21st Reform Group Meeting

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Decommissioning of nuclear power plants and storage of nuclear waste: comparison of organization models and policy perspectives

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Agenda

1) Motivation
2) Technological System and Organization Matrix
3) Case Studies
4) Conclusion

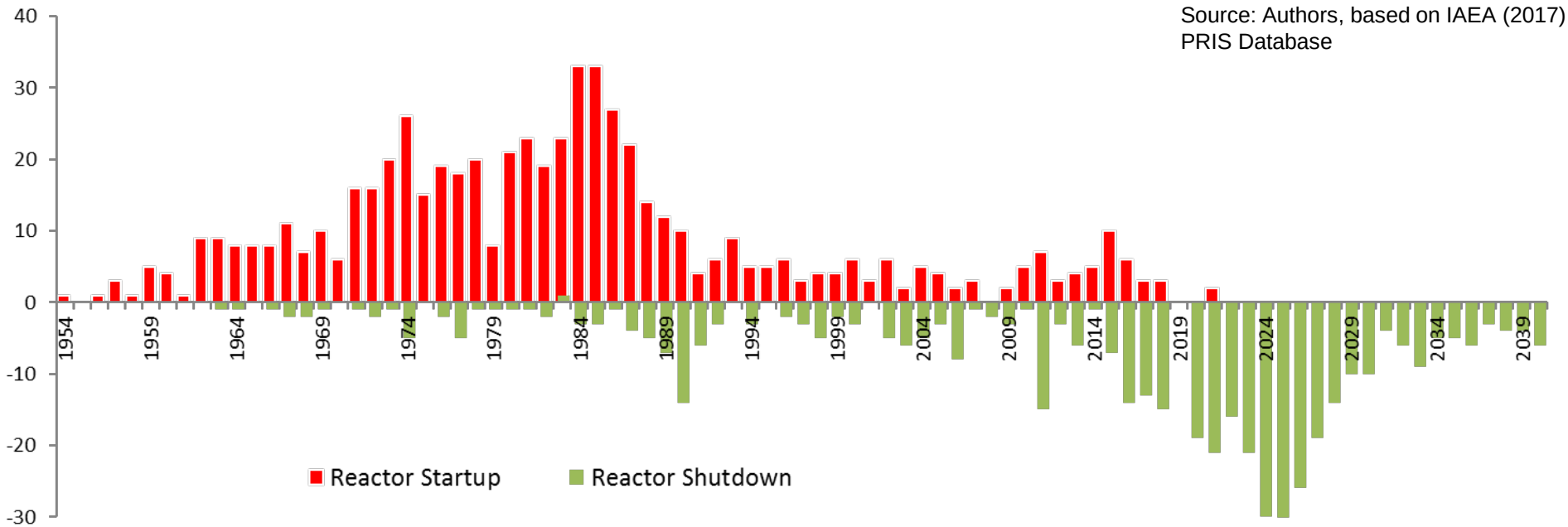
Agenda

1) Motivation
2) Technological System and Organization Matrix
3) Case Studies
    1) Germany
    2) United Kingdom
    3) United States of America
4) Conclusion

Agenda

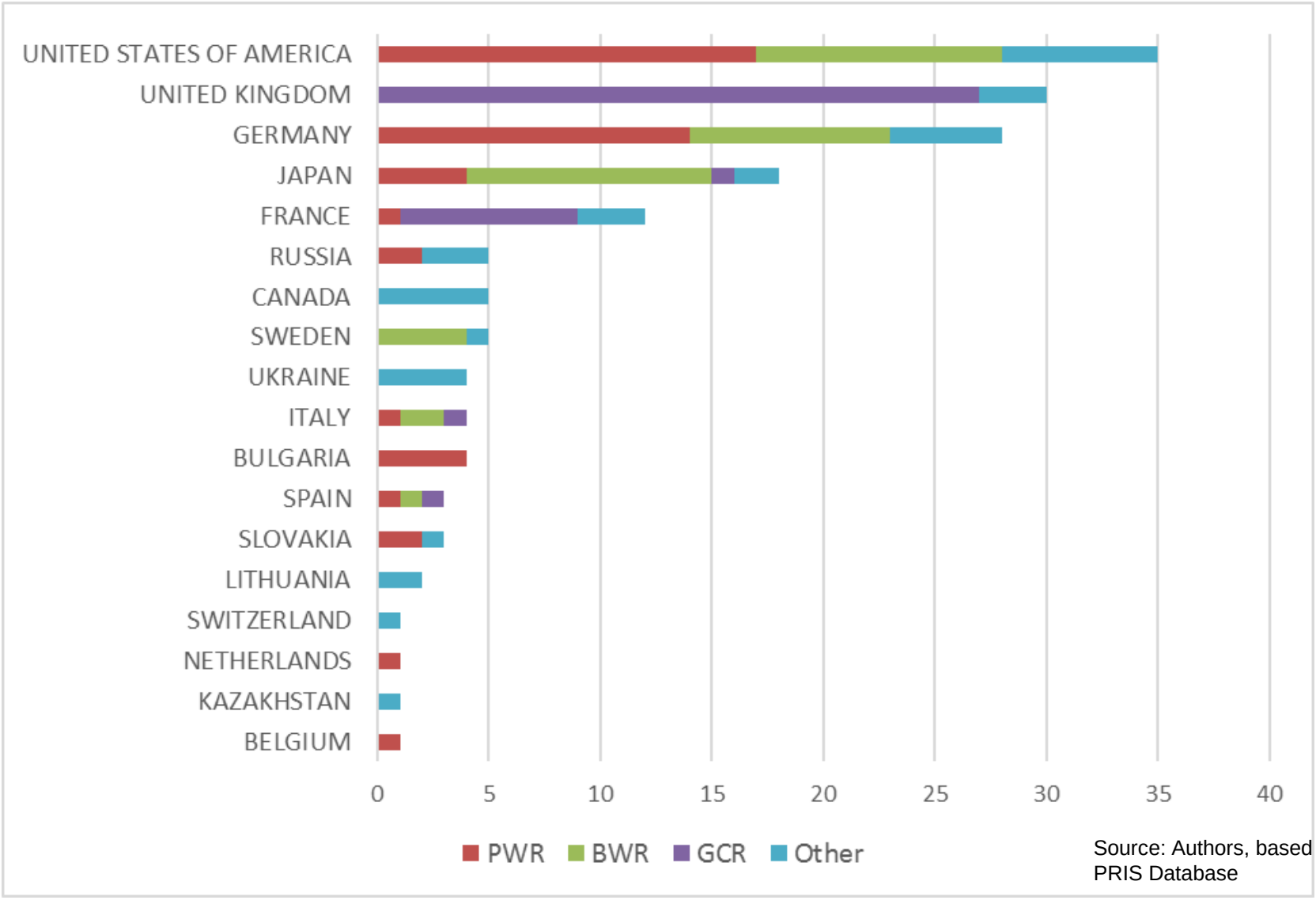
1) Motivation
2) Technological System and Organization Matrix
3) Case Studies
    1) Germany
    2) United Kingdom
    3) United States of America
4) Conclusion

Outlook – Global development of the Nuclear Power Plant Fleet



- About 440 commercial reactors are currently operating. Most of them constructed during the 1970s and 1980s.
- Many reactors will reach their technical-lifetime very soon, which causes a growing demand for decommissioning and dismantling services.
- The search for High Level waste disposal facilities is on-going. In Finland the construction licence of the 1st geological disposal facility was granted in 2015.

Outlook – Shut-down reactors worldwide



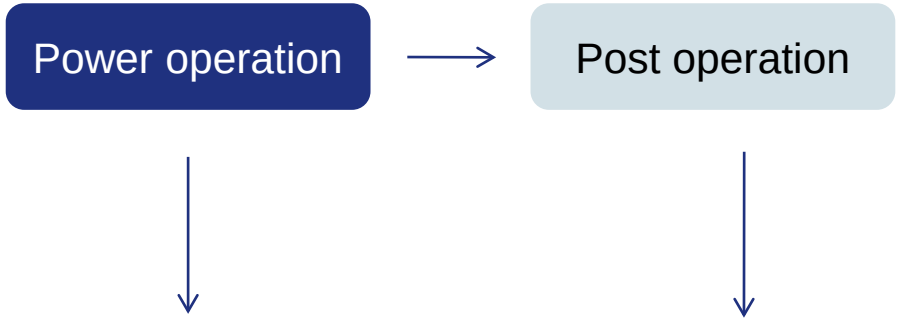
Source: Authors, based on IAEA (2017) PRIS Database

Agenda

1) Motivation
2) Technological System and Organization Matrix
3) Case Studies
    1) Germany
    2) United Kingdom
    3) United States of America
4) Conclusion

From operation to decommissioning & dismantling

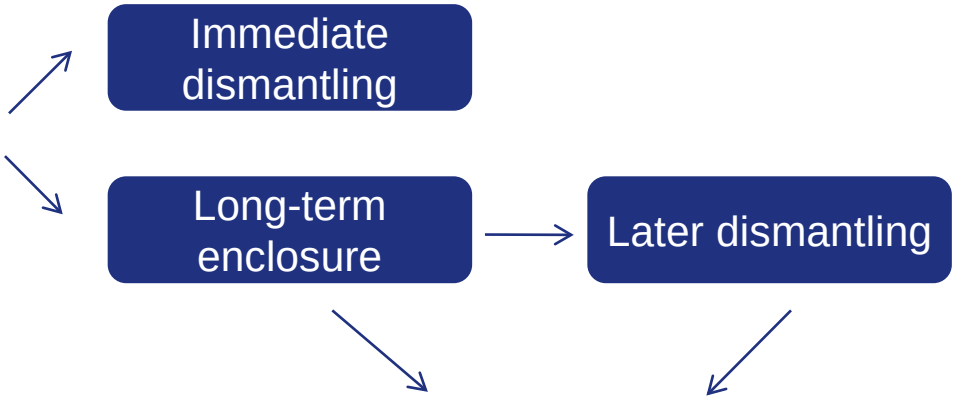
Operating phase:



- Operating company makes the first application for decommissioning and dismantling before the shutdown of the NPP.

- Removal of nuclear fuel elements and of nuclear waste from operations.
- Sample taking at systems and components.
- Decontamination of facilities and systems.

Decommissioning phases:



- Beginning of real dismantling.
- Removal of the nuclear constructions at the power plant site.
- New trend: Deferred Dismantling
- Third seldomly used strategy: Entobment

Typical stages of the decommissioning process

Typical choice of a decommissioning licensee: Immediate Dismantling or Long-term Enclosure.

The five stages of decommissioning („from the outside to the inside“):

- **Stage 1:** Deconstruction of systems which are not needed for decommissioning, Installation of the logistic in the hot zone.
- **Stage 2:** Deconstruction of higher contaminated system parts e.g. the steam generator or parts of the primary coolant. Preparation of the deconstruction of the larger and highly activated components.
- **Stage 3:** Deconstructions in the hot zone, e.g. deconstruction of activated material, like the reactor pressure vessel and its internals, and the biological shield.
- **Stage 4:** Deconstruction of contaminated system parts, removal of operating systems e.g. cranes or filtration systems and decontamination of buildings. Goal is the release from regulatory control.
- **Stage 5:** Demolition or other use of the buildings.

Source: Wealer et al. (2015)

Organizational models for decommissioning and radioactive waste management (RAW)

Production / Financing	A) Public enterprise	B) Private enterprise (decentral or status quo)	C) Public tender (centralized or decentralized)	D) Further Alternatives
1) Public budget				
2) External segregated fund				
3) Internal segregated fund				
4) Internal non segregated fund				
5) Further Alternatives				

Source: Seidel and Wealer (2016), based on Klatt (2011)

High-level waste management

Decommissioning NPPs

Agenda

1) Motivation
2) Technological System and Organization Matrix
3) Case Studies
4) Conclusion

Agenda

1) Motivation
2) Technological System and Organization
3) Case Studies
    1) Germany
    2) United Kingdom
    3) United States of America
4) Conclusion

Agenda

1) Motivation
2) Technological System and Organization
3) Case Studies
    1) Germany
    2) United Kingdom
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4) Conclusion

Decommissioning Monitoring for Germany I/II

8 commercial power reactors with running or terminated decommissioning process

Reactor concept	NPP	Shut-down	Operator/Owner	Current Status	Begin of decommissioning	Planned termination
BWR	Lingen	1977	RWE	2015: license granted	-	-
	Gundremmingen A	1977	75% RWE; 25% E.ON	Stage 4	1983	-
	Würgassen	1994	E.ON	completed	1997	2014
PWR	Mülheim-Kärlich	1988	RWE	Stage 3	2004	2021
	Greifswald 1-5	1989-1990	Energiewerke Nord GmbH	Stage 4	1995	-
	Rheinsberg	1990	Energiewerke Nord GmbH	Stage 4	1995	2025
	Stade	2003	66,7% E.ON; 33,3% VENE GmbH	Stage 4	2005	2015
	Obrigheim	2005	EnBW	Stage 4	2008	2020 -2025

Source: updated Wealer et al. (2015)

- Terminated decommissioning projects: HDR Grosswelzheim (25 MW) (1988-1998), Kernkraftwerk Niederaichbach (110 MW) (1987-1995), VAK Kahl (1988-2010) (15 MW).
- Other NPPs in decommissioning process:, MZFR Karlsruhe (57 MW) (Stage 4), THTR-300 (LE) (296 MW), AVR Juelich (2003, Stage 3) (13 MW), KNK II (21 MW) (1993, Stage 3)

Source: Wealer et al. (2015)

Decommissioning Monitoring for Germany II/II

9 NPPs in post operation and Gundremmingen B (closes in 2017)

Reactor concept	NPP	Operator	FE	SFR	Defuelling ends in	Beginn of D&D	Estim. D&D duration
BWR	Brunsbüttel*	66.6% VENE; 33,3% E.ON	517	12	2017 (ended)	2017	10-15 years
	Gundremmingen B	75% RWE; 25% E.ON	3008		-	-	-
	Isar 1	E.ON	1734	44	2018	2017	10 years
	Krümmel	50% VENE; 50% E.ON	1094	62	-	2019/2020	10-15 years
	Philippsburg 1	98,45% EnBW	886	29	2017	-	15 - 20 years
PWR	Biblis A	RWE	440	59	2016	2017	15 years
	Biblis B	RWE	506	235	2017	2017	15 years
	Grafenrheinfeld	E.ON	597		-	-	-
	Neckarwestheim 1	98,45% EnBW	347	84	2017	2017	15 years
	Unterweser	E.ON	413	77	2019/2020	-	until 2025

- * Vattenfall awarded the contract to dismanlte the RVI to Areva-EWN joint-venture in 2017

Source: updated Wealer et al. (2015)

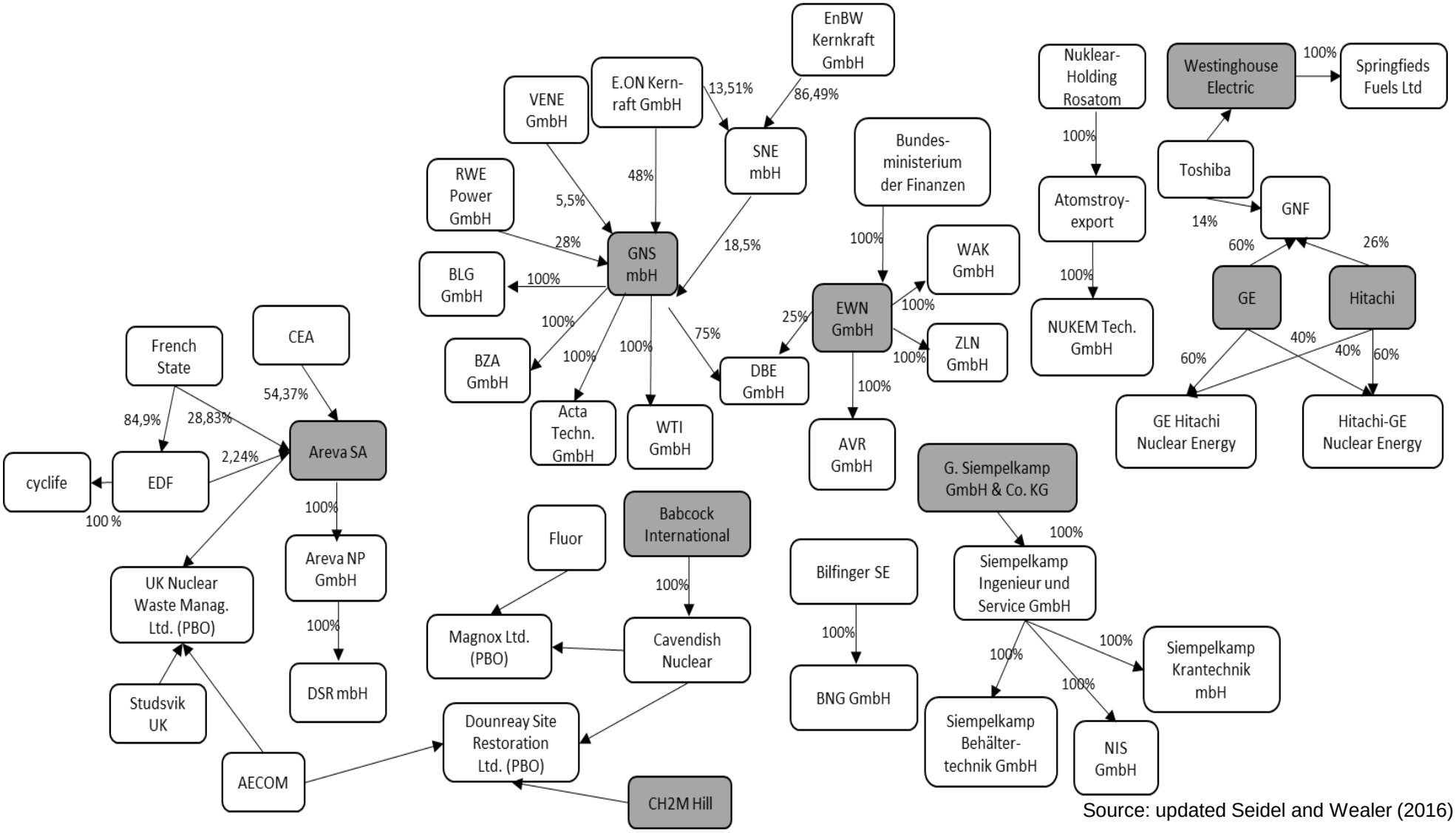
Source: Wealer et al. (2015)

Monitoring of the decommissioning market – Companies involved in the different decommissioning projects in Germany

NPP and current stage	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5	Overall Involvement
Niederaichbach (completed)		Babcock Noell and EWN				
VAK Kahl (completed)		NIS	NUKEM (RVI), NIS	NIS	NIS	
Würgassen			Areva GmbH (RVI)			Siempelkamp
Gundremmingen A			NUKEM			
Stade		GNS Studsvik	Areva GmbH (RVI), NIS mit EON (RPV)			Sat. Kerntechnik
Greifswald 1 + 2			EWN (RVI, RPV)			EWN
Greifswald 3 – 5			Mammoet transport to ZLN			EWN
Obrigheim		Babcock Noell and EWN	EWN (RVI, RPV)			
Mülheim-Kährlich		Sat Kerntechnik				Siempelkamp
Jülich			Mammoet removal of the RPV for storage			EWN
Biblis A	NIS					
KNK II			EWN			EWN
MZFR Karlsruhe			EWN			EWN

Source: Wealer and Seidel (2016)

Only a few and highly interconnected specialized decommissioning and RAW companies



Source: updated Seidel and Wealer (2016)

Radioactive waste management in Germany

- Deep Geological disposal of LLW and ILW (Konrad in construction, 2022 estimated)
- Deep geological facility for HLW estimated to start operations around 2080
- Due to missing disposal facilities centralized and decentralized interim storage facilities were constructed
- Interim Storage facilities lose operating licenses in the 2040s
- Over 300,000 m^3 of LLW needs disposal solution
- Geological facility Asse II has a continuous inflow of groundwater from the overburden into the mine
    - 46,930 m3 of LLW and ILW stored in 125,787 casks must be retrieved

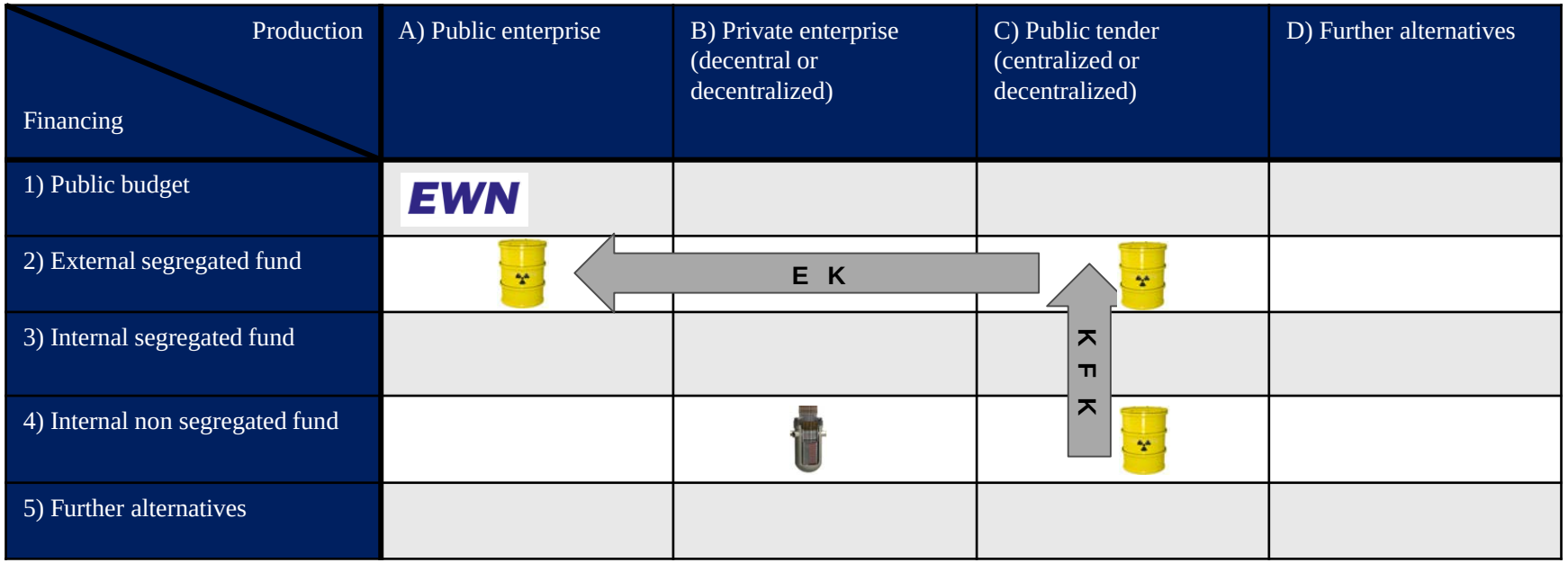
Organization Model for Germany after the reform recommended by EK and KfK

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



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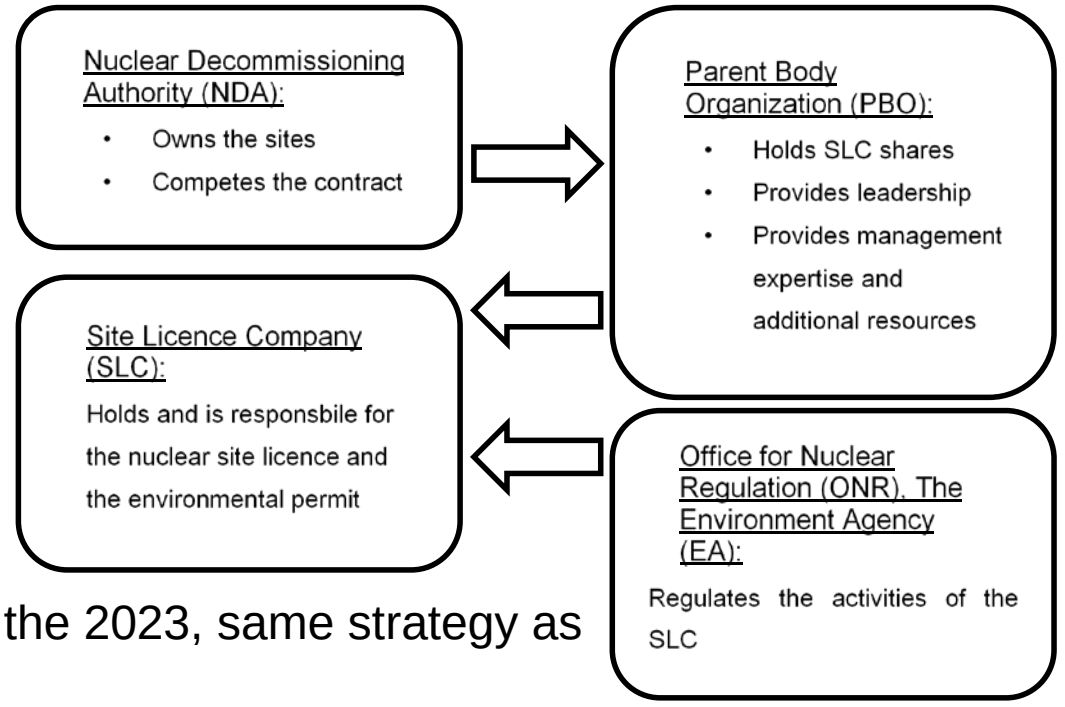
Decommissioning in the United Kingdom

- Difference between legacy fleet and NPPs in operation (15 NPPs operated by EDF Energy)
- In permanent shut-down: 30 NPPs (26 Magnox GCRs) all owned by the NDA (NDA estate accounts for over 1.000 hectares of nuclear licensed land and over 10,000 plants and buildings that need to be demolished)
- Long-Term Enclosure, the reactors will be dismantled after 85 years, goal: achieve end state by 2125 of all sites
- With the exception of Wylfa, all NPPs are defueled
- NDA cost estimates: 130 billion Euros
- First shutdown of EDF Energy GCRs in the 2023, same strategy as for the Magnox reactors



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

Organization Model United Kingdom

Production:

- NDA tenders decommissioning work in long-term contracts (public procurement)
- RWM Limited (NDA subsidiary) plans and builds
- LLW dipsosal facilities tendered to private companies (Studsvik UK and Areva)
- There is the possibility that the decommission responsibility is transferred to the NDA from the EDF Energy

Financing :

- Legacy fleet paid by public budget
- EDF Energy pays into the Nuclear Liability Funds, owned by the Nuclear Trust (public)
- If EDF Energy wants to receive payments from the fund to meet liabilities it can only be made by application
- NDA acts as an agent

Financing \ Production	A) Public enterprise	B) Private enterprise (central or decentralized)	C) Public tender (centralized or decentralized)	D) Further alternatives
1) Public budget	Sellafield Ltd, Magnox		Magnox	
2) External segregated fund	EDF ENERGY	EDF ENERGY	Takeover option by the NDA	
3) Internal segregated fund				
4) Internal non segregated fund				
5) Further alternatives				

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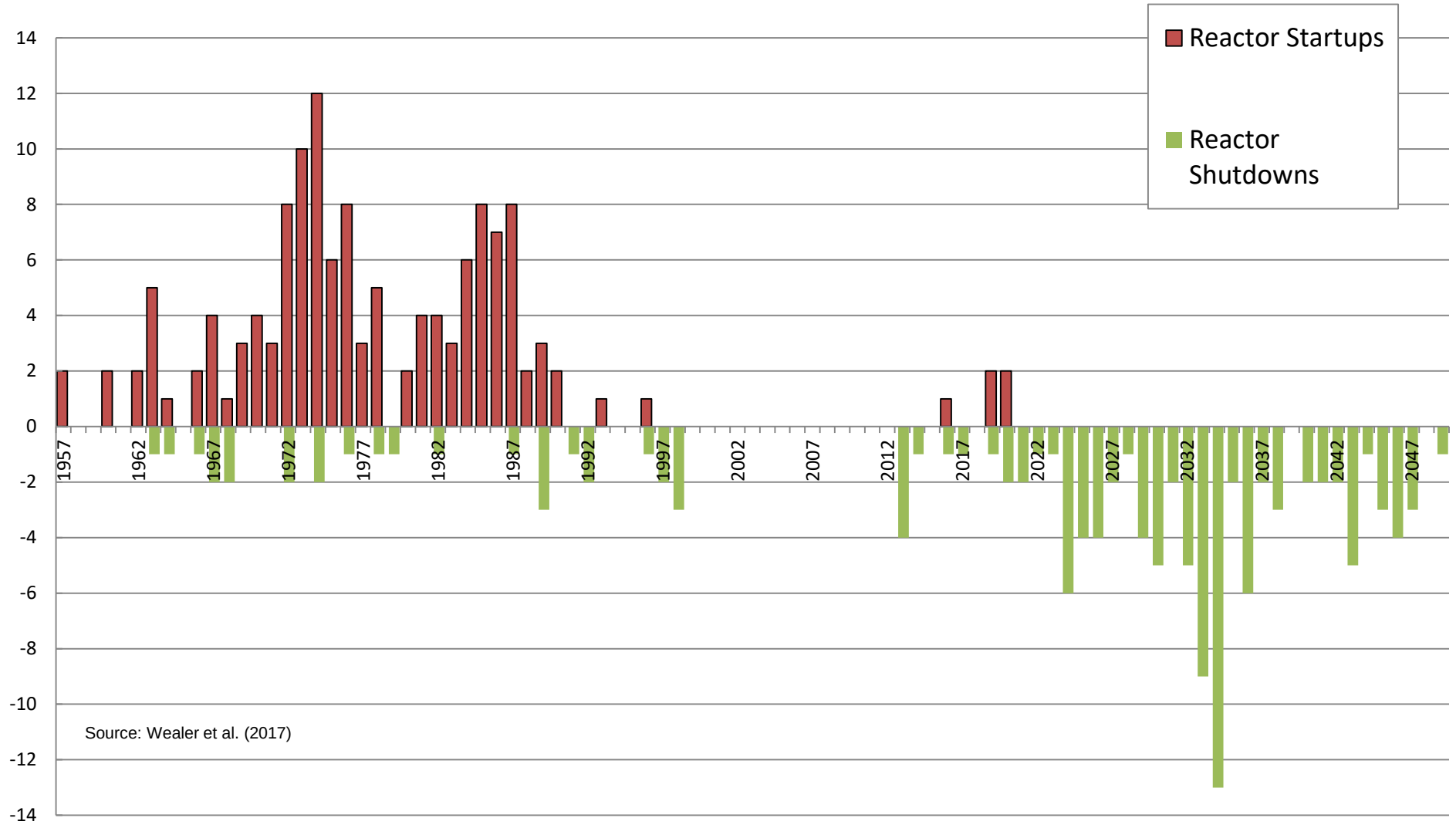
US nuclear power reactor grid connections and permanent shutdowns (1957 – 2050)



Decommissioning in the United States of America

- Operators can chose ID, LTE, or Entombment
- 13 fully decommissioned NPPS, 6 reactors in the decommissioning process, 1 post-op, 12 in LTE, 3 in Entombment
- Short decommissioning time with an average period of 10 years, in some cases large components have been removed in one piece and disposed of
- High variance in actual decommissioning costs: 280-1,500 USD/kW
- Licensees use a “ NRC decommissioning funding formula” to estimate costs, GAO showed that decommissioning formula is outdated (studies published in 1978)
- Private operators can invest their trust fund in accordance with NRC standards (funds to be held by independent trustee, inv. May not be made in reactor licensees, not more than 50% in nuclear industry)

Radioactive waste management in the United States of America

- 79,000 MT SNF, 78% stored in pools
- Nuclear Waste Policy Act (NWPA) of 1982 directs the DOE to build and operate a repository (original deadline was 1998)
- Yucca Mountain (NV) approved by Congress in 2002, federal funding stopped in 2011
- Decentralized interim storage facilities for HLW (ISFSI) in the responsibility of the licensees
- DOE spent over 10 bn USD in legal penalties, could amount to 20.8 bn USD by 2020
- DOE Pilot Interim storage facility by 2021, private interim storage facility around 2025
- Low-Level Radioactive Waste Policy Amendments Act of 1985 (LLRWPAA) places the responsibility for LLW disposal with the state in which it is generated. It also includes provisions to incentivize states to form state compacts
- 4 LLW near-surface disposal facilities, privately contracted fees

Organization Model for the United States of America

Production:

- Remains scope of the utilities, transfer of the decommissioning license to third party possible
- LLW disposal facilities operated by private companies
- HLW: scope of the DOE
- DOE Pilot Interim storage facility by 2021
- Interim storage facility operated by private company around 2025 (Holtec, Waste Control Specialist), DOE responsible for siting and licensing

Financing :

- NRC requires that every licensee must provide financial assurance for decommissioning: prepayment, insurance or parent company guarantee or external fund
- Balance of Nuclear decommissioning trust fund: 53 bn USD (2014), around 600€/kW
- Exelon reported shortfalls for three reactors 6-83 m USD
- Fee of 0.10 cent USD per kWh for the nuclear waste fund abandoned after 2014

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

Organization models (HLW) in Western Europe and the US

Production / Financing	A) Public enterprise	C) Private enterprise (central or decentralized)	B) Public tender (centralized or decentralized)	D) Further alternatives
1) Public budget				
2) External segregated fund			Takeover option by the NDA	
3) Internal segregated fund				
4) Internal non segregated fund				
5)Further alternatives			Source: updated Seidel and Wealer (2016)	

Conclusions and Lessons-Learned for Western Europe and the US

- Decommissioning is technologically challenging and completed large-scale NPP decommissioning projects are scarce.
- High market concentration for decommissioning and waste management services, specialized nuclear companies are in financial troubles.
- LLW Management and clear waste classifications important for decommissioning.
- Interim storage facilities were needed due to missing HLW disposal facility and high inventory of SNF.
- Integral decommissioning and waste management plans are needed in respect to the long timeframe and the existing interdependences.
- Clear separation of regulator and operator is important.
- New organization models are needed:
  - third party holds decommissioning licence (EnergySolutions in the US).

Conclusions and Lessons-Learned for Western Europe and the US – Financing

- Cost increases in most projects
- High variance for future cost estimations
- Each funding system has (dis-) advantages.
  - Internal: higher ROI, higher risk
  - External: more transparency and control
- Especially for HLW: all cost estimations are underlying uncertainties due to
  - long-time scales,
  - cost increases
  - and estimated interest and inflation rates

Proposed Organization Model – DIW, TU Berlin

Production:

- Decommissioning:
  - Assumption: Current practice of each operator individually decommissioning its NPP leads to unnecessary high costs
  - Synergy and scale effects are possible in the bundling of reactor types or generations
  - Decrease in costs in contrast to the experienced increase in costs in most projects
  - Possible market design: Auctioning (Europe wide) of the decommissioning projects

Financing :

- Decommissioning and Radioactive Waste Management:
  - In respect to the long timeframe and the existing interdependences, one external segregated fund under public control for both processes seems the most suitable
  - Especially considering the foreseeable problems concerning the waste management (interim storage, construction of HLW disposal facility etc.) the utilities should not shift off their responsibility with transferring a certain amount to the fund

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

Thank you for your attention!

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