Directorate of Intelligence

~~Secret~~

micro

23555

CIA/SOV----/87-10032-X------

The Soviet Nuclear Power Program After the Chernobyl' Accident

A Research Paper

~~Secret~~

SOV 87-10032X
June 1987

Copy

Warning Notice	Intelligence Sources or Methods Involved (WNINTEL)
National Security Information	Unauthorized Disclosure Subject to Criminal Sanctions

Dissemination Control Abbreviations	NOFORN (NF)	Not releasable to foreign nationals
	NOCONTRACT (NC)	Not releasable to contractors or contractor/consultants
	PROPIN (PR)	Caution—proprietary information involved
	ORCON (OC)	Dissemination and extraction of information controlled by originator
	REL...	This information has been authorized for release to...
	WN	WNINTEL—Intelligence sources or methods involved
	A microfiche copy of this document is available from OIR/DLB (482-7177); printed copies from CPAS/IMC (482-5203; or AIM request to userid CPASIMC). Regular receipt of DI reports can be arranged through CPAS/IMC.	Classifie Declassify: OADR Derived from multiple sources
	All material on this page is Unclassified.	

Directorate of
Intelligence

~~Secret~~

The Soviet Nuclear Power Program After the Chernobyl' Accident

A Research Paper

This paper was prepared by the
Office of Soviet Analysis. Comments and queries are
welcome

Reverse Blank

~~Secret~~
SOV 87-10032X
June 1987

The Soviet Nuclear Power Program After the Chernobyl' Accident

Key Judgments

Information available as of 1 May 1987 was used in this report.

The disruptions to the Soviet nuclear power industry through 1990 caused by the Chernobyl' accident will be minor when measured in broad economic terms and will not derail Soviet intentions to increase reliance on this energy source. The Soviets remain strongly committed to reducing dependence on oil and gas, antinuclear elements of public opinion will have only a weak effect, and the large investment and substantial infrastructure in the commercial nuclear program will ensure continued growth. Beyond 1990, however, some modification of the nuclear power program is likely; a few changes could set back the timetable by several years. These would probably involve the design and location of future nuclear plants and a shift in emphasis resulting from the competition of coal and oil interests for investment resources.

The USSR—and to some extent its CEMA partners—will bear a variety of energy-related costs because of the Chernobyl' accident. The loss of electricity generated by the Chernobyl' reactors and the increased use of fossil fuels in thermal power plants to partially offset the loss are key short-term consequences. Eastern Europe already had to bear some of the burden of electricity cuts during the 1986-87 winter period of peak power demand. During 1987 enough power plant capacity probably will be restored at Chernobyl' or brought on line elsewhere to alleviate this problem. Longer term consequences for the Soviet civilian nuclear industry include the investment writeoffs of at least three reactors at Chernobyl' and the costs of improvements to the safety of other Chernobyl'-type reactors. A rough total of these capital costs shows them to be the equivalent of two or three years' investment in the industry. Since the accident, Moscow has also spent about $80 million on Western equipment for use in the entombment of the destroyed reactor and in other aspects of the recovery.

Despite increased costs, we expect the Soviets will strive to minimize the impact of the accident on their long-term plans for nuclear power and will continue broadening the role of this energy source. We believe they will be largely successful in this damage-limitation effort. The fixes proposed for implementation over the next several years for Chernobyl'-type reactors are not likely to take them out of service for long, and the costs are manageable. Moreover, power plants with Chernobyl'-type reactors have long been slated to play a diminishing role in the Soviet nuclear program of the 1980s and 1990s as the emphasis shifts to other reactor types. These other types represent 80 percent of the nuclear energy capacity currently under construction or planned.

SOV 87-10032X
June 1987

Longstanding problems in manufacturing components for nuclear power plants and delays in plant construction will account for the majority of the shortfalls in bringing new capacity on stream between now and 1990, overshadowing the impact of Chernobyl' on the growth of the USSR's commercial nuclear program. The cumulative effect of the Chernobyl' accident (both the direct effects and the turmoil caused by the recovery effort) will probably mean that only three or four fewer new nuclear reactors (out of 35 planned) will be completed during the 1986-90 plan period. The loss of these reactors and delays in the construction of others will mean that roughly 10 percent less electricity will be produced from nuclear power. We believe the USSR will have about 48,000 megawatts of commercial nuclear capacity by yearend 1990 (compared with 28,300 megawatts in 1985) and will produce some 260 billion kilowatt-hours of electricity at nuclear power plants in 1990 (compared with 167 billion kilowatt-hours in 1985).

The Soviets are likely to encounter only a minor domestic backlash against nuclear power. The psychological blow of Chernobyl' may be enough to catalyze some Soviet groups with reservations about nuclear energy and the supporters of other energy sources into challenging plans for some nuclear facilities. Advocates of other reactor types and other energy sources will use the accident to bolster their arguments. The plans most vulnerable to pressure for nonnuclear alternatives are those for eight Chernobyl'-type reactors where little construction has taken place and those for 20 units of a new type of nuclear plant designed to be sited near cities to provide a dedicated source of heat beginning in the 1990s

The Soviets have sought a high-profile involvement of the West in the postaccident events. Moscow chose the International Atomic Energy Agency (IAEA) as the forum in which to defuse Western concerns about radioactive contamination and safety in the USSR's nuclear program. The Soviets will probably continue to use the IAEA to certify that the proposed modifications to Chernobyl'-type reactors are adequate and that all Soviet reactors are safe—particularly types they hope to export.

Given the long-term need to monitor the environment and the leadership's intent to keep expanding its nuclear energy program, Moscow is likely to look to the West for radiation monitoring and decontamination equipment and, possibly, nuclear power plant components and services. A role for the West as supplier of plant components is more likely if Moscow chooses to

Secret

accelerate construction of pressurized-water reactors to replace Chernobyl'-type reactors that may be canceled; Soviet equipment suppliers have not been able to meet the demand at the current pace of construction.

Any market in the USSR for Western nuclear vendors is likely to be highly competitive. Firms from the United States, France, Finland, West Germany, Sweden, Great Britain, and Japan can offer many comparable components and services.

BLANK PAGE

Contents

Scope Note

For several decades the Soviets have viewed nuclear energy as the key to growth in the electricity supply—and recently in the heat supply—in the European USSR. The Chernobyl' accident on 26 April 1986, however, has robbed the commercial nuclear power program of some momentum and challenged many Soviet concepts regarding its safety, reliability, and low costs. The special August 1986 meeting of the International Atomic Energy Agency showed that the Soviets were beginning to make changes based on their analysis of the accident. This meeting also revealed that the Soviets expect to study their nuclear program a good deal more, which means we are now getting only a first look at the possible changes

This report explores how the Chernobyl' disaster will probably influence the USSR's plans for nuclear power and heat supply and evaluates the implications for total primary energy production.

The Soviet Nuclear Power Program After the Chernobyl' Accident

Short-Term Consequences of the Accident

The accident that destroyed reactor unit 4 of the Chernobyl' nuclear power plant in late April 1986 had many and varied consequences—from the tragic human costs (see inset) to marginally greater fossil-fuel consumption, safety upgrades on Chernobyl'-type reactors, and some reexamination of the commercial nuclear program in the USSR.

The Accident: Prescription for Disaster

The Soviet accident report filed with the International Atomic Energy Agency (IAEA) indicates that the errors that doomed unit 4 began on 25 April when technicians started a poorly executed experiment to test the emergency electricity supply to the reactor. Major violations of the procedures for reactor operations were committed, such as switching off the emergency shutdown system and operating the reactor with too many control rods withdrawn. These human errors, coupled with a design flaw that allowed reactor power to surge when uncontrolled steam generation began in the core, set up the conditions for the accident.

The final moments of the accident occurred in a period of about 40 seconds at 0123 local time on Saturday, 26 April. Operator errors had put the reactor in an unstable condition, so reactor power increased rapidly when the experiment began. Subsequent analysis of the Soviet data by US experts suggests the power surge may have accelerated when the operators tried an emergency shutdown of the reactor.[1] According to Soviet data, the energy released was, for a fraction of a second, 350 times the rated capacity of the reactor. This burst of energy resulted in an instantaneous and violent surge of heat and pressure, rupturing fuel channels and releasing

[1] An expert team assembled by the Department of Energy has evaluated the final hours of unit 4. For details see DOE/NE-0076, November 1986, *Report of the U.S. Department of Energy's Team Analyses of the Chernobyl'-4 Atomic Energy Station Accident Sequence*

The Human Costs of the Chernobyl' Accident

The 31 initial casualties resulting from the explosion that destroyed unit 4 will ultimately account for only a minor part of the human toll of the Chernobyl' disaster. Two power plant workers were killed immediately, and burns and high radiation exposures eventually claimed the lives of another 29 people—most of them firemen and site emergency personnel. Soviet doctors reported that nearly 300 people received enough radiation to require hospitalization. These individuals will experience substantial additional risk of cancer.

Longer term health consequences in the USSR will result from radioactive contamination spread by the accident over an area of about 1,000 square kilometers. Many thousands of persons were exposed to this radiation (or will be exposed to residual amounts of radiation as daily routines are reestablished), increasing their long-term risk of cancer. This cancer threat poses unique medical and psychological problems, even though the overall statistical increase in cancer rates is likely to be minimal.

Soviet reactions to the accident included a massive evacuation and a cleanup effort that will probably be a long-term battle. An area with a 30-kilometer radius around the reactor was evacuated, and Moscow reported that about 135,000 people were moved. In addition to these official evacuees, perhaps as many as 270,000—mostly women and children—left cities (such as Kiev) in the region around the reactor site but outside the evacuation zone. The official evacuation started about 36 hours after the explosion and took about 10 days to complete. Most evacuees will never be able to return to their homes. Nearly all of the 135,000 evacuees have been resettled, about half in new homes

---

steam that disrupted large portions of the core. Some of the shattered core material was propelled through the roof of the reactor building.

The hot core material that was released started about 30 separate fires in the unit 4 reactor hall and turbine building, as well as on the roof of the adjoining unit 3. All but the main fire in the graphite moderator material still inside unit 4 were extinguished in a few hours by the heroic efforts of firefighters. The graphite fire continued to burn for nearly two weeks—carrying radioactivity high into the atmosphere—until it was smothered by sand, lead, dolomite, and boron dropped from helicopters.

Unit 3 was shut down four hours after the destruction of unit 4. Units 1 and 2, located several hundred meters from unit 4, continued producing electricity for 24 hours after the accident. The Soviets reported considerable radioactive contamination of units 1, 2, and 3.

Electricity Losses and Increased Fuel Use

For five months following the destruction of the Chernobyl'-4 reactor, the plant's three surviving reactors were idled. This loss of generating capacity—roughly 10 percent of the total in the Ukraine—would have led, if uncompensated, to an average monthly deficit in electricity production of 2.4 billion kilowatt-hours (kWh). But, during the summer lull in electricity demand, the Soviets were in a favorable position to offset much of this potential deficit by stepping up electricity production from power plants burning fossil fuels. Beginning in September, however, the seasonal upsurge in demand for electricity probably eliminated most of the painless adjustment mechanisms.[2]

The Ukraine experienced electricity problems even during the summer lull in demand. Ukrainian party chief Vladimir Shcherbitskiy, in a July speech, called for additional energy conservation measures, and Ukrainian Council of Ministers chairman Aleksandr Lyashko noted that some enterprises needed to change to night shift work to reduce daytime electricity demand. These steps were a likely preparation for coping with the prospective shortage of electricity, since the Soviets were only able to restore two reactors at Chernobyl' to partial service by the onset of winter.

The effect on total fuel demand of the effort to offset Chernobyl'-induced electricity losses appears to have been minor. Given the fuel-use capability of the replacement plants, the Soviets were probably using an extra 45,000 barrels per day (b/d) of oil, 220 million cubic meters per month of natural gas, and 400,000 tons per month of coal.[3] During the five-month period when the Chernobyl' plant produced no electricity, the nationwide demand for fuel oil increased 1 to 2 percent, natural gas use grew 0.2 percent, and coal use rose by 0.3 percent.

In addition to the power losses at Chernobyl', the Soviets are expecting cuts in output during 1987 at the four other nuclear power plants operating RBMK (Chernobyl'-type) reactors. fixes to improve safety will reduce power output at these plants by about 10 percent, or nearly 10 billion kWh, in 1987. Soviet have not indicated whether this is a one-time loss in power generation due to temporary downtime or a derating of the capacity of these reactors.

Returning the Chernobyl' Plant to Service

As soon as the Chernobyl' accident was under control, Moscow began promoting a rapid recovery of power-generating capability at the idle plant, evincing concern for longer term considerations affecting the nuclear power program as well as for the immediate exigencies:

- Moscow desired to spare the economy the degree of electricity shortfall that would come in winter unless much of the Chernobyl' capacity was returned to service.

[3] The total monthly fuel bill was nearly 800,000 tons of standard fuel. A unit of standard fuel contains the energy equivalent of 7,000 kilocalories per kilogram, or 12,600 Btus per pound.

- With roughly half the Soviet nuclear power plant capacity in Chernobyl'-type reactors, restoration of confidence in these units was imperative.

- The leadership probably viewed the recovery of the Chernobyl' plant as an implicit test for the management of the nuclear industry—proof that nuclear power is reliable and that Soviet management is competent.

The Soviets restarted Chernobyl' unit 1 in late September and unit 2 in November, thereby missing their early optimistic goal.[4] Adequately decontaminating the site to resume operations tested Soviet ingenuity and resources (see inset on page 6). A major reallocation of managers and technicians was needed to solve problems such as the entombment of the destroyed reactor and decontamination of the highly radioactive turbogenerator hall, which houses the turbines of all four of the plant's units [redacted] Part of the price for this success was a slowdown in the construction of at least three reactors at other power plants due for startup in 1986. Intermittent operation of Chernobyl' units 1 and 2 through mid-December suggested that problems remained.

The fate of Chernobyl' unit 3 is still uncertain. Although entombment of unit 4 is now complete, the recovery of unit 3 will drag on for some time, especially if critical electrical and ventilation assemblies were damaged in the fires following the accident or if radiation contamination is too extensive for rapid cleanup. If the reactor of unit 3 is not fully recovered, Moscow will have to reassess the "shared facilities" design at RBMK reactors. Three nuclear power plants now use this type of design and one other such plant is at an early stage of construction.[5]

[4] Shortly after the April accident, plans were announced to restart Chernobyl' units 1 and 2 in June. During August the deadline for restart was shifted to October as the Soviets became more concerned about radiation exposures of operations staff.

[5] In order to save on plant investment and simplify designs, the Soviets construct RBMK plants to share facilities for functions such as reactor hall ventilation or water treatment. Although designs for Western nuclear power plants use similar logic, a much greater effort and investment are made to assure that the integrity of functions is maintained in the event of disruption at any one reactor.

Meanwhile, the Soviets appear to have abandoned efforts to recover the partially constructed units 5 and 6. This was announced without elaboration by the chairman of the State Committee for Utilization of Atomic Energy, Andronik Petrosyants, on 25 April 1987. Factors in stopping construction probably include high radiation at the site, rising construction costs, and possibly difficulties in recruiting skilled labor to finish the project.[6]

Short-Term Economic Costs

The immediate economic costs of the accident include:

- The opportunity costs of using additional fuel oil in plants replacing electricity from Chernobyl' instead of selling the fuel oil for hard currency.

- Increased purchases of Western equipment to facilitate the cleanup after the accident.

- The diversion of construction labor, equipment, and materials to the tasks of decontaminating the Chernobyl' plant and surrounding area, entombing the destroyed reactor of unit 4, and building new housing for the evacuees.

The forgone hard currency earnings from reduced sales of heavy fuel oil at prevailing world-market prices during 1986 potentially amounted to roughly $100 million. This opportunity cost was halved when two Chernobyl' units were brought back on line in December 1986. Continued losses of potential sales of fuel oil (at the reduced level) will nevertheless equal nearly $10 million per month until another 2,000 megawatts (MW) of power plant capacity is brought into the power network, probably late this year

[6] Unit 5 is 85 percent complete and unit 6 is 15 percent complete. In addition to decontamination and construction work on the power plants themselves, housing and basic amenities would need to be organized for the 10,000 to 13,000 workers needed to finish construction. These people and their families were displaced from the heavily contaminated town of Pripyat'

A Chronology of the Recovery Effort at the Chernobyl' Nuclear Power Plant

1986	
26 April	*Reactor unit 4 explodes, causing fires in that unit and some damage to adjoining unit 3. Radioactive contamination forces shutdown of undamaged units 1 and 2 and suspension of construction on units 5 and 6.*
28 April	*Soviets publicly acknowledge the accident.*
14 May	*Gorbachev appears on TV, describing the accident and announcing goals for recovery.*
15 May	*Tunnel for access to the area under the unit 4 reactor started; construction on entombment for unit 4 begun.*
22 May	*First recovery timetable announced, proposing to complete entombment and "prepare" units 1, 2, and 3 for operation by 15 June.*
2 June	*Restart of units 1 and 2 scheduled for October; restart of unit 3 put on hold.*
4 July	*Tunnel to unit 4 completed.*
19 July	*Special CPSU Politburo meeting discusses Chernobyl' investigation results, announces reorganization of nuclear power industry.*
25-29 August	*IAEA special meeting on Chernobyl' held in Vienna.*
29 September	*Unit 1 restarted; unit 2 restart promised in two weeks.*
10 October	*Plans for units 3, 5, and 6 announced—unit 3 restart scheduled for mid-1987; construction on units 5 and 6 to resume after unit 3 brought on line.*
13 October-8 November	*Unit 1 shut down for "adjustments."*
8 November	*Unit 2 reactor restarted; trial operation at low power.*
15 November	Pravda *reports entombment of unit 4 complete.*
5 December	*TASS announces that units 1 and 2 are on line and ready for normal service.*
1987	
11-16 January	*IAEA director Hans Blix inspects entombment and "verifies" its integrity.*
13 March	*Soviet press reports that units 1 and 2 are operating at full power.*
25 April	*The chairman of the USSR's State Committee for Utilization of Atomic Energy, Andronik Petrosyants, announces that units 5 and 6 will not be completed.*

Table 1
The USSR's Nuclear Program in an International Perspective

Country	Capacity (Yearend 1986 [a]) *(megawatts)*	Reactors (Yearend 1986 [a])	Output (1986 Total [a]) *(billion kilowatt hours)*	Percent Share of Total Power Output
United States	87,241	95	433.5	16
France	47,170	49	254.2	70
Soviet Union	29,312 [b]	42 [b]	161.0	10
Japan	24,686	32	164.8	29
West Germany	18,295	17	117.4	33
Britain	12,940	37	59.1	19
Canada	11,813	17	74.5	16

[a] Preliminary data.
[b] Does not include Chernobyl' units 3 and 4.

Announced changes in fuel enrichment at existing reactors will initially cost about 115 million rubles. There will also be hard currency costs; by September 1986 some $80 million had been spent on imported goods to aid the recovery. Much of the cost of these imports could be charged to the nuclear program because they were used in the entombment of the Chernobyl' unit 4 reactor. The eventual costs to the nuclear industry are likely to be much higher.[7]

The Soviets have made relatively small purchases from the West to facilitate cleanup after the accident, speedily return Chernobyl' units to use, and construct new housing for workers displaced from their apartments and homes by radioactive contamination. The Soviets bought a wide variety of products: remote-controlled robots and tunneling equipment for decontamination work and entombment of the unit 4 reactor, radiation monitoring equipment, radiation protection items for personnel, and prefabricated housing units. In addition, the USSR received from international contributors several million dollars worth of donations in the form of cash, medical supplies, and household items

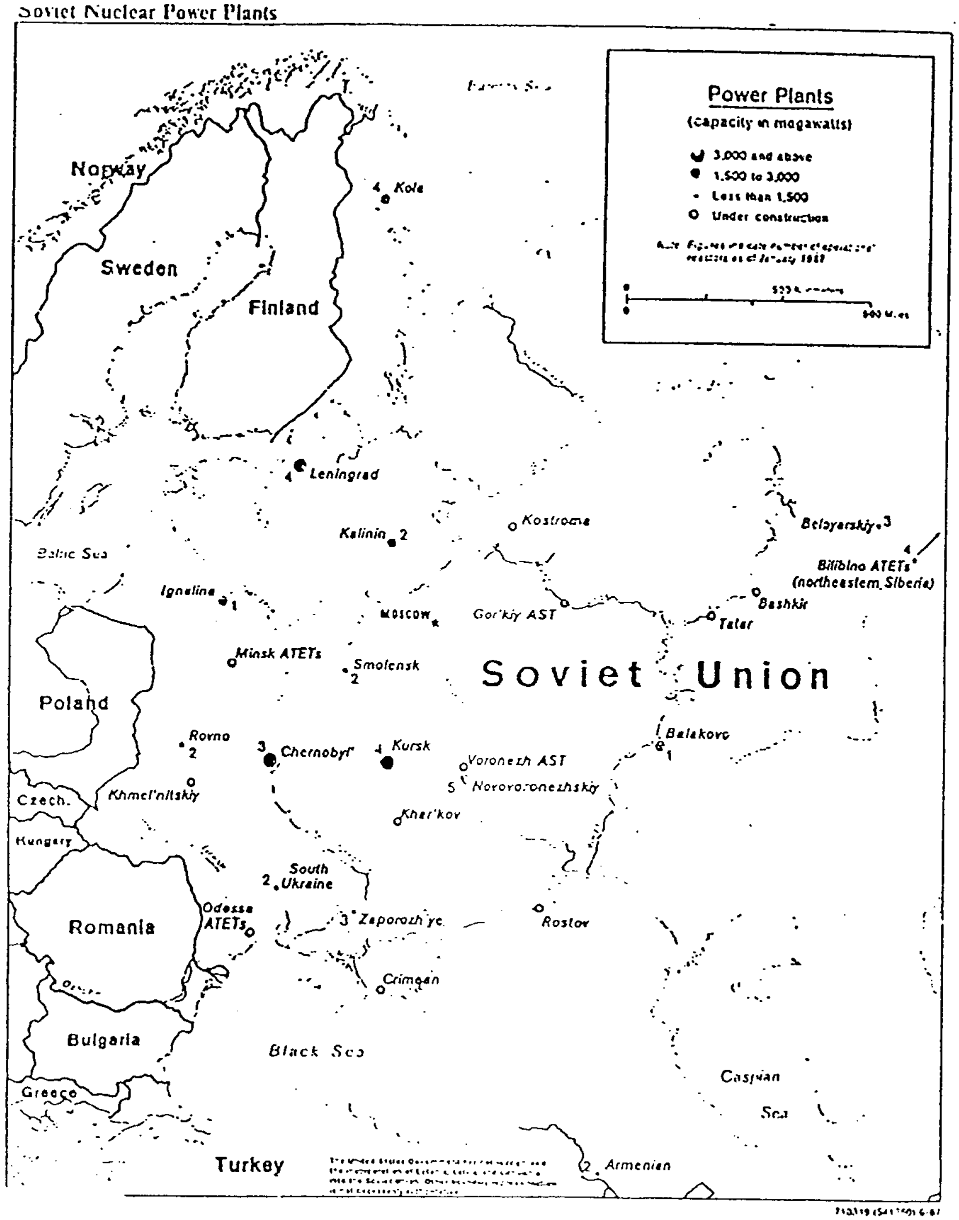
[7] Unconfirmed Soviet estimates of the cost of the Chernobyl' accident range from 2 billion to 25 billion rubles. The minimum estimate was quoted in the Soviet press during the summer of 1986 and probably accounts for only direct damage to the plant, immediate site cleanup, and possibly population relocation expenditures. The higher estimate was provided unofficially [redacted] The upper estimate would probably cover a total accounting of the costs of cleanup and recovery and probably represents a projection of expenses through 1990

Managing the Nuclear Power Capacity

Background

The USSR ranks among the leaders worldwide in the development of peaceful uses of nuclear energy (see table 1). After a quick start as the first country to operate a nuclear power plant, the USSR fell behind the United States and, later, France. Soviet industry has not been able to meet in timely fashion the technological and logistic challenges of nuclear power plant construction, so plant startups are lagging three to five years behind original plans. The USSR, nevertheless, has managed ambitious nuclear power research that has yielded the world's largest capacity reactors used for commercial applications, one of the most advanced breeder-reactor programs, and numerous designs that Soviet energy planners hope to implement in future uses of nuclear energy in urban/municipal and industrial projects (see figure 2).

Soviet Nuclear Power Plants



USSR: Commercial Nuclear Reactor and Plant Types

RBMK. A graphite-moderated, boiling-water reactor currently used at the Chernobyl', Leningrad, Kursk, Smolensk, and Ignalina nuclear power stations. It is produced in two standardized capacities: 1,000 MW and 1,500 MW (electrical rating). Although boiling-water reactors are used outside the USSR, there is no close Western counterpart to the RBMK, which is operated only in the USSR.

VVER. A pressurized-water reactor, in which the water is used as both a moderator and a coolant. It is produced in two standardized capacities: 440 MW and 1,000 MW (electrical rating). This reactor is similar to many Western designs. VVERs are operated in the USSR at the Armenian, Balakovo, Kola, Novovoronezhskiy, Rovno, South Ukraine, and Zaporozh'ye plants. VVER reactors are also operated in Eastern Europe and Finland.

BN. A fast-breeder reactor that, as its name implies, will produce or "breed" nuclear fuel for other reactors as it operates. This reactor is cooled by liquid sodium. The Soviets are running two prototypes: 350 MW and 600 MW (electrical rating). Plans call for the design, construction, and operation of 800-MW and 1,600-MW versions. Only a few other countries have mastered this technology on a similar scale.

AST, ATETs. These two types of nuclear plants are designed to supply heated water for centralized heating. The AST will use a specially modified reactor of 500 MW (thermal rating) that the Soviets plan to dedicate solely for centralized heat supply to cities. Production has just started on this reactor. Current plans call for its use at Gor'kiy and Voronezh by 1990 and eventually at many other cities. The ATETs plant will supply both electricity and heated water to cities. The ATETs will use a VVER-1000 reactor to power a steam turbine-generator, modified to permit release of heated water to the central heat network in cities. Although the ATETs design incorporates a standard VVER reactor model, the loss of energy to the heat network lowers the electrical rating of the reactor to 900 MW. Current plans call for startup of ATETs plants at Odessa, Minsk, and Khar'kov by 1990 and extensive use in the European USSR in later years.

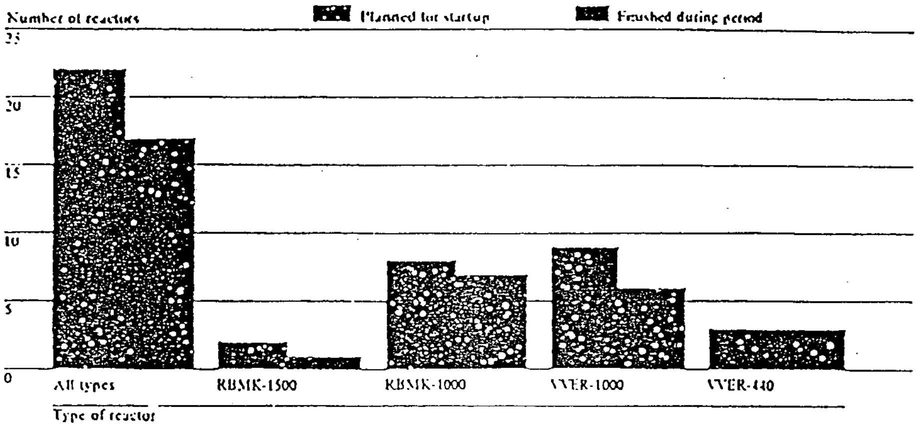
An important difference in viewpoint exists between the Soviets and the West on the economics of commercial nuclear power. In the West, the focus on the "bottom line" of financial projections means that the cost and revenue projections for an individual utility play the leading role in decisions on how much nuclear power capacity to build or, as more recently, in decisions to cancel nuclear projects. The Soviets, on the other hand, are less guided by the costs of individual projects than by the cost-benefit ratio of a proposed power plant with respect to Soviet fuel-supply logistics and the reliability and quality of electricity supplied to end users.[4] In the USSR, nuclear power plants are highly valued because they substantially reduce the burden of fossil-fuel production and transportation, and, until Chernobyl', nuclear plants were more reliable electricity producers than either fossil-fueled or hydroelectric plants. Although nuclear power plants are likely to become more costly as Chernobyl'-inspired design modifications are implemented, they will retain their attractiveness in the Soviets' broader economic evaluation.

Choice of Reactor Types

After making a commitment to nuclear power, Moscow turned to the RBMK graphite-moderated, boiling-water reactor in the 1960s and 1970s (see inset). This enabled the USSR to get substantial

[4] Inadequacies in electricity supply—including low voltage, AC frequency below established limits, and intermittent brownouts or cutoffs are chronic in the USSR.

Construction of Soviet Commercial Nuclear Reactors, 1981-85



nuclear power capacity on line during the protracted period of tooling up to produce other types of reactors. The RBMK was less technically demanding to build than other large-capacity reactor types. Consequently, the RBMK-1000 and RBMK-1500 are the backbone of the current program. The Soviet pressurized-water model has two standardized capacities (VVER-440 and VVER-1000).[a] The larger version is scheduled to become the workhorse of the 1990s. Moscow hopes the prototype fast breeder reactor (BN-600) will become the model for expansion in the 1990s and beyond to increase efficiencies in the nuclear fuel cycle and to lower costs. Within the next year or so, the Soviets will probably begin operating a new reactor (AST-500), which will replace some fossil-fueled plants in supplying hot water to centralized heating systems

Maintaining the RBMK Option

The seriousness of the Chernobyl' accident has overshadowed the history of more than 80 reactor-years of RBMKs operating reliably and without serious incident, according to the available evidence. A number of positive characteristics of RBMK reactors, described in Soviet technical handbooks, are probably still valid and will contribute to a Soviet willingness to keep these reactors operating. The RBMK-1000 reactor in recent years has had a better record for on-time assembly than other large power reactors (see figure 3). Plants with this reactor can generate more electricity on an annual basis than either fossil-fueled or VVER-equipped power plants of equivalent capacity because the RBMK is subject to fewer unplanned outages.[b] Online refueling capability helps RBMK reactors to maintain high utilization rates.

[a] The numeric part of a power-reactor designation refers to the capacity of the reactor. For the VVER, RBMK, and BN reactors this capacity is expressed in megawatts of electricity generation capability. For the AST reactor, this capacity is expressed in megawatts of thermal (heating) capability

[b] In 1985, for example, the 14 RBMK-1000 reactors averaged 72-percent utilization of capacity, while the six online VVER-1000 reactors averaged 64 percent and a representative sample of fossil-fueled generating capacity averaged 70-percent utilization.

Because the 14 existing RBMK reactors compose 53 percent of the nuclear power plant capacity and provide 6 percent of all the electricity generated in the USSR (60 percent of nuclear-generated power), a prolonged safety-related equipment refitting of existing reactors could seriously disrupt the Soviet electricity supply. We believe Moscow is not planning extensive modification of RBMKs, although Soviet inquiries to Western companies suggest Moscow is considering a retrofit of additional equipment besides that mentioned in their accident report to the IAEA.[11] The Soviets appear to have rejected wholesale upgrading of RBMK containment on the grounds of technical difficulty and costs.[12]

The technical shortcomings of the RBMK reactor that contributed to the accident include a complex nuclear core that requires moderately sophisticated monitoring with computer-assisted control, and the potential instability of the nuclear reactions in the core during low-power operating conditions or if coolant is rapidly lost. These were known to Soviet specialists well before the Chernobyl' events. Reporting in the Soviet nuclear industry's technical journals showed that design engineers were working on these problems, so fixes may not require extraordinarily long downtimes or construction delays.

Another concern surfaced by the catastrophe is the possible vulnerability of Soviet nuclear power stations to multiple reactor failure. All five of the existing plants using RBMK reactors are built around pairs of reactors. The explosion at Chernobyl' unit 4 damaged components of unit 3, calling attention to the risk that other events such as major fires or large pipe ruptures in one reactor could endanger the other member of a pair. Modifications to reduce this risk of multiple reactor failure in future plants would require time-consuming redesign work, which would increase construction costs.

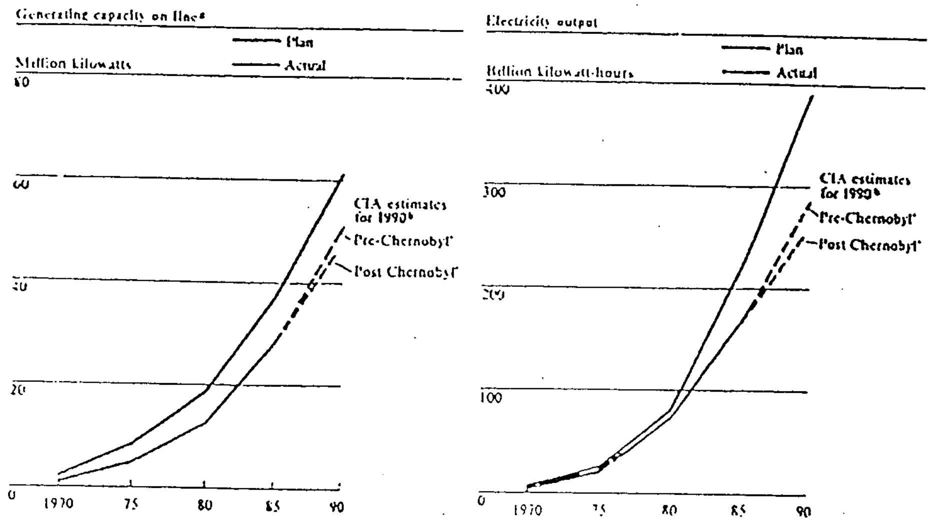
Modifying the RBMKs. Of the 29 RBMK reactors built or planned, the projects most vulnerable to cancellation if basic design flaws cannot be easily remedied are the eight reactors at the earliest stages of construction. These are located at the existing Kursk and Smolensk plants and at the proposed Kostroma plant. In an April 1987 announcement of the remaining RBMK projects, the Soviets implied, by omission, that the four reactors at Kostroma had been dropped. The Kostroma plant is in the earliest stages of design and site preparation work and could be canceled with the least disruption. The plans cited in the Soviet press call for construction of four 1,500-MW RBMK reactors at Kostroma, due to come on line at two-year intervals from 1992 to 1999. A power station operated on natural gas could be proposed as an effective alternative to the Kostroma nuclear plant, since large gas-fired power plants are already in existence in the region. A gas-fired replacement for Kostroma could be built with only minor delays to the plan for expanding power-generating capacity.

Replacement of Smolensk units 5 and 6 (RBMK-1500s) and Kursk units 5 and 6 (RBMK-1000s) would pose greater problems. Although assembly has just begun on some of these reactors, abandoning them would mean a costly writeoff of the construction infrastructure that is already being used to complete four other reactors at each location. Replacement electricity-generating capacity could be either conventional gas-fired or even nuclear, using VVER reactors. It is unlikely that the Power Ministry could complete the process of site selection, design, and construction of this replacement capacity in time to avoid a tightening of power supplies to the central region, because the units at Smolensk and Kursk were expected on line in the early 1990s.

[11] Western suppliers have been contacted about equipment for hydrogen monitoring and ignition to detect and prevent the formation of an explosive mixture that could result in the Chernobyl'-type destruction of a nuclear reactor. Other possibilities for retrofits may involve adding backup emergency core cooling and improving the automated reactor-control systems.

[12] The Soviets have already set a precedent on refusal to retrofit for containment. Soviet planners had decided by the mid-1970s to add containment to designs for pressurized-water reactors (VVERs). The containment function was incorporated in phases, with later model VVER-440 reactors receiving containment or localization of certain critical components. In 1980 the Soviets built their first reactor with full containment, equivalent to that used in the West. They did not, however, retrofit any of the eight earlier model VVER-440s with containments. The decision not to enforce the same safety standards at all VVERs was probably influenced by the technical difficulty of such extensive reconstruction and by costs, estimated by some Western experts to equal the original investment in the reactors

Soviet Nuclear Power: Performance Versus Plan



[a] Total capacity on line at end of five-year plan; 1990 capacity includes nuclear heating plants.
[b] Midpoints of established ranges.

Seven RBMK reactors are in later stages of construction, with four at an advanced stage, including the reportedly canceled Chernobyl' units 5 and 6. Modifications already proposed by the Soviets could probably be done on the remaining five without major extensions to completion times. If the Soviets decide to curtail the RBMK construction program sharply—following through on Petrosyants' announcement about the two Chernobyl' units—they still might be able to salvage some prestige. Moscow would be able to claim, with some justification, that they are only accelerating a long-planned shift to VVER reactors. The emphasis in construction of nuclear power plants has moved from RBMK reactors to VVER reactors over the last three five-year planning cycles. In the 1976-80 plan period, six of the 11 completed reactors were RBMKs, and in 1981-85 the share declined to eight of 17. The plan for 1986-90 shows only seven RBMKs among the 35 reactors due for completion.

Outlook for Achievement of Nuclear Industry Goals for 1990

Soviet targets for nuclear power plant capacity and output were out of reach even before the Chernobyl' accident shocked the nuclear industry (see figure 4). The targets call for starting electricity output or heat

Table 2
USSR: Plan for Additions to Nuclear Power Plant Capacity
(Scheduled Startups, 1986-90)[a]

1986	
Kalinin 2	VVER-1000
Zaporozh'ye 3	VVER-1000
Chernobyl' 5	RBMK-1000
Ignalina 2	RBMK-1500
Rovo 3	VVER-1000
Balakovo 2	VVER-1000
Khmel'nitskiy 1	VVER-1000
Gor'kiy 1	AST-500
1987	
Zaporozh'ye 4	VVER-1000
Smolensk 3	RBMK-1000
Balakovo 3	VVER-1000
1988	
Kalinin 3	VVER-1000
Zaporozh'ye 5	VVER-1000
Chernobyl' 6	RBMK-1000
Rovno 4	VVER-1000
Balakovo 4	VVER-1000
Crimean 1	VVER-1000
Rostov 1	VVER-1000
Odessa ATETs 1	VVER-1000
Voronezh 1	AST-500
1989	
Zaporozh'ye 6	VVER-1000
Tatar 1	VVER-1000
Smolensk 4	RBMK-1000
South Ukraine 3	VVER-1000
Minsk ATETs 1	VVER-1000
Khmel'nitskiy 2	VVER-1000
Ignalina 3	RBMK-1500
Gor'kiy 2	AST-500
1990	
Rovno 5	VVER-1000
Crimean 2	VVER-1000
Rostov 2	VVER-1000
Odessa ATETs 2	VVER-1000
Khar'kov ATETs 1	VVER-1000
Kursk 5	RBMK-1000
Voronezh 2	AST-500
Totals	
New capacity	New reactors
32,000 MW (electrical)	24 VVER-1000s
2,000 MW (thermal) in ASTs	5 RBMK-1000s
	2 RBMK-1500s
	4 AST-500s
	35 All types

[a] Original plan, subject to annual revisions during 1986-90.

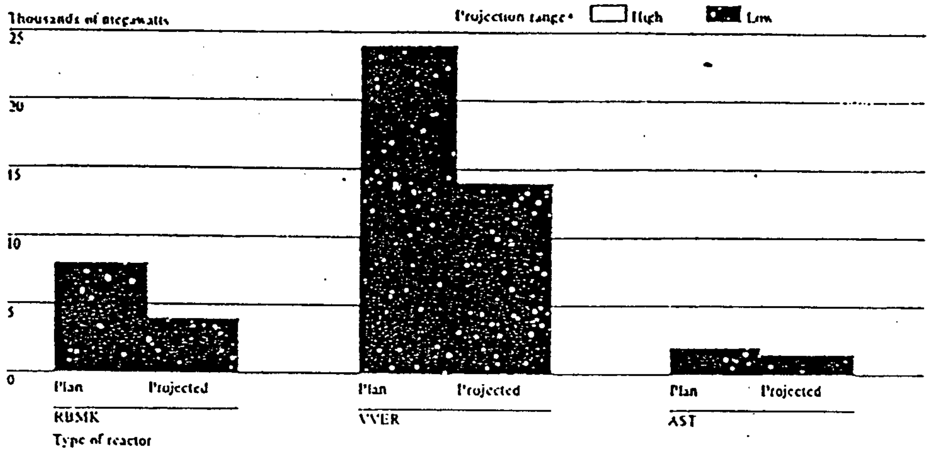
generation at as many as nine new reactors in a single year, 1988 (see table 2).[11] The 1990 electricity output goal for nuclear power is even more ambitious than the capacity goal—390 billion kWh, compared with the 167 billion kWh produced in 1985

[11] Soviet near-term plans for nuclear power were summarized in the 12th Five-Year Plan (1986-90). Full details of the plan have not been published, but the general goal is clear—a doubling of operational nuclear power plant capacity, from 28,300 MW in 1985 to about 60,000 MW in 1990. An alternative plan for 41,000 MW of new capacity, which would bring total nuclear capacity in 1990 to about 70,000 MW, has also been cited by Soviets in the nuclear industry. This total is not confirmed, however, in the literature on construction at individual plants. The 41,000-MW target probably represents both the capacity they hope to bring on line and the capacity in late stages of construction.

Before the Chernobyl' accident, we estimated that the Soviets would achieve good growth in both capacity and output but still fall short of plans for 1990. We projected that capacity would increase to about 50,000 MW and that electricity production would grow to about 285 billion kWh. Such an outcome would have been consistent with Soviet performance, which continues to fall short in component manufacture and plant construction.

As a result of the Chernobyl' accident (both the direct effects and the turmoil caused by the recovery effort), we estimate that by yearend 1990 nuclear capacity

New Capacity at Soviet Nuclear Facilities, Planned and Projected, 1986-90



[a] CIA estimates.

will reach only 48,000 MW and electricity output only 260 billion kWh. We expect that three or four fewer new reactors will be completed because labor and materials have been drawn from other nuclear plant construction sites to speed the Chernobyl' recovery (see figure 5). Indeed, Chernobyl'-induced delays are likely to affect much, if not all, of the construction of nuclear power plants. Such delays on unit 1 at the Odessa nuclear heat-and-power plant, unit 2 at the Voronezh AST, and possibly unit 5 at the Kursk plant could postpone startup of these units until the early 1990s.

In making these projections we assume that the Soviets will succeed in limiting the disruptions caused by retrofitting RBMKs and will not have to disrupt construction of the VVER-1000 reactors, including almost all of those due on line by 1990, for safety upgrades (see table 3). These assumptions are based on our observation that only a few individuals in the Soviet nuclear-power decisionmaking hierarchy (the CPSU, the scientific community, and involved ministries) have expressed reservations about the basic form of the nuclear program

Assuring the Future: VVER and AST Reactors

The VVER and AST reactors, representing 80 percent of the capacity under construction or planned, are the future of the Soviet nuclear program to the year 2000. The Soviets want to use these reactor types in power plants, in plants supplying heat to centralized municipal distribution networks, and in plants

Table 3
USSR: Actual and Projected Additions to Nuclear Power Plant Capacity, 1986-90

1986		1990	
Kalinin 2	VVER-1000	Rovno 4	VVER-1000
Zaporozh'ye 3	VVER-1000	Zaporozh'ye 5	VVER-1000
Rovno 3	VVER-1000	Rostov 2	VVER-1000
1987		Kalinin 3	VVER-1000
Balakovo 2	VVER-1000	Odessa ATETs 1	VVER-1000 [a]
Ignalina 2	RBMK-1500	Kursk 5	RBMK-1000 [a]
Gor'kiy 1	AST-500	Totals	
1988		New capacity	
Zaporozh'ye 4	VVER-1000	18,000 to 20,000 MW (electrical)	
Crimean 1	VVER-1000	1,500 MW (thermal) in ASTs	
Rostov 1	VVER-1000	New reactors	
Khmel'nitskiy 1	VVER-1000	14 to 15 VVER-1000s	
Voronezh 1	AST-500	1 to 2 RBMK-1000s	
Gor'kiy 2	AST-500	2 RBMK-1500s	
1989		3 AST-500s	
Ignalina 3	RBMK-1500	20 to 22 All types	
Balakovo 3	VVER-1000		
South Ukraine 3	VVER-1000		
Smolensk 3	RBMK-1000		

[a] Delay to 1991 possible.

that will provide both electricity and heat to municipal and industrial customers. Because these reactors are central to the expansion of the USSR's nuclear program, their involvement in a Chernobyl'-inspired safety review that resulted in major changes in equipment and procedures would have a larger impact on growth prospects for the nuclear industry than would changes to RBMK reactors alone. Such a safety review has already been suggested as a possibility by several leading scientists in the USSR's nuclear establishment

The nuclear power plants under construction that will use VVER and AST reactors are already caught up indirectly in the post-Chernobyl' activity. Construction of a VVER-1000 reactor at Rovno in the Ukraine was accelerated so that the loss of Chernobyl' to that region could be reduced. Despite some delays, this reactor started generating electricity in 1986 instead of in 1987 as we had projected earlier. Construction at several other plants, however, slowed as resources were drawn off to complete the entombment of the destroyed reactor at Chernobyl' or to accelerate the installation of safety modifications

Another set of postaccident concerns that could affect VVER and AST reactors relates to the number of reactors colocated at any one plant. Some Soviet specialists may challenge the wisdom of colocating multiple reactors that can be rendered inoperable for months or years by an accident in one unit. Plans made before the Chernobyl' accident call for most plants to colocate four to seven reactors. Reducing the number of reactors at plants would substantially slow the growth and increase the cost of the nuclear power program. The larger number of smaller plants would also reduce economies of scale in operation and maintenance.

In addition, the widespread radioactive contamination around Chernobyl' and the increased risks of cancer to people exposed to this radioactivity are likely to motivate Soviet specialists to reconsider the decision to locate nuclear heating plants in heavily populated areas. At present, in order to operate economically, plants supplying both electricity and heated water for central heating are located 25 kilometers or less from the heat-distribution network of a city. Plants that produce only heated water for heating are sited even closer—within 15 kilometers of the centers of major cities.[14]

Before the Chernobyl' accident, Soviet nuclear specialists had convinced critics in the USSR that the nuclear heating plants were equipped with safety backups adequate to ensure that their proximity to cities posed acceptable risks. Construction is under way on nuclear heating plants at Gor'kiy, Voronezh, Odessa, Minsk, and Khar'kov that are scheduled to come on line before 1990. Canceling or modifying these plants probably would be prohibitively expensive, according to Soviet calculations. The post-Chernobyl' safety reviews are likely, however, to reopen the discussion of site locations for the roughly 20 nuclear heating plants that exist only on paper in long-term plans.

Until the mid-1970s Soviet experts believed that the probability of a major accident in a nuclear power plant was so small that massive and expensive containment structures were unnecessary. All later model reactors (both RBMK and VVER), however, have some form of containment. The earlier uncontained reactor models may now come under closer scrutiny since Chernobyl' has shown the potential impact of what had been considered a low-probability event. If the Soviets decide to improve safety, the eight uncontained VVER reactors may be reviewed first because of the potential risks if the integrity of components is breached

[14] Existing Soviet standards for nuclear plant locations—minimum distances of 3 kilometers (km) from any populated area, 25 km from cities with populations of at least 300,000, or 40 km from cities with populations of 1 million or more—were amended for nuclear heating plants (ASTs) following a review in the late 1970s.

Impact on Soviet Nuclear Energy Policy

At the time of the Chernobyl' accident, a distinctive Gorbachev imprint on the USSR's nuclear goals was not yet apparent. Gorbachev's new assignments at energy ministries were too recent to have had a visible effect on the nuclear program—the new Minister of Power and Electrification was appointed in March 1985. The new leadership in the various major energy ministries (oil, natural gas, coal, and power) apparently did not alter the long-term energy goals when the opportunity presented itself in late 1985. At that time, the plan for 1986-90 (pushing natural gas production and calling for sustained growth in oil output) and the existing Long-Term Energy Program (setting goals for expanded roles for coal and nuclear energy in the 1990s and beyond) were publicly endorsed without changes.

Early in 1986, however, there were signs that the Gorbachev energy team was considering some shift away from coal, with a corresponding greater emphasis on nuclear power in the longer term. A key element in the program for a coal resurgence—direct-current ultra-high-voltage (UHV) electricity transmission—was challenged on the grounds of high development costs and lack of progress in achieving new technical capabilities. The critics of coal argued that nuclear power plants are better suited to supplying electricity to the Urals than would be UHV transmission lines linked to distant coal-fired power stations.[15]

Since the accident, a number of Soviet viewpoints relating to the effects of Chernobyl' on the USSR's nuclear program have been set forth in the Soviet media and expressed by Soviet officials in conversations with Western counterparts. There appears to be broad agreement on several judgments:

- The USSR's need for nuclear energy as the main alternative to fossil fuels was not changed by the Chernobyl' disaster.
- Operator error in performing tests at unit 4 was the chief, although not the sole, cause of the disaster.
- Soviet targets for completing nuclear power plants and for generating electricity in 1990 should not be changed.

Some disagreement among Soviet authorities is evident, however, on:

- The extent to which the basic design flaws in the RBMK reactor that contributed to the destruction of Chernobyl' unit 4 and damage to the adjoining unit 3 can be fixed.[11]

- The amount of work needed to restore reliable operation of Chernobyl' units 1 and 2 and provide housing and services to workers.

- The feasibility of returning Chernobyl' unit 3 to operation and whether construction could be resumed on Chernobyl' units 5 and 6 (a decision not to recover units 5 and 6 was apparently made in March/April 1987).

- The functions and authority of the several organizations that deal with nuclear energy.

[11] For example, the first official statements on the cause of the accident singled out operator error and poor management in the Power Ministry and State Committee for Safety in the Nuclear Industry. By 19 July the Politburo had extended its public criticism to include the firing of a key designer of the RBMK reactor, an official in the semisecret Ministry of Medium Machine Building. By implicating design shortcomings as at least a contributing cause of the accident, the Politburo had called into question not only the design integrity of existing and planned RBMKs but also possibly the design philosophy underlying the entire nuclear program. It was not until the August IAEA special meeting that the Soviets directly acknowledged that design faults were partly responsible for the seriousness of the accident.

Given the complexity of these issues, the contradictory viewpoints on some matters, and the number of bureaucracies involved in making the necessary decisions, Soviet policies on the nuclear program could remain unsettled for another year or more. The immediate attention of decisionmakers was directed at Chernobyl' cleanup activities, the effort to entomb unit 4, and the recovery of units 1, 2, and 3. Meanwhile, the nuclear industry has been rocked by reorganization and uncertainty about the authority of key players such as the Power Ministry, the State Committee for Nuclear Safety, and the new Ministry of Atomic Energy (see inset).

An Underlying Commitment to Nuclear Power
Nevertheless, Soviet spokesmen continue to affirm a strong commitment to the growth of nuclear energy. This commitment is bolstered by the large infrastructure dedicated to the nuclear industry—a factor that will carry considerable weight with policymakers as they review long-term plans for nuclear energy. Long-range goals for Soviet nuclear power to the year 2000 were defined in terms of their projected impact on economywide fuel use.

Specifically, Moscow had set goals for the development of nuclear energy during the 1986-2000 period that were designed to mesh with other energy programs so that:

- Consumption of oil and gas could be reduced.
- Retirements of obsolete power plants could be speeded.
- The quality of electricity supply could be improved.
- Fossil fuels could be conserved in increasing quantities by using nuclear energy in more applications.
- Growth in the demand for electricity in the European USSR could be met; nuclear power stations are concentrated in the area west of the Ural Mountains.

Our conversion of these targets to actual reactor construction goals implies that over 120,000 MW of power plants and about 20 nuclear heating plants would have to be added during the 1986-2000 period.

Reorganization of the Soviet Nuclear Program

After studying the results of the Chernobyl' investigation in July, the CPSU Politburo began a reorganization of the Soviet nuclear industry. It fired the head of the All-Union State Committee for Nuclear Safety and the main designer for RBMKs, as well as key personnel in the Ministry of Power and Electrification and in the Ministry of Medium Machine Building (probably for its role as overseer of RBMK design).[a] In addition, the Politburo set up a new Ministry of Atomic Energy and increased the party's influence on the operation of nuclear plants by assigning people from the central CPSU apparatus instead of local party representatives to each nuclear power station.

Major questions remain on which organizations and people will wield authority for such functions as operation of nuclear power plants, preparation and disposal of nuclear fuel, enforcement of safety rules, construction of nuclear plants, and fabrication of components. [redacted] *many areas of authority have yet to be clearly defined. The Ministry of Atomic Energy, for example, will assume responsibility for operating all nuclear power plants, taking over from the Ministry of Power and Electrification and the State Committee for the Utilization of Atomic Energy (staffed with nuclear experts from the Ministry of Medium Machine Building). Whether even more authority will be transferred from other key ministries to the new Atomic Energy Ministry is not now evident.*

[a] The responsibilities of the Ministry of Medium Machine Building include functions in both military and civilian nuclear programs. The civilian nuclear industry depends on this ministry for nuclear fuel, for design and construction work on the RBMK reactor, and for expertise in nuclear materials transportation, storage, and reprocessing

The Soviets appear to have begun work—ranging from preliminary paperwork on the plant designs to actual plant construction—on about three-quarters of the projects needed to meet the long-term goals (see table 4). More than half of these nuclear projects are in the earliest stages of development, however, and some 30,000 to 40,000 MW of the nuclear capacity needed to achieve the objectives for the year 2000 has not yet been approved at even the drawing-board stage.

Disagreement, moreover, is evident in the Soviet media on several aspects of nuclear energy development over the longer term. Among the points at issue are:

- The adequacy of Soviet nuclear safety standards and standards of enforcement.
- Whether reactor types other than the RBMK (VVER or AST) should receive thorough safety reviews.
- The need for a reevaluation of quality control in component manufacture for nuclear plants.
- The criteria for site locations of future nuclear plants.
- The feasibility of pushing ahead with more and larger breeder reactors.
- The need for development of an inherently safe reactor.

Before Chernobyl' the Soviet safety philosophy was based on a perception of the probability of certain types of accidents rather than on an evaluation of the consequences of both probable and unlikely occurrences. The Soviets believed that their nuclear plant designs, operating parameters, and rules for plant operations assured that any failures would be small events that could be contained safely. [redacted] stated that "as a result of the Chernobyl' nuclear accident, the Soviets have buried forever the fail-safe argument concerning nuclear power." If the Soviet nuclear industry is instructed to give greater weight to ensuring safety for even low-probability events with major consequences, this new philosophy will impact on plant site selection, designs, component manufacture, and plant operation.

Table 4
The Soviet Nuclear Program to the Year 2000: Outlook Before Chernobyl'

	Capacity (MW)	Plants	Reactors
Total planned	170,000 to 180,000 [a]	60 to 70	230 to 250
Operating (generating power as of 24 April 1986)	28,312	15	41
Of which RBMK	15,500	5	15
Capacity at some phase of construction or planning	111,300 [a]	39	162
Of which RBMK	19,500	6/1 [b]	15
Construction at main facilities	35,000 [a]	16/8 [b]	36
Of which RBMK	7,000	3/0	6
Site preparation	19,300 [a]	11/3	18
Of which RBMK	4,500	3/0 [b]	3
Planning and design	31,000 [a]	12/5 [b]	29
Of which RMBK	8,000	3/0 [b]	6
Site proposals	26,000 [a]	18	38
Of which RBMK	None	None	None
Capacity awaiting go-ahead on site selection and design	30,000 to 40,000	6 to 15	30 to 45
Of which RBMK	Unknown	Unknown	Unknown

[a] Includes capacity partially or wholly dedicated to supplying heat for space heating and industrial-process applications.
[b] Number at left of diagonal (/) shows total of plants with activity in the category, number on right shows plants exclusively in the category.

We believe the Soviets will try to accommodate both old and new safety philosophies to minimize costs and delays. Existing plants and plants at advanced stages of construction would continue to be judged according to the current safety standards. The new safety philosophy would be phased in at plants on the drawing board and possibly at selected plants now in the earliest stages of construction. This approach to a more comprehensive safety philosophy would leave plans for new nuclear power plant capacity untouched in the 1986-90 period but could lead to delays in the 1990s. Support for this theory of Soviet reactions was evident [redacted] in December 1986. [redacted] construction of RBMKs would cease after the last two Chernobyl' reactors were completed (units 5 and 6, scheduled for the early 1990s). We believe the Soviet reference to a construction halt on RBMKs would still allow for completion of many of the remaining 15 reactors now at some phase of assembly.[f]

The plans for power plants based on VVER reactors will probably survive the post-Chernobyl' scrutiny, although some additional safety requirements could be mandated. However, the slowing of the Soviet

[f] If new safety measures that go beyond what has already been proposed make new RBMK reactors prohibitively expensive, the Soviets could drop as many as six RBMK reactors that are now in very early stages of planning. Such an action could be taken without a major impact on electricity supply if Moscow is willing to rapidly replace these reactors with conventional thermal power plants fueled by natural gas.

The Manufacturing Infrastructure for the Nuclear Power Industry

The manufacturing infrastructure for the Soviet nuclear power industry is divided into two more or less distinct subsets. One group, composed of over 500 major enterprises, makes components for RBMK reactors. The logistic nightmare of the RBMK support industry is a main reason this reactor has been scheduled for gradual phaseout. The other—and much smaller—group of support enterprises manufactures components for VVER reactors and is scheduled to produce for the breeder reactor program. In the latter group of enterprises are the Izhorsk Heavy Equipment plant near Leningrad and the Atommash plant outside Volgodonsk, two of the largest nuclear-component-fabrication facilities in the world. But the Atommash plant has shown a disappointing performance since production of VVER pressure vessels began in 1978. Far from being a showcase nuclear assembly plant, Atommash has been plagued with problems—poor management, production of substandard components, and plant damage from ground subsidence.

nuclear program as well as safety reviews will probably mean that the economic rationale for a large-scale breeder-reactor program currently targeted to start in the late 1990s will be eroded.

The Influence of Nuclear-Industry Infrastructure

The large investment the Soviets have made in manufacturing plants that supply the nuclear industry will bolster their commitment to a growing and little-changed program (see inset). Plants manufacturing components for Soviet-designed reactors are located not only in the USSR but also throughout Eastern Europe. The Soviets have invested tens of billions of rubles and millions of dollars of hard currency imports in building and equipping their facilities. They have accomplished many of their goals for centralizing component production and for integrating the capabilities of the CEMA. The East European countries, for example, can produce nearly all the components for power plants using VVER-440 reactors—with the notable exception of nuclear-fuel assemblies. Moreover, VVER and RBMK nuclear power plants built in the USSR contain many key components manufactured in Eastern Europe.

Because it appears likely to Western observers that the failure of or an inadequate operational range of certain components could have contributed to the Chernobyl' accident, the absence of repercussions in the Ministry of Power Machine Building or the Ministry of the Electrical Equipment Industry is surprising. The IAEA special meeting on Chernobyl' provided insight on this matter. According to the Soviet account of the accident, improper designs, not poorly built components, explained entirely the inability of certain systems to perform as expected.[a] Thus, in a perverse way, the Chernobyl' accident is good news for the equipment manufacturing ministries because they were implicitly certified as competent. Indeed, it is possible that more resources will be assigned to them so that equipment for modifications can be produced quickly.

Antinuclear Voices in the USSR

Antinuclear movements as they exist in the West are not possible in the USSR. Moscow's control organs probably would effectively prohibit the organization of an antinuclear group of substantial size and almost certainly would prevent public demonstrations or circulation of publications containing views opposed to official policies on nuclear energy. The Soviets have also minimized the opportunities for an antinuclear lobby by mounting an effective pronuclear campaign that advertises the advantages of nuclear power: fuel savings, less environmental impact than coal, and lower overall costs.

Nevertheless, antinuclear sentiments exist in the USSR, and they receive some degree of official acknowledgment. Three groups that have questioned

[a] In the nuclear industry, as in other Soviet industries, responsibilities for designs of equipment and plants are handled by institutes and bureaus that operate nearly independently of the manufacturing and construction organizations that use the designs

the nuclear program are likely to respond to the Chernobyl' accident with increased activity: (1) specialists on ecology, (2) those regional Communist Party authorities who have shown reluctance to back nuclear projects, and (3) scattered individuals who reveal a grassroots expression of doubt and concern about the locations and operations of nuclear plants.

Although Soviet ecologists have generally supported the nuclear program as providing an energy source much less disruptive to the environment than fossil fuels, particularly coal, a few scientists have criticized the impact of nuclear energy. The most prominent of these critics has been Nikolai Dollezhal, original designer of the Chernobyl'-type reactors. In an article published in a leading Soviet journal in 1979, Dollezhal argued that a large nuclear program in the European USSR could eventually require withdrawal of lands from agricultural production, make excessive demands on water resources, and release ecologically threatening quantities of heat into the atmosphere. Dollezhal's solution (to consolidate nuclear power plants in large, remote complexes) could now gain more backing from ecologists, whose opinions recently have had increasing, though still minor, influence on policy formulation.[a]

Since the Soviets are unlikely to allow direct questioning of the safety of nuclear plants, the ecology issue could provide an acceptable surrogate for use by groups whose real concerns are safety and public health. A harder look at the ecological impact of nuclear power could jeopardize the extensive use of this energy source for central heating, because the reactors used for this purpose must be located close to populated areas. Moreover, ensuring that nuclear facilities are more ecologically benign probably would drive up the capital costs of most nuclear plants.

Many regional party and government organizations saw real advantages to nuclear power and supported nuclear power plant projects. A few regions (the Ukraine, for example) gambled heavily on the successful operation of nuclear power plants; nearly all new power plant construction there since the late 1970s has been nuclear. The leadership of the Georgian republic, however, opposed building nuclear plants until early 1986, when the construction of a power station was announced. The basis for opposition to nuclear plants in Georgia was not fully discussed in the Soviet press, but concern about radiological consequences on Georgian agriculture was evident. The Chernobyl' catastrophe is likely to revive the Georgian antinuclear lobby, which may now be more successful in arguing that untapped hydro resources and local coal deposits can meet future Georgian electricity needs.

Impact on Resource Allocation and Trade

The assorted production and research bureaucracies of the energy ministries that compete for resources with nuclear power (oil, gas, and coal) will use the Chernobyl' accident and its associated capital costs as an opportunity to promote their claims for investment resources at the expense of the nuclear industry (see inset). In the short term, the oil and natural gas industries may be the quickest to take advantage of the Soviet nuclear industry's setback. Oil and gas provided 70 percent of the USSR's energy production in 1986 and will remain the most important Soviet energy sources well into the 1990s. Spokesmen for oil and gas industry interests will be able to make the case that over the next several years these fuels will be even more necessary for the Soviet economy because the nuclear industry will fall short of plans while it is reorganizing and regrouping in reaction to Chernobyl'. The oil and gas interests will probably link this argument to a bid for increases in their already escalating requirements for investment and skilled labor, promising that they can meet the energy needs of the economy.

Coal is nuclear power's main long-term competitor. Coal-based energy strategies have backers in the State Planning Committee (Gosplan), in the Power

[a] The view that ecologists, or arguments couched in ecological language, have had influence on Soviet policymaking is supported by their role in recent events: the decision not to divert Siberian rivers, the followup to the Dnester River chemical spill, and the "nuclear winter" line in nuclear weapons debate.

Capital Costs of the Chernobyl' Accident

At a minimum, the nuclear industry will need to write off the 400-million-ruble reactor destroyed at Chernobyl'. If the Soviets must abandon Chernobyl' unit 3 and the work done on units 5 and 6 because they are too contaminated to recover, another 800 million rubles of investment would be lost. Additional outlays of hundreds of millions of rubles would be necessary if new rapid shutdown equipment for reactors is installed at all RBMKs. The VVER reactors, particularly the eight early, uncontained ones, may also need safety upgrades that, if extensive, could cost several hundred million rubles.

During 1981-85, yearly spending on equipment and construction for nuclear plants averaged nearly 2 billion rubles, almost 35 percent of all power industry investment. Additional sums, perhaps several hundred million rubles, are annually invested in infrastructure for the nuclear industry. A rough total of the capital costs of the accident (ranging from actual to possible) to be borne by the nuclear industry shows these to be the equivalent of two or three years' current investment.

Ministry, in the Coal Ministry, and in many research institutes. Expanded coal use is supported in the Soviet Long-Term Energy Program; planners are counting on coal, in conjunction with nuclear power, to supply nearly all new energy output once natural gas production levels off in the mid-1990s. However, the Soviets have not been devoting the resources needed to get the coal industry moving toward its ambitious goals. The industry's leadership is now in a strong position to bid for a larger resource share, using the argument that coal-fired plants will be able to deliver electricity more cheaply and safely than nuclear plants.

Soviet Purchases From the West
The Soviets are likely to continue to need Western equipment for monitoring radiation and health, amounting to several million dollars per year for at least a decade. Moscow probably hopes to meet these specialized needs through IAEA-sponsored donations but will import what is necessary. Other products and services that the Soviets may want to purchase from the West are reactor simulators and teaching aids for training reactor operators and equipment for nondestructive testing of nuclear power plant components.

A more important role for Western imports is possible in the next few years if the Soviets want to accelerate their VVER program or decide to implement rapidly safety features used in reactors operated in the West. For example, the Soviets would probably need service contracts with Western machine-tool specialists to boost construction of VVER reactors because effective utilization of machine tools that have been purchased in the West is essential to the production of the major components used in these reactors. Many components of a generic nature (such as pipes, valves, and pumps) could also be purchased from the West, since these would require little modification to operate in Soviet plants.

Any market in the USSR for Western nuclear vendors is likely to be highly competitive. Firms from the United States, France, Finland, West Germany, Sweden, Great Britain, and Japan can offer many comparable components and services.

Soviet Nuclear Sales Abroad
Before the Chernobyl' accident, the USSR was stepping up its campaign to sell nuclear power plants in the West. The accident has dampened the prospects of all suppliers of nuclear power plants but may have a more lasting impact on Western suppliers than on the Soviets (see inset). The Soviets have tried to sell nuclear power plants with VVER reactors to new customers in 12 countries in the past two years. The Soviets agreed, several months before Chernobyl', to supply a nuclear power station to North Korea, hosted

---

Impact of Chernobyl' on Nuclear-Support Industries—Are the Soviets in Better Shape for a Comeback Than the West?

With the likely exceptions of France and Japan, most developed Western countries (including the United States) could suffer greater setbacks to their nuclear-support industries during the next decade than will the USSR as a result of reactions to Chernobyl'. While the nuclear industry in the developed West and several other countries—South Korea, Taiwan, the Philippines, and India—was in recession before Chernobyl', before the fall in oil prices, and even before the Three Mile Island accident, there were several immediate backward steps in the months after the Chernobyl' accident. Austria and the Philippines finally chose to give up their previously troubled nuclear programs. A number of planned orders for new stations—in Finland, the Netherlands, and Italy—were put on hold, permanently in some cases. Further postponing of orders for nuclear power plants is most likely to occur in the West as doubts about nuclear power increase. As a result, shakeouts and retrenchment in the developed West's nuclear-support industries are now more the rule than the exception: possibilities for new business are dwindling at home, and reactor-export possibilities are shrinking. In another five years or so, industrial capacity in the West devoted to supplying nuclear power plants could be greatly reduced.

In contrast, new orders for nuclear plants in the USSR continue. Because the state-operated nuclear power equipment industry of the USSR can weather this period of slack international demand for nuclear plants, the Soviet Union could find itself in a better position than most suppliers in the West to take advantage of a rebound in nuclear plant orders in the 1990s. Such a rebound currently seems remote. Nevertheless, selling nuclear power plants and equipment could again become lucrative if confidence in nuclear power is restored and conventional energy costs rise sharply

---

a Chinese visit to Soviet nuclear plants, sought Kuwaiti assistance as a broker for possible sales in the Middle East, and offered to sell nuclear plants to India, Egypt, Morocco, and Indonesia. Before Chernobyl' they also discussed constructing reactors in Syria, Iraq, and Libya, and planned to bid on plants for Finland and Yugoslavia. In the wake of the Chernobyl' disaster, the Soviets probably have lost some nuclear plant sales; Finland (with two operating Soviet reactors) and Yugoslavia immediately put their nuclear orders on hold, while other potential Soviet customers indicated that nuclear plans were being reviewed.

Before the Chernobyl' accident, Soviet nuclear plant marketers hoped to get several commitments for purchases of VVER reactors. Potential buyers in Finland and Yugoslavia seemed close to placing orders cumulatively worth roughly several billion dollars over the next five to seven years. Given the trade arrangements between each of these countries and the USSR, however, these transactions probably would have been largely barter agreements, with very little hard currency transferred to the Soviets. Although the Soviets were actively discussing contracts for commercial nuclear plants with a number of other non-Bloc potential buyers, this segment of business was at a preliminary stage.

The Soviets are jointly engaged with the East European countries (Bulgaria, Czechoslovakia, East Germany, Hungary, Poland, and Romania) in marketing Soviet-designed nuclear plants to power industries inside and outside the CEMA area. These plants use the VVER pressurized-water reactor in either of two capacities: 440 MW or 1,000 MW. Reactors of the Chernobyl' type have never been offered for export. With the exception of nuclear fuel, all of the components for the VVER-equipped plants can be manufactured in Eastern Europe, largely in Czechoslovakia, East Germany, and Hungary. The 1,000-MW VVER reactors currently being marketed have full containment and other safety features functionally comparable to those used in the West. The Soviets are also jointly marketing a VVER-440 nuclear power reactor with a Finnish company that operates a plant of this model in Loviisa, Finland.

In public testimonials, a number of East European officials have reaffirmed their confidence in the safety and reliability of Soviet-designed reactors. Privately, however, East European energy experts concede that the Chernobyl' accident has increased concern about the safety systems engineered into Soviet designs (especially the older VVER-440s without even Soviet-type containment), but they expect that Soviet-designed reactors will continue to be operated, built, and ordered. '

The East Europeans have a large stake in the success of Soviet-designed VVER models—19 reactors with a combined capacity of about 8,000 MW are now operating in these countries, and 50 others (some 36,000 MW) are under construction or on order. Although we believe that the East Europeans will follow through on plans for nuclear energy, their nuclear programs could experience delays (while public confidence is restored with safety reviews) and increased costs.