-82 and the larger units in 1988 and 1992. The four older units have been a focus of international concern since this model is seen as the most dangerous Soviet design still in use, and because of the poor maintenance record at the site.

When political changes in Eastern and Central Europe opened Bulgaria's nuclear program to international scrutiny, the IAEA (International Atomic Energy Agency) studied the safety of the VVER 230 reactors and recommended that at least two of the units be closed down immediately. The Bulgarian government refused to do this, citing the serious energy supply problems noted above. Given this refusal and the concern over the safety of these reactors, the Kozloduy complex became the first to receive financial support from the internationally funded nuclear safety account being managed by the European Bank for Reconstruction and Development (discussed elsewhere in this report).[(30)]

This funding, and the upgrading it will support comes after a two-year program involving a number of European Community members in which operators were given help in basic "housekeeping" (i.e., routine maintenance and equipment testing) at the site. This program was necessary just to bring the station up to its original, albeit inadequate, safety standards. Operators

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(28) Howard Witt, "Officials Dare to Re-open Unsafe Reactor," *Ottawa Citizen*, 24 November 1993, p. A5.

(29) Yanko Yanev and Ian Facer, "Backfitting Kozloduy for Continued Operation at Less Risk," *Nuclear Engineering International*, December 1992, p. 16.

(30) "EBRD Rescues Kozloduy Nuclear Reactors," *The Petroleum Economist*, Vol. 60, No. 8, August 1993.

were also encouraged to improve their "safety culture" and operating practices by being twinned with operators at a French nuclear power station.[31]

Bringing the reactors at the Kozloduy complex up to international standards will cost hundreds of millions of dollars, according to most estimates. The international community will certainly be called on to provide most of the funding since Bulgaria shares the desperate financial situation of other former communist countries.

F. Czechoslovakia

The former Czechoslovakia, which has now separated into the Czech Republic and Slovakia, depended on nuclear power for about 28% of its electricity. The Czech Republic now operates the four VVER 213 reactors at Dukovny while Slovakia is responsible for the four first generation VVER 230 reactors at Bohunice, as well as four nearly completed VVER 213s at Mochovce.[32]

The rectors in these two countries evoke many of the same safety concerns as do all other older, Soviet-designed reactors, although for the reactors at Dukovny, there is less concern, since the Czechs insisted on making most of the equipment themselves, rather than using less reliable Soviet equipment. The licences for the Bohunice 1 and 2 were changed in 1990 so that they could continue to be operated from 1992 to 1995 only if a total of 81 measures were introduced to improve safety and efficiency of operation. The measures are being implemented progressively and are on schedule. Operation beyond 1995 will require major reconstruction of the units, which the government had agreed would happen only if costs remained between U.S. $200 and $400 million. More recently, safety regulators in Slovakia recommended that the necessary upgrading for post-1995 operation go ahead, with no mention of the cost limitation.[33] International aid will be forthcoming through the CEC (Commission of European Communities) technical assistance program (the PHARE Program).[34]

There is also a great deal of concern about the mounting stocks of spent fuel. In the past, all spent fuel was shipped to the Soviet Union for reprocessing and disposal. New spent fuel

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(31) Yanev and Facer (1992), p. 17.

(32) "East European Energy Report," *Financial Times*, Issue 17, February 1993, p. 11.

(33) *Nucleonics Week*, 11 November 1993, p. 1.

(34) "What's to be Done about Old VVER-440s?" *Nuclear Engineering International*, May 1992, p. 49.

storage facilities are urgently needed, and a dry storage facility at Dukovny is being planned. In the longer term, France and Britain are both urging the new governments in the Czech and Slovak Republics to ship their fuel to the West for reprocessing.[35]

In terms of increasing energy demand, a recently completed government study in the Czech Republic forecast that the country would require 2,000 MW of additional electrical capacity by the year 2010. The current government in that country has expressed the opinion that completion of the two partially built VVER 1000 reactors at Temelin would be the cheapest way of providing that power. The Temelin site is in southern Bohemia near the Austrian border, and the government of Austria does not want to see these Soviet designed reactors brought into use. As an alternative they have suggested cooperation in developing other sources of electricity. Nuclear opponents within the country are arguing that an ambitious electricity conservation program could reduce current consumption by as much as 50% and make completion of the reactors unnecessary. No final decision on this question has been reached.[36]

G. Hungary

Like many other former Soviet satellites, Hungary uses nuclear reactors designed and built by Soviet experts. Unlike most of those other countries, however, there is a high degree of input from Hungarian engineers and the country therefore has an indigenous nuclear industry. As a result of this local input, the four VVER 213 reactors at Paks are viewed by western experts as well built and well run.[37] In fact, at the end of 1990, units 2 and 4 were ranked among the world's top ten reactors with cumulative (lifetime) load factors of 88.9% and 86.5% respectively. Units 1 and 3 are rated at 81.2% and 85.8%. The load factor is a measure of reliability of the reactor.[38]

The exceptional performance of the Paks reactors can also be attributed to the emphasis which the Hungarians put on training and retraining of personnel. Unlike many other central and eastern European countries, Hungary has invested in a nuclear power plant simulator. Operators all receive 80 hours of simulator retraining every year, including accident management

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(35) "West Rescues East's Nukes," *Petroleum Economist*, June 1992, p. 14.

(36) "East European Energy Report," February 1993, p. 7.

(37) "Eastern Europe's Nuclear Power," *The Economist*, 24 July 1993, p. 20.

(38) "Datafile: Hungary," *Nuclear Engineering International*, March 1992, p. 52.

training. The simulator is also used to test emergency procedures and to verify changes in operating procedure.

The reactors have been continually upgraded over the years since they came on-line (between 1983 and 1987). For example, there is now a computerized environmental monitoring system in place around the Paks complex. Also, the original, Soviet-designed instrumentation and control system has been replaced by one designed in Hungary. There is an active national research program to continue upgrading these stations. The program focuses on accident prevention; severe accident analysis; emergency preparedness; regulatory control and supervision; and international relations and public acceptance.(39)

Hungary now gets about 50% of its electricity from nuclear power. Future peak demand is forecast to increase by 1,000 MW by the year 2000, and will likely be met by combined-cycle or gas powered co-generation facilities. Over the same time frame an additional base load plant will also be required and nuclear power is being considered, along with coal-fired generation. Hungary is seeking bids for any additional nuclear plants from several western countries, including France, Germany, Canada and the U.S.(40)

INTERNATIONAL AID FOR IMPLEMENTING SAFETY IMPROVEMENTS

The problem of safety in eastern and central Europe's nuclear power stations has been of concern to countries around the world since the accident at Chernobyl. The need for urgent action to address these concerns was voiced in many international forums, including the 1991 World Economic Summit in London, the Lisbon European Council and the G-7 Summit in Munich in 1992.(41) Because of its geopolitical, historical and economic position, the European Community feels that it has an important role to play in providing assistance to its neighbours in the former Soviet Union and other east European countries to improve the safety of their reactors. The EC has therefore developed two programs of assistance. One, known as the PHARE program, is aimed at

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(39) *Ibid*.

(40) "Still Making Headway - Just," World Survey, *Nuclear Engineering International*, June 1992, p. 15.

(41) Sergio Finzi, "Contribution of the Commission of the European Communities," Special Session, Nuclear Power in Eastern Europe and the CIS - An International Challenge?, World Energy Conference, Madrid, Spain, September 1992, p. 1.

central and eastern European States. The other, the TACIS program, is for the states of the ex-USSR.

Assistance under both programs covers all aspects of safety of nuclear installations. It includes aid directly to the plant operators as well as to any organization, including the regulatory authorities, which play a role in assuring their safety. There are three basic steps to the plan. First there is to be a thorough evaluation of the design, operation and maintenance practices of nuclear power plants. The second stage involves establishing a plan for retrofitting plants and the third phase is the performance of all analyses and studies needed to support the implementation of the necessary changes.(42) An essential part of the EC plan is to support, not duplicate, any efforts in these areas by the IAEA. All groups involved in providing aid agree that the monetary needs are so great that close cooperation to avoid any overlap is absolutely essential.

The PHARE program started in 1990 and now covers work in Poland, Hungary, Czechoslovakia, Bulgaria, Rumania and Lithuania (not all of whom have Soviet-designed reactors, but do have nuclear safety issues to deal with). Total funding under this program for 1990 and 1991 amounted to ECU 20.5 million with 12.7 million going to Bulgaria; 7 million to Czechoslovakia, 0.5 million to Lithuania; and 0.3 million for Poland.(43) The large amount dedicated to Bulgaria reflects the concern over the serious safety problems at the Kozloduy plant, considered by most western experts as the most dangerous Soviet-designed reactor. A further ECU 3.5 million was set aside for continuing work at Kozloduy for 1992. Another ECU 20 million went to other countries in 1992.(44)

The TACIS program of technical assistance to the states of at the former Soviet Union, began in 1991 and in that year funding for nuclear safety work was set at ECU 54.5 million. This budget was divided between measures to improve the operational safety of the different designs of VVER and RBMK reactors, and measures to strengthen the regulatory authorities in the new states. The funding for 1992 was roughly the same. While representing a significant contribution to identifying what needs to be done, it must be recognized that considerably larger sums of money will be required for the actual upgrading work to be completed.(45)

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(42) *Ibid.*, p. 3.

(43) 1 ECU (European Currency Unit) = Cdn. $1.50 (approx.).

(44) Finzi (1992), p. 3.

(45) *Ibid.*, p. 4.

The 1992 Munich G-7 Summit acknowledged this need for an international fund, to which the countries present at the summit agreed to contribute. It was not until early in 1993 that the fund actually got off the ground. It will be administered by the European Bank for Reconstruction and Development (EBRD) with decisions for financing being made by a steering committee representing the donor countries.(46) Pledges to the fund for 1993-95 are as follows: France - ECU 40 million; Germany - ECU 40 million; Japan - ECU 4 million; UK -ECU 10 million; Italy - ECU 10 million; U.S.A. - ECU 1.5 million.(47)

In addition to these multilateral programs, Canada, Sweden, Finland and the U.S. have bilateral agreements related to nuclear safety. Canada has committed Cdn. $30 million which will be used to fund part of the international RBMK safety review, examine the potential use of Russian hardware at the Cernovoda complex in Rumania and help in the establishment of an environmental centre in Russia. Sweden is involved in the RBMK safety review and is funding a safety assessment of the Ignalina 2 unit. This contribution is approximately U.S. $10.5 million.

Finland is contributing about U.S. $ 6.6 million to two projects. One involves the Kola plant in Russia, where Finland will use experience with the VVER design at Loviisa to improve operational safety. Finland is also involved with part of the international RBMK safety efforts at Leningrad, where it is assessing the probability of fires and how to limit their consequences and looking at the reliability of certain reactor components.

The United States has a complex series of bilateral programs which provided U.S. $3.2 million to Eastern European projects in 1991, including work at Kozloduy and a number of training programs. For 1992, U.S. $4.85 million was allocated by the U.S. Department of Energy, the Nuclear Regulatory Commission and several private companies (Bechtel/Electrotek) again for a variety of programs including improvements in operational safety at Bohunice in the Czech Republic and at Kozloduy in Bulgaria, as well as for more training programs. Also in 1992, the U.S. contributed U.S. $22 million to Russia and the Ukraine for help in a number of areas including completing safety analyses, training regulators, improving fire protection, assisting with programs to handle wastes, spent fuel and other nuclear materials, etc.(48)

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(46) "East European Energy Report" (1993), p. 1.

(47) "Into the Labyrinth: A Guide to Aid for Operators of Soviet-Supplied Reactors," *Nuclear Engineering International*, May 1993, p. 40.

(48) *Ibid*., p. 41.

CONCLUSION

The opening of the former Soviet block countries to outside scrutiny gave western experts unprecedented access to details of nuclear power programs in that part of the world. What they found is not particularly reassuring. Assessments of the safety of many of the older nuclear power plants have revealed some alarming technical and operational problems. International action to help these new countries assess and deal with these problems has been slowly gathering momentum.

Many of the necessary assessments have now been completed and the international funding mechanisms are in place. However, economic conditions and energy supply problems are making it difficult for the newly emergent countries to meet western expectations for upgrading, shutting down and/or replacing the most dangerous reactors. Clearly the effort to enhance the safety of existing nuclear power plants will be a lengthy and a costly one. Given the consequences of failure, however, there is little choice but for the international community to continue to work closely with the countries of the former Soviet Union and its allies.

APPENDIX

THE SAFETY OF NUCLEAR POWER PLANTS IN CENTRAL AND EASTERN EUROPE

AN OVERVIEW AND MAJOR FINDINGS OF THE IAEA PROJECT ON THE SAFETY OF VVER 440 MODEL 230 NUCLEAR POWER PLANTS

Source:International Atomic Energy Agency (1993), p. 13-14.

2.3. Study of Generic Safety Issues

The Secretariat has started to prepare a series of documents on generic VVER-440/230 safety issues, the aim being to clearly identify the work still required in order to resolve the issues identified in the IAEA Project. It will also provide information on the work already performed or underway in other countries to avoid unnecessary duplication of work.

The following is a complete listing of generic safety issues and their underlying safety concerns:

- **Applicability of Leak Before Break Concept**

  Because the VVER 440/230 plants have a very limited capacity to cope with primary circuit breaks, the detection of leaks before catastrophic failures of the primary coolant boundary is most important. Applicability of the leak-before-break concept needs to be established.

- **Reactors Pressure Vessel (RPV) Embrittlement**

  The safety of RPV subject to radiation embrittlement needs to be resolved. Conclusions of studies to estimate the temperature at which the steel becomes brittle (Nil Ductility Temperature), effectiveness of the method used to recover the vessel material properties (annealing) and rate of embrittlement after annealing should be compiled.

- **Instrumentation and Control (I&C)**

  Review of I&C logic and set points is required. Information to control room operators is poor and means of processing information are also poor and need to be improved.

- **Accident Analysis**

  A comprehensive accident analysis using modern computer codes is required. A broad spectrum of pipe breaks and transients should be analyzed including confinement response and estimation of radiological consequences when applicable.

- **Operational Procedures**

  Procedures for normal operation and emergency conditions need to be developed, validated and operators should be trained to use them.

- **Operators Training**

  Improved operators training is required including accident management. Development and use of simulators and modern training material is needed.

- **Probabilistic Safety Assessment (PSA)**

  Plant specific PSAs would be required to evaluate backfitting options. The level of detail of the PSA should be defined consistent with the intended use of the PSA results.

- **Confinement**

  Qualification of confinement needs to be addressed including evaluation of structural strength, testing of venting flaps and tightness.

- **System Modifications**

  The impact of system modifications should be assessed, in particular with reference to safety injection and spray systems, service water and feedwater system. Electric power supply and actuation signals to these systems should also be considered.

- **Fire Protection**

  A study of fire protection including fire detection and fire fighting capabilities is needed. Design weakness regarding lack of physical separation and diversity should also be addressed.

- **Antiseismic Measures**

  Assessment of seismic safety margins and evaluation of programs underway to enhance seismic protection is needed.

- **Equipment Qualification**

  A review of qualification of sensors, actuators and other electrical and mechanical equipment under accident conditions is required. Special attention to environmental conditions following an accident is needed.

- **Safety Analysis Report**

  A Safety Analysis Report does not exist for VVER 440/230 NPPs. Information available is scarce and should be completed and extended to form a comprehensive safety analysis report.