ENC 2005: Nuclear power in Europe

BY DICK KOVAN

While some national programs face curtailment, others are proceeding with new reactor construction.

THROUGHOUT EUROPE, THE indications of a renewed interest in nuclear energy that were seen at ENC 2002 have taken root. Finland is carrying forward the parliament's decision to build its fifth nuclear power plant; the choice of plant has been made, the contract—for a 1600-MWe European Pressurized water Reactor (EPR)—has been signed, and construction has begun. In France, following a lengthy national debate, the National Assembly sanctioned further nuclear construction, and Electricité de France has announced the site for its first new EPR station. Many other European countries have said that the nuclear option remains on the table, and most are following the United States in investing to extend the lives of their operating plants.

At the time of ENC 2002, five eastern European countries with relatively significant nuclear programs were negotiating their joining the European Union (EU). In May 2004, these countries—the Czech Republic, Hungary, Lithuania, Slovakia, and Slovenia—formally joined the EU. All but Slovenia operate Soviet-designed reactors. In order to complete the negotiations, these countries agreed that the safety of their reactors would be brought up to Western standards. In the EU's view, however, the earliest Soviet-designed reactors could not be upgraded to an acceptable level and therefore would have to be closed. These reactors are Bulgaria's Kozloduy Units 1–4, Lithuania's Ignalina-1 and -2, and Slovakia's Bohunice-1 and -2. The agreements finally signed include closure dates for these units.

Despite signing the agreements, all of these countries determined that the safety upgrades they had implemented at these plants should allow them to continue to operate, but EU representatives have refused to change their minds. Nevertheless, these eastern European countries have all made significant progress in improving safety and performance, and all are planning to build more nuclear plants.

Following are reports on the status of the nuclear programs in both eastern and western European countries. The statistics accompanying each report are derived from the *Nuclear News* World List of Nuclear Power Plants (March 2005, p. 35), for the numbers of reactors, and the International Atomic Energy Agency's Power Reactor Information System, for the 2004 electricity production and unit capability factor.

Belgium

Number of operational reactors (total capacity, net MWe), 2004	7 (5801)
2004 production, GWh (share of total, percent)	44 857 (55)
Unit capability factor in 2004, percent	89.5

In mid-2004, Belgium's new federal minister for energy announced a new national energy policy study looking forward to 2030. The study is to be conducted in light of the country's plans to phase out nuclear power. Existing legislation calls for the closure of the country's power reactor units once each reaches 40 years of commercial operation, but with the proviso that an exception can be made on the grounds of security of supply. If this policy does not change, the first nuclear unit would close in about 2015. The government was not helped in its intentions by the results of a report earlier in 2004 by the country's Federal Planning Bureau that said nuclear represented the most effective way for the country to meet its greenhouse gas reduction targets.

The country has seven pressurized water reactors located at two stations, Tihange and Doel, which are owned and operated by Electrabel. The plants generate more than half of the country's electricity. Electrabel also has a 25 percent share in the output of the two Chooz B units in France. Reciprocally, Electricité de France owns half of Tihange-1. Electrabel continues to undertake modernization projects to keep the plants up to the latest standards of safety and performance.

Belgium maintains a considerable fuel manufacturing capability, including plutonium fuel. Belgonucleaire's mixed-oxide (MOX) fuel rod production plant at Dessel continues to provide MOX fuel for plants throughout Europe.

Provisions for dealing with spent fuel and decommissioning the nuclear power plants will be the responsibility of Synatom, in which the government possesses a controlling interest, ensuring that it can block any decision. An interim storage facility for vitrified high-level waste is located at the Belgoprocess site in Dessel. At the end of December 2004, 196 canisters of vitrified high-level waste were in storage there.

Radioactive waste management and disposal are mainly the responsibility of Belgium's waste management agency, ONDRAF. Research is performed by the nuclear research center in Mol (SCK-CEN) and by universities and other research institutes, as well as engineering companies.

The process for choosing a site for a repository for low- and intermediate-level short-lived waste is nearing the final stages. A few years ago, three municipalities agreed to undergo investigations as to their suitability for siting a repository. Once each of the three have decided whether or not to put themselves forward as candidates, ONDRAF believes it can prepare a final proposal for a repository for submission to the government before the end of 2006. The federal government will then decide on not only the specific site, but also on the technical disposal concept, the social integration of the project, and the financing arrangements. A repository can be operational by 2015–2020 at the earliest. Filling the repository will take about 30 years and will be followed by its covering and closure and a monitoring phase of a few hundred years.

ONDRAF also maintains a heavy research program focusing on developing the technology needed for a deep geological repository, in a deposit of what is known as

Boom clay, for irradiated fuel and long-lived high-level and intermediate-level packaged wastes.

In 1995, ONDRAF and SCK-CEN set up a joint geological research venture based at the High Activity Disposal Experimental Site (HADES) underground research laboratory at Mol. The venture is now called EIG EURIDICE—the European Underground Research Infrastructure for Disposal of nuclear waste In a Clay Environment. Its main tasks are:

- Undertaking studies on the feasibility of the disposal of radioactive waste in clay layers.
- Managing the HADES underground disposal research facility.
- Carrying out *in situ* experiments to demonstrate the feasibility of disposing of radioactive waste in deep clay layers.

ONDRAF's 2004–2008 R&D program comprises general research and a spent fuel research program. Besides a variety of geological studies, the general program looks at repository facilities, including:

- Design, testing, and validation of engineered barrier system components.
- A heater test to demonstrate that the behavior of the clay is as predicted under thermal load.
- A plug test to demonstrate the feasibility of hydraulically sealing the disposal galleries.
- Studies on the disturbances caused by deep disposal in Boom clay and on the conditions and retention capabilities of the engineered barrier system.

The spent fuel research program studies specific aspects of irradiated fuel: leach resistance, operational and long-term safety, criticality, repository design issues, containment integrity during the heat-emitting phase (longer than for vitrified wastes), and engineered barrier system conditions and retention.

SCK-CEN continued with its preliminary design work and R&D for Myrrha, the multipurpose accelerator-driven nuclear source, which will also be suitable for transmuting long-lived radioactive wastes into shorter-lived wastes. It will take another few years of these activities before a decision on construction can be made.

Bulgaria

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . . 4 (2722)
2004 production, GWh
(share of total, percent) 15 598 (42)
Unit capability factor in 2004, percent 75.5

In April 2005, the Bulgarian government authorized the construction of a nuclear power station at Belene, on the Danube River, Bulgaria's border with Romania, where work to build two 1000-MWe VVER pressurized water reactors had begun in the 1980s. That project was suspended in 1992 because of financial problems and pressure from environmental groups. The go-ahead for completing a nuclear station at the site followed a series of public discussions on the results of an environmental impact assessment and a feasibility study for the project. Those discussions indicated very strong political and public support for the project at the local and national levels.

Following this decision, the state-owned National Electricity Company (NEK) began a tendering process to choose a contractor to construct the plant. In July, NEK invited two consortia—one led by Russia's Atomstroyexport, and the other, the Consortium Skoda Alliance, led by Skoda JC, of the Czech Republic—to submit final bids to design, construct, and commission two nuclear units at the site. The project involves completing the partially built (about 40 percent) Unit 1, started in 1986, and building a second, more advanced unit. The final contract is expected to be awarded in January 2006, with the first unit scheduled to be operational in 2011, and the second in 2013. A new company will be set up to own and operate the plant, with the government holding a majority stake. The project has an estimated cost of €2–€3 billion ($2.5–$3.7 billion).

For the past decade, NEK's first nuclear station, at Kozloduy, has provided 40–47 percent of the electricity produced annually in Bulgaria. The Kozloduy reactors are the most economical generating units in the country. At the end of 2002, however, NEK was forced to close the two oldest reactors at the station, leaving four units operating. The closure of Kozloduy-1 and -2 was a condition of an agreement reached between the government and the European Commission during negotiations for Bulgaria's joining the European Union (EU). The agreement also calls for Units 3 and 4 to shut down by the end of 2006. Since the agreement was made, Kozloduy has remained an important political issue in Bulgaria, with most politicians and the public demanding that the two units remain in operation beyond 2006.

According to the Bulgarian Atomic Forum, prejudices concerning "the old Soviet-engineered nuclear reactors" in eastern Europe are still strong enough to prevent the commission from taking into account the excellent safety record of the Kozloduy units, as stated by a peer review mission of EU experts in November 2003. The forum also noted that the amount of electricity Bulgaria exports per year to other Balkan countries (about 5900 GWh) is equal to the production of these two reactors. Many Bulgarians remain hopeful that the decision will be reconsidered before 2007, when Bulgaria is set to become a member of the EU.

Kozloduy's reactors were built in pairs, starting in 1970. The first two, VVER-440/230 models, went into commercial operation in the 1970s. Units 3 and 4 were enhanced VVER 230s, which incorporated many of the improved safety features of the 213 model, including stainless steel cladding of the reactor pressure vessel. These two went into commercial operation in the early 1980s. The commissioning of the final two reactors, 1000-MWe VVER-1000/320 models, was completed in 1988 and 1993. The site includes a spent fuel storage facility, as well as an interim storage facility for low- and medium-level radioactive waste.

Following the first safety review undertaken by the International Atomic Energy Agency (IAEA) in 1991, large-scale renovations of Units 1–4 at Kozloduy were implemented. The work was undertaken in close consultation with the IAEA, the World Association of Nuclear Operators (WANO), and the EU to improve safety and bring the reactors closer to international norms. From 1998 to 2002, a more thorough modernization was undertaken in line with IAEA safety criteria to bring the units into conformity with current world standards. This was approved by the Bulgarian Nuclear Regulatory Agency, but only fully implemented on Units 3 and 4. An upgrade and modernization program for Units 5 and 6 will extend to 2006, but there is no great concern about the safety of these units, which conform to international standards.

Backed up by a number of peer reviews, the Bulgarians argue that following extensive renovations to Kozloduy-3 and -4, their level of safety is comparable to that of plants in the West. In 2002, the Bulgarian parliament decided that these units would not be closed down until after Bulgaria had gained EU membership, despite the EU's insistence that they close by the end of 2006, prior to the country's admission. An IAEA mission reported very favorably in July 2002. Then, in 2003, after a two-week scrutiny by 18 international inspectors, WANO reported that the units met all necessary international standards for safe operation. This confirmed the earlier IAEA report. The Bulgarian government is still aiming to renegotiate the agreement to keep Units 3 and 4 operating until their current licenses expire (in 2011 and 2013), giving the units a 30-year operating life.

In 2003, a consortium of BNFL Environmental Services, Electricité de France, and the Bulgarian subcontractor, ENPRO, was awarded a contract to manage the decommissioning of Kozloduy-1 and -2.

Czech Republic

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . .6 (3472)
2004 production, GWh
(share of total, percent) 24 817 (32)
Unit capability factor in 2004, percent 78.9

As part of its preparations for joining the European Union (EU), the Czech government took steps to deregulate its energy

Temelin: Long-range plans envision the possible addition of two more reactors.

market including making plans to sell off shares in Ceske Energeticke Zavody (CEZ), which operates the country's two nuclear power stations, Dukovany and Temelin. An economic downturn, however, forced the government to cancel its plan, as it considered offers from major foreign companies to be too low. Since then, CEZ's financial situation has continued to strengthen, and the company is now the largest enterprise on the Czech stock market, the 10th largest electricity utility in Europe, and the second largest electricity exporter (after Electricité de France).

Just before ENC 2002, Temelin's first unit entered an 18-month trial operation and Unit 2 had started its commissioning phase. The operation of the two 981-MWe VVER-1000 pressurized water reactors has put the nuclear share of Czech electricity production to about 32 percent. Government commitment to the future of nuclear energy remains strong. According to the State Energy Policy of 2004, the government foresees the construction of two large reactors, probably at Temelin, to replace the reactors at Dukovany after 2020.

Construction at Temelin, which began in 1982, was halted at the time of the breakup of the Soviet Union. Later, the government of Czechoslovakia (at that time the Czech and Slovak Republics were still one country) decided to complete two units (four were originally planned). In the course of construction, CEZ made a number of design changes to bring the plant up to internationally accepted safety standards. These included instrumentation and control (I&C) system replacement, new core and fuel, a new radiation monitoring system, an improved primary circuit diagnostic system, and upgraded electrical systems. Other safety improvements introduced included the addition of hydrogen recombiners and new fire protection equipment. New safety analysis reports were prepared, along with a new probabilistic safety assessment, a new approach to accident management, reviews of operating methods, development of a new training system for operational personnel (aided by a full-scope simulator), and adoption of Western reactor core management techniques.

Work at Temelin progressed slowly owing in large part to the difficulty of installing a new digital I&C system, which called for complete recabling of the plant. The cost escalated to nearly $3 billion. Westinghouse was awarded contracts for the new I&C systems, the supply of nuclear fuel and associated components, the diagnostic and monitoring system, and the radiation system.

Dukovany, the Czechs' first commercial nuclear station, with four VVER-440/213 reactors, began operating in 1985. While Dukovany has continued to operate well, in 2003, CEZ began an ambitious upgrade program costing about $425 million. Besides improving its competitiveness and meeting EU safety standards, the aim of the upgrade is to extend the plant's operating license from 30 to 40 years.

As the European Commission considered the Temelin and Dukovany reactors to be upgradeable to Western safety levels, nuclear safety should not have been a major issue in negotiations for the Czech Republic's joining the EU. The neighboring Austrians protested the operation of Temelin, however, and even threatened to veto the Czech Republic's joining the EU. Austrian demonstrators had at times blocked border crossing points between the two countries. Among the consequences, the Czech government and CEZ made the project one of the most open and transparent of any nuclear plant. There was a high-level exchange of information and views with Austria under European Commission mediation (the Melk Protocol) to resolve some of their differences. The Czechs did take some additional safety measures because of these contacts.

In past years there had been a significant Czech uranium production industry that once provided 2500 tU/yr. There is now only one underground mine, Dolni Rozinka, in operation. Although the government had intended to close it this year, rising uranium prices are making it consider extending its operation. The country is able to source its own uranium, but conversion, enrichment, and fuel fabrication have to be done elsewhere. Fuel for Dukovany is supplied by TVEL, and fuel for Temelin is supplied by Westinghouse. Uranium-related activities are carried out by the state-owned Diamo Company, which is now mainly involved in the decommissioning and restoration of some 20 mining and milling sites. The program is expected to last until 2040.

Spent fuel is stored at each plant, first in spent fuel pools and then in dry storage facilities. A low- and intermediate-level waste repository is operated by the Radioactive Waste Repository Authority at Dukovany, which takes wastes from both plants. Attempts to site an underground repository have been unsuccessful, primarily because of local opposition at sites deemed geologically suitable.

Two research reactors are operated by the Rez Nuclear Research Institute and another by the Czech Technical University in Prague. Rez was privatized in 1992 and is now owned by CEZ (52 percent), with Slovak Electric and Skoda also holding shares; the government has one special share. An interim storage facility for spent research reactor fuel is located at Rez. The institute now provides a wide range of services for operators of nuclear power plants and industry, as well as for government agencies, including those involved in energy policy, nuclear safety, radiation protection, and health. It also provides irradiation services, research, radioactive waste management, production of radiopharmaceuticals, education and training, and many other activities.

Finland

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . .4 (2656)
Under construction
(total capacity, net MWe), 2004 . . . . . .1 (1600)
2004 production, GWh
(share of total, percent) 21 779 (27)
Unit capability factor in 2004, percent 93.4

The construction license for Finland's fifth nuclear plant, a 1600-MWe European Pressurized water Reactor being built at Olkiluoto, was issued to Teollisuuden Voima Oy (TVO) in February of this year. TVO had signed the contract for the supply of the plant with Areva and Siemens AG in December 2003 following an extensive and competitive tendering process. The reactor is expected to begin operation in 2009. The project represents the largest ever industrial investment in Finland. TVO was founded in 1969 by a number of companies to build and operate large power plants, supplying the electricity to shareholders at cost.

The government's decision to build a new nuclear plant was approved by the Finnish Parliament on May 24, 2002, a few months before the previous ENC. By then, the question of how to deal with spent fuel had been resolved by Parliament, which ratified the construction of a final repository in the Finnish bedrock at Eurajoki (Olkiluoto) in 2001. Before being put to a vote by Parliament, the local municipality had approved the plan.

The last time Parliament considered the construction of a fifth unit was in 1993. Although the proposal was only narrowly defeated, the industry waited several years before putting forward a proposal again. In 1998, environmental impact assessments at different sites were undertaken and a comprehensive economic case for new nuclear construction was prepared. This case was based on a major cost study published in 2000 that concluded that nuclear is the cheapest option for new power capacity in Finland. The country has few indigenous energy resources, there are no new hydro sources available for development, and even wind conditions are relatively weak in Finland for generating purposes.

Industry has retained good political and public support for nuclear power. Members of Parliament have had open debates and free votes on the issues. The public is widely consulted, and communities affected by major projects have an ultimate veto. Decision-making procedures are clearly defined. For example, in 1983, the government set out its main objectives and a schedule for a national nuclear waste management program that it has kept to.

Finland's four operating reactors, two operated by TVO at Olkiluoto and two by Fortum Heat & Power Oy at Loviisa, generated 21 779 GWh in 2004, more than one-quarter of the country's electricity. All units have recorded world-class capacity factors and reliability throughout their operation. Commercial profitability has also been boosted by extensive modernizations, including upratings, ensuring that the plants can compete in the open Nordic power market. The initial 660-MWe net capacity of the Olkiluoto boiling water reactors, built by Sweden's Asea-Atom (now part of Westinghouse), was increased to 840 MWe in two stages, in 1982–84 and in 1995–98. Fortum's two units at Loviisa are Russian-designed VVER pressurized water reactors supplied by Atomenergoexport, now rated at 488 MWe (net), a 9 percent increase, following a plant improvement program during 1996–98. The Loviisa units have an expected operating lifetime of 50 years. Western safety philosophy has always been applied at the Loviisa units, which are equipped with Western safety automation systems and containments. Until 1996, spent fuel generated at Loviisa was shipped to Russia. It is now stored on site. The state is the majority shareholder in the parent company, Fortum, which also has shares in TVO.

Waste management for both nuclear stations is handled by Posiva Oy, which was set up by the two operators in 1995. The company is now constructing an underground rock characterization facility, called Onkalo, at the Eurojoki repository site. The planned repository will require no monitoring after closure. The government decided, however, that retrievability was a prerequisite. An encapsulation plant will be built aboveground, where the fuel rods will be placed in boron steel canisters that will be enclosed in copper capsules, a technology developed in Sweden.

Posiva operates repositories for low- and intermediate-level waste at Olkiluoto and Loviisa, where the radwaste is placed in caverns and silos excavated in underground rock near the power stations. There are plans to expand the facilities to take decommissioning waste.

The cost of the repository program and other waste management activities is included in the price of nuclear-generated electricity. The money is collected on an annual basis from the generators and deposited into the State Nuclear Waste Management Fund.

Finland's decision to build another nuclear station was driven by the well-known advantages of nuclear energy, most of which are particularly relevant. Finland's energy consumption is one of the highest in the West because of the energy-intensive structure of its industry, its high standard of living, and its cold climate. Half of the energy is consumed by industry, about one-fifth is used for space heating, and more than 10 percent for transportation.

Electricity plays a particularly key role in driving Finland's economy, which enjoys surprisingly low prices, despite the need to import more than 70 percent of all energy consumed. About 50 percent of the primary energy is consumed in electricity generation, which is highly efficient owing to the high proportion of combined heat and power production, which meets one-third of Finland's total power demand, one of the highest figures in the world. Furthermore, in comparison with many countries, Finland is already highly energy-efficient, so gaining a significant improvement will be difficult and expensive. The share of bioenergy in electricity production (based on its forest industry) is the highest of all industrialized countries in Finland, at 13 percent in 2003.

Finland and its Nordic neighbors have formed a common electricity market that is totally deregulated. Despite access to the Nordic electricity market, the possibility of importing more electricity is expected to decline significantly, because there is only limited opportunity to increase hydropower production, and transmission capacity with the rest of Europe and Russia is also limited. The situation will worsen if Sweden fulfills its policy of phasing out nuclear power.

Olkiluoto: At the Unit 3 construction site, the pouring of concrete around reinforcing steel for the base mat began in August.

France

Number of operational reactors
(total capacity, net MWe), 2004 . . . .59 (63 363)
2004 production, GWh
(share of total, percent) 426 800 (78)
Unit capability factor in 2004, percent 83.0

Thanks to the nuclear program launched in the 1970s, nuclear power now accounts for the lion's share of France's power production. In 2004, the 58 commercial power reactors operated by Electricité de France (EdF) generated more than 78 percent of the country's electricity. Hydropower accounted for 12 percent. Domestic consumption was 477.2 TWh, and EdF exported 60 TWh. This means that France imported only half of its total energy requirements, compared with 74 percent in 1973.

The surprisingly large victory of the pronuclear center-right coalition in the elections of 2002 has allowed a strong pronuclear energy policy to develop. The leading role played by nuclear energy was confirmed in legislation passed on July 13, 2005, that laid down the outline of France's energy policy. Before the government put together its energy bill, a lengthy national energy debate was organized, starting in 2003. The debate concluded that nuclear power should continue to play a key role in the French energy mix. Two issues considered in the debate were the need to replace the existing fleet of nuclear power plants starting around 2020, and global warming. The new legislation not only keeps the nuclear option open, but also includes commitments to reduce greenhouse gas emissions. To fulfill the policy, the government says it will optimize the use of renewables, nuclear power, and technological innovations.

With this legislation passed, the government agreed to EdF's request to build a European Pressurized water Reactor (EPR) as a demonstration project to ensure that the capability to replace its current reactors at the end of their lifetimes with EPRs is available. EdF plans to build its first 1600-MWe EPR at Flamanville for operation in 2012. As a final step before construction begins, however, a national public debate on this specific project is being held between October 2005 and February 2006, with major meetings organized in the largest towns and cities throughout the country. The aim is to ensure that the Flamanville project does not go ahead without the public's having every opportunity to raise questions and debate the issues.

France is also looking beyond the EPR. The government is actively participating in the Generation IV initiative on the development of the next generation of nuclear reactors. In February 2005, Canada, France, Japan, the United Kingdom, and the United States signed a framework agreement in Washington, D.C., heralding the start of operational cooperation for the Gen-IV program.

Flamanville: The addition of a third unit (an EPR) already has official approval, but a public debate must be completed before work can begin.

Beyond that, France, on behalf of the European Union, has won the battle to site the International Thermonuclear Experimental Reactor, which will be constructed at the Cadarache nuclear research center. The French government worked hard to win this project in order to ensure that the Commissariat á l'Energie Atomique (CEA) remains at the forefront of nuclear research and development.

Earlier in this decade, with nuclear's prospects not looking particularly bright, France's extensive activities as a reactor vendor and a provider of fuel cycle services and R&D were consolidated into a single organization. The first step was the merging of the nuclear activities of Framatome and Germany's Siemens company to create Framatome ANP in January 2001. In September 2001, CEA-Industrie, Cogema, and Framatome ANP were organized into a new holding company called Areva. The Areva name is now used to promote the group, which has seen considerable success, with major nuclear orders in China, as well as the sale of its first EPR to Finland and the planned Flamanville project.

Investigations into the long-term management of high-activity and long-life nuclear waste have also made progress. Under the terms of what is called the Bataille Act, adopted in 1991, a research program was set up to investigate three areas: partitioning and transmutation of long-lived radwaste into short-lived material, retrievable and nonretrievable disposal in deep geological layers, and improving packaging and storage. The work was to be completed in 15 years, after which the government must submit to parliament an overall appraisal of the research and a policy proposal for managing the waste in 2006. The research is led by the CEA and Andra, the national agency for the management of radioactive waste, which have already submitted the summary reports for their areas of responsibility. A public debate has started on their results.

Short-lived low-level and intermediate-level radioactive waste is disposed of at two sites: the Manche repository, which is now filled and in the process of being closed, and the Aube disposal center in Soulaisne, which opened in 1992. A storage center for VLLW (very low-level waste) has started up near Aube.

The government is planning to complete the opening of the electricity market by July 2007 as required under EU directives. More than any other European country, France has resisted opening its electricity market, particularly because EdF has been used by successive French administrations as an instrument of public policy to provide employment and drive the economy. In the meantime, while EdF has benefited by being able to enter the open markets of other countries, other companies have found it very difficult to penetrate the French market.

In July 2004, parliament authorized the government to sell up to 30 percent of its shares in EdF. This November, the government gave the go-ahead for selling off just 15 percent. The government said that EdF needs the funds for new investments, adding that as the world's leading nuclear operator, the company must be given the means of consolidating and building on its success. At the same time, however, the prime minister decided to shelve plans for the partial privatization of Areva.

In the field of enrichment, Cogema's Eurodif subsidiary, which operates the Georges-Besse plant, a gaseous diffusion facility with a capability of 10.8 million separative work units (SWU), supplies about half of Europe's uranium SWU market. Because diffusion requires a large amount of power, Cogema has decided to replace the plant with a centrifuge facility.

Section continued

Obrigheim: The reactor closed during 2005, but utilities hope to delay the closure of any more reactors.

Germany

Number of operational reactors
(total capacity, net MWe), 2004 . . 18 (20 643)*
2004 production, GWh
(share of total, percent) 158 390 (32)
Unit capability factor in 2004, percent 89.1
* includes Obrigheim, which closed during 2005

The German federal election held on September 18, 2005, did not result in the expected clear victory of the pronuclear Christian Democrats over the Socialist/Green coalition. This means that the nuclear industry's expectation that Germany's nuclear phaseout legislation would be reversed will not be realized as soon as it had thought. Because, however, the industry does not believe that the energy policy of the previous government is economically viable in the long term and would not meet the government's Kyoto commitments to limit greenhouse gas emissions, it does expect important changes. Furthermore, the industry believes that the attitude of the German public toward nuclear power is becoming more pragmatic, as it now understands that the consequences of replacing nuclear power with renewable energy sources will be higher energy prices, as well as higher emissions.

While new construction remains unlikely, the industry is looking forward to eventually being able to extend reactor lifetimes, initially to 40 years (from the 32-year average under the 2002 phaseout legislation) and then individually seeking extensions to 60 years, as in the United States. Some sort of legislation would have to be passed to allow an extension, and so the industry is looking at various alternatives. The issue of final storage of waste, however, is probably in more urgent need of a political solution.

On the whole, 2004 was a good year for nuclear power in Germany. Nuclear power plants have continued to perform exceptionally well, fuel transports were carried out without any major interruptions, the construction of interim storage facilities progressed, and there were few antinuclear demonstrations. With 18 plants still operating throughout 2004, nuclear generation reached 158 390 GWh, exceeding the previous year's electricity production. For the sixth consecutive year, the Isar-2 reactor was the top performer, generating 12.2 TWh.

Despite operating a comparatively small number of reactors, Germany produced the fourth-highest amount of electricity in 2004, behind the United States, France, and Japan. While all nuclear plants are operated largely in the baseload regime, some run for a time in load-following and frequency stabilization modes. Nuclear actually accounted for about half of the baseload generation in Germany last year.

Under the terms of the phaseout agreed to by the main utilities, the maximum production of each reactor was capped, equivalent to an operational life of 32 years. The agreement also prohibited the construction of new nuclear power plants for the time being. The operators also agreed to stop sending fuel for reprocessing after 2005; this required that on-site storage of spent fuel be constructed at several plants. In addition, the utilities agreed not to restart the Mülheim-Kärlich unit, which state authorities had prevented from operating since 1988. Since the agreement was reached, two stations have closed—Stade in 2003, and Obrigheim in 2005—leaving 17 operational units. The permit to begin decommissioning the Mülheim-Kärlich plant was issued in July 2004.

The previous government also severely disrupted the waste management program, having opposed the use of the Gorleben salt dome for the construction of a high-level waste repository, and the Konrad mine as a repository for all low-heat generating waste. The Green party environment minister said he had severe doubts with regard to the suitability of the Gorleben site, and he temporarily stopped the underground exploration at the site (the "Gorleben moratorium"), insisting that sites in other host rocks be investigated for their suitability. Furthermore, the licensing procedure for the Konrad repository project was terminated. The government then came up with a plan to develop a single repository in a deep geological formation for the disposal of all types of radioactive waste.

As it happened, in October 2005 the Federal Office for Radiation Protection confirmed the suitability of rock salt as a host medium for a repository. This uncertainty was one of the reasons given by the previous government for stopping further exploration at the Gorleben site. According to Walter Hohlefelder, president of the German Atomic Forum, this means that "the issues of doubt concerning [the suitability of] the Gorleben salt dome raised by the Federal Government have been cleared," and the exploration could therefore continue.

Some other nuclear projects have progressed at long last. The Heinz Meier-Leibnitz research reactor at Garching (FRM-II) has been commissioned, the final stage of expansion of the Urenco enrichment plant in Gronau has been approved, and the license for a capacity increase in the Advanced Nucler Fuels GmbH fuel fabrication plant in Lingen has been granted.

Hungary

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . . 4 (1755)
2004 production, GWh
(share of total, percent) 11 209 (34)
Unit capability factor in 2004, percent 72.7

The Paks nuclear station houses four reactors that in 2004 generated about 34 percent of Hungary's electricity. The government and the Hungarian public believe that security of supply cannot be maintained without nuclear power, which is also considered the cheapest way to reduce greenhouse gas emissions. Without nuclear power, the government says, its Kyoto targets for reducing emissions cannot be met.

Based on these considerations, the government has said that the nuclear option will remain an element of Hungarian energy strategy over the next 20 years and that it is ready to provide the necessary political support for ensuring the extended operation of the Paks plant beyond its original 30-year design lifetime.

The four Paks units, all second-generation VVER-440/213 reactors, were supplied by Russia's Atomenergoexport. The construction of the first two units started in 1974, and of the second two, in 1979. The plants were connected to the grid between 1982 and 1987. A subsequent modernization program has increased the ratings of Units 2 through 4 from the basic 440 MWe to 460 MWe, and Unit 1 to 470 MWe.

In the past five years, extensive work has been done to prepare the case for extending the operating license. An expert team has prepared a detailed assessment of the plant status, the aging and lifetime prognosis of plant structures, systems, and components, and defined the renovation that is needed. The assessment showed that the continuation of operation for another 20 years is feasible. Paks also plans to increase each unit's electrical power to 500 MWe.

The Paks plant was the first of the former Soviet Bloc reactors to be upgraded to meet modern safety standards. It was also the first plant to undergo a peer review by the World Association of Nuclear Operators.

Between 1996 and 2002, a program of safety improvements was initiated based largely on the results of the Advanced General and New Evaluation of Safety (AGNES) project, which reevaluated the safety of the plant according to Western standards using up-to-date assessment tools. AGNES revealed no dramatic new conditions to challenge the fundamental safety of the units. The subsequent $300-million modernization program, using the plant's own internal resources, included the following:

- Renovation of the reactor protection system.
- Improvements in seismic safety.
- Replacement of instrumentation and control cable penetrations and cable using loss-of-coolant accident–resistant cables.
- Enhancement of fire safety.
- Implementation of steam generator leak management measures.
- Modification of the primary overpressure protection system.
- Addition of emergency iodine filter systems.
- Implementation of measures to reduce human error potential.

Independent international reviews, including an International Atomic Energy Agency Operational Safety Review Team (OSART) mission in 2001, confirmed that the safety upgrade program has raised technical standards to the level of those of Western nuclear plants of the same age. To date, all vessels have maintained their material toughness with adequate safety margins. The OSART team noted some good initiatives, including a program to improve standards in material conditions and housekeeping throughout the whole plant and a "pool of talents" program to develop the managerial and technical potential of its workforce.

In April 2003, however, an incident occurred that caused the plant operators to take a new look at safety performance. During a fuel cleaning operation, some fuel elements in a cleaning tank were severely damaged when the fuel overheated. While the cause of the incident was soon established, assessments by the plant, the Hungarian safety authority, and the IAEA pointed to some underlying problems in safety culture. The plant then instituted a number of measures to strengthen the culture at all levels of the organization, from top management down.

For a time in the 1980s and early 1990s, Hungary mined uranium ore, sending yellowcake to Russia, which supplied the plants with fuel assemblies. It now sources uranium from other countries. While fuel assemblies still come from Russia, contracts are now awarded through an open bidding process.

Spent fuel from the early years of Paks operation was sent to the Mayak reprocessing facility in Russia. These shipments ceased in 1995. Spent fuel is now stored at the site in a modular vault-type dry storage system that began taking fuel in 1997; extensions in storage space are made as the need arises. There are also treatment and storage facilities for radwaste at the station. Preliminary geological investigations for a repository for spent fuel and high-level waste are being carried out at abandoned uranium works. A Central Nuclear Financial Fund was set up to finance waste management and decommissioning at the Paks station.

A waste treatment and disposal facility for institutional (non-nuclear power) low- and intermediate-level waste has been operated at Püspökszilágy since 1976. Investigations to find a suitable location for a new repository for all such waste identified a site at Bátaapáti. Earlier this year, the local community voted to approve the project.

The Atomic Energy Research Institute (KFK AEKI) operates the 10-MWe Budapest Research Reactor, which started up in 1959 and was rebuilt in 1991, and the Technical University of Budapest operates a 100-kW training reactor.

Lithuania

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . .1 (1187)
2004 production, GWh
(share of total, percent) 13 917 (72)
Unit capability factor in 2004, percent 68.9

After the breakup of the Soviet Union, Lithuania was left with two operating nuclear reactors at Ignalina, which were built to provide power to a region well beyond its borders. While this meant that the country could earn substantial revenue by exporting power to its neighbors, the international pressure to close down the RBMK Chernobyl-type reactors was intense, particularly from European Union countries, which considered them "non-upgradeable" to acceptable safety standards.

Despite having to agree to close down its only nuclear power plant as a condition for admission to the EU, Lithuania's energy policy is to remain a nuclear country. At the International Ministerial Meeting on nuclear power in March of this year, the government said it would welcome other countries' investing in new nuclear units in Lithuania. In the meantime, the government continues to explore ways to keep the remaining operating unit, Ignalina-2, running through 2025, well beyond the current 2010 deadline for closure. There remains considerable public and political support within the country to keep the plant operating, as its importance to the economy is recognized.

Ignalina consisted of two 1500-MWe RBMK boiling light-water graphite-moderated reactors, which had been downgraded to 1300 MWe. Unit 1 was declared commercial on May 1, 1984. Unit 2 was to begin operating in 1986, but commissioning was postponed for a year after the Chernobyl accident. Construction of a third unit,

Ignalina: The planned closure of Unit 2 in 2009 is now being rethought by some officials.

which began in 1985, was suspended in 1989, and the existing structure was later dismantled.

Lithuania, like most countries in the Soviet Bloc, felt it had little choice after gaining independence but to keep its nuclear plants operating. Adopting a highly transparent policy in operating the plant, Lithuania sought international assistance to help improve safety. Sweden was the first country to provide the operator with both financial and technical assistance, starting in 1992. With this support, Ignalina undertook an engineering assessment to identify strengths and weaknesses of the plant. This led to the establishment of the first Safety Improvement Program (SIP), which was carried out from 1993 to 1996. SIP 1 was financed from the plant's own funds, as well as through grants from the European Bank for Reconstruction and Development's (EBRD) Nuclear Safety Account and other assistance from Western countries, including the United States, but mainly from Sweden via the Swedish International Project on Nuclear Safety.

While the SIP focused on improving safety, under the terms of the agreement with the EU Lithuania undertook to shut down Unit 1 before 2005, and Unit 2 by the end of 2009. Unit 1 was shut down on December 31, 2004, as promised.

In return for Lithuania's shutting down the reactors, the EU promised substantial assistance, not only for decommissioning the plant, but to compensate for the social and economic impact of the plant's closure. Lithuania has said that if the needed financing is not provided, it will keep Ignalina-2 operating. In the meantime, Lithuania is planning to modernize its electricity system and to construct new fossil plants after 2010, although it would prefer to continue to operate Unit 2, as well as construct more nuclear capacity, if possible.

In 2001, the European Commission, together with 10 European countries, set up the Ignalina International Decommissioning Support Fund (IIDSF) at the EBRD, which provides funds to help Lithuania carry out the closures. Besides decommissioning activities, IIDSF has financed new boiler stations for the plant and for the nearby town of Visaginas as a substitute source of steam and heat in place of Ignalina-1. It also set up an "energy support package" to provide financial assistance for Lithuania's energy sector after the closure of the plant. The objective is to increase reliability and efficiency of energy use in Lithuania.

As a first major step, a consortium of European companies, led by Britain's NNC Ltd., was awarded a contract to set up a project management unit (PMU) to manage the preparation for decommissioning. The consortium, which also includes Belgatom and SwedPower International, together with their subcontractor, STEAG (Germany), was jointly staffed by Ignalina personnel. Financing comes from both the state Ignalina decommissioning fund and the IIDSF.

The main goal of the PMU team was to work out the final decommissioning plan for Unit 1, including the fuel unloading program. The projects undertaken included:

- Construction of the heat and steam plant to supply station needs after shutdown.
- Construction of a dry spent fuel storage facility.
- Construction of a storage facility for low- and intermediate-level waste.
- Construction of a facility for burning combustible low-level waste.
- Development of an archive and database for the decommissioning projects.

With the closure of Unit 1, Ignalina is transferring its usable fuel to Unit 2. As this operation does not directly affect the shutdown of Unit 2, the IIDSF donors refuse to finance it.

Separate from the decommissioning, a second SIP program is continuing. Projects under SIP 2, which started in 1997, include:

- Commissioning of interim spent fuel storage casks.
- Replacement of the instrumentation and control system with a state-of-the-art system.
- Commissioning of a full-scope replica simulator.
- Installation of a number of safety and protection systems.

During 2004, a Diverse Shutdown System was installed, and the Safety Analysis Report (SAR) was completed for Unit 2. The SAR was one of the key technical documents needed to obtain a long-term operating permit for the unit, which will allow it to operate beyond 2010 if a political agreement with the EU can be achieved.

The Netherlands

Number of operational reactors (total capacity, net MWe), 2004	1 (449)
2004 production, GWh (share of total, percent)	3605 (4)
Unit capability factor in 2004, percent	91.1

After winning the 2002 elections, the current government abandoned the antinuclear policy of the previous center-left coalition, which was to close the country's sole operating nuclear power plant, Borssele, the following year. Although not all members of the new government (a coalition of liberals and Christian Democrats) support nuclear power, they did agree to postpone the closure of Borssele for 10 years, until the end of 2013. Recently, negotiations have started between the government and Elektriciteits Produktiemaatschappij Zuid (EPZ), the owner of the plant, to consider the possibility of yet another extension of the lifetime period in exchange for investing in renewables, energy conservation, and clean fossil fuels. It is now likely that the Borssele plant will continue generating as long as it is safe and economically viable to do so.

Furthermore, aware of the growing concerns over energy supply and global warming, the government has said it cannot rule out a greater reliance on nuclear energy. A government representative has said, however, that investments in new nuclear plants are not very likely. The government will nevertheless review existing national laws and regulations to ensure that there is clarity about the conditions under which new units could be built in the future. In this context, special consideration will be given to the issue of radwaste, as well as to the measures required to prevent terrorist attacks on nuclear installations. The government also said it would continue to support nuclear research.

Borssele, a 449-MWe pressurized water reactor, started commercial operation in 1973. Between 1995 and 1997, EPZ undertook a major modernization program (costing about €250 million; about $294 million). Recently, EPZ received a license to increase the enrichment of the fuel it uses, to achieve a higher burnup. Also, improvement to the turbo-generator system will facilitate an increase in power level of 30 MWe. In 2004, Borssele produced 3.6 TWh (net), or 3.8 percent of total power consumed in Holland, which has to import electricity from other countries.

In 2004, EPZ extended its fuel reprocessing contract with Cogema. After considering the possibility of abandoning the reprocessing route, EPZ decided that because all of its facilities are designed for reprocessing, the company would continue the policy.

Commercially, uranium enrichment is the most important part of the fuel cycle for the Netherlands. Urenco Nederland BV has a license for a production capacity of 2800 tonnes of separative work units per year (tSWU/y) and plans to increase it to 3500 tSWU/y.

NRG (the Nuclear Research and consultancy Group) undertakes most nuclear R&D in the Netherlands. The company operates the High Flux Reactor (HFR) in Petten, one of Europe's major research reactors and the main producer of radioisotopes and radiopharmaceuticals for the whole of Europe. The HFR is also used for materials irradiation, fuel development, and research into actinide burning. Work has recently started to convert the reactor from using high-enriched to low-enriched uranium. It should be completed by summer 2006. NRG, along with Mallinckrodt and the European Commission Joint Research Center, have launched a study on constructing a replacement research reactor at Petten. The HFR, which started operations in 1961, is expected to operate only until 2015.

NRG also carries on long-established research in Holland on advanced reactors, notably the high-temperature reactor (HTR). The company undertakes research and other services for the South African Pebble Bed Modular Reactor (PBMR) project. NRG is also developing its own HTR concept called ACACIA (AdvanCed Atomic Cogenerator for Industrial Application), a small high-temperature reactor of about 60 MW, designed for countries with little or no infrastructure.

High-level waste is stored in HABOG, a dry-storage facility operated by the Central Organization for Radioactive Waste (COVRA). Vitrified high-level waste returning from British Nuclear Fuels plc (U.K.) and Cogema (France) will be stored there, together with the spent fuel from the research reactors in Petten and Delft, for up to 100 years. COVRA also operates facilities for the treatment and storage of low- and intermediate-level radioactive wastes at Borssele. In early 2002, the shares in COVRA were transferred from the utilities and research organization to the government.

Romania

Number of operational reactors (total capacity, net MWe), 2004	1 (706)
Under construction (total capacity, net MWe), 2004	4 (2566)
2004 production, GWh (share of total, percent)	5144 (10)
Unit capability factor in 2004, percent	89.4

Romania has one operating nuclear plant, Cernavoda-1, a CANDU 6 reactor designed by Atomic Energy of Canada Limited (AECL). In 2004, the plant, which is located on the Danube River, generated 5144 GWh of electricity, 10.07 percent of the country's total. The plant, which is owned and operated by S. N. Nuclearelectrica (SNN), has performed extremely well since startup in 1996.

Cernavoda-1 is the first of five units planned for Cernavoda in the late 1970s. The lack of financial resources and a drop in power demand after 1990 resulted in the suspension of construction work on Units 2–5. In 2000, the government made the completion of Cernavoda-2 a high priority and provided some €60 million (about $71 million) to the project. Further funding was raised in 2002–03, with a €382.5-million package announced by the government, including €218 million (about $257 million) from Canada. In 2004, a €223.5-million (about $264 million) Euratom loan was approved by the European Commission for the completion of Unit 2, including safety upgrades.

The construction of Cernavoda-2 was resumed in March 2003. AECL, in partnership with Ansaldo (Italy) and SNN, is managing the project, which has a total cost of €777 million (about $916 million). The new Liberal-Democratic coalition government continues to support the project as an important element in rehabilitating the country's aging power system, ensuring security of supply, and reducing CO_2 emissions.

The completion of Unit 3, currently kept in a "state of preservation" along with Units 4 and 5, is also on the government's agenda. Financing is expected to be organized early in 2006, with construction starting by the end of 2007 and plant commissioning planned for 2010–2011. The unit was almost 15 percent completed when construction stopped, including the civil works for the reactor containment, turbine building, and service buildings. Very little equipment or materials had been supplied.

The government has said that Unit 3 must be carried out as a private venture, probably with foreign investment, and without state guarantees. Several potential investors were approached in 2003–2004, including AECL (Canada), Ansaldo and Enel (Italy), CENG DEMIR (Turkey), KHNP (Republic of Korea), and AFEN and ISPAT SIDEX (Romania).

SNN has announced a declaration of intent to complete Cernavoda-4 and -5 by 2020.

Despite the fact that 60 percent of its generating plants are over 20 years old and do not operate at full capacity, Romania, which exported about 1 billion kWh in 2004, is the second biggest power exporter in the region after Bulgaria.

Romania is self-sufficient in uranium and heavy-water production. It is the largest producer of crude oil in central and eastern Europe, with proven reserves of 1.2 billion barrels, and has useful natural gas reserves. Current crude oil and natural gas production covers half of local demand. It also has extensive coal deposits, but they are of poor quality.

The state-owned SNN, formed in 1998, has three branches: CNE PROD, which operates Cernavoda-1; CNE INVEST, which is in charge of completing Unit 2 and preserving the remaining three units; and FCN-Pitesti, the nuclear fuel manufacturer.

FCN-Pitesti, a licensed CANDU 6 fuel manufacturer, provides all the fuel for the plant. In 2004, it completed an expansion program that doubled its capacity and started manufacturing the fuel for the initial load of the second unit.

The government established the Romanian Nuclear Agency to provide technical assistance in developing policies in the nuclear area as well as to promote and monitor nuclear activities in Romania. The back end of the fuel cycle is the responsibility of the Romanian National Agency for Radioactive Waste Management (ANDRAD). Set up in 2004, ANDRAD is now developing the secondary legislation on waste management, final disposal, and decommissioning of nuclear facilities.

Spent fuel is stored at the reactor site for up to eight years. It is then sent to the dry storage facility based on the Macstor system designed by AECL. The first module was commissioned in 2003. At final capacity, this interim storage, designed for 50 years of operation, will have 27 modules.

Preliminary studies are being carried out concerning a deep geological repository. The construction of a low- and intermediate-level waste repository is planned at a site near Cernavoda.

The Romanian Authority for Nuclear Activities, founded in 1998, undertakes R&D and design development in nuclear safety, nuclear fuel, radiological protection, and other topics. It also produces the heavy water for Cernavoda. The safety authority is the National Commission for Nuclear Activities Control, which was set up under the

Cernavoda: Construction is now well advanced on Unit 2.

Nuclear Act of 1996. It licenses nuclear sites and operations.

A 14-MWt TRIGA research reactor operating at the research center at Pitesti is being converted from high-enriched uranium (HEU) to low-enriched uranium under an IAEA project. The HEU will be returned to the United States. Also, a 2-MW Russian research reactor is being decommissioned at the Bucharest-Magurele facility.

Russia

Number of operational reactors
(total capacity, net MWe), 2004 . . . .31 (20 843)
Under construction
(total capacity, net MWe), 2004 . . . . . .6 (5275)
2004 production, GWh
(share of total, percent) 133 017 (16)
Unit capability factor in 2004, percent 75.4

Russia's 31 operating reactors at 10 nuclear power stations provide 16 percent of total electricity production in the country (21 percent in the European part of Russia). In 2004, the output of Russian nuclear plants was 133 017 GWh, 96 percent of the production in 2003. The capacity factor was 73 percent, below the record 76 percent achieved in 2003.

During a cabinet restructuring in 2004, the Ministry for Atomic Energy was replaced by the new Federal Atomic Energy Agency (FAEA, known as Rosatom), which reports to the Russian president. Its commercial entities include Rosenergoatom, the nuclear power operator; TVEL, which is responsible for fuel activities; and Atomstroyexport, which is responsible for foreign construction projects.

Nuclear power, which is the most dynamic branch of Russia's electric power industry, underpins the electricity grid structure in the European part of the country. Under the government's *Energy Strategy to 2020*, which was approved in 2003, nuclear power is expected to generate 23 percent of the country's total power, while meeting 50 percent of the increase in demand.

During the 1990s, with the country under severe economic pressures, there was little investment in nuclear plants. The situation began to change in December 2001 when Volgadonsk-1 (previously called Rostov), a VVER-1000, went into commercial operation. In 2004, Unit 3 at Kalinin began operation. Another milestone was the completion of life extension work in 2001 on the country's oldest operating VVER-440, Novovoronezh-3, allowing licensed operation beyond the 30-year design lifetime. Rosenergoatom is now providing substantial investment to extend the operating lifetimes of its reactors and improve capacity factors; it hopes to achieve an overall plant average of 80 percent by 2006, and 85 percent by 2011.

Under the current plan, Russia will commission three VVER-1000 units by 2011: Volgodonsk-2, Balakova-5, and Kalinin-4. Russia has been working on an advanced BN-800 (an 800-MWe sodium-cooled fast reactor), which is expected to be commissioned at Beloyarsk after 2011. A prototype lead-cooled fast reactor (BREST-300), which is part of the Generation IV International Forum program, is also planned for construction at Beloyarsk. The authorities have also suggested that the partially built Kursk-5, a graphite-moderated, water-cooled RBMK reactor, might be completed. Russia is also developing a 1500-MWe VVER design and plans to build barge-mounted nuclear power plants, nuclear/pumped storage power plants, more nuclear heat and power plants, and nuclear power/aluminum production plants.

Russia's Atomstroyexport is constructing several foreign nuclear power plants, including two VVER-1000 units in China (Tianwan), two in India (Kudankulam), and a single unit in Iran (Bushehr). The company was also involved, along with Framatome ANP, in the completion of the Khmel'nitskiy-2 and Rovno-4 projects in Ukraine and is bidding for new projects in China.

Russia continues to be the main supplier of fuel services for VVER reactors, supplying the fuel for some 76 power reactors in 13 countries, or 17 percent of the global market. Over 40 percent of global enrichment services are of Russian origin.

Russia had hoped to develop a market for the storage of foreign spent fuel. There has been a proposal, backed by the U.S. Nonproliferation Trust Project, to build a spent fuel storage facility in far eastern Russia, but the transport of fuel from likely customers, such as Japan, Korea, and Taiwan, requires U.S. consent. Until the issue of Russia's assistance to Iran is resolved, this is unlikely to be given. In fact, the Iran issue has stopped virtually all cooperation between the two countries on civil nuclear projects. Only programs designed to prevent weapons proliferation or nuclear terrorism are going ahead.

Since the first shipment of low-enriched uranium was sent to the United States under the "Megatons to Megawatts" program, Russia has delivered about 7350 metric tons (t) of material downblended from 250 t of high-enriched uranium—half of the total 500 t envisaged by the agreement. In terms of nuclear disarmament, this means the irreversible dismantling of about 10 000 warheads. All the monetary proceeds from implementing the agreement are channeled to the Russian federal budget. This is a source of financing for programs to improve the safety of Russian nuclear power plants, the conversion of defense enterprises, and the environmental rehabilitation of contaminated territories.

Russia's nuclear fuel cycle facilities are operated either by the FAEA or by its joint stock companies, such as TVEL. Excess capacities are offered to foreign utilities on a commercial basis. Russia has four centrifuge enrichment plants with a total capacity of 15 000 tSWU/yr. Nuclear fuel fabrication is carried out by TVEL at two plants, Electrostal and Novosibirsk. Spent fuel from the VVER-440 reactors, the BN-600 fast reactor, and naval reactors is reprocessed at Mayak. Recycled uranium is used in fresh RBMK fuel, while separated plutonium is stored. High-level wastes are vitrified and stored. No repository for high-level waste is yet available.

A mixed-oxide fuel plant for disposing of military plutonium under a disposition agreement with the United States is planned for construction at Seversk, in Siberia, based on a French design.

Slovakia

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . .6 (2442)
Units under construction
(total capacity, net MWe), 2004 . . . . . . .2 (810)
2004 production, GWh
(share of total, percent) 15 624 (55)
Unit capability factor in 2004, percent 84.2

In February 2005, Slovakia's economics minister authorized the sale of 66 percent of Slovenské Elektrárne, the country's nuclear operator, to Italy's Enel S.p.A. for €840 million (over $1 billion). Slovenské Elektrárne, which operates six Russian-designed VVERs, is the largest electricity generator in Slovakia and the second-largest in central and eastern Europe. The company's reactors generated more than 15 000 GWh in 2004, supplying over half of the country's power. The Slovakian power system is in a strategic position in the heart of Europe, with good power connections to both eastern and western European markets. When the last nuclear unit began commercial operation, Slovakia became both self-sufficient in electricity supply and a power-exporting country. The government remains strongly committed to the future of nuclear energy, which also has good public support.

Slovakia's six nuclear power reactors include Bohunice-1 and -2 (also known as Bohunice V1), first-generation VVER-440/230 reactors, and Bohunice-3 and -4 (Bohunice V2) and Mochovce-1 and -2, which are second-generation VVER-440/213s. The Bohunice units began supplying electricity to the grid between 1978 and 1985. The Mochovce units began operation in 1998 and 2000 after undergoing significant upgrades, including the replacement of the instrumentation and control systems, with assistance from Western companies. Work on two more units at Mochovce was halted in 1994.

As a condition of joining the European Union, the Slovak government agreed to

Bohunice: Despite extensive upgrades, Units 1 and 2 are to be shut down.

close the Bohunice V1 units in 2006 and 2008 because of perceived safety deficiencies in these early models, despite a $250-million reconstruction program completed in 2000. The refurbishment included the replacement of the emergency core cooling systems and modernization of the control systems. Most of the work was financed by the operator, who claims that all the design safety deficiencies have been overcome by the upgrade, and this has been confirmed by all international expert safety review missions. In 2001, the operating licenses of the two units were extended for another decade. This added weight to the Slovak government's view that the European Commission was wrong to demand their early closure, a view shared by Slovak industry and the general public.

Since 1990, significant improvements have raised the safety level of Bohunice-3 and -4 to that of western European reactors of the same vintage. The condition of the pressure vessels indicates that annealing will not be necessary. The ongoing modernization program (1999–2008) includes, for example, the installation of in-service diagnostic systems, the renovation of instrumentation and control systems, the improvement of electrical systems, and fire and seismic upgrading, with a view to extending operational life to 40 years (2025).

Nuclear plant construction started at Mochovce in 1983 but was suspended in 1993, when Units 1 and 2 were 90 and 75 percent complete, and Units 3 and 4 were between 30 and 40 percent complete. Work on the first two was revived in 1995. Unable to get funding for the project on acceptable terms from the European Bank for Reconstruction and Development, the Slovak government arranged financing from Czech, French, German, Russian, and Slovak banks. The project, implemented by a consortium of Framatome, Siemens, and Russian suppliers, made Mochovce the first Soviet-designed reactor to meet international safety standards.

Preservation work has been carried out on Units 3 and 4 since 1992. While the government remains supportive of nuclear power and wants the two units to be completed, it has said it would not help finance the project.

The management of Slovakia's radioactive waste, spent fuel, and decommissioning is handled by a branch of Slovenské Elektrárne, SE-VYZ, which operates facilities at both power plant sites. The Bohunice radioactive waste processing center treats most liquid and solid wastes generated from the operation of the nuclear plants and other users (medical, research, and industry). It features technologies for solid waste sorting, liquid radioactive waste concentration and cementation, vitrification, high-pressure compacting, and incineration. The low- and intermediate-level waste is stored at the National Fission Product Waste Storage facility at Mochovce. Spent fuel is stored in the interim spent fuel storage facility at Bohunice. The process to select a site for an underground high-level waste and spent fuel repository has started.

Slovenia

Number of operational reactors (total capacity, net MWe), 2004	1 (656)
2004 production, GWh (share of total, percent)	5204 (39)
Unit capability factor in 2004, percent	91.4

Krsko, Slovenia's only nuclear power plant, is a two-loop Westinghouse pressurized water reactor that supplies more than a quarter of the country's electrical power. In 2004, Krsko delivered 5204 GWh to the grid and recorded a capacity factor of 90.45 percent. The plant, operated by Nuklearna Elektrarna Krsko (NEK), has been operational since 1983. Its original capacity of 632 MWe was increased to 656 MWe with the replacement of the steam generators, part of a modernization and safety improvement program completed in 2000 that was undertaken to ensure that the safety level of the plant remains in line with similar reactors in the European Union (EU). The program included the installation of a full-scope, plant-specific simulator on the site so that NEK can take full responsibility for operator training.

Krsko was built as a joint project of the electric utilities of Slovenia and those of neighboring Croatia. In December 2001, the two countries signed a bilateral agreement on the joint management of the plant, which entered into force on March 11, 2003. Besides stipulating that Croatia will receive half of the electricity generated, the agreement settled a number of issues relating to the ownership and use of the plant, the long-term disposal of nuclear waste, and decommissioning, for which two separate funds were to be established and maintained in the two countries. The agreement also allows for the extension of the plant's operating life beyond its 40-year design lifetime.

Spent fuel generated at Krsko is stored on site in the spent fuel pool. As the spent fuel pool would have reached its full capacity in 2003, a reracking project was undertaken to extend the number of spent fuel assembly storage locations. The facility now has enough capacity to store all the spent fuel that will be produced during the design lifetime of the plant, with the possibility of further expansion. Solid radioactive operational waste is treated, packed into steel drums, and placed in the on-site solid waste storage facility.

Since 2001, Krsko has undergone a number of independent reviews and assessments of its safety, including a pilot International Atomic Energy Agency (IAEA) Review of Accident Management Program mission and an IAEA Operational Safety Review Team (OSART) mission. The OSART found that the plant's senior management is committed to improving the operational safety and reliability of the plant, with a long-term perspective. The team spotlighted many areas of good performance, including the following:

- Priority is given to safety at all levels, with a focus on safety culture.
- Plant management has in-depth technical knowledge and a strong background in nuclear plant operation.
- The plant has made effective use of computer technology to plan work, track activities, and communicate within the plant.
- The safety culture is strong, driven by top management that encourages "safety thinking" in employees and contractors and fos-

ters an open relationship with the local community.

Slovenia also has a research reactor, a central storage facility for low- and intermediate-level solid radioactive waste from nonpower users, and a uranium mine and mill that are being decommissioned.

The 250-kilowatts thermal TRIGA Mark II reactor at the Jozef Stefan Institute was initially licensed in 1966. It was relicensed for steady-state and pulsed operation after refurbishment and reconstruction in 1992. It is used for research, training of Krsko personnel, and the production of radioactive isotopes for medicine, industry, and nuclear chemistry.

The Central Radioactive Waste Storage facility, which is located at the Jozef Stefan Institute, is used for interim storage of low- and intermediate-level solid radioactive waste from the research center and other small waste-producers such as medical, research, and industrial users of ionizing radiation. Substantial progress has also been made toward the selection of a location for final disposal of all low- and intermediate-level radioactive waste. The country's Agency for Radwaste Management has invited all communities to participate in the site selection process.

The Zirovski Vrh Uranium Mine and Mill was in operation from 1985 to 1990, producing 452.5 tons of yellowcake. Both the mine and the mill are undergoing decommissioning and remediation.

In July 2002, the Slovenian Parliament adopted the Act on Ionizing Radiation Protection and Nuclear Safety, bringing Slovenia in line with EU regulations and international agreements on nuclear safety. The act gives the responsibility for nuclear safety and radiation protection to the Slovenian Nuclear Safety Administration. On May 1, 2004, Slovenia became a member of the EU, and the act was amended to harmonize with EU directives.

Spain

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . .9 (7584)
2004 production, GWh
(share of total, percent) 60 888 (23)
Unit capability factor in 2004, percent 92.3

Spain has a total of nine nuclear units: Almaraz-1 and -2, Asco-1 and -2, Cofrentes, José Cabrera, Santa Maria de Garona, Trillo-1, and Vandellos-2. Another unit, Vandellos-1, a gas-cooled reactor, was shut down in 1989. The nuclear plants have performed particularly well over the past decade. In 2004, the nine units produced 60 888 GWh of electricity, nearly 23 percent of the country's total generation.

Spain's first nuclear power plant, José Cabrera, started commercial operation in 1968. In the early 1970s, construction was started on seven second-generation reactors, five of which were completed. In the early 1980s, construction began on five third-generation plants. Following a 1983 moratorium, however, only two were completed—Trillo-1 and Vandellos-2. In 1994, the five units under construction were formally abandoned. Compensation to the companies for losses due to the moratorium have been paid by way of a "nuclear moratorium" levy added to consumer tariffs. The compensation finishes at the end of 2006.

Barsebäck: Unit 2 was closed during 2005.

Spain is notable for uprating its nuclear power plants. By 2004, the total nuclear capacity had increased by about 600 MWe since the 1990s. A further 200 MWe or more is expected to be added over the next few years. Plant availability rates are very high, reflecting the good condition and maintenance of the plants. Production costs have decreased steadily over the past several years.

As part of its proposed electoral program in the runup to the 2004 general elections, the Socialist Party, which unexpectedly defeated the "Partido Popular" (after the Madrid terrorist attacks), said it would shut down Spain's nuclear power plants in succession, replacing them with renewable energy sources such as wind energy (which provided 5.51 percent of total generation in 2004). While the government now also proposes that greater use be made of renewable energy sources, along with energy conservation and greater efficiency, in order to comply with its Kyoto commitments, it is considered very unlikely that Spain will meet them. With respect to 1990 levels, emissions have already increased by more than 40 percent.

The Spanish radioactive waste management agency ENRESA (Empresa Nacional de Residuos Radiactivos) was set up in 1984 to undertake the management of low- and intermediate-level radioactive waste, spent fuel, and the decommissioning of the nuclear power plants. It is now the only state-owned part of the nuclear fuel cycle in Spain. According to the 2004 update of ENRESA's General Radioactive Waste Plan, which is subject to approval by the Ministry of Industry, Tourism and Commerce, the total cost for the whole Spanish power reactor program is estimated at €12 billion (about $14 billion).

The revenues required to cover the costs have been collected directly as a component of the electricity tariff. As of March 31 of this year, however, the generating companies themselves will have to make the annual payment to ENRESA for each kWh produced, integrating the extra cost into their generation prices.

In 2003, ENRESA concluded phase 2 of its decommissioning plan for Vandellos-1, a 480-MWe gas-graphite reactor, which closed after 18 years of operation because of damage caused by a turbine fire that was uneconomical to repair. After a 30-year SAFSTOR period, the remainder of the plant will be removed.

Low- and medium-level waste is stored at the El Cabril facility in the northwest part of the province of Cordoba. Spent fuel is stored in pools at the nuclear plants. Only the Trillo plant also operates a dry storage facility. ENRESA is planning to build a central away-from-reactor storage facility for all high-level wastes, including vitrified waste arising from the reprocessing of Vandellos-1 fuel in France. Research continues on deep geological disposal, as well as other techniques, with a decision on final disposal to be made after 2010.

In 1972, ENUSA (Empresa Nacionel del Uranio, SA) was set up to take over all of the nuclear front-end activities. The company shut down its main uranium mining complex, the Saelices el Chico, in 2000 because of the low profitability of this facility, aggravated by the drop in prices on the international market. Since 1974, 5670 t of uranium concentrate was produced at the site. ENUSA has a 10 percent stake in mining in Niger and an 11 percent stake in Eurodif, which owns the diffusion enrichment plant in France. ENUSA's Juzbado plant, commissioned in 1985, produces BWR and PWR fuel elements for Spain's reactors and also supplies other customers in Europe.

Sweden

Number of operational reactors
(total capacity, net MWe), 2004 . . . .11 (9451)*
2004 production, GWh
(share of total, percent) 75 039 (52)
Unit capability factor in 2004, percent 92.4
* includes Barsebäck-2, closed during 2005

The original nuclear phaseout legislation in Sweden followed a 1980 referendum that was called in response to the heated debate over nuclear energy triggered by the Three Mile Island-2 accident in the United States. The referendum included three options—all of which were for phasing out nuclear power. The government decided, however, that it would allow the startup of six reactors that were either ready to operate or under construction, which meant there would be a total of 12 reactors in operation. Following the referendum, the Swedish parliament passed legislation setting a phaseout date of 2010.

Unable to develop a viable alternative energy strategy to replace the phaseout policy, government and parliament adopted a new strategy in 1997: It would scrap the 2010 phaseout date, which means that there is no time limit on the operation of the remaining reactors, but would shut down the Barsebäck station. Parliament then passed the 1998 "Act on Phasing-out Nuclear Power," which allows the government to decide to close a nuclear power plant provided losses incurred by the owner are compensated by the state. After a series of legal actions and negotiations, the owner, Sydkraft, finally shut down Barsebäck-1 on November 30, 1999. The government had to pay Sydkraft considerable compensation, which included the transfer of shares in the Ringhals nuclear plant, owned by Vattenfall, the state-owned utility. Most of the 4 TWh of lost power generation has been compensated for by means of electricity imports, partly from Danish and German fossil power units.

In 2002, the government appointed a "negotiator," who was given a mandate to discuss with the industry and other stakeholders the conditions of a gradual phaseout of nuclear power, including the closure of Barsebäck-2, and other energy supply issues.

The negotiator finally decided that he could not reach a timely agreement with the energy industry. Sweden's governing Social Democrats then reached an agreement with the country's Left and Center parties to close Unit 2 in 2005. The reactor was shut down in May.

While the government remains committed to devising a comprehensive nuclear phaseout plan, possibly based on the German model, Swedish industry has gained strong public support for the argument that the nuclear plants should be allowed to operate as long as they are safe.

Despite the phaseout plans, Sweden's nuclear operators have maintained high performance levels, continuing to supply about half of the country's electricity, with hydro power providing another 50 percent. All four Swedish nuclear stations reported record production figures for 2004. The total nuclear generation of 75 039 GWh, which is the highest ever in Sweden, was just over 50 percent of the total.

With Barsebäck-2 closed, Sweden now has 10 operating nuclear power reactors at three sites—Ringhals, Oskarshamn, and Forsmark. The operating companies have all announced modernization programs, including major power uprates, which will take many years to carry out. In response to these plans, the safety authority has issued new regulations on backfitting the aging reactors to meet modern safety standards.

Sweden boasts a fully operational system for handling radioactive wastes, which are managed by SKB, the Swedish Nuclear Fuel and Waste Management Company, set up by the operators. The decision to limit nuclear power to the initial 12 nuclear plants led the utilities to abandon a reprocessing strategy and turn to the direct disposal of spent fuel. This required developing technology to encapsulate spent fuel and engineering a suitable repository structure. The basic plan devised by SKB—known as KBS-3—involves the construction of a repository in bedrock at a depth of about 500 meters. The fuel rods will be placed inside copper canisters, and the canisters emplaced into drilled holes and surrounded by bentonite clay, which protects them against the movement of the surrounding rock. The regulator has said that it finds no obstacles to the plan.

SKB has developed the canisters and plans to construct an encapsulation plant at Oskarshamn. Research to identify characteristics for a repository and on the final disposal method is carried out at the nearby Äspö Hard Rock Laboratory at a depth of 500 meters. Hundreds of experiments have been carried out since the start in 1995. Since 2000, SKB has been conducting a prototype repository research project at Äspö, which involves six full-scale copper canisters deposited in vertical holes at a depth of 450 meters. Electric heaters are used in place of spent nuclear fuel to simulate the heat from the fuel. The tunnel in which the canisters are located is backfilled with bentonite and plugged with concrete. The innermost part of the project is planned to continue until 2021.

The site selection procedure is well advanced. Since the 1970s, SKB had been studying the Swedish bedrock to identify suitable geologies. Between 1993 and 2000, it conducted feasibility studies in eight municipalities for a suitable location for a deep repository. From these, SKB started investigations at Oskarshamn and Östhammar (near Forsmark) in 2002. SKB expects to submit a permit application for the encapsulation plant, which is intended to be located next to the existing interim storage facility in Oskarshamn, in 2006. A permit application for the deep repository itself is planned to be submitted in 2008.

SKB also operates an interim spent fuel storage facility (CLAB) and an underground repository for low- and intermediate-level waste (SFR). CLAB, located near the Oskarshamn plant, stores fuel in deep pools in underground caverns, 30 meters below the surface. SFR is located in bedrock with about a 50-meter rock cover. It is built underneath the bottom of the Baltic Sea, about 1 km out from the harbor at Forsmark. SFR was the first of its kind in the world when it went into operation in 1988. To finance waste management, plant operators pay a fee to the state for each generated kilowatt-hour, and funding is administered by the Nuclear Waste Fund.

The Oskarshamn plant has permission from the government to use mixed-oxide (MOX) fuel based on the plutonium from the reprocessing of OKG spent fuel sent to BNFL in the 1970s and 1980s. Work is ongoing to design this fuel and also to make the necessary preparation for the transport. The MOX fuel is planned to be inserted after 2006.

Switzerland

Number of operational reactors
(total capacity, net MWe), 2004 . . . . . .5 (3220)
2004 production, GWh
(share of total, percent) 25 432 (40)
Unit capability factor in 2004, percent 90.6

Switzerland's five nuclear power stations (Beznau-1 and -2, Mühleberg, Gösgen, and Leibstadt) proved their continuing reliability in 2004, delivering 25 432 GWh to the grid—some 40 percent of Swiss electricity. The Gösgen and Mühleberg plants again achieved record production figures.

In December 2004, the Federal Council approved the new Nuclear Energy Act, which came into force on February 1, 2005. The new act lifts the earlier moratorium on the construction of new nuclear plants and facilities. It also removes restrictions on the operating lifetime of reactors and establishes mechanisms for the management of radioactive waste, including disposal.

While the new law allows the reprocessing of spent fuel, it introduces a 10-year moratorium on any new reprocessing contracts. It also extends the public's right to an optional referendum on any authorization to build new nuclear installations.

Bruno Pellaud, president of the Swiss Nuclear Forum, said that the new nuclear law creates a favorable legal framework for the industry. It is now very important, he said, for the industry to maintain its modernization program to ensure that it can prolong plant operation from 40 to 50—even 60—years, which is now allowed under the law.

Regarding new construction, he said that public discussions on building new nuclear stations have shown a change in tone, becoming much more relaxed. He listed three reasons for this:

- Scientific realities about the benefits of renewables and the need for nuclear power to reduce carbon dioxide emissions. This is in stark contrast to the enthusiasm previously shown when wind generators were first starting up.
- Economic realities about the competitive costs of nuclear energy, despite what opponents claim.
- Attitudes of the latest young generation of voters toward nuclear power that are more favorable than those of previous generations.

The new law also requires that issues regarding the disposal of radioactive wastes be resolved, and the government has set into motion the process for dealing with high-level waste.

At the end of 2002, the National Cooperative for the Storage of Nuclear Waste (Nagra) submitted to the Federal Council disposal feasibility documentation for dealing with the country's spent fuel, as well as high-level and intermediate-level waste. Nagra's report, based on an opalinus clay formation in the Zuercher Weinland region, shows that these categories of waste can be disposed of safely in Switzerland. In their reviews of the project, delivered in September 2005, the Swiss Federal Nuclear Safety Inspectorate, the Federal Commission for the Safety of Nuclear Installations, and the Commission for Nuclear Waste Management all came to the conclusion that as required by law, the feasibility of disposal had been demonstrated. Site selection, however, is still a matter for the future.

In August 2005, following a request from the government for further assessments, Nagra submitted another report on potential host rocks and regions suitable for disposal. These are the crystalline basement, the clay-rich formations of the Lower Freshwater Molasse, and the opalinus clay, with possible areas in the country listed. In Nagra's opinion, the opalinus clay has geological advantages as compared with the other host rocks. The report is intended to provide a basis for decision-making concerning future steps in a national disposal program.

As part of the public consultation process, the documents were made publicly available on September 13. The council expects to make its decision on whether the feasibility of final storage has been proven during the second half of 2006. Assuming a positive decision, the government must then develop a plan to identify acceptable sites, along with the procedural steps to be taken and the criteria for selection. It will also set the rules for participation in the process. The criteria will include minimum geological requirements. Socioeconomic and local planning aspects will also play an important part.

The demonstration of disposal feasibility for low- and intermediate-level waste was already judged by the federal government as having been successfully achieved in 1988. Following detailed investigations at various locations in Switzerland, Nagra proposed Wellenberg, in the canton of Nidwalden, as the site in 1993. While the local community twice voted in favor of the project, it was refused by the voters of the canton in 2002. The federal government is presently working on the requirements for an evaluation concept. This involves defining selection criteria and procedural steps. The option of locating the LLW/ILW repository at the same site as the HLW repository must also be taken into consideration.

Ukraine

Number of operational reactors
(total capacity, net MWe), 2004 . . . .13 (11 207)
Under construction
(total capacity, net MWe), 2004 . . . . . .5 (4750)
2004 production, GWh
(share of total, percent) 81 813 (51)
Unit capability factor in 2004, percent 85.1

In August and October 2004, Khmel'nitskiy-2 and Rovno-4, both VVER-1000 pressurized water reactors, were connected to the Ukraine grid, bringing their long and interrupted construction to an end. The construction was carried out by a consortium of Framatome ANP and Atomstroyexport under contract to Energoatom, the country's nuclear power operator. At the same time, it was announced that the construction of Khmel'nitskiy-3 would proceed. The government has also announced plans to build up to 11 new reactors by 2030.

With two additional reactors generating power at the end of the year, bringing the total number of operating units to 15, nuclear production increased to 81 813 GWh in 2004, about 51 percent of total domestic electricity production. Load factors have increased steadily since the country became independent of the former Soviet Union, reaching 81.4 percent in 2004, the first time it has been above 80 percent. Plants have recorded continuing improvements in operational safety as well.

Nuclear power development in Ukraine started in 1970 with the construction of the country's best-known nuclear station—Chernobyl, with four RBMK graphite-moderated, water-cooled reactors. The first unit was commissioned in 1977. Unit 4 was destroyed in the 1986 accident; Unit 2 was shut down after a turbine hall fire in 1991; Unit 1 was closed in 1997, and Unit 3 at the end of 2000.

Ukraine's other nuclear power stations are South Ukraine and Zaporozhye. All 15 reactors at the four sites are VVER pressurized water reactors. At the end of 1995, Zaporozhye-6 was connected to the grid, making Zaporozhye the largest nuclear power station in Europe.

The decision to complete the construction of Khmel'nitskiy-2 and Rovno-4 (K2/R4) without the promised help of the Group of Seven (G7) countries (Britain, France, Germany, Italy, Japan, Canada, and the United States) and the European Union (EU) was made in 2003, following years of unsuccessful negotiations with the European Bank of Reconstruction and Development (EBRD) acting on behalf of the G7 and the EU.

Under the terms of the original 1995 agreement reached between the G7 countries and Ukraine, the G7 promised to ensure financial provisions to decommission the Chernobyl site and to compensate Ukraine for the resulting loss of power in return for closing the remaining operating units by 2000. The EU countries in particular had hoped to find a non-nuclear alternative to completing K2/R4. With the two nuclear units nearly completed, however, Ukraine did not agree that that there were any better options.

Finally, as Chernobyl-3 was being shut down, the EBRD approved in principle the completion of K2/R4, with a number of conditions. These included the establishment of a fully independent regulator, the implementation of safety improvements at all of the remaining 13 nuclear power reactors, and electricity market reform, which would include the privatization of energy distribution companies and increases in tariffs. After more negotiations, a final agreement was reached that ensured that the funding needed to complete the plants—which EBRD experts assessed to be \$1.48 billion, including necessary safety improvements—would be made available. Before a deal could be signed, however, Ukraine told the EBRD that it was unwilling to accept some of the conditions, such as a drastic increase in electricity tariffs, and that it also disagreed with the \$1.48-billion cost assessment. The Ukrainian authorities decided to complete the units without the promised aid, based on a construction program that Russian contractors calculated would cost about $500 million.

Because the EU and the EBRD had an interest in ensuring that the plants would be safe, however, they continued talks with Ukraine. Finally, after a review of the safety upgrade measures to be undertaken under Ukraine's plan, which were compared with the measures that were to be performed under the EBRD's earlier construction and improvement program, they agreed to finance additional safety upgrades after the plants were commissioned.

In the meantime, the decommissioning and cleanup of Chernobyl are continuing. Plans are well advanced to build a new, more durable containment structure over the Unit 4 shelter, or "sarcophagus," which is being carried out by the international Shelter Implementation Project. This project is funded by the International Chernobyl Shelter Fund, which is managed by the EBRD. The new confinement, an arch-shaped steel structure, will isolate the existing shelter and its waste and fission product inventory from the environment for up to 100 years. It will also create a safer working environment for future waste management operations. The cost of building the new shelter is estimated at over $1 billion. Other projects under way at Chernobyl include the construction of an interim spent fuel storage facility and waste processing facilities.

Energoatom's current priorities are to increase safety, bring load factors up to 83–85 percent, and extend the working lives of the reactors by 10–15 years. A large share of the primary energy supply in Ukraine comes from the country's uranium and coal resources. The remainder is oil and gas, mostly imported from Russia.

Ukraine depends on Russia for its fuel, although it does contribute part of the uranium from its own mining operations, along with some zirconium alloy. In order to diversify nuclear fuel supplies, Energoatom started a qualification project for the use of Westinghouse-manufactured fuel in its VVER-1000s. The Ukrainian energy and fuel ministry is also looking at possible domestic production of nuclear fuel to reduce its dependence on Russia.

While some spent fuel is being sent to Russia for reprocessing, most is being stored. A long-term dry storage facility for spent fuel has operated at Zaporozhye since 2001. A centralized dry storage facility has been proposed. Beginning in 2011, high-level wastes from reprocessing Ukrainian fuel will be returned from Russia. Investigations are being carried out for a deep geological repository for high- and intermediate-level wastes, including all those arising from the Chernobyl decommissioning and cleanup.

United Kingdom

Number of operational reactors
(total capacity, net MWe), 2004 . . . .23 (11 852)
2004 production, GWh
(share of total, percent) 73 680 (19)
Unit capability factor in 2004, percent 90.8

In 2004, Britain's nuclear plants supplied 73 680 GWh, 19 percent of total U.K. electricity production, considerably less than in the 1990s, when nuclear contributed a quarter or more of the country's electricity. The decrease is due in part to a number of technical problems with several of the reactors.

The United Kingdom now operates 23 reactors, including first-generation Magnox gas-cooled reactors, second-generation advanced gas-cooled reactors (AGR), and a Westinghouse pressurized water reactor (Sizewell B). While the government has said it has not ruled out new nuclear construction—if it were necessary to meet its Kyoto emissions targets—its actual commitment to the future of nuclear energy remains uncertain. The prime minister, however, has promised a new energy review in 2006 in which the nuclear question is to be given a high priority.

The most significant nuclear event of this year was the startup on April 1 of the Nuclear Decommissioning Authority (NDA), which took over ownership of most of the civil nuclear sites and responsibility for dealing with the country's historic wastes. This included all of the public sector civil nuclear liabilities held by the U.K. Atomic Energy Authority (UKAEA) and most of those held by British Nuclear Fuels plc (BNFL), together with the related BNFL assets. In total, this meant 39 reactors and five fuel reprocessing plants, as well as other fuel cycle and research facilities on 20 sites, including Sellafield, Capenhurst, Springfields, Drigg, and the elderly Magnox reactors, which came under BNFL's wing in 1998; all the Magnox reactors should be closed by 2010. The assets would include the "substantial" revenue stream from the Thorp reprocessing plant and the mixed-oxide (MOX) fuel fabrication plant at Sellafield.

In 1996, all AGRs and the Sizewell B plant were transferred into the private sector, under British Energy (BE). BE, as well as BNFL, then had ambitions to pursue business prospects outside Britain. BNFL purchased the nuclear assets of Westinghouse and ABB. British Energy, looking to North America, joined Exelon to form Amergen, which purchased several nuclear power plants in the United States, and set up a Canadian venture that eventually leased the Bruce nuclear station in Ontario. Both companies were also assessing the possibility of new construction. Separately, BNFL took a substantial stake in the South African Pebble Bed Modular Reactor project.

In March 2001, the government introduced a new set of electricity trading arrangements to stimulate competition at a time when considerable overcapacity existed because of the construction of new gas-fired plants. The effect was a collapse in electricity prices to below production cost for BE. By fall 2002, BE was forced to ask the government to bail it out, to keep it from going into bankruptcy proceedings. With government backing, a restructuring deal was struck among BE, its shareholders and creditors, and the government. Besides virtually wiping out shareholder value, the agreement included the sell-off of the company's overseas assets. At the beginning of 2005, all legal requirements were met, and the company was relisted on the stock exchange, now mostly owned by the creditors. The company is now focusing on raising the performance of its AGRs, which have suffered a number of long, unplanned outages over the past several years, and pursuing life extension of the plants.

After the near collapse of BE, the government also decided that the question of what to do with the historic wastes at Sellafield and other U.K. liabilities was becoming urgent and that the plan to partially privatize BNFL was no longer viable. It then decided to transfer the nuclear liabilities of BNFL and the UKAEA and the assests of BNFL to the new NDA, and have BNFL and UKAEA develop into nuclear contracting organizations.

When the NDA came into existence on April 1, 2005, BNFL and the UKAEA continued to operate most of their former facilities under contract to the NDA. The plan, however, is that this arrangement is to be only temporary; starting in 2008, the NDA will put site management contracts out to tender, with BNFL and the UKAEA having to compete against other companies, including American ones, for the jobs. The relationship between the NDA and BNFL is now much the same as between the U.S. Department of Energy and its contractors.

To prepare for its new position, BNFL restructured itself. Most of its activities, including managing the Sellafield facilities and the Magnox reactors, were combined into a new business, the British Nuclear Group (BNG), which took over responsibility under contract to the NDA. In addition, a new nuclear science and technology company called Nexia was formed as a subsidiary to provide research and technology services on a commercial basis. As for the future, the board of BNFL decided that the main businesses of the company—BNG and Westinghouse—were best run completely commercially and proposed that they should be sold off.

Britain's failure to develop waste solutions for intermediate- and high-level waste goes back many years. To get on top of this situation, the government in 2001 set up the

Committee on Radioactive Waste Management (CoRWM), whose job it was to develop and undertake a consultation procedure that would lead to a recommendation on the best option, or combination of options, for the long-term management of the country's higher activity waste. CoRWM is expected to deliver its recommendations by July 2006.

The government has also taken control of UK Nirex Ltd., which was formed by the industry and the government in 1982 to develop an intermediate-level waste disposal facility. This should give Nirex needed independence from the nuclear industry in order to achieve greater transparency, thereby gaining public support for its plans.

From the outset, the United Kingdom has been self-sufficient in all parts of the fuel cycle, except uranium production. Sellafield's Thorp reprocessing plant, commissioned in 1994, takes oxide fuel, predominantly for international customers. In the United Kingdom, recycling plutonium is not regarded as economical, and so separated plutonium is stored indefinitely. BNG also operates a Magnox fuel reprocessing plant that is due to close in 2012, following the closure of all the country's Magnox plants.

For economic reasons, BNFL was planning to shut its 6000 t/yr conversion plant at Springfields. Early in 2005, however, Cameco bought 10 years of conversion services starting in 2006, at 5000 tU/yr. Feed will come from Cameco's Blind River refinery in Ontario. The conversion plant is now managed by Westinghouse under contract to the NDA.

Britain has only one radioactive waste repository, the Drigg facility, which takes solid low-level radioactive wastes. Intermediate-level waste is stored at Sellafield and other source sites, pending disposal. High-level wastes are stored at Sellafield. Some have been vitrified there and are stored in stainless steel canisters in silos. All HLW is to be stored for 50 years before disposal, to allow cooling.

One aspect of reprocessing that has brought Britain under considerable political pressure, particularly from Ireland and the Scandinavian countries, has been the release of effluents from Sellafield. While insisting that there were no health effects from the releases, in 2004, after several years of research and development, BNG commenced an effluent treatment innovation that will cut discharges of technetium-99 from the site by 90 percent.

Part of the long-term problem of decommissioning gas-cooled reactors in the United Kingdom is that costs are much higher than for light-water reactors because of the large volume of material (particularly concrete) and the need to dispose of significant quantities of the radioactive graphite moderator. NN