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The Soviet/CEMA Nuclear Power Programs and Their Requirements for Enriched Uranium

A Research Paper

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The Soviet/CEMA Nuclear Power Programs and Their Requirements for Enriched Uranium

Key Judgments

Information available as of 31 August 1983 was used in this report.

Total installed nuclear generating capacity in the Soviet Union and other CEMA countries increased from about 1,000 megawatts (electrical) at the start of the 1970s to over 22,000 megawatts by the end of 1982. Well-publicized, long-range Soviet/CEMA plans call for approximately 100,000 megawatts of installed capacity by 1990 in Soviet-designed and -fueled reactors.

We have examined in detail all available information from [redacted] of existing reactors, those under construction, and those in various planning stages. On the basis of this examination, we believe that a capacity of about 100,000 megawatts will not be achieved in 1990, but probably will be achieved at some time in the mid-1990s. We estimate that actual capacity as of 1990 could be as high as 88,000 megawatts, but is more likely to range from 60,000 to 70,000 megawatts.

The fraction of Soviet uranium enrichment capacity allocated to the Soviet/CEMA nuclear power program increased from essentially zero in the early 1970s to a cumulative total of about 15 percent of output—22,000-metric-ton separative work units (MTSWU)—by the end of 1982. We believe this demand will rise dramatically (to 80,000 or more MTSWU) by 1990, [redacted].

In addition to supporting its own nuclear power program and those of other CEMA countries, the Soviet Union operates a commercial toll-enrichment program through which it sells uranium enrichment services (not the uranium itself) to the nuclear power programs of various Western countries. The toll enrichment program began in 1973. Cumulative enrichment requirements from the program amounted to about 24,000 MTSWU by the end of 1982 and are expected to increase to about 50,000 MTSWU by the early 1990s.

Taken together, the Soviet/CEMA nuclear power programs and toll-enrichment program requirements for enriched uranium will account for [redacted] of total capacity by 1990. By the mid-1990s, we believe that total Soviet requirements for enriched uranium (including those for nuclear weapons and naval nuclear propulsion, as well as power reactors and toll enrichment services) will outstrip our projections of Soviet capacity. It is therefore likely that the Soviets will bring additional production on line between now and the early 1990s.

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Introduction

The strong growth of nuclear power in the Soviet Union and other CEMA [1] countries in the 1970s will continue in the 1980s and early 1990s. All nuclear power stations in the Soviet Union and most of the existing and planned stations in the other CEMA countries are built around Soviet-designed reactors that use uranium fuel slightly enriched in the isotope uranium-235 (U-235). The Soviet Union provides the fuel for all these reactors, placing an increasingly large burden on its enriched uranium production capacity.

The Soviet uranium isotope separation plants that produce enriched uranium for military purposes (nuclear weapons and the naval nuclear propulsion program) must also supply the enriched uranium for Soviet/CEMA nuclear power and the toll enrichment program, a commercial endeavor in which the Soviet Union sells enrichment services (not the uranium itself) to Western nuclear power programs. Our estimates of the production capacity available to supply enriched uranium for nuclear weapons necessarily are based on subtracting nonweapon demand (particularly requirements for nuclear power programs) from estimates of total enrichment capacity.

Because of the complex variety of uranium enrichments necessary for various weapon and nonweapon applications, both enrichment capacity and enrichment demand are usually expressed in terms of separative work units (SWU) rather than quantities of material. The SWU is an internationally recognized measure, which quantifies the separative work involved in producing a given amount of enriched uranium for any given assay (enrichment level) of the uranium feed, product, and waste (tails). This report first describes the requirements of each Soviet reactor type in terms of metric tons of material at various enrichments and then converts these quantities to metric ton SWU (MTSWU). The totals are discussed entirely in terms of MTSWU.[2]

Our analysis of these programs and their requirements for enriched uranium is based primarily on data available from open Soviet and East European publications, but our conclusions about future growth in nuclear power are strongly influenced by [ ].

Soviet Power Reactor Types and Their Separative Work Requirements

A modeling approach was developed to establish the separative work requirements of each class of Soviet reactor. The approach aims only at establishing the separative work requirements of a "typical" reactor within each class. Such an approach is necessary because the Soviets do not publish data on current or projected nuclear power program requirements for uranium, enriched uranium, or separative work. They have, however, published relatively detailed descriptions of each type of reactor. They also routinely announce the start of new reactors and publish their plans for construction of additional reactors. They publish information on the amount of power generated each year at the various operating nuclear power

[1] CEMA—Council for Mutual Economic Assistance: Council members which have or are scheduled to have Soviet power reactors are Poland, East Germany, Romania, Hungary, Czechoslovakia, Bulgaria, Cuba, and the USSR.

[2] SWU are usually characterized as kilogram-SWU (KGSWU) or MTSWU, depending on the units used for the equivalent amounts of material. In this report we use only MTSWU. For a more complete explanation of the concept of the SWU and its relationship to enrichment plant operation, see CIA Report ER 77-10468 (Unclassified), August 1977, *Nuclear Energy*.

Conversion of quantities of enriched uranium of a given enrichment to the equivalent in SWU involves calculations that are quite sensitive to the assumed assay (enrichment level) of the plant waste. For the calculations used in this report we used a tails assay value of 0.2 percentage point. [ ].

stations. There is no single document or publication that contains all of this information. The information instead must be assembled from an assortment of Soviet books, journal articles, scientific papers, and news items. From the reactor data, it is possible to determine the amounts and enrichment of the initial and replacement fuel loads and the amount of power generated before each refueling. The electric power data provide a basis for determining how long a typical reactor will operate before refueling. By totaling over time the typical reactor data of each type, it is possible to calculate overall fueling requirements.

There are two major types of Soviet-designed and -fueled power reactors: pressurized water reactors and boiling water reactors. The pressurized water reactors are designated by the Soviets as VVER. Two versions are being produced, a 440-megawatt (electrical) model designated VVER-440 and a 1,000-megawatt (electrical) model designated VVER-1000. Two earlier models are also in operation, the VVER-210 and the VVER-365. The boiling water reactors are of the graphite moderated pressure tube type and are designated RBMK. There are two important versions, 1,000- and 1,500-megawatt (electrical) models designated RBMK-1000 and RBMK-1500, respectively. Smaller versions exist but not in significant numbers. The VVERs are found in both the Soviet Union and the other CEMA countries. Because of publicly stated Soviet nonproliferation policy and the ability of the RBMK reactor to produce plutonium suitable for use in nuclear weapons, we do not believe these reactors will be built outside the Soviet Union. The VVER-440 and the RBMK-1000 are currently operational in sizable numbers. The VVER-1000 and the RBMK-1500 are just being introduced into service. (

In addition to these basic reactors, the Soviets are continuing to develop a third type—liquid-metal-cooled, fast-breeder reactors. Only two major breeder reactors are currently in operation: a 350-megawatt prototype designated BN-350 and a 600-megawatt prototype designated BN-600. Several small liquid-metal-cooled research reactors are also in operation. Currently, the impact of the breeder reactors on separative work requirements is of some significance because they are fueled with highly enriched uranium. On numerous occasions, senior Soviet nuclear officials have stated their intent to use plutonium to fuel their breeders. However, these statements generally refer to a time in the 1990s when breeders will be built on a commercial basis. They have never indicated if, or when, they plan to switch to plutonium fuel for the prototypes. In this paper, we assume that only uranium fuel is used in breeder reactors. (

VVER Pressurized Water Reactors

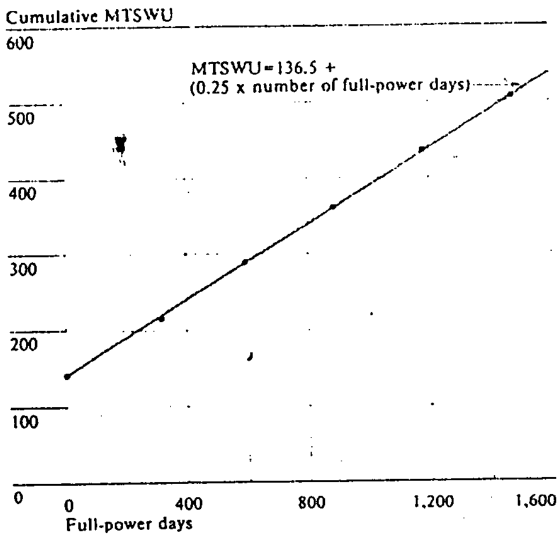
In the VVERs, the nuclear fuel is loaded in a lattice arrangement inside a steel pressure vessel. The fuel is cooled and the neutrons moderated by circulating water. The reactor is kept under high pressure to prevent the water from boiling within the reactor itself. Another large vessel called a pressurizer is used to maintain and regulate the pressure in the primary coolant loop (the coolant path through the reactor itself). Hot water from the reactor vessel is circulated through a steam generator (heat exchanger) where steam is produced for the turbines. (

VVER-440. The core of the VVER-440 consists of 349 fuel assemblies, each of which contains uranium dioxide equivalent to 120 kilograms of elemental uranium. Total core load is thus about 42 metric tons of elemental uranium. The degree of enrichment of the uranium contained in various parts of the core is varied systematically during the initial (transition) period of operation while the reactor is being brought to equilibrium (steady-state utilization of the nuclear fuel). The initial core usually consists of 114 assemblies with uranium enriched to 1.6-percent U-235; 133 assemblies with uranium enriched to 2.4 percent; and 102 assemblies with uranium enriched to 3.6 percent. (

According to published Soviet, East European, and Finnish data, the first fuel replacement in the VVER-440 occurs after the equivalent of about 320 full-power days of operation, with the 114 1.6-percent assemblies being replaced with a set consisting of 12 2.4-percent and 102 3.6-percent assemblies.[3] The second refueling occurs after about 595 full-power days, with 121 of the 2.4-percent assemblies being replaced with a set consisting of 19 fresh 2.4-percent assemblies and 102 3.6-percent assemblies. The third refueling occurs at about 890 full-power days, with 12 of

[3] A full-power day is 24 hours of operation at full-rated power. (

Figure 1
Separative Work Requirements
for a Typical VVER-440



The points show the requirements for the typical VVER-440 fueling schedule described in the text, with the initial load requirement of 136.5 MTSWU at zero full-power days. The linear function shown by the orange line was used to calculate the separative work requirements of the VVER-440s as a class.

the 2.4-percent assemblies and 102 of the 3.6-percent assemblies being replaced with fresh fuel of these two enrichments. From this point forward, 12 of the 2.4-percent assemblies and 102 of the 3.6-percent assemblies are replaced approximately every 295 full-power days.

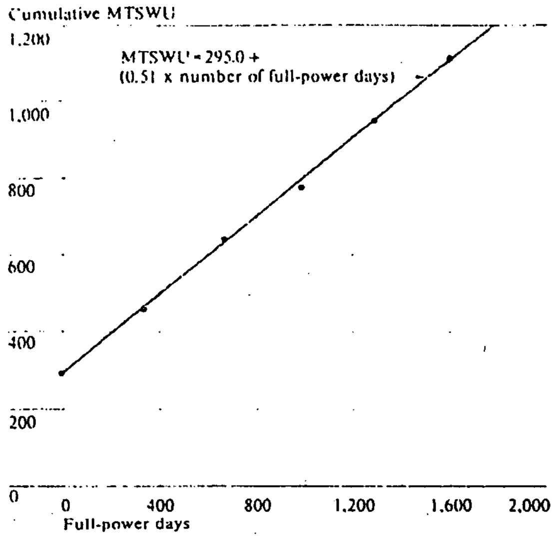
The separative work required to produce the various quantities and grades of enriched uranium for the typical fueling schedule just described is shown in figure 1 in terms of MTSWU versus full-power days of operation. The points on the graph show the requirements for the initial load and each reload. The initial load requires 136.5 MTSWU. Thereafter, the reactor requires an additional 0.25 MTSWU for each full-power day of operation during both the transition and equilibrium cycles.

The relationship between full-power days and calendar days will depend on the rate at which the reactor is operated. Data from actual Soviet operating experience suggest that a typical VVER-440 operates about 120 full-power days during the first year, about 220 full-power days during the second year, and about 255 full-power days during the third year. In the first three years of operating, the reactor produced electric power equivalent to about 600 days of full-power operation. Thereafter, if all goes as expected, the reactor should operate at a rate of about 75 percent (275 full-power days per year). Combining this information with the relationship between separative work requirements and full-power days shown in figure 1, the VVER-440 requirements can be summarized as follows:

Initial load:	136.5 MTSWU
First three years:	47.7 MTSWU per year (three-year average)
After three years:	68.8 MTSWU per year.

VVER-1000. The design core of the VVER-1000 consists of 151 assemblies, each of which contains uranium dioxide equivalent to 441 kilograms of elemental uranium. Total core load is about 66 metric tons of elemental uranium. Current Soviet planning indicates that most VVER-1000s will use a three-year fuel cycle with an initial core consisting of 54 assemblies with uranium enriched to 2 percent, 54 assemblies with uranium enriched to 3 percent, and 43 assemblies with uranium enriched to 4.4 percent. Based on detailed calculations, the refueling schedule for this reactor is as follows. After about 350 full-power days, the 54 2-percent assemblies will be replaced with 42 4.4-percent and 13 3.0-percent assemblies. After about 670 full-power days, the 54 3-percent assemblies will be replaced with 13 3-percent and 42 4.4-percent assemblies. The 43 4.4-percent assemblies originally in the core will be replaced after

Figure 2
Separative Work Requirements for a Typical VVER-1000



The points show the requirements for the typical VVER-1000 fueling schedule described in the text, with the initial load requirement of 295.0 MTSWU at zero full-power days. The linear function shown by the orange line was used to calculate the separative work requirements of the VVER-1000s as a class.

approximately 980 full-power days with 13 3-percent and 42 4.4-percent assemblies. Thereafter, 13 3-percent and 42 4-percent assemblies will be added every 318 full-power days.

The separative work required to produce the enriched uranium for the VVER-1000 fueling schedule just described is shown in figure 2 in terms of MTSWU versus full-power days of operation. This figure is exactly analogous to figure 1 on the VVER-440. The initial load requirement is 295 MTSWU. The reactor requires an additional 0.51 MTSWU for each full-power day of operation during both the transition and equilibrium cycles. (

There are no statistical data on which to base an estimate of VVER-1000 rates of operation. For planning purposes, the Soviets probably assume values similar to those of the VVER-440. On this basis, the separative work requirements for the VVER-1000 can be summarized as follows:

Initial load:	295.0 MTSWU
First three years:	97.4 MTSWU per year (three-year average)
After three years:	139.6 MTSWU per year. (

RBMK Boiling Water Reactors

In the RBMK reactors, high-pressure tubing is embedded in a graphite block to form vertical fuel channels. The nuclear fuel assemblies are loaded into these channels and cooled by water pumped through the channels. The cooling water is allowed to boil to produce steam for the turbines.

RBMK-1000. The core of the RBMK-1000 contains 1,693 fuel channels. Each fuel assembly contains uranium dioxide equivalent to 113 kilograms of elemental uranium for a total core load of about 192 metric tons of elemental uranium. Although early RBMK-1000s used uranium enriched to 1.8 percent, operational reactors are using (as will future reactors) 2-percent enriched uranium. (

The fuel replacement schedule as the reactor is brought to equilibrium is much more complex than in the VVERs. In early RBMK reactors only 1,453 fuel channels were initially loaded with fuel assemblies; the remaining 240 channels were loaded with auxiliary rods containing neutron-absorbing material. These auxiliary absorbers were replaced with fuel assemblies at a rate of about 40 absorbers every 100 full-power days of operation until, after roughly 600 full-power days, all 240 had been replaced and the reactor was fully loaded with fuel. A varying number of the original fuel assemblies were also replaced. It is assumed that the same type of scheme is used in reactors loaded with 2-percent enriched fuel. Based on this assumption the reactor does not reach equilibrium (design utilization of the nuclear fuel) until after 1,500 full-power days, after which fuel replacement attains a more nearly constant rate of 394 assemblies about

Table 1
Fuel Replacement Schedule of a Typical RBMK-1000

Equivalent Full-Power Days [a]	Fuel Assemblies Replaced [b]	Total Extra Absorbers Remaining	Total New Fuel Assemblies Required
0 (initial load)		240	1,453
100	6	200	46
205	24	160	64
305	27	120	67
410	30	80	70
510	33	40	73
610	34	0	74
715	33		33
815	38		38
915	150		150
1,020	145		145
1,120	150		150
1,225	145		145
1,325	135		135
1,425	125		125
1,530	120		120
1,630	130		130

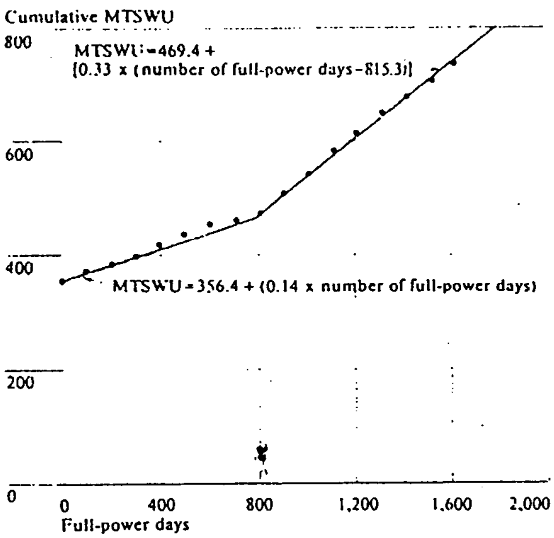
[a] Calculated from Soviet fuel burnup specifications and rounded to the nearest five full-power days.
[b] The RBMK-1000 is capable of being refueled while operating. It is not known whether the Soviets replace several assemblies/absorbers per day or wait until the reactor is not operating to perform the refueling. Because of this online refueling capability, the Soviets are not bound to a fixed schedule. The values in this table should be treated as representative only.

every 318 full-power days. Table 1 shows in greater detail the assumed replacement schedule for absorbers and fuel assemblies in a typical RBMK-1000.

The separative work requirements for the fueling schedule described in the table are shown in figure 3 in terms of MTSWU versus full-power days. The relationship is much more complex than in the two VVER reactors, but it can be adequately approximated for estimative purposes by two linear functions. The initial load requirement is 356.4 MTSWU. During approximately the first 800 full-power days, the reactor requires an additional 0.14 MTSWU per full-power day; thereafter, this requirement increases to 0.33 MTSWU per full-power day.

From published Soviet data, we know that RBMKs have shown somewhat better operating rates than VVERs: about 180 full-power days in the first year, 240 in the second, and 255 in the third. Thereafter, they seem to maintain about the same rate as the VVERs, that is, 75 percent. A typical RBMK will operate an average of 225 full-power days per year during the first three years and 275 full-power days thereafter. The separative work requirements of the

Figure 3
Separative Work Requirement for a Typical RBMK-1000



The points show the requirements for the typical RBMK-1000 fueling schedule described in the text, with the initial load requirement of 356.4 MTSWU at zero full-power days. The linear functions shown by the orange lines were used to calculate the separative work requirements of the RBMK-1000s as a class.

RBMK-1000 can be summarized as:

Initial load:	356.4 MTSWU
First three years:	31.6 MTSWU per year (three-year average)
After three years:	90.8 MTSWU per year. (s)

RBMK-1500. We have much less information on the RBMK-1500 than on the RBMK-1000, as none of the former are yet operational. Various Soviet publications indicate that the fuel enrichment will be the same (2 percent), the total uranium load about the same, the core configuration the same or very similar, and the degree of fuel utilization (burnup) the same as in the RBMK-1000.

The initial load will be at least approximately the same as that for the RBMK-1000. Since the reactor is designed to produce 1.5 times as much power as the RBMK-1000 from essentially the same amount of fuel (at the same enrichment level and the same planned burnup), the separative work requirement to support the fuel replacement schedule should be higher by roughly the same factor. If we assume that RBMK-1500s will operate the same number of effective full-power days as current RBMK-1000s, then its separative work requirements will be as follows:

Initial load:	356.4 MTSWU
First two years:	44.0 MTSWU per year (two-year average)
After two years:	140.3 MTSWU per year.

Breeder Reactors
In Soviet fast-breeder reactors the nuclear fuel is cooled by liquid sodium metal. Sodium is an excellent heat transfer agent and has a high boiling point; thus, the reactor core of the fast reactor is much more compact, and the reactors are operated at a much lower pressure than either the RBMKs or VVERs. Since sodium becomes radioactive as it is irradiated in the reactor core and since it reacts violently with water or steam, an intermediate sodium loop is placed between the primary (radioactive) coolant loop and the steam/water loop.

Two large prototype fast breeders currently are producing a limited amount of electric power in the USSR: the BN-350 at Shevchenko, which provides heat for desalinization as well as electric power, and the BN-600 at Beloyarsk. The Soviets are planning to build a larger version (probably 800 megawatts) that will serve as a prototype for future commercial breeder reactors. This prototype cannot be operational until 1990 at the earliest. Both operating prototypes are currently fueled with enriched uranium, but the Soviets plan to switch the BN-600 to a mixture of plutonium and uranium oxide (mixed oxide) fuel at some future date. The proposed BN-800 as well as all commercial breeders will use mixed oxide fuel.[4] Plutonium for these reactors will be obtained by reprocessing irradiated fuel from VVER and RBMK reactors. The breeders will produce more plutonium than they consume, but requirements for plutonium to start up additional breeder reactors will greatly exceed production (in the breeder reactors themselves) through at least the mid-1990s. (

BN-350. The initial core of the BN-350 has two active zones: 109 assemblies (3.2 metric tons) of 17-percent enriched uranium and 90 assemblies (2.6 metric tons) of 26-percent enriched uranium. The reactor has axial and radial blankets containing 59.5 metric tons of natural or depleted uranium. The Soviets indicated that refueling should occur approximately every 65 full-power days. Initially, about one-third of the 17-percent fuel is replaced, probably with 26-percent fuel and about one-tenth of the blanket is replaced with new blanket assemblies. This process continues until there is significant utilization in the 26-percent fuel (at about 300 full-power days), after which the 26-percent fuel is gradually replaced. Operating this reactor at 275 full-power days per year would require about 247.5 MTSWU.

BN-600. Operation of the BN-600 is probably very similar to that of the BN-350. The initial core consists of 234 assemblies (5.0 metric tons) of 21-percent enriched uranium and 162 assemblies (3.5 metric tons) of 33-percent enriched uranium in the central region and axial and radial blankets containing a total of 40.6 tons of natural or depleted uranium. Fuel for this reactor probably is replaced about every 195 full-power days of operation. At 275 days per year of effective full-power operation, this reactor would consume 313.5 MTSWU.

Other Reactors

In addition to the large RBMKs, VVERs, and breeder reactors, the Soviet Union has operated two prototype VVERs, two prototype RBMKs, four small heat and electric reactors, and a small breeder reactor. The prototype VVERs consist of 210- and 365-megawatt units at Novovoronezh. A 100-megawatt RBMK and a 200-megawatt RBMK with super heating are in operation at Beloyarsk. Four 12-megawatt RBMK-type reactors producing industrial and home heat as well as electricity are in operation at Bilibino. A 60-megawatt experimental fast reactor, the BOR-60, is in operation at Melekess. The requirements for enriched uranium for these reactors are small compared to the other reactors, and the reactor-specific data will not be presented in this report. Assuming that these reactors operate about 275 full-power days per year, the total yearly requirement for enriched uranium would be approximately 130 MTSWU. (

The Soviets are planning to install a large number of reactors, which will produce heat for industrial and residential purposes. The first of a planned pair of these reactors is currently under construction at Gorkiy. When complete, this station will consist of two 500-megawatt (thermal) reactors. Data on the precise nuclear fuel characteristics of these reactors are not available, but their effect on total separative work requirements will be minor for the next decade because of their small numbers. (

Growth of the Nuclear Power Program

Official statements, [redacted] indicate that the installed nuclear generating capacity in the Soviet Union increased from around 1,000 megawatts at the start of the 1970s to over 17,000 megawatts in 1982. Current capacity (not including miscellaneous small reactors) consists of nine VVER-440s, two VVER-1000s, 10 RBMK-1000s, and two breeder reactors. Publicized Soviet plans project increases, which, if achieved, would result in an installed capacity in the Soviet Union of up to 85,000 megawatts by the end of 1990

CEMA countries other than the USSR have 4,840 megawatts of installed nuclear capacity consisting of 11 VVER-440 reactors. Current plans call for an

[4] A breeder reactor is so named because it produces or "breeds" more fissionable fuel than it consumes. It does this by using excess neutrons from the fission of fuel to convert the U-238 isotope of uranium to plutonium. This plutonium is eventually recovered, purified, and fabricated into fuel. It is highly desirable that plutonium be used in the first fuel loading because it gives off more excess neutrons when it fissions, resulting in a much faster rate of conversion.

increase by the end of 1990 to as much as 37,000 megawatts, including uncertain plans for various Western-origin reactors. There is a lack of data as to the actual breakdown by country of this figure. Of the total, we can account for about 19,000 megawatts in terms of Soviet-designed and -fueled VVER-440 and VVER-1000 reactors nominally scheduled for completion by 1990. The Soviets are also committed to construct and fuel two VVER-440 reactors in Libya.[5] (Soviet-designed VVER-440 reactors in Finland are not included in these figures because their separative work requirements are accounted for under the Soviet toll enrichment program.)

Total installed capacity in Soviet-fueled reactors at home and abroad (other than in Finland) was thus about 22,000 megawatts at the end of 1982. If all of the goals discussed in the two preceding paragraphs were achieved, total installed capacity in Soviet reactors by 1990 would be about 100,000 megawatts, a figure frequently mentioned in Soviet public statements. (One recent Soviet projection stated that the total Soviet/CEMA program would be 100,000 to 120,000 megawatts by 1990. This value may include an indeterminate number of Western-origin reactors under consideration in Eastern Europe.) (s)

We have examined in detail all available information [redacted]

This examination revealed that the Soviets and their CEMA allies (plus Libya) have at least 127 Soviet-origin reactors in the construction or planning stage. It is clear that there are specific plans to construct all or most of the planned reactors. The completion of all of these reactors would add about 120,000 megawatts to the current total, making a grand total at some time in the late 1990s or early 2000s of about 143,000 megawatts (70 percent in the Soviet Union, the remainder abroad). In the unlikely event that all construction schedules were optimally fulfilled, the total capacity by the end of 1990 would be about 88,000 megawatts, somewhat less than the Soviets' general planning figure of 100,000 megawatts. To meet even this reduced goal, the Soviets would have to place 75 reactors in operation over the next seven years. Historically, they have not met their announced nuclear power goals on time, and it is not at all likely that they will meet this formidable goal on schedule. Unless unforeseen circumstances intervene,[6] we believe that a capacity of about 100,000 megawatts will be achieved not in 1990 but probably at some time in the mid-1990s. We estimate that actual capacity as of 1990 could be as high as 88,000 megawatts but is more likely to range from 60,000 to 70,000 megawatts.

Total Separative Work Requirements of the Soviet/CEMA Nuclear Power Program

Total past and projected separative work requirements of the nuclear power program were calculated by combining the data in appendix A with the data given earlier on the separative work requirements of each reactor type. In performing the calculations, we allowed a nominal period of one year to fabricate the enriched uranium into fuel. To reflect this, we offset the requirements by one year, that is, we treated each year's requirement as though it fell due in the preceding calendar year. The resultant year-by-year requirements are given in appendix B in terms of annual MTSWU for each reactor type and in terms of cumulative MTSWU for reactors of all types.

The data in appendix B show that the separative work needed to support the Soviet/CEMA nuclear power programs increased from negligible amounts in the

[5] The Soviets have shown an interest in exporting additional reactors and have held general discussions with Finland, Yugoslavia, India, Turkey, China, North Korea, and Syria. [redacted]

[6] Our projection of the Soviet/CEMA commercial nuclear program assumes that nuclear power will continue to receive a high priority in energy plans and top priority in the expansion of the electric power sector. There are, however, circumstances which could result in a much delayed nuclear program. For example, a nuclear power plant accident, in which a major design fault is revealed, could cause significant delays while flawed components are redesigned. Economic factors, such as severe capital investment constraints or reduced growth in electricity demand over an extended period also could result in slower-than-expected expansion of the Soviet/CEMA nuclear program.

early 1970s to about 3,000 MTSWU per year by 1982. Cumulative requirements through 1982 amounted to more than 22,000 MTSWU. These requirements will increase by large factors in the remainder of the 1980s. In the unlikely event that the Soviet/CEMA programs achieve the maximum of 88,000 megawatts by 1990, annual requirements will increase to about 14,000 MTSWU and the cumulative requirement through 1990 will be about 91,000 MTSWU. Achievement of what we regard as the more likely level of 60,000 to 70,000 megawatts in 1990 will still result in very large increases: to roughly 11,000 MTSWU annual and about 80,000 MTSWU cumulative as of the end of 1990.

Annual MTSWU values given in appendix B illustrate the rate of growth and the effect of the different reactor types on enriched uranium requirements as well as the manner in which this changes with time. In future years, the VVER-1000 will have a disproportionately large impact; by 1990 this one reactor type will account for well over one-half of the separative work requirements of the Soviet/CEMA nuclear power program. When considering the overall impact on Soviet enriched uranium allocation, cumulative values in appendix B are more significant than annual values. We have no way of knowing exactly when the Soviets may produce the material to satisfy any given annual requirement, that is, the extent to which they may have preproduced material in the past or may do so in the future. Thus, our estimate is the minimum amount of separative work expended for nuclear power. (

Accuracy of Soviet/CEMA Separative Work Calculations

The separative work requirements shown in appendix B for the period through 1982 are based on actual Soviet installed nuclear capacity. These values may be regarded as accurate, subject only to relatively minor error inherent in our method of calculating the separative work requirements of the two major reactor types currently in operation. This methodological error becomes increasingly important, however, in future projections. We emphasized in an earlier section that our method of calculating is essentially a modeling approach and that the results are valid only for a "typical" reactor of that class. In this limited sense, the calculated values probably are quite accurate for the VVER-440 and the RBMK-1000, because the fuel loading and replacement cycles of these two established classes are well known and their historical operating rates well established. Individual reactors operate at differing rates, and there is undoubtedly some variation in fuel replacement cycles from reactor to reactor. In general, however, our "typical" VVER-440 and RBMK-1000 reactors probably are well representative of their respective classes. Since almost all of the current capacity consists of these two types, the error in the cumulative separative work totals for the period through 1982 should be relatively small, but we are unable to calculate the error beyond that general statement.

Information on fuel loading and replacement cycles and operating rates of the new types, the VVER-1000 and RBMK-1500, is much more limited, rendering our "typical" models of these two classes somewhat speculative (particularly so in the case of the Soviet RBMK-1500). Since these two classes will assume an increasingly greater share of total capacity over the coming decade, errors in calculating separative work requirements of each reactor type will have an increasingly greater impact on total separative requirements. Uncertainties about fuel loading and replacement cycles have a potentially important impact on the future projections, not only because of our imperfect understanding of current fueling plans for the VVER-1000 and RBMK-1500, but because the Soviets may well change these plans over the next decade. (Conceivably, this could be done, not only with respect to the VVER-1000 and RBMK-1500 but also with respect to the VVER-440 and RBMK-1000.) We cannot now assess quantitatively the impact of uncertainty in this area, but it is not likely to decrease future requirements substantially. The Soviets have published studies on alternative power reactor loading schemes for both VVER and RBMK reactors. In general, Soviet thinking in this area seems geared to reducing the overall costs of producing electricity by reducing fuel fabrication costs. None of the alternative concepts appear aimed directly at reducing separative work requirements per reactor. (

Over the long run, nuclear power separative work requirements may be reduced as a result of reprocessing, that is, extracting the usable plutonium and uranium from the used nuclear fuel. [redacted] The Soviets stated that they intend to use the recovered plutonium in fast breeder reactors, sharply reducing the rate of increase of separative work requirements for this reactor type beginning in the mid-1990s. Recycling of recovered uranium could occur sooner, perhaps by the late 1980s. However, because of the long cooling period before spent fuel is shipped from the reactor (currently five years) and the rapid expansion in the number of reactors, the impact of reprocessing on Soviet separative work requirements over the next decade probably will be quite small.

The Toll-Enrichment Program

In addition to supporting its own nuclear power program and those of the other CEMA countries, the Soviet Union sells uranium enrichment services to the nuclear power programs of various Western countries through a commercial toll enrichment program. The uranium to be enriched is provided in all cases by the customer, not by the Soviet Union. Each sales contract specifies the waste (tails) assay, usually about 0.2 percent. The contracts are not classified and information on sales is generally available from commercial sources.

The Soviet toll enrichment program began in 1973 and grew rapidly through the 1970s to its present level averaging 2,500 to 3,000 MTSWU per year. (This provides a hard currency income of roughly $350 million per year.) Existing contracts call for continuation at roughly this level through the 1980s, declining to about 1,000 MTSWU in the early 1990s. Actual levels cannot be predicted much beyond 1990, however, because of uncertainty about potential new contracts. The cumulative total through 1982 amounted to about 24,000 MTSWU and, on the basis of existing contracts, is expected to grow to about 50,000 MTSWU by the early 1990s. A year-by-year listing of annual and cumulative totals is given in table 2. (u)

Table 2
Toll-Enrichment Contracts (MTSWU)

Year	October 1983	
	Annual	Cumulative
1973	328	328
1974	460	788
1975	332	1,120
1976	2,026	3,146
1977	3,639	6,785
1978	3,571	10,356
1979	4,995	15,351
1980	3,380	18,731
1981	2,981	21,712
1982	2,581	24,293
1983	2,824	27,117
1984	2,776	29,893
1985	2,709	32,601
1986	2,540	35,141
1987	2,563	37,704
1988	2,939	40,643
1989	2,908	43,551
1990	2,841	46,392
1991	957	47,349
1992	957	48,306
1993	957	49,263

Impact of Combined Requirements for Nuclear Power and Toll Enrichment

Taken together, the Soviet/CEMA nuclear power program and toll enrichment program requirements for enriched uranium will account for [redacted] of total enrichment capacity by 1990. As figure 4 indicates, there are large uncertainties on our present estimates of enrichment capacity, reflecting the fundamental limitations of analyses [redacted].

[redacted]

Figure 4
Combined Nuclear Power Enrichment Demand and Estimated Capacity Cumulated Through Time
Cumulative MTSWU (in thousand)

the accelerating demand for enriched uranium (driven primarily by the expanding Soviet/CEMA nuclear power and toll enrichment requirements)[7] will outstrip our projections of Soviet capacity for the mid-1990s. We therefore believe that the Soviets will bring additional production on line between now and the early 1990s.

[7] Enriched uranium requirements for military requirements—nuclear weapons and naval propulsion—will be overshadowed by the burgeoning nuclear power/toll enrichment demands in the 1990s. We judge that military demand has leveled off (as with the United States) after many years of growth.

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Appendix A

Existing and Planned Nuclear Power Reactors in the USSR and Other CEMA Countries

All known Soviet-origin power reactors—those operational, under construction, or planned—are listed in this appendix. The startup dates for those reactors not yet operational reflect the assumption of *optimal schedule fulfillment*. These dates should be regarded in each case not as our best estimate but *as the earliest possible date*:

- All reactors, which might reasonably be expected to be complete by the end of 1985, are already under construction. [ ].

- Those reactors expected to be completed after 1985 are either at nuclear power stations [ ] or at power stations announced by the Soviets but not yet begun. (All Soviet/CEMA power reactors are parts of nuclear power stations with multiple reactors.) In the first case, we have followed Soviet practice by estimating that each reactor at a given station will begin operations one to two years after completion of its immediate predecessor in the construction series. In the second case, we have assumed that the first reactor at the station will not be operational for at least seven years after its construction start is first announced by the Soviets and that each successive reactor will follow at an interval of one to two years.

- In a few cases, we have specific Soviet/CEMA projected dates that conflict with our methodology. In these cases, we used the Soviet/CEMA date only if it is later than the one produced by our methodology.

Table 3
Known Soviet-Origin Power Reactors

Name	Reactor Type	Actual or Earliest Operational Date •
Bulgaria		
Belene-1	VVER-1000	Mid-1990
Belene-2 •	VVER-1000	Late 1991
Belene-3 •	VVER-1000	Mid-1993
Belene-4 •	VVER-1000	Mid-1995
Kozloduy-1	VVER-440	Late 1974
Kozloduy-2	VVER-440	Early 1976
Kozloduy-3	VVER-440	Early 1981
Kozloduy-4	VVER-440	Mid-1982
Kozloduy-5	VVER-1000	Early 1988
Kozloduy-6	VVER-1000	Early 1990
Cuba		
Isle-of-Pines-1	VVER-440	Mid-1988
Isle-of-Pines-2	VVER-440	Early 1990
Czechoslovakia		
Bohunice-1	VVER-440	Early 1979
Bohunice-2	VVER-440	Early 1980
Bohunice-3	VVER-440	Early 1984
Bohunice-4	VVER-440	Late 1984
Dukovany-1	VVER-440	Mid-1984
Dukovany-2	VVER-440	Late 1985
Dukovany-3	VVER-440	Mid-1986
Dukovany-4	VVER-440	Mid-1987
Mochovce-1	VVER-440	Late 1987
Mochovce-2 •	VVER-440	Late 1988
Mochovce-3 •	VVER-440	Early 1990
Mochovce-4 •	VVER-440	Mid-1991
Temelin-1 •	VVER-1000	Mid-1990
Temelin-2 •	VVER-1000	Late 1991
Temelin-3 •	VVER-1000	Late 1992
Temelin-4 •	VVER-1000	Late 1993
New-PWR-1 •	VVER-1000	Mid-1992
New-PWR-2 •	VVER-1000	Mid-1993
New-PWR-3 •	VVER-1000	Late 1994
New-PWR-4 •	VVER-1000	Late 1995
New-PWR-5 •	VVER-1000	Mid-1996
New-PWR-6 •	VVER-1000	Mid-1997
New-PWR-7 •	VVER-1000	Mid-1998
New-PWR-8 •	VVER-1000	Mid-1999
East Germany		
Lubmin-1	VVER-440	Late 1974
Lubmin-2	VVER-440	Late 1975
Lubmin-3	VVER-440	Late 1977
Lubmin-4	VVER-440	Mid-1979
Lubmin-5	VVER-440	Mid-1984
Lubmin-6	VVER-440	Late 1985
Lubmin-7	VVER-440	Mid-1987
Lubmin-8	VVER-440	Early 1989
Niedergorne-1	VVER-1000	Early 1990
Niedergorne-2 •	VVER-1000	Mid-1991
Niedergorne-3 •	VVER-1000	Late 1992
Niedergorne-4 •	VVER-1000	Mid-1994
Hungary		
Paks-1	VVER-440	Late 1982
Paks-2	VVER-440	Early 1984
Paks-3	VVER-440	Mid-1985
Paks-4	VVER-440	Mid-1987
Paks-5 •	VVER-1000	Early 1991
Paks-6 •	VVER-1000	Early 1992
Libya		
Sirte-1 •	VVER-440	Mid-1990
Sirte-2 •	VVER-440	Early 1992
Poland		
Zarnowiec-1	VVER-440	Early 1989
Zarnowiec-2 •	VVER-440	Early 1990
Zarnowiec-3 •	VVER-1000	Early 1992
Romania		
Moldavia-1 •	VVER-1000	Early 1993
Moldavia-2 •	VVER-1000	Early 1995
Moldavia-3 •	VVER-1000	Early 1997
USSR		
Armenian-1	VVER-440	Late 1976
Armenian-2	VVER-440	Late 1979
Balakovo-1	VVER-1000	Mid-1985
Balakovo-2	VVER-1000	Early 1987
Balakovo-3	VVER-1000	Early 1988
Balakovo-4	VVER-1000	Early 1990
Bashkir-1	VVER-1000	Mid-1989

Table 3 (continued)
Known Soviet-Origin Power Reactors

Name	Reactor Type	Actual or Earliest Operational Date ᵃ	Name	Reactor Type	Actual or Earliest Operational Date ᵃ
Bashkir-2 ᵃ	VVER-1000	Mid-1990	Kostroma-1	RBMK-1500	Late 1990
Bashkir-3 ᵃ	VVER-1000	Mid-1991	Kostroma-2 ᵃ	RBMK-1500	Early 1992
Bashkir-4 ᵃ	VVER-1000	Mid-1992	Kostroma-3 ᵃ	RBMK-1500	Early 1994
Bashkir-5 ᵃ	VVER-1000	Early 1994	Kostroma-4 ᵃ	RBMK-1500	Early 1996
Bashkir-6 ᵃ	VVER-1000	Early 1995	Khrakov-ATETS-1 ᵃ	VVER-1000	Late 1992
Beloyarsk-1	RBMK-100	Mid-1964	Khrakov-ATETS-2 ᵃ	VVER-1000	Mid-1994
Beloyarsk-2	RBMK-200	Early 1968	Kursk-1	RBMK-1000	Late 1976
BN-350	BN-350	Mid-1973	Kursk-2	RBMK-1000	Early 1979
BN-600	BN-600	Mid-1980	Kursk-3	RBMK-1000	Late 1983
Chernobyl-1	RBMK-1000	Late 1977	Kursk-4	RBMK-1000	Late 1985
Chernobyl-2	RBMK-1000	Late 1978	Kursk-5	RBMK-1000	Mid-1989
Chernobyl-3	RBMK-1000	Late 1981	Kursk-6 ᵃ	RBMK-1000	Mid-1991
Chernobyl-4	RBMK-1000	Late 1983	Leningrad-1	RBMK-1000	Late 1973
Chernobyl-5	RBMK-1000	Early 1987	Leningrad-2	RBMK-1000	Mid-1975
Chernobyl-6	RBMK-1000	Late 1988	Leningrad-3	RBMK-1000	Late 1979
Chernobyl-7 ᵃ	RBMK-1500	Mid-1991	Leningrad-4	RBMK-1000	Early 1981
Chernobyl-8 ᵃ	RBMK-1500	Early 1993	Minsk-ATETS-1 ᵃ	VVER-1000	Early 1989
Chernobyl-9 ᵃ	RBMK-1500	Early 1995	Minsk-ATETS-2 ᵃ	VVER-1000	Early 1991
Chernobyl-10 ᵃ	RBMK-1500	Early 1997	Novovoronezh-1	VVER-210	Late 1964
Crimea-1	VVER-1000	Mid-1988	Novovoronezh-2	VVER-365	Late 1969
Crimea-2	VVER-1000	Mid-1989	Novovoronezh-3	VVER-440	Late 1971
Crimea-3 ᵃ	VVER-1000	Early 1991	Novovoronezh-4	VVER-440	Late 1972
Crimea-4 ᵃ	VVER-1000	Mid-1992	Novovoronezh-5	VVER-1000	Mid-1980
Ignalina-1	RBMK-1500	Early 1984	Odessa-ATETS-1	VVER-1000	Mid-1988
Ignalina-2	RBMK-1500	Late 1985	Odessa-ATETS-2 ᵃ	VVER-1000	Mid-1990
Ignalina-3 ᵃ	RBMK-1500	Mid-1989	Rostov-1	VVER-1000	Early 1987
Ignalina-4 ᵃ	RBMK-1500	Mid-1990	Rostov-2	VVER-1000	Late 1988
Kalinin-1	VVER-1000	Mid-1984	Rostov-3 ᵃ	VVER-1000	Mid-1990
Kalinin-2	VVER-1000	Mid-1986	Rostov-4 ᵃ	VVER-1000	Mid-1992
Kalinin-3 ᵃ	VVER-1000	Mid-1989	Rovno-1	VVER-440	Late 1980
Kalinin-4 ᵃ	VVER-1000	Mid-1990	Rovno-2	VVER-440	Late 1981
Khmelnitskiy-1	VVER-1000	Mid-1987	Rovno-3	VVER-1000	Late 1985
Khmelnitskiy-2	VVER-1000	Mid-1989	Rovno-4	VVER-1000	Late 1987
Khmelnitskiy-3 ᵃ	VVER-1000	Mid-1991	Rovno-5 ᵃ	VVER-1000	Early 1989
Khmelnitskiy-4 ᵃ	VVER-1000	Late 1992	Rovno-6 ᵃ	VVER-1000	Mid-1990
Kola-1	VVER-440	Mid-1973	Smolensk-1	RBMK-1000	Late 1982
Kola-2	VVER-440	Late 1974	Smolensk-2	RBMK-1000	Mid-1984
Kola-3	VVER-440	Early 1981	Smolensk-3 ᵃ	RBMK-1000	Mid-1987
Kola-4	VVER-440	Early 1984	Smolensk-4 ᵃ	RBMK-1000	Early 1989

Table 3 (continued)
Known Soviet-Origin Power Reactors

Name	Reactor Type	Actual or Earliest Operational Date [a]
Smolensk-5 [a]	RBMK-1500	Mid-1990
Smolensk-6 [a]	RBMK-1500	Mid-1992
South-Ukraine-1	VVER-1000	Late 1982
South-Ukraine-2	VVER-1000	Mid-1985
South-Ukraine-3	VVER-1000	Mid-1987
South-Ukraine-4 [a]	VVER-1000	Early 1989
Tatar-1	VVER-1000	Early 1989
Tatar-2 [a]	VVER-1000	Early 1991
Tatar-3 [a]	VVER-1000	Early 1992
Tatar-4 [a]	VVER-1000	Early 1994
Volgograd-ATETS-1 [a]	VVER-1000	Early 1994
Volgograd-ATETS-2 [a]	VVER-1000	Mid-1996
Zaporozhe-1	VVER-1000	Late 1984
Zaporozhe-2	VVER-1000	Late 1985
Zaporozhe-3	VVER-1000	Early 1987
Zaporozhe-4	VVER-1000	Mid-1988
Zaporozhe-5 [a]	VVER-1000	Early 1990
Zaporozhe-6 [a]	VVER-1000	Mid-1991

[a] Planned

Appendix B

Summary of Separative Work Units, by Year and by Reactor Type (Optimum Scheduling)

Year	Reactor Type	MTSWUs	Cumulative MTSWUs
1963	Beloyarsk-1	97	
	Novovoronezh-1	80	
Total		177	177
1964	Beloyarsk-1	10	
	Novovoronezh-1	35	
Total		45	222
1965	Beloyarsk-1	10	
	Novovoronezh-1	35	
Total		45	267
1966	Beloyarsk-1	10	
	Novovoronezh-1	35	
Total		45	312
1967	Beloyarsk-1	10	
	Beloyarsk-2	233	
	Novovoronezh-1	35	
Total		278	590
1968	Beloyarsk-1	10	
	Beloyarsk-2	35	
	Novovoronezh-1	35	
Total		80	670
1969	Beloyarsk-1	18	
	Beloyarsk-2	35	
	Novovoronezh-1	35	
	Novovoronezh-2	86	
Total		174	844
1970	Beloyarsk-1	18	
	Beloyarsk-2	35	
	Novovoronezh-1	35	
	Novovoronezh-2	25	
Total		113	957
1971	Beloyarsk-1	18	
	Beloyarsk-2	35	
	Novovoronezh-1	35	
	Novovoronezh-2	25	
	VVER-440	136	
Total		249	1,206
1972	Beloyarsk-1	18	
	Beloyarsk-2	35	
	BN-350	282	
	Novovoronezh-1	35	
	Novovoronezh-2	25	
	VVER-440	319	
Total		714	1,920
1973	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	171	
	Novovoronezh-1	35	
	Novovoronezh-2	25	
	RBMK-1000	356	
	VVER-440	413	
Total		1,063	2,983
1974	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	171	
	Novovoronezh-1	35	
	Novovoronezh-2	25	
	RBMK-1000	387	
	VVER-440	507	
Total		1,188	4,171
1975	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	171	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	62	
	VVER-440	486	
Total		845	5,016
1976	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	

Summary of Separative Work Units, by Year and by Reactor Type (Optimum Scheduling) (continued)

Year	Reactor Type	MTSWUs	Cumulative MTSWUs
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	774	
	VVER-440	711	
Total		**1,858**	**6,874**
1977	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	183	
	VVER-440	575	
Total		**1,131**	**8,005**
1978	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	954	
	VVER-440	889	
Total		**2,216**	**10,221**
1979	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	516	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	660	
	VVER-440	1,004	
	VVER-1000	295	
Total		**2,848**	**13,069**
1980	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	217	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	809	
	VVER-440	1,276	
	VVER-1000	97	
Total		**2,772**	**15,841**
1981	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	217	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,196	
	VVER-440	1,417	
	VVER-1000	97	
Total		**3,300**	**19,141**
1982	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	217	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	664	
	VVER-440	1,328	
	VVER-1000	392	
Total		**2,974**	**22,115**
1983	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,791	
	RBMK-1500	356	
	VVER-440	1,961	
	VVER-1000	531	
Total		**5,325**	**27,440**
1984	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,231	
	RBMK-1500	44	

Summary of Separative Work Units, by Year and by Reactor Type (Optimum Scheduling) (continued)

Year	Reactor Type	MTSWUs	Cumulative MTSWUs
	VVER-440	1,987	
	VVER-1000	1,513	
Total		5,461	32,901
1985	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,024	
	RBMK-1500	400	
	VVER-440	1,919	
	VVER-1000	1,311	
Total		5,340	38,241
1986	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,736	
	RBMK-1500	184	
	VVER-440	2,395	
	VVER-1000	2,727	
Total		7,728	45,969
1987	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,619	
	RBMK-1500	184	
	VVER-440	2,416	
	VVER-1000	3,351	
Total		8,256	54,225
1988	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	

Year	Reactor Type	MTSWUs	Cumulative MTSWUs
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	2,065	
	RBMK-1500	636	
	VVER-440	2,573	
	VVER-1000	4,691	
Total		10,651	64,876
1989	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,415	
	RBMK-1500	1,392	
	VVER-440	2,960	
	VVER-1000	6,436	
Total		12,889	77,765
1990	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,889	
	RBMK-1500	812	
	VVER-440	2,824	
	VVER-1000	7,165	
Total		13,376	91,141
1991	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,623	
	RBMK-1500	1,308	
	VVER-440	2,913	
	VVER-1000	8,880	

Summary of Separative Work Units, by Year and by Reactor Type (Optimum Scheduling) (continued)

Year	Reactor Type	MTSWUs	Cumulative MTSWUs
Total		15,410	106,551
1992	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,741	
	RBMK-1500	1,328	
	VVER-440	2,866	
	VVER-1000	8,218	
Total		14,839	121,390
1993	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,741	
	RBMK-1500	1,468	
	VVER-440	2,950	
	VVER-1000	9,953	
Total		16,798	138,188
1994	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,800	
	RBMK-1500	1,704	
	VVER-440	2,971	
	VVER-1000	10,125	
Total		17,286	155,474
1995	Beloyarsk-1	18	
	Beloyarsk-2	45	
	BN-350	247	
	BN-600	313	
	Novovoronezh-1	35	
	Novovoronezh-2	28	
	RBMK-1000	1,800	
	RBMK-1500	1,844	
	VVER-440	2,992	
	VVER-1000	10,385	
Total		17,707	173,181