4 Germany

Germany's nuclear power program started in 1955 after the country officially renounced the development and possession of nuclear weapons. Germany's first nuclear power plant, the prototype reactor VAK at Kahl, Bavaria, began operating in 1960. At the start of 2011, there were 17 nuclear power reactors in operation at 12 sites with a total capacity of 21.5 GWe, producing around 23 percent of Germany's electrical power. Following the March 2011 Fukushima accidents, the government shut down eight reactors immediately and announced plans to close the remaining nine by 2022.

Germany's current spent fuel policy has been shaped by:

1. The nuclear phase-out law of 2002 and subsequent policy changes in 2010 and 2011;

2. The end of foreign reprocessing of Germany's spent fuel; and

3. The search for a repository.

Until 2005, utilities had the option of sending spent fuel for reprocessing in France or the UK or to a central interim storage facility at Gorleben for eventual direct disposal. Since 2005, as part of the Atomic Energy Law 2002 amendment, the only option has been interim storage of spent fuel at the reactor site where it has been produced and subsequent geological disposal. The only shipments have been to Gorleben of high level waste from reprocessing in the UK and France. A site for geological disposal of spent fuel and high level waste has not yet been determined. Exploration and research activities continue to focus on the Gorleben salt dome in Lower Saxony, but the site remains politically and socially controversial.

The nuclear phase-out law of 2002 and policy changes in 2010 and 2011

On 14 June 2000, under a federal coalition government of Social Democrats and the Green Party, Germany adopted a policy to phase out nuclear energy that came to be known as the "nuclear consensus." The primary rationales were the risks of reactor accidents and the problem of nuclear waste management. It was argued that the consensus decision would help calm the prolonged and severe social and political conflict over nuclear energy in Germany.

The “Nuclear Phase out Law” of 2002 amended Germany’s Atomic Energy law to ban the construction of new nuclear power plants in Germany.[135] It also fixed a maximum production of electrical energy from each existing plant to approximately the amount that would be generated in a total operating time of 32 years.[136]

The federal elections of 2009, however, brought to power a coalition of Christian Democrats and Liberals that decided to delay the nuclear phase-out so that nuclear energy would be available as a bridge to a carbon-free, renewable-energy electricity supply. An amendment to the Atomic Energy Act was published in December 2010.[137] It extended the average operating times of the reactors by the equivalent of about 12 years.[138]

After the Fukushima Daiichi nuclear-power plant accident of March 2011, the German Government reversed itself and decided to shut down eight reactors immediately and the remaining nine between 2015 and 2022.[139] The amount of spent fuel that will be discharged will be similar to that expected under the original phase-out plan.

Figure 4.1 shows the locations of Germany’s nuclear power plants, spent fuel interim storage facilities, nuclear research centers and sites of disposal projects.

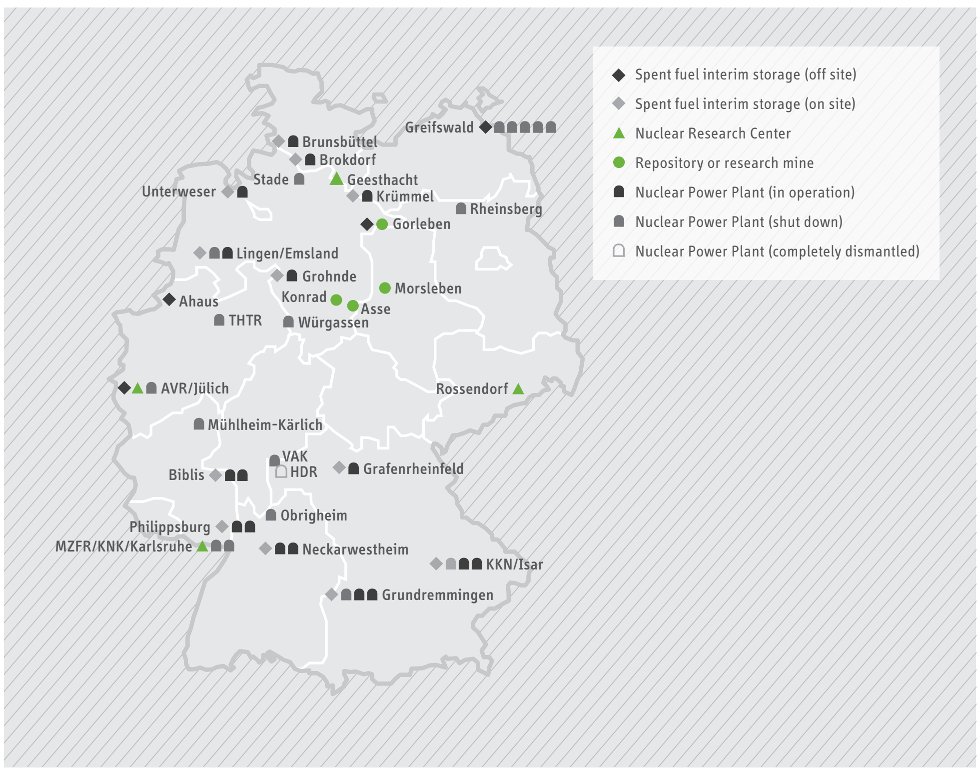

Figure 4.1: Locations of Germany’s nuclear power plants, spent fuel interim storage facilities, nuclear research centers and sites of disposal projects. *Source: Öko-Institut.*

The quantities of spent fuel that would be discharged for average operating times of 32 years are shown in Figure 4.2.

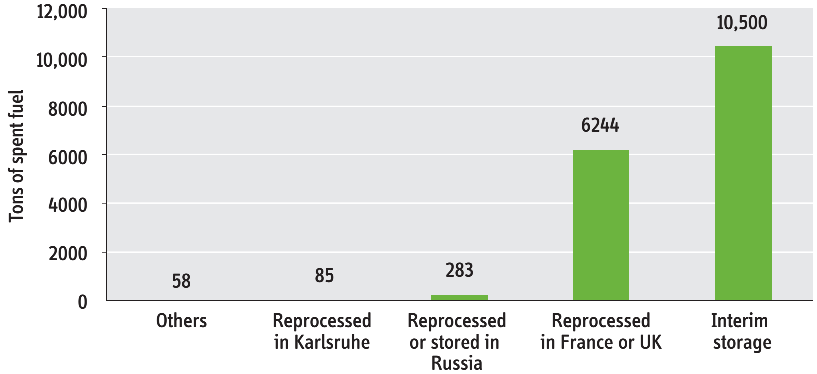

Figure 4.2: Disposition of German spent fuel by 2022 for phase-out shown by amounts of original heavy metal in the fuel. Interim storage is the only option open for spent fuel management today.

More than 75 percent of the spent fuel currently stored for direct disposal is at the reactor sites. The remainder, which is stored in centralized storage facilities, is mostly spent fuel from Soviet-designed East German nuclear power plants at Greifswald and Rheinsberg. This fuel is stored in the "Zwischenlager Nord" (ZLN, Northern Interim Storage) at Greifswald in Mecklenburg-West Pomerania.[140]

The management of spent fuel from research and prototype reactors with a total mass of 187 tons (heavy metal) is discussed below.

An additional 280,000 m^3 of radioactive waste of other types, generated by nuclear-power-plant decommissioning, operation, research, etc. is expected by the year 2080 (assuming an average nuclear power plant operating time of 32 years).

The rise and fall of reprocessing

Reprocessing was part of the plan for Germany's nuclear program from the very beginning. The French and the UK nuclear programs, where reprocessing was originally introduced to recover plutonium for weapons, no doubt influenced these developments. In the 1950s and 60s, Germany's powerful chemical industry was a driving force in the development of its reprocessing capabilities.

As in other countries with advanced nuclear programs, Germany's interest in reprocessing was driven by the idea of plutonium breeder reactors and a "closed fuel cycle" in which plutonium would be produced from uranium-238 and recycled as fuel. This vision was laid out in the 3rd German Atomic Program for nuclear activities for the period 1968-1972, which included the construction of a prototype fast-neutron breeder reactor and a pilot reprocessing plant in Karlsruhe.

The Karlsruhe pilot reprocessing plant (WAK) started operation in 1971. During its first years, it reprocessed spent fuel from research and pilot reactors. Later spent fuel from commercial nuclear power reactors was reprocessed as well. In parallel, Germany's nuclear utilities negotiated contracts with the French and UK reprocessing industries.

Starting in 1973, Germany's government began to require the nuclear utilities to prove that they had made provisions for spent-fuel management as a condition for the licensing of new nuclear power plants for construction and operation.[141] In 1974, in connection with its commitment to KNK I and KNK II breeder reactor projects in Karlsruhe, the government embraced "integrated waste management," with uranium and plutonium recycling presented as a solution both for waste management and for reliable nuclear fuel supply.[142] Thus, reprocessing became a central part of the German nuclear program and remained so despite the high costs of reprocessing which became evident in the following years.

The reprocessing of about 85 tons of spent power reactor fuel and about 104 tons of research and prototype reactor spent fuel was carried out at WAK between 1971 and 1990.[143] Sixty cubic meters of liquid high-level waste from these activities was vitrified between September 2009 and December 2010 as part of the decommissioning of WAK, resulting in 140 canisters of vitrified high-level waste. These canisters were shipped in five transport and storage casks to the ZLN at Greifswald in February 2011 for storage until a geological repository is available.

The total cost of the decommissioning and waste management from WAK, including waste disposal and other waste management activities is estimated at € 2.6 billion (US$ 3.5 billion). As of January 2008, € 2.2 billion (US$ 3.0 billion) had been spent on the decommissioning project.[144]

A first attempt to construct a commercial reprocessing plant in Germany failed in 1979. After intense public and political debate, plans for a so called "nuclear waste management center," including reprocessing, conditioning, storage and disposal facilities, in Lower Saxony were reduced to plans for a geological repository.

At the beginning of the 1980s, Bavaria offered to provide a site for a reprocessing plant. Construction at Wackersdorf started in 1987 but was halted in 1989 because of strong public resistance and economic reasons. Instead, Germany's nuclear utilities invested in France's reprocessing facility at La Hague. Until 2005, they sent about half of their spent fuel to France and the UK for reprocessing and placed the other half in domestic interim storage, mainly in wet or dry storage at reactor sites, for direct disposal.

The Nuclear Phase Out law of April 2002 terminated spent fuel shipments to reprocessing facilities abroad as of June 2005.[145] The safety risks and costs associated with such shipments were given as the main reasons.[146] The Environment Minister also pointed to the benefits of abandoning the plutonium economy and minimizing spent fuel and high-level waste transport.[147]

The plutonium that has been separated from reprocessed German spent fuel is being recycled in mixed oxide (MOX) fuel for use in Germany's nuclear power reactors. Germany's entire stock of separated plutonium is to be eliminated before the power reactors complete their previously planned operational times of 32 years.[148] As of the end of 2008, the utilities hoped to load the last MOX fuel into a reactor in 2016.[149] Should reprocessing of Germany's remaining spent fuel at the UK's THORP plant be further delayed due to technical problems, there still would be six years, according to the 2002 phase-out schedule, before Germany's last nuclear power plant is shut down.

Ten German pressurized water reactors (PWRs) and two boiling water reactors (BWRs) have been licensed to use MOX fuel. For the PWRs, the limits on the MOX fraction of the core range from 9 to 50 percent. The two BWRs at Gundremmingen (KRB B and C) are licensed to use up to 38 percent. Thus far, a maximum of 33 percent of MOX fuel has been used in a PWR and 24 percent in a BWR.[150]

Vitrified high-level reprocessing waste is returned to Germany in dual-purpose transport and storage casks and stored in the centralized interim storage facility at Gorleben (Table 4.1).

Number of casks	From La Hague	From Sellafield
Total	108	21
Returned by November 2010	97	0
Planned	1 shipment of 11 casks in 2011	Start of shipments after 2013

Table 4.1: Casks of high level waste to be returned to Germany from reprocessing abroad. *Source: Federal Office for Radiation Protection (BfS).*[151]

Management of spent fuel and HEU from research reactors

The first research reactor to go critical in Germany was the FRM reactor at Garching near Munich in 1957. The most recent, which began operating in 2004, is the FRM II reactor located at the same site.

Spent fuel from Germany's early prototype reactors (VAK, MZFR, KKN and KNK II, HDR) was reprocessed in Germany or abroad. Mixed uranium/plutonium oxide fuel was produced for the fast breeder prototype reactor SNR 300 but never used. This fuel was reprocessed in France and the plutonium is being used in light water reactor MOX fuel.

The fuel of the helium-cooled, graphite-moderated "pebble-bed" AVR and THTR reactors was highly-enriched uranium fuel and thorium in particles embedded in graphite balls 6 cm in diameter. The irradiated fuel is stored in transport and storage casks at the Research Center in Juelich and the interim storage facility at Ahaus.

Germany's other research reactors were fueled with low or highly enriched uranium. Low-enriched uranium fuel has been reprocessed in Germany and the recovered uranium blended and reused as light water reactor fuel. Highly enriched uranium (HEU) has been returned when possible to the country of origin for disposal.

Spent fuel of Russian origin of the former eastern German Rossendorf research reactor is currently stored at Ahaus. In 2010, a license for the return of this fuel to the Mayak reprocessing plant in Russia was requested in the context of the Global Threat Reduction Initiative, one of whose missions is to clean out global stocks of HEU spent fuel. Due to concerns about the environmental conditions at the Mayak plant, however, no license was granted by the German federal government.

For U.S.-origin HEU fuel from research reactors that have agreed to be converted from HEU to LEU fuel, U.S. law currently allows a return for HEU fuels irradiated by May 2016. Some German research reactors that have been converted will still be online after that. Also the FRM II reactor is currently being fueled with highly enriched uranium of Russian origin. No return of its spent HEU fuel to the United States is therefore possible. Current plans foresee the storing of wastes that are not returned to the country of origin at the interim storage facility in Ahaus followed by disposal in a geological repository.

Repositories: the Asse and Gorleben projects

The Asse facility was established in 1965 as a mine for research into waste disposal but became, in fact, a repository for low- and intermediate- level waste. The mine is now endangered by an inflow of brine and possible structural instabilities.

Over the past forty years, there have been major efforts in Germany to site a geological repository for the disposal of high-level waste and spent fuel. To date, however, no site has been officially selected.

The Asse repository for low- and intermediate-level waste. From 1967 to 1978, low- and intermediate-level waste in the Federal Republic was disposed of—nominally for research purposes—in the former Asse salt mine. In the former German Democratic Republic, another salt mine located at Morsleben was used for disposal of low- and intermediate-level waste. Its operation started in 1970 and was continued after German unification until 1998. Both projects have been stopped for safety reasons.[152]

In the Asse repository, 131 salt chambers at thirteen levels were dug through 1964. In the years 1965 till 1978 about 125,800 barrels of low- and intermediate- level waste with total radioactivity at time of emplacement of about 10^{16} Bq (270,000 Ci) were disposed in 13 chambers at 511 m, 725 m and 750 m depth. Due to poor documentation, uncertainties exist regarding the exact inventories.

Since 1988 an inflow of brine at a rate of about 12 cubic meters per day has been measured in the southern area of the mine. If this flow should increase, there would be dangers of flooding and of a collapse due to salt weakening and dissolution.

The main cause of this problem is that the Asse mine was excavated close to the outer boundary of the salt dome and not backfilled before it was converted into a repository. Being operated under the mining law, inadequate attention was paid to nuclear matters, and no assessments of long term radiological consequences were performed, although there were no plans for retrieval of the waste. Warnings from a regional NGO, which stressed the dangers of flooding and collapse, were ignored.[153]

Planning for the closure of the Asse repository started in 1997. The objective is to prevent the flooding and collapse of the mine and the release of radioactive substances to the biosphere. A group of regional representatives has been involved in the discussion of options for the closure since late 2007. In 2009, the status of the Asse mine was officially changed from a research project to a radioactive waste repository. It now has to be operated according to the atomic law. As a result appropriate attention is now paid to radiation protection. Furthermore the licensing procedure for the closure of the repository requires providing the inhabitants of the region opportunities to express their concerns.

An assessment of the feasibility of retrieving the waste packages in Asse began in 2010. In parallel, measures to increase the stability of the mine are being undertaken. Due to uncertainties regarding the condition of the waste packages and chambers, possible retrieval techniques and the time required, a final decision to start the retrieval of all the waste will not be taken before a three-phased feasibility study is completed. The first phase was licensed in spring 2011 after a one-year period of planning.

The Federal Ministry of the Environment which is responsible for the Asse budget announced recently that costs for waste retrieval and closure of the mine cannot be predicted until the plan for closure is finalized[154] Costs of € 2 to 4 billion (US$ 2.7 to 5.4 billion) have earlier been quoted in the media. The fees totaling about € 8.5 million that were paid by waste producers when the waste was delivered to the site do not come anywhere near covering these costs.[155]

The problems in the Asse repository have stirred up the public debate on the suitability of salt formations and of the concept of geological disposal in general. This has influenced the debate over high-level waste disposal in general and the Gorleben salt dome in particular.

The saga of Gorleben. German initiatives to locate a geological repository for spent fuel have focused on the Gorleben exploration mine in Lower Saxony adjacent to the Gorleben interim storage facility. Originally, in the 1970s, Gorleben was proposed as the location of a "national waste management centre" where reprocessing, waste conditioning, interim storage and disposal would all take place. Political considerations, such as its location near the border with East Germany, played a role in the selection of the site. When that plan proved to be politically infeasible, Gorleben became in 1977 a candidate site for a repository for all types of radioactive waste. Later, its purpose was narrowed further to the disposal of heat generating waste, i.e., mainly spent fuel and high-level reprocessing waste.

Because of this history, there was no official process by which alternative sites in Germany were ranked on the basis of their potential suitability for a radioactive waste repository.

Above-ground studies of the suitability of the Gorleben site started in 1979 and underground exploration began in 1986. Two vertical shafts in the center of the salt dome provide access to the exploration mine. The main horizontal tunnel is at a depth of 840 m.

There are plans to explore nine areas. By 2000, exploration of the area "EB 1" had been nearly completed and about € 1.5 billion (US$ 2.0 billion) had been spent.

The selection of Gorleben has been controversial since the very beginning. The nuclear consensus of October 2000 therefore included a moratorium on further exploration there. Instead, the Federal Office for Radiation Protection (BfS), which is responsible for nuclear waste disposal in Germany, started a research program with the intention of clarifying generic safety-related issues that are independent of specific sites. BfS published the results of this research program in November 2005.[156] A key conclusion was that:

> "There is no host rock that will always guarantee the highest level of repository safety. … Different options can only be compared if the comparison is made between specific sites and repository concepts. This leads to the conclusion that a comparison of sites is necessary."

The new federal government elected in 2009 decided to end the Gorleben moratorium. The Christian Democratic minister of the environment announced the decision to

- Restart exploration activities, and
- Perform a preliminary safety assessment on the basis of existing data within 2 years.[157]

The selection of the areas of the Gorleben salt dome that are to be explored is being influenced by private salt mining rights. The Atomic Energy Act of 2010 allows for the possibility of compulsory government purchase of such rights, but there has been as yet no indication that the Government will make use of this right within the next several years. Exploration activities are being performed under the German mining law until the decision to construct a repository has been taken. The use of the mining law in this way has been criticized by some groups as a way to avoid the formal public involvement that would be required under the atomic law.

In contrast to other countries, where political setbacks in the siting process led to revised procedures and a re-start, the lack of political consensus in Germany has thus far prevented the establishment of a site-selection process based on broadly-accepted standards. The 2010 extension of the operational times of Germany's nuclear power plants made such a consensus more difficult by increasing the political and societal tensions relating to nuclear power. The June 2011 decision to return to a rapid phase-out may have created the conditions for a site-selection process to go forward. Several state premiers announced their support of a countrywide site selection process.[158]

Designing a siting process

In 1999, prior to the passage of the Nuclear Phase-out Law, the Federal Minister of the Environment, who belonged to the Green Party, constituted a "Committee on a Site Selection Procedure for Repository Sites" (AkEnd) charged with developing a new framework for a siting procedure that would be transparent and impartial.[159] AkEnd worked from February 1999 to December 2002. Its basic recommendation was a criteria-based approach that would take into account long-term safety, regional development interests and the willingness of the regional population to participate in the process.

AkEnd also recommended that the site selection procedure should include public and independent expert involvement at both the national and potential host region levels.[160] The AkEnd process ended in 2003, however, with the failure to establish a negotiation group representing the Federal and State (Länder) governments, industry and stakeholder groups to carry out the next phase of specifying the site-selection process.[161] There was no single reason for this failure but the following considerations may have contributed:

- For the states (Länder), it is not very appealing to host a potential disposal site. Their preparedness to open up a selection process on the basis of a "blank map", as recommended by the AkEnd, was therefore not very high;

- For the nuclear industry, the expected cost of a broad site selection process may have been an important consideration;

- The Federal ministries may also have been reluctant to join in negotiations that were completely open but whose conclusions would be binding on them.

In November 2008, the Federal Ministry for the Environment, Nature Protection, and Nuclear Safety (BMU) organized a stakeholder symposium on nuclear waste disposal that brought together a broad range of stakeholders as a first but very small and fragile step towards further dialogue.

A Disposal Dialogue Forum (FED) was established as an inter- and intra-disciplinary group of members of the planning team for the 2008 stakeholder symposium. This forum has held regular meetings for about 2 years. Two members of the FED, both representatives of the Gorleben region, ended their participation, however, in protest over the extension of the nuclear power plant operational times, the restart of the exploration of the Gorleben salt dome on the basis of mining law instead of the atomic law,[162] and the continuation of shipments of high-level waste from La Hague to the Gorleben interim storage facility. As a result, the FED's future is unclear.

At the beginning of 2011 the "Gorleben Dialogue" was started by the BMU[163] In a first stage, an online survey was performed that offered a public opportunity to express expectations and provide recommendations regarding topics and measures for public participation during exploration activities and preliminary safety assessments. Subsequently a proposal for the organizational structure was published by the BMU.[164] The central forum is the so called Confidence Committee that is empowered to co-decide on: relevant questions for the safety assessment, the necessity of additional exploration measures, independent assessments and research, organization and topics of peer review, and on public relations. Half of the seats in this committee will be filled by representatives of the Gorleben region.

An Information Forum and an Expert Committee will support the process by providing information to the public and scientific support to the Confidence Committee respectively. Half of the members of the Information Forum are to be regional representatives and half of the members of the Expert Committee can be named by the region. A national Expert Committee is to be established to provide scientific support on all questions of disposal unrelated to the Gorleben project.

The success of this process will depend on the extent to which it can accommodate strong and well organized citizens' initiatives and the degree to which openness of outcomes of the preliminary safety assessment is assured and made transparent to stakeholders and the public.

Conclusion

Although the long history of the geological repository siting debate at Gorleben is complex, some general lessons can be extracted:

1. Successful implementation of a sustainable siting procedure, including broad acceptance of safety criteria takes much longer than the four-year interval between elections and, as a result, becomes liable to political reversals;

2. Implementation of a siting procedure is more complex in a federal system such as Germany's because many powers reside with the states (Länder) and the election cycles at the two levels are out of phase.

3. The siting process is further complicated if there is simultaneously a debate over new nuclear-generating capacity or over the question of extending the operating times of existing nuclear power plants.

4. Transparency of assessment and exploration activities and of decision-making processes is essential if a site selection process is to be politically sustainable. This becomes more difficult if, as was the case in Germany, such transparency is not designed in from the very beginning of the process.

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