23d REFORM Group Meeting
October 14-18, Salzburg

Decommissioning of Nuclear Power Plants

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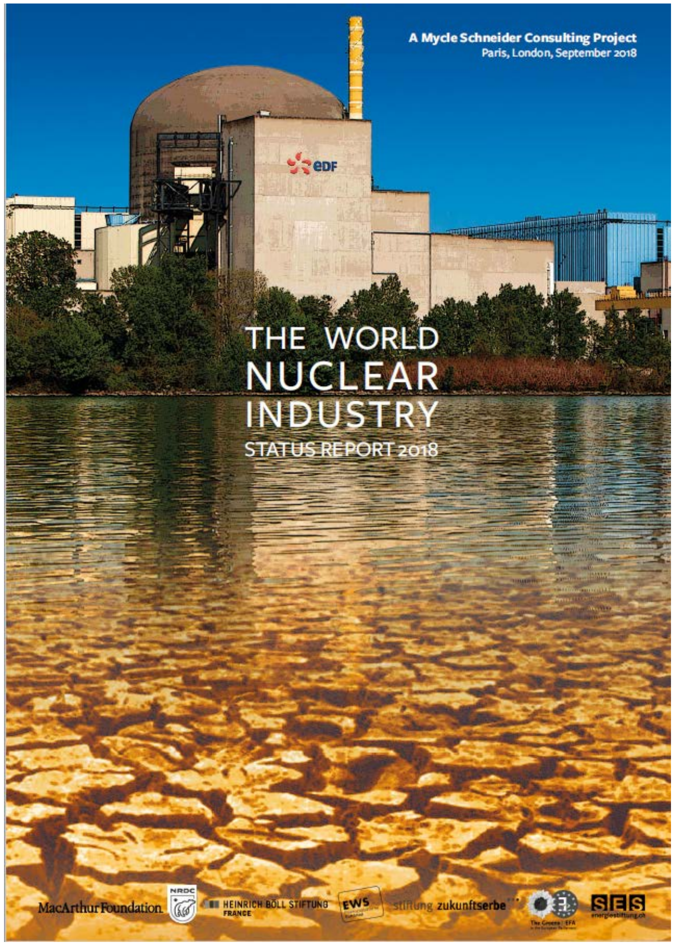
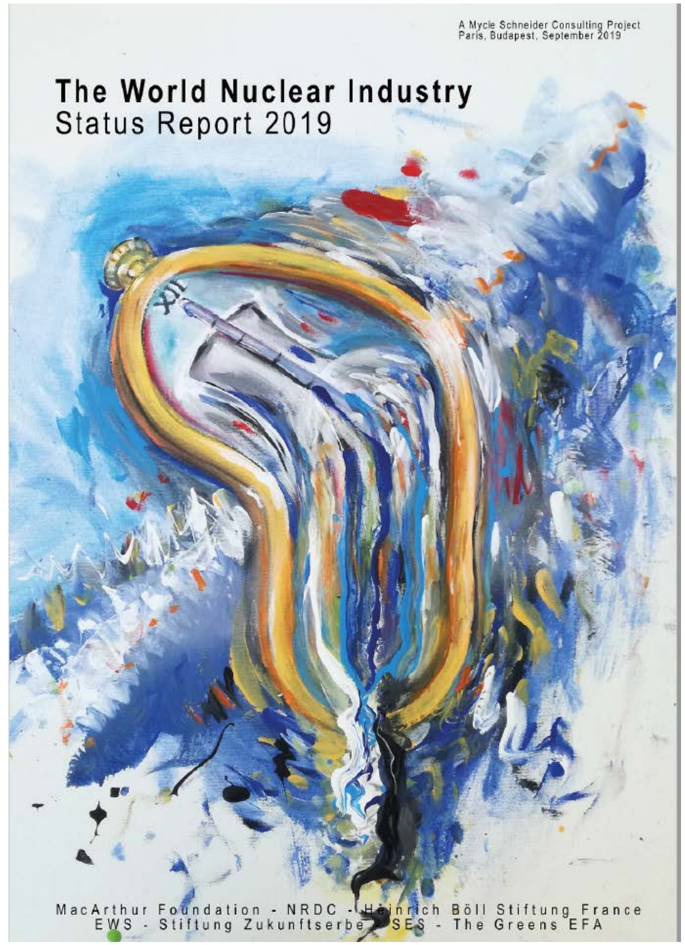
The Decommissioning Status Report in WNISR2018 and WNISR2019

Since 2018 the World Nuclear Industry Status Report (WNISR) includes a chapter on decommissioning: "The Decommissioning Status Report", on which the following presentation is largely based on.





Agenda

1) Motivation
2) Elements of decommissioning policy
3) Global survey of completed decommissioning projects
4) Key findings in selected case studies
5) Conclusion

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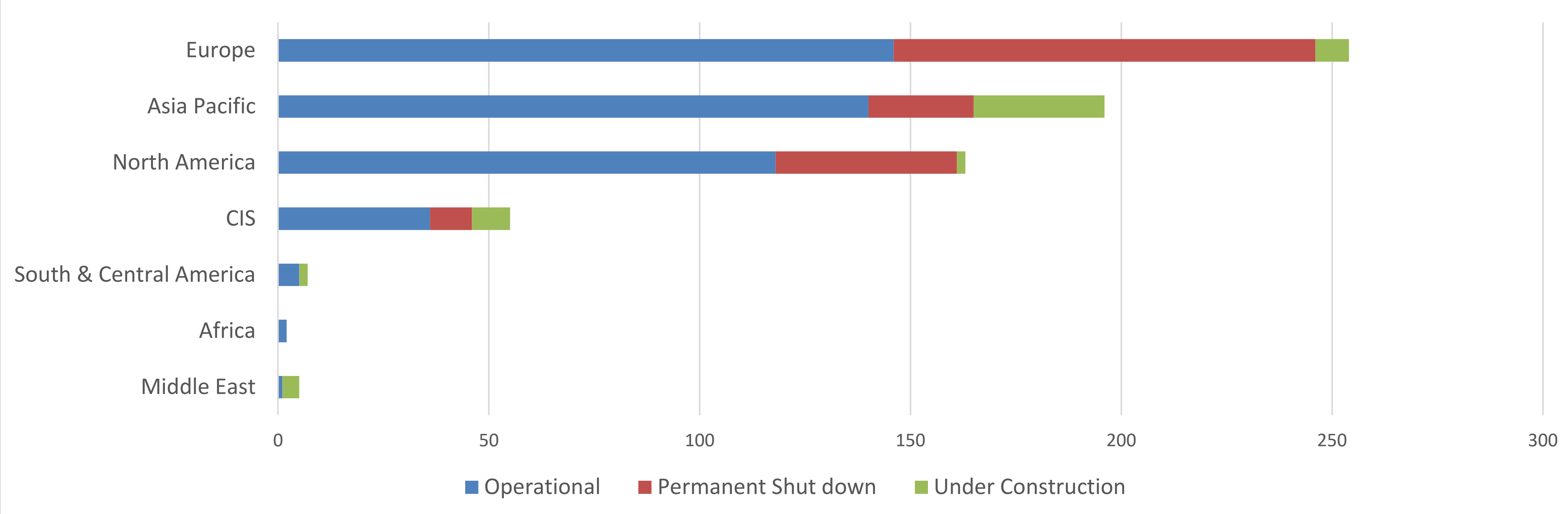
Decommissioning is outpacing construction



As of 1 July 2019: 181 permanently shut down reactors, or 78.1 GW of capacity.

Assuming a 40-year average lifetime:

- **a further 207 NPPs by 2030,**
- **additional 125 by 2059.**

Not accounting for 28 in LTO, 85 NPPs which started operating before 1979 and 46 reactors under construction.

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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

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

Source: Wealer et al. (2015), WNISR (2018)

Standard Procedures of Decommissioning

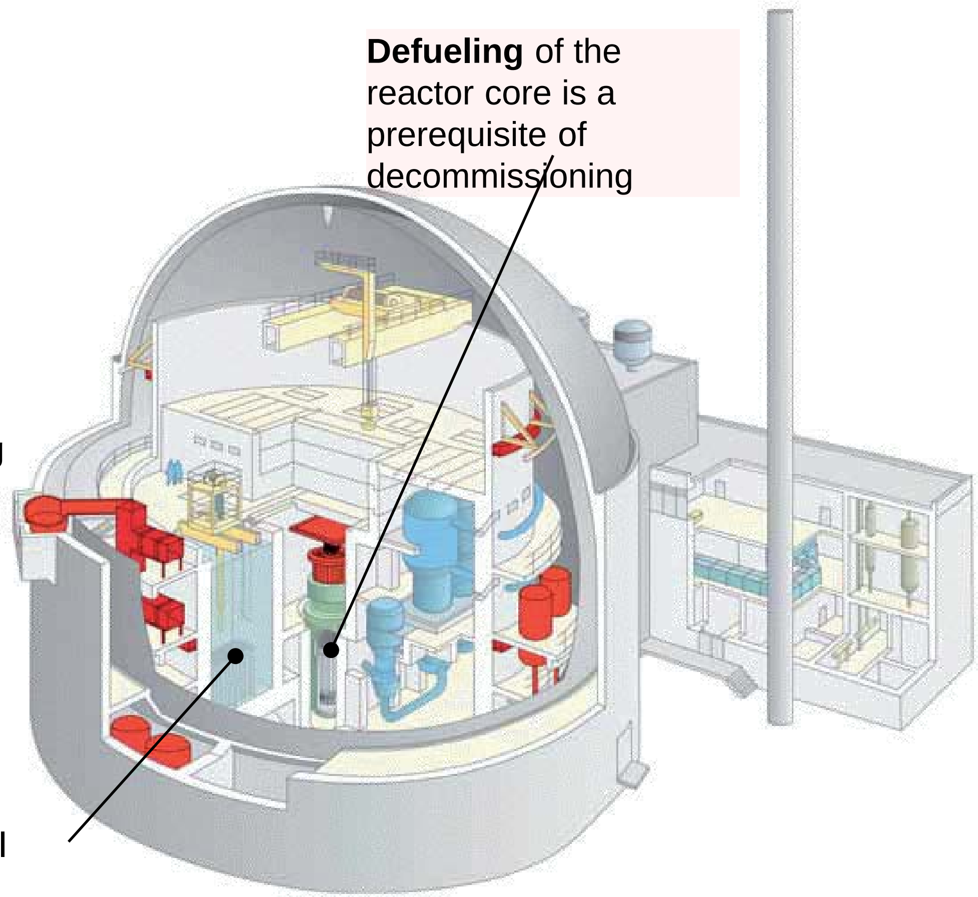
Warm-up-Stage

- 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

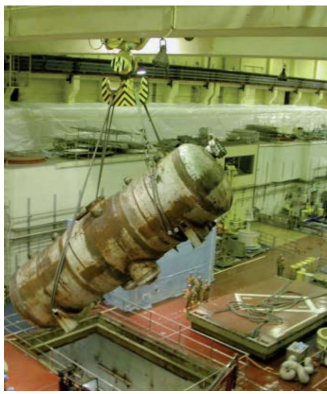


Image: GSR (2017)

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

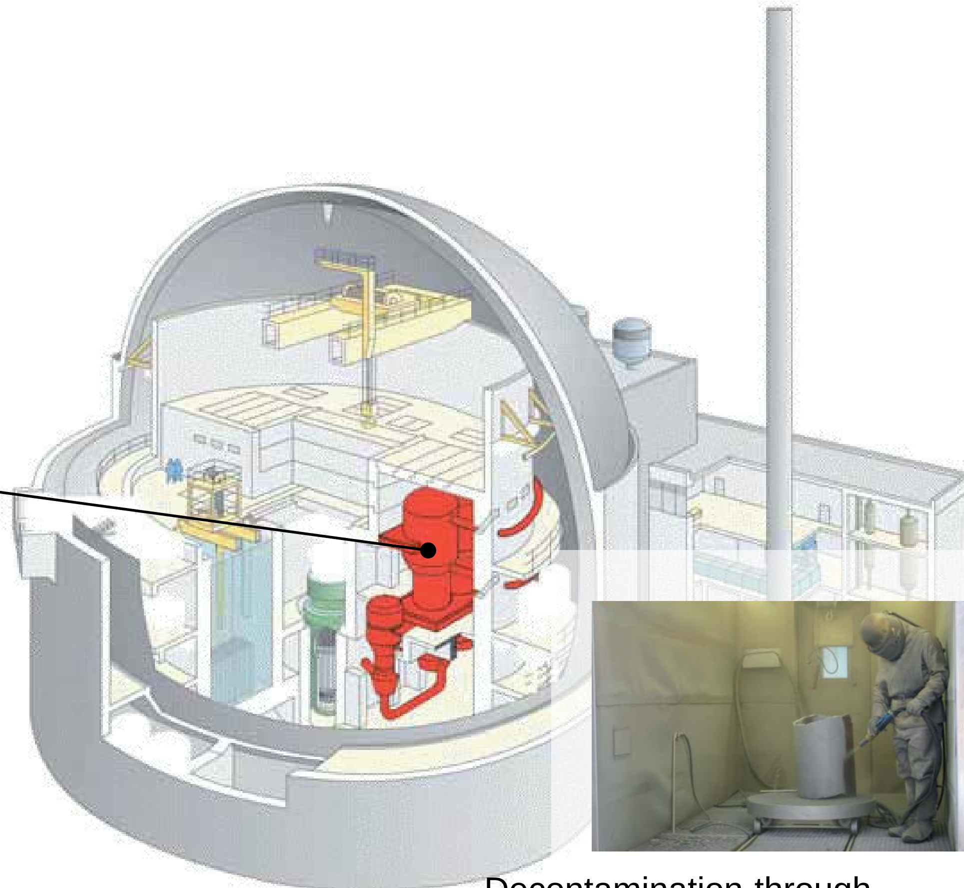
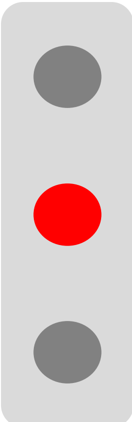


Image: GSR (2017)

Decontamination through sandblasting

Standard Procedures of Decommissioning



Hot-Zone-Stage

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

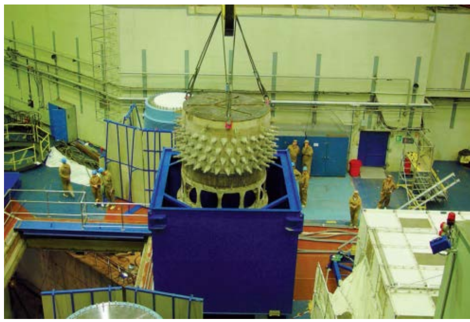
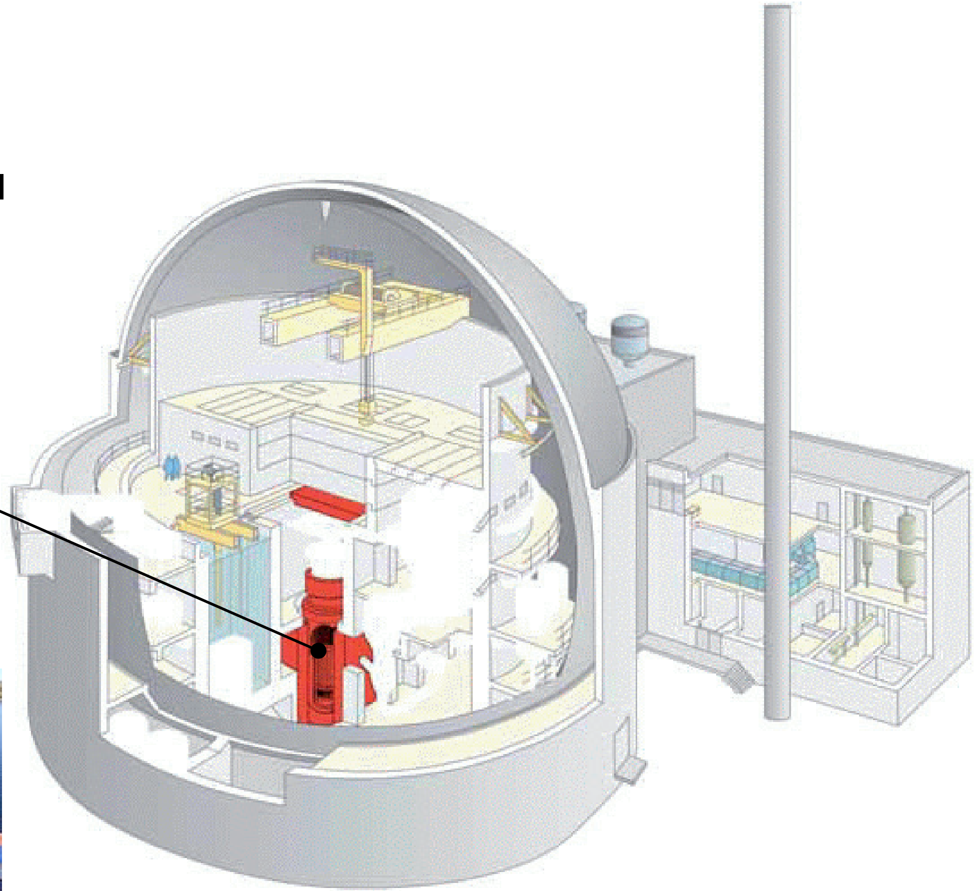
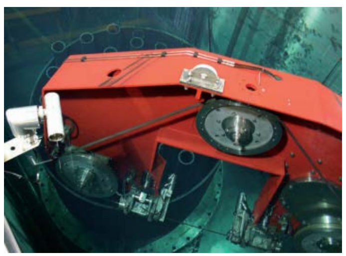


Image: GSR (2017)



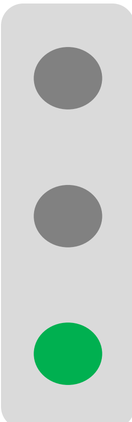
Remote controlled underwater cutting



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

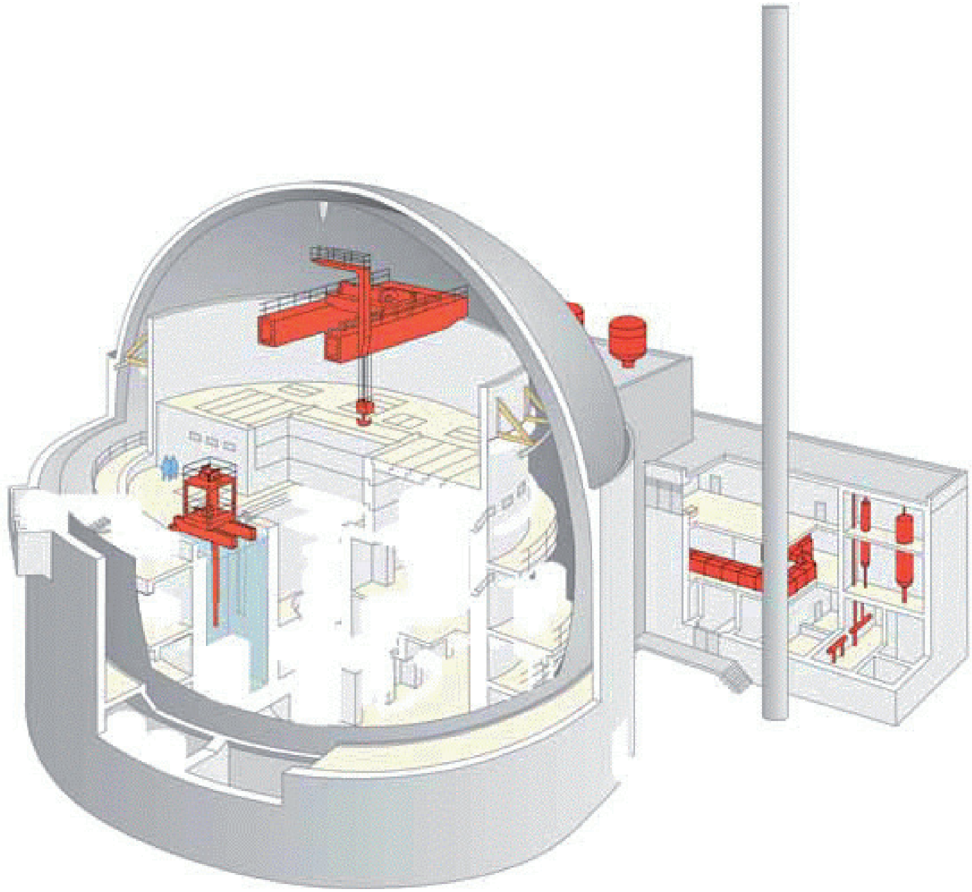


Image: GSR (2017)

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)

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

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.

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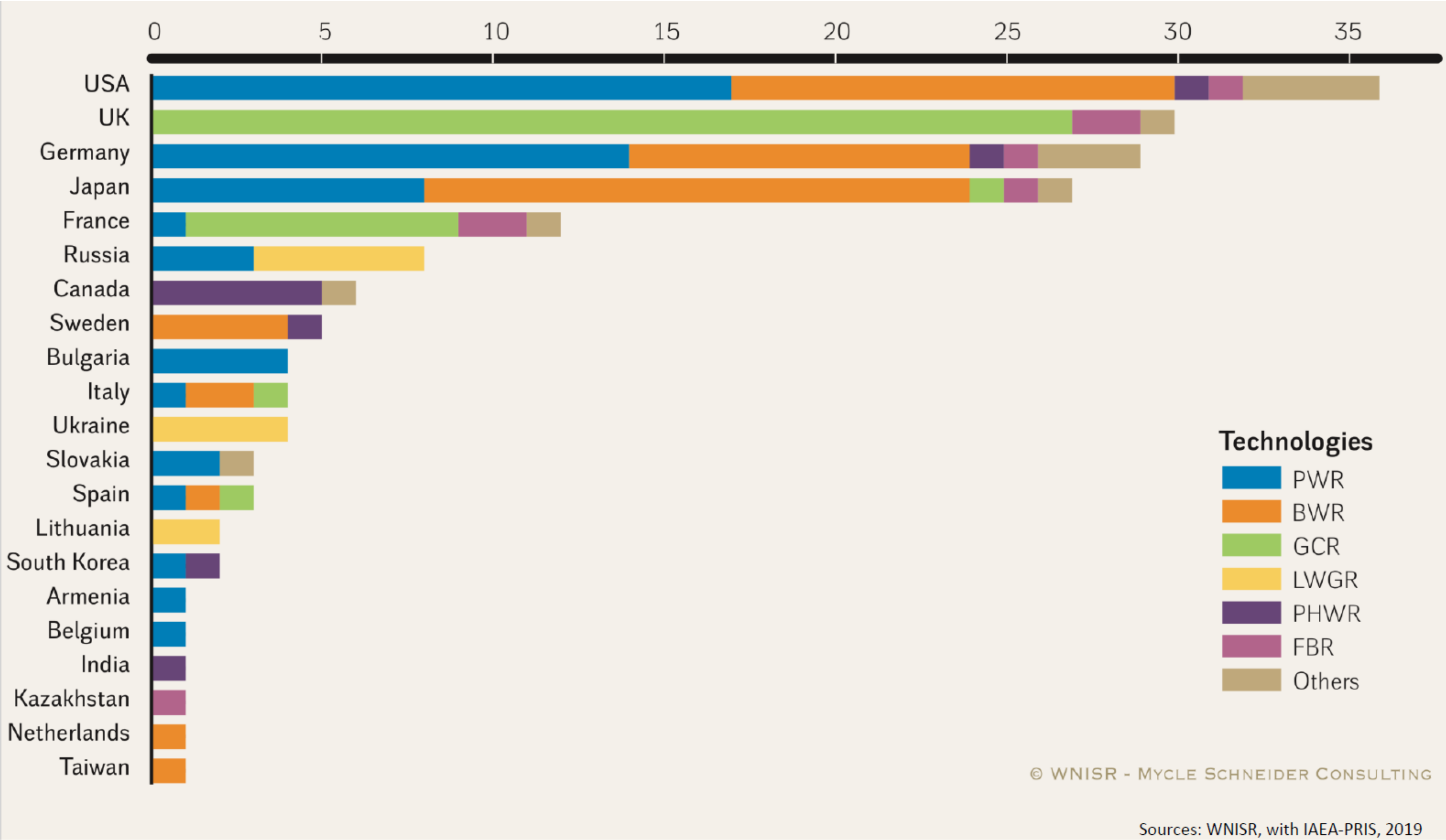
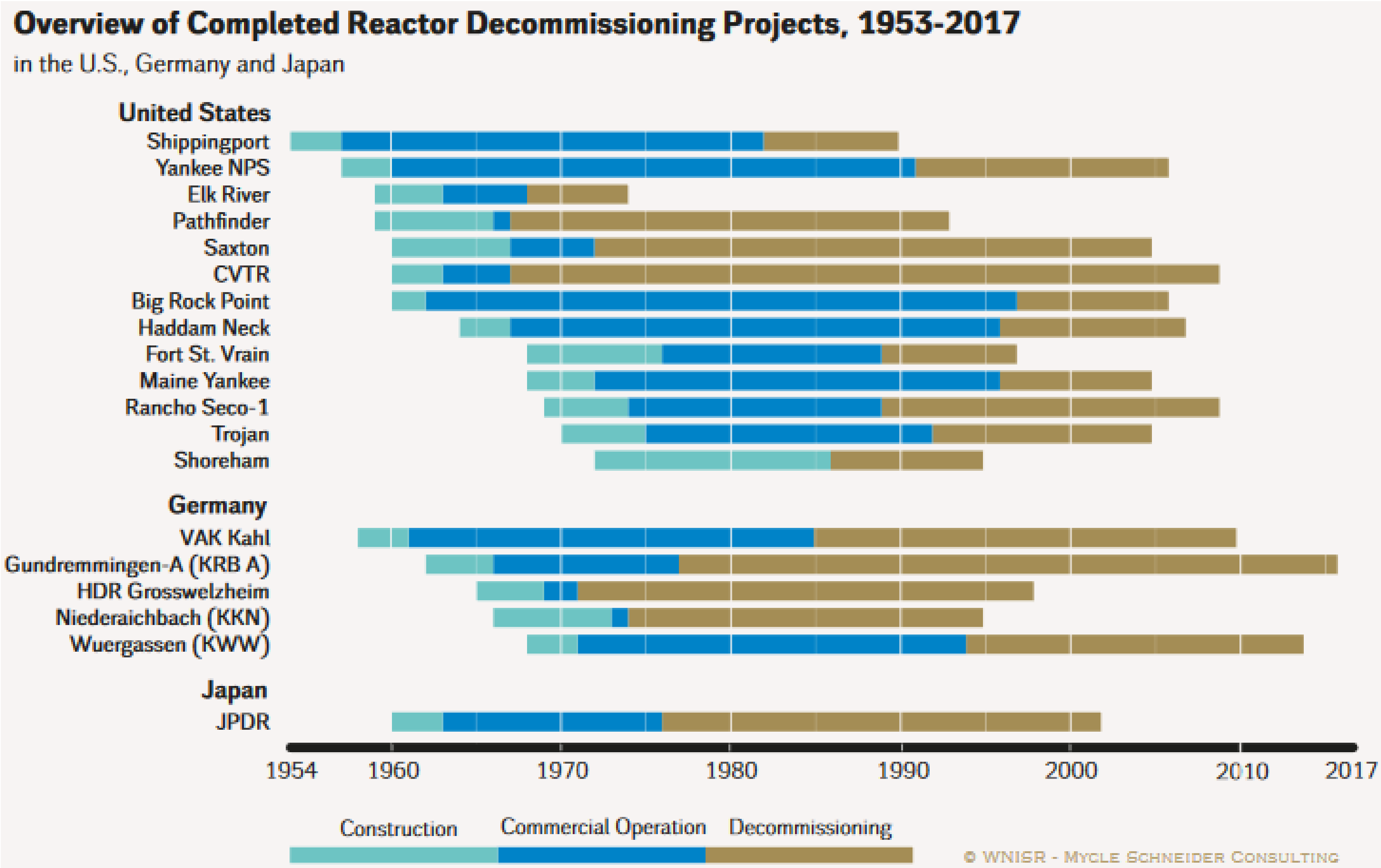
Around 78% or 140 reactors are using 3 reactor technologies: PWR (54), BWR (48), GCR (38, 27 in the UK).



The average duration of the decommissioning process, independent of the chosen strategy, is around 19 years



Global survey – only 19 decommissioned reactors or 6 GW of capacity

Country	Reactor	Capacity in MW	Decommissioning End in	Operational Years
Germany	**5**	**1,017 (total)**		
	Niederaichbach	100	1995	1
	HDR Großwelzheim	25	1998	2
	VAK Kahl	15	2010	24
	Würgassen	640	2014	23
	Gundremmingen-A	237	2016	11
Japan	**1**	**12 (total)**		
	JPDR	12	2002	13
United States of America	**13**	**4,922 (total)**		
	Elk River	22	1974	5
	Shippingport	60	1989	25
	Pathfinder	59	1993	1
	Shoreham	809	1995	0
	Fort St. Vrain	330	1997	13
	Maine Yankee	860	2005	24
	Saxton	3	2005	5
	Trojan	1,095	2005	17
	Yankee NPS	167	2006	31
	Big Rock Point	67	2006	35
	Haddam Neck	560	2007	29
	Rancho Seco-1	873	2009	15
	CVTR	17	2009	4
Total		**5,951**		

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Overview of Reactor Decommissioning in 11 Selected Countries (as of May 2019)

Together with the six case studies reviewed in WNISR2018 and updated in WNSIR2019, we cover a total of 159 closed reactors, representing almost 87 percent of the worldwide closed fleet.

Country	Closed Reactors	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	27	26	0	0	0	1 [4%]
United Kingdom	30	0	0	0	30	0
USA	36	6	0	5	12	13 [36%]
Spain	3	1	0	1	1	0
Italy	4	4	0	0	0	0
Lithuania	2	2	0	0	0	0
Russia	8	0	0	0	8	0
South Korea	2	2	0	0	0	0
Total	**159**	**54**	**5**	**14**	**67**	**19**

Sources: various, compiled by WNISR, 2019

Key Findings in the USA

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.

USA	05-2018	05-2019
"Warm-up-stage"	4	6
of which defueled	*1*	*1*
"Hot-zone-stage"	0	0
"Ease-off-stage"	5	5
LTE	12	12
Finished	13	13
of which greenfield	*6*	*6*
Shut-down reactors	**34**	**36**

Source: WNISR (2018, 2019)

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

It seems that the new organizational model of selling the license to a decommissioning contractor, identified in WNISR2018 (Zion-1/2, Lacrosse), gains popularity.

- Vermont Public Utility Commission approved the operating license transfer for the Yankee reactor from Entergy to Northstar, including decommissioning trust fund of US$571 million.
- Duke Energy announced that it plans to sell the operating license for Crystal River-3, which is currently in LTE, to the Northstar and Orano joint-venture.
- On 17 September 2018, Oyster Creek, a 619 MW GE BWR-2 (Mark 1) reactor and the first "commercial" and then oldest reactor in the U.S., was closed after 49 years of operation, 11 years before its license expires in 2029. Exelon will now defuel the plant with plans to sell it to the newly created joint venture Comprehensive Decommissioning International consisting of Holtec International (U.S. waste management company) and SNC-Lavalin (Canadian engineering company).
- Comprehensive Decommissioning International plans to acquire the decommissioning licenses of two Entergy reactors in the coming years: Pilgrim, closed in 2019 and Palisades, planned to close definitely in 2022.

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

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

Of the ten reactors undergoing decommissioning in 2019, a majority of six were sold to decommissioning companies. The waste management company EnergySolutions seems to be involved in most if not in all U.S. decommissioning projects.

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.

Key Findings in Germany: No tangible progress

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

Gundremmingen-A (2.2bn €, €9,300/kW) and Würgassen (1bn €, €1,600/kW) est.) de facto decommissioned.

No tangible progress in 2018: only Neckarwestheim-1 and Philippsburg got defueled.

Germany	2015	05-2018	05-2019
“Warm-up-stage”	10	10	10
of which defueled	*0*	*2*	*4*
“Hot-zone-stage”	3	4	4
“Ease-off-stage”	9	8	8
LTE	2	2	2
Finished	4	5	5
of which greenfield	*3*	*3*	*3*
Shut-down reactors	**28**	**29**	

Key Findings in France: Underprovisioning, long time horizons

While EDF operates 58 PWRs, the legacy fleet (12) consists mainly of GCRs (8).

EDF’s new strategy aims to release the GCRs from regulatory control only by the beginning of the 22nd century. In addition, there is not even a theoretical disposal rout for graphite.

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 more time, that the technical feasibility is not fully assured, and that the process will cost overall much more than EDF anticipates.

Key Findings in Spain

Only 3 closed NPPs or 1,067 MW but three main reactor types (PWR, BWR, GCR).

José Cabrera (214 MW PWR) in "Hot-Zone", underwater segmentation of reactor vessel and internals, done by Westinghouse. Vessel sent to Cabril Waste Repository, internals stored on-site in interim storage facility. In 2016, cost estimate doubled to US$259 million (~US$1,800/kW). Decommissioning on time with estimated 10 years.

Vandellos-1 (480 MW GCR) defueled. Although some decommissioning work was done, WNISR considers it in LTE (enclosure period of 25 years).

Santa Maria de Garona (446 MW BWR), closed in 2012. Nuclenor (Iberdrola/Endesa) will defuel the reactor, then NPP will enter decommissioning.

Spain	May 2019
"Warm-up-stage"	1
of which defueled	*0*
"Hot-zone-stage"	0
"Ease-off-stage"	1
LTE	1
Finished	0
of which greenfield	*0*
Shut-down reactors	**3**

In Spain, decommissioning and waste management is seen as an essential public service.

- The operator is responsible for all activities prior to decommissioning (e.g. defueling the reactor, conditioning of operational wastes, ~ 3 years). Once these activities are completed the site is temporarily transferred to Enresa which then becomes the decommissioning licensee.
- Spain describes decommissioning and waste management as an essential public service and assigns these tasks to the state-owned company Enresa.
- Enresa plans all decommissioning and waste management activities. While LTE is applied for the GCR, all LWRs are bound to be immediately dismantled to a greenfield site (~ 10 years).
- After decommissioning, the site will be returned to its former owner.
- Enresa is also responsible for managing the funds and liabilities for decommissioning.
- The external segregated fund is fed by two fees, the rate of which is regulated.
- After decommissioning starts, there are no more payments to the fund and in the case of a shortfall, it would be the full responsibility of the decommissioning licensee Enresa and hence the taxpayer to cover these costs.

Italy: While 30 years after abandoning nuclear, Italy is just starting decommissioning.

In 1999, the state-owned Sogin was established during the privatization process of Enel with the task to decommission Italy’s nuclear power plants as well as finding a national waste storage site.

At the same time, the initial strategy of LTE was changed to ID.

Until 1987, during the operation of the nuclear power plants, the operator ENEL set aside internal, non-segregated funds.

The early closure of the reactors prevented the operator of accumulating the total and needed amount of decommissioning funding. The funds, around €800 million (US$904 million), were transferred to Sogin after its creation in 1999;.

Now, funds are accumulated through a levy on the electricity price.

The resources are still held in internal and unrestricted funds, only they are now in state hands and money has been partly used for purposes of public interest other than decommissioning; the state is free to use the money being paid to CCSE for any purpose. However, in the end the state and hence the taxpayer remains responsible for all decommissioning and waste disposal costs.

In Lithuania, a RBMK reactor is for the first time undergoing decommissioning; 50% funded by the EU.

Lithuania operated two RBMK-1500 reactors at the Ignalina station. The two NPPs were closed in 2004 and 2009 as a requirement to join the EU and the EU covers more than half of the costs for the decommissioning of Ignalina.

The two reactor cores are defueled, but the spent fuel in the pools has not yet been evacuated as the interim storage facility is delayed by more than 10 years.

Although no license has yet been granted, decommissioning work (e.g., in the turbine building or auxiliary buildings) is being carried out.

The decommissioning end date has, since 2011, been postponed by further 9 years to 2038. It is planned to decommission Ignalina to "brownfield" status.

Between 2010 and 2015: costs increased by 67% to US$3.8 billion and the country faces a financing gap of €1.6 billion (US$1.8 billion).

A 2016 report by the European Court of Auditors concluded that the EU funding programs for decommissioning have not created the right incentives for timely and cost-effective decommissioning. The auditors conclude that the funding programs should be discontinued after 2020, when EU support for Lithuania will have totaled €1.8 billion (US$2 billion).

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Conclusion: Key Findings

- No reactor completed decommissioning worldwide since WNISR2018. Still, only 19 reactors, with a capacity of 6 GW were fully decommissioned.
- 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.
- Early nuclear countries France, Canada, UK, Russia have not yet decommissioned one single reactor.
- Not one graphite-moderated reactor has yet been decommissioned; this also holds true for Light Water Cooled and Graphite Moderated Reactors such as the Chernobyl-type RBMK.
- In the US, selling decommissioning licenses to a contractor is gaining popularity. Limited-liability decommissioning companies appear to operate according to business incentives that are starting to attract regulatory and legal attention.
- Difference in decommissioning policy (e.g. removal of large components, definition of decommissioning and cost estimates) makes international comparisons difficult.
- In all the cases, interim storage facilities were needed, hindering decommissioning or even rendering the regulatory release of the site impossible.
- Decommissioning is only at its very beginnings.

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.

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 financial stamina