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

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Agenda

1) Motivation
2) Technological system and organization matrix
3) Western Europe: Lessons-Learnt
4) Organization models in Sweden and Switzerland
5) Conclusion

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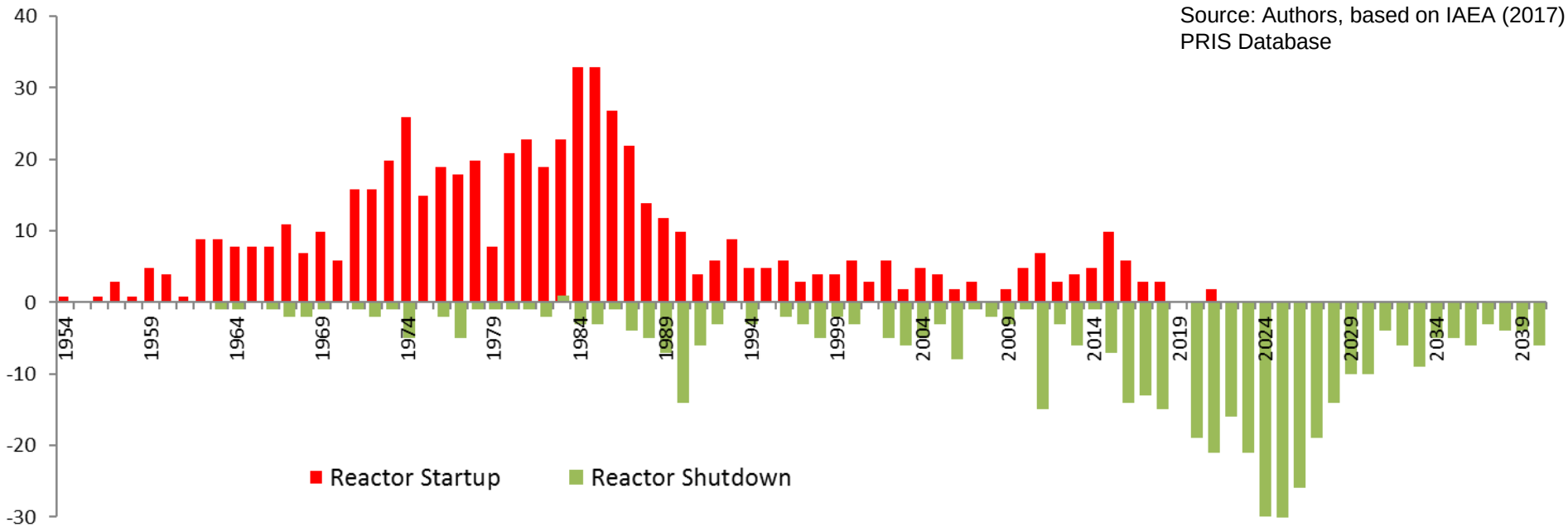
Outlook – Global development of the nuclear power plant fleet



- About 440 commercial reactors are currently operating.
- Many reactors will reach their technical-lifetime soon, which causes a growing demand for decommissioning and dismantling services.
- In Finland the construction licence of the 1st geological disposal facility was granted in 2015.

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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 activated components.
- **Stage 3:** Deconstructions in the hot zone, e.g. deconstruction of 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: 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

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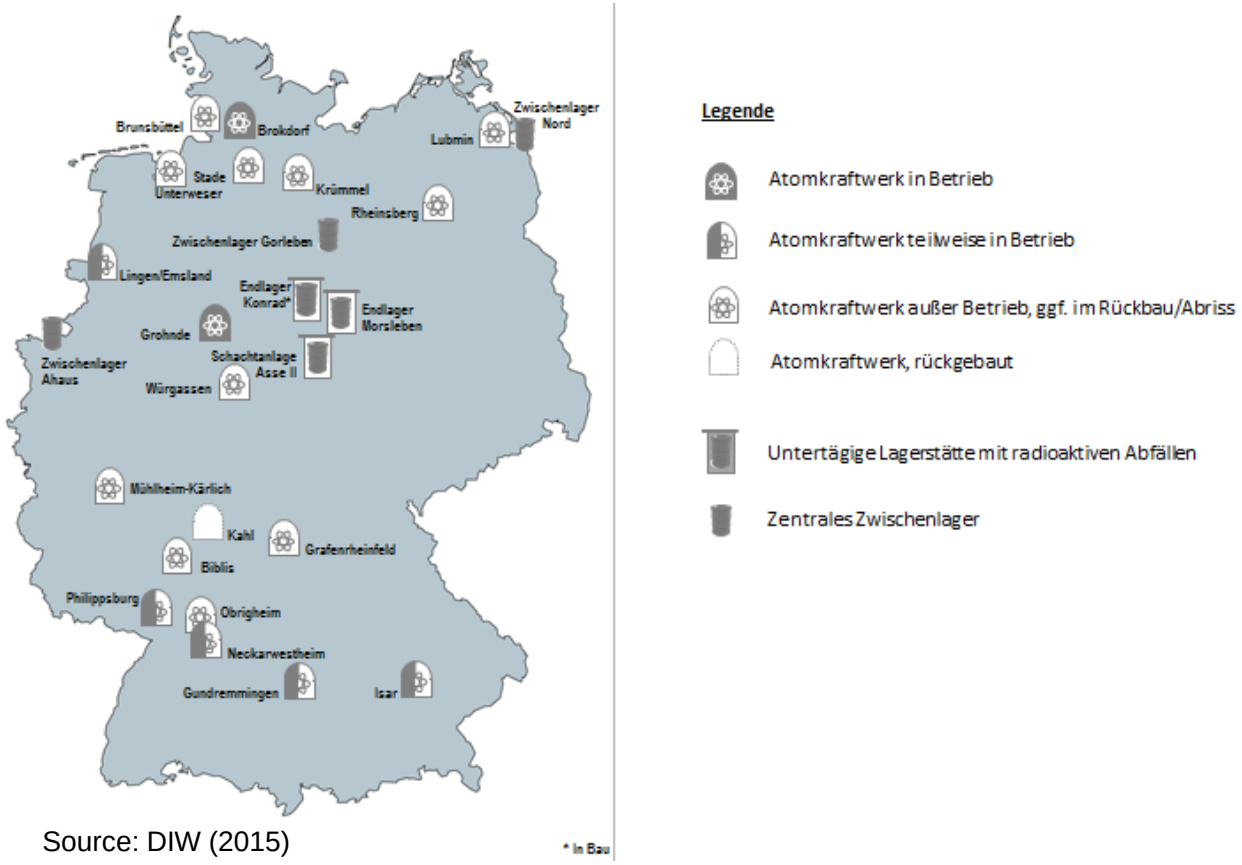
Germany – Point of inception

- Operational: 8 (6 PWRs, 2 BWRs)
- Nuclear Share of electricity production in 2016: 13.12 %
- Installed operational capacity: 10.8 GW
- In Permanent Shutdown:28

Nuclear power plants and storage sites



Source: DIW (2015)

Decommissioning monitoring for Germany

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)

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

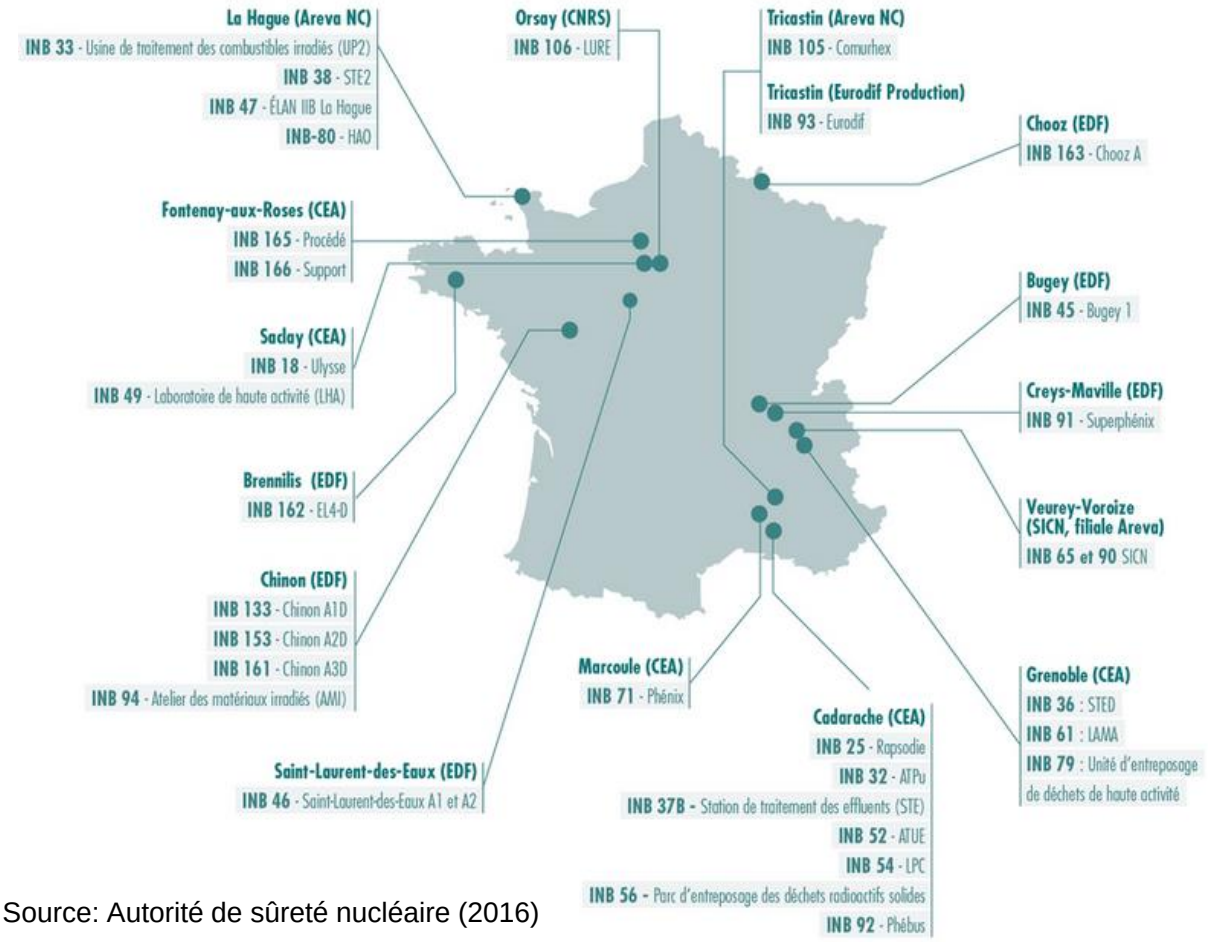
EK: Commission on high-level waste management
KFK: Commission on financing the nuclear phase-out

Financing \ Production	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			K F K	
4) Internal non segregated fund				
5) Further alternatives				

France – Point of inception

- Operational: 58 PWR operated by EDF
- Nuclear Share of electricity production in 2016: 72.28 %
- Installed capacity: 63,2 GW
- Under Construction: 1
- In Permanent Shutdown:12

Decommissioning sites



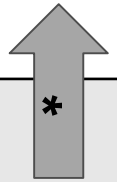
Source: Autorité de sûreté nucléaire (2016)

Decommissioning monitoring for France

NPP	Operator	Reactor type -Model [MWel]	Operating Time	Stage	Initial end of Decommissioning	Planned end of Decommissioning
EL-4 (Brennilis)	EDF	HWGCR [70 MW]	1968 – 1985	Partial dismantling	2015	2028 (estimated)
Super -Phenix (Creys-Malville)	EDF	FBR – Na-1200 [1.200 MW]	1986 - 1998	Stage 3		2026
Chooz – A	EDF	PWR [305 MW]	1967 – 1991	Stage 3	2016	2025
Bugey-1	EDF	GCR – UNGG [540 MW]	1972 – 1994	LTE	2026	22nd century
Chinon A-1	EDF	GCR – UNGG [540 MW]	1964 – 1973	LTE	2031	2056
Chinon A-2	EDF	GCR – UNGG [540 MW]	1965 – 1985	LTE	2034	22nd century
Chinon A-3	EDF	GCR – UNGG [540 MW]	1966 – 1990	LTE	2035	22nd century
St. Laurent A-1	EDF	GCR – UNGG [390 MW]	1969 – 1990	LTE	2031	22nd century
St. Laurent A-2	EDF	GCR – UNGG [465 MW]	1971 – 1992	LTE	2036	22nd century
G-1	CEA	GCR – UNGG [2 MW]	1956 -1968	ID		
G-2	CEA (80%), EDF (20%)	GCR – UNGG [39 MW]	1959 – 1982	ID		
G-3	CEA	GCR – UNGG [40 MW]	1969 - 1984	ID		
Phenix	CEA (80%), EDF (20%)	FBR – PH-250 [130 MW]	1974 – 2010	ID		

Organization model for France

(*) Once the construction of the HLW facility begins, the provisions will be transferred to ANDRA

Production / Financing	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				

United Kingdom – Point of inception

- Operational: 15 (14 GCRs, 1 PWR) operated by EDF Energy
- Nuclear Share of electricity production in 2016: 20.4%
- Installed operational capacity: 8.88 GW
- In Permanent Shutdown: 30

Decommissioning sites and corresponding SLCs

Source: Invernizzi (2016, p.6)

Decommissioning monitoring for United Kingdom

Reactor concept	Site	Reactor type	Operating time	Strategy	SLC	License terminates in
GCR	Berkeley	Magnox [2x 138 MW]	1962 – 1988/89	LTE	Magnox Ltd	2083
	Bradwell	Magnox [2x 123 MW]	1962 – 2002	LTE	Magnox Ltd	2104
	Chapelcross	Magnox [4x 48 MW]	1959/60 -2004	LTE	Magnox Ltd	2128
	Dungeness A	Magnox [2x 225 MW]	1965 – 2006	LTE	Magnox Ltd	2111
	Hinkley Point A	Magnox [2x 235 MW]	1965 – 2000	LTE	Magnox Ltd	2104
	Hunterston A	Magnox [2x 150 MW]	1964 – 1989/90	LTE	Magnox Ltd	2090
	Oldbury A	Magnox [2x 217 MW]	1967/68 – 2011/12	LTE	Magnox Ltd	2106
	Sizewell A	Magnox [2x 210 MW]	1966 – 2006	LTE	Magnox Ltd	2110
	Trawsfynydd	Magnox [2x 195 MW]	1965 - 1991	LTE	Magnox Ltd	2098
	Wylfa	Magnox [2x 490 MW]	1971/72 – 2012/15	LTE	Magnox Ltd	2106
	Windscale AGR	AGR [24 MW]	1963 – 1981	LTE	Sellafield Ltd	2120
	Calder Hall	Magnox [4x 49 MW]	1956/59 – 2003	LTE	Sellafield Ltd	2120
Other	Dounreay PFR	FBR [234 MW]	1976 – 1994	LTE	DSRL	2333
	Dounreay DFR	FBR [11 MW]	1962 – 1977	LTE	DSRL	2333
	Winfrith SGHWR	SGHWR [92 MW]	1968 - 1990	LTE	Magnox Ltd	2019

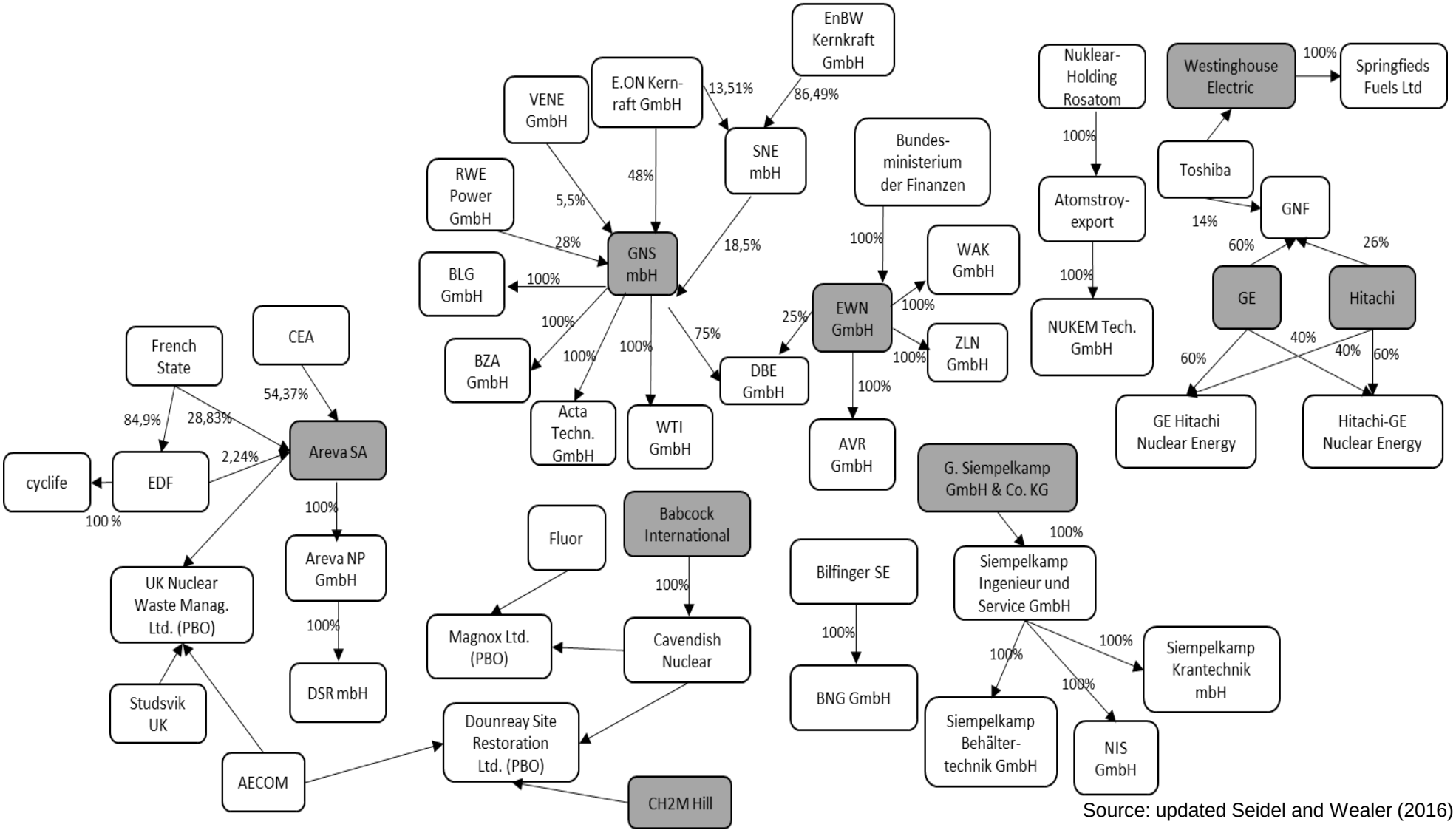
Organization model for the United Kingdom

Production / Financing	A) Public enterprise	B) Private enterprise (decentral 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				

Conclusions and Lessons-Learnt for Western Europe

- Decommissioning is technologically challenging, delay in most projects and completed projects are scarce.
- High market concentration for decommissioning and waste management services, specialized nuclear companies are in financial troubles (Westinghouse and Areva).
- LLW disposal facilities and clear waste classifications are important for decommissioning.
- Interim storage facilities were needed due to missing HLW disposal facility.
- Integral decommissioning and waste management plans and cost studies for each NPP are needed in respect to the existing interdependences.
- Clear separation of regulator and operator important.
- Cost increases in most projects and a high variance for future cost estimations.
- Each funding system has (dis-) advantages. Internal: higher ROI, higher risk. External: more transparency and control.
- one external segregated fund under public control for both processes seems the most suitable even if it also could not overcome the problem of too low cost estimations.

Only a few and highly interconnected specialized decommissioning and RAW companies



Source: updated Seidel and Wealer (2016)

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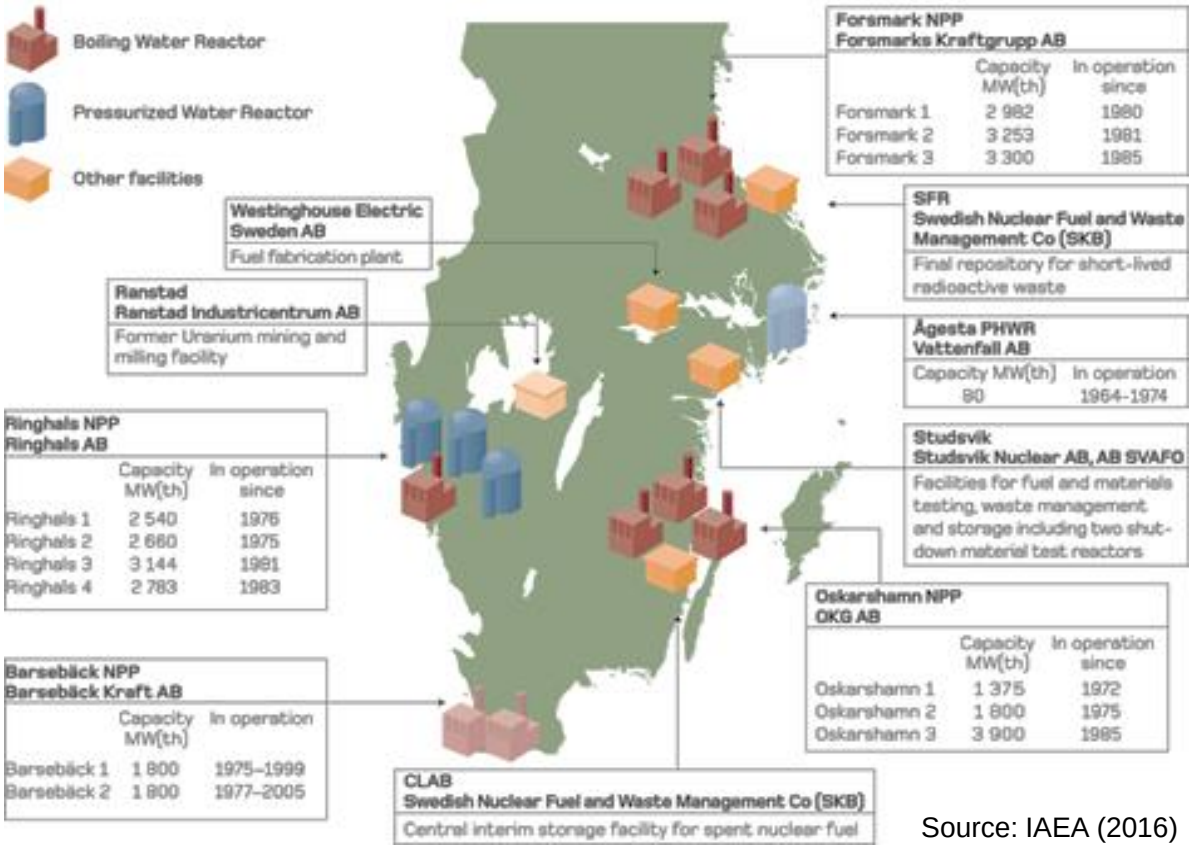
Sweden – Point of inception

- Operational: 8 (5 BWRs, 3 PWRs)
- Nuclear Share of electricity production in 2016: 40.03%
- Installed operational capacity: 8.5 GW
- In Permanent Shutdown:5



Source: IAEA (2016)

Decommissioning monitoring for Sweden

NPP	Operator	Reactor type -Model [MWel]	Strategy	Operating Time	DEM License
Barsebäck-1	Barsebäck Kraft AB	BWR - ABB-II [600 MW]	LTE	1975 – 1999	2027
Barsebäck-2	Barsebäck Kraft AB	BWR - ABB-II [600 MW]	LTE	1977 - 2005	
Agesta	AB Svafo	PHWR [10 MW]	LTE until 2020	1964 – 1974	
Oskarshamn-2	Oskarshamns Kraftgrupp AB	BWR – ABB-II [638 MW]		1975– 2015	
Oskarshamn-1	Oskarshamns Kraftgrupp AB	BWR – ABB-I [638 MW]		1975– 2015	

Organization model for Sweden

Operators (amongst others the state-owned Vattenfall) are responsible for decommissioning
Utilities-owned (predominantly Vattenfall) SKB is responsible for waste management

Production / Financing	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				

Switzerland – Point of inception

- Operational: 5 (2 BWRs, 3 PWRs)
- Nuclear Share of electricity production in 2016: 34.44%
- Installed operational capacity: 3.33 GW
- In Permanent Shutdown: 1, Lucens (HWGCR [6MW]), completely dismantled

Possible sites for a deep geological repository in Switzerland

Source: Bundesamt für Energie (2016)

Organization model for Switzerland

Operators (majority canton-owned) are responsible for decommissioning
Nagra is to prepare and implement solutions for the disposal of all kinds of radioactive wastes, which includes the construction and operation of the geological facilities.

Production / Financing	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				

Conclusion - Applied Lessons-Learnt in Switzerland and Sweden

Lessons-Learnt	Sweden	Switzerland
Large-scale decommissioning experiences	☒	☒
Operational waste management facilities		
LLW	✓	☒
ILW	Site found	☒
HLW	Site found	☒
Operational interim storage facilities	✓	✓
Integral decommissioning and waste management plan	✓	☒
Detailed cost estimates regularly updated	✓	✓
one external segregated fund under public control for both processes	✓	Two funds
Risk assessment or nuclear specific inflation rate	✓	✓
follow-up liability in case of bankruptcy	☒	☒

Thank you for your attention!

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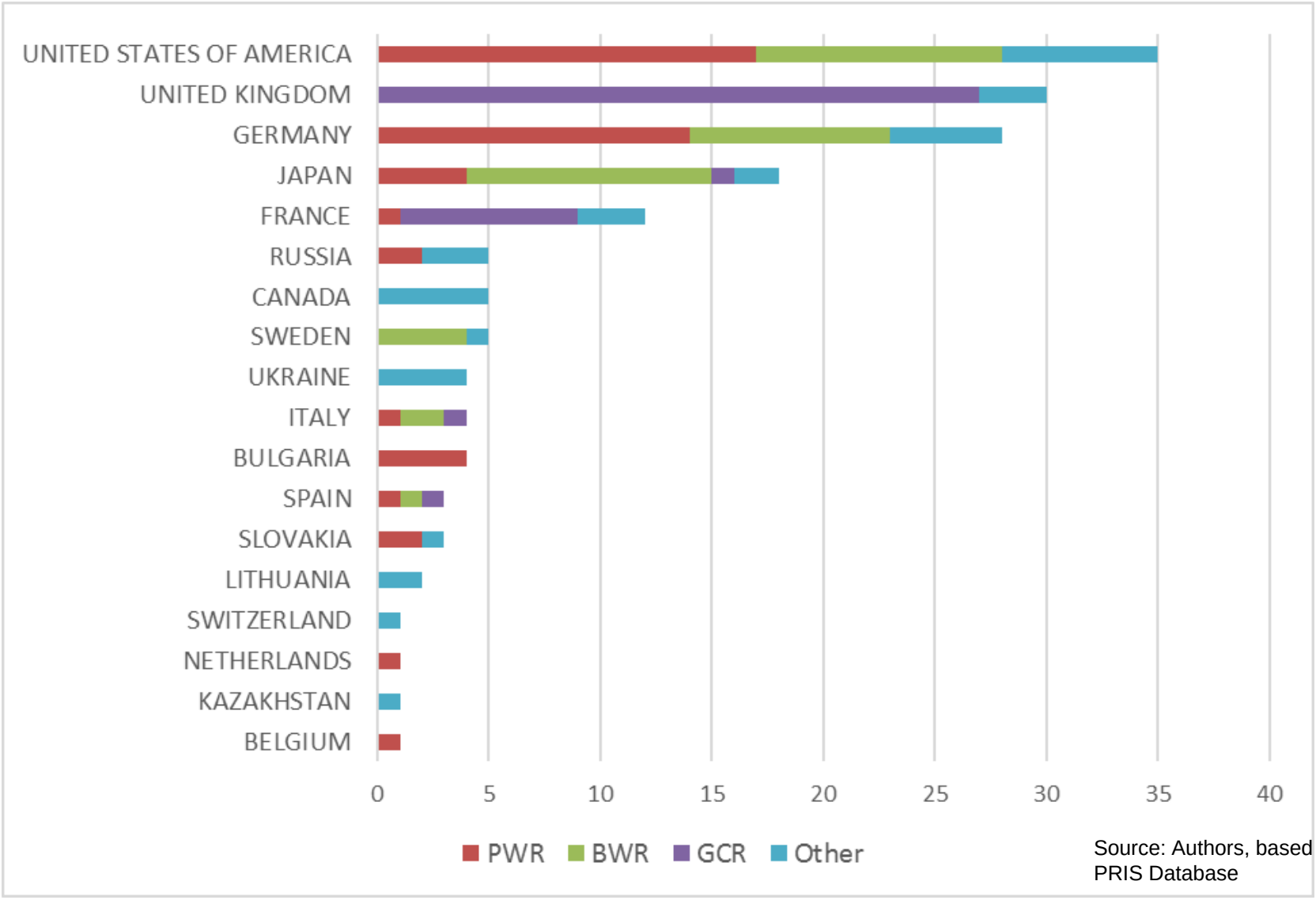
Back-up

Outlook – Shut-down reactors worldwide



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

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 dismantle the RVI to Areva-EWN joint-venture in 2017

Source: updated Wealer et al. (2015)

Source: Wealer et al. (2015)