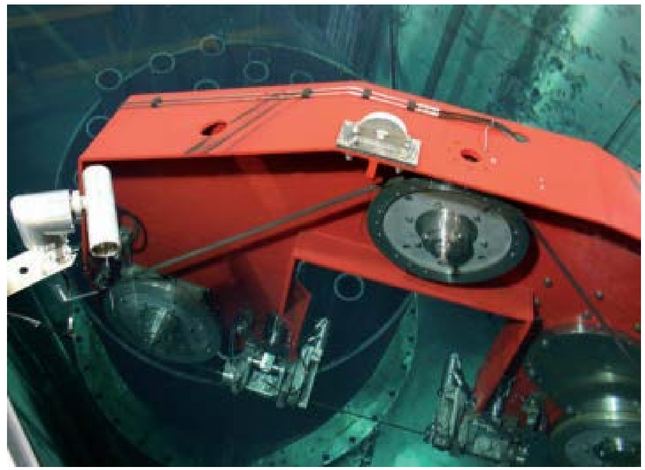
22nd REFORM Group Meeting,
August 26-31, Salzburg

Decommissioning of Nuclear Power Plants: Global Survey with Focus on USA, Germany, and France

Source: Del Olds



Source: GRS

Source: National Geographic

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Agenda

1) Motivation
2) Elements of Decommissioning Policy
3) Global Survey
4) Case Studies
    1) France
    2) Germany
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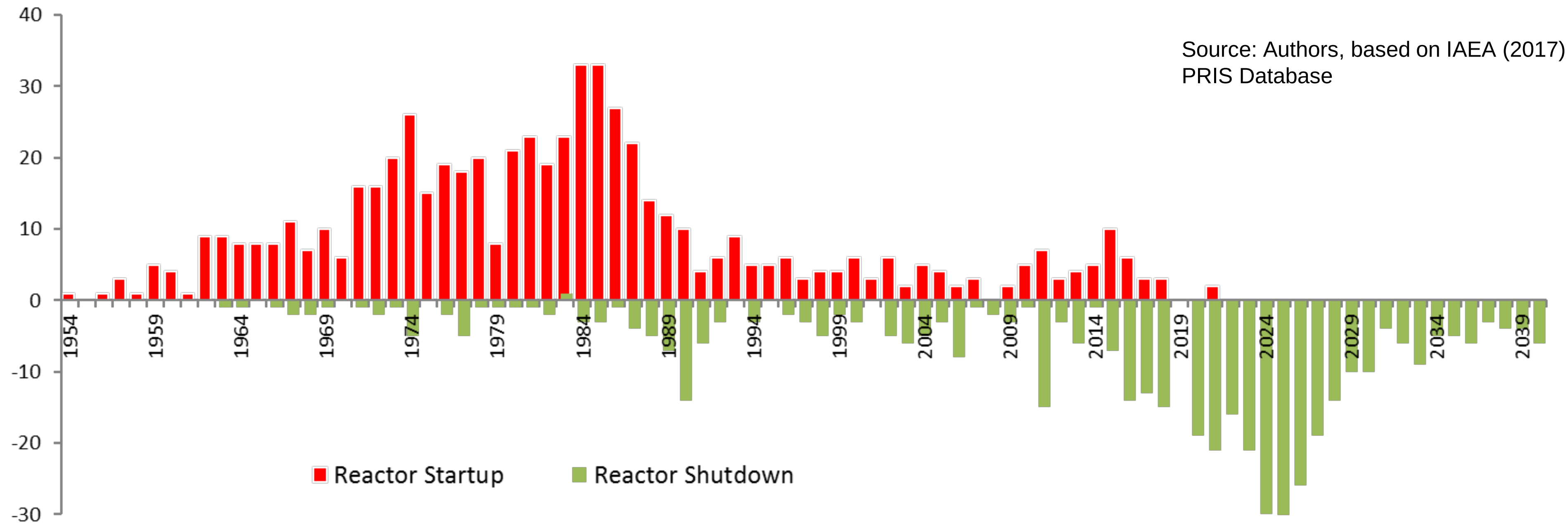
Outlook – Global Development of the Nuclear Power Plant Fleet



As of 1 July 2018: 173 permanently shut down reactors, or 74 GW of capacity.

By 2030: a further 216 reactors will shut down (grid connection: 1978-90).

By 2057: additional 111 will be shut down.

Not accounting for 81 operational reactors (grid connection before 1978), and additional 33 reactors in LTO.

IAEA (2004) estimates a 100 US$billion value decommissioning market until 2050

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Decommissioning – What Does it Mean?

Decommissioning refers to the ***administrative*** *and* ***technical actions*** *taken to remove all or some of the regulatory controls from an authorized facility so the facility and its site can be reused.* ***Decommissioning includes activities such as planning, physical and radiological characterization, facility and site decontamination, dismantling, and materials management.*** - IAEA

5-Stage-Classifiaction

1) Peripheral Systems
2) Machinery and higher contaminated parts
3) RPV and biological shield
4) Remaining contaminated systems
5) Greenfield or further proceedings of the building

Source: Wealer et al. (2015)

3-Stage-Classification

- **Warm-up-Stage**: Measures prior to the treatment of the hot zone
- **Hot-zone-Stage**: Removal of the RPV and biological shield
- **Ease-off-Stage**: Measures to release site form regularly control

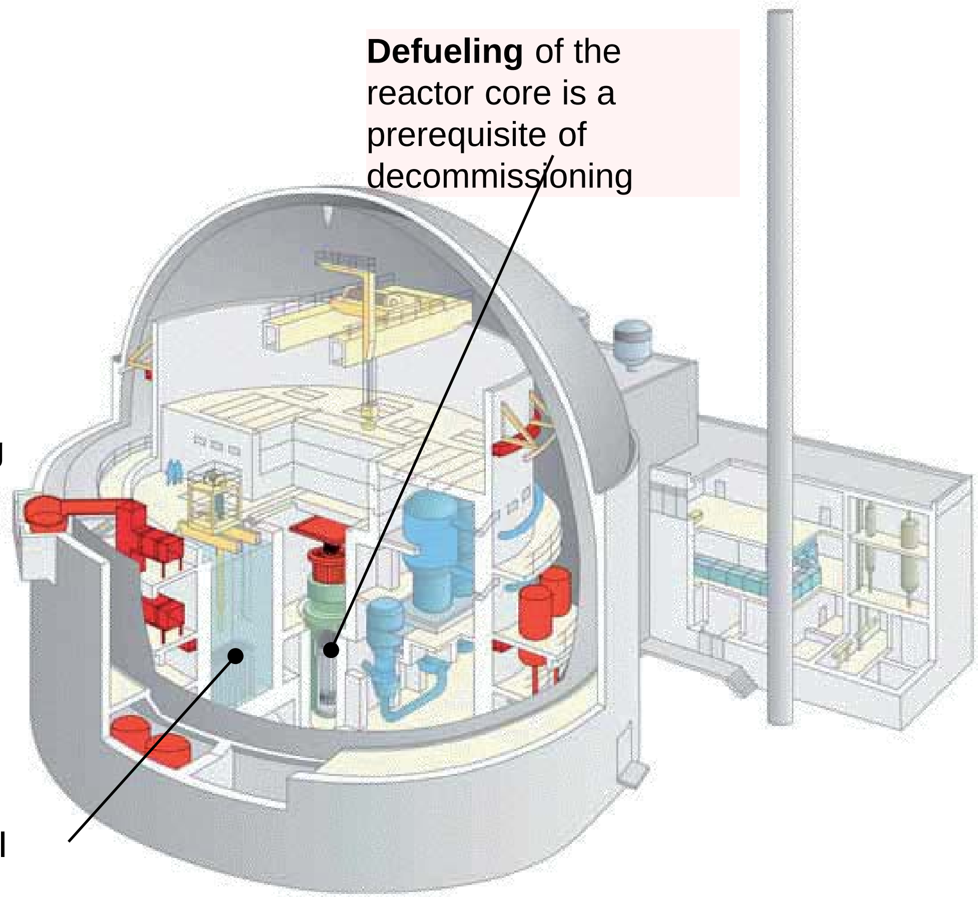
Standard Procedures of Decommissioning

Warm-up-Stage

- Defueling the reactor
- Overview of all radioactive inventory
- Removal of **peripheral parts and machinery**, that are not needed during the decommissioning phase
- Set up of a technical and logistical **infrastructure for the decommissioning project**

On-site transport of SNF

Image: GSR (2017)



Defueling of the reactor core is a prerequisite of decommissioning

Spent fuel pool

Image: GSR (2017)

Standard Procedures of Decommissioning

Warm-up-Stage

- Deconstruction and dismantling of higher contaminated parts, e.g. the steam generator

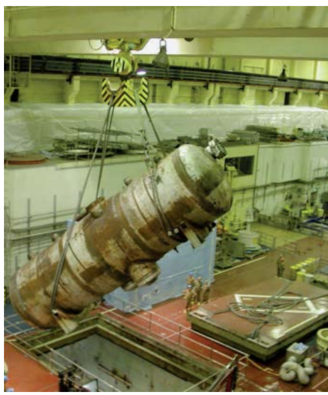


Image: GSR (2017)

- Preparations for the dismantling of highly contaminated (or activated), large scale parts

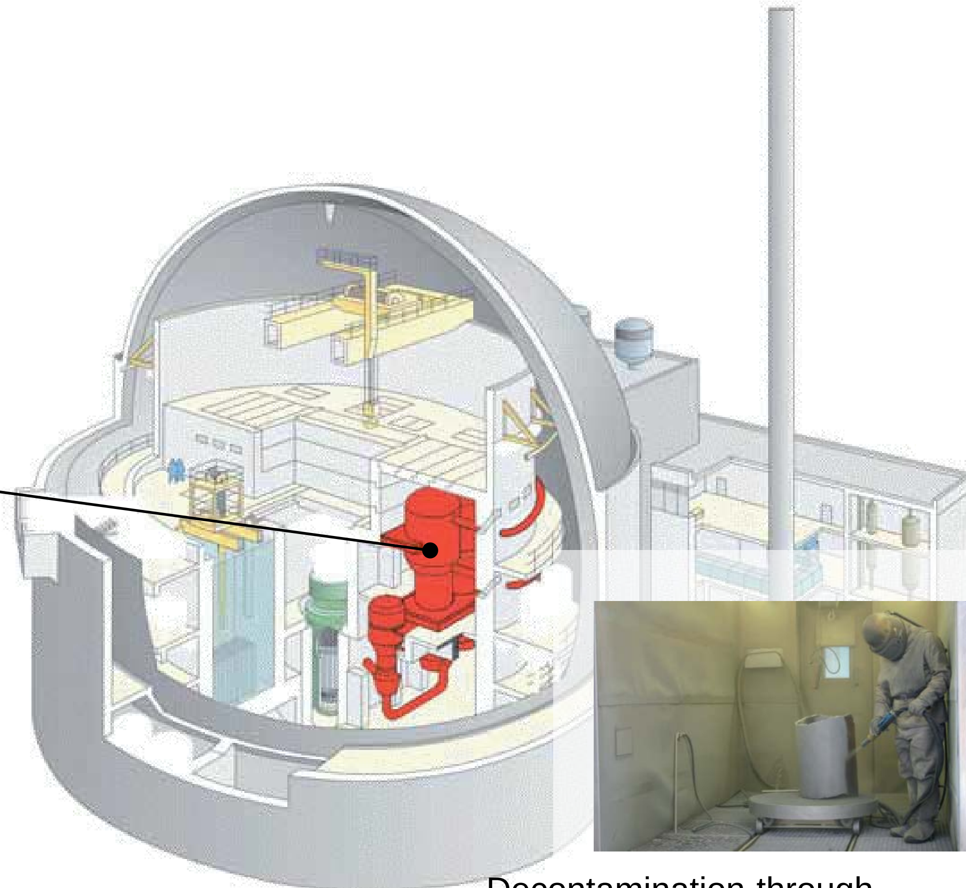
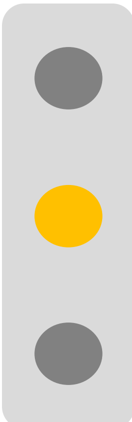


Image: GSR (2017)

Image: GSR (2017)

Decontamination through sandblasting

Standard Procedures of Decommissioning



Hot-Zone-Stage

- Deconstruction and dismantling of **highly contaminated parts e.g. RVP, biological shield**

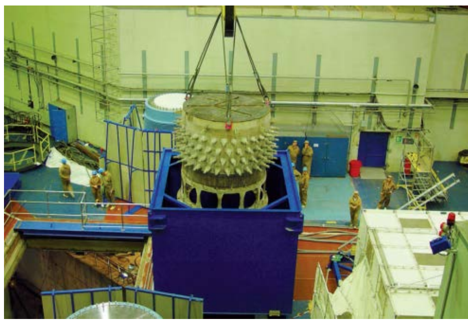
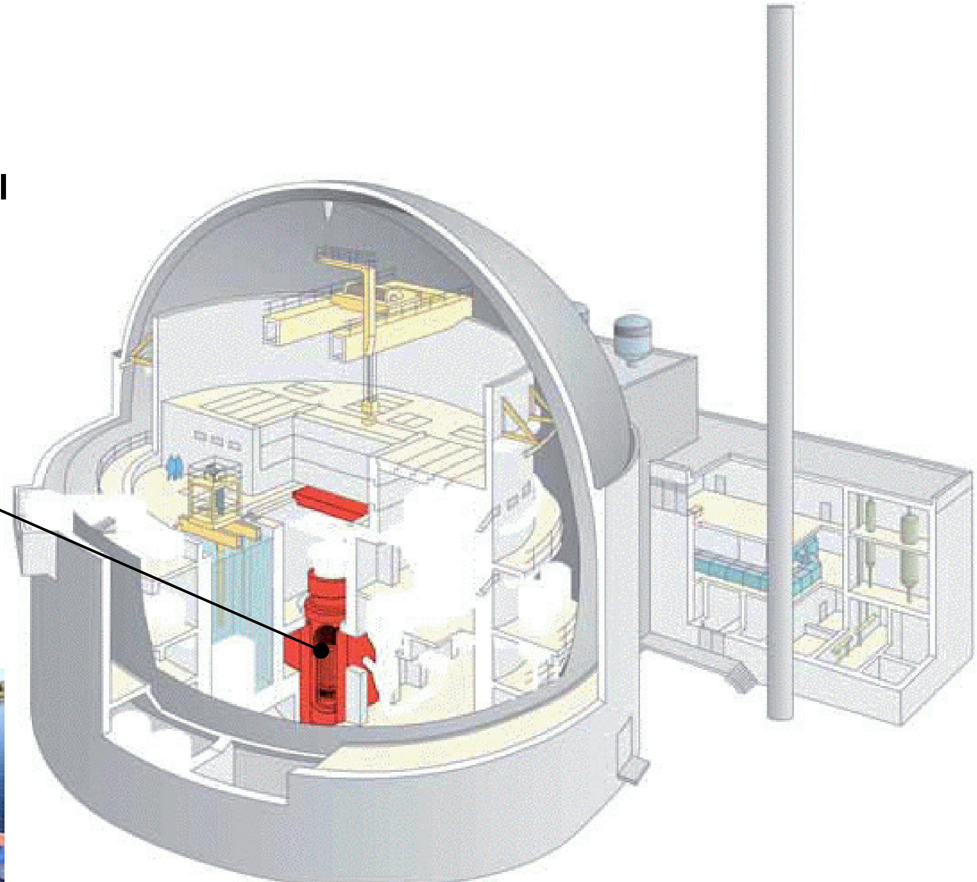
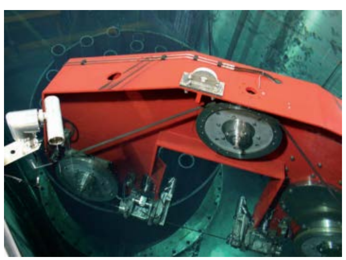


Image: GSR (2017)



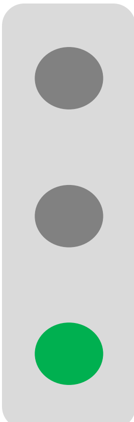
Remote controlled underwater cutting



Images: GSR (2017)

One-piece removal

Standard Procedures of Decommissioning



Ease-off-Stage

- Deconstruction and dismantling **remaining parts and machinery**
- **Decontamination** of the buildings

Image: GSR (2017)

Markings for surface decontamination

- Release from regulatory control

Image: GSR (2017)

Measurements for release

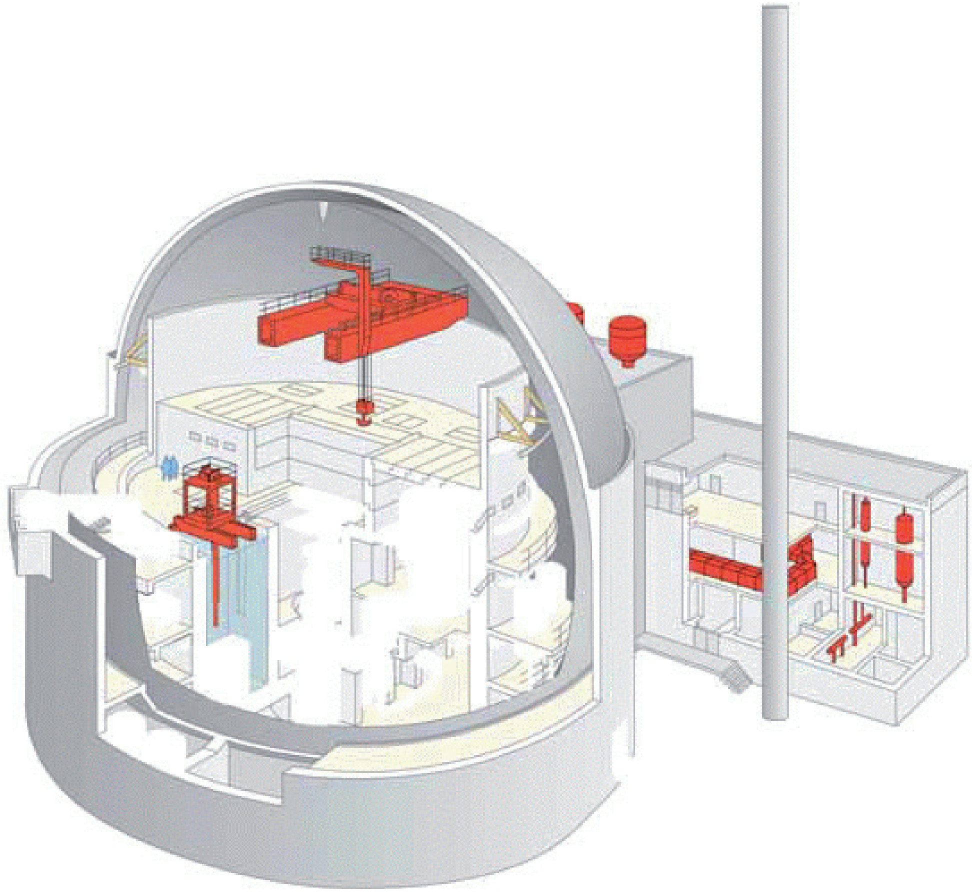


Image: GSR (2017)

Standard Procedures of Decommissioning

Ease-off-Stage

- Demolishing of the buildings
  - **Greenfield**: No further nuclear related purpose of the site
  - **Brownfield**: Further “generation use” (e.g. gas turbine) or further nuclear related uses of the site, e.g. (interim) storage facility for nuclear waste

Images: GSR (2017)

Possible Strategies of Decommissioning

	+	-
IMMEDIATE DISMANTELING (ID)	▪ Skill and expertise of the operating staff is key for decommissioning ▪ Clear line of responsibilities ▪ High public interest ▪ More financial security	▪ High safety precautions due to high intensity of radiation ▪ Larger volumes of radioactive waste ▪ Lack of motivation of the workforce
LONG TERM ENCLOSURE (LTE) or DEFERRED DISMANTLING (DD)	▪ Lower intensity of radiation due to radioactive decay ▪ Possibility to raise more decommission funding during the period of enclosure ▪ Possibility to co-ordinate the decom. of different units in multiple plants	▪ Risk of losing – trained staff and knowledge about the facility – clear lines of responsibilities – public interest ▪ Risk of bankruptcy or other financial trouble of the company in charge
ENTOMBMENT	▪ Relatively easy to realize	▪ *Out of sight, out of mind:* no dismantling of the reactor ▪ Unpredictable risks ▪ Constant occupation over a long period requires staff and fanancial stamina

Organizational models for decommissioning (and radioactive waste management)

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 non segregated fund				
4) Internal segregated fund				
5) Further Alternatives				

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

Financing of the Decommissioning Process

Public budget—State authorities take over the responsibility and with that the accumulation of financial resources via taxes, e.g. the Nuclear Decommissioning Authority in the U.K. or the German government in the case of the former East German plants.

External segregated fund—The operators pay their financial obligation into a publicly controlled and managed fund. Here, private or state-owned external, independent bodies manage the funds, e.g. centralized funds for the whole industry or decentralized funds for each operator; e.g. for the operational nuclear plants in the U.K., and most of the private utilities in the U.S.

Internal non-segregated fund—The operator of a nuclear facility is obliged to form and manage funds autonomously. Here, the operator manages the financial resources, which are held within their own accounts as reserves; e.g. in Germany.

Internal segregated fund—The operator feeds a self-administrated fund, which is separated from the other businesses; e.g. in France , Japan, and Canada.

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Global Survey

In the first quarter of 2018 154 units were globally undergoing (in various stages) or awaiting decommissioning.

Of the 19 decommissioned NPPs (6 GW) – on average 16 years after shutdown.

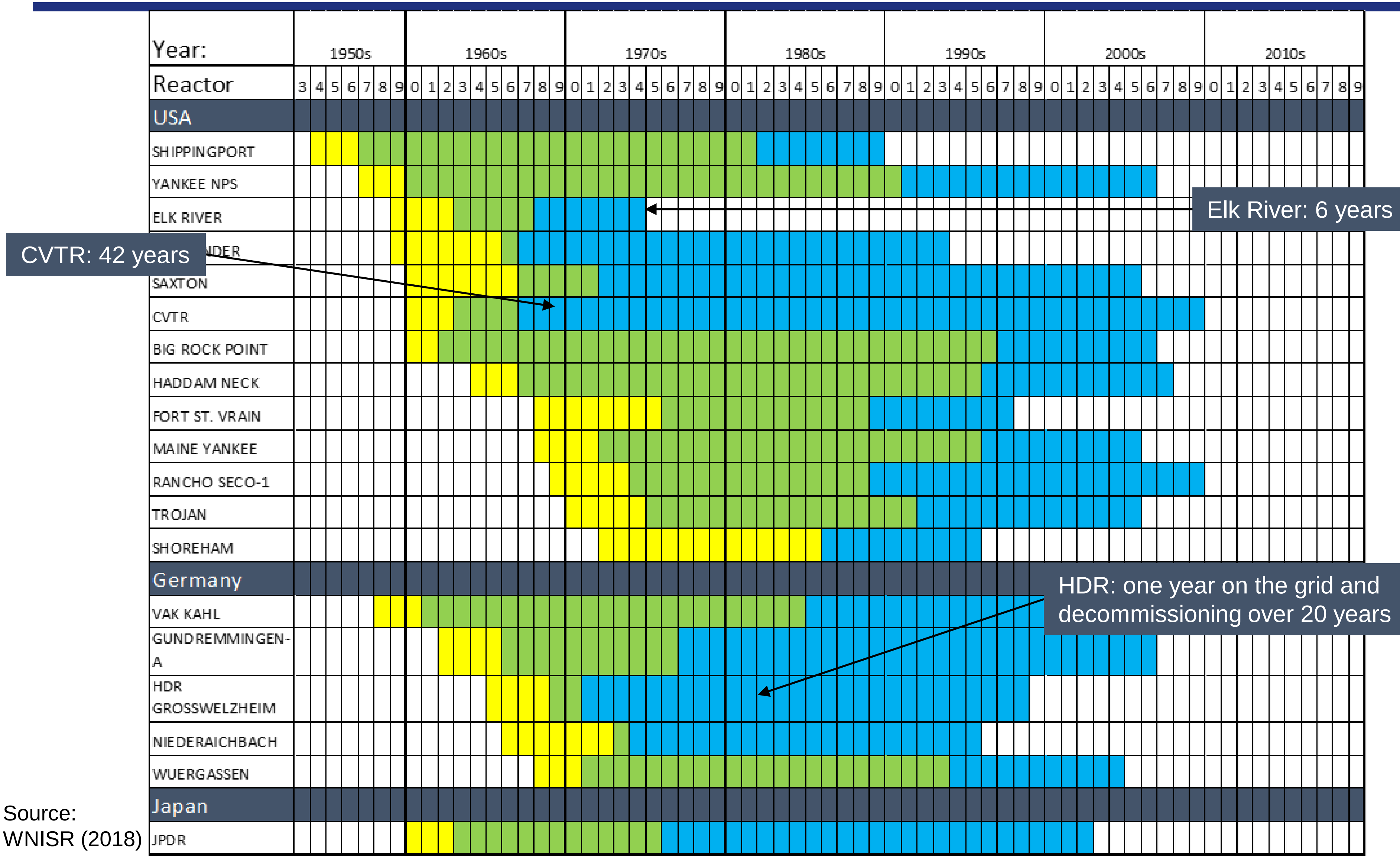
Only 10 sites have been returned to a greenfield.

The only countries to have completed the decommissioning process are the United States (13), Germany (5), and Japan (1).

Country	Shut-down NPPs	Decommissioning Process				
		Warm-up	Hot Zone	Ease-off	LTE	Completed
Canada	6	0	0	0	6	0
France	12	3	1	0	8	0
Germany	29	10	4	8	2	5 [17%]
Japan	25	20	0	0	0	1 [4%]
United Kingdom	30	0	0	0	30	0
United States	34	4	0	5	12	13 [38%]
Total	136	37	5	13	58	19 [8%]

Source: WNISR (2018)

Global Survey – Completed Decommissioning Projects



Source: WNISR (2018)

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Key Findings in France

12 reactors (8 GCR UNGG, 1 HWGCR, 2 FBR, 1 PWR) were shut down.

While EDF operates 57 PWRs (1 in LTO), the legacy fleet consists mainly of GCRs.

French Regulation stipulates Immediate Dismantling (ID).

EDF's strategy shift in 2016: Decommissioning start of the first GCR Chinon A-1 in 2031 as an example for future GCR projects. LTE is de facto applied for 6 GCRs to await decommissioning.

In addition, there is not even a theoretical disposal rout for graphite.

Only one PWR (Chooz-A) undergoing decommissioning. Since 2014, first underwater dismantling of an RPV.

9 reactors are the scope of EDF, 3 CEA.

Decommissioning monies are managed in internal segregated funds.

France	May 2018
"Warm-up-stage"	3
of which defueled	*2*
"Hot-zone-stage"	1
"Ease-off-stage"	0
LTE	8
Finished	0
of which greenfield	*0*
Shut-down reactors	**12**

Source: WNISR (2018)

Organizational Challenges: Underprovisioning, long time horizons

Current cost estimates for EDFs shut-down fleet are around €6.5 billion, while EDF has only set aside €3.3 billion.

The costs for the legacy fleet have increased steadily and doubled since 2001, when they were estimated to be around €3.3 billion.

For the operational fleet EDF expects total costs of around €23 billion, which corresponds to around €300/kW of installed capacity, quite low by international standards.

In a recent report on the technical and financial feasibility of the decommissioning process, the French National Assembly alleged that EDF shows "excessive optimism". The report concluded that decommissioning and clean-up will take <u>more time</u>, that <u>the technical feasibility is not fully assured</u>, and that the process <u>will cost overall much more</u> than EDF anticipates.

EDF's new strategy aims to release the GCRs from regulatory control only by the beginning of the 22nd century.

Key Findings in Germany

Immediate Dismantling was the most applied strategy - now set by law.

EUR 6.5 billion bill for the state only for the decommissioning of the 6 Soviet reactors of the former GDR (currently in EOS but deferred dismantling).

EUR 19.7 billion estimated costs for decommissioning in 2014 set aside in internal non-segregated funds.

The utilities are still responsible for decommissioning and for the conditioning of waste, but all the downstream tasks (mainly storage) will be done by public companies and paid from the waste fund.

Only 3 reactors (140 MW) have been released from regulatory control.

Gundremmingen-A (1bn €) and Würgassen (2.2bn latest cost est.) de facto decommissioned.

Germany	2015	May 2018
"Warm-up-stage"	10	10
of which defueled	*0*	*1*
"Hot-zone-stage"	3	4
"Ease-off-stage"	9	8
LTE	2	2
Finished	4	5
of which greenfield	*3*	*3*
Shut-down reactors	**28**	**29**

Source: WNISR (2018)

Organizational Challenges: Oligoply, 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 January 2018, PreussenElektra awarded a decommissioning contract to Zerkon, a consortium led by waste management company GNS and Westinghouse Electric Sweden. Contract includes the dismantling the RVI of six plants.

GNS is utilities-owned with PreussenElektra being the major shareholder with 48 percent of the shares.

Only one of the 8 reactors shut down after 3/11 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.

Key Findings in the United States of America

Operators can chose ID, LTE, or Entombment; LTE: Limited enclosure time of 60 years.

Average decommissioning period of 14 years. 8 reactors were decommissioned under 10 years (removal of RPV as whole).

Strategy to remove large components in one piece in the Hot-Zone.

Possible use of explosives to demolish concrete buildings.

High cost variance: US$280/kW (Trojan) to US$1,500/kW (Connecticut Yankee)

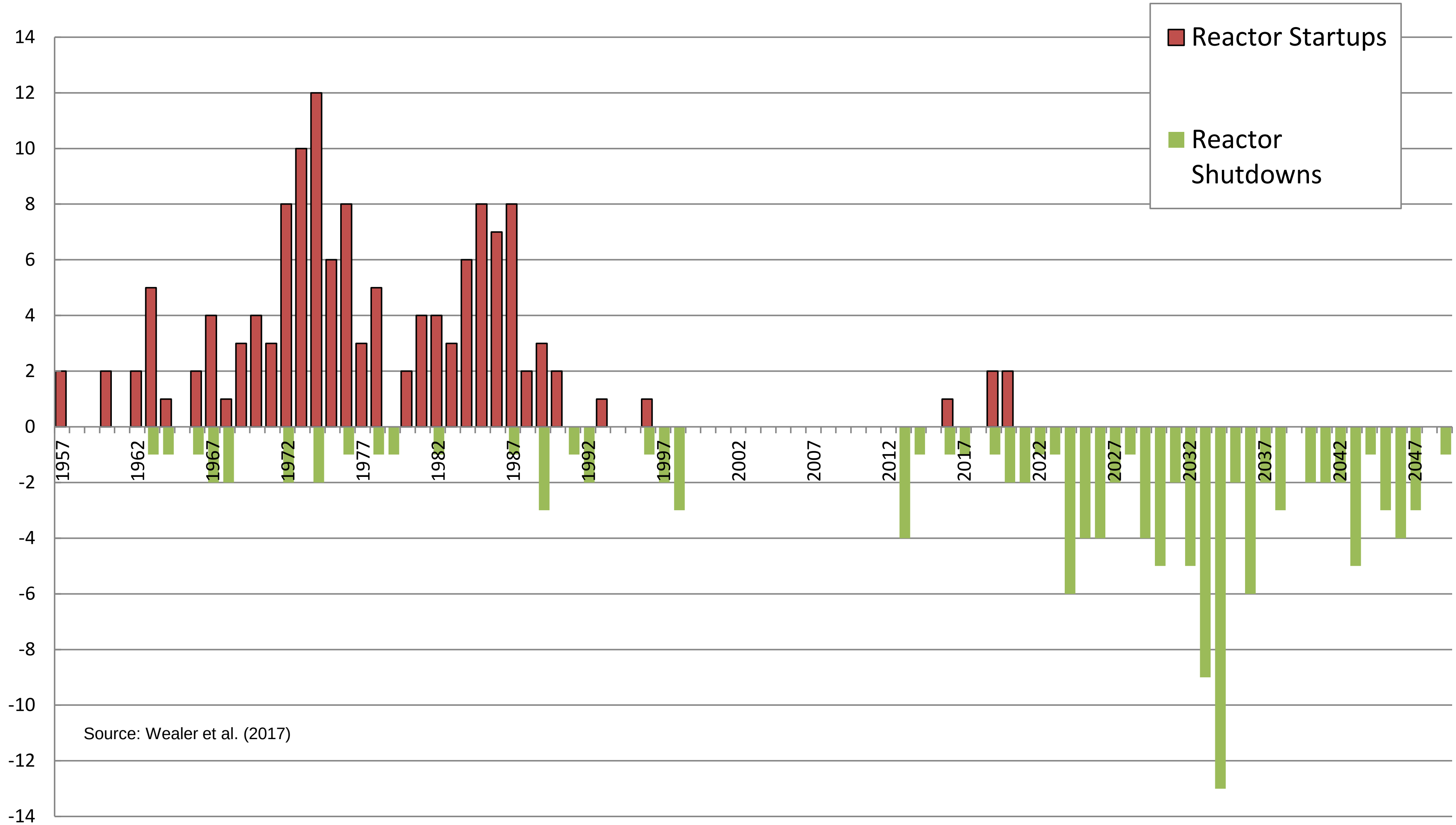
External segregated fund (Nuclear Decommissioning Trust Fund): USD 64 billion in 2016.

The site license might be reduced to the Independent Spent Fuel Storage Installation.

United States of America	May 2018
"Warm-up-stage"	4
of which defueled	*1*
"Hot-zone-stage"	0
"Ease-off-stage"	5
LTE	12
Finished	13
of which greenfield	*6*
Shut-down reactors	**34**

Source: WNISR (2018)

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



New development: transfer decommissioning license from the operator to a waste management company

Zion-1 and -2 in Illinois: Exelon transferred the license to EnergySolutions.

Goal: reap efficiency gains through the (co-)management of the decommissioning process by a company owning disposal facilities.

Vermont Yankee: U.S. company Northstar has entered into a purchase and sale agreement with Entergy. The deal would include the transfer of the decommissioning trust of US$571 million (Entergy has promised to add another US$125 million). Entergy and Northstar are proposing this model also for the Pilgrim, Indian Point and Palisades stations.

These developments are problematic as limited-liability companies are only financially liable in the case of an accident or other legal dispute up to the value of their assets.

Therefore, if the decommissioning funds are exhausted, such a third-party company could declare bankruptcy, leaving the bill for the taxpayer.

Overall, there is an increasing risk, that the NDT will not be sufficient to cover the costs (outdated NRC-formula based on studies between 1978 and 1980).

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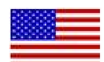
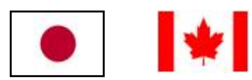
Organizational models for decommissioning in the Case Studies

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

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

Conclusion

The country case studies also suggest that both, duration and costs have been largely underestimated. The few projects that have started encounter, in nearly all the cases, delays as well as cost increases.

Japan will enter a difficult phase in the near future—as the first reactor pressure vessel of a commercial reactor has to be removed yet.

The U.S. have decommissioned the highest number of reactors (13), but these case studies cannot be used as a reference for other cases, e.g. the removal and consequent burial of large-scale parts.

In all the cases, interim storage facilities were needed, hindering decommissioning or even rendering the regulatory release of the site impossible.

The early nuclear states UK, France, and Canada have not fully decommissioned a single reactor.

In addition, going forward, decommissioning faces a challenge in a context of low electricity prices placing a further strain on the competitiveness of nuclear power plants—and low provisions on behalf of the companies.

Thank you for your attention!

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Back-Up

Key Findings in Japan

No valuable experience with decommissioning yet.

The Fukushima Accident (March 2011) caused serious trouble to the internal decommissioning funds of the operator. A strategy of Safe Storage of approx. 10 years is likely to be applied for the majority of the reactors.

Reactors can receive a unique lifetime extension of 20 years under the revised regulation (induced by the investigations of the Fukushima accident).

Full market liberalization in 2016 makes the accumulation of decommissioning funds even more difficult.

Estimated costs appear moderate and affordable but are subjected to uncertainties due to lack of experience.

Japan	May 2018
"Warm-up-stage"	20
of which defueled	*1*
"Hot-zone-stage"	0
"Ease-off-stage"	0
LTE	0
Finished	1
of which greenfield	*1*
Shut-down reactors	**25**

Organizational Challenges: Underprovisioning, Fukushima

Historically, electric utilities had to establish tangible fixed assets for the expenses of decommissioning during the period of operation through surcharges on the retail price of electricity and based on the output of a facility.

Since 3/11: total decommissioning costs are allocated by the straight-line method over the period of operation and safe storage and the surcharges were decoupled from the electricity output of a reactor.

To cover the financial shortage, many operators chose the strategy of intermediate storage (5-10 years) for their reactors in order to collect more money.

In 2015, METI estimated an average of ¥71.6 billion per reactor but more recent estimates for the five latest reactors slated for decommissioning were significantly raised to ¥160 billion (US$1.46 billion) per reactor.

Another issue for the decommissioning process in Japan is that companies are permitted to temporarily divert decommissioning funds for other business purposes and thus risking that the funds are not available when needed.