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Nuclear Waste in Germany

TU berlin WIP

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Agenda

1) Overview of German nuclear infrastructure
2) German waste classification system
3) Quantities of waste
4) Waste management policies and facilities
5) Costs and financing
6) Summary

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2) **German waste classification system**
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The German nuclear infrastructure

Source: www.atommuellreport.de

- 1957: Eltville program (PHWR, FBR, HWGCR, …)
- 1961: grid connection of VAK Kahl (LWR)
- 1970s: Plans for a complex nuclear disposal center in Gorleben including a SNF reprocessing plant, fuel fabrication plants, and deep geological disposal (DGD).
- By the late 1980s, West Germany had 19 nuclear power plants in operation (~ 30% nuclear share).
- Around 231,000 tons of uranium were extracted in the GDR, making the country the fourth largest uranium producer of its time worldwide.
- Uranium enrichment plant in Gronau operated by a subsidiary of URENCO Ltd. (1/3 Preussen Elektra and RWE, 1/3 UK and Dutch government each).
- Fuel fabrication plant in Lingen, Framatome manufactures fuel assemblies as well as powder and pellets for supplying all of Framatome's fuel fabrication plants.
- 2019: 7 operational NPPs, 29 shut down, 5 decommissioned (3 greenfield).

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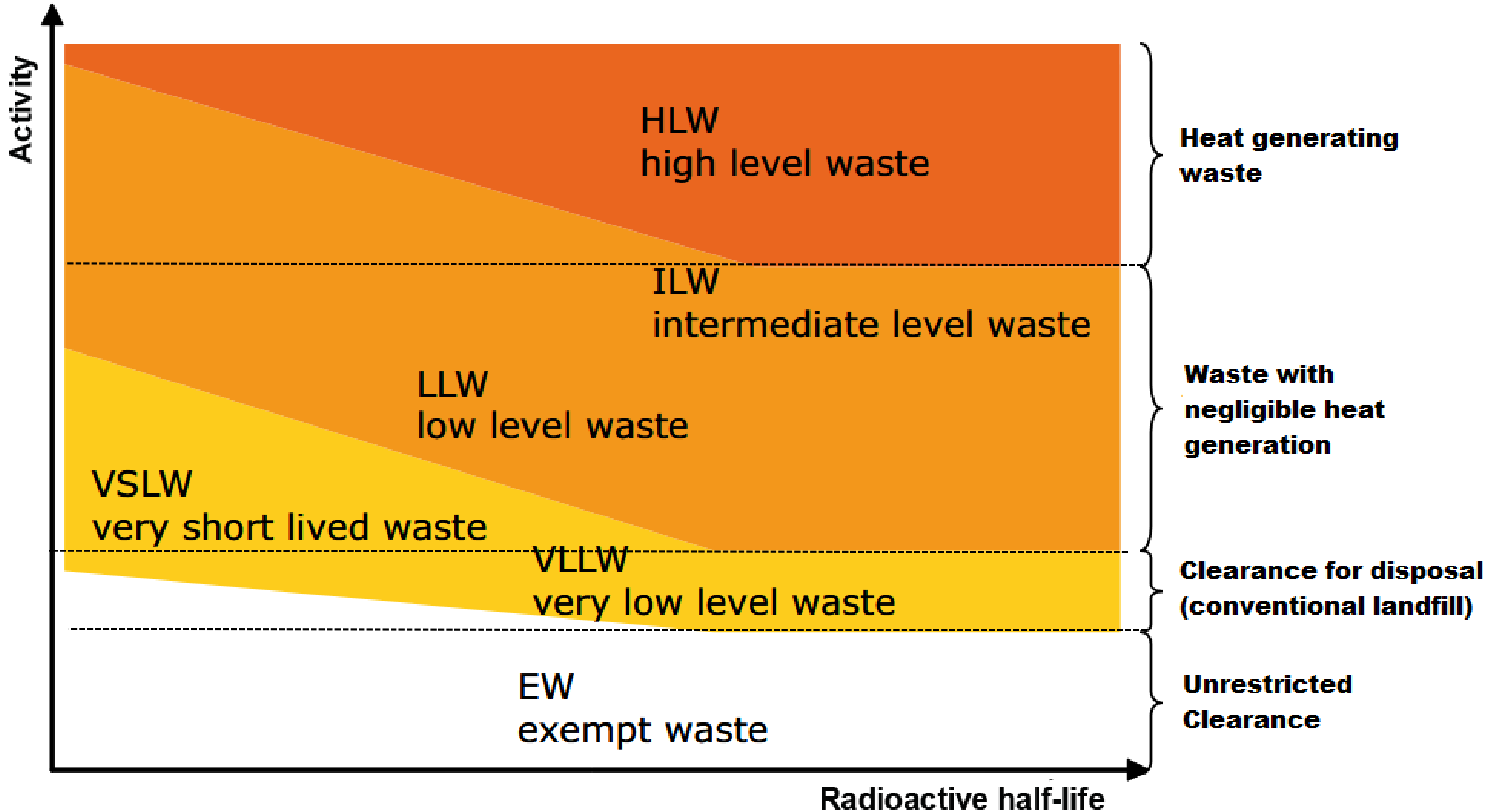
Radioactive Waste Classification



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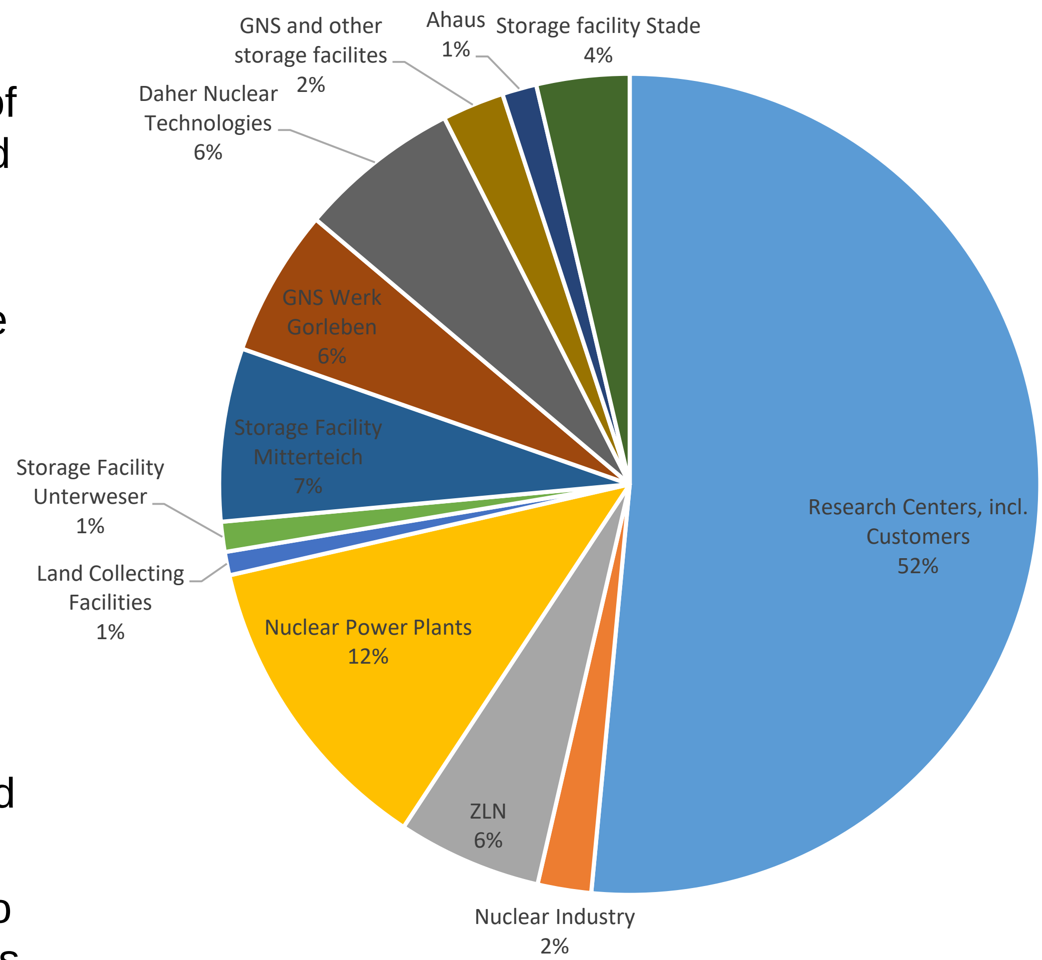
Around 120,000 m³ of waste with negligible heat generation are stored in various forms across the country

- Around **120,000 m³** (including research facilities) are stored in various forms across the country, not including around 21,000 tons of waste, that has not undergone some form of conditioning (i.e. waste in its original form) and is stored on the producers' sites.
- The stored waste is divided according to its processing state. Around **100,000 m³** of waste has been conditioned into Konrad containers, these are licensed for storage in the disposal facility Konrad. An additional 3,000 m³ has undergone product control.
- Around **45,200 m³** (commercial NPP) are currently in interim storage in decentralized interim storage facilities (at the NPP sites) as well as in the centralized interim storage facilities (Gorleben, Mitterteich, Greifswald and Ahaus, around 24,000 m³).
- All waste with negligible heat generation are to be disposed of in the Konrad facility, which has a capacity of **303,000 m³.**

Storage locations of waste with negligible heat generation



Source: based on Joint Convention Report by the Government of Germany (2018)

Germany has also disposed waste with negligible heat generation in two DGD facilities, half of which needs retrieval.

Around 84,100 m^3 of waste with negligible heat generation have been "disposed" of in two deep geological disposal facilities (DGD).

In the former DGD facility Morsleben (Saxony-Anhalt, 1971-1991 and 1994-1998), 37,131 m^3 was disposed of.

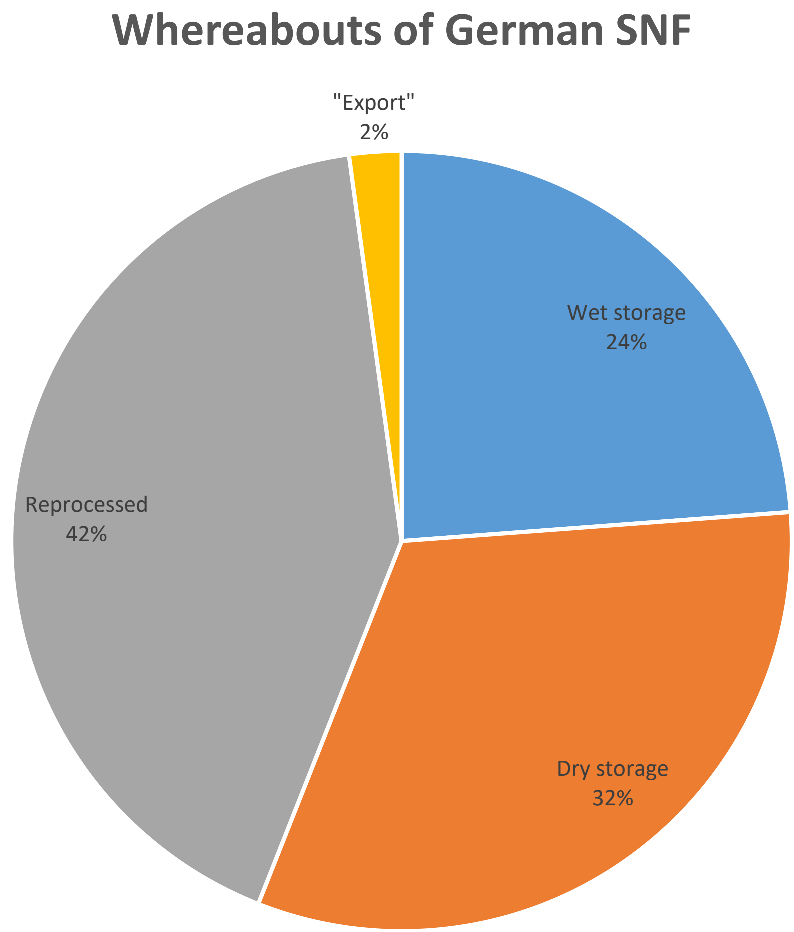
Around 47,000 m^3 was disposed of in the DGD Asse II (Lower Saxony, 1967-1978). However, the pressurized salt is losing its stability and groundwater inflow makes continued dry operation impossible.

- Asse II is in danger of collapsing. In 2010, the complete retrieval of the estimated **220,000 m^3** of mixture of radioactive waste and salt was announced although in practice it may not be technically feasible to retrieve all of it.
- Until today the disposal strategy is not decided and recovery has not started. One option is to dispose of the waste in the future DGD for HLW, if technically possible. The most costly scenario would be the search for and construction of a third DGD.

Germany has a legacy over large amounts of SNF currently in interim storage

So far: 15,155 t HM of spent nuclear fuel (SNF) have been produced.

- 6,343 tons were sent for reprocessing
- In addition, 577 m^3 from reprocessing is currently stored mostly at reactor sites
- There are still 26 casks containing waste from reprocessing stored in France and the UK
- 327 tons were “otherwise managed”, i.e. exported without return (VVER fuel to Hungary and USSR and to Sweden (CLAB))
- 8,485 tons are in interim storage, of which 3,609 tons still in wet storage in pools at reactor sites
- Germany expects that around **27,000 m^3** of heat-generating waste will be disposed of in one deep geological disposal facility.



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The Fukushima catastrophe in March 2011 had a catalytic effect on German nuclear waste policy.

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- With support from parties across the political spectrum, the government decided to shut down all nuclear power plants by 2022.
- A working group was set up to find a compromise between the political parties and the federal and state interests regarding the future policy for a DGD facility.

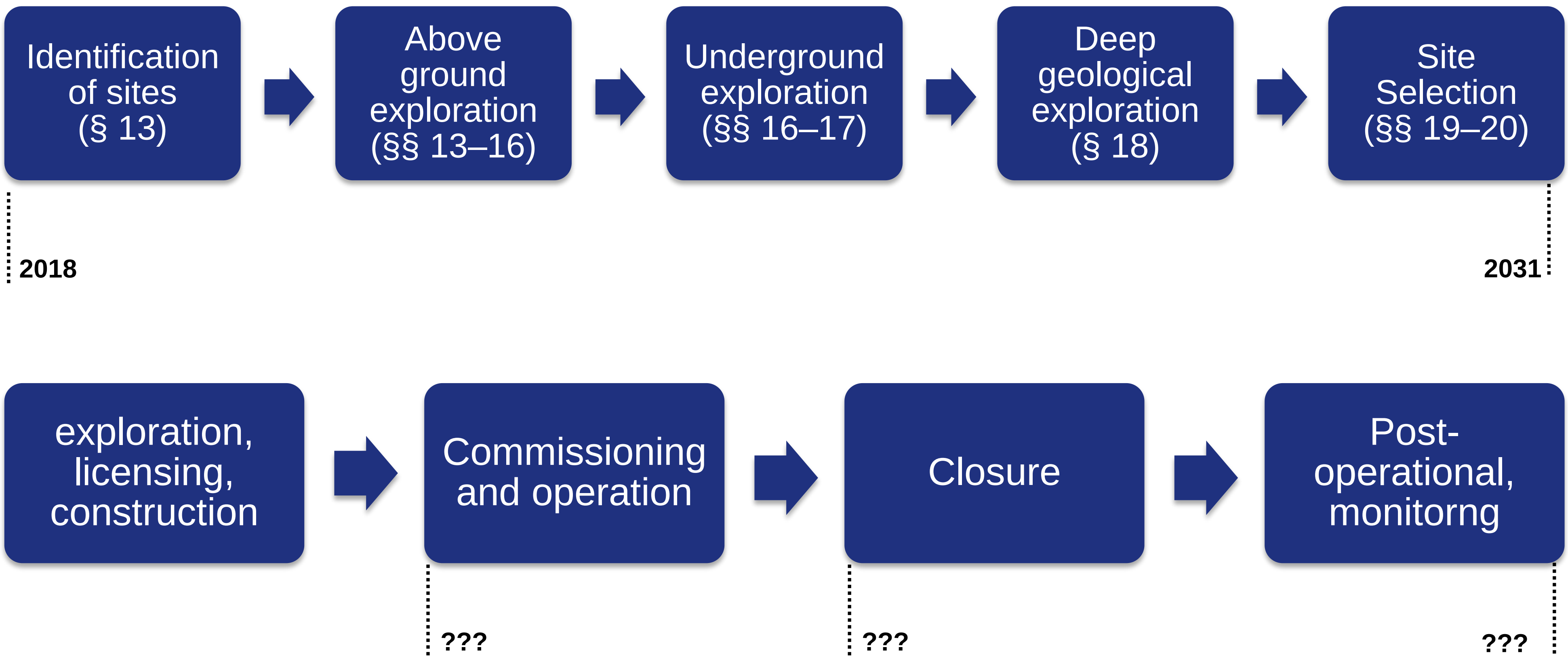
Two years later, the parliament passed the 2013 Repository Site Selection Act (StandAG) and work in the Gorleben salt bed has been set on hold.

In 2014, the Commission on the Storage of High-Level Nuclear Waste was set up to audit the StandAG and develop recommendations for the site selection process.

- They define safety standards, assessment criteria and an adaptive procedure to enable revisions of decisions and to establish retrievability of the disposed waste. Furthermore, the site selection process is to be opened to all potential host rocks in Germany: claystone, rock salt and crystalline rock. Its final report recommends a three-phase process accompanied by public participation.

Timeline based on Repository Site Selection Act

The government implemented these recommendations in its 2017 revision of the StandAG and set an aspirational date to f<u>ind a site by 2031</u>.



The German government rearranged the responsibilities of its various agencies.

In parallel, the German government rearranged the responsibilities of its various agencies.

- In 2016, a new law transferred tasks previously undertaken by the public authority for radiation protection (**BfS**) to the public authority for the safety of nuclear disposal (**BfE**) and the new federal company for radioactive waste disposal (**BGE**).
- All the federal regulation, licensing, and supervisory tasks are bundled in the BfE; the operational tasks of site selection, building and operation of the DGDs was transferred to the BGE, which is also responsible for the construction of the Konrad mine (now scheduled to open in 2027, more than half a century after site selection).
- The ownership of the interim storage facilities for HLW was transferred to the federally owned company for interim storage (**BGZ**). In the coming years, the LILW storage facilities on the reactor sites will also be transferred to the public company.

To monitor the site selection procedure and to implement public participation, a pluralistically composed National Civil Society Board (NBG) was established. It started work in December 2016. The institutionalized participation of civil society is a new approach for Germany.

So far, public attention for the new site selection procedure and its participation process is weak.

The issue of interim storage

BGZ takes over interim storage facilities:

- Centralized storage facilities: 01.08.2017
- Decentralized storage facilities: 01.01.2019
- Decentralized storage facilities for waste with negligible heat generation: 01.01.2020

All interim storage facilities are licensed for 40 years of operation.

Centralized interim storage facilities: Ahaus (2036), Gorleben (2034)

13 decentralized interim storage facilities: 2034 ~ 2042

In addition, all transport and storage casks are licensed for 40 years since the point of time they are filled.

This raises technological (e.g. hot cell), organizational (responsibility of BGZ), and financial questions (e.g. who pays for it).

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Under the Atomic Energy Act the operators of NPPs must pay for decommissioning and waste management

For historic reasons, two different funding systems are in place:

- one for the former East German reactors, which are now publicly owned and financed. For example, the funding for the decommissioning of the former GDR Greifswald and Rheinsberg power plants is completely provided by the Federal Ministry of Finance. Here, the last cost estimate (in 2016) for both sites was around €6.5 billion (US$7.3 billion) in total.
- The other funding system is for facilities in private ownership. There are also some prototype reactors in mixed-ownership. Here a proportional split of the costs between the public and the private utilities is clarified by special arrangements.

In 2015, an auditing company on behalf of the German government estimated the cost of decommissioning and waste management for 23 commercial nuclear power plants at undiscounted €47.5 billion (US$53.4 billion), including:

- €19.7 billion (US$22.1 billion) for decommissioning and dismantling,
- €9.9 billion (US$11.2 billion) for casks, transport, and operational waste,
- €5.8 billion (US$6.5 billion) for interim storage,
- €3.7 billion (US$4.2 billion) for a disposal facility for waste with negligible heat generation,
- and €8.3 billion (US$9.3 billion) for a disposal facility for heat-generating waste.

If the polluter-pays-principle had been applied rigorously, the operators would have had to file for bankruptcy

The nuclear utilities have built up €38.2 billion (US$42.9 billion) in provisions.

- These funds have been collected from consumers via electricity prices.
- Clearly, the estimated costs for these processes exceed the provisions.
- If the polluter-pays-principle had been applied rigorously (which it should have, according to the Atomic Energy Act), the operators would have had to file for bankruptcy.
- Concerns grew that the operators could leave the bill, in the case of bankruptcy, to the public and that safety and security during decommissioning, storage and waste management could be neglected for economic reasons.
- In response, the government set up a commission (KFK) to review the financing system.

The commission recommended changing the funding system fundamentally, transferring financial and organizational obligations for the waste management from the operators to the federal government. The recommendations were integrated into the new law.

The utilities are still responsible for decommissioning and conditioning, but are exempted from all downstream waste tasks.

Setting up an external, segregated fund for waste management

- Accordingly, the utilities had to pay the amount of their former provisions for waste management of €24.1 billion, including a risk premium, into an external, segregated public fund.
- The Fund for the Financing of Nuclear Waste Management was set-up in mid-2017 to ensure that the money is invested 'securely and profitably'.
- Yet responsibility and future risks will have to be borne by the public, **infringing the polluter-pays-principle**.
- In its first financial year, the fund only invested a fraction of its assets and the majority is still held at the Bundesbank at an interest rate of 0.4 percent. This led to around €39 million in interest expenses during the fund's first six months of existence.

	Nuclear Waste	**Decommissioning**
Financing scheme	External segregated fund	Internal non-segregated and unrestricted
Accumulated by	investment of the funds	Provisions by operators
Total cost estimates	US$19.8 billion*	US$22.2 billion for 23 commercial reactors US$940/kW
Set aside funds	US$27.2 billion*	US$26.7 billion**

* including interim storage, LILW and HLW disposal
** in 2017, including provisions for casks, transport, and conditioning (also of operational waste).

The limits of basic liability for decommissioning and waste management

Even in countries in which the polluter-pays-principle is a legal requirement, an operator of a nuclear power plant will not be held financially liable for any problems arising during the long-term storage (i.e. after disposal) of the waste.

For instance, at the Asse II site in Germany, LILW needs to be recovered from an abandoned salt mine at an estimated cost of €4-6 billion covered by taxpayers; while the fees collected for the disposal of radioactive waste during operation of the mine amount to only €8.25 million.

Source: Kristof (2010)

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1) Motivation
2) Waste classification system
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Summary

- Fukushima accident in 2011 had a catalytic effect on German nuclear policy.
- After agreeing to disconnect all nuclear power plants stepwise until 2022, political attention was shifted to decommissioning and storage/disposal.
- A new site selection procedure was institutionalized through a reshuffling of agency responsibilities, the creation of new federal companies and regulators, and the implementation of an external, segregated fund for waste management.
- Germany has a legacy of large amounts of waste currently in interim storage, both in centralized interim storage facilities and at reactor sites. Germany classifies its waste as two types: radioactive waste with negligible heat generation and radioactive waste with heat generation.
- The future disposal path for high-level waste is still highly uncertain, with Germany only now entering the site selection process.
- The construction of the deep geological disposal facility at Konrad for low- and intermediate-level waste is still ongoing, and currently the facility is planned to open in 2027.
- Interim storage of spent nuclear fuel and high-level waste will at least last until 2050, at best.
- All estimated future costs – especially future costs related to waste management – are uncertain due to cost increases and interest rates. It is questionable whether the financial resources set aside in the fund will cover these costs.
- Unclear: waste from Asse II. Is there a need for a 3d repository?
- Unclear: technological, organization, and financial issues from interim storage

Thank you for your attention!

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Backup

Overview and the Nature of the Funds

Internal non-segregated fund:

- operator pays into a self-administrated fund and manages the financial resources, which are held within its own assets**.**

Internal segregated fund:

- operator is obliged to form and manage funds autonomously
- assets must be segregated from other businesses or earmarked for decommissioning and waste management purposes

External segregated fund:

- operators pay their financial obligation into an external fund
- private or state-owned independent bodies manage the funds
- one fund can cover the whole industry or there can be one for each operator
- external fund can exist with or without transfer of the liabilities and with or without a short-fall guarantee by the operator

Public budget:

- State authorities take over the financial responsibility including the accumulation of financial resources (for instance via taxes and levies)

The main scenario is to build up a fund year by year over the entire expected lifetime of a nuclear power plant or facility

The accumulation of the funds can either be achieved by y a fee, a levy set on the sale of electricity, “internally” by the operators who set aside funds from the revenue obtained from the sale of electricity, or by the investment of the funds.

A crucial aspect is whether funds or future provisions are based on discounted or undiscounted costs:

- If the costs are not discounted, the operators have to set aside the full amount of the estimated costs. Only a few nuclear funding systems use undiscounted costs
- If costs are discounted, the funds are expected to grow over time. Here the provisions are determined using the inflation rate until the due date and then discounted with an interest rate, which is supposed to represent the expected rate of return
- The employed discount rates range widely (for example, 5.5 percent in Germany versus 1.5 percent in Spain).
- A cost escalation rate is not always assumed (e.g. in Germany a “nuclear-specific inflation rate” of 1.97 percent is calculated on top of the inflation rate)
- Applying only the general inflation rate could eventually lead to an underestimation of the costs and hence the amount of the funds

In Germany, for instance, the set aside funds of €24.1 billion for all waste management related activities are expected to grow nearly fourfold to €86 billion by 2099.

Cost Experiences are Scarce and Cost Estimations are Underlying High Unsecurities

In order to accumulate funds, costs need to be estimated. This is a critical aspect of funding, especially for unknown projects like a deep geological facility for high-level waste.

Different cost estimation methods are conceivable (e.g. order-of-magnitude estimate, budgetary estimate, definitive estimate).

In reality, most cost estimates are budgetary estimates based on studies and estimates from the 1970s and 1980s, which are then extrapolated.

In most cases, the waste management organization is responsible for developing cost estimates for the long-term management of radioactive waste. This organization can be state-owned (such as in the UK, Germany and Spain) or in some cases utility-owned, as in Sweden and Switzerland.

In most cases cost estimates are not publically available (e.g. in Germany, the cost of both decommissioning and long-term waste management is based on expert opinions, produced by the private companies for the utilities and not public).

Financing Schemes for (Interim) Storage

The costs and the financing schemes for interim storage depend heavily on the available waste management infrastructure and disposal paths.

As there is currently no disposal solution for HLW, all the nuclear countries are faced with both technological, organizational, and financial interim storage issues. Countries with no disposal solution for LILW increasingly face financing of storage for LILW with a growing number of reactor shutdowns.

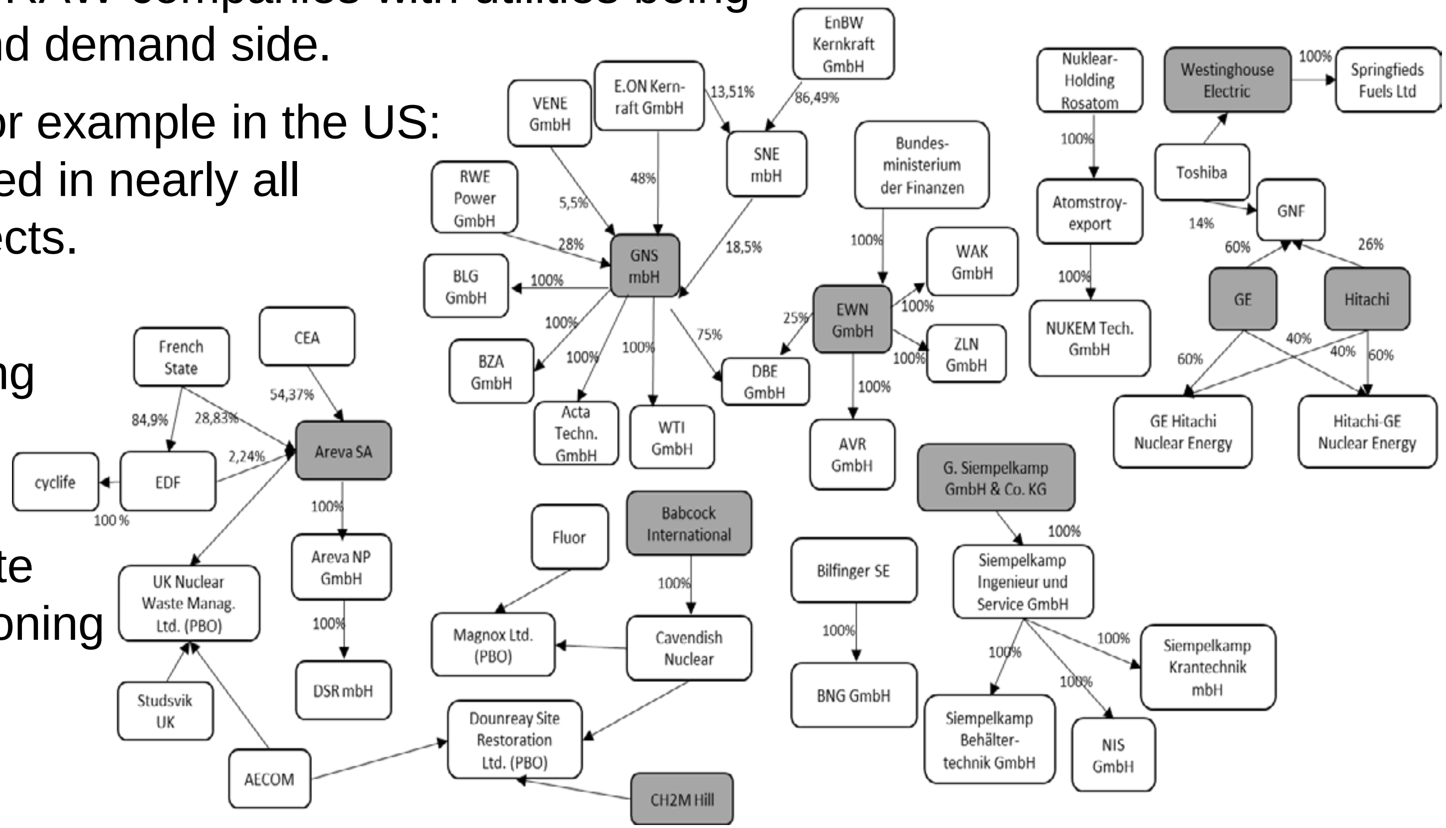
The costs for interim storage of waste can be paid:

- from operational revenues (as at CEZ in the Czech Republic, Switzerland)
- From set aside provisions (e.g. in Germany: estimated discounted costs were around €5.8 billion in 2014, now transferred to an external segregated fund)
- From a public fund (e.g. in Sweden, the costs for the centralized interim storage facility CLAB are paid by the Nuclear Waste Fund).

In France, EDF estimates an additional €18.7 billion (US$21.1 billion) for spent fuel management (for example storage, reprocessing), and another €1.2 billion (US$1.4 billion) for waste removal and conditioning. This amounts to €51 billion (US$57.5 billion) only for handling and storing the waste generated from operation.

Provision of Waste Management Services

- Only a few and highly interconnected specialized decommissioning and RAW companies with utilities being active on the supply and demand side.
- Large market power, for example in the US: Energysolutions involved in nearly all decommissioning projects.
- State is in most cases responsible for providing high-level waste management services.
- In some cases, the state overtakes decommissioning too (Spain).



Source: Wealer et al. (2015)

Storage and Disposal Costs

For waste management, costs depend heavily on the disposal technologies, clearance levels of the waste, the waste quantities, or in some cases compensation schemes for the local communities who agreed to host the repositories.

Some (undiscounted) cost estimates for geological disposal:

- **France: €31 billion**
- **USA: US$96 billion**
- **Germany: €8.3 billion (US$9.3 billion)**

For HLW disposal, it is important to keep in mind that all published figures are estimates, as no country has yet opened or even constructed a deep geological disposal facility for HLW. site Gorleben.

Depending on the nature of the funds, a major source of resource accumulation is the investment of the funds

Here a conflict of interest arises between the operator and the regulator in choosing the investment strategy.

The operator will typically prefer riskier investment strategies with higher rates of return, while the regulator will ideally prefer a more secure investment strategy and accept lower rates of return.

In Sweden, for instance, following the financial crisis of 2008, the rate of return on long-term bonds was lower than expected, and concerns of underfunding grew, leading to a change of the investment strategy. Since 2017, the funds can now be put into less secure investments than government bonds.

Cost Estimations - Methodologies

In order to accumulate funds, costs need to be estimated. This is a critical aspect of funding, especially for unknown projects like a deep geological facility for high-level waste.

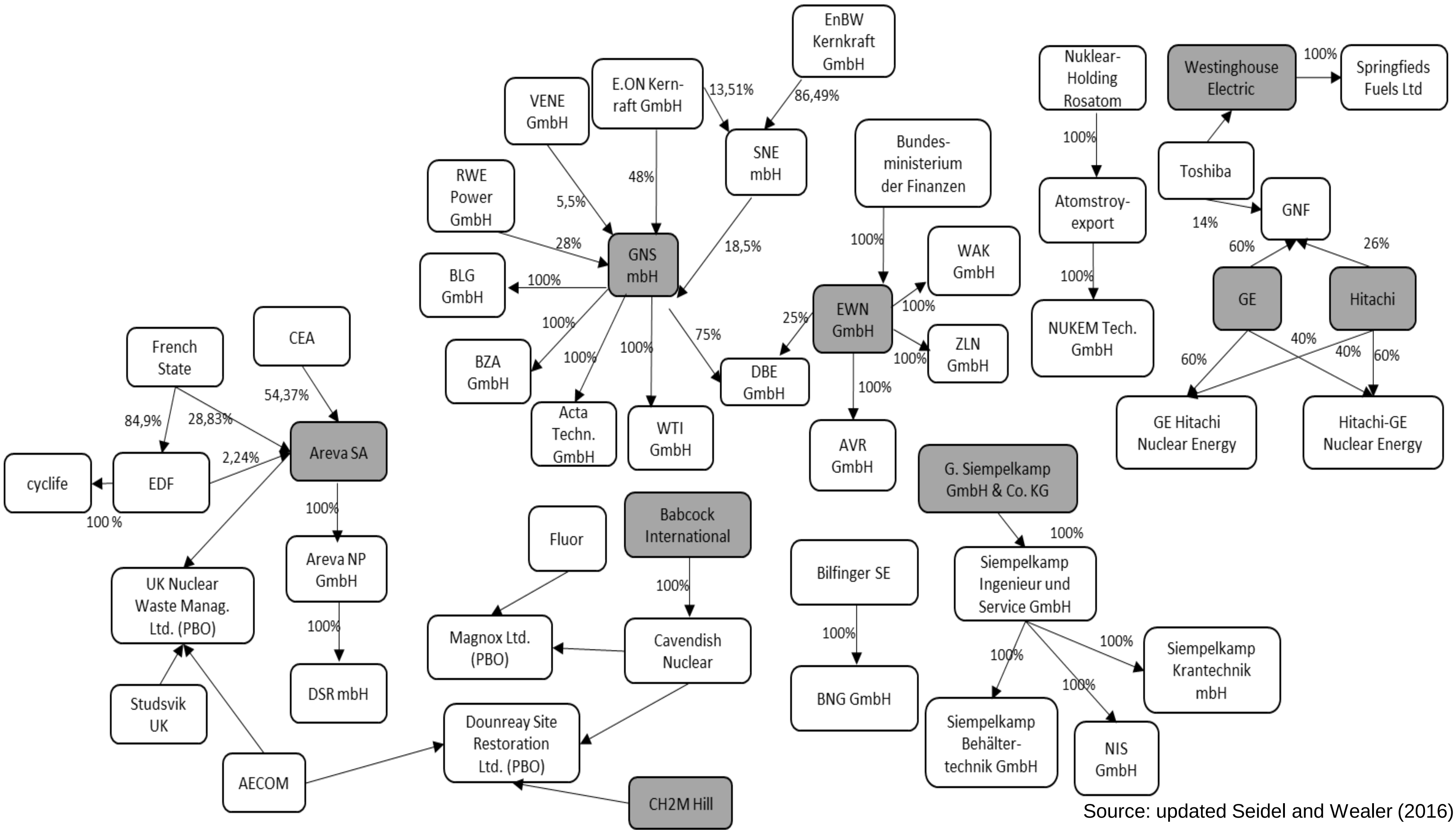
Different cost estimation methods are conceivable:

- **the "order-of-magnitude estimate" is a rough calculation without detailed engineering data (for example by taking some cost figures in international literature for granted and only slightly adapting them to the situation in the country, by scaling up or down factors and approximate ratios).**
- **The "budgetary estimate" is based on the use of flow sheets, layouts and equipment details, where the scope has been defined but the detailed engineering has not been performed (for example, modelling based on reference cases or differentiated modelling for every individual facility).**
- **In the "definitive estimate", the details of the project have been prepared and its scope and depth are well defined.**

Radioactive waste management in the United Kingdom

- Reprocessing of Magnox fuel stops in 2020
- Biggest challenge: extracting, characterizing and safely packaging legacy wastes
- Not yet a disposal solution for the graphite waste from GCRs, 60,000 tonnes alone on the Magnox sites
- All HLW and most SNF is stored at Sellafield
- Interim storage facilites have been installed at all the Magnox sites
- Site selection process for HLW disposal site failed in 2008
- Current estimation for geological facilty for HLW is 2040
- In 2016, EDF Energy set up a dry cask storage facility for SNF at Sizewell B

Only a few and highly interconnected specialized decommissioning and RAW companies



Source: updated Seidel and Wealer (2016)

Organization Model for Germany after the reform recommended by EK and KfK

Production:

- Decommissioning:
  - Stage 3 mostly tendered to specialized companies or deferred strategy applied
- Radioactive Waste Management:
  - Interim storage facilites now owned and operated by the public company BGZ
  - Construction, licensing, and operation of the geological facilities was the scope of the government (BfS, now responsibility of public company BGE

Financing :

- Decommissioning
  - Estimated costs for 23 NPPs 830€/kW (19.719 bn €)
  - Cost increases between 2.9% and 6% (1,400-10,000 €/kW)
- Radioactive Waste Management:
  - Installation of a new external fund (**KfK**) with a sum of around 23 billion Euro including a risk premium
  - All disposal related risks will be the in the responsibility of the public fund – infringes the polluter pays principle
  - Concerns: amount is not high enough to bear all future costs

Production / Financing	A) Public enterprise	B) Private enterprise (decentral or decentralized)	C) Public tender (centralized or decentralized)	D) Further alternatives
1) Public budget	EWN			
2) External segregated fund		E K		
3) Internal segregated fund			KFK	
4) Internal non segregated fund				
5) Further alternatives				

Organizational Challenges: Oligopoly, further delays very likely

Germany is currently exploring large-scale decommissioning. The work is carried out by the utilities while some works are tendered to specialized companies.

Wealer et al. (2015) suggest a potential oligopoly and the potential abuse of market power due to market concentration. Some solidification for this suggestion could have been observed in 2018: PreussenElektra awarded the dismantling of the RVI of six plants to a consortium led by waste management company GNS and Westinghouse. GNS is utilities-owned with PreussenElektra being the major shareholder with 48 percent of the shares.

Possible economies of scale with WH/GNS decommissioning six NPPs.

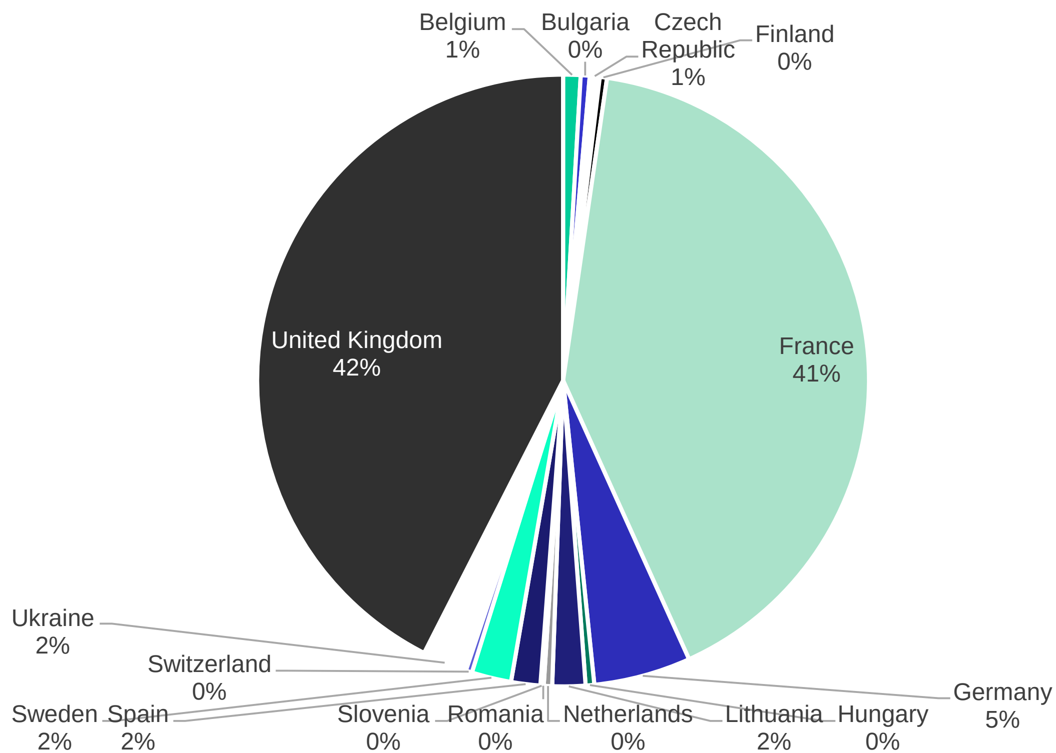
Only one of the 8 reactors shut down after Fukushima has been defueled: The special fuel rods of Brunsbüttel were sent to Sweden and are thought to be sold to the US.

Insufficient number of storage and transport casks for SNF, while casks for the special fuel rods are still missing.

Low- and intermediate level waste in Europe (in interim storage and disposed), as of December 31, 2016 (rounded figures)

Country	LILW in interim storage [m3]	LILW disposed [m3	Total generated LILW [3]
Belgium	23,200	No disposal facility operational.	**23,200**
Bulgaria	11,900	No disposal facility operational.	**11,900**
Czech Republic	1,750	11,500	**13,250**
Finland	1,970	7,600	**9,600**
France	180,000	853,000	**1,033,000**
Germany	45,200	84,100	**129,300**
Hungary	10,600	876	**11,500**
Lithuania	44,000	No disposal facility operational.	**44,000**
Netherlands	11,100	No disposal facility operational.	**11,100**
Romania	1,000	No disposal facility operational.	**1,000**
Slovenia	3,400	No disposal facility operational.	**3,400**
Spain	6,700	32,200	**38,900**
Sweden	13,800	39,000	**52,800.**
Switzerland	8,400	No disposal facility operational.	**8,400**
Ukraine	59,400*	No disposal facility operational.	**59,400**
United Kingdom	130,000	942,000	**1,072,000**
Total	**552,400**	**1,970,000**	**2,522,000**

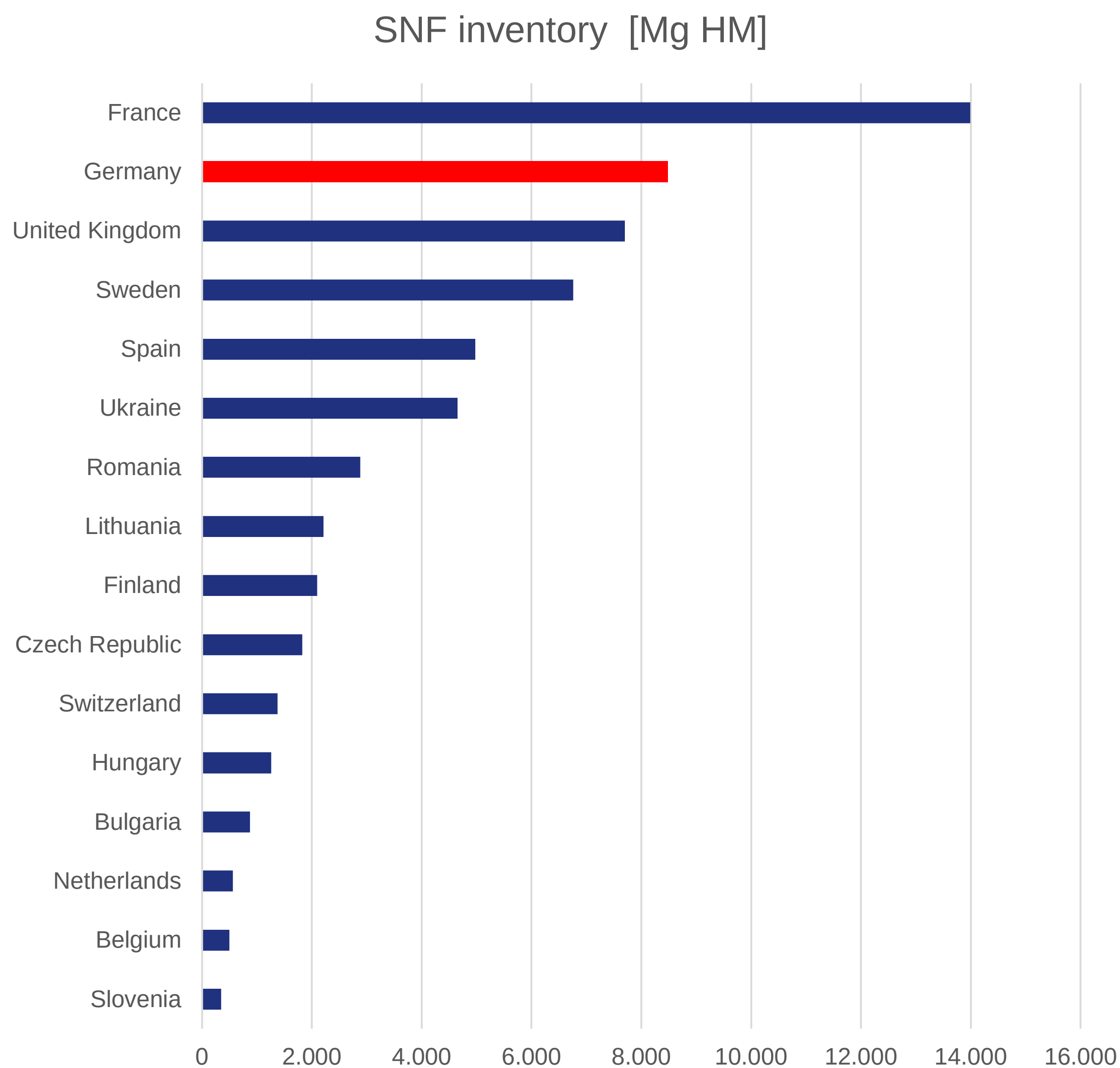
As of today, less than half of the observed countries have installed disposal facilities, mostly for LLW and not ILW: the UK, France, Spain, Hungary, Finland, Czech Republic, Sweden and Germany. But these countries have disposed of altogether close to 2 million m3 of operational waste.



Source: The World Nuclear Waste Report (2019)

Reported SNF inventories in Europe and amount in wet storage, as of December 31, 2016

Country	SNF inventory [tons]	SNF in wet storage [%]
Belgium	501**	47%
Bulgaria	876	90%
Czech Republic	1,828	36%
Finland	2,095	100%
France	13,990	100%
Germany	8,485	43%
Hungary	1,261	17%
Lithuania	2,210	64%
Netherlands	80***	100%
Romania	2,867	45%
Slovenia	350	100%
Spain	4,975	91%
Sweden	6,758	100%
Switzerland	1,377	60%
Ukraine	4,651****	94%
United Kingdom	7,700	100%
Total	**ca. 60,500**	**81%**



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