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Chernobyl': A Year Later

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A Research Paper

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Chernobyl': A Year Later

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A Research Paper

This paper was prepared by members of the
Chernobyl' Task Force from the Office of Soviet
Analysis, the Office of Scientific and Weapons
Research, the Office of European Analysis,

Comments and queries are welcome and may be
directed to the Chief, Economic Performance
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Chernobyl': A Year Later

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Scope Note

This paper provides a broad assessment of the effects of the Chernobyl' nuclear power plant accident of 26 April 1986. It examines the political as well as physical aspects of Soviet responses to the accident, the safety aspects of the basic design and post-Chernobyl' modifications of the Soviet RBMK reactors, and the human toll from radiation released by the accident. It also examines implications for Soviet nuclear power programs and agriculture, social and political reactions within the USSR, and consequences for Eastern and Western Europe.

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Chernobyl': A Year Later

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Summary

*Information available
as of 15 July 1987
was used in this report.*

A year after launching a massive and largely effective effort to cope with the world's worst nuclear accident, the USSR has managed to contain most of the political and economic fallout. Moscow defused Western government criticism by cooperating with the International Atomic Energy Agency in detailing the accident and outlining safety enhancements for RBMK (Chernobyl'-type) reactors. Even today, however, the regime's credibility remains tainted by its initial, futile attempt to conceal the full scope of the accident and its reluctance to discuss the safety of the USSR's remaining nuclear power plants.

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The sharp international criticism brought on by Moscow's initial silence embarrassed General Secretary Mikhail Gorbachev, who had been promoting a new policy of openness (*glasnost*), and he distanced himself from the crisis to minimize his personal responsibility. Although the Chernobyl' accident has made it difficult for Gorbachev to portray the leadership in Moscow as reasonable and accountable, the break in his political momentum appears to have been temporary. After several weeks, he mounted a public relations campaign to limit damage to his regime's reputation, and his subsequent domestic reform measures have largely deflected public attention from Chernobyl'. The accident gave impetus to Gorbachev's drive for openness by showing that suppressing information about domestic problems can backfire. But, while the leadership has been able to overcome the initial credibility gap to some extent, public apprehension about the long-term consequences of radiation on human health, the safety of nuclear power facilities, and the environment continues at a heightened level.

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After a brief period of bureaucratic bungling and disorganization immediately after the accident, the Soviets mobilized both civilian and military assets to effectively control the radioactive releases and evacuate about 135,000 persons, as well as livestock. By December 1986 they had entombed the destroyed reactor and decontaminated most of the Chernobyl' environs sufficiently to permit shift work, though not habitation. Efforts to return the Chernobyl' power plant to service and to resettle the displaced populace continue.

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Two of the three surviving Chernobyl' reactors are generating electricity, and the third is being decontaminated. The partly built Chernobyl' units 5 and 6, however, have been canceled—a writeoff of roughly 500 million

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rubles. Soviet statements place the cost of the accident in a range of 2 to 25 billion rubles. The minimum estimate probably accounts only for the entombment, immediate site cleanup, compensation paid to evacuees, and population relocation expenses. The higher estimate probably includes the indirect costs of cleanup and recovery (possibly including safety enhancements to RBMK reactors) through 1990. []

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The human toll of the accident will not be known for decades. In addition to the 31 known fatalities, radiation exposure could cause cancer deaths to increase by as many as 10,000—estimated by statistical extrapolation—in the European USSR over the next 70 years (an increase of about one-tenth of 1 percent in the number of cancer deaths) and by as many as 4,000 in affected portions of Eastern and Western Europe (an increase of less than one-hundredth of 1 percent). These estimates are subject to large uncertainties, however, and the outcome will depend partly on the type and extent of medical attention given to those exposed. Nevertheless, concern about the possible consequences of exposure and psychological reactions, even among those who have no identifiable health effects from radiation, will continue. []

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The turmoil and costs of the recovery will make it harder for the regime to act on Gorbachev's initiatives for social programs, including more housing and better health care throughout the USSR. The resources diverted to Chernobyl'-related medical problems—for example, the purchase of Western radiation detection equipment—are likely to further strain the Soviet health-care delivery systems, at least in the short term. These systems have proved inadequate to deal with many medical problems associated with contemporary industrial society and have been the subject of recent criticism from the top leadership. []

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The impact on Soviet agriculture is likely to be too small to measure. The Chernobyl' plant is not in a major farming area, and most radioactive material passed largely over forests and swamps. Levels of contamination sufficient to affect crop growth or to raise the radioactivity in products to potentially carcinogenic levels were local, and health-threatening damage to farming regions beyond the immediate area of the accident has not been evident. Even in affected farming areas, the potential loss of agricultural output can be limited if the Soviets adopt measures to reduce the radiation exposure of workers, shift from sensitive crops such as beans and peas to less sensitive ones such as wheat and oats, and lime the soil to reduce uptake of the long-lived cesium-137 isotope. []

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Disruptions to the Soviet nuclear power industry through 1990 will be minor and will not derail Soviet intentions to increase reliance on this energy source. For the 1986-90 period, for example, the cumulative reduction in electricity production resulting from damage to the Chernobyl' plant and related slowdown at the other nuclear power plants will be about 100 billion kilowatt hours, or about 1 percent of projected total electricity production. From a Western viewpoint, the Soviets face a dilemma:

- They can continue operation of the RBMK reactors, which pose a continuing, if remote, safety hazard because of fundamental deficiencies that no reasonable modifications can eliminate.
- They can shut down the RBMKs, losing nearly half the USSR's nuclear power capacity.

Moscow's decision to keep its existing RBMK reactors on line reflects economic necessity and a belief that the safety threat can be dealt with adequately by a combination of hardware modifications and better management of reactor operations.

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Safety improvements to RBMK reactors so far have centered on procedures, operator training, and a few hardware modifications. Even the main modifications planned will not address key safety concerns such as the RBMK's lack of full containment. These concerns, as well as escalating costs, probably were major factors in the decision to stop construction of at least six RBMK reactors.

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Beyond 1990 some changes to the nuclear program are likely; a few could set back the timetable by several years. These changes would probably involve the design and location of future plants and a shift in emphasis resulting from the competition of coal and oil interests for investment resources. (C NF)

In Eastern and Western Europe, fears about the near-term environmental and political consequences of the accident have eased, and the focus has shifted to concern about their own nuclear energy programs. The Chernobyl' accident bolstered antinuclear sentiment, focusing regime and popular attention on environmental issues in Eastern Europe and making nuclear power a more salient political issue in many West European countries. Eastern Europe remains committed to an ambitious nuclear program based largely on Soviet technology; most of these countries, however, are seeking safety equipment and expertise from Western—including US—firms. Most West European governments are conscious of the potential of nuclear energy for reducing dependence on imported energy. France and, to a lesser degree, the United Kingdom and West Germany remain committed to continued production of nuclear power; but a long debate is expected in many countries, particularly in Italy.

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Chernobyl': A Year Later

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Coping With Disaster

At 0123 hours, on the morning of 26 April 1986, the Soviets faced the world's worst nuclear reactor disaster—the Chernobyl' accident. The accident resulted from a series of improper actions by the power plant operators in handling a reactor of inherently flawed design (see inset).¹ The area immediately surrounding the destroyed reactor was contaminated with dangerous quantities of radioactive materials. The graphite reactor moderator was burning and discharging highly radioactive material from the fuel. Thousands of plant workers and their families in the vicinity were in jeopardy from this radiation. The Kiev region, with over 2.5 million inhabitants, was less than 100 kilometers (km) away.

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Phase I—Controlling Radioactive Releases

Hot fragments of nuclear fuel and graphite expelled in the explosion at the Chernobyl'-4 reactor started more than 30 fires at the plant (see figure 1). The immediate response by on-site personnel was to fight the fires in the buildings in order to minimize damage to the rest of the plant. According to the Soviets, an early attempt to use water from the reactor's cooling system to prevent the graphite from igniting proved ineffective because the accident had severed critical pipes. This left two options—let the fire burn itself out or attempt to smother it. Soviet press accounts confirmed the latter choice. Beginning on 27 April, the Soviets used helicopters to drop a mixture of sand, boron, lead, clay, and dolomite onto the reactor to extinguish the burning nuclear core, reduce the release of radioactive material, and prevent a

chain reaction from occurring in the core. This mixture was well suited for the task. The melting lead acted as a heat sink and provided some radiation shielding. The boron absorbed neutrons to reduce fissioning, and the dolomite decomposed to form a carbon dioxide blanket over the core to smother the fire.

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Potentially serious errors were made by local authorities in responding to the accident. The report to the Ministry of Internal Affairs (MVD) headquarters in Kiev that initiated the emergency situation plan was only about the fire. Even after it was known that high levels of radioactivity were present, the accident was handled for many hours only as a site emergency. Moreover, there was no contact between the organization responsible for radiation safety of the site and the organization responsible for radiation safety of the surrounding area.

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High-level response was delayed initially because Moscow did not believe the kind of accident reported by site personnel to be possible. It was not until a group of experts arrived at the scene and saw parts of the reactor core lying on the ground that Moscow appreciated the scope of the disaster.

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One of Moscow's first acts was to establish a government commission and dispatch it to the site. This commission took over direction of the emergency response and recovery efforts shortly after arriving in Chernobyl' on the evening of 26 April. The success of subsequent efforts was clearly due to that group's ability to mobilize both military and civilian resources and to make decisions quickly.

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By the morning of 27 April, the necessity for evacuation became apparent, and planning probably had begun for the use of buses from Kiev to evacuate the people. The situation in the city of Pripyat', some 3 km west-northwest of the destroyed reactor, deteriorated sharply,

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The Chernobyl' Accident: A Capsule Account

The events leading up to the accident began with a test of a reactor safety subsystem during a scheduled maintenance shutdown. Soviet power reactors, like most others, depend on auxiliary diesel generators to supply emergency electrical power to the reactor in the event of a loss of normal supplies of electricity. The Soviets were concerned, however, about the period of up to half a minute between the loss of normal power and the beginning of power supply from the diesel generators. The fatal test involved a scheme to use the rotational inertia of the turbogenerators, which are operated by steam from the reactor, to generate electricity to bridge this interval.

The turbogenerator test had been performed previously but was not successful, and a modification to the turbogenerator was to be tried this time. The modified test was submitted to safety authorities for approval. The authorities took no action, and—since the request was not disapproved—the operators of Chernobyl'-4 decided to proceed with the test on the date of the scheduled shutdown.

The experiment began to deviate from its planned course almost from the beginning. Instead of being decreased as scheduled from a full power level of 3,200 megawatts thermal (MWt) to a level of 700 to 1,000 MWt (at which the experiment was to be performed), the power level was held at about 1,600 MWt for several hours on request from the regional electricity dispatcher. When continuation of the power decrease was authorized, operator mistakes and accumulation of a neutron-absorbing isotope of xenon

caused the reactor to become unstable, and the power level collapsed. After several hours of struggling, the operators managed to bring the reactor back up to a level of about 200 MWt—but in an extremely unstable condition. The operators bypassed a number of safety procedures to achieve this power level, and at that juncture the number of control rods in the core was far below the allowable minimum. Very little steam was being produced in the core—a dangerous condition in RBMKs because an increase in the steam content of the reactor coolant in the core can, in that circumstance, cause a rapid increase in power. Although the reactor was in a dangerous condition not foreseen in the test program, the operators decided to proceed.

To begin the test, the operators shut off steam to the turbogenerator. As the turbogenerator began to run down, the main coolant pumps connected to it began to slow. This led to slower coolant waterflow in the core and to increased boiling. As the steam content of the coolant increased, power began to rise, causing more boiling. This process continued, feeding on itself, and became uncontrollable before the operators' efforts to shut the reactor down could take effect. The combined effects of heat and pressure ruptured the fuel channels, and the resulting release of steam ruptured the core vault and destroyed the reactor building. Pieces of fuel and graphite from the core were carried for several hundred meters, and radioactive particles were literally transported around the world.

[redacted] the decision to evacuate was made at 1000 hours on the morning of 27 April, and some 47,000 persons were evacuated from the Pripyat' area beginning that afternoon. Academician V. A. Legasov told a visiting American delegation in January 1987 that earlier evacuation was not possible because intense radiation blocked the evacuation route.

In the first few days of May the situation appeared to be worsening. The material that was dropped on the reactor initially reduced emissions but also contained the heat. The temperature of the reactor's core started to rise, leading to an increase in the amount of radioactive material being released. In addition, the wind was shifting toward the city of Chernobyl' some 15 km away. Given this situation and political pressure from Politburo members visiting the area, some

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44,000 people were evacuated from the city of Chernobyl' and environs beginning on 4 May (see figure 2). Subsequently, more people were removed from a 30-km radius of the damaged plant, bringing the officially reported number of evacuees to 135,000. Fear of contamination from fallout of radioactive material from heavy rain was apparently such a concern that the Soviets used intensive cloud seeding to help prevent rain at the reactor site. [redacted] (b)(3)

In addition, fears intensified that the material in the nuclear core would "melt through" into water pools under the reactor and cause a steam explosion that could damage or destroy the unit 3 reactor and disperse more radioactive material from unit 4. On 4 May the Soviets began recovery efforts on the ground in the area immediately surrounding unit 4. They began pumping out the water pools under the damaged reactor and pumping liquid nitrogen into the core region to help reduce the heat buildup (see figure 3). These actions proved effective, and by 12 May the Soviets announced that the fire was under control and that the emissions of radioactive material had ceased.

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Technical problems, however, continued to mount. The weight of the material dropped by the helicopters (5,000 tons by Soviet claims) added to fears that the building support, which had been weakened by the accident, might collapse. [redacted]

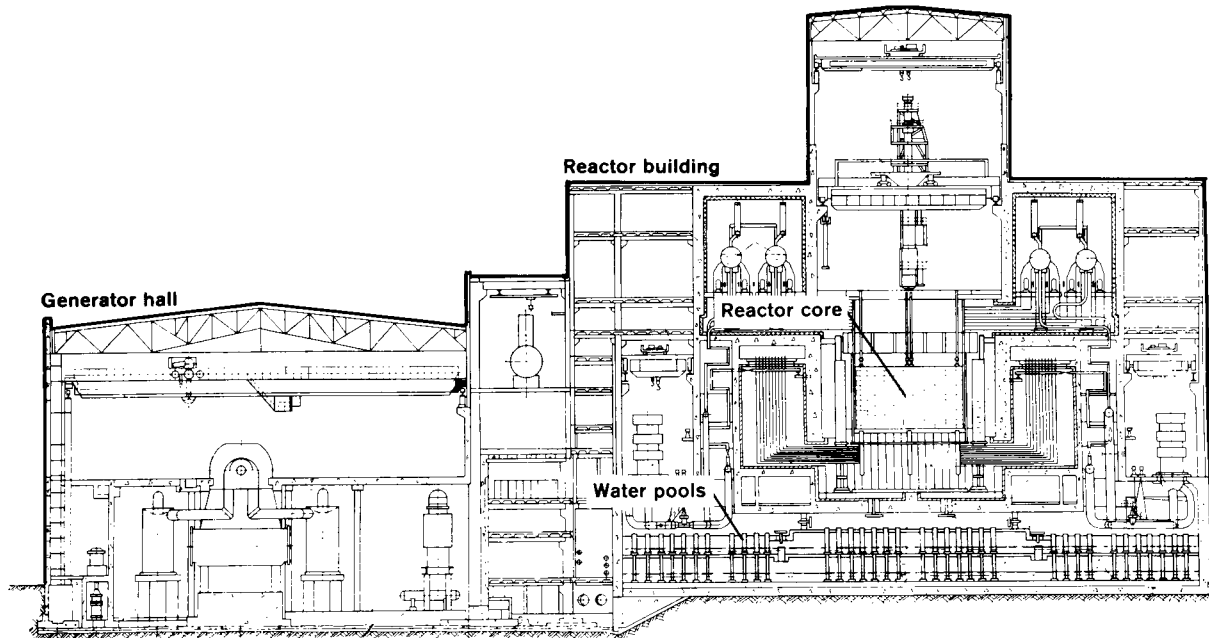
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(b)(3)**Phase II—Site Decontamination and Entombment**

As the Soviets sensed they were gaining control of the situation, they began to turn their attention to decontaminating the site and the surrounding area, as well as devising a method to permanently entomb the damaged reactor. It was apparent through both Soviet statements and actions that they pursued parallel approaches to solving problems at Chernobyl'. For example, at an August 1986 meeting of the International Atomic Energy Agency (IAEA) on the incident, they openly discussed the various techniques being considered for the entombment of unit 4, especially the problem of controlling air flow through the entombment. In addition, [redacted] they had

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Figure 3
Cross-Sectional View of RBMK



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[redacted] constructed an octagon-shaped cap configured to cover the stack of the damaged reactor. We also observed them practicing moving the cover; however, it was never used. Apparently the Soviets were so committed to finding a solution quickly that they were willing to fund various efforts in order to select the "best" one.

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We believe that the emergency measures—including tunneling under the unit 4 reactor to reinforce its base and decontaminating the site and surrounding area—required contingents of miners and construction specialists, as well as the use of more than 20,000 to 30,000 troops, many from units specially trained for chemical, biological, and radiological warfare. The use of such large numbers of troops was dictated by

the need to limit individual exposure to radiation. The activity also entailed considerable costs in terms of equipment, fuel, and materials. The Soviets, however, probably gained valuable experience in decontaminating equipment and facilities on a large scale. [redacted]

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The Soviets used a variety of decontamination techniques. [redacted] in addition to removing the topsoil in the immediate area of the reactors, they also were covering the ground with solutions and slurries that would chemically immobilize the radioactive material or simply keep radioactive dust from blowing into cleaned areas. The military units established a series of decontamination sites on the major

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roads leading to the damaged reactor and made extensive use of helicopters for decontamination. As a final step, the reactor site area was paved with concrete blocks and covered with earth. In addition, the Soviets spent considerable effort to prevent radioactive material from contaminating local sources of drinking water. They built runoff trenches, dammed stream channels to create catch basins, and constructed an underground wall to prevent seepage into the Pripyat' River of ground water from the power plant's highly contaminated cooling basin. [redacted]

As decontamination efforts progressed, the number of workers at the site was increased substantially in order to entomb the damaged reactor. Beginning in June, a four-level stairstep or "wedding cake" structure was constructed over the damaged nuclear reactor (see figure 4). Each level was constructed by building a retaining wall on the level below, then filling the space between the wall and the reactor building with concrete and earth. On top of this the Soviets created a fifth level consisting of ventilation and instrumentation tubes to monitor the status of the reactor. These tubes formed the floor of a "garret" upon which the final roof was placed. The entombment was completed in early December 1986.

[redacted]

The Soviets have claimed that, although it is 95 percent decontaminated, Pripyat' will not be suitable for permanent habitation for more than 10 years. The pitch-coated roofs of the town's buildings acted as a trap for the radioactive particles blown from the reactor, and decontamination of these roofs began in the spring of 1987. The Soviets have created the "great wall" of Chernobyl—a fence surrounding a zone with restricted entry. From the power plant site, this amoeba-shaped zone extends about 30 km to the north and west and about 15 km to the south and east (see figure 5). Radiation levels at the fence in January 1987 were reported to be about 0.7 milliroentgens per hour—a significant decrease from earlier levels but still 12 times the Soviet standard for unrestricted access. [redacted] statements by Western experts who have visited the area indicate that decontamination procedures have worked well. Indeed,

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habitation and many preaccident activities are being resumed in some areas outside the fenced exclusion zone. [redacted]

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Phase III—Recommissioning Other Chernobyl' Units

Several months after the accident, the CPSU Politburo announced a decision to return the other reactors at the site to full operation. At first glance, this did not appear to be a problem since these units were not damaged in the explosion of unit 4. The Soviets, however, eventually revealed that the operators did not immediately shut down the other units when the accident occurred, and their ventilation systems sucked significant amounts of radioactive material into operational areas. Cleanup of these units proceeded concurrently with the entombment of unit 4. By late September, [redacted] the Soviets were in the final phases of checking out unit 1 before its restart. The Soviets announced restart of the unit on 1 October, and we confirmed this from Landsat imagery of 6 October. Unit 2 restarted on 8 November, according to the Soviet press. [redacted]

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Subsequent Landsat imagery of the reactor site showed that at least two unannounced reactor shutdowns occurred between October and early December. It is still unclear if the Soviets experienced maintenance problems compounded by some of the new fixes and the high levels of radioactivity in the cooling pond or if the observed shutdowns were part of a thorough checkout/recommissioning program. Since early December, both units have appeared to be operational, although they apparently did not reach full power until early March. [redacted] the Soviets have exchanged some of the water in the cooling basin with clean river water in a gradual, controlled manner. Apparently they are still concerned about the effects of radioactive materials in the basin water on power plant operations, and they feel that the exchange can be accomplished without increasing contamination of the Pripyat' River to an unacceptable level. [redacted] work in progress in the area around the [redacted] uncompleted reactors for units 5 and 6, the cancellation of these units was announced—without elaboration—in April 1987. [redacted]

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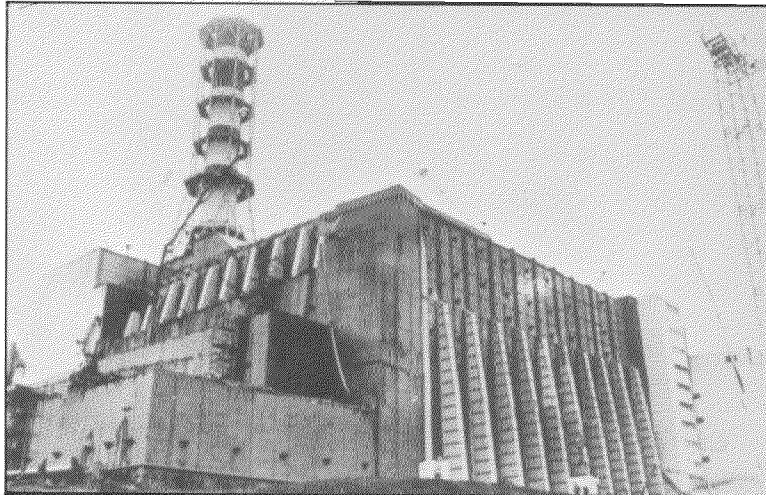
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Figure 5
Fenced Exclusion Zone Around Chernobyl' Nuclear Power Plant



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Safety Modifications to RBMKs: Progress and Implications

In the aftermath of the Chernobyl' accident, the Soviets are rethinking their nuclear power safety philosophy and are clearly concerned about the possibility of other serious accidents.²

From a Western viewpoint, the Soviets face a dilemma:

- They can continue operation of the RBMK reactors, which pose a continuing, if remote, safety hazard because of fundamental deficiencies that no reasonable modifications can eliminate.
- They can shut down the RBMKs, losing nearly half the USSR's nuclear power capacity.

Moscow's decision to keep its existing RBMK reactors on line reflects economic necessity and a belief that the safety threat can be dealt with adequately by a combination of hardware modifications and better management of reactor operations. []

The Soviets' response to the situation thus far has been largely cosmetic. They have asserted that the Chernobyl' accident was the result of "unimaginable" operator errors of a sort now foreclosed by administrative changes and hardware modifications to the reactor. Some of the RBMK safety improvements proposed by the Soviets at the August 1986 IAEA meeting have been implemented, but serious safety concerns remain. There is no feasible solution, for example, to the problem of the RBMK's lack of a full containment system []

The safety improvements implemented thus far have centered on procedural changes, upgraded operator training, and a few hardware modifications. More comprehensive hardware changes, such as increasing the fuel enrichment, will be incorporated over a period of several years. These changes probably will decrease the RBMK's vulnerability to the specific type of

² A review of reactor safety has been alluded to in the Soviet press. Specific areas of concern and possible fixes have been discussed by Soviet nuclear specialists with their Western counterparts, []

[] The All-Union Nuclear Safety Committee has been reorganized and apparently has been given increased authority with respect to implementation of safety measures. []

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accident that occurred at Chernobyl', but they may adversely affect other aspects of reactor operation. The changes also will increase the operating cost of RBMKs. []

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Administrative Actions and Operational Improvements

The Soviets have taken a number of steps to prevent the sort of improper operator actions that caused the accident. A new Ministry of Atomic Energy has been created to oversee the operation of nuclear power plants. Studies of reactor operations also have been conducted since the accident, focusing on problems such as the level of operator education. Operator training has been stepped up, and an RBMK training school and simulator, which had been under construction at the Smolensk nuclear power plant before the Chernobyl' accident, has been completed. Regulations and procedures governing reactor operation have been tightened to guard against dangerous actions by operators. The Soviets have also installed limit switches on the control-rod drives to prevent the complete removal of the rods and have planned modifications to make it harder for a single operator to disable the reactors' emergency protection systems. Instrumentation also will be upgraded: plans call for the installation of meters to display margins of reactivity and warn of main-coolant-pump cavitation.³ The improved instrumentation will alert operators when potentially dangerous situations arise. []

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Equipment and Design Improvements

There is little doubt that the proximate cause of the accident was the actions of the operators, but the accident would not have been possible except for a number of dangerous RBMK design characteristics. These features make the RBMK vulnerable not only

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³ In order for a nuclear reactor to operate, a chain reaction involving some steady rate of nuclear fissions (criticality) must be maintained. Reactivity is the measure of the reactor's potential to depart from that steady rate of fission, that is, to increase or decrease power. A display of reactivity provides operators with information needed to prevent dangerous power surges that could result if the critical level is greatly exceeded. []

Coolant-pump cavitation occurs when the pressure of water entering a pump falls to the point where the pump cannot move water. When this happens, coolant flow is interrupted and the reactor core will overheat unless the problem is corrected. []

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Dangerous Characteristics of RBMK Reactors

Positive Void Coefficient of Power. *One of the most dangerous features of the RBMK is that the release of energy increases as more of the water in the fuel channels boils and forms steam. This characteristic (called a positive void coefficient of power) is a function of the materials and geometry of the RBMK's core. The primary effect of the RBMK's cooling water on the nuclear processes is to absorb neutrons; the absorption decreases the efficiency of the fission process in the reactor. Thus, a loss of water from the core results in increased fissioning and power increases. In an emergency situation, when more steam is formed because of fuel overheating or a drop in coolant pressure, the power will increase, compounding the situation. This is the mechanism that led to the destruction of the Chernobyl'-4 reactor.*

Increasing the ratio of fuel (uranium-235) to moderator (graphite) in the core will ameliorate this condition. The Soviets are investigating a number of options to change the ratio, including increasing the enrichment of uranium-235 in the fuel of all RBMKs and increasing the number of holes in the graphite

cores of RBMKs under construction. Replacing the current fuel with fuel of higher enrichment will be a gradual process taking place over a number of years; meanwhile, the positive void coefficient will continue to be a concern. The Soviets have issued regulations raising the minimum number of control rods that must be in the core from 30 to some 70 to 80 as an interim safeguard. This lowers fuel burnup, thus raising the average enrichment level of the fuel. These modifications should reduce the positive void coefficient, though it is not clear whether it can be eliminated entirely.

Positive Reactivity Effect of Control Rods. *Initial emergency insertion of a fully withdrawn control rod (a procedure called a SCRAM) causes a power increase in an RBMK. When a control rod in an RBMK is fully withdrawn, there is a water-filled space about 1 meter long below the tip of a graphite displacer that is attached to the bottom of the rod to improve neutron economy. Since the primary effect of water on neutron processes in the core of an RBMK is to absorb neutrons, displacement of water by the graphite tips of the control rods will cause an initial*

to the accident sequence that occurred at Chernobyl' but also to other accident scenarios. Because many of these deficiencies cannot be remedied, the RBMK will continue to be considerably less safe than other types of reactors. The Soviets are, however, attempting to rectify some of the problems (see inset).

Disadvantages of Safety-Related Changes

All of the stated modifications will improve the safety of RBMKs to some extent, though none will raise these reactors to Western safety standards. The RBMK is a particularly difficult reactor to control, and its cooling system is very complex and relatively delicate. For example, the rupture of more than two or three of the nearly 1,700 coolant channels in the core would be sufficient to overpressurize the compartment containing the core, causing the same type of catastrophic accident as occurred at Chernobyl'.

The proposed modifications may also produce side effects that will reduce safety margins somewhat. Increasing the enrichment of the fuel, for example, will increase power peaking in fresh fuel, reducing heat-transfer margins and making power control more difficult. Additional neutron-absorbing rods also must be installed in the core to compensate for the increased average enrichment, thus reducing the total number of channels available for fuel rods and decreasing thermal margins in the remaining fuel. The disadvantages of the modifications, however, must be balanced against the benefits of reducing immediate safety hazards such as the positive void coefficient.

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increase in reactivity; that is, a tendency to increase power. The Soviets have confirmed that the sudden insertion of all the rods when an emergency shutdown was attempted during the initial part of the Chernobyl' accident caused an increase in reactivity that aggravated the rapid power increase. The Soviets have effectively solved this problem by placing limit switches on the control rod drives to prevent operators from removing the last 1.2 meters of the control rods. We believe this modification has been implemented on most, if not all, RBMKs. []

Slow SCRAM Speed. Another deficiency of the RBMK design is the slow speed of its emergency protection system, or SCRAM system, which automatically inserts all control rods into the core to stop the nuclear chain reaction as rapidly as possible. The time required for insertion of fully withdrawn rods into an RBMK is about 20 seconds, compared with only a few seconds for actuation of the SCRAM systems of Western reactors. The RBMK's control rods are withdrawn by cables, and redesign of the control-rod drives to increase insertion speed would be difficult, if not impossible. The Soviets stated in

their report to the IAEA in August 1986 that, instead, a special high-speed control system is to be developed for use in a few control-rod channels. No further information has been provided on progress in implementing this system. Unless the Soviets develop an effective SCRAM system capable of significantly reducing reactor power within a few seconds, the RBMK will continue to be vulnerable to rapidly developing accidents. []

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Lack of Containment. All Soviet-designed reactors built before the mid-1970s, including RBMKs, lack systems to contain the consequences of a major accident. Later RBMKs have a form of pressure-suppression system, but it is not equivalent to the full containment systems on Western reactors. The sheer size and complexity of the RBMK probably would make a Western-style containment infeasible. []

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[] the only planned measure to limit the consequences of future accidents at RBMKs is to stockpile lead, sand, and boron—the materials initially used to cover the destroyed Chernobyl' reactor—at the reactor sites in order to expedite the response to a serious accident. []

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All of the proposed changes will make RBMKs more expensive to operate. Fuel cycle costs will be considerably increased as a result of the increase in fuel enrichment and nonoptimal burnup, which are necessary to reduce the positive void coefficient. If power-peaking problems force the Soviets to operate their RBMKs at less than their full design capacity, costs will be even greater. This may be a more severe problem for the RBMK-1500s, which operate at 50 percent more power than the RBMK-1000s with essentially the same core. []

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Impact on Weapons-Material Production Potential

The RBMK is the technological descendant of the USSR's reactors that produce military weapons material, but RBMKs have not been used for weapons-grade plutonium production. The proposed modifications to the RBMKs will, if anything, decrease their

potential for such production. RBMKs do have a potential for producing some tritium at little cost, however, and the proposed modifications to decrease the positive void coefficient will significantly enhance this potential. The neutron-absorbing rods that must be used to compensate for the increased fuel enrichment could be made of a lithium compound that produces tritium when irradiated. Incorporating these absorbers in the core will increase the RBMKs' fuel-cycle cost, but this increase must be borne for safety reasons in any case. The additional cost of processing the tritium would be small. []

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The amount of tritium that the modified RBMKs could produce has not yet been determined, but it is likely to be substantial. We judge that if the Soviets

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choose to fully utilize this potential, they could easily satisfy their tritium needs for nuclear weapons for the foreseeable future. [redacted]

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Radiological Consequences

The Human Toll From Exposure

According to a report compiled by the US Nuclear Regulatory Commission, the release of radiation from the Chernobyl' explosion and fire may cause about 10,000 more cancer deaths than would otherwise occur in the European USSR over 70 years.⁴ This number is about one-tenth of 1 percent of the Soviet prediction for normal occurrence of fatal cancers during the period. Individual risks may, of course, be higher—especially for some residents of the area spanning the headwaters of the Pripyat' River in the northern Ukraine and southern Belorussia west of Chernobyl'. The occurrence of some 4,000 more cancer deaths over 70 years in affected portions of Eastern and Western Europe would be completely masked by the 70 million or so cancer deaths predicted in that population over that time (it would be an increase of less than one-hundredth of 1 percent).

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At the Accident. So far, official reports of the accident list 31 fatalities, 29 of which were attributed to acute radiation sickness.⁵ The condition of the victims—as was the case with the survivors—was complicated by trauma from burns suffered fighting the reactor fire. Radiation exposure suppresses the production of blood cells that fight infection; it also suppresses the body's immune-response system. In conjunction with severe burns (in which the integrity of the skin as a natural barrier against external infection is lost), radiation

⁴ Estimating the number of fatal cancers that may result from radiation released by the Chernobyl' explosion and fire is necessarily speculative. Studies of the consequences for human health must rely to a large extent on parameters (such as rates of radiation exposure to the population and the effects of low radiation doses on health) for which the appropriate values are uncertain [redacted]

⁵ One additional fatality has been reported by the Soviet newspaper *Nedelya*—Soviet filmmaker Vladimir Shevchenko. His death in March 1987 was attributed to radiation exposure received while filming a documentary on the Chernobyl' accident. [redacted]

exposure causes a much more serious course for the victim, and the risk of death by infection is high. [redacted]

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Dr. Robert Gale, who performed 13 bone marrow transplants on the most serious cases in this group, told the American Association for the Advancement of Science on 15 February 1987 that 500 people had been hospitalized with acute radiation sickness and that 461 had been released. The Soviets reported on 24 April 1987 a total of 237 casualties from acute radiation syndrome in four radiation injury classes. The nature of these exposures was diagnosed and treatment provided according to clinically derived dose estimates. [redacted]

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The Soviets used at least two separate methods to determine individual dose. First, they used cytogenetic dosimetry, a technique in which the body's own chromosomes are used as biological dosimeters. However, this is a labor-intensive process. According to Dr. Gale, a second common method was used because of the large number of casualties; it was more timely, and its prediction tracked well with the clinical course of the patients. This method used a computer model to track and predict the rate of decline of certain key blood components. Western studies have shown that the rate of this decline correlates well with actual radiation dose. The Soviets treated the patients by administering antibiotics to fight infection and platelets to promote blood clotting. [redacted]

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Over the long term, the survivors will incur a substantial increase in their individual risk of cancer (on the order of 5 to 20 percent). To some extent, the consequences of this may be partially offset by the sharply increased level of medical surveillance these persons will receive. Some of the survivors of high radiation doses (about 300 to 400 rem) are likely to experience a more immediate effect—sterility for up to several years. The Soviets reported that several of the survivors received doses in this range. (Doses of approximately 500 or more rem reportedly cause permanent sterility.) [redacted]

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Evacuees, Recovery Workers, and General Population. The 135,000 evacuees from the region around the Chernobyl' nuclear power plant are at high risk from radiation exposure (see inset). Having been exposed to an average dose of about 12 rem, according to Soviet calculations, these individuals are subject to an increase in the statistical probability of cancer of less than 2 percent. For the group as a whole, the risk for cancer has risen to 12.7 percent from a natural incidence of 12.5 percent.⁶

The Soviets almost certainly are understating the effects of radiation on recovery workers. They announced that the recovery workers were being exposed to 25 rem. According to international standards, the 25-rem guideline is correct for accidents of this kind—in an emergency situation. But the number of persons is to be kept small, volunteers are recommended, and they should not be in their primary years of procreation. Contrary to this intent, the Soviets have applied the guideline in the recovery operation to relatively young workers and to very large numbers of people. We believe that many of the Soviet troops used in the recovery operations probably received 25 rem (roughly double the average dose to the individual evacuees). The risk of cancer is, therefore, proportionately higher for these recovery workers than for the evacuees. []

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Diplomatic sources, foreign visitors, and Soviet media report that many citizens continue to believe that radioactivity released during the accident will present a serious threat to life and the environment for many years to come. The psychological consequences may extend to many who have no identifiable health effects from radiation. Because of continuing rumors about Chernobyl', citizens as far away as Leningrad worried during the winter of 1986-87 about an increase in diphtheria and other diseases due to lowered resistance, which they are attributing to radiation.

⁶ The risk values on which these estimates are based are derived from the epidemiological data on persons exposed to radiation from the atom bombs at Hiroshima and Nagasaki. Inadequacies exist in these data. In particular, for radiation doses below about 10 rem, any excess risk of cancer is too small to be detected directly in the exposed populations—therefore, at lower doses, risk estimates represent extrapolations from theoretical models. []

Letters in the press indicated that some women were electing to have an abortion rather than risk an abnormal child. Responding to continued popular anxiety, the Ukrainian party newspaper announced the formation of special information centers to answer questions on radiation throughout the affected regions. The creation of such centers eight months after the accident indicates regime recognition that public trust had eroded. []

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Providing Care. A new All-Union Radiation Medical Center has been established in Kiev under the direction of Anatoliy Romanenko, the Ukrainian Health Minister. According to Romanenko, the center has established an all-union registry to monitor the radiation effects and cancer development in the population exposed to radiation. But it is not clear whether the medical center is receiving enough resources to do its job. []

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The resources diverted to Chernobyl'-related medical problems are likely to further strain the Soviet health-care delivery system, which has proved inadequate to deal with many medical problems associated with contemporary industrial society and has been the object of recent criticism from the top leadership. One of the shortages exposed was an acute lack of radiation-detection equipment for medical use, and the Soviets have been buying Western equipment to fill the gap. []

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Contamination of Water Supply

The Chernobyl' power plant is located roughly 25 kilometers north of the Kiev reservoir, which supplies the bulk of the drinking water for the Ukraine's capital. Some radioactive particles were undoubtedly carried to the reservoir by winds and by the two major rivers feeding it from the north—the Pripyat' and the Dnepr. Soviet officials took prompt measures to contain any contaminated runoff or ground-water seepage from the Chernobyl' plant and have continued to monitor the Kiev reservoir and the rivers. They report that levels of radioactivity are below established norms. As a preventive measure, however, Kiev was provided with a reserve water-supply system that draws from the Desna River (which flows from the

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Evacuation and Relocation

New homes built for Chernobyl' evacuees, Buda-Koshelevskiy Rayon, northwest of Gomel' [redacted]

Moscow announced the evacuation of 135,000 persons from the regions surrounding the Chernobyl' nuclear power plant: approximately 30,000 from Belorussia's Gomel' Oblast and the remaining 105,000 from the Ukraine. The total number of those who left the area is probably much larger, since many fled on their own from cities such as Kiev, Chernigov, and Gomel'. [redacted]

[redacted] All the children from Kiev, along with 58,000 children evacuated from the northern Ukraine, were dispersed among Young Pioneer camps and summer resorts in other republics. Gomel' Oblast evacuated over 60,000 additional children to summer camps. [redacted]

By the end of the summer of 1986, it was clear that most of the evacuated population would not be returning for the winter, and more permanent

resettlement would be needed. Belorussia resettled 10,000 families in hastily constructed prefabricated houses in the northern rayons of Gomel' Oblast. A few more thousand have recently returned after decontamination of their homes. [redacted]

The Ukrainian government planned to replace about 12,000 abandoned homes in the villages surrounding the Chernobyl' plant by this summer; 8,000 have already been built. Plant personnel have been allocated 14,000 apartments in the Kiev-Chernigov region. More than 27,000 people have been resettled in the 52 new villages built since the accident. About 1,000 plant workers at the recently restarted reactor units 1 and 2 live in Zelenyy Mys, a partially completed settlement about 40 km from Chernobyl' originally planned to house 10,000 station workers. It has since been downgraded to house only 5,000 workers. [redacted]

To date, most of the Pripyat' evacuees have not been permitted to return to their former homes. Radiation levels in the city are apparently still considered too high for permanent habitation, but the city's administrative buildings are currently being occupied. Yevgeniy Velikhov, vice president of the USSR Academy of Sciences, told a US Senate committee in January 1987 that 120,000 evacuees had settled elsewhere, along with their possessions and livestock. [redacted]

northeast) and from a number of artesian wells. In October 1986, a US radiation team visiting Kiev was told that, even though water from the Dnepr was safe, it was not being supplied to Kiev for "morale reasons." [redacted]

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The Potential Risks of Cancer in Eastern Europe

One of the most uncertain of the long-term costs of the Chernobyl' accident is the additional risk of

cancer in Eastern Europe as a result of radioactive releases. Estimates of the effects on health of small increases in radiation from background levels are highly sensitive to assumptions relating to a wide range of factors. Moreover, among nonspecialists, these effects are poorly understood. The highest radiation doses in Eastern Europe probably occurred in

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northeastern Poland and northeastern Romania. Although the increased risk of cancer in the region is very slight, uncertainties about the cause of future cancer cases will breed rumors implicating Soviet handling of the accident. [redacted]

[redacted] Polish physicians already are attributing increased numbers of liver and intestinal diseases around Warsaw to the Chernobyl' fallout, we believe that the cited increase in health problems more probably is related to anxiety about the consequences of the Chernobyl' accident than to radiation effects. (Radiation in small doses is unlikely to affect the liver.) Moreover, local regimes' attempts to counter rumors of continued radiation hazard by issuing ill-conceived rebuttals can fuel popular fears, as occurred in Bulgaria in the spring of 1987. Lingering health concerns are unlikely to foster more open protests, but they will deepen still further East European resentment of the USSR. [redacted]

Economic and Social Consequences in the USSR

The cost of cleaning up after the accident and the loss in electricity production probably will result in some diversion of resources away from General Secretary Mikhail Gorbachev's economic modernization effort and will make it harder for the regime to deliver on its promises of better health care, more housing, and safer work conditions. Moscow announced in December that 800 million rubles had been set aside for direct compensation in housing and short-term subsidies for the Chernobyl' victims. The rest of the cleanup operation—entombing the damaged fourth reactor, decontaminating the remaining reactors and the plant environment, and protecting the water and soil from contamination—was initially projected by Moscow to cost 2 billion rubles, but [redacted]

[redacted] this estimate was too conservative. A Soviet engineer [redacted] estimated the cost of cleanup would eventually total 25 billion rubles. Some of the expenses have been offset by the Chernobyl' Aid Fund, which collected over 500 million rubles through the "voluntary" contribution of one day's wages by every Soviet worker [redacted]

Impact on Energy Production

The energy program of the USSR, and to some extent the energy programs of its partners in the Council for Mutual Economic Assistance (CEMA), will bear a variety of short-term and long-term costs related to the Chernobyl' accident. These costs will be associated with reduced electricity generation, reactor write-offs, and nuclear-plant safety modifications. [redacted]

The loss of electricity generated by the Chernobyl' reactors and the consequent increase in fossil-fuel use by replacement power-plant capacity are key short-term consequences. Eastern Europe probably was forced to bear some of the burden of the 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. For the 1986-90 period, the cumulative reduction in electricity production resulting from damage to the Chernobyl' plant and related slowdowns at other nuclear power plants will be about 100 billion kilowatt hours. This amount is equivalent to roughly 10 percent of the nuclear-generated electricity production, or 1 percent of the total electricity production, projected for the period. Longer term consequences for the Soviet civilian nuclear industry include investment writeoffs at Chernobyl' and the costs of modifications to improve the safety of other Chernobyl'-type reactors. These capital costs roughly total the equivalent of two or three years' investment in the industry.⁷

Impact on Nuclear Power Industry Goals

The primary effects of the Chernobyl' accident on the Soviet nuclear power program through 1990 will be a somewhat slower growth of generating capacity and electricity production. Before the accident we projected that by 1990 nuclear power capacity would increase to about 50,000 megawatts (MW) and electricity production to about 285 billion kilowatt-hours (kWh) per year. This outcome—though short of Soviet goals—would have been consistent with the industry's [redacted]

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past performance. Now we estimate that the capacity will rise to 48,000 MW and electricity production will reach only 260 billion kWh by 1990. We expect that the direct effects of the Chernobyl' accident and the turmoil caused by the recovery effort will postpone the completion of three or four reactors until after 1990. Although Chernobyl'-induced bottlenecks are likely to have some effect on other power plant construction, the additional delays to most projects will probably not be serious. [REDACTED]

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We believe that the Soviets will be largely successful in limiting the impact of Chernobyl' on their long-term plans for nuclear power. Beyond 1990, modification of some portions of the program is likely. Increased concern with safety will probably not cause significant delays in the construction of the VVER-1000 pressurized-water reactors that are to become the mainstay of the nuclear power program. The greatest potential for change lies in plans for the use of nuclear energy in centralized heat supply for cities. If new safety concerns force postponement or even curtailment of nuclear heating plant construction, the cumulative impact of these changes would require the addition of heating facilities burning gas or coal—a setback to Soviet hopes to reduce use of fossil fuels.

The farm sector of the region was seriously disrupted. The evacuation meant abandonment of a number of farms and thus of the private plots of farm employees—a major source of potatoes and other vegetables for the local market. It also meant moving large numbers of livestock, with the consequent stress-related reduction in productivity. The Soviet press cited a Ukrainian official as saying that more than 50,000 cattle, 9,000 hogs, and the animals from private plots—perhaps another 10,000—were removed from contaminated areas. [REDACTED]

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[REDACTED] large numbers of livestock were also removed from Belorussia's Gomel' Oblast. Indeed, contrary to early Soviet reports that some livestock were slaughtered, Moscow radio reported on 29 May 1986 that all cattle from the accident zone were "fully preserved." [REDACTED] large numbers of animals were successfully moved to farms outside the evacuation area and revealed no major slaughter or animal-disposal sites. [REDACTED]

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Impact on Agriculture

The Chernobyl' nuclear plant is not located in a major agricultural area, and the initial plume of radioactivity passed largely over forests and swamps. Moreover, Soviet data show that the 30-km-radius evacuation zone accounts for only a minuscule share of Ukrainian agricultural output. Levels of contamination sufficient to affect the growth of crops or to raise their radioactive content to potentially life-threatening levels appear to have been concentrated within the fenced exclusion zone. Visible damage to vegetation has not been evident more than a few kilometers from the site of the accident. [REDACTED]

Despite all the disruption, the local press continued to report during the months after the accident that plans for the production and sale of all livestock products were being achieved and even overfulfilled in the Chernobyl' rayon and in neighboring rayons. In addition, supplies of food generally were maintained at accustomed levels for the evacuees as well as throughout the Ukraine, Belorussia, and the Baltic republics. The authorities quickly set up monitoring systems to prevent contaminated food from entering trade channels, but there was some uncontrolled use of milk from privately owned cows that may have contained

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radioactive iodine. Similarly, the French Embassy reported that some contaminated meat reached the market in Moscow, but that the degree of contamination was not harmful.

The USSR's official report on the accident noted that irradiation levels outside the 30-km zone around the nuclear plant cannot dramatically affect the composition of plant and animal communities. The same report outlined the extent and degree of radioactive contamination, and it became clear that the affected area was highly irregular in shape, as had been expected. Soviet press reports had noted that the area contaminated was largely restricted to about 1,000 square km and a few outlying pockets. This tallies

fairly closely with the area outlined in the official report as encompassing radiation levels of 5 millirems per hour as of late May 1986—a boundary that has been followed closely by the fence subsequently constructed to keep people and animals from straying into potentially dangerous areas.

Outside the evacuated area, field work on farms and private plots continued as usual. Targets for spring plantings reportedly were met throughout the Ukraine and Belorussia. Apparently the small area of land taken out of crop production was easily replaced by expanding cultivated areas on farms in other parts of both republics.

By late May 1986 some evacuees had returned to their homes, and, in June, [redacted] farmwork under way within the 30-km zone but outside the fence enclosing the area of heavy contamination. Aided by favorable rainfall through most of the summer and fall, the Ukraine and Belorussia harvested near-record or record quantities of vegetables, potatoes, and grain. Production of meat, milk, and eggs reached new highs in both republics. [redacted]

The 1986 performance of the agricultural sector in both the Ukraine and Belorussia confirms that the impact of the Chernobyl' accident on agriculture was minimal and, despite the persistence of radioactive contamination, will not be significant in the future. Moreover, the continued Soviet reports that the water in the Kiev reservoir remains safe suggest that earlier fears of heavy contamination downstream in the Dnepr were baseless. [redacted]

In the long run, radiation effects on agricultural production will depend on many variables, including the types and quantities of isotopes dispersed, soil types and quality, topography, and drainage. In addition, some plants do not take up radiation through their roots and thus can be grown in lightly contaminated soils. Careful monitoring and decontamination procedures substantially reduce the danger to field workers. [redacted]

In contaminated areas, the presence of longer lived isotopes such as cesium-137 will require continued attention to special agricultural practices and radiation monitoring. At this time, our lack of precise data on the composition of the radioactive fallout and on soil types and differentials in the affected area preclude detailed assessment of future effects on farm output. [redacted]

The potential loss of agricultural production, moreover, will be affected by the extent and nature of active measures taken by the Soviets. Liming, for example, reduces the uptake of cesium-137. Shifting from sensitive crops such as beans and peas to less sensitive ones such as wheat and oats can also help. In late December 1986, authoritative Soviet officials commented that resumption of farm activity over

most of the 30-km zone would be possible. As of mid-June 1987, however, no general farming activity within the fenced area had been reported or observed. [redacted]

Social and Political Fallout in the USSR

The Chernobyl' nuclear accident presented a serious problem for Gorbachev and his efforts to portray the new leadership in Moscow as reasonable and accountable. Moscow's initial failure to report the accident left it open to charges of disregard for human life and eroded public confidence in the regime. The break in Gorbachev's political momentum appears to have been temporary. He rebounded to mount a public relations campaign to limit the damage to his regime's reputation, and his subsequent reform measures have deflected public attention from Chernobyl' to a considerable extent. By demonstrating that suppressing information about domestic problems can backfire, the accident gave added impetus to Gorbachev's drive for openness (*glasnost*) in the Soviet media. Yet Chernobyl' awakened public interest in nuclear safety, heightened concern about environmental and health issues, and increased discussion of these issues in the intellectual community. These concerns are not likely to evaporate, and the population will probably be more attentive to future regime performance in these areas. [redacted]

The initial Soviet response to the Chernobyl' nuclear accident was similar to that of the shutdown of the Korean airliner in 1983. In each case an information blackout was imposed until international pressure forced a grudging admission of the event followed by a propaganda counterattack. Gorbachev sought to distance himself from the crisis and remained silent until 14 May, almost three weeks after the accident. The Soviet people and the world at large were only belatedly informed of the disaster on 28 April at the angry insistence of Sweden, which recorded radioactive fallout from Chernobyl' that morning. [redacted]

Once the leadership realized the story was out, Moscow employed several tactics to minimize its responsibility for what happened and to regain credibility at home and abroad. The authorities have:

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- Blamed lower-level officials for mishandling the situation in order to insulate top leaders from criticism.
- Insisted that Chernobyl' was the USSR's first nuclear accident and alleged that reactor safety problems have been more common and serious in the West.
- Depicted the mishap as a failure of a handful of people rather than of the system and highlighted the courage and self-sacrifice of the Soviet people in dealing with it.
- Denounced Western media for making political capital from the accident and used the nuclear mishap to push Soviet arms control proposals.
- Minimized the long-term health risks and exaggerated progress in decontamination and reconstruction operations. []

The initial public relations debacle strengthened Gorbachev's argument for greater media openness in discussing domestic shortcomings. Several articles in *Pravda*, for example, pointed out that a lack of complete information had encouraged harmful rumors. Supporters of Gorbachev's openness policy, like Soviet journalist Fedor Burlatskiy, criticized the domestic media's early silence as costing the regime credibility. The public relations effort that was finally launched bore the imprint of Gorbachev's policy. On several occasions the Soviet media have promptly reported on accidents causing loss of life and publicized punitive measures taken against the officials responsible. []

The heavy play given to the theme of foreign overreaction to the catastrophe had some success in shifting the focus of Soviet public criticism to the West. Many citizens accepted Soviet propaganda that the West was responsible for the panic and hysteria surrounding Chernobyl' and that the accident presented less public danger than the accidents at Three Mile Island in 1978 and at the Union Carbide plant in Bhopal, India. []

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From the outset, the top leadership was able to some extent to avoid becoming the target of public anger by making scapegoats of local authorities. According to Soviet media, 27 Communist Party officials already have been expelled from the party. Six Chernobyl'

nuclear plant officials, including the former plant director and chief engineer, went on trial in July 1987 for safety violations that allegedly caused the accident. []

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Nevertheless, Soviet citizens continue to blame the top officials for initially concealing the accident, and some think the regime's response to the disaster put the lie to Gorbachev's openness policy. Letters from Chernobyl' workers recently published in a Soviet journal have demanded an investigation of city officials in Kiev and Prip'yat' for failing to properly protect the population from the effects of radiation fallout and for delaying the evacuation. []

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Faced with the initial information blackout, some Soviet citizens turned to Western radiobroadcasts, and some relied on connections to party and government officials who had more complete information or on personal contacts with foreigners. Many residents of Kiev and other Soviet citizens especially resented the lack of precautions taken in the affected areas, in part because they learned that neighboring countries such as Poland and Finland were warning their populations and instituting preventive measures against radioactive iodine. []

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Public concern has been fueled from the beginning by Moscow's restrictions on releasing to its citizens hard statistics about the radioactive fallout and the effects of radiation. At a public lecture in Leningrad, for example, citizens asked why radiation levels were kept secret and demanded to know if Chernobyl' would cause an increase of cancer cases among the Soviet population. In the spring of 1987, Soviet reporters complained that the authorities were still tightly controlling information on Chernobyl'. []

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The psychological reaction to the disaster is not limited to those who suffered measurable health effects of radiation. Indications are that a large segment of the Soviet population believes the public is in danger from radiation and will continue to link genetic abnormalities, cancers, and poor health in general to the Chernobyl' accident. Continued popular fear and doubt over Chernobyl' may prove to be an

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ongoing irritant with potential for social tension for decades to come. Whenever attention is focused on the consequences of the accident, there is a resurgence of public anxiety and anger. For example, people worried that the 1987 spring thaw and flooding would raise radiation levels in the Pripjat' and Dnepr River watershed areas. []

Antinuclear sentiment and consciousness of environmental issues are still growing among the Soviet public in the aftermath of Chernobyl'. Local Soviet press accounts indicate that concern about the safety of the nuclear industry is particularly high in areas with Chernobyl'-type reactors, like Kursk, Leningrad, Smolensk, and Ignalina. Soviet scientists have joined writers in a spirited debate over the wisdom of siting nuclear plants near large cities. In April 1987, for example, some 60 members of the Ukrainian Academy of Sciences signed a petition opposing the completion of units 5 and 6 at Chernobyl'. Reportedly, the petition was about to be published by *Literaturnaya gazeta* when Moscow decided to shelve the expansion plans for the nuclear plant, conceivably in response to public opposition. []

Dissatisfaction with the regime's handling of Chernobyl' has also provoked active protest, particularly among natives of the Baltic republics:

- A Communist youth paper reported a work stoppage during the summer of 1986 by about 300 Estonian conscripts who were forcibly sent to help decontaminate the Chernobyl' 30-km zone. []

- In Lithuania, there were active demonstrations in June 1986 against the construction of a reactor similar to the one at Chernobyl'.
- In Latvia and Estonia, where ethnic populations constitute only a bare majority, citizens reportedly protested the resettlement of Ukrainian and Belorussian Chernobyl' refugees because they viewed these Slavic "immigrants" as further evidence of Moscow's desire to dilute Baltic nationalities. []

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In terms of public relations, the regime clearly paid a price for the accident. The leadership has been able to overcome the initial credibility gap to some extent, but not the heightened public apprehension over long-term consequences of radiation on human health, the safety of nuclear power facilities, and the environment. Further, the need to divert state funds into containing the disaster may result in a reassessment of Gorbachev's initiatives for social programs, including better housing and health care, and undermine the regime's ability to deliver on its promises. []

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Consequences for Eastern Europe

Most East European regimes remain committed to nuclear power based on the use of Soviet-designed nuclear plants. Heightened concern about nuclear safety and the environment will, however, delay construction programs, raise costs, and complicate the region's efforts to solve its energy problems.⁸ It has already led most of the countries in the region to turn to the West for nuclear safety technology. []

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Economic Costs Bearable

The immediate economic costs have proved manageable and temporary for the most part. The East Europeans had to destroy some crops and dairy products, and they lost some hard currency earnings. The hard currency losses have not proved substantial, apparently because fears of possible contamination of East European products quickly subsided and the countries were able to reestablish their former market positions. Total costs, including losses in food exports to developing countries and reduced earnings from tourism, may have reached \$300 million. []

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Soviet compensation may have reduced the losses somewhat. [] Hungary was allowed to sell some of its food exports to the USSR for hard currency instead of rubles as partial compensation. Moscow may have extended the same offer to others. Also, Moscow allowed the East European countries as a group to run up a record trade deficit in 1986. []

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The shutdown of the Chernobyl' reactors and other electricity-supply problems strained the intra-CEMA electricity grid, forcing the East Europeans to operate their thermal power stations at a high rate of capacity utilization during the summer and fall of 1986 and to postpone normal maintenance and repair. This heavy reliance on thermal electricity prevented the accumulation of adequate fuel inventories for the winter, and the region's energy buffer was inadequate to meet the demand for power during the region's harshest winter in a decade. Hungary, which is the most dependent of the East European economies on Soviet electricity, used hard currency to import electricity from Austria and Switzerland. []

Political Costs Fleeting

Moscow's handling of the accident strained relations with its East European allies for a time and damaged the regimes' tenuous credibility with their citizens. The USSR's failure to give a timely warning of the release of radioactivity from Chernobyl'—despite a CEMA agreement requiring such notification—reportedly angered senior regime leaders and fanned existing anti-Soviet sentiment in East European populations. The governments were put in the awkward position of having to calm anxious citizens and take protective measures against contamination without embarrassing Moscow and without raising doubts about their commitment to CEMA's ambitious nuclear program. East European anger and demands for compensation may have prompted the unprecedented meeting between Soviet leader Gorbachev and East European party leaders following last summer's regular session of the Warsaw Pact's Political Consultative Committee. []

A year later, the political imbroglio over the accident is largely behind the East European regimes. These regimes have no interest in unduly aggravating Moscow and are now more concerned about the impact of Gorbachev's new policies on them. The incident served as another reminder to cynical populations about the subservience of their governments to the USSR. It also reminded the regimes of their lack of both clout in Moscow and popular support at home. []

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The chief political consequence of the accident is the credibility it gave to the concerns voiced by the small but growing environmental movements in Poland, East Germany, Czechoslovakia, Hungary, and Yugoslavia. Chernobyl' has focused popular and regime attention on environmental problems, demonstrating how pollution problems transcend national boundaries. While these nonviolent movements pose no direct threat to Communist rule in Eastern Europe, they are popular movements outside the party structure that challenge some regime goals such as rapid industrial growth. The governments in most countries are concerned about environmental problems and tolerate limited ecological movements, but monitor them closely to prevent them from adopting anti-regime tactics. []

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The Future of Nuclear Power

We believe that the concerns raised about safety will be the most lasting effect of Chernobyl' on Eastern Europe's nuclear energy programs.⁹ Despite the accident, the regimes remain committed to nuclear power as a means to cope with dwindling reserves of conventional fuels, unreliable Soviet energy deliveries, and increasing air pollution.¹⁰ This was confirmed at a meeting of the CEMA nuclear working group last November, when the region agreed to plans to increase nuclear capacity from 8,000 MW to 50,000 MW by the year 2000 (figure 7). This renewed commitment is significant because East European nuclear construction programs were already lagging from cost overruns and shortages of funds, key materials, and expertise. []

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Nevertheless, the accident embarrassed East European governments by aggravating public anxiety about nuclear energy and calling into question regime plans for more nuclear plants, especially ones using Soviet technology and supplies. []

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⁹ All of the region's 19 Soviet-designed reactors, as well as those under construction, are pressurized-water reactors, as opposed to the graphite-moderated (RBMK) reactors. []

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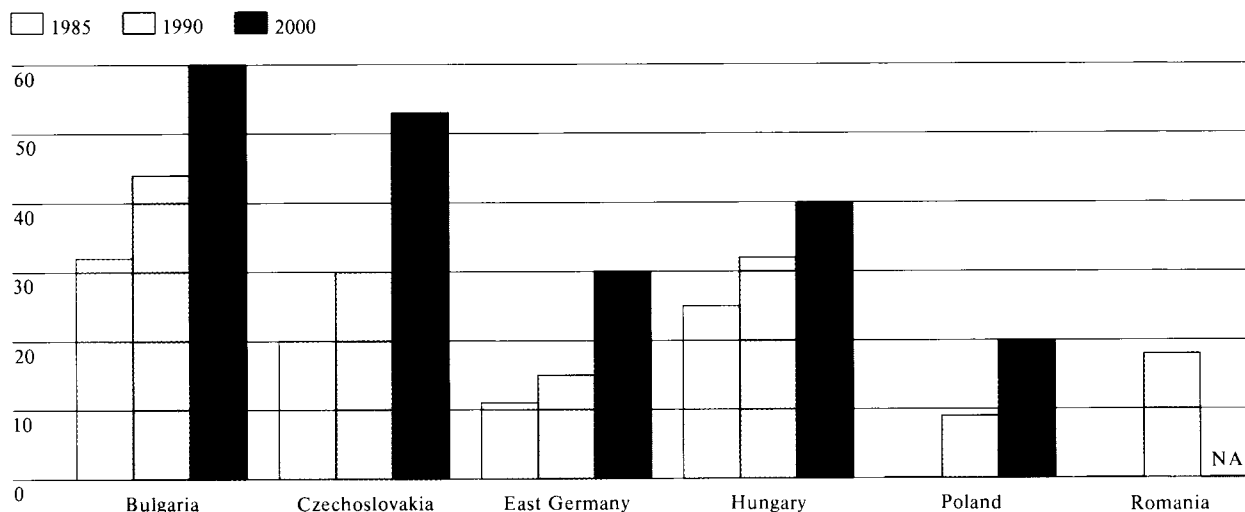
¹⁰ East German leader Erich Honecker is an apparent exception in his qualms about nuclear power. After the accident, he publicly stated that he did not believe that nuclear power "could be the last word." East Germany possesses large reserves of highly polluting lignite coal, but it also plans to triple the share of electricity generated by nuclear power by the year 2000. []

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Figure 7
Share of East European Electricity Output From
Nuclear Power: 1985, 1990^a, 2000^a

Percent



^a These projections by the regimes should be treated with caution. The East Europeans have fallen short of past construction goals, and current building of reactors is beset by delays.

Sources: Press, official statistics.

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To alleviate public concerns, the official media have reiterated the necessity of nuclear power, stressed the safety of reactors, and publicized new measures to ensure reactor safety. In particular, most countries are seeking nuclear safety technology and consulting services from Western—including US—firms, particularly in computer simulation, risk assessment, and monitoring systems. Finally, some future plants probably will be sited in more remote areas and will have cooling systems more reliable than those now in use in the region. (b)(3)

In East Germany, Poland, Czechoslovakia, Hungary, and Bulgaria, belated interest in Western nuclear technology will not lead the regimes to shift procure-

ment from Soviet-designed reactors to Western ones. The regimes cannot afford the large hard currency expenditures and extended program delays such a shift would entail. Energy officials in these countries generally perceive no fundamental flaws in Soviet nuclear engineering. From the perspective of the interested East European countries, acquiring Western safety technology and services can bring Soviet reactors up to acceptable safety standards while keeping construction delays and hard currency costs within tolerable bounds. (b)(3)

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Romania is the only country in the Soviet Bloc that reportedly has reversed its stance on using Soviet reactors because of Chernobyl'. President Ceausescu decided after the accident to postpone indefinitely—or possibly cancel—plans to install three Soviet VVER-1000 reactors at a plant in Romanian Moldavia during the next decade, according to sources of the US Embassy in Bucharest. Romania is now installing five Canadian reactors at Cernavoda. Despite the construction delays and hard currency shortages affecting that project, Bucharest may order additional Canadian reactors—possibly five—for other planned sites. []

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With one US-built reactor, Yugoslavia is the only East European country where the future of nuclear energy has become highly uncertain. A broad-based antinuclear movement spurred by the Chernobyl' accident has forced Belgrade to reconsider plans to build several nuclear plants on which US and other foreign firms were bidding. Although bids on one plant are being reviewed, Belgrade has postponed a decision on nuclear power development until late December 1987 at the earliest, pending a reassessment of the country's energy needs by the federal government. Should Belgrade decide to proceed with its nuclear power program, doubts about Soviet technology may undercut Moscow's efforts to persuade Belgrade to switch from Western to Soviet-designed nuclear plants. []

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Consequences for Western Europe

One year after the Chernobyl' accident, West European fears about its short-term environmental and political consequences have eased. Despite some highly visible opposition, West European governments remain committed to continued use of nuclear energy—in no small measure because of a desire to reduce dependence on imported energy. Nuclear energy already accounts for one-third of the electricity consumption within the European Community, making possible yearly savings of fossil fuels equivalent to 100 million tons of crude oil and reductions in the air pollution caused by coal-burning power plants. In

many of the countries, reliance on nuclear energy is much greater than that in the United States, as shown below:

	Percent of Electricity Generated By Nuclear Power
France	70.0
Belgium	59.8
Sweden	42.0
Switzerland	34.3
West Germany	30.0
United Kingdom	19.3
United States	16.0
Italy	2.0

[]

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In the first few months following the Chernobyl' accident, concerns centered on protecting public health from the fallout of radioactive material emitted from the destroyed reactor. Food and water supplies were examined for traces of radioactivity, and several hundred million dollars' worth of contaminated food was destroyed. []

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Concerns now center on the long-term health impact of the radiation exposures experienced by the populace and on the safety of nuclear power plants. By focusing attention on the potential dangers of nuclear power plant accidents, Chernobyl' has sharpened the debate on nuclear energy and fueled antinuclear sentiment among various groups. The need for comprehensive safety programs is being stressed, and some Western experts criticize the Soviets' continued use of RBMK reactors and their apparent refusal to place stronger containments around them. []

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Heightened Domestic Political Tension

Chernobyl' has made nuclear power a more salient political issue in many West European countries. Governments have sought to dampen public fears and have looked to the IAEA to be an outlet for public fear and anger over the accident. This approach has had some success: the involvement of the IAEA as a forum for international dialogue and investigation of

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the accident has enabled West European leaders to mollify their publics somewhat. But the prospect is for a long and acrimonious debate. []

France. The Chernobyl' accident did not evoke a particularly strong reaction in France, largely because there is no major opposition to the French nuclear program. The French committed themselves to nuclear energy in 1980 and already generate 70 percent of their electricity from it. This share is projected to increase to 80 percent by 1990. Seventeen plants are under construction. The government's success can be explained by its ability to exploit French nationalism in support of a program to ensure France's energy independence. In addition, the nuclear program is not at the mercy of local legislative bodies as it is in West Germany. Nonetheless, Chernobyl' has cut into public support for nuclear power; those in favor of nuclear power have decreased from two-thirds to one-half. This still represents decidedly more support for nuclear power than in the rest of Western Europe, where polls show roughly one-third of the people in favor of nuclear power and a slightly larger number against. []

West Germany. The environment has been a major concern of voters for several years. The Chernobyl' accident refocused public attention on the environmental dangers of nuclear power, making powerful new enemies for West Germany's nuclear program and forcing the government to react. Within two months of the accident, Chancellor Helmut Kohl created the Environment Ministry, largely to counter the charge that Christian Democrats—because of their alliance with big business—were less concerned about the environment than the other parties. Kohl also took the lead in proposing an international conference on nuclear safety cooperation, which was held under IAEA auspices in September 1986. The opposition Social Democratic Party (SPD) has pledged to abolish atomic energy over the next decade, even though SPD governments in the 1970s were responsible for turning on 17 of West Germany's 20 existing plants. []

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Nuclear power was not a key issue in Chancellor Kohl's electoral victory on 25 January. The victorious coalition almost certainly will seek to put into opera-

tion a fast breeder plant at Kalkar and a commercial reprocessing plant at Wackersdorf, while retaining newly enacted nuclear safety measures. The SPD and Greens will continue to oppose these projects at the state and local levels, where responsibility largely lies for implementing environmental policies and financing new energy facilities. []

Overall, the prospects for expanding the nuclear industry appear dubious. There have been no new contracts for nuclear plants in nearly 10 years, and three-quarters of the population favor abandoning nuclear energy at some time, according to opinion polls. Nonetheless, no nuclear plants were closed as a result of Chernobyl', and construction of five new plants continues. []

United Kingdom. British public reactions to Chernobyl' have been strong—although less dramatic than in West Germany—but the government remains committed to nuclear power. Polls have shown that 75 percent of Britons oppose the construction of new nuclear plants, and the environmental organization Greenpeace has set its sights on the planned new Sizewell reactor 120 km from London. Despite intense opposition to expansion of the Sizewell plant, the government decided in March 1987 to proceed with construction. This first move toward expansion of the United Kingdom's nuclear power capacity since the Chernobyl' accident was hailed by advocates of nuclear power in the United Kingdom and France as an important endorsement of the future of nuclear power in Western Europe. []

The government has been heartened by the February 1987 publication of the results of a four-year planning inquiry. The so-called Layfield Report strongly endorses the safety and economy of the planned reactor. It also warns that any decision to get rid of nuclear reactors in the European Community would lead to a serious energy crisis with rapidly increased dependence on foreign supplies of coal and oil. The Labor Party, however, is pledged to cancel Sizewell and to phase out existing nuclear stations. The future of the nuclear program would be dim if Labor takes power. []

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Italy. Until its fall in the spring of 1987, the ruling coalition government in Italy sustained support for nuclear energy despite the Chernobyl' accident and despite internal divisions. The new government will face opposition on this issue from the new "green" party and other parties on the Italian left. The opponents hold that nuclear power should be phased out. Nuclear power accounts for only 2 percent of Italy's power capacity, and the Italian debate turns primarily on whether this share should be expanded. Since Italy depends on foreign sources for 81 percent of its energy needs, far more than any of its West European industrial rivals, there are compelling reasons for it to proceed with nuclear power, thus ensuring a prolonged and acrimonious debate. []

Elsewhere in Western Europe. In the wake of Chernobyl', the Netherlands has halted expansion of its nuclear program. In Belgium, the construction schedule for new power plants has been postponed because of political party disputes. Finland postponed plans to purchase its fifth reactor from the Soviet Union. In Switzerland, the Soviet accident prompted authorities to halt construction of new nuclear power plants; still, it is difficult for Switzerland to close operational plants because the country's water resources have been fully exploited. The only alternative is increased dependence on foreign energy sources. In Sweden, the government has been able to resist demands from the powerful antinuclear lobby for swifter action and is adhering to the referendum timetable that calls for dismantling all active reactors by the year 2010. The Chernobyl' accident reinforced decisions not to institute nuclear power in Denmark and Greece, and to decommission Austria's only reactor, which, as a result of a 1978 referendum, was never placed in service. []

International Repercussions

The Chernobyl' accident underscored the extent to which the nuclear energy issue transcends national boundaries and requires international cooperation to avoid catastrophes or to deal with their consequences if they occur. Chernobyl' temporarily soured Soviet-West European relations but has had little lasting impact. Moscow's initial failure to acknowledge the nuclear accident raised suspicions about the veracity and thoroughness of subsequent Soviet disclosures. Nonetheless, Moscow was able to defuse the potentially damaging impact of these suspicions through its continued public disclosures of accident details as well as its cooperation with the IAEA. []

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Within Western Europe, the new transnational perspective has already been manifested on borders between Denmark and Sweden; France, West Germany, and Luxembourg; and West Germany and Austria, as demonstrators have protested plans to build, turn on, or operate nuclear power plants in neighboring countries. As Chernobyl' demonstrated, tensions and suspicions over nuclear accidents can be further exacerbated when the states involved span the East-West divide in Europe. Chernobyl' has convinced many West and East Europeans that they are part of an entity having many shared concerns. In the end, it may have the effect of helping to increase West European receptivity to proposals for East-West cooperation on a variety of issues unrelated to nuclear power. []

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