CHAPTER 4

The Soviet Nuclear Power Industry

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The Soviet Nuclear Power Industry

Soviet planners see nuclear energy as an increasingly important source of electricity. Current plans call for nuclear power to generate most of the incremental electricity provided to the European U.S.S.R. in this decade. The Soviet nuclear program has logged impressive gains. The portion of electricity supplied by nuclear power rose from 0.5 percent in 1970 to more than 5 percent in 1980; and production increased more than twentyfold, from 3.5 billion kilowatt hours (kWh) to as much as 73 billion kWh, over the same period.[1] Moreover, the current Five Year Plan (FYP) calls for nuclear's share of electricity production to more than double to 14 percent by 1985 and estimates for the year 2000 have ranged as high as 33 percent.[2] The ease with which the U.S.S.R. is able to adjust to its problems in the coal and oil industries will depend in part on its ability to fulfill—or at least approach—these targets.

This chapter summarizes Soviet policy toward nuclear power, describes the present state of the Soviet nuclear power industry, and evaluates Soviet planners' goals for the contribution of nuclear-generated electricity to the energy balance in 1985 and 1990. It also examines the past and potential contribution of Western equipment and technology to that industry.

[1] '}!~(jrt{)n2ic'h{~.sh{l>u *gazeta*, No. 12, 1981, p. 1, gives a figure of 73 billion kWh. Earlier estimates were 70.5 billion kWh.

[2] W. Lepkowski, "U. .S.S.R. Reaches Takeoff in Nuclear Power-, *Chemical and Engineering News*, Nov. 6, 1978, pp. 31-36.

SOVIET POLICY CONSIDERATIONS

The Soviet Union has generated electricity from nuclear power since 1954, when its first nuclear power station (NPS) came online at Obninsk, near Moscow. The Soviets are proud of the fact that the U.S.S.R. was the first country in the world to produce commercial nuclear-powered electricity. At the same time, development of the nuclear industry was slow, and Soviet-installed nuclear capacity at the end of 1980 was about one-fourth that of the United States in the beginning of that year–13,460 megawatts (MW) as opposed to 52,300 MW.[3] The two industries have also experienced different patterns of growth. While nuclear capacity in the United States expanded rapidly in the 1960's and early 1970's, the pace of the Soviet industry did not begin to accelerate until middecade, just the time, in fact, that the program in the United States was beginning to slow.

There are several factors that have contributed to the Soviet Union's policy to expand its nuclear industry. Its growth is related to the recognition that fossil fuel resources have become increasingly difficult and expensive to exploit. As the oil, coal, and gas of the European U.S.S.R. have been depleted, production has shifted northward and eastward to Siberia, causing both extraction costs and the cost of transporting energy to the consumer to rise greatly. Nuclear power has therefore become an economically viable option, particularly since power stations are largely located in the more densely populated European part of the country.

[3] Eric Morgenthaler, " I+; astern Energy: Soviet Bloc is Pushing Nuclear Powerplants Even as U. S. Pulls Back, " *Wall Street Journal*, Jan. 4, 1980, pp. 1, 4, op. cit.

Soviet nuclear policy is also marked by relatively little anxiety over safety and environmental issues compared to the West. Soviet ideology has characteristically reflected a boundless faith in technology and the beneficial effects of technological developments on the welfare of mankind. Accidents such as the one that occurred at Three Mile Island are attributed by the Soviet press to the irresponsible behavior of profit-seeking private firms, rather than to any dangers inherent in nuclear power. The press assumes that in the U.S.S.R.—where private enterprise does not officially exist, and production is carried out by planners armed with what are considered rational, scientific methods—the welfare of the citizenry and of the environment will be carefully considered.[4] The official Soviet position is that concerns over the safety of nuclear power are founded on ignorance. This point is illustrated in a 1971 statement of A. M. Petrosyants, Chairman of the State Committee on the Utilization of Atomic Energy:

> It can be stated that nuclear power stations are no more dangerous than any other industrial type plant, and can be sited in any densely populated area and even within the confines of large cities . . . Widespread publicity on the safety of nuclear power stations, explanations of the facts with demonstrations of how nuclear power stations operate, are indispensable measures in sweeping away the skepticism and lack of confidence observed in some parts of the population in some instances.[5]

Despite recent publicity in the West over alleged large-scale nuclear accidents in the Soviet Union,[6] there is no evidence that this position has changed.

Soviet nuclear policy may also be at least partly driven by a desire to demonstrate conspicuous technological achievement in a large-scale program that the U.S.S.R. itself regards as necessary to its role as a world superpower. A successful nuclear program is seen as a means of enhancing the prestige of the nation and providing visible evidence of the superiority of socialism. The power station at Obninsk, for example, has been hailed as "a triumph of advanced Soviet science and technology. It confirmed with new strength the indisputable advantages and the richest creative potentialities of the socialist society."[7] This is not so much a reflection of any Soviet world lead in terms of installed nuclear capacity—in 1980, the U.S.S.R. lagged behind the United States, Japan, and France in this respect–as much as an affirmation of the fact that Soviet advances in this area have proceeded with little direct technical help from the West. This technical independence is underscored by the fact that the Soviet Union has had recent successes exporting its nuclear reactors (e.g., to Finland); that breeder technology is more advanced in the U.S.S.R. than in the West (with the possible exception of France); and that Western scientists are quite impressed with Soviet fusion research.

Factors such as these have contributed to the rapid growth of the nuclear sector in the U.S.S.R. and to the formulation of ambitious plans for the next decade. The following sections describe the present state of the atomic power industry and discuss and evaluate these targets.

[4] Gloria Duffy, *Soviet Nuclear Energy: Domestic and International Policies* (Santa Monica, Calif.: Rand Corp., December 1979), p. 38.

[5] A. M. Petrosyants, "Nuclear Power in the Soviet Union," *Soviet Atomic Energy*, No. 3, March 1971, pp. 297-302.

[6] See, for example, John R. Trabalka, L. Dean Eyman, and Stanley I. Auerbach, "Analysis of the 1957-1958 Soviet Nuclear Accident," *Science*, July 1, 1980, pp. 345-353.

[7] Oleg Kazachkovskiy, "Condition and Outlook for Work To Create AES With Fast Neutron Reactors," *Ekonomicheskoye sotrudnichestvo stran-chlenov SEV, No. 2,* 1980, p. 1, in JPRS 76,135, July 30, 1980, pp. 1-8.

PRESENT NUCLEAR POWER CAPACITY AND PRODUCTION IN THE U.S.S.R.

In 1976, the 25th Party Congress adopted the Tenth FYP (1976-80), which called for the production of 1,340 billion to 1,380 billion kWh of electricity in 1980. Of this, 80 billion (about 5.8 percent) was to be provided by nuclear power stations.[8] Although production failed to meet this ambitious target, Soviet accomplishments in the area of nuclear electrification over the plan period were impressive.

1980 CAPACITY AND PRODUCTION

As table 28 demonstrates, Soviet nuclear powerplants produced 73 billion kWh (or 70.5 billion kWh, depending on which Soviet source is used) in 1980, nearly 3 % times as much as in 1975 and over 25 percent more than in 1979. Installed capacity at the end of 1980 reached 13,460 MW, having nearly doubled in 3 years. Nuclear powerplants accounted for 5.6 (or 5.4) percent of all electricity produced in 1980 and 5.1 percent of installed electrical capacity as of December 31, 1980.[9] On a Btu basis, it is estimated that nuclear energy accounted for a little over 1 percent of Soviet primary energy output in 1980.[10]

This energy is currently being produced from at least 29 online reactors that are distributed among 13 sites. These sites are listed in tables 29 and 30, and shown in

[8]E. E. Jack, J. R. Lee, and H. H. Lent, "Outlook for Soviet Energy," in Joint Economic Committee, U.S. Congress, *Soviet Economy in a New Perspective* (Washington, D. C.: U.S. Government Printing Ofice, 1976), p. 466.

[9]Total installed capacity (all sources) as of Jan. 1, 1981, was taken from *Ekonomicheskaya gazeta*, No. 12, March 1981, p. 2. The installed nuclear capacity (13.5 million kW) was then divided by this total (267 million kW) to derive the indicated percentage.

[10]L. Melentyev and A. Makarov, "Future Development of the Fuel-Energy Complex," *Planovoye khozyaystvo*, No. 4, April 1980, pp. 87-94, in JPRS 75,903, June 19, 1980, pp. 13-22.

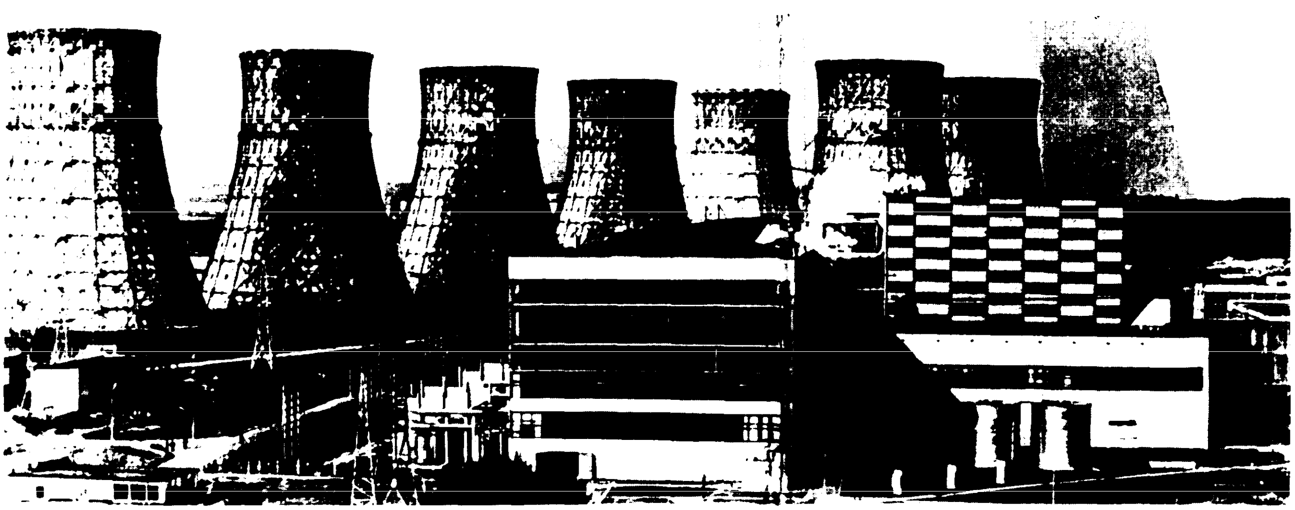


Photo credit TASS from SOVFOTO

The Novovoronezh NPS

Table 28.—Production of Electricity by Soviet Nuclear Power Stations

Year	Production (billion kWh)	Percent of total production	Installed nuclear capacity (end of year, million kW)
1960	Negligible	—	—
1965	1 .4[b]	0.3[g]	**0.3**[c]
1970	3.5[b]	0.5[g]	**0.9**[b]
1975	20 2[b]	1.9[g]	**4.7**[b]
1976	26.4[c]	2.2[g]	**5.7**[c]
1977	34.8[d]	3.0[g]	**7.1**[c]
1978	44.8[d]	3 7[g]	**9.1**[e]
1979	54.8[f]	4.4[h]	**1 1.4**[i]
1980 (plan)	80.0[b]	5.8[b]	**18.4**[b]
1980 (actual) . .	70.5[j] (73.0)[k]	5.4[j] (5.6)[k]	**13.5**

SOURCES [a]E.E. Jack, J R Lee and H H Lent Outlook for Soviet Energy in Joint Economic Committee U S Congress *Soviet Economy in a New Perspective* (Washington DC U S Government Printing Off Ice, 1976) p 462

[b]*Energetika SSSR v 1976-1980 g* A M Nekrasov and M G Pervukhin, (eds) (Moscow Izd Energiya 1977), pp 11 61 and 62

[c]L Dienes and T Shabad *The Soviet Energy System* (Washington D C V H Winston and Sons 1979), p 153

[d]*Ekonomicheskaya gazeta* No 7 (February 1980) P 1

[e]*Elektricheskiye stantsii* (J anuary 1979) pp 2 and 3

[f]*Elektricheskiye stantsii* (April 1980) p 7

[g]Calculated by dividing the figure in column 2 by total elect ricity produced in the given year as reported in the Soviet statistical yearbook *Narodnyoye khozyaystvo SSSR v 1978 g* (Moscow Izd Statistika 1979) p 142

[h]Calculated by dividing the figure in column 2 for 1979 by the total elect ricity produced in that year as reported in *The U S S R in Figures* for 1979 (Moscow Izd Statistika 1980) p 107

[i] The Co/urn bus *Dispatch* (Columbus Oh to) Jan 29, 1980, p A-6

[j]*Elektricheskiye stantsii* (January 1981) p 2

[k]*Ekonomicheskaya gazeta* No 12 (1981) P 1

figure 8. Most Soviet nuclear power stations are located in the European portion of the country, primarily to the west of the Volga River, where electricity demand is concentrated, but there is also some demand for nuclear plants in remote regions (e.g., the Bilibino NPS), apparently because of the high cost of other energy sources.

In both regions, the Soviets are interested in using nuclear energy to provide district heating as well as for generating electricity. The first heating plants may already be in operation, and it is claimed that six atomic heating and cogeneration plants will be built during the Eleventh FYP. Because of Soviet confidence in the safety of nuclear power, there is little written about the environmental implications of locating nuclear power stations in populated areas. In fact, in the case of nuclear district heating (where heat losses are highly sensitive to transmission distances), the plants are actually to be sited within urban areas.

REACTOR TYPES

The Soviets have experimented with a number of types and sizes of reactors, but they are now concentrating on two models that will be standardized to facilitate mass production: large capacity channel reactors and pressurized water reactors. The former are the most commonly used. Called RBMKs (the initials stand for the Russian words for "large capacity channel reactors"), they supply approximately 8,000 MW or 61.6 percent of the total capacity of operational nuclear power stations. RBMKs are boiling water reactors; they are light-water cooled and graphite moderated. The reactor consists of a large pile of graphite with small tubed channels running throughout. Some channels house the fuel rods while others allow for coolant flow.

There are several advantages to the RBMK. Its modular design allows the reactor to be almost entirely assembled on the station site, with only a few components requiring preassembly at the manufacturing plant; it is capable of online refueling; and it provides the capacity to detect a failed fuel element in a given pressure tube during operation. This latter characteristic permits immediate removal and reinstallation of the fuel element without shutdown.[11] The RBMK also uses lightly enriched uranium and produces more plutonium than the other most common model. The U.S.S.R. is now the only country actively engaged in the construction of this type of reactor, the United States having abandoned plans for its commercial development some years ago.

[11]Joseph D. Lafleur and Victor Steno, "NRC Team Visit to U. S. S. R., Feb. 5-18, 1978, " information report No. SECY-78-1113, Mar. 21, 1978, p. 11.

Table 29.—Soviet Nuclear Power Stations in Operation

Station name	Location	Reactor No.	Year of initial operation	Reactor designation)	Hated reactor capacity, MW(e)	Reactor type)
Obninsk	Obninsk	1	1954	—[a]	5	BWR
Siberian	Troitsk[h]	1	1958	—	600[b]	BWR
Dimitrovgrad	Dimitrovgrad	1	1965	VK-50	50[c]	BWR (Vessel)
	(Formerly Melekess)	2	1969	BOR-60	12	Breeder
Beloyarskiy	Zarechnyy	1	1964	AMB-100	100	BWR
		2	1967	AM B-200	200	BWR
		3	1980	BN-600	600	Breeder
Novovoronezhskiy	Novovoronezhskiy	1	1964	VVER-21O	210[d]	PWR
		2	1969	VVER-365	365	PWR
		3	1971	VVER-440	440	PWR
		4	1972	VVER-440	440	PWR
		5	1980	VVER-1000	1,000	PWR
Shevchenko	Shevchenko	1	1973	BN-350	350[e]	Breeder
Kola	Polyarnyye Zori	1	1973	VVER-440	440[f]	PWR
		2	1974	VVER-440	440[f]	PWR
Bilibino[g]	Bilibino	1	1974	EGP-6	12	BWR
		2	1974	EGP-6	12	BWR
		3	1975	EGP-6	12	BWR
		4	1976	EGP-6	12	BWR
Leningrad	Sosnovyy Bor	1	1973	RBMK-1000	1,000	BWR
		2	1975	RBMK-1000	1,000	BWR
		3	1979	RBMK-1000	1,000	BWR
Kursk	Kurchatov	1	1976	RBMK-1000	1,000	BWR
		2	1979	RBMK-1000	1,000	BWR
Armenian	Metsamor	1	1976	VVER-440	405[i]	PWR
		2	1979	VVER-440	410[i]	PWR
Chernobyl	Pripyat	1	1977	RBMK-1000	1,000	BWR
		2	1978	RBMK-1000	1,000	BWR
Rovno	Kuznetsovsk	1	1980	VVER-440	440	PWR

[a] In U S sources this reactor has been designated as the AM-1 (Dienes and Shabad, op cit p 156) and the VAM 1 (Sutton op cit p 243)

[b] The station reportedly has a total capacity of 100 MW in 1958 At present the station is said to have a capacity which significantly exceeds 600 MW' (A M Petrosyants op cit p 123

[c] According to Petrosyants op cit p 171 the VK 50 reactor was upgraded to 65 MW(e) in 1974

[d] This capacity reportedly was raised to 240 MW in February 1965 and briefly to 280 MW in January 1969

[e] If the Schevchenko reactor were used exclusively to produce electricity its capacity would be 350 MW(e) In fact, only 150 MW(e) of capacity are devoted to generation of electricity while the balance is used to produce 120000 metric tons of desalinated sea water per day

[f] These two reactors of the station s first phase reportedly have been operating at capacities as high as 470 MW each (940 MW total) since December 1978

[g] This station generates commercial heat as well as electricity

[h] According to Dienes and Shabad op cit p 153 this location is given in U S lists of foreign reactors Soviet sources have not identified the Siberian station's location

[i] It is not clear why these two reactors are rated at lower capacities than other VVER 440's, one source [*Atomnaya energiya* (May 1977) p 419] relates the lower capacities to cooling conditions of the reactors

[j] PWR = pressurized water reactor (vessel type) which is designated VVER in Russian, BWR = boiling water reactor one Series of Which IS designated RBMK in Russian in the West the RBMK often is described as a light water-cooled graphite moderated reactor (LGR or LWGR)

SOURCES A M Petrosyants *Sovremennyye problemy atomnoy nauki i tekhniki v SSSR* (Moscow Atomizdat 1976) pp 1181921 *Sovetskaya atomnaya nauka i tekhnika* (Moscow Atomizdat 1967) pp 91-110 *Izvestiya akademii nauk SSSR energetika i transport No* 5 (1977), pp 13-31 *Elektrifikatsiya SSSR (1967* 1977991 P S Neporozhniy (ed) (Moscow Izd Energiya 1977), p 50 *Elektricheskiye stantsii No 2* (February 1978) pp 8 13 No 2 (February 19801 pp 711, and No 6 (June 1980) pp 28 *Kommunist* (Jan 1 1980) p 1 and Feb 29 1980), p 1 *Atomnaya energiya* (April 1980), pp 220-223 *Stroiteinaya gazeta* (Apr 9 1980) P 1 L Dienes and T Shabad, *The Soviet Energy System* (Washington D C V H Winston & Sons, 1979) pp 153, 156. and 157 A C Sutton *Western Technology and Soviet Economic Development* [Stanford Calif Hoover Institution Press. 1973) p 243 *Trud* (June 1 1980) p 1 *Izvestiya* (Dee 25, 1980) p 1

Table 30.—Estimated Total Operating Electric Generating Capacity of Soviet NPS's as of Dec. 31, 1980[a]

Station	Total capacity, MW(e)
Obninsk.	5
Siberian.	600
Dimitrovgrad	77
Beloyarskiy	900
Novovoronezhskiy	2,485
Shevchenko	150
Kola	940
Bilibino	48
Leningrad	3,000
Kursk	2,000
Armenian	815
Chernobyl	2,000
Rovno	440
Grand total....	13,460

[a]These are not rated capacities, but OTA's best estimates of the actual operating capacities at each station

SOURCE Table 29.

The next most commonly used reactors, pressurized water reactors, supply approximately 4,200 MW or 31 percent of current capacity. They are known as VVERs in the Soviet Union (for the Russian words "water-water power reactors"), and are similar to models available in the West. Light water is used in these reactors as both moderator and coolant. A large, cylindrical, steel pressure vessel houses the fuel and control rods along with other necessary internal apparatus. The high pressures involved dictate that major components, including the reactor vessel, be manufactured and tested before shipment to the station site for final assembly.

REACTOR MANUFACTURE

Thus far, the expansion of Soviet nuclear capacity in 1,000-MW increments has been based almost exclusively on the RBMK-1000 reactor, the components for which can be produced at ordinary manufacturing plants. Pressure vessels for reactors of the VVER series require specialized production facilities.

One enterprise that produces pressure vessels and equipment for reactors of both types is the Izhora Plant Production Association near Leningrad. Izhora began producing main power equipment for NPSS in 1964. In order to manufacture this equipment, it has had to undergo extensive expansion and retooling, and it is now the main supplier of nuclear power reactors. Izhora is producing 1,000-MW VVER reactors to be installed at NPSS under construction in the Southern Ukraine and at Kalinin, and it has begun making an RBMK-1500 unit for the Ignalina NPS.[12] However, this enterprise alone will not be able to produce all the reactors required in the next decade. Some of this burden has been shifted to Czechoslovakia's Skoda Works, which has been assigned the task of producing the smaller VVER-440 pressure-vessel reactors. In the Soviet Union, a major share of the burden is to be assumed by the gigantic new Volgodonsk Heavy Machine Building Plant, better known as "Atommash."[14] As Atommash reaches full capacity (by 1990), more and more reliance will be placed on the VVER-1000.

When Atommash is fully operational, it will produce VVER-1000 pressure-vessel reactors on an assembly-line basis, at the rate of eight reactors per year. Since Atommash is designed to specialize in reactor production, this rate of output, if achieved, undoubtedly will outstrip that of a more conventional (albeit upgraded) manufacturing enterprise like Izhora.

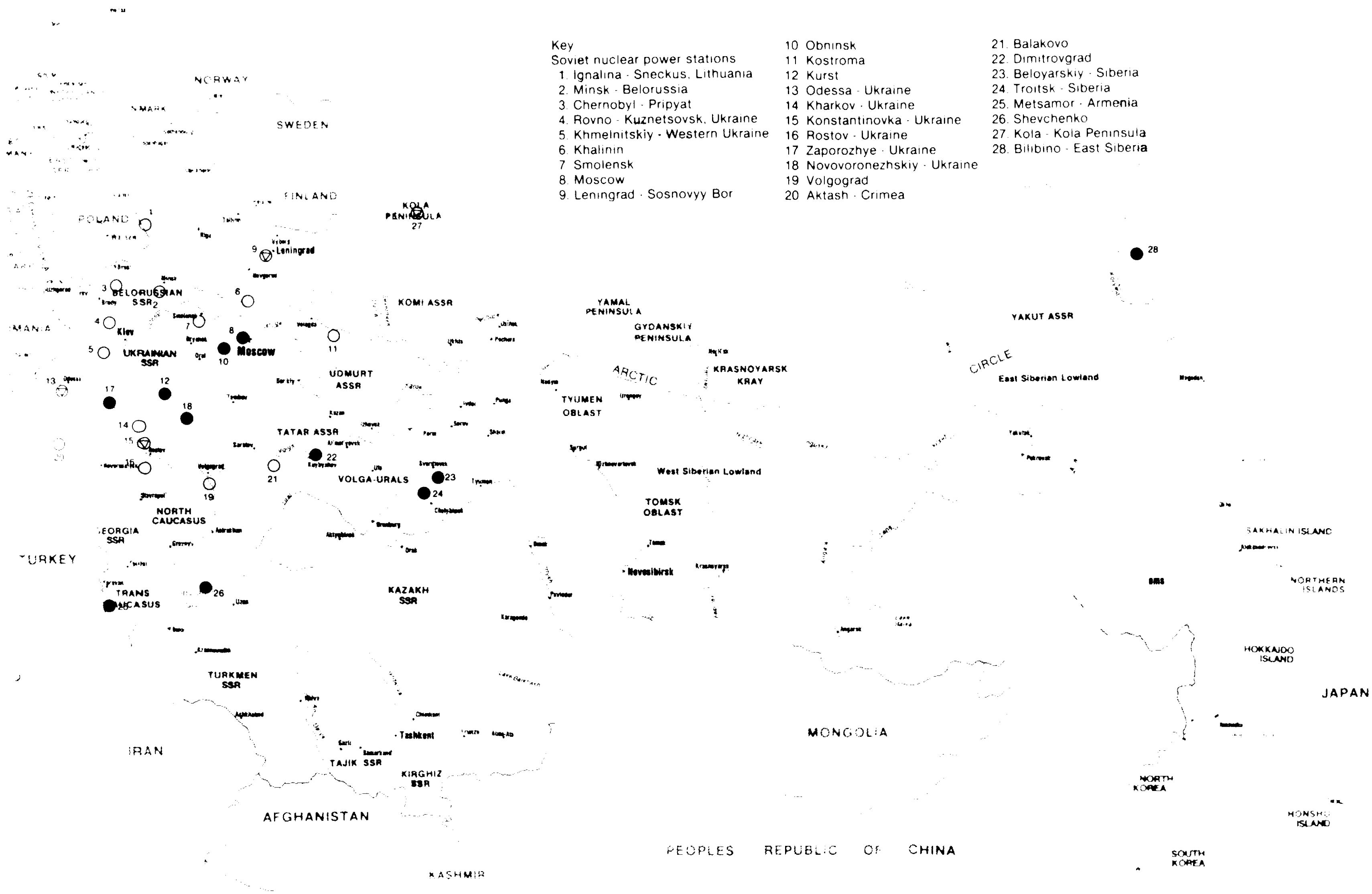
In addition, the Soviets have long been interested in introducing commercial breeder or fast-neutron reactors (designated either

[12]Yu. Sobolev, "The Direction for the Search, " *Sotsialisticheskaya industriya*, Nov. 3, 1979, p. 2 in JPRS 75,069, Feb. 5, 1980, pp. 1-3); "Heroes of Izhora, " *Leningradskaya pravda*, Dec. 19, 1980, p. 2.

[13]Various items of largely Soviet-designed equipment for NPSS are being or will be produced in East European CMEA countries, for use both in these countries and in the Soviet Union. For a description of this "division of labor, " see Vyacheslav Zorichev and Yevgeniy Fadeyev, "The Course for Accelerated Growth of Atomic Power, " *Ekonomicheskoye sotrudnichestvo stran-chlenov SEV, No. 6, 1979*, pp. 51-55.

[14]Because of the growth in size and scope of operations since its inception, this plant has been redesignated as a production association. See Anatoliy Mashin, "First Phase, " *Znamya*, No. 3, March 1979, pp. 190-199, in JPRS 73,863, July 19, 1979, pp. 1-13.

Figure 8.—Soviet Nuclear Reactor



SOURCE Office of Technology Assessment

Existing   Additional capacity, under construction   Under construction

BOR or BN in Soviet terminology) in order to make better use of available nuclear fuel supplies. The major characteristic of this type of reactor is that it "breeds" or produces more fuel than it consumes. Systematic investigation of fast-neutron reactors began in 1948, and the first Soviet reactor of this type was started up at Obninsk in 1956. In 1969 the BOR-60 went into operation in Dimitrovgrad, and in 1973 the first demonstration breeder reactor began operating in Shevchenko on the east coast of the Caspian Sea. This reactor has a generating capacity of 150 MW, as well as the ability to desalinate 120,000 cubic meters of seawater per day. In April 1980, the BN-600, with an electrical generating capacity of 600 MW, went into operation as Unit 3 at the Beloyarskiy station.[15] These three reactors currently account for 5.8 percent of Soviet nuclear generating capacity.

At one time it was expected that large-scale commercial stations equipped with breeders would be ready by the early 1980's. However, recent Soviet literature suggests that this stage will not be reached until the end of the 1990's. Technical difficulties with the use of sodium and other liquid metals as heat-transfer agents are the primary problem (no moderator is used in breeders and the high temperatures involved necessitate the use of liquid metal, usually sodium, as the coolant), but unexpectedly high costs associated with all basic processes in the external fuel cycle have also been cited.[16]

PAST CONTRIBUTION OF WESTERN EQUIPMENT AND TECHNOLOGY

Although the U.S.S.R. collaborates with its East European allies on nuclear development, its progress has been largely autonomous. The Soviet nuclear power industry has relied heavily on domestic equipment, purchasing relatively little from the West. Western controls on the export of nuclear technology have almost certainly been an important reason for this self-sufficiency, although shortages of foreign exchange and pride in Soviet technology would probably have led to some restraint in purchases of Western equipment in any case.

Soviet purchases of primary nuclear components such as reactors and reactor parts from the West have been infrequent and poorly documented.[17] However, the U.S.S.R. has purchased equipment that could be used in nuclear powerplants. Although evidence is incomplete,[18] documented purchases consist mostly of machine tools, heavy equipment, and engineering services slated for Atommash and Izhora. These have been sold by firms in Italy, West Germany, Japan, Sweden, France, and the United States. Italy seems to be the country most heavily involved in such trade; several Italian companies have supplied equipment, mainly machine tools, to Atommash and Izhora.

Besides heavy manufacturing equipment, Atommash and Izhora are said to be receiving well-outfitted quality control laboratories, including large destructive-testing equipment, from European, Japanese, and North American sources. The Soviet nuclear

[15] Kazachkovskiy, op. cit, pp. 3-4: Peter Feuz, "The Nuclear Push in the U.S.S.R. and Eastern Europe," *Power Engineering*, No. 8, Aug. 1978, pp. 100-101; "Late Breeder in the Ural Mountains," *Wirtschaftswoche* (Dusseldorf), No. 18, May 2, 1980, pp. 14-16, in JPRS 75,973, July 2, 1980, pp. 8-16.

[16] N. Dollezhal and Y. Koryakin, "Nuclear Power Engineering in the Soviet Union," *The Bulletin of the Atomic Scientists*, No. 1, January 1980, pp. 33-37, (Originally published in the September 1979 issue of *Kommunist*.)

[17] U.S. Department of Commerce trade statistics report only two entries under SITC Code 7117, "nuclear reactors and parts thereof." one is a 1978 export of $448,700 from the United States; the other $329,000 from West Germany in 1976. No further unclassified information on either sale could be found. OTA has been told, however, that a West German firm was to deliver all fittings and equipment for the nuclear cycle in three Soviet powerplants with a combined generating capacity of 1,880 MW; the delivery was to be completed before the end of 1980.

[18] The remainder of this section is based on various issues of *Soviet Business and Trade* and on *Nucleonics Week*, Nov. 8, 1979, p. 12. In general, Soviet sources make no mention or only passing reference to the use of foreign equipment. For example, one Soviet source noted in passing that metal refining equipment from a Swiss firm is used at the Izhora Plant Association. See V. P. Goloviznin, "Soviet Power Equipment-The Basis for the Development of Power Engineering in Our Country," *Energomashinostroyeniye*, No. 4, April 1980, pp. 2-4 in JPRS I, 9176, July 2, 1980, pp. 11-18, especially p. 14.

industry has also been acquiring valves from at least one Western source, a Canadian firm that has supplied valves for the Novo-voronezhskiy NPS; and the Belgorod Power Machine Building Plant reportedly has introduced technology for automatic argon-arc welding of austenitic steel pipeline units for NPSs. The technology uses AM-11 automatic welding units manufactured by a U.S. firm.[19]

The U.S.S.R. also may be purchasing large capacity cranes, both for building NPSs and for handling heavy items at manufacturing plants. In 1976, there was speculation in the industry that foreign bids would be solicited for 1,200-ton cranes for Atommash, but OTA has been unable to confirm any completed transactions. Similarly, in 1979 the U.S.S.R. reportedly ordered three 300-metric-ton truck-mounted cranes from a West German firm. These cranes are technically well-suited for use at nuclear facilities.

It is important to note that none of these purchases appears in an area in which the Soviets lack technology. Moreover, OTA found no evidence that equipment of the sort described has been sought or purchased in massive amounts or that the Soviets have thus far sought large-scale active Western cooperation in their nuclear industry.

1980 PLAN FULFILLMENT

As table 28 shows, the Soviet nuclear power industry was originally charged with producing 80 billion kWh of electricity during 1980, and completing some 18,000 MW of installed capacity by the end of that year. By early 1980, it was clear that these targets could not be reached and in February of that year a revised production goal of 71.9 billion kWh was published. As of December 31, 1980, installed nuclear capacity was approximately 13,460 MW, a figure that takes into account the start of unit 1 (440 MW) at the Rovno NPS in December 1980.[20] This is well below the plan target of 18,400 MW.

Failure to meet the plan was largely due to delays in the installation of nuclear power stations. These delays were apparently the result of a variety of systemic problems and were more closely associated with the construction industry and suppliers of material and equipment than with technological difficulties. Although one of its production lines has been opened, Atommash is now several years behind schedule. The long lead-times required to install reactors and to make nuclear power stations fully operational make it unreasonable to blame Atommash for past failures to meet goals for installed capacity or production of nuclear electricity. However, problems in bringing Atommash online may become a major factor in any failures to meet nuclear targets in the 1980's.

Soviet literature provides numerous accounts of the difficulties encountered in the building of nuclear power stations,[21] including poor organization of labor, as well as delays on the part of ministry officials, designers, builders, and suppliers of materials, construction modules, and equipment. Similar complaints can be found even in the construction of the BN-600 breeder reactor (unit 3 at the Beloyarskiy NPS)—where the Soviets felt themselves to be in

[19] N. V. Kulin, V. G. Medalye, and I. Ye. Shulman, "The Status and Prospects for the Advancement of Welding Production at Nuclear Machine Building and Boiler Building Enterprises," *Energomashinostroyeniye*, No. 1, January 1981, pp. 28-30. The Belgorod plant is a boiler building plant that is believed to produce auxiliary equipment for NPSs.

[20] ~~t all sources agree with this 13,460-MW figure. A Soviet article, " Results of the Advancement of Electric Power in 1980 and Tasks for 1981," *Elektricheskiye stantsii*, No. 1, January 1981, pp. 2-4, reports the total capacity of Soviet NPSs at the end of 1980 as 12,300 MW. In part. this discrepancy can be explained by lower Soviet figures for [he capacities of the Dimitrovgrad, Kola, and Novovoronezhskiy NPSS, which would account for a difference of 105 MW (see tables 29 and 30). In addition, the Soviet total may exclude the capacity of the Siberian NPS (600 MW). Finally, the Soviet figure may not take into account unit 1 of the new Rovno NPS. For purposes of this report, and on the basis of documented evidence, OTA includes the capacity increments apparently omitted from the reported Soviet figure for total nuclear capacity.

[21] G. Dolzhenko, "Sanctions'! Forget It!" *Stroitelnaya gazeta*, July 16, 1980, p, 2.: Zh. Tkachenko, "Y"ou Cannot Replace Metal With Messages," *Sotsialisticheskaya industriya*, Apr. 2, 1980, p. 2, in JPRS 75,973, July 2, 1980, pp. 17-20.

the international technical spotlight.[22] In this case, the general contractor was several months late in issuing technical documentation; equipment and materials were late or defective; there was a shortage of spare parts; and when equipment did arrive at the construction site, managerial personnel and skilled workers were in such short supply that there frequently were long delays before the equipment was installed or even properly stored.

Such problems are not peculiar to the Soviet nuclear power industry, although they may be exacerbated by the high technological standards required for nuclear equipment. Similar sorts of complaints are published regularly in the Soviet press and cover a variety of industries. To a certain extent, too, these problems may be seen as "growing pains." Installed nuclear capacity rose an average of 1,760 MW per year during the period 1976-80, v. only 760 MW per year in 1971-75. As computed from table 28, the annual rate of addition continued to increase during the late 1970's, rising from 1,000 MW in 1975-76 to 2,300 MW in 1978-79. The Eleventh FYP (1981-85) projects continued rapid growth and it is clear that nuclear power's contribution to the Soviet energy balance will accelerate in the next decade. Nevertheless, it is likely that this rapid buildup in the rate of construction of nuclear power stations has itself created numerous problems for the future and that the difficulties described above will persist as the industry struggles to meet the 1985 and 1990 targets.

[22] "Late Breeder . . . ," op. cit.

NUCLEAR CAPACITY AND PRODUCTION: FUTURE PROSPECTS

TARGETS FOR 1985

Soviet goals for nuclear power are ambitious. The draft of the Eleventh FYP calls for the generation of 1,550 billion to 1,600 billion kWh of electricity from all sources in 1985, of which 220 billion to 225 billion kWh, or about 14 percent, are to be generated at nuclear power stations.[23] In order to achieve these goals, 24,000 to 25,000 MW of additional nuclear generating capacity are to be installed during the FYP. If these installation goals are achieved, the U.S.S.R. will have about 38,000 MW of installed nuclear capacity by the end of 1985.[24] (The United States had 52,300 MW of nuclear capacity as of January 1980.[25])

These targets assume a high utilization rate for nuclear generation facilities. The rate for 1985, calculated as the ratio of planned nuclear electricity production during 1985 to estimated midyear planned capacity in 1985, implies that the Soviets expect to operate nuclear stations for an average of about 6,250 hours per year during 1985. This rate is not impossible, but it is substantially higher than the utilization rate of 5,420 hours achieved in 1980.[26]

TARGETS FOR 1990

Current Soviet goals for 1990 are less explicit. One Western journal cited a 1990 nuclear capacity target of 80,000 MW in one issue, while another issue 6 months later reported a goal of 90,000 MW.[27] In a speech de-

[23] "Draft of the Main Directions of Economic and Social Development of the U.S.S.R. for 1981-1985 and for the Period of 1990," *Izvestiya*, Dec. 2, 1980, pp. 2-7.

[24] This assumes that the Soviet Union had 13,460 MW of effective nuclear power generating capacity, as of Dec. 31, 1980. Addition of 24,000 to 25,000 MW of capacity during the Eleventh FYP would result in total nuclear capacity at the end of 1985 of 37,460 to 38,460 MW. OTA has used the approximate midpoint of this range—38,000 MW.

[25] Morgenthaler, op cit.

[26] Calculated from table 28 using estimated capacity as of July 1, 1980, 13,020 MW.

[27] "Afghanistan Imperils Co-operation on Soviet Programme," *Nuclear Engineering International*, February 1980, p. 5; Richard Knox, "Progress in the U, S, S.R.," *Nuclear Engineering International*, August 1980, p. 14.

livered in December 1978, P. S. Neporozhniy, the Minister of Power and Electrification, spoke of reaching 100,000 MW of nuclear capacity in the following 10 to 12 years,[28] and a West German newspaper has quoted 1990 targets of 100,000 and 110,000 MW, concluding that one "cannot accurately determine from Soviet data what the U.S.S.R. wants to have ready or wants to build by 1980 or 1990."[29]

Soviet goals for 1990 are contingent on the achievements of the industry by 1985. Reported downward revisions in the 1985 goals make it likely that targets for 1990 also have been adjusted and that any existing plans for 100,000 to 110,000 MW have now been abandoned. Barring large-scale infusions of Western equipment (e.g., turnkey NPS projects), a possibility that will be discussed in more detail below, the published goal that OTA regards as being most reasonable is 80,000 MW. The discussions that follow assume this figure, which would require the addition of 42,000 MW of nuclear capacity during the Twelfth FYP (1986-90), given that 38,000 MW of capacity were in place at the end of 1985. If these capacity goals are achieved by 1990, the Soviets would have the ability to generate approximately 410 billion to 475 billion kWh of nuclear electricity per year, depending on one's assumptions regarding utilization rates. 30

SOVIET ABILITY TO MEET PLAN TARGETS

The following sections evaluate the potential for success of these plans, identifying the major obstacles likely to be encountered, and noting the areas in which Western technology and equipment might make the greatest contribution. This evaluation is organized around four key areas:

1. construction of the stations;
2. manufacturing reactors, steam equipment, and electrical machinery;
3. facilities for the external fuel cycle, which include supply of enriched uranium for reactor fuel and the storage and disposal or reprocessing of spent fuel; and
4. computer technology to support station operation. (Electricity transmission lines and pumped storage electricity generating capacity are discussed in ch. 5).

For purposes of this discussion, OTA has assumed a profile of yearly additions to nuclear capacity. This profile is illustrated in figure 9, which also shows the actual annual additions between 1975 and 1980. The latter increased from about 1,000 MW in 1976 to about 2,300 in 1979, falling to 2,040 in 1980. In order to add 24,000 to 25,000 MW by 1985 and 42,000 more by 1990, the Soviets could proceed at any of a number of different paces. The one shown in figure 9—successive increments of 3,000, 4,000, 5,000, 6,000, and 7,000 MW to 1985 and 7,000, 8,000, 8,000, 9,000, and 10,000 MW to 1990—is not the only possible profile, but it is a reasonable one to serve as an illustration of the demands that will be placed on the Soviet nuclear industry to achieve a total of 80,000 MW installed capacity by 1990.

Table 31 presents much of the published information on nuclear power stations that are now under construction or planned. Rated reactor capacities have not been published for all of these, but those that have been released total 41,820 MW (excluding unit 6 at Rovno)—enough to cover the entire capacity addition called for in the Eleventh FYP and roughly 40 percent of the likely addition during the Twelfth FYP.

Several features of these planned additions are noteworthy. First, only three more VVER-440 reactors are scheduled to be built

[28] "Speech of P. S. Neporozhniy," *Izvestiya, Dec. 1,* 1978, p. 4.

[29] "From Lake Baikal to the Elbe River," *Wirtschaftswoche* (Dusseldorf), No. 46, Nov. 12, 1979, pp. 64, 68, 70, 71, 74, and 76, in JPRS 674,792, Dec. 19, 1979, pp. 20-29.

[30] The low end of the range assumes an operating rate of 5,420 hr/yr, the rate achieved in 1980, while the upper assumes the operating rate apparently sought for 1985, 6,250 hours. Mid-1980 capacity is estimated as 75,300 to 76,300 MW.

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Photo credit TASS from SOVFOJO

NPS control room in the U. S. S. R., 1980

for domestic NPSS, two for the Kola NPS and one for Rovno. Production of this type of reactor is to shift to the Skoda Works in Czechoslovakia, and such reactors will be installed in Eastern Europe and exported elsewhere, e.g., to Cuba or non-Communist Third World countries. Second, most announced capacity additions will involve 1,000-MW reactors. Of the 31 reactors of this size that have been scheduled, nine are RBMKs and 22 are VVER units, the latter to be produced primarily by Atommash. Third, there are plans to install four RBMK- 1500 reactors at the Ignalina NPS in Lithuania," and possibly several more at the Smolensk and Kostroma NPSs.[32] Finally, there are plans to eventually build on RBMK-2400,[33] but no details on the installation of such reactors before 1990 have been published.

Construction

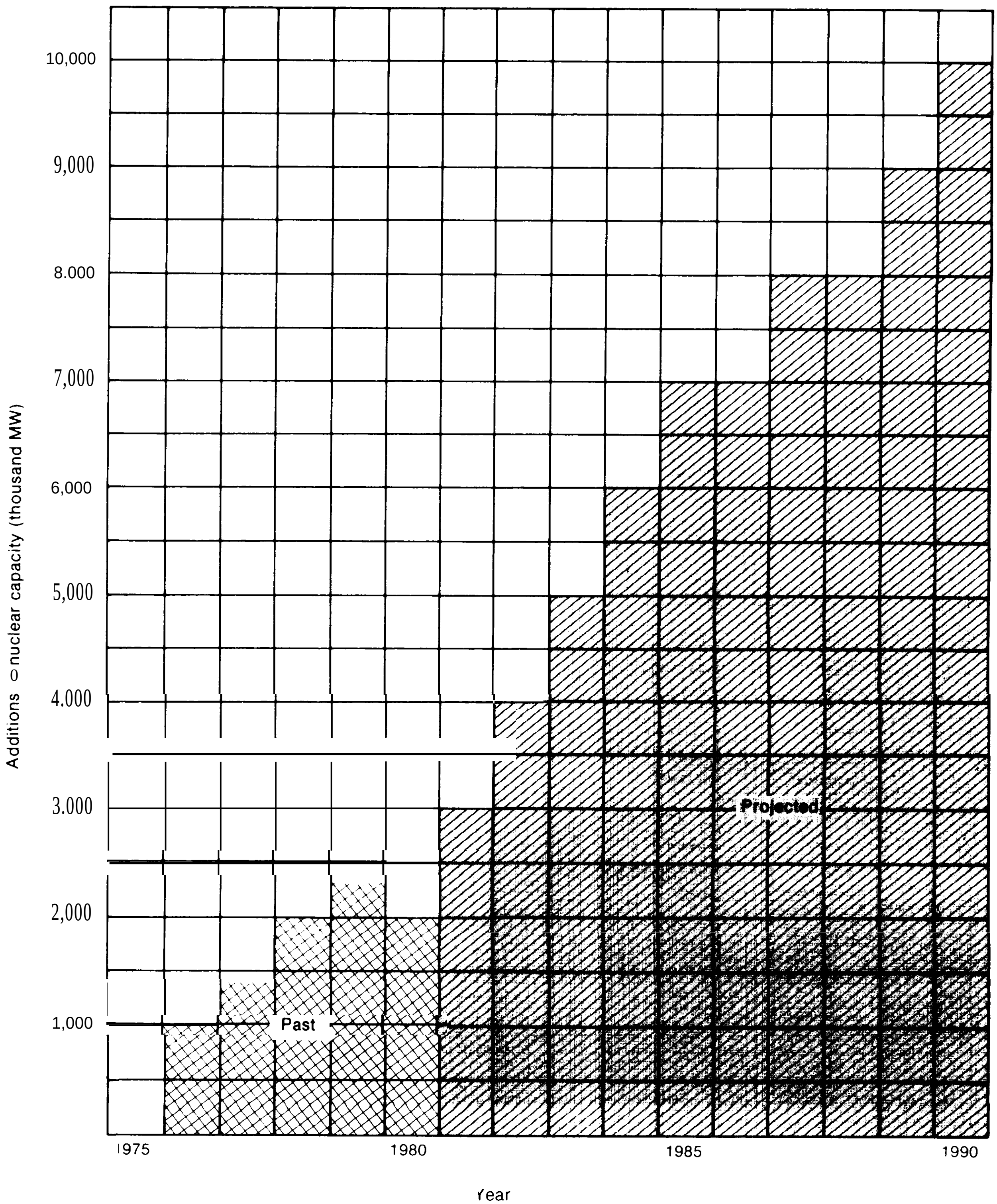
Time.–Plans that call for the addition of 24,000 to 25,000 MW of nuclear capacity by 1985, and an additional 42,000 MW by 1990 can only be realistic if they allow sufficient time for the construction of new plants. The Soviets themselves have maintained that the construction time norms are 6 years for

[31] *Atomic Science and Technology in the U.S.S.R.* (Moscow: Atomizdat, 1977), p. 26. The RBMK-1500 is an upgraded version of the RBMK-1OOO. See A. M. Petrosyants, *Problems of Atomic Science and Technology* (Moscow: Atomizdat, 1979), p. 139.

[32] F. Ovchinnikov, "By Advancing Tempos, " *Sotsialisticheskaya industriya*, Jan. 30, 1981, p. 2.

[33] N. A. Dollezhal, "Atomic Power Engineering: Scientific-Technical Tasks of Development, " *Vestnik akademii nauk SSSR*, No. 7, July 1978, pp. 46-61.

Figure 9.— Past and Projected Additions to Nuclear Generating Capacity



SOURCE: Office of Technology Assessment.

Table 31.— Planned New Nuclear Electric Generating Capacity in the U. S. S. R., Post-1980

Station name	Location	Reactor No	Year of Initial operation	Reactor designation	Rated reactor capacity, MW(e)	Reactor type[e]
Existing Station						
Kola	Polyarnyye Zori	3	1981	VVER-440	440	PWR
		4	1982	VVER-440	440	PWR
Leningrad	Sosnovyy Bor	4	1981	RBMK-1000	1,000	BWR
Kursk	Kurchatov	3	1981	RBMK-1000	1,000	BWR
		4	By 1985	RBMK-1000	1,000	BWR
Chernobyl	Pripyat	3	1981	RBMK-1000	1,000	BWR
		d	By 1985	RBMK-1000	1,000	BWR
New Stations:						
Rovno[a]	Kuznetsovsk	2	1981	VVER-440	440	PWR
		3	1983	VVER-1 000	1,000	PWR
		4	—	VVER-1000	1,000	PWR
		5	—	VVER-1000	1,000	PWR
		6	By 1992	VVER-1000d	1,000	PWR
Southern Ukrainian[a]	Konstantinovka	1	1981	VVER-1000	1,000	PWR
		2	By 1985	VVER-1000	1 000	PWR
		3	—	VVER-1000	1,000	PWR
		4		VVER-1000	1,000	PWR
Kalinin[a]	Udomlya	1	By 1985	VVER-1000	1,000	PWR
		2	By 1985	VVER-1000	1,000	PWR
		3	By 1985	VVER-1000	1,000	PWR
		4	By 1985	VVER-1000	1,000	PWR
Smolensk[a]	Desnogorsk	1	1981	RBMK-1000	1,000	BWR
		2	By 1985	RBMK-1000	1,000	BWR
		3	By 1985	RBMK-1000	1,000	BWR
		4	By 1985	RBMK-1000	1,000	BWR
Ignalina[a]	Snieckus	1	By 1985	RBMK-1500	1,500	BWR
		2	By 1985	RBMK-1500	1,500	BWR
		3		RBMK-1500	1,500	BWR
		4		RBMK-1500	1,500	BWR
Western Ukrainian[a]	Khmeinitskiy	1	By 1985	VVER-1000	1,000	PWR
		2	By 1985	VVER-1000	1,000	PWR
		3	—	VVER-1000	1,000	PWR
		4		VVER-1000	1,000	PWR
Odessa[b]	Near Odessa	1	— c	VVER-1000	1000	PWR
Gorkly[b]	Gorkiy	2		VVER-1000	1,000	PWR
Minsk[b]	Minsk		—	—		
Kharkov[b]	Kharkov	—		—	—	
Volgograd[b]	Volgograd	—	—	—		
Zaporozhye[a]	Energodar	1	—c	VVER-1000	1,000	PWR
		2		VVER-1000	1,000	PWR
		3	—	vVER-1000	1,000	PWR
		4	—	vVER-1000	1,000	PWR
Balakovo[a]	Balakovo		—c	VVER-1000	1,000	PWR
Rostov[a]	Near Volgodonsk		—c	VVER-1000	1,000	PWR
Crimean[a]	Aktash	—	—c	VVER-1000	1,000	PWR
Tatar	Nizhnekamsk	—			—	—
Bashkir	Nertekamsk	—	—			—
Kostroma		—		RBMK-1500	1,500	BWR

[a] **The station reportedly are under construction**

[b] The Odessa station is to be the first of a series of large nuclear heat and power stations (NHPS) located near major urban centers, A small (48.MW) NHPS is in operation at Bilibina. Although virtually any type of reactor theoretically can be adapted to this type of station, preference reportedly is being given to PWR's, but evidence suggests that there will be at least two. Plans for the period 1981-1985 also call for NHPS's to be built in Minsk, Kharkov, and Volgograd, the reactor type for these stations is not known.

[c] Unspecified amounts of capacity are to be Introduced at these stations during the period 1981.1985.

[d] The Rovno NPS is to have six units by 1992, starting with Unit 3, they are to be based on the VVER-1000 reactor

[e] See notes to table 29

SOURCES A M Petrosyants, *Problemy atomnoy nauki i tekhniki* (Moscow: Atomizdat, 1979), p 139 *Atomnaya nauka / tekhnika v SSSR* (Moscow Atomizdat, 1977), p 26 *Atomnaya energiya*, Vol 43, No 5 (November 1977), pp 418.420 *Elektricheskiye stantsii*, No 6 (June 1980), pp 2-5, No 10 (October 1980), pp 10-14; and No 12 (December 1980), pp 60-63. *Teploenergetika*, No 7 (July 1979), pp 2-9; and No. 8 (August 1980), pp 2-5 *Ekonomicheskaya gazeta*, No 1 (January 1981), pp 11 and 12, and No 12 (March 1981), p 2 *Izvestiya* (December 2, 1980), pp 2-7 *Pravda* (Jan 6, 1981), p 1. *Sotsialisticheskaya industriya* (Jan 30, 1981), p 2 *Stroitelnaya gazeta* (July 16, 1980), p. 2 *Soviet* Geography, various Issues.

an NPS equipped with two VVER-1000 reactors and 6 years, 3 months for an NPS with two RBMK-1000 reactors.[34] While only one VVER-1000 has been installed to date, experience with smaller VVER reactors and with the RBMK-1000 suggests that these estimates may be optimistic.

Unit 1 at the Novovoronezhskiy NPS (VVER-210) was begun in 1957, but did not go into operation until 1964.[35] The first phase of the Leningrad NPS (equipped with two RBMK-1,000 units) was under construction for 7 years, as was the first phase of the Chernobyl NPS (also equipped with two RBMK-1000 units).[36] Unit 1 (an RBMK-1000) of the Kursk NPS took 6 years to build and unit 2 (also an RBMK-1000) required 3 years, stretching the total time of phase 1 to 9 years.[37] In the case of the Armenian NPS, where construction began in 1971, unit 1 (VVER-440) achieved criticality in December 1976 and full-power operation in November 1977; however, unit 2 (VVER-440) did not come online until 1979—8 years after construction began.[38] These experiences would suggest that 7 years is a more realistic estimate of the time required to bring the first two units of an NPS online.

According to F. Ya. Ovchinnikov, Deputy Minister of Power and Electrification, in mid-1979 the U.S.S.R. had 20 NPSs with a total rated capacity of over 60,000 MW in operation or under construction.[39] If additions to capacity proceed at the rate suggested in figure 9, the Soviets could have 60,000 MW *installed* capacity before the end of 1988. This allows over 9 years for completion of all of the nuclear power stations reported by Ovchinnikov. On the surface, therefore, the contemplated additions to capacity are consistent with Soviet experience and seem realistic in terms of construction time.

There is an additional dimension, however. Expenditures for construction and assembly work are not spread evenly over the time required to build an NPS. Rather, they begin at a low level, rise steadily until the fourth and fifth years of construction, and then fall off. During construction of an NPS equipped with two VVER-1000 reactors, for example, only 4 percent of total construction and assembly costs is incurred in year 1, but 24 percent of total costs is incurred in year 4 and a similar amount in year 5. In the case of an NPS equipped with two RBMK-1000 reactors, the percentages rise from 7 percent in the first year to 20 percent in year 4 and 20 percent in year 5.[40]

As a result, it may be relatively easy to begin the construction of an NPS, and it may be easy to complete one that is in the late stages of construction, but great effort on the part of the construction industry is required during years 3 to 5. Based on their past experience with the construction of nuclear power stations, it is possible that the Soviets could succeed during the 1980's in beginning the construction of all planned NPSs, and could complete by 1990 those that are nearly finished. But, the U.S.S.R. might still reach the end of the decade with a great deal of unfinished construction because many NPSs were stalled in the demanding third to fifth construction years.

Required Investment.–Although Soviet data on per unit investment cost is notoriously unreliable, OTA has attempted to convey a rough idea of the order of magnitude of investment entailed in Soviet nuclear plants. A number of estimates of the investment cost per kilowatt of nuclear

[34] N. Ya. Turchin, et al., *Building Fuel and Atomic Power Stations* (Moscow: Stroyizdat, 1979), vol. II, p. 505.

[35] Lafleur and Steno, op. cit., app. B, p. 20.

[36] William F. Savage, " Report of the Second Meeting of the U.S.-U.S.S.R. Joint Committee for Cooperation in the Field of Energy" (Washington, 1), (7.: U.S. Department of Energy, Dec. 15, 1977), p. 12; V. P. Akinfiyev, A. D. Gellerman, and V. K. Bronnikov, "Experience in Assimilating the Rated Capacity of the First Phase of the Chernobyl NPS," *Elektricheskiyestantsii*, No. 2, Feb. 1980, pp. 7-11.

[37] S. Troyan, "Labor Watch of the Atom," *Izvestiya*, Feb. 1, 1979, p. 1, in JPRS 73,092, Mar. 28, 1979, pp. 39-41.

[38] U.S. Nuclear Regulatory Commission, op. cit., app. B, p. 26.

[39] F. Ya. Ovchinnikov, "Nuclear Power Engineering Is a Quarter Century Old," *Teploenergetika*, No. 7, July 1979, pp. 2-5, in JPRS I, 8700, Oct. 4, 1979, pp. 1-8.

[40] V. B. Dubrovskiy, et. al., *Building Atomic Electric Power Stations* (Moscow: Izd. "Energiya" 1979), p. 187.

capacity have appeared in Soviet publications and have ranged from as low as 175 rubles/kW to as high as 413 rubles/kW, depending on the date of the estimate, the cost categories encompassed by the estimate, the assumed size of the power station, and the prospective site.[41]

The most authoritative recent estimates of specific capital investment are probably those that appeared in a February 1979 article by A. Troitskiy, a deputy head of the Department of Power and Electrification of Gosplan.[42] Troitskiy's estimate for the "Center," which best typifies the European U. S. S. R., where most plants are likely to be built, is 380 rubles/kW. This figure includes all associated costs—transmission lines, mining uranium, providing housing for construction workers, etc.

Assuming that the Soviet Union does add the 24,000 to 25,000 MW of capacity called for in the Eleventh FYP, and using Troitskiy's figure, the total cost of additions to nuclear capacity during the period 1981-85 should be 9.1 billion to 9.5 billion rubles. The Eleventh FYP target for planned capital investment in the period 1981-85 is 711 billion to 730 billion rubles. Given that industry has usually been accorded about 35 percent of the total, planned industrial investment in the period is probably about 250 billion rubles. The cost of additions to nuclear capacity therefore constitutes about 3.6 to 3.8 percent of industrial investment. However, investment in the electric power industry as a whole has been usually about 4.6 percent of the total. This means that the nuclear program, which will account for 45 to 50 percent of new electric capacity by 1985 (see ch. 5), could take up about 80 percent of all electric power investment.

This is a large burden indeed—and if even greater increases in nuclear capacity are to be realized in the 1986-90 period, the investment problem can only intensify. Nuclear plant construction on this scale will therefore place much greater demands on the Soviet economy in the coming decades. On the one hand, it is hard to argue from these figures that the aggregate investment demands cannot be met, if the U.S.S.R. is prepared to rearrange its priorities and direct a larger share of total investment funds to this sector. On the other hand, such a reallocation is likely to cause painful readjustments in the Soviet economy and "losers" in the system can be expected to resist the change.

Labor Requirements.—Although data on the construction labor requirements in the nuclear power industry are scarce, available information suggests that these requirements are heavy. An idea of their order of magnitude might be gleaned from the following calculation. In nonnuclear power stations, the lowest levels of labor expenditure achieved in construction were 2.4 to 2.7 person-days/kW of installed capacity.[43] If the Soviets were able to add nuclear capacity with a rate of labor expenditure of only 2.5 person-days/kW of capacity, addition of 24,000 to 25,000 MW during the period 1981-85 would require 60 million to 62.5 million person-days of construction and installation work, while the indicated addition of 42,000 MW during the Twelfth FYP would require about 105 million person-days.[44] If the time profile shown in figure 9 were followed, the construction labor embodied in annual commissioning would rise

[41] Turchin, et al., op. cit., vol. 1 I, p. 894; A. Troitskiy, "Electric Power: Problems and Perspectives, " *Planovoye khozyaystvo, No. 2,* February 1979, pp. 18-25. For a thorough discussion of Soviet estimates of nuclear power costs, see William J. Kelly, Hugh L. Shaffer, an J. Kenneth Thompson, "The Economics of Nuclear Power in the Soviet Union, " presented at the 55th Annual Conference of the Western Economic Association, San Diego, June 1980. (Forthcoming in *Soviet Studies.*)

[42] *Troitskiy,* Op. cit., p. 20.

[43] Turchin, et al., op. cit., vol. II, p. 896.

[44] Interestingly, the figure of 2.5 person-days/kW is approximately correct for construction of nuclear power plants in the United States, if U.S. figures are revised to make them more compatible with Soviet practice. See L.M. Voronin (cd.), *Atomnyye elektricheskiye stantsii, No. 2* (Moscow: Izd. "Energiya, " 1979), p. 47. However, the 2.5 person-day figure (derived from Soviet fossil-fired power construction) understates labor requirements for construction of Soviet NPSS, if one can judge from figures on labor requirements *per ton* of equipment. As an example, it is estimated in Voronin that the amount of installation labor required per metric ton of equipment installed is 2 to 2.5 times greater for an N PS than for an analogous fossil-fired power station. Ibid., p. 68.

from 5.8 million person-days in 1979 to 7.5 million in 1981 and 25 million in 1990. Assuming, further, that the average construction worker provides 250 person-days of labor per year, a work force of 23,200 would have been required to deliver the 1979 total, while 30,000 workers would be required in 1981 and 100,000 in 1990.

This growing need for workers to build nuclear power stations comes at a time when the total demand for construction labor appears to be outstripping the supply. It is true that the Soviet Union has a large construction labor force. In 1979, 11.2 million workers and office employees were employed in construction, 10.1 percent of all employment in the national economy. But the rate of growth of construction employment has begun to slow,[45] and in the last 3 years the absolute increment to total construction employment has fallen successively. These declining growth rates do not signify a diminished interest in construction on the part of Soviet planners, but rather a necessary adjustment of the economy in general to slow growth in the labor force.[46] As a result, all sectors of the Soviet economy are under pressure to achieve output gains through increases in labor productivity rather than through expansion of employment.

The use of mechanization and automation as solutions to these problems has met with limited success in the construction industry. F. Sapozhnikov, Deputy Minister of Power and Electrification, has observed that "nonindustrial and technologically ineffective solutions"' still are used in the construction of nuclear power stations, and that the share of manual labor remains high.[47] One reason for this seems to be that specially developed equipment and tools for installation work have not been introduced into practice fast enough to keep up with the rapid growth rate of nuclear construction projects.[48]

Other approaches to productivity improvements have been tried, including an effort to reduce onsite labor requirements by increasing the amount of assembly work carried out at factories before components are shipped to the construction site. It has also been suggested that the turnover rate for construction labor could be reduced (and labor productivity increased) if more attention were paid to the needs of construction workers for housing, health care, entertainment, and other social amenities.[49]

Despite the growing demand for workers to build nuclear power stations and the declining rate of growth of the total construction labor force and of the nonagricultural labor force, overall labor shortages need not impede nuclear power development if Soviet authorities plan ahead and allocate their available workers carefully. According to the rough estimates above, nuclear plant commissioning in 1979 would have required an aggregate amount of construction and installation labor equal to only 0.2 percent of the 11.2 million worker construction labor force available in that year. Projected commissionings in 1985 and 1990 would represent only 0.3 and 0.9 percent of the 1979 labor force, respectively. Although there appear to be limited opportunities to shift workers from construction of fossil fuel or hydroelectric power stations, the aggregate labor requirements to support NPS construction need not pose a serious problem.

While the Soviet construction labor force as a whole may be adequate, shortages of individual skills could well arise. Installation is a crucial part of the activity involved in building a nuclear power station, and when

[45] All figures from U.S. S. R., op. cit., pp. 387 and 388.

[46] See Murray Feshbach and Stephen Rapawy, "Soviet Population and Manpower Trends and Policies," in *Soviet Economy in a New Pespective*, compendium submitted to the Jo int Economic Corn mittee of the U, S. Congress, Oct. 14, 1976 (Washington. 1). ('.: [J. S. Government Printing Office, 19761, p. 13,3.

[47] F. Sapozhnikov, "Energy, Heat, and Light for All," *Stroitelnaya gazeta* Dec. 21,1979, p. '2, in J PRS *75,069,* Feb. 5,1 980,pp.1 8-20.

[48] Yu. S. Medvedev, "Methods of Increasing the Efficiency of TES, A E S Equipment I ntallation, *Energeticheskoye stroitelstvo, No.* 11, November 1979, pp. 7-11, in JPRS L8955, Feb. 28, 1980, pp 7-16. Medvedev implies that this lag exists.

[49] Ovchinnikov, "By Advancing Tempos," op. cit., p. 2.

construction reaches the heavy installation stages at a large plant, more than 2,000 installation workers may be needed onsite for up to 1 to 1.5 years.[50] If a number of plants were to reach the installation stage at about the same time, a severe shortage of installation workers could result.

Construction Support.–Besides labor, the Soviet nuclear program will require adequate support in the way of equipment and facilities for construction and installation work.[51] An important equipment category at nuclear construction sites is large cranes and other hoisting equipment to move building materials such as steel structures and to install heavy components such as reactor vessels. This equipment will become increasingly important as the construction of nuclear plants is based more and more on standardized modular components—large, prefabricated pieces—which reduce labor costs and speed the work at the site.[52] Available hoisting equipment may already be in short supply; one source mentions the possibility of using this equipment for both construction and installation work by combining these two phases of operations wherever possible.[53]

Besides more and better construction equipment, the Soviet Union sees a need to improve the organization and management of construction operations in order to efficiently utilize both equipment and available labor. One form of improvement, as mentioned above, is the timely scheduling of construction and installation operations at an NPS site so that scarce equipment can be shared. On a larger scale, an attempt is being made to organize nuclear station construction work on a "flow-line" basis, much like that in the housing construction industry.[54] As a model for further efforts in this direction, a new type of facility called a nuclear power construction combine (NPCC) is being created in the city of Energodar, at the site of the Zaporozhye plant, now under construction. The NPCC is to manufacture metallic and reinforced-concrete structural and, presumably, to assemble these pieces into buildings at the plant site.[55]

More NPCCs will probably be organized,[56] but it is not clear how many construction projects would be supported by each combine and, therefore, how many combines will be needed to support the entire nuclear program to 1990. Nor has the level of capital and labor investment in NPCCs been determined. While additional staff and equipment will no doubt be required, it is conceivable that the combines could be formed, in part, on the basis of existing construction organizations and equipment. The aim is to save time and money by using labor and equipment efficiently. Since construction delays have been a major source of bottlenecks in the Soviet nuclear program, these aims take on particular significance.

Plant and Equipment Requirements

This section discusses plant and equipment requirements for the U.S.S.R. to meet its nuclear targets for 1985 and 1990. These requirements include major components of NPSs—reactors, turbines, and generators.

Reactors.–As noted above, the growth of Soviet nuclear generating capacity over the next 10 years will be based on 1,000-MW reactors of the RBMK (graphite-moderated) and the VVER (water-moderated) series, and also on the RBMK-1500. The announced plans for expansion and new construction of Soviet nuclear power stations summarized in table 31 more than cover the capacity needed

[50] Medvedev, op. cit.

[51] Russian construction terminology distinguishes the work of "constructing" or erecting the buildings of a nuclear station from the work of "installing" the reactors and other equipment housed in these buildings. Installation (rnontazh) often is more specialized and intricate work and, thus, requires more highly skilled labor than does construction *(stroitelstvo)*. As an industry, "construction" takes in both types of work, and it is in this sense that the word is used here.

[52] D. B. Fedorchukov, "Basic Directions for Raising the Effectiveness, Quality, and Rates of Construction of Nuclear Power Stations, " in Voronin (cd.), op. cit., pp. 49-57.

[53] Medvedev, op. cit., p. 13.

[54] Fedorchukov, op. cit., p. 56.

[55] A. Podgurskiy, "NPS's—On a Flow Line! " *Stroitelnaya gazeta*, May *5, 1980,* p. 1.

[56] Fedorchukov, op. cit., p. 56.

to reach the 1985 goal of 24,000 to 25,000 MW of additional capacity. At stations where the types and capacities of new reactors are known, the new capacity planned by 1985 amounts to at least 27,320 MW—some 780 MW more than needed to achieve the assumed goal of 38,000 MW by the end of 1985. Table 31 also shows at least ten 1,000-MW units (including units 3 and 4 at Rovno) and three 1,500-MW units to be added, presumably after 1985. Together with the aforementioned 780 MW, these additional units give a total of 17,280 MW of capacity to apply toward the anticipated growth in 1986-90, leaving some 24,720 MW of new capacity unaccounted for. Some flexibility exists in choosing how to cover this remainder.

From table 31, it appears that the U.S.S.R. is building nuclear power stations according to a regular pattern with either four 1,000- or 1,500-MW units per station, ” each unit consisting of a reactor and accompanying turbine-generator sets. Typically, the Soviets construct stations in “phases” (ocheredi) of two power units each. Assuming that this pattern continues, it is logical to assume that planned stations for which total capacities have not been announced will have at least four units and, therefore, four reactors of 1,000- to 1,500-MW capacity each. ”

Table 31 shows seven prospective stations for which total capacities have not been announced. However, the type of reactor to be installed at four of these stations is known; OTA has therefore assigned at least one reactor of the designated type to each station and included these reactors in the figures given above for planned new capacity. Assuming that the four stations will have at least three more reactors of the same type when completed, the stations will account for additional capacity totalling 13,500 MW and consisting of nine VVER-1000 reactors at three of the stations and three RBMK-1500s at one (Kostroma).

If the remaining three stations, which are to be heat and power plants, were to have at least two VVER-1000 units each (by analogy with Odessa), all seven nuclear power stations would provide a total of 19,500 MW of new capacity, or 5,220 MW less than the 24,720 MW needed to attain the 1990 goal. One conceivable way of covering this difference would be by building one more *ochered* of two 1,000 MW units at three of the stations. This would signify a departure from current practice. It is also possible that plans for other sites have not yet come to light. Neither of these possibilities alters the crucial question: How many 440-, 1,000-, and 1,500-MW units are needed to attain the desired goal, and can the Soviets produce and bring them online?

In order to equip those stations for which reactors types are given in table 31 (excluding unit 6 at Rovno), the Soviet nuclear industry must be supplied with three VVER-440 reactors and at least 24 VVER-1000s, nine RBMK-1000s, and five RBMK-1500s. In addition, based on the alternatives discussed for covering the remaining capacity, as many as 21 more VVER-1000s, and at least three more RBMK-1500s may be required. In all, besides the 440-MW units, this would mean the production of some 45 VVER-1000 reactors, 9 RBMK-1000S, and 8 RBMK-1500s before 1990. One factor that may affect the choice of the reactor mix is that the RBMK-1500 is as yet unproven in practice; operating experience at the Ignalina station may determine its future.

In summary, the growth of the Soviet nuclear power industry in the next 10 years

‘-one exception to this pat tern is the Rovno station, which is planned to have six units. However, the first two are VVER-440 reactors, both of which originally were planned to come onstream by the end of 1980; only one of them did. The four subsequent units are to be VVER-1000s, thus conforming to the genera] construction pattern for the 1980’s. Another exception may be the nuclear heat and power station near Odessa, which apparently will have two 1,000-MW units.

“”I’his strategy was outlined at a conference held in May 1980 at the site of the Zaporozhye plant. It was noted that the rated capacity of stations under construction in the next 10 years will be 4,000 to 6,000 MW, based on units with capacities of 1,000” to 1,500 MW. See “Conference on the Flow-Line Construction of N PS’S and the Curtailment of Labor Expenditures and Duration of Construction, *Atomnaya energiya*, vol. 49, No. 4, October 1980, pp. 264 and 265.

will be based largely on 1,000-MW reactors of the VVER and RBMK series and also on the RBMK-1500, an upgraded version of the 1,000.[59] The 440-MW class of VVERS is apparently being phased out; additional units of this size are to be installed only at Kola and Rovno. Although the U.S.S.R. seems committed to the larger classes of reactors and has designed many of its new stations accordingly, there is some flexibility as to which reactors to install. This flexibility is mainly in the choice between the RBMK-1000 and the RBMK-1500. If problems develop with the RBMK-1500, the Soviets could in principle substitute the RBMK-1000. If continued indefinitely, however, such substitutions would result in a capacity shortfall that would have to be covered in some way, such as by the installation of more 1,000-MW units.

It must be noted that reactor substitution is economic only between the 1,000- and 1,500-MW RBMK units and not between this reactor series and the VVER series. Unless a decision were made very early, substituting between the RBMK and VVER would be difficult and costly. Therefore, if there were a production shortfall in VVER-1000 reactors, stations designed to receive these could not employ the RBMK-1000 without a fundamental redesign. It is possible of course that construction schedules could be altered so that work on stations with RBMKs could move ahead and ones needing VVERs delayed. This would mean that more of the RBMKs could be installed than VVERs in order to keep up with capacity growth plans and to allow the solution of production problems. Eventually, in order to fulfill nuclear capacity goals either Soviet nuclear manufacturers would have to supply the needed reactors of both series, or some other measure—such as the import of reactor equipment—would have to be adopted.

Soviet hopes for domestic reactor production rest on Izhora and Atommash. OTA has attempted to determine the demands that might be placed on these facilities during the next 10 years. The results, broken down by facility and year, are shown in table 32. This table is not a prediction for installed capacity or facility output over the next 10 years. Rather, it combines numerous statements from the Soviet press and open literature regarding the future of the nuclear industry with OTA's own understanding of that industry's development. It endeavors to show what the U.S.S.R. *must* accomplish if it is to achieve its goals. The most important of the assumptions that underlie table 32 are as follows:

1) The table assumes the Soviet stated goals of adding 24,000 to 25,000 MW of installed capacity by 1985 and achieving 80,000 MW by the end of 1990.

2) The table assumes that annual production of nuclear capacity at an individual facility in any given year will equal or exceed production in the previous year.

3) The table assumes that Izhora now has the ability to produce annually reactors having a total capacity of about 5,000 MW. This assumption is based on three pieces of evidence. First, representatives of the U.S. Nuclear Regulatory Commission were told during a visit to Izhora on February 10, 1978, that the plant had an annual capacity of 5,000 MW or more.[60] Second, a 1980 article lists 1980 production obligations for the plant that total at least 5,320 MW (three VVER-440s, two RBMK-1000s, and two VVER- 1000s).[61] Finally, the nuclear plans incorporated in the recently adopted Eleventh FYP would be absurd if Izhora were not capable of producing about 5,000 MW of capacity per year. OTA has postu-

[59] The 50-percent increase in capacity in the RBMK-1500 is achieved by increasing the amount of coolant circulated through the core, thereby yielding more steam. For comparative specifications on the two reactors, see T. Kh. Margulova, *Atomnyye elektricheskiye stantsii* (Moscow: Izd. "Vysshaya shkola," 1978), p. 181; and *Atomnaya nauka . . .*, op. cit., p. 37.

[60] Lafleur and Steno, op. cit.

[61] V. V. Krotov, "The Contribution of the Power Machine Builders to the Fuel-Energy Complex of the Country," *Energomashinostroyeniye, No.* 1, January 1980, pp. 2-5.

Table 32.—Projected Production of Nuclear Reactors and Export Potential
(MW)

Year	Production capacity			Domestic requirements	Available for export
	Izhora	Atom mash	Total		
1981 ..,............	5,000	1,000	*6,000*	5,000	1,000
1982	5,000	1000	*6,000*	6,000	0
1983	5,000	2,000	7,000	7,000	0
1984	5,000	2,000	7,000	7,000	0
1985, ...	5,000	3,000	8,000	8,000	0
1986	5,000	4,000	9,000	8,000	1,000
1987	5,000	5,000	10,000	9,000	1,000
1988	6,000	5,000	11,000	10,000	1,000

SOURCE Office of Technology Assessment

lated that Izhora will continue to produce reactors at a rate of 5,000 MW per year until 1988, when a rise to 6,000 MW is assumed. This second assumption may well be too conservative. It is possible that Izhora's capacity will expand more rapidly.

4) The table takes into account indications that the Skoda Works will assume primary responsibility for providing VVER-440 reactors for Eastern Europe, but also assumes that the U.S.S.R. will provide some VVER-1000 reactors for Eastern Europe during the Twelfth FYP (see below and ch. 9).

5) Finally, the table discounts Soviet statements that seven VVER-1000 reactors, produced at Atommash, will be shipped by 1985; and that Atommash will be fully operational, producing 8,000 MW per year, by 1990.[62] Assuming that 2 years must be allowed for the installation of a reactor, it is unlikely that Atommash can supply seven 1,000-MW reactors for installation during the 1981-85 period. Four is a more probable total (i.e., annual production of 1,000, 1,000, and 2,000 MW in the years 1981, 1982, and 1983).

Given these assumptions, table 32 demonstrates the rate at which both Izhora and Atommash must produce reactors if nuclear capacity—and therefore nuclear electricity production–goals are to be met. One vulnerable point in these projections is Atommash, the successful and timely completion of which will dictate the success of the Soviet nuclear program and, to some extent, the program of the Council for Mutual Economic Assistance (CMEA) countries. Construction of Atommash, which is being carried out in stages, has been underway since 1976. Originally planned for startup in 1977, the plant's first stage, with a rated output of 3,000 MW of nuclear capacity per year, was not operating until the end of 1978.[63] This delay is indicative of progress with the project as a whole. Since its inception, it has been beset with both internal and external problems that are frequently publicized in Soviet newspapers and journals. These include excessive idle time and poor organization of workers at the construction site, as well as delays in the deliveries of equipment and materials from external suppliers. The labor problem is complicated by shortages of workers in the plant and at the construction site. As a result, construction of Atommash is estimated to be at least 2 years behind schedule; although the first 1,000-MW reactor vessel was completed in

[62]''Five Year Plan Accelerates Nuclear Programmed," *Nuclear Engineering International,* January 1981, p. 4: V. Pershin, "TO Eliminate Disproportions, " *Sotsialisticheshaya industriya* Jan. 30, 1981, p. 2.

[63]''Building the Atommash Plant, " *Culture and Life, No. 5, 1976,* p, 10; and "Chronicle of Events,'" *Stroitelnaya gazeta,* Dec. 12, 1980, p. 1.

February 1981, series production at the plant probably will not begin before 1983 or 1984.[64]

Even after the plant is completed, there are likely to be problems with acquiring skilled workers to operate its sophisticated machinery. As recently as 1979, efforts to train such workers—for example, operators of automatic welding equipment—were said to be highly inadequate to meet the needs of Soviet industry as a whole, let alone those of Atommash.[65] Fortunately it appears that the reconstructed Izhora plant will be able to compensate for at least some of the difficulties at Atommash.

The profile assumed here should permit the Soviets to meet domestic requirements for reactors and to supply 1,000 MW for export in the years 1981, 1986, 1987, and 1988. During the first of these years such exports would take the form of VVER-440s (two), while in the later years exports would be in the form of VVER-1000s. It must be noted, however, that it is not clear that these exports will necessarily be sufficient to support the planned Soviet role in CMEA cooperative nuclear power development.

As chapter 9 notes, Eastern Europe plans to have installed nuclear capacity totaling some 37,000 MW by 1990. Until 1985, nuclear powerplants built in CMEA countries will be based on the VVER-440; in the period 1986-90, the plan is to switch to the VVER-1000. The needed VVER-440s presumably will be supplied mainly by Skoda, with one or two reactors possibly coming from Izhora.[66] Since no plans have been announced for building VVER-1000s outside the U. S. S. R., the intent seems to be for these units to be supplied by the Soviet Union. Thus, some undetermined portion of that plant's output after 1985 will be designated for export. Overall, according to the CMEA agreement, the Soviet Union is to supply about 50 percent of the basic equipment for nuclear plants in Eastern Europe, but the U.S.S.R. might well decide to allocate Atommash's early units to Eastern Europe to offset future hydrocarbon requirements there.[67] This could strain Soviet manufacturing facilities as they attempt to keep pace with large-scale nuclear growth both at home and abroad, particularly if Skoda is slow in building to capacity. Moreover, the U.S.S.R. has in the past exported reactors outside CMEA. Should it wish to continue these exports, facilities would be taxed even further.

In sum, although Soviet plans for expansion of nuclear power are reasonable, they undoubtedly pose a difficult task for plants that manufacture reactor equipment. In the past, the capacity of Soviet industry to meet the increasing needs for this equipment has been inadequate. More recently, Atommash has become operational, albeit with construction lagging behind schedule, and Izhora has been reconstructed and its capacity significantly upgraded. It is therefore possible that the U.S.S.R. will be able to produce reactors fast enough to meet domestic requirements and to maintain some exports —two 400-MW units in 1981 and at least 1,000 MW per year after 1985.

Steam Turbines.–The planned expansion of Soviet nuclear power will also necessitate increased production of steam turbines. In principle, the power generation equipment used in nuclear power stations is essentially the same as that in nonnuclear thermal plants. This is particularly true of turbines, and Soviet designs of steam turbines for nuclear stations sometimes duplicate or incorporate design features of those used in fossil-fired stations. This means that Soviet manufacturing plants have been able to ap-

[64] "Obligated by the Initiative," *Soltsialisticheskaya industriya*, Feb. 14, 1980, p. 2, in JPRS 75,741, May 2, 1980, pp. 1 and 2; "Commentary by the Industrial Construction Department, *Stroitelnaya gazeta*, Dec. 12, 1980, p. 1; "Soviets Building Nuclear Reactor Assembly Line, *The Columbus Dispatch*, Oct. 13, 1980, p. A-8. According to a report in *Izvestiya*, Feb. 21, 1981, p. 3, Atommash completed its first reactor as planned.

[65] V. Pershin, "Personnel for Atommash," *Trud*, Feb. 9, 1979, p. 2, in JPRS 73,015, Mar. 16, 1979, pp. 14-16.

[66] The VVER-440 may also be exported to non-CMEA nations. Two of these rectors are in operation at the Loviisa NPS in Finland, and at least one other country–Libya-has purchased a Soviet power reactor. For more on the Libyan deal, see Gloria Duffy, op. cit., pp. 84-86.

[67] Zorichev and Fadeyev, op. cit., p. 53.

ply some of their experience in making turbines and generators for fossil-fuel power stations to steam and electrical equipment for nuclear stations, and also that similar kinds of problems are likely to occur. By the same token, the demands of the nuclear power industry do place new requirements on these plants. Output of equipment must be increased to keep pace with nuclear growth, and the equipment itself, especially turbines, must be compatible with reactor systems.

Current Soviet practice is to install at least two turbines with each reactor. The VVER-440 reactor uses two 220-MW turbines, and the VVER-1000 and the RBMK-1000 units use two 500-MW turbines. The addition of the RBMK-1500, however, will require development of a 750-MW turbine for use with saturated steam. In addition, work reportedly is under way to produce turbines with a rated capacity of 1,000 MW, in order to couple the VVER-1000 and RBMK-1000 with a single turbine.[68]

These steam turbines can be either "low-speed" or "high-speed" units, operating at 1,500 and 3,000 rpm respectively. In the United States, for large capacity turbines (500 MW or more) operating in saturated steam, the low-speed design is considered more suitable; large high-speed turbines operate better and last longer when run on superheated steam. This is because large, high-speed turbines used with steam at low parameters require very long blades in the low-pressure sections of the turbine, and the high velocities at the outer ends involve too much stress. Such difficulties would explain reported Soviet problems with the high-speed (3,000 rpm) 500-MW turbines used with the 1,000-MW reactors. Based on U.S. experience, it is reasonable to expect that unless the Soviet nuclear industry switches to low-speed (1,500-rpm) turbines, it will probably encounter even greater problems with the 750- and 1,000-MW turbines that it plans to use in the near future.

[68] Margulova, op. cit., pp. 184,224.

It is interesting that Soviet experts seem to have weighed the costs and benefits and concluded that high-speed turbines are more promising, although considerable expenditures have already been made on preparing designs for powerhouses using the low-speed variety.[69] The only low-speed turbines known to be in place to date are two 500-MW turbines manufactured for the VVER-1000 reactor of unit 5 at Novovoronezhskiy.[70] At the same time, the U.S.S.R. is pursuing the development of high-speed turbines with capacities of 750 and 1,000 MW. Fabrication of the latter has begun, although there is no evidence that a 750-MW high-speed turbine is actually yet in production.

In sum, with the possible exception of the 750-MW size, the Soviet Union is producing turbines of both types and with the unit capacities that it needs, including 1,000 MW. However, only one size–500 MW–actually is in use; the large turbines remain unproven in practice. Whether problems will be encountered, particularly with the high-speed equipment, remains to be seen. Preference does seem to be for the high-speed type. More of these are in service, at stations with the RBMK-1000. Part of the reason for this preference may be that Soviet nuclear manufacturing facilities are not yet adequately equipped to produce high-capacity, low-speed turbines, which are bulkier and more metal-intensive.

Major Soviet turbine and generator manufacturers have been expanding and upgrading their facilities for purposes of turning out more and better equipment. One such plant—the Kharkov Turbine Plant Production Association–has been designated the chief enterprise for the development of low-speed turbines. Another leading manu-

[69] B. M. Troyanovskiy, *Turbines for Atomic Electric Power Stations*, (Moscow: Izd. "Energiya," 1978); V. Krotov, "Power Machine Buildng and Scientific-Technical Progress," *Planovoe khozyaystvo, No. 5, 1981,* p. 8.

[70] See table 28 and G. 1. Grigorash, "Turbogenerators of the Kharkov Plant 'Elektrotyazhmash' for NPS's," *Elektricheskiye stantsii, No. 8,* August 1980, pp. 5-8. Grigorash notes that the Kharkov Turbine Plant has been designated as the chief Soviet enterprise for designing low-speed turbines for nuclear stations.

facturer that has been undergoing expansion and remodeling is the Leningrad Metal Plant Production Association.[71] These two associations appear to be the major suppliers of turbines for the nuclear industry.

Despite such efforts, an official of the power machine building industry observed in 1979 that too little attention has been given to turbine construction, with the result that that industry cannot provide proper nuclear equipment." No evidence was found to suggest that this situation has improved. Too many problems with the high-speed turbines larger than 500 MW may inhibit plans for the growth of the nuclear industry. In the case of the 750-MW turbine, the option exists, if necessary, to fall back to the 500-MW size, at least until any problems with the former are resolved. The same should be true with 1,000-MW turbines.[73] At some point, however, if the goals of its expansion plans are to be met, the Soviet nuclear industry will have to be assured of supplies of the larger turbines.

Generators.—As with steam turbines, turbogenerators are essentially the same for both fossil-fired and nuclear plants, and some generators are able to operate in either type of station[74] Development of larger and larger turbines requires the creation of generators to match. Turbines and generators must be designed to produce alternating current power at the correct frequency. High-speed generators are designed with two magnetic poles and low-speed with four poles. Turbines and generators are direct-coupled and installed in sets, so that a generator will be required for each new turbine unit produced.

As power stations are built with larger unit capacities, generators too must be designed with higher rated capacities–1,000 MW and 2,000 MW in the case of those destined for nuclear plants. In the past, generator production has been a chronic source of bottlenecks in nuclear construction. Now responsibility for large generators is being given to plants like Elektrotyazhmash in Kharkov and the Elektrosila Electrical Machine Building Production Association in Leningrad, facilities that have extensive experience in designing generators for nonnuclear stations.[75] Elektrotyazhmash has been expanded and charged with producing four-pole generators with capacities of 500 and 1,000 MW. The first two 500-MW generators of this type were manufactured for unit 5 at Novovoronezhskiy, but present plans include 1,000-MW generators. Although no evidence was found regarding large capacity two-pole generators for high-speed turbines, expanded production facilities at Elektrotyazhmash seem to be adequate to manufacture both two- and four-pole generators with capacities as large as 2,000 MW.[76]

Summary.—If Soviet claims are accurate, the U.S.S.R. is fully technologically capable of developing the necessary equipment for its nuclear power industry, including reactors and compatible turbine-generator sets. While limited options exist for deciding which type of equipment to use, the burden of supplying this equipment rests with manufacturing plants. There is evidence that such plants are already having difficulty meeting the demands being placed on them by the nuclear program. OTA has not investigated the extent of Soviet investment in manufacturing other nuclear plant equipment—valves, tubing, etc.—but all evidence suggests that difficulties may be widespread in the nuclear industry. This is not implausible, given the problems faced by Soviet industry as a whole in fulfilling output quotas. Moreover, these difficulties undoubtedly will

71G. A. Shishov, "The 'Leningrad Metal Plant' Production Association in the Tenth Five-Year Plan, " *Energomashinostroyeniye*, No. 9, September 1980, pp. 5-8.

[72]V. Krotov, "Prospects for Power Engineering Dictate, " *Sotsialisticheskaya industriya*, Feb. 3, 1979, p. 2, in JPS 73,015, Mar. 16, 1979, pp. 8-11.

"It should be noted that constraints on the substitutability of turbines increase as the construction of a station proceeds. The turbine size must be decided and the order for this equipment placed prior to the start of construction of the stations's turbine hall.

[74]rigorash, op. cit.

"'Ibid., p. 5.

"'Ibid.

be aggravated by the increasing rate of growth of nuclear power and the demands for supporting this growth.

The External Fuel Cycle

An important part of the infrastructure for nuclear power generation is the external fuel cycle–the supply of uranium and the system for disposal or reprocessing of spent fuel and wastes. Little information is available on the first part of the fuel cycle in the Soviet nuclear industry. The size of uranium supplies is an official State secret and there is virtually no unclassified information regarding Soviet plants that manufacture the fuel elements themselves.[77]

Based on what is known about its consumption of uranium, the U.S.S.R. seems to be accumulating a substantial stockpile.[78] This may, in part, be a response to perceived worldwide scarcity of this element. OTA is unable to judge whether stockpiling will provide the U.S.S.R. with uranium adequate to support its nuclear program, but on the evidence of its announced plans, the U.S.S.R. seems to be confident that it has or can get the uranium it will need in the years ahead. The emphasis on breeders presumably is at least partly based on ensuring adequate uranium supplies. 'g Moreover, it apparently has adequate enrichment capacity to convert the uranium to usable fuel for its reactors. The demand for Soviet enriched fuel will increase as more and more VVER reactors are installed in the U. S. S. R., in Eastern Europe, and in Third World countries. These reactors require more highly enriched fuel than do the RBMK models. The growing demand for this fuel may put a strain on the enrichment industry in the U. S. S. R., but it must be noted that this industry already exports its services abroad, including to Western Europe and more recently to the United States.[80]

The other end of the external fuel cycle–disposal or reprocessing of spent fuel and other waste material—is discussed somewhat more openly in the Soviet literature, although little quantitative information is available. Although Soviet experts recognize the increasing importance of dealing with wastes from NPSs, current disposal methods should be adequate for some years. Despite its rapid growth, the total nuclear generating capacity of the U.S.S.R. is still relatively small compared, for example, to that of the United States. The amount of spent fuel produced is therefore correspondingly small.

Commercial reactors in the U. S. S. R., like those in other countries, operate on a "once-through" fuel cycle. After the fuel has been burned up in the reactor, it is discharged to interim storage.[81] At Soviet nuclear power stations, the spent fuel elements are placed in water-filled storage basins that cool the fuel and allow it to decay over time.[82] Eventually, this spent fuel, its radioactivity significantly lessened during interim storage, will be transported to special plants for reprocessing in order to recover reusable fissile materials, particularly uranium and plutonium.

Technology for reprocessing spent fuel has been available in the Soviet Union since about 1950, [83] and there is reason to believe that reprocessing has also been in practical

"-Peter Feuz, "The Nuclear Push in the U.S.S.R. and Eastern Europe," *Power Engineering*, No. 8, August 1978, pp. 100 and 101. See also Dienes and Shabad, op. cit., for information on the location of the uranium industry.

[78]Duffy, op. cit., p. 68.

[79]Jean A. Briggs, "Soviet Nuclear Power: Tortoise and Hare'?" *Forbes*, vol. 122, No. 9, Oct. 30, 1978, pp. 123-126, reported that the U.S.S.R. imports uranium from East Germany and Czechoslovakia. Regarding the need to seek outside sources of uranium, Petrosyants, op. cit., p. 268, declared that the development of the nuclear industry and nuclear power in the ''socialist countries" (including the U.S.S.R.) "in no wav depends on supplies of uranium from the capitalist world."

"'fluffy, op. cit., p. v; Theodore Shabad, "Russian Uranium Exported to the United States, " in *The New York Times*, Aug. 17, 1981.

"For a discussion of nuclear fuel cycles in non-Communist countries, see 1. Spiewak and J. N. Barkenbus, "Nuclear Proliferation and Nuclear Power: A Review of the NASAP and INF'CE Studies, "Nuclear *Safety, No.* 6, November-December 1980, pp. 691-702.

"*Atomic Science* ., op. cit., p. 154.

'Ibid., p. 153. For a description of a process designed by Soviet scientists for what they call "regeneration" *(regeneratsiya)* of spent fuel, see pp. 153-159 of this source.

use there for some time. Indeed, American scientists suspect that the U.S.S.R. was extensively involved in chemical separation of nuclear wastes as early as the mid-1950's.[84] If this is true, the Soviet Union may already have practical experience with the technology it will need to eventually perform full-scale commercial reprocessing. It has been estimated that full-scale reprocessing of spent fuel will not be economical in the U.S.S.R. until Soviet nuclear stations are producing 1,500 tons of spent fuel per year—about as much as the United States was producing from 60 reactors in 1978. At that time, total U.S. nuclear capacity was some 47,000 MW.[85] Based on OTA's projection in figure 9, the U.S.S.R. will not reach this level until after 1985. This reasoning is supported by a 1978 Soviet source that maintained that while no reprocessing plant had yet been built in the U. S. S. R., that country would have reprocessing in the 1980's.[86]

Besides spent fuel, the operation of NPSs produces other waste products, primarily liquid wastes, of high, medium, and low radioactivity. Highly radioactive liquid waste results mainly from reprocessing, and the Soviet nuclear industry, therefore, will probably not have to handle large amounts of these products until after 1985. By and large, nuclear plants produce wastes of medium and low radioactivity .87

As a nuclear industry grows, so does the problem of liquid-waste disposal. In response, Soviet scientists reportedly are developing various permanent disposal methods, from deep underground burial in natural geological formations to different ways of concentrating and solidifying waste material (depending on its level of radioactivity), and at least one Soviet source considers the problem of deep burial of low- and medium-level waste to be solved.[88] Concentrated low-level wastes from research facilities are already being stored underground at Zagorsk, near Moscow, and at Dimitrovgrad. In the future, high-level wastes are to be compacted, solidified, and encapsulated for storage in abandoned salt or coal mines .89

Computers

Computers have been used more intensively for process control applications in nuclear facilities than elsewhere in the power generation industry, but the U.S.S.R. evidently recognizes a need for wider use of this technology.[90] This need will grow as the number of NPSs and the demands placed on them increase.

The Soviet Union reportedly began developing computerized control systems for fossil-fired power stations as early as 1961, and development of these systems for nuclear stations began in 1971.[91] Nevertheless, there is evidence that Soviet NPSs lack components such as microprocessors and other control equipment to support their functions. For example, Western observers have noted that Soviet NPSs employ manually operated plumbing in reactor cooling systems. The computer systems themselves are said to be relatively primitive,[92] and new systems are introduced into plants slowly. If the Soviets do not meet their goals for the construction of NPSs in the Eleventh and Twelfth FYPs, it will not be due primarily to deficiencies in computer control systems.

[84] Duffy, op. cit., p. 64.

[85] Biggs, op. cit., pp. 126, 124.

[86] John J. Fialka, "Soviets Think They've Solved Atom Safety Problems, " *Washington Star*, Oct. 1, 1978, pp. A-1 and A-10.

[87] Petrosyants, op. cit., p. 356, notes that relatively small amounts of highly radioactive waste also are produced in the operation of NPSs. At the same time, V. B. Dubrovskiy, et al., op. cit., p. 33, states that such waste products are not formed at NPSs, Small amounts of highly radioactive waste undoubtedly are produced by industrial and research reactors.

[88] Petrosyants, op. cit., pp. 356-366.

[89] Briggs, op. cit., p. 126.

[90] Ye. P. Stefani and V. I. Gritskov, "The Status and Prospects for the Development of Computerized Technological Process Control Systems for Power Units of Thermal and Nuclear Power Stations, " *Teploenergetika*, *No. 7*, July 1980, pp. 2-7.

[91] Ibid., pp. 2 and 3.

[92] Fialka, "Russia's Nuclear Program . . .," op. *cit.*

REQUIREMENTS FOR NEW EQUIPMENT AND TECHNOLOGY

NUCLEAR CAPACITY AND PRODUCTION: LIKELY ACHIEVEMENTS

Based on the foregoing analysis of the problems facing the Soviet nuclear power industry and its surrounding infrastructure, OTA has developed a set of projections for likely levels of achievement of nuclear capacity and electricity y production.

As noted above, the Soviet Union has set a goal of adding 24,000 to 25,000 MW of nuclear capacity during the Eleventh FYP period. If this goal is achieved, total installed nuclear capacity at the end of 1985 would be about 38,000 MW. If the 1985 target is reached, or not seriously underfulfilled, there is good reason to believe that the Soviets would set a goal of 80,000 MW of installed capacity by the end of 1990. Figure 9 presented a time profile of capacity additions that would permit the U.S.S.R. to meet these goals. This profile hypothesized successive increments of 3,000, 4,000, 5,000, 6,000, and 7,000 MW during the period 1981-85, followed by additions of 7,000, 8,000, 8,000, 9,000, and 10,000 MW during the Twelfth FYP.

The above discussion has indicated that the U.S.S.R. should be capable of producing reactors fast enough to meet domestic requirements, to export 1,000 MW in 1981, and at least 1,000 MW per year after 1985. Therefore, reactor production itself is not a particularly weak link in the Soviet nuclear power industry. The picture is less sanguine with respect to other requirements for meeting the capacity targets assumed for 1985 and 1990.

Bottlenecks will probably develop in construction and installation work. The contemplated rate of commissioning of nuclear capacity implies a need to triple the size of the construction labor force. If the rate of addition of generating capacity (of all forms) were expected to moderate in the 1980's, it might be possible to meet this need for labor by drawing workers from nonnuclear power projects. But no such moderation is in prospect. Gross additions to generating capacity (all forms) are to rise from 52,000 MW in the Tenth FYP to about 64,000 MW in the Eleventh FYP, and about 85,000 MW in the Twelfth FYP (see ch. 5). Furthermore, since there appears to be no prospect that the absolute rate of construction of fossil-fired and hydroelectric powerplants will decrease during the coming two FYP periods, it may not be possible for nuclear projects to draw any workers (on net) from these competing projects unless there are substantial increases in the productivity of construction labor. Power station construction overall probably will require large numbers of additional workers, while NPS construction in particular will require a great deal of additional specialized construction and installation labor (e.g., workers to assemble and install reactors and associated equipment).

A second area in which bottlenecks may develop is the production of turbines and generators. The Soviets have not yet mastered the production of low-speed 500-MW turbines, high-speed 750-MW turbines, and high-speed 1,000-MW turbines. All of these will be needed in the present decade. If technical problems arise, the Soviets may be forced to fall back on the more tested high-speed 500-MW turbine that has found widespread application in conjunction with the RBMK-1000. Generator problems may develop in the production of the four-pole 500-MW models needed to go with the new low-speed 500-MW turbines. A more serious problem may be a general shortage of capacity to manufacture generators. As in the case of labor, no help will come from a reduced burden of fossil-fired and hydroelectric capacity additions. The U.S.S.R. could reduce its exports of turbines and generators, but it is not clear that this action would in-

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crease its ability to produce the types of turbines and generators needed for nuclear power stations.

As a result of these factors–likely delays in construction of NPSs and delays in installation work at NPSs, plus shortfalls in the production of turbines, generators, and other equipment required for NPSs—OTA expects the Soviet nuclear program to fall behind schedule. Although estimates of developments 5 and 10 years into the future are necessarily speculative, it seems reasonable to adopt as an optimistic or best-case projection the expection that the Soviets will have installed 36,000 MW by the end of 1985 (v. 38,000 MW planned) and 75,000 MW by the end of **1990** (v. **80,000 MW** planned). If the U.S.S.R. achieves 36,000 MW of capacity by the end of 1985, its nuclear power stations will generate about 190 billion to 210 billion kWh of electricity during that year.[93] Achievement of 75,000 MW by the end of 1990 should lead to generation of 400 billion to 445 billion kWh in 1990.[94]

"Estimated by multiplying projected capacity for mid-1985 (33,800 MW) by operating rates of 5,663 to 6,259 hr/yr. The former rate is the estimated 1980 rate, while the latter is the 1985 operating rate implied by targets announced for the Eleventh FYP.

"Estimated capacity for mid-1990 (71,000 MW) operated for 5,663 to 6,259 hr/yr.

THE POTENTIAL ROLE OF WESTERN EQUIPMENT AND TECHNOLOGY

Despite the achievements justly claimed by the U.S.S.R. in developing and upgrading its nuclear technology and equipment, there is room for new technology and equipment available in the West. For example, while some spent fuel reprocessing apparently is being carried out, the U.S.S.R. has not yet built a commercial-size plant for this purpose. Such a plant will require large-scale production equipment that may still be lacking despite the long-standing availability and use of basic reprocessing technology. In addition, there may be alternative processes that have not been developed or explored thoroughly in the U. S. S. R..

Another area that probably could benefit from new technology and equipment is the manufacture of metal parts, such as turbines and reactor tubing. Soviet metallurgical processes and fabrication techniques for these parts seem to be less advanced than similar processes and techniques used in the United States. A third area of technological need is in control equipment, particularly microprocessors.

Soviet experts have themselves noted some areas where new or improved equipment is needed. According to one article, the horizontal drum-type steam separators currently used with RBMK reactors should be replaced with more efficient vertical separators, a process that requires more research.[95] A new type of reactor vessel made of prestressed steel-reinforced concrete is being developed for a 500-MW reactor for nuclear heat and powerplants,[96] and according to another source, work is being done and more is needed to find better materials and designs for the motors of main circulatory pumps of nuclear stations.[97] In the area of steel pressure vessel fabrication, Soviet industry is said to lack progressive forging technology for making reactor vessels. There are reports, however, that such technology is being introduced at Atommash.[98] Finally, it has been suggested that one way to improve the American uranium

[9]G. V. Yermakov, "Scientific and Technical Tasks for the Advancement of Atomic Power in the U.S.S.R.," E1ektricheskiye stantsii, No. 7, July 1979, pp. 5-9.

[9]'ibid., p. 8.

"O. L. Verber, et. al., "High-Power Asynchronous Electric Motors for Main Circulatory Pumps of Nuclear Power Stations, " *Elektricheskiye stantsii*, No, 9, September 1980, pp. 5-9.

[98]Ye. N. Moshnin and S. A. Yeletskiy, "Directions of the Advancement of Forging and Pressing Production Technology of Atomic Machine Building, *Energomashinos troyeniye*, No. 1, January 1980, pp. 36-38.

enrichment industry is through the use of advanced isotope separation processes such as laser enrichment.[99] Conceivably, such processes could also be applied in the U.S.S.R.

While the acquisition of these technologies would undoubtedly benefit the Soviet nuclear industry, it may be that more mundane needs in the area of construction equipment and manufacturing of parts for nuclear reactors, turbines, and generators would be more critical for the fulfillment of 1985 and 1990 plan targets. These needs include heavy machinery for manufacturing plants; large capacity cranes for construction and installation work; small parts such as valves and circulatory pump motors; and small computer components and other electronic control equipment.

One way for the U.S.S.R. to fill both kinds of needs is to purchase technology and equipment from the West. There are two possible motives for making such purchases, depending on whether the need is technical or economic. In the first instance, the Soviet Union is motivated to make foreign purchases because its own scientists and engineers have not yet developed or will not be able to develop the desired equipment or technology. OTA believes that this need is slight, if it exists at all, in the Soviet nuclear industry. Soviet nuclear power R&D capabilities apparently have been and will continue to be adequate to meet virtually all the requirements of the nuclear industry for new equipment and technology.

Economic motives are far more likely to animate Soviet trade with the West in this area, largely because of the widespread systemic problems that have caused bottlenecks in the nuclear program as well as in other areas of the Soviet economy. As a result of such problems, domestic equipment and technology cannot be introduced or manufactured fast enough to keep pace with planned nuclear expansion. These delays have apparently led the Soviets to seek outside sources for additional supplies of equipment and technology to augment domestic sources, and there is no reason to believe that such purchases will not continue or indeed increase–if development of these items in the U.S.S.R. remains costly in comparison.

If the Soviets fail to meet their plan targets for installed nuclear capacity, they should have continued interest in acquiring equipment from the West. Under these circumstances, the U.S.S.R. might well attempt to purchase an entire nuclear power station from the West on a turnkey basis. This option would be attractive from several points of view. Purchase of one 4,000- to 5,000-MW NPS would fill the gap between the assumed target capacity for 1990 and OTA's projected actual capacity. In addition, although the Soviets have a highly developed nuclear technology, purchase of such a plant from an advanced Western nation probably would have substantial technology transfer benefits. It might also be possible to reduce the immediate financing and foreign exchange cost of the project by negotiating a barter arrangement in which the Soviets would pay for the plant in part by supplying electricity to Western countries (e.g., to West Germany).[100]

Alternatively, the U.S.S.R. might choose to purchase selected components for nuclear powerplants in order to compensate for particular shortfalls in domestic equipment production. Since the Soviets seem likely to have an adequate supply of reactors, their purchase seems unlikely unless the Soviets foresee technology transfer benefits. However, shortfalls in domestic production of turbines, generators, and other components could occur and could lead to Soviet interest in Western imports.

Nuclear power is a high-priority sector in the Soviet Union and probably has been able

[99]Spiewak and Barkenbus, op. cit., p, 695.

[100]At least one such barter deal has already been suggested by the Soviet Union. The deal, whereby West Germany would have built a nuclear station in Kaliningrad in exchange for electric power, fell through in 1976 for economic and political reasons.

to command foreign exchange to finance imports. It seems likely that the volume of Soviet imports for this industry has been constrained by Western export restrictions and by the adequacy of Soviet-made equipment, rather than by the availability of foreign exchange to this sector or the availability of Western credits.

If trade restrictions are relaxed, Soviet purchases of nuclear equipment are likely to rise even if purchases must be made on a cash basis. The availability of Western credit on liberal terms probably would lead to larger volumes of imports. A barter deal in which the Soviets acquired a turnkey NPS and paid for it over a number of years with exports of electricity would almost certainly be the most attractive alternative from the Soviet perspective because the project would be self-amortizing.

In short, even though the Soviet Union has developed a substantial nuclear power sector relying largely on its own efforts, the major surge planned for the 1980's is likely to encounter problems, and progress will probably not be as fast as the Soviets hope. This gap between expectations and results could create interest in the possibility of importing Western nuclear components. If Western trade restrictions were relaxed, Soviet needs for equipment and traditional Soviet interest in Western technology could lead to substantial imports for this industry. Liberal credit terms are not essential to such trade, but might result in greater volumes. However, Soviet imports are likely to be limited to amounts needed to meet plan targets for NPS capacities. The prospects of the United States in competing for shares in this hypothetical market are discussed in chapter 6.

SUMMARY AND CONCLUSIONS

This chapter has described the recent growth of the Soviet nuclear industry, including officially announced plans for adding 24,000 to 25,000 MW of nuclear generating capacity by 1985 and another 42,000 MW by 1990. While these plans are feasible in terms of the number and capacity of planned power stations and required levels of investment, OTA has identified a number of potential problems.

Many of these problems relate to the construction of NPSs. Past experience suggests that completion of facilities will lag behind plan targets. Although nuclear construction need not necessarily be hampered by insufficient labor in general, highly skilled installation workers may be in short supply. Shortages of materials and equipment, poor organization of available resources and equipment, and lack of experience in installing and bringing online the relatively untried VVER-1000 reactor may also contribute to delays.

Another potentially important source of bottlenecks in the Soviet nuclear program is inadequate capacity to manufacture turbines and generators. In addition, Soviet industry seems to lack experience with, and perhaps manufacturing capacity for, producing low-speed turbines, which the U.S. nuclear industry has found more suitable than high-speed turbines for running on the low-parameter steam generated by nuclear reactors. A similar situation may exist with respect to four-pole generators used with the slower turbines. Evidence suggests that the U.S.S.R. intends to install low-speed turbines with VVER-1000 reactors, as is the case with unit 5 at the Novovoronezhskiy NPS. If so, turbines and generators needed for new NPSs with these reactors could be in short supply if manufacturing plants are unable to turn out this equipment in sufficient quantities.

Thus, despite a record of self-sufficiency in the nuclear industry, shortages of equipment and materials at home could force the U.S.S.R. to seek these products abroad. The CMEA countries have adopted a long-range plan for cooperative nuclear development that will support the U.S.S.R. program by providing additional sources of needed products. In addition, the Soviet Union is known to be engaged in trade with Western countries for this purpose. Although such trade so far has been modest and for the benefit of Soviet plants manufacturing nuclear equipment, it is possible that the situation could change as the demands of the industry grow. (See ch. 12 for a discussion of potential deals in Italy and West Germany. The role of the United States in this trade is discussed in ch. 6.)

In summary, OTA believes that while announced and estimated Soviet goals for nuclear growth to 1990 are attainable in principle, given the systemic problems that continue to hamper Soviet economic growth in general and that seem to be aggravated by the qualitative and quantitative demands of the nuclear industry for materials, equipment, and labor, the U.S.S.R. will probably fall *at least* 5,000 MW short of its targets. The demands of the nuclear industry will place great strain on other already overburdened areas of the Soviet economy, particularly the construction industry and nuclear manufacturing plants. To relieve some of this strain, the U.S.S.R. might wish to rely on foreign trade, both with CMEA countries and with the West, as it has done in the past. If shortfalls in domestic production are coupled with delays in or curtailment of supplies of needed equipment and technology from the West, the U.S.S.R. planned rate of nuclear growth will probably slow.