The future of nuclear decommissioning – a worldwide market potential study

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Abstract

In the 1950s, nuclear power generation became important and many facilities were built. Today, because of political, technical or economic reasons many reactors are being or will be decommissioned. This highly impacts energy policy regarding future energy supply and the handling of decommissioning, including dismantling capacities, regulatory control, equipment, expertise, funding or final nuclear disposal sites.

This study provides a desk-based research and a scenario analysis of the present and future situation of 540 nuclear power reactors in 18 countries worldwide until 2047. For that purpose, IAEA PRIS database is extended on reactor-level by information on future usage, political decisions, preferred decommissioning strategies and the durations of the post-operational and dismantling phase.

The projected market potential will continuously unfold after 2019 until mid-2030s to a stable, annual market volume of 75-85 GW_e in dismantling. In the next decade, main dismantling

markets are USA, Japan and Germany with a capacity reduction of 131.5 GW_e until 2047. Germany and USA offer a stable market potential. In Japan and France, the political decisions on pending reactors and prolongations of operation times strongly influence nuclear retirements. Ukraine, Spain, Sweden and Canada are interesting smaller markets in the next years.

Keywords

nuclear reactors; nuclear decommissioning; national nuclear shutdown/decommissioning policies; international decommissioning market potential; policy implications

Highlights

- Different nuclear decommissioning strategies induce challenges for national energy policies.
- Main dismantling markets in the next decade are USA, Japan, and Germany.
- In Japan and France, political decisions on many pending reactors/retirements are still due.
- Until 2047, 259 GW_e electrical power generation capacity have to be replaced in the considered countries
- Potential bottlenecks are expertise, dismantling equipment and shifts to deferred dismantling.

1. Introduction

Since the 1950s, the peaceful use of nuclear power generation has been present in many countries worldwide and contributes nowadays to a significant share (11%) to the worldwide energy supply (DAtF, 2016). In early 2018, 450 commercially used nuclear power reactors in 31 countries were in operation (IAEA PRIS). The majority of these reactors are located in the USA, France and Japan. Worldwide, more than 60% of the nuclear capacity is over 25 years old, raising important questions in the medium term about the schedule for retirements (World Energy Outlook (IEA, 2014), p. 347, OECD/IEA, 2017). By 2025, it is probable that 50 of 129 European nuclear reactors in operation (39%) need to be shut down and by 2030 about 90% of all present existing European nuclear reactors are expected to be shut down, if no retrofit measures are undertaken for prolongations of their operation life (European Commission, 2016a, p.5-7).

The technical and scientific advances and improvements in the nuclear power generation sector led to long life expectancies and allow up to 60-80 operating years. After their operation life, nuclear reactors are shut down, disconnected from the grid and have to be decommissioned. Decommissioning decisions and strategies depend on the single facilities' technology, age, and condition, but also the countries' policy, the national energy mix and price structure, the countries' climate goals (IEA, 2014; OCDE/IEA, 2017) as well as the societal acceptance. Furthermore, safety, radioactive waste management, power generation capacity replacement, transmission capacities in the grid, and energy security are in the focus during nuclear decommissioning (World Energy Outlook (IEA, 2014), p. 347). This leads to an increased focus on retrofitting, replacement or shutdown measures of nuclear reactors and raises questions of direct or deferred dismantling strategies[1], decommissioning schedules,

[1] In principle, three decommissioning strategies can be distinguished: First, the direct dismantling, the deferred dismantling and the safe entombment of the whole facility (dismantling is not planned) (IAEA, 2011). Most countries prefer the direct or deferred dismantling as recommended by the International Atomic Energy Agency (IAEA, 2011).

capacity replacements and nuclear waste storage. Furthermore, nuclear power plant operators are confronted with increasing cost for retrofitting their facilities, due to increased safety requirements[2]. This induces a massive change in the energy sector, waste treatment and long-term storage in the affected countries that needs to be regulated (Wendling, 2002, p. 1; VDI-Gesellschaft Energietechnik, 2002; Thierfeldt and Schartmann, 2012; Bonnenberg and Mischke, 1996, p. 9) and managed by the respective stakeholders. The main characteristics of nuclear decommissioning projects are the long project durations (10 to 20 years or longer), high costs of between hundreds of million up to a few billion Euros per facility, the safety requirements, the legal country-specific obligations and permits as well as the high number and diversity of involved stakeholders.

The aim of this study is to identify the nuclear reactor-based dismantling market potential, its development in the coming years, and the consequences for energy policy. As nuclear decommissioning is increasing and decisions do not only depend on the reactor age, but also on the reactor condition, options for subsequent use, energy market conditions, political decisions or final disposal capacities, a future projection is needed. To the authors, no similar reactor-based approach is known. Consequently, a definitive capacity planning of authorities, technical knowledge and dismantling capacities of the local or national industry and energy production replacement is difficult.

Addressees of the study are political decision makers that are interested in the future energy supply of their countries and in planning the decommissioning funding, the capacities for regulatory control and final disposal sites for nuclear waste. Also, energy providers and operators are interested in the speed of nuclear phase-out, replacement of power plant

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[2] Also, triggered by nuclear accidents (e.g. Chernobyl, Fukushima) many countries revised the risk assessments of their nuclear facilities and decided to shut down nuclear reactors in recent years. Because of the accident in the nuclear reactors of Fukushima Daiichi in 2011, the German government shut down of nearly half of the nuclear power reactors and legally manifested the nuclear phase-out by 2022. In Japan, all existing 50 nuclear reactors were shut down and 37 are so still, waiting for a political decision on their restart or decommissioning in the next years (Schneider et al. 2017, p. 56). In 2016 and 2017, only five Japanese nuclear reactors were back in operation (Schneider et al., 2016, p.149, IAEA PRIS) while a third reactor was shutdown.

capacities and grid transmission in countries e.g. for market entering strategies or acquisition of required expertise and technology.

Thus, the imposed research questions in this study are:

- What is the current and future status of nuclear power generation reactors worldwide and when are their planned or projected grid disconnection and dismantling dates?
- Which nuclear dismantling markets are interesting for companies and what is their expected development over time?
- What are the consequences of future nuclear dismantling for national energy policies?

In the following, an overview of the current state of nuclear power generation and decommissioning (see section 2) and the methodology, the data and scenario analysis (see section 3) are given. Focus of the study is the decommissioning of commercial nuclear power generation reactors[3]. Then, an analysis of the future dismantling markets (see section 4) is provided. Based on this, we derive policy implications and describe future nuclear dismantling markets (see section 5). Finally, a summary, critical appraisal and an outlook on future research are given in section 6.

2. Research methodology and current state of nuclear power generation and decommissioning

2.1 Methodology

To estimate the number of nuclear reactors that will be decommissioned in the future 30 years, this study is providing a desk-based data research and analysis on reactor-level (section 3.1), a scenario analysis (sections 3.2 and 3.3), a comparison to existing projections (see section 3.4) and a comprehensive country-specific market analysis (section 4) to identify future

[3] Nuclear pilot and research facilities are excluded from the study due to their high heterogeneity, diverse utilizations and their minor influence on the energy supply.

decommissioning markets (section 5). For this, individual nuclear power reactors and their operation, shutdown[4], and decommissioning strategy (deferred/direct dismantling or safe entombment), technology type, market location, regulations framework conditions and potential are researched and analysed. Since safe entombment[5] is only applied very rarely (IAEA, 2011), we will focus on direct and deferred dismantling in the following.

The basis for the data research is the PRIS database from the International Atomic Energy Agency (IAEA) listing 540 nuclear reactors in the considered 18 countries (see Annex Table B and section 2.2). As there is lacking detailed information on the reactors' status in "permanent shutdown" in PRIS, this dataset is extended by desk-based research on reactor level (see section 3.1). Based on this, our market potential study includes the time, market location, market framework conditions and the product (here: reactor technology). With respect to time, the start of power generation was researched for each reactor to determine its age and number of operational years[6]. Data was raised for the incurred or expected shutdown date. If the exact date was not fixed yet, the earliest, latest, and expected shutdown date was assumed based on the respective national strategy as a baseline as follows: The start shutdown date $S_{(shutdown)}$ was either known (fixed) or unknown. The known shutdown date equals the expected shutdown $S_{(shutdown,exp.)}$. If it was unknown, the earliest and latest shutdown equal the respective national regulation[7]. The earliest shutdown is determined by the expiring of reactors operating licences and the latest shutdown equals the maximum number of prolongations and maximum operating lifetime according to respective national regulation. However, no probabilities are associated with the earliest, expected and latest shutdown dates.

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[4] This includes the taking off the grid and the removal of the nuclear fuel.
[5] This includes the conversion of the nuclear facilities into a safe form (IAEA 2011, p.4) without a planned future dismantling.
[6] This might differ due to regulatory exceptions (especially in France) and due to intermediate refurbishments.
[7] For example, the Atomgesetz (AtG) for German nuclear reactors, the expiring of the 10-year revision period of the ANS in France, the expiring of the 40-year revision period in Japan, data after retrofitting in Canada, and information from reactor operators in the considered countries. All references used for the evaluation of national regulations, restrictions and framework conditions can be found in Table 6.

With respect to the market location, countries were differentiated as they have very specific and differing legal regulations, authorisation and prolongation processes and energy policies. In this study, we consider the following 18 countries: Belgium, Bulgaria, Canada, France, Germany, Italy Japan, Lithuania, South Korea, Russia, Slovakia, Spain, Sweden, Switzerland, Taiwan, UK, Ukraine, and USA. We consider 540 (80%) of the listed 672[8] reactors in PRIS database. Largest shares of non-considered reactors are the rather new 57 Chinese (8%) and 28 Indian (3%) reactors. Thereof, 61 are in operation and 24 are in construction. Altogether, we consider nearly all of the existing nuclear reactors that are or will be decommissioned in the coming decades.

Furthermore, we differentiated reactor technologies considering physical structure, shutdown times, regulatory obligations relating to deferred or direct dismantling, as well as demand for equipment and expertise.

For the scenario analysis (see sections 3.2 and 3.3), five scenarios were constructed using different influencing criteria on the shutdown dates as well as the post-operational and dismantling durations. The scenario projection was done for the years of 2027, 2037, and 2047 and compared to existing studies (section 3.4).

2.2 Data and current state of nuclear power generation and decommissioning

An overview of electricity generation with nuclear power is given in many literature sources, e.g. for the current status of nuclear energy generation programmes worldwide see the World Energy Outlook (IEA 2014, p. 357). However, in existing literature known to the authors, such as IEA (2014), OECD/NEA 2015, 2016, Wealer et al. (2015), IAEA (2016a), no overview of

[8] According to PRIS (status: April 2018), thereof 450 are in operation, 56 are in construction and 166 are in permanent shutdown.

detailed decommissioning data on reactor-level is provided. On reactor-level, the International Atomic Energy Agency (IAEA) provides open source data on the current status of nuclear reactors worldwide in PRIS database. In the following, this data is used for the description of the current state and as a basis for the scenario analysis for the future nuclear power and dismantling market.

Beside IAEA PRIS database, S&P Global World Electric Power Plants Database (PLATTS) provide commercial data[9] on the current electrical power plants worldwide, but no structured information on the nuclear dismantling market, projections or market potentials. Further data on individual nuclear reactors and for country-specific information is available at the World Nuclear Association[10], at IAEA's Country Nuclear Power Profiles[11] and at the Nuclear Energy Agency of OECD[12]. Since the IAEA data of the PRIS is open source, we use these data and extend it by our further researched and collected data to provide a transparent market analysis.

Nuclear dismantling companies are both interested in the number and type of reactors that will be decommissioned (see Figure 1). France[13] and the UK are the only countries with a considerable share of gas-cooled reactors (GCR) as well as Russia with its high-temperature gas-cooled reactors (HTGR). In all countries (except Russia), the main shares constitute of Boiling Water Reactors (BWR) and Pressurized Water Reactors (PWR) technology. Korea, Ukraine, Belgium, Slovakia and Bulgaria have almost exclusively PWR technology. A compact overview of the analysed data including the number of reactors in operation, the average and median age of the nuclear reactors, the number of the most common reactor types BWR, PWR, gas-cooled and graphite-moderated LGWR[14] is given in Table 1.

[9] Cost for the database: 4655 USD (source: https://www.platts.com.es/products/world-electric-power-plants-database, status July 2018)
[10] http://www.world-nuclear.org/
[11] https://cnpp.iaea.org/pages/index.htm
[12] https://www.oecd-nea.org/pub/
[13] In the case of France, this includes many very small and old reactors that are shut down or already in dismantling. The reactors in operation are exclusively PWR.
[14] Besides the reactors in operation, the listed numbers of reactor types include also the reactors in permanent shutdown.

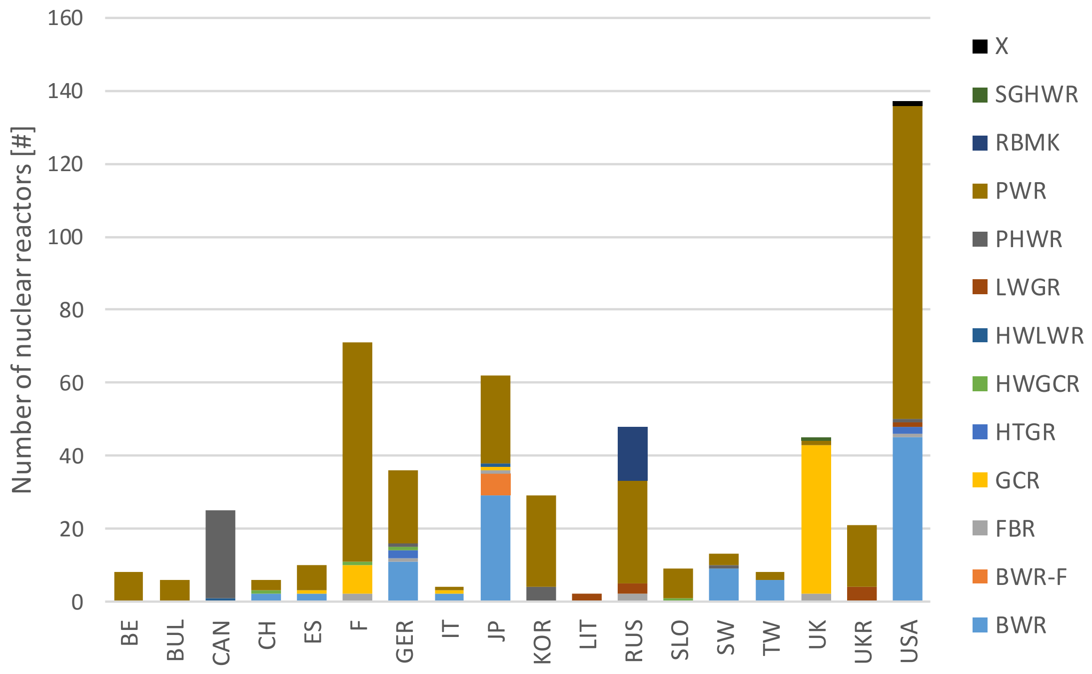

Figure 1: Number of different nuclear reactor types per country [#] (status: 2018)[15],[a].

[15] Abbreviations: HTGR: high-temperature gas-cooled reactor, PWR: pressurized water reactor, BWR: boiling water reactor, FBR: Fast Breeder Reactor (USA, RUS), PHWR: pressurized heavy-water reactor, HWGCR: heavy-water gas-cooled reactor, GCR: gas-cooled reactor, SGHWR: Steam-generating heavy water reactor, HWLWR: Heavy Water Light Water Reactor (Gentilly (CAN), Fugen (JP), Winfrith (UK)), BWR-F: damaged boiling water reactor in Fukushima (JP), LWGR: light-water cooled graphite-moderated reactor, RBMK: Russian light-water cooled graphite-moderated reactor (=LWGR), X: organically cooled reactor Piqua, USA

Table 1: Number, average age, median age and type of nuclear reactors per country[b]

		Reactor age		Number of reactors per reactor type				
	Number of reactors in operation (or ready-for-operation in Japan)	Average age of nuclear reactors	Median age of nuclear reactors	Number of BWR	Number of PWR	Number of GCR	Number of graphite-moderated LGWR [#]	Others
Country	**[#]**	**[years]**	**[years]**	**[#]**	**[#]**	**[#]**	**[#]**	**[#]**
Belgium	7	39	34	0	7	0	0	0
Bulgaria	2	27	27	0	6	0	0	0
Canada	19	33	32	0	24 (PHWR)	0	0	1
France	58	31	31	0	60	8	0	3
Germany	7	30	31	11	20	0	0	5
Italy	0	49	52	2	1	1	0	0
Japan	42	28	28	29	24	1	0	8
Lithuania	0	31	31	0	0	0	2	0
Russia	37	30	33,5	0	28	0	18	2
Slovakia	4	24.5	24.5	0	8	0	0	1
South Korea	24	19	18	0	24 + 4 (PHWR)	0	0	0
Spain	7	35.8	33	2	7	1	0	0
Sweden	8	37	36	9	3 + 1 (PHWR)	0	0	0
Switzerland	5	42	45	2	3	0	0	1
Taiwan	6	35	34.5	4	2	0	0	0
UK	15	32	33	0	1	41	0	3
Ukraine	15	26.6	30	0	17	0	4	0
USA	99	36	38	45	86	0	1	5

More than 60% of all nuclear reactors in PRIS are older than 30 years and 37% are older than 40 years (see Table 1 and Table 2). The USA, France and the UK have a high number of ageing nuclear reactors. Especially in the USA there is a high number of reactors between 30-35 years (33) and 40-45 years (39) old (see Table 2). A darker colour (red) indicates a higher number of nuclear reactors in this age class and country. In UK, a large share of nuclear reactors are more than 50 years old (>53%), while in France, more than 76% of the reactors are older than 30 years.

Table 2: Heat map of nuclear reactors' age distribution in age classes and location of the reactor by country [cumulated number of nuclear reactors per category] in 2018[c]

Age classes [years]	BE	BUL	CAN	CH	ES	F	GER	IT	JP	KOR	LIT	RUS	SLO	SW	TW	UK	UKR	USA	Total
0-5 years						1			2	6		10	2		2		2	5	30
5-10 years									1	3		2							6
10-15 years									3	2		1					2		8
15-20 years						1			1	4		1	2						9
20-25 years			1			4			8	5		1				1	1	2	23
25-30 years		1	3		1	7	3		10	2		2				4	2	6	41
30-35 years	2	1	7	1	5	24	9		11	5	2	8	2	2	2	6	8	33	128
35-40 years	2	2	4	1	1	21	5	1	7	1		7	2	4	3		5	14	80
40-45 years	3	2	4			3	8		13	1		9		5	1	5	1	39	94
45-50 years			4	3	3	3	6		4			3	1	1		3		20	51
50-55 years			1	1		5	4	3	2			3		1		12		12	44
55-60 years	1		1			2	1									11		4	20
60-65 years												1				3		2	6
Total	**8**	**6**	**25**	**6**	**10**	**71**	**36**	**4**	**62**	**29**	**2**	**48**	**9**	**13**	**8**	**45**	**21**	**137**	**540**

3. Data extension and scenario analysis

3.1 Data extension

To describe the status of nuclear reactors, the IAEA PRIS database uses the terms "Permanent shutdown", "Operational"[16] and "Under construction". Since we want to describe the status of every reactor in more detail, we use more detailed denominations for "permanent shutdown" listed in Table 3 that are relevant for decommissioning planning.

[16]In Japan, due to Fukushima many nuclear reactors were disconnected from the power grid but are "ready-to-operate". They await political decision for restart and operation or shut down and decommissioning. PRIS database lists them as "operational".

Table 3: Status of nuclear reactors in IAEA PRIS and in our denomination

<table>
<tr><th></th><th>Our denomination:</th><th>PRIS denomination:</th></tr>
<tr><td>0</td><td>Decommissioning completed</td><td>-*</td></tr>
<tr><td>1</td><td>In decommissioning</td><td rowspan="4">Permanent shutdown</td></tr>
<tr><td>2</td><td>In safe entombment/deferred dismantling</td></tr>
<tr><td>3</td><td>In preparation for safe entombment/deferred dismantling</td></tr>
<tr><td>4</td><td>In shutdown</td></tr>
<tr><td>5</td><td>In operation</td><td rowspan="2">Operational</td></tr>
<tr><td>6</td><td>Ready for operation</td></tr>
<tr><td>7</td><td>Under construction</td><td>Under construction</td></tr>
<tr><td>8</td><td>Others</td><td>-*</td></tr>
<tr><td></td><td>* This category does not exist in PRIS. When the decommissioning is completed, the reactor will be removed from the database and released from nuclear surveillance.</td><td></td></tr>
</table>

To classify each reactor “in permanent shutdown” anew, we used information of World Nuclear Association (WNA)[17], of IAEA’s Country Nuclear Power Profiles[18], of the Nuclear Energy Agency of OECD[19] and other literature sources, online data, legal regulation and current political decisions were gathered and evaluated (see Table 6 and references) (status: April 2018).

The investigated current reactor status shows that the main share of operating reactors are in the USA, France and Russia (see Figure 2). Reactors in deferred dismantling or in preparation for safe enclosure are in the UK, USA, Canada and Japan. However, in some countries like in Germany, Italy, Bulgaria and Lithuania the share of reactors in dismantling processes increases.

By 2017, only 17 nuclear power reactors have been fully dismantled worldwide (WNN, 2017). In 2018, our extended IAEA PRIS database listed 21 power reactors that were completely decommissioned. These include 14 reactors in USA, 4 in Germany, 2 in France and 1 in Japan[20]. On average, these 21 nuclear reactors were operated for 49.4 years. The four largest

[17] http://www.world-nuclear.org/
[18] https://cnpp.iaea.org/pages/index.htm
[19] https://www.oecd-nea.org/pub/
[20] USA: Big Rock Point, CVTR, Elk River, Fort St. Vrain, Haddam Neck, Maine Yankee, Pathfinder, Rancho Seco-1, San Onofre-1, Saxton, Shippingport, Shoreham, Trojan, Yankee NPS; GER: VAK Kahl, HDR Grosswelzheim,

facilities (in the USA) have been shut down in 1989, 1992 and 1997. The remaining completely dismantled facilities in other countries are research reactors or other nuclear facilities. The decommissioning durations of these reactors range from 1 to 40 years. Fort St. Vrain and Pathfinder (both USA) were converted to and are still used as conventional power plants. Thus, their decommissioning duration in the database is only 1 to 2 years (decontamination). On average dismantling took 12.8 years[21]. However, for three reactors no dismantling end dates could be investigated (Elk River (USA) and G-2/G-3 Marcoule (F)).

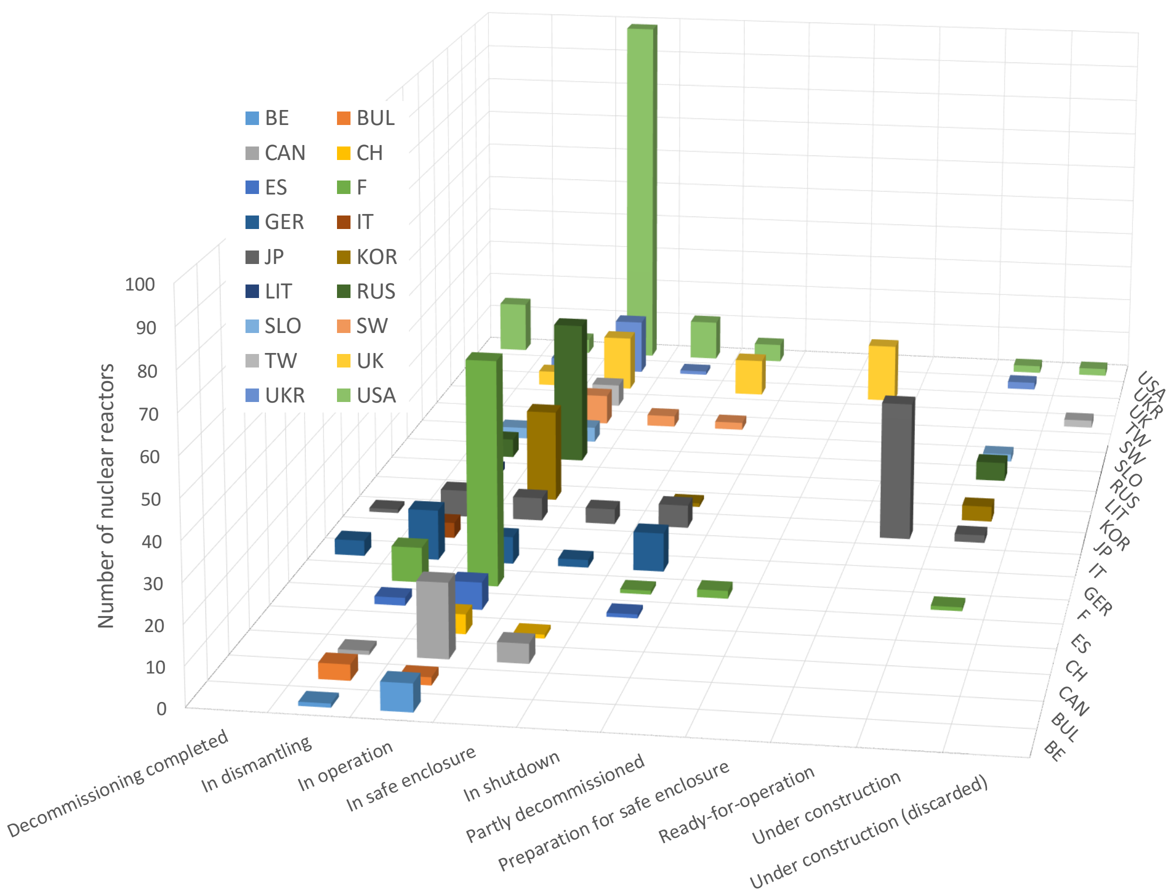

Figure 2: Number of nuclear reactors and their current status and location by countries (status: 2018)[d].

Wuergassen, Niederaichbach. Eight of them had a small installed electric power capacity (<100MWe), only four reactors had more than 850 MWe installed electric power capacity. Furthermore, G2 and G3 Marcoule in France and JPDR in Japan arealready decommissioned. This includes 8 BWR, 2 GCR, 1 HTGR, 1 HWGCR, 1 PHWR and 8 PWR. However, G-2 and G3 (Marcoule) and JPDR are not yet decommissioned to the green field.

[21] 12.5 years for reactors in USA, 14.75 years for reactors in Germany and 10 years for the Japanese reactor.

Due to our extension of PRIS database, we can further differentiate reactors in permanent shutdown (see Figure 3). The diagram opposes the PRIS reactors statuses to the actual status [MW el. power]. It can be seen that about 36% of the reactors' capacity in permanent shutdown is actually in shutdown process (21.4 GW_e, orange) and 43% of the reactors capacity is already in dismantling (yellow). 16% of the reactors capacity is in safe enclosure (blue) and the remainder is in preparation for it (grey). The large share of these reactors (21.4 GW_e, orange) comprises the future dismantling market in the next decade. The majority of this market potential is located in Germany (10 reactors, on average 1,100 MW per reactor) and USA (5 reactors, on average 800 MW per reactor). In UK, only smaller reactors are in preparation for safe enclosure and in shutdown.

For energy policy, not only the number of reactors but especially the electrical capacity of nuclear power plants that will be decommissioned is important to derive the necessary substitutional electrical power supply for each country. The age of nuclear reactors (see Figure 4), but also other factors like shutdown start dates or national regulation on prolongation are considered in the following scenario analysis to estimate the electrical capacity that will be shut down in the 18 considered countries. It can be seen, that the age of the reactor and the dismantling (brown) are not directly related. Reactors in dismantling are between 32 years and more than 53 years old. Pending Japanese reactors in "ready-to-operate" status (red) range from 9 to 44 years.

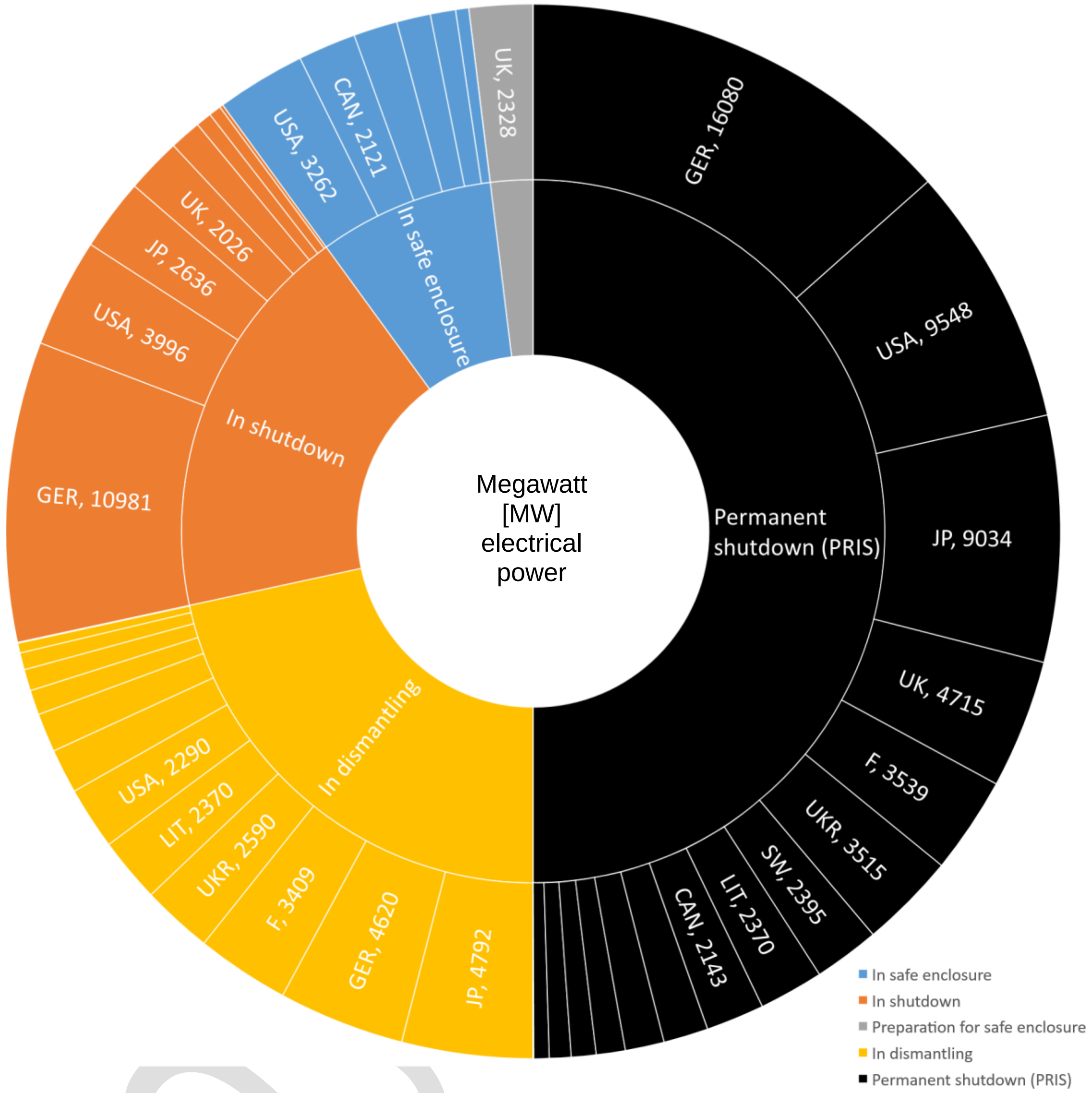

Figure 3: Comparison of nuclear reactors status according to existing PRIS category "Permanent Shutdown" (black) with the new, detailed breakdown of our dataset (coloured)[e].

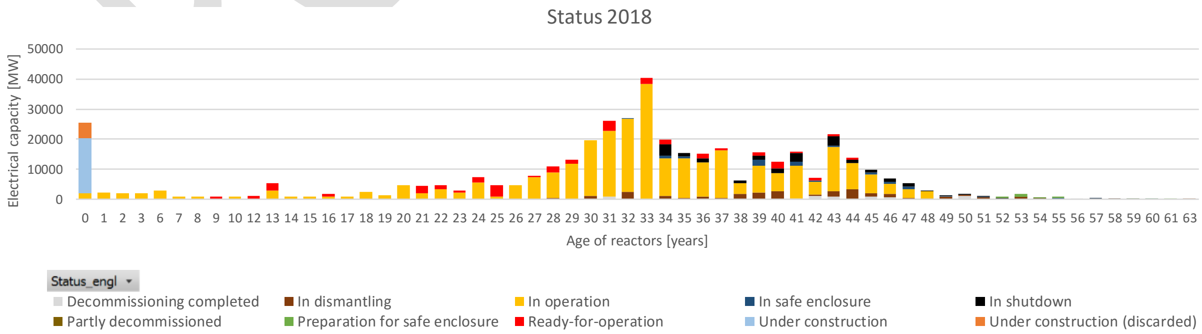

Figure 4: Status of nuclear reactors, electrical capacity [MW] and age [years] with further differentiation in the status description according to own reactor-level research (status: 2018)[f].

3.2 Scenario construction

As political decisions and other influencing factors and uncertainties of nuclear phase-out such as incidents, energy markets, individual power plant operator decisions or price structures are very diverse in the considered 18 countries, the scenarios in this study are kept rather simple. The scenario construction is based on three main parameters: the reactors' individual shutdown year, the post-operational phase duration and the dismantling phase duration. These parameters are varied to create five scenarios (see Table 4). In the following, for the five scenarios we either use available information ($S_{(shutdown,exp.)}$) or calculated the earliest, expected[22] and latest **shutdown date** per reactor according to national regulations.

Furthermore, the expected, projected direct dismantling or deferred dismantling start date per reactor was used when available (fixed and published), and determined when not. When unknown, the expected dismantling start was calculated by the $S_{(dismantling)} = S_{(shutdown,exp.)}$ + post-operational phase duration. The post-operational phase duration differs between countries (see Table 4) and also depends on the chosen decommissioning strategy. Thus, also the decommissioning strategy was researched for each reactor. If no reactor-specific information was found, we assumed the national standard values of operating time, usual shutdown time and national strategy and as the baseline in the respective country[23].

The post-operational phase and dismantling phase durations are assumed to be country-specific (see Table 4). However, when there was no national value available, literature values were used. Literature proclaims that the post-operational phase for the permanent shutdown and dismantling takes 1-5 years (Laraia, 2012, p. 118) or 2-3 years (Thierfeldt and Schartmann, 2012, p. 31) to remove the fuel assembly, operating medium and waste within the operating license of the nuclear power plant. A post-operational phase less than 2 years is not to be expected due to physical limitations of the radiation exposure and radiation

[22] This refers to the most probable or likely shutdown date but is not related to a certain probability.
[23] See Table 6, e.g. deferred dismantling for all nuclear reactors for 85 years in UK

absorption. The duration of this phase differs in the considered countries between 2 and 12 years. However, some countries do not distinguish the duration of the post-operational phase, but only denominate the total decommissioning duration. As only 21 nuclear facilities have been completely dismantled yet, for many countries literature are assumed to the dismantling phase duration (see Table 4).

Table 4: Country-specific scenario parameters [years][g]

	Post-operational phase duration [years]			Dismantling phase duration [years]		
	Expected	Minimum	Maximum	Expected	Minimum	Maximum
BE	5	5	5	10	9	11
BUL	10	8	12	10	9	11
CAN	0	0	0	10	9	11
CH	5	5	5	10	9	11
GER	5	5	5	10	9	11
ES	4	4	4	10	9	11
F	5	5	5	10	9	11
IT	5.5	5	6	10	9	11
JP	7.5	5	10	7.5	5	10
KOR	4	4	4	10	9	11
LIT	5.5	5	6	10	9	11
RUS	4	3	5	5	5	5
SLO	5	5	5	13	13	13
SW	1	1	1	10	9	11
TW	8	8	8	15	15	15
UK	10	10	10	10	10	10
UKR	5.5	5	6	10	9	11
USA	2	1	5	10	10	10
Average	**5.5**	**5**	**6**	**10**	**9**	**11**

Legend:		
	Light grey:	no country-specific information
	Zero values:	Phase included in operational phase
	4	Experience value from one reactor in the country

All scenarios can be seen in Table 5. Scenario 1 can be regarded as the baseline scenario as it combines the expected shutdown start with the moderate post-operational phase and dismantling durations. Scenario 3 with its assumed earliest shutdown and minimum post-operational and dismantling durations represents the earliest nuclear decommissioning, while

Scenario 5 can be considered as the latest decommissioning scenario. If no national values are available (see Table 4), default parameter values of Table 5 are used in the scenario calculation.

Scenario projections are calculated in two-year granularity until 2047. For the projections, we assume that reactors under construction in 2018 are in operation in 2023. With an expected operation life time of minimum 40 years, this will have no impact on the decommissioning projection but the number of reactors in operation might be slightly overestimated. And, we assume that current decommissioning projects will be finished by 2019.

Also, it is assumed that in 2019 the 37 pending ready-to-operate Japanese nuclear power reactors are either back in operation or in shutdown/post-operational phase according to their age. This fits to assumptions in the World Energy Outlook (IEA, 2014, p. 390). In Scenario 1, 33 reactors will be back in operation while 4 will be in shut down. This is a strong assumption, as a political decision for all 37 reactors in 2019 is not very probable. This underestimates the scenario results regarding the number of reactors in operation and in shutdown.

Furthermore, we assume that if the reactor dismantling is already (partly[24]) completed or reactors are in deferred dismantling (especially in the UK[25]) in 2018, their status is unchanged in later years. It is assumed, that all countries (except UK) follow the direct dismantling strategy[26].

At the moment, there are 28 reactors in safe enclosure[27]. Nuclear reactors in operation or in post-operational phase in UK in 2018 are assumed to follow the deferred dismantling strategy until 2047. In baseline Scenario 1, this affects 34 British reactors until 2047. Reactors in preparation for deferred dismantling in 2018 are assumed to reach that status 5 years later.

[24] This applies for Chinon A-1 and A-2 in France.
[25] Typically, enclosure times range between between 60 and 80 years.
[26] In USA, principally direct dismantling, safe enclosure with max. 60 years and entombment are feasible decommissioning alternatives (Nuclear Energy Institute, 2016). However, direct dismantling is the preferred strategy applied in the scenario analysis.
[27] USA (11 reactors), Germany (2 reactors), Japan (5 reactors), Sweden (3 reactors), Switzerland (1 reactor), Canada (5 reactors) and Ukraine (1 reactor).

Table 5: Scenario construction and its related parameter values

Scenarios	Start of shutdown (on reactor-level)	Scenario parameters Post-operational phase durations (on national level)	Dismantling phase durations (on national level)
Scenario 1 *(expected / baseline development)*	Expected start date	Moderate duration (5.5 years*)	Moderate duration (10 years*)
Scenario 2 *(intermediate scen1/scen3)*	Expected start date	Minimum duration (5 years*)	Minimum duration (9 years*)
Scenario 3 *(earliest decommission)*	Earliest start date	Minimum duration (5 years*)	Minimum duration (9 years*)
Scenario 4 *(intermediate scen1/scen5)*	Expected start date	Maximum duration (6 years*)	Maximum duration (11 years*)
Scenario 5 *(latest decommission)*	Latest start date	Maximum duration (6 years*)	Maximum duration (11 years*)

*: default value, if no national value (see Table 4) is available

3.3 Scenario analysis results

Real and projected number of nuclear reactor shutdowns per year show an increasing trend (see Figure 5). The figure includes the slowly increasing floating average over three periods both for the already occurred (blue dotted line) and projected permanent shutdowns (orange dotted line). Today, ca. 26 GW_e of nuclear power reactors are in dismantling phase (see Figure 6). By 2027, 37-86 GW_e will be dismantled in Scenarios 1, 2, 4, and 5. The dismantled electrical capacity in 2027 ranges from 37 to 142 GW and in 2037 from 71 to 184 GW. Largest deviation occurs in Scenario 3 with the earliest start date of reactor decommissioning. By 2037, this will sum up to 71-105 GW_e exceeding 25% of installed capacity in all scenarios (see Figure 7). In Scenario 3 (earliest decommissioning), by 2037 up to 50% of todays' installed electric power capacity will be dismantled or in dismantling. In 2047, in Scenarios 1, 2, 4 and 5 ca. 75 to 100 GW_e will be decommissioned. In Scenario 3, this number is almost twice as high. By 2047, in Scenario 1 (baseline) the level of nuclear power capacity in operation will reduce considerably from 339 to 80 GW_e and the share of power reactors in dismantling will increase and stay on a certain level (nuclear dismantling market volume) of 75-85 GW_e until the mid-2030s (see brown band in Figure 6).

Highest country-specific market potential can be seen in the USA (light blue), Japan (orange) and Germany (grey) (see Figure 8). The dismantling market volume [installed electrical capacity in MW] is shown per country and sorted according to the cumulated sum of dismantled megawatts. Largest markets are depicted in the bottom of the figure. This is USA (rank 1, light blue), Japan (rank 2, orange), Germany (rank 3, grey), Ukraine (rank 4, yellow), Korea (rank 5, blue), Taiwan (rank 6, green), UK (rank 7, darker blue) and Spain (rank 8, maroon). While in USA and Japan the dismantling market increases continuously until the beginning of the 2040s, in Germany the market is limited to the complete decommissioning of its total reactor stock in 2037. Furthermore, an intermediate peak around 2040 and a following kink or at least a stagnation of the total nuclear dismantling market are expected.

The rise of decommissioned reactors between 2018 and 2019 in Figure 6 and Figure 8 is based on the assumption that current decommissioning projects will be finished by 2019. However, this might not be the case. Instead, the real number of completely decommissioned reactors will increase more slowly probably until the mid-2020s.

Further country-specific results regarding the decommissioning market conditions and regulations are described in section 4.

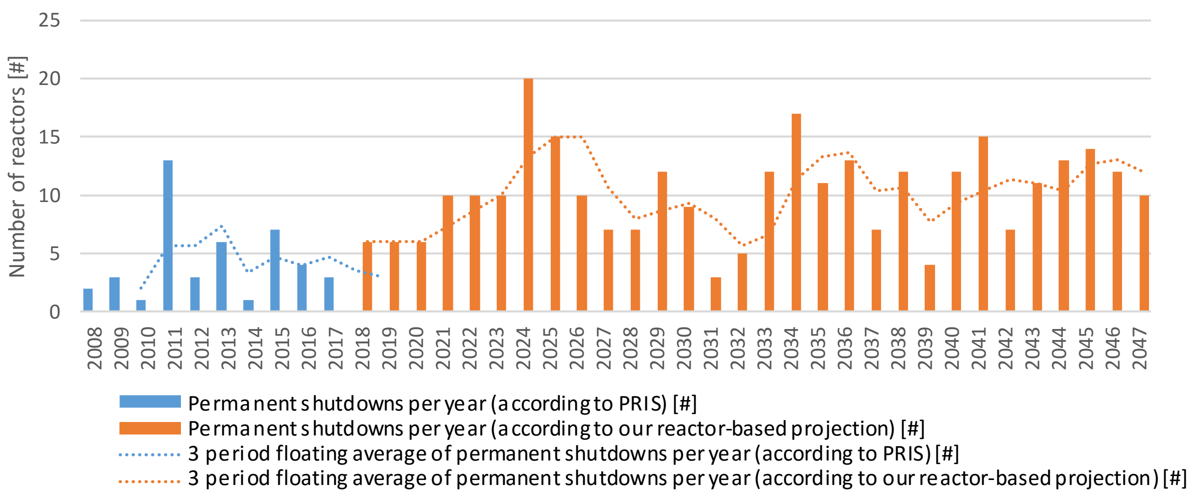

Figure 5: Permanent nuclear reactor shutdowns per year (blue: [h], all PRIS countries) and future nuclear reactor shutdown projection per year (orange:[i], considered 18 countries).

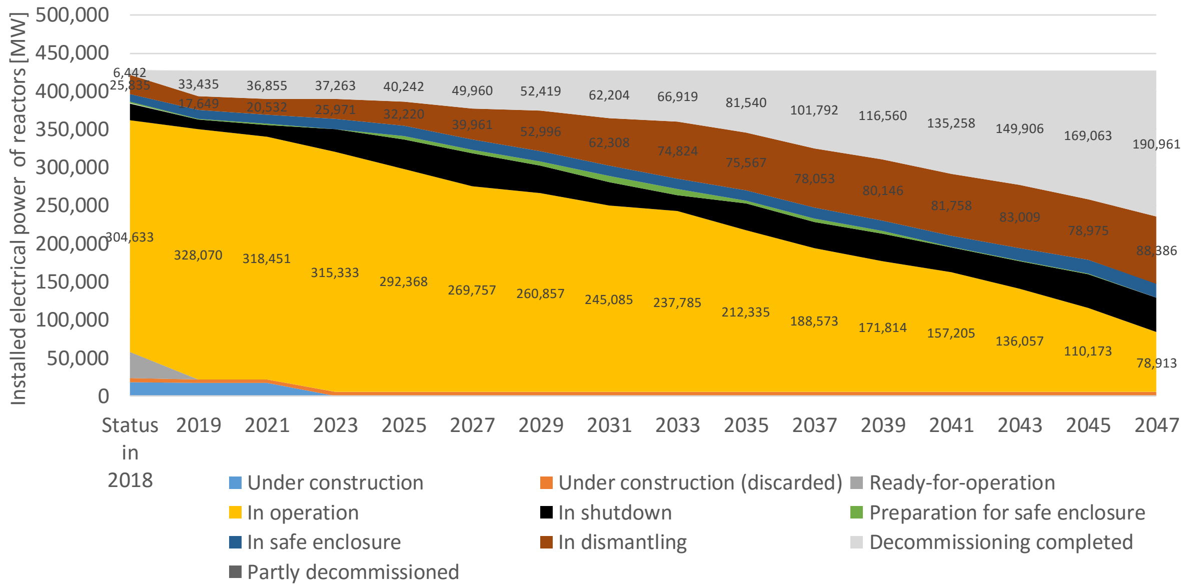

Figure 6: Projected status of nuclear power reactors in Scenario 1[28]

[28] Scenario 1 is calculated with expected shutdown dates on reactor-level, a moderate country-specific post-operational phase duration (default: 5.5 years) and a moderate country-specific dismantling duration (default: 10 years) [cumulated installed MW].

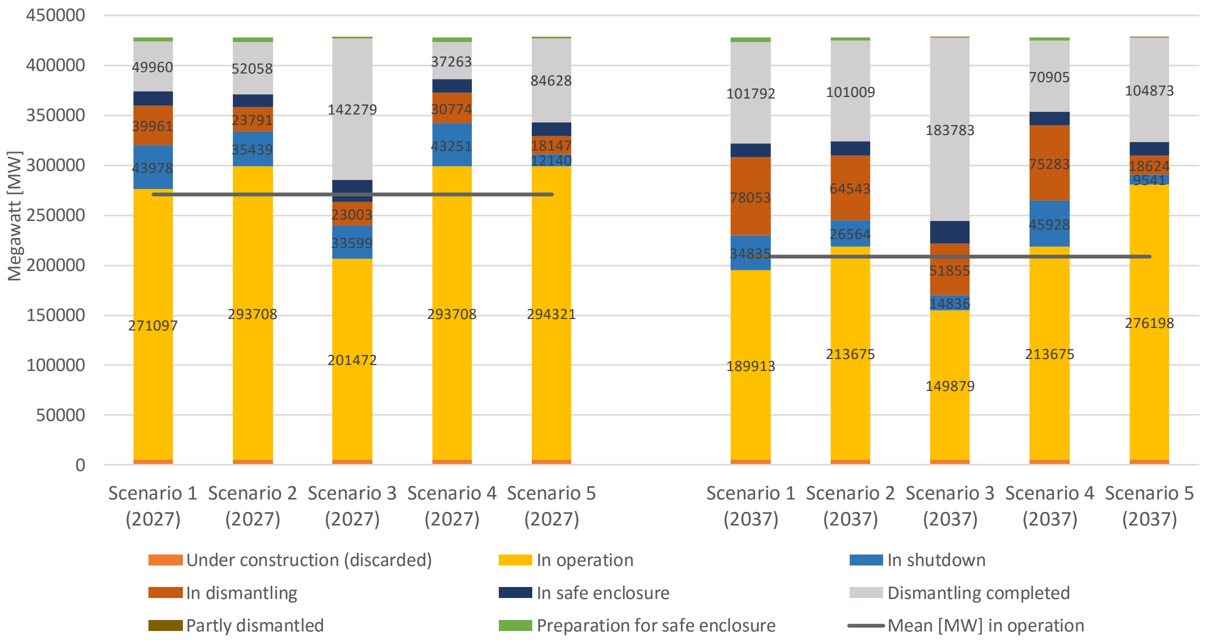

Figure 7: Projected status of nuclear reactors in five scenario projections for 2027 and 2037 with the mean installed megawatt of the power reactors in operation (black line)[29]

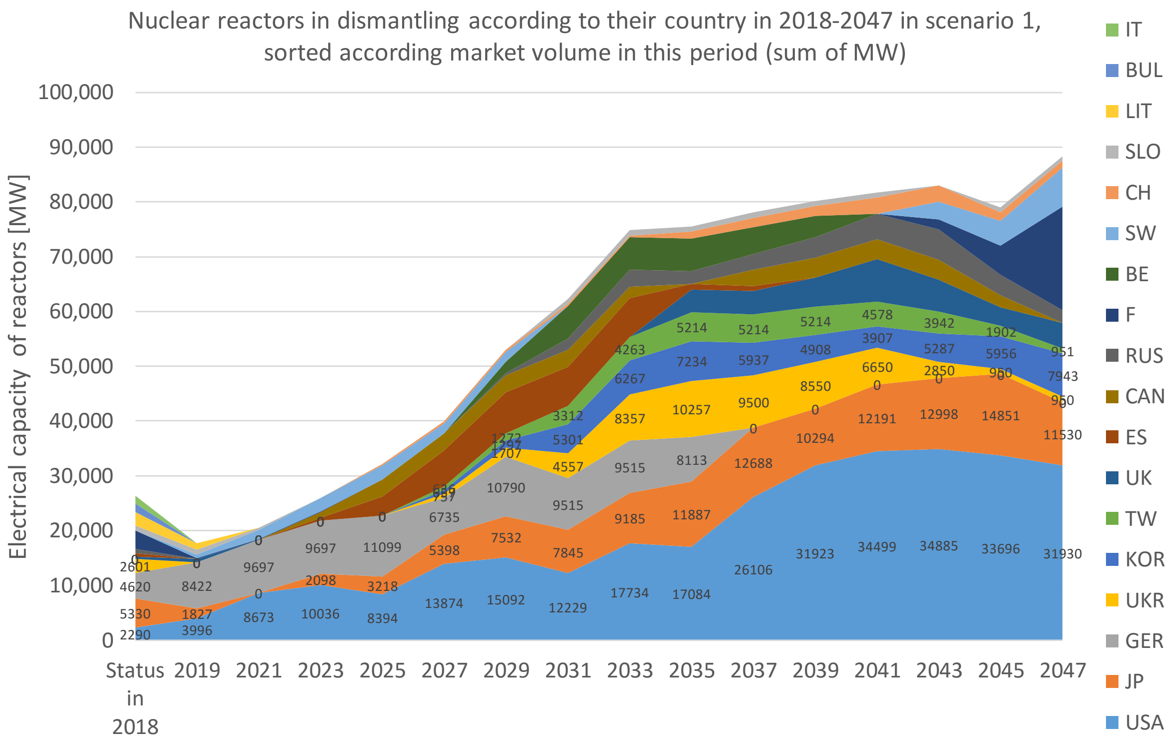

Figure 8: Nuclear reactors in dismantling in 2018 and projected for the period 2019-2047 (according to Scenario 1).

[29] Scenarios are calculated with with country-specific dismantling durations (default: 9,10, or 11 years) and country-specific post-operational phase durations (default: 5, 5.5, 6 years) (see Table 5).

3.4 Comparison to existing studies

Future nuclear energy scenarios are described in several studies on international and national levels (e.g. IEA, 2014; OCDE/IEA, 2017). Existing studies (IEA 2014, OECD/NEA 2015 and 2016, Wealer et al. (2015), IAEA 2016a) see massive nuclear shutdowns, but only mention single dismantling activities in some countries or state the current status of reactors in permanent shutdown or in decommissioning without future projection (IAEA (2016a), p. 54-58).

WNN states that “to date, over 110 commercial power reactors, 48 experimental or prototype reactors, over 250 research reactors and a number of fuel cycle facilities have been retired from operation” (WNN, 2017). This does not reflect the 166 PRIS reactors that are currently in permanent shutdown. And, projections are not provided by WNN.

According to OECD/NEA projection, by 2019 eight reactors are planned to be retired including 2 reactors in Germany (2.7 GW_e), 2 in Sweden (1.6 GW_e), 3 reactors in USA (2.1 GW_e) and 1 in Switzerland (with unknown capacity) (OECD/NEA 2016, p.21) (OECD/NEA, 2015). This contradicts our projection of 9[30] nuclear reactors that will be shut down in 2019.

In the US, OECD/NEA (2016) projects a constant nuclear power production (ca. 780 TWh/year) and installed electrical power capacity until 2035 (OECD/NEA, 2016, p. 16-19). In Canada, until 2025 about 40% of the installed capacity is shutdown (from 14 to 8.4 GW_e). A refurbishment of 10 Canadian reactors is envisioned, but only a single decommissioning is reported (OECD/NEA, 2016, p. 43). In France, between 2025 and 2035 the installed capacity might shrink by up to 50% from 63.2 to 37 GW_e, strongly depending on pending political decisions. OECD/NEA summarise French decommissioning activities by facility operators and not by reactors. This makes it hard to track the decommissioning market potential and progress (OECD/NEA, 2016, p. 54).

[30] This includes: CHINSHAN-1, CLINTON-1, FITZPATRICK, OHI-1, OHI-2, PALISADES, QUAD CITIES-1, QUAD CITIES-2, TOKAI-2.

For Canada, USA, Ukraine and France, no detailed information is given on future reactor shutdowns. OECD/NEA (2016) and Wealer et al. (2015) further detail the nuclear phase-out by 2025 and decommissioning situation in Belgium and Germany. For Switzerland, Japan and Korea no projection of future nuclear power generation is given. The decommissioning in Ukraine is not mentioned in OECD/NEA (2016), where we project 15 reactors to be decommissioned in the considered time frame. And for Russia, only the decommissioning of Novovoronezh 1 and 2 is mentioned (OECD/NEA, 2016, p. 60), while we project 27 reactors to be dismantled until 2047.

In the World Energy Outlook of OECD/IEA, the nuclear retirements are considerably with around 150 GW_e (ca. 200 reactors, 44% of the fleet) in the period to 2040 which is equivalent to 38% of the current capacity (OECD/IEA, 2014, p. 388) with the vast majority in Europe, the United States, Russia and Japan (IEA, 2014, p. 27). And, IEA sees an acute challenge to replace the shortfall in generation especially in Europe (IEA, 2014, p. 27).

However, the report only roughly estimates the closure reactors for 8 countries/regions only by the reactors' age, particularly in the European Union, Russia, Japan and United States (OECD/IEA, 2014, p. 387f.). However, a projection for single reactors is not given. According to OECD/IEA the rate of retirements picks up in the first half of the 2020s and then again in the late 2030s (OECD/IEA, 2014, p. 388).

In contrast, according to our projection the dismantling market volume highly increases between 2020 and 2030 and stagnates between 2030 and 2045 on a high level (see Figure 8). In the period to 2040, decommissioning costs of more than $100 billion with considerable uncertainties are estimated by (OECD/IEA, 2014, p. 27f.). After 2045, our projection indicates a further market increase. Also, OECD/IEA mentions a potential strategy shift to deferred dismantling due to capacity bottlenecks in expertise and dismantling equipment (OECD/IEA, 2014, p. 388).

4. Country specific detailed information

The market analysis was complemented by research and compilation of specific national guidelines, national nuclear authorities' regulations on safety, radioactive waste and storage, technical requirements, national energy policies and main decisive criteria that affect nuclear retrofitting and prolongation of operational time, service times, shutdown, direct and deferred dismantling (see Table 6). The table shows the national nuclear power supply shares, the technical operating life times, the regulations and the decommissioning strategies in the considered countries including references. Due to political decisions, Italy and Lithuania have no reactors in operation left. Thus, they have a sum of installed power capacity of 0 GW_e.

Operating life times range from 20 years (UK) to 50 years (Sweden). Prolongation based on retrofit measures range from 0 (Germany), to 30 years (Russia, Canada) and 40 years (USA[31]) (WNA, 2016p). Since in most countries deferred or direct nuclear dismantling projects have not been completed yet, information on dismantling durations is often rare or based on estimations.

[31] Twice prolongation by 20 years is currently discussed in the US.

Table 6: Main criteria of nuclear decommissioning affecting nuclear retrofitting and prolongation of operational time, service time shutdowns, direct and deferred dismantling in 18 industrialised countries with a large proportion of nuclear power generation

Country	Sum of installed power capacity	Total sum of electricity supplied by nuclear power plants and nuclear share of	Normal operation duration	Possibility of prolongation of operation	Prolongation of operation	Duration of post-operational phase	Possibility of deferred dismantling	Duration of deferred dismantling	Planned duration of direct dismantling	Source / Reference
	[GW_e]	[TWh]	[years]	[yes/no] [times]	[years]	[years]	[yes/no]	[years]	[years]	
Belgium	5.913	24.8 (37.5%)	40**	Yes, (preferred is 1x)	10	5	Yes, but not probable	No information	No information	European Commission, 2016b, p. 32; Kennes et al., 2008;WNN, 2014
Bulgaria	1.926	14.7 (31.3 %)	30	Yes, 1x	30	8-12 (for first 2 reactors)	No information	No information	No information	European Court of Auditors, 2016; Schneider et al., 2016, p.199
Canada	13.524	95.6 (16.6%)	25	Yes, 1x	30-35	No information (included in operation phase)	Yes, preferred strategy	30	No information	Bruce Power, 2016b; IAEA,2015; OECD and NEA,2015, p.39; Schneider et al.,2016, p. 121
France	63.13	419 (76.3%)	not predetermined, 10-yearly review	Yes, 1-5x	10 (each prolongation), max. 60 years of operation	5	Yes, but not prefer-red	No information	No information	ASN, 2016, p. 459; EU Commission, 2016b, p.32; Schneider et al., 2016;Ternon-Morin and Degrave, 2012;WNA, 2016f
Germany	10.799	86.8 (14.1%)***	40	No	0	5	Yes, but only applied in 2 experimental reactors	No information	No information	IAEA,2015; Laraia, 2012; RWE, 2016; Wealer et al., 2015, p.52
Japan	40.3, 2.538 GW (after Fukushima)	4.3 (0.5%)	40	Yes, 1x	20	5-10	Yes	5-10	3-4	IAEA, 2015; OECD and NEA, 2011a, p.3;Schmittem, 2016, p.5; Schneider et al., 2016, p.149

[32] Source: IAEA, 2016

Italy	0	0 (0%)	-	No	0	No information	No	0	No information	WNA 2016c; IAEA 2015; SOGIN 2016a-d
Lithuania	0	0 (0%)	No information	No information	No information	No information	No information	No information	No information	European Court of Auditors, 2016; WNA 2016i; IAEA, 2015
Russia	26.557	182.8 (18.6 %)	30	Yes	15-30	3-5	Yes, both versions applied	No information	5	Ananiev et al., 2015, p.10; IAEA,2015
Slovakia	1.814	14.1 (55.9%)	30	Yes, 1x, (linked to EU membership)	0	5	No	0	13 (incl. shutdown, but already delayed)	European Court of Auditors, 2016; IAEA,2015; WNA 2016k
South Korea	23.073	157.2 (31.7%)	30 (Wolsong 1, Kori 1), 40 (others)	Yes, up to 2x	10 (each prolongation)	4	No information	No information	9+2	Hyung, 2013; IAEA, 2004, p.15,51; Joo Hyun Moon, 2013, p.421; KHNP, 2016; Schneider et al., 2016, p. 168
Spain	7.121	54.8 (20.3%)	40*	Yes, no information on the number of times	10 (each prolongation)	No information (Jose Cabrera 1needed 4 years)	Yes, but not preferred	Until 2028 (38 years) for a single reactor	No information	European Commission, 2016b, p.32 ; IAEA, 2015; Schneider et al.,2016, p.190
Sweden	9.486	54.5 (34.3%)	40-50	Yes	10-20	1	Yes, applied in two cases but not preferred	Unclear, dismantling is permitted only when a final storage is ready	No information	Ake Anunti et al., 2013, p. 97;Barsebäck, 2016 ; IAEA, 2015; Larsson et al.,2013, p.94; Oskarsson, 2016, p.13;SSM, 2008 ; WNA, 2016d
Switzerland	3.333	22.2 (33.5%)	Un-limited***	No, but adherence to safety regulation required	0	5	No information	No information	No information	BWK,2016; FAZ,2016; IAEA,2015; Schneider et al., 2016; WNA, 2016n
Taiwan, China	5.214	(16%) (2016)	40	No	0	8 (for first reactor Chinshan 1)	Not for Chinshan 1, no information for the other reactors	No information	15 (for Chinshan 1)	Nuklearforum Schweiz,2011; Taiwan Power Company, 2014; WNA, 2016q

UK	8.883	63.9 (18.9%)	20 (design life time) with periodical reviews[33]	Yes, up to 4x (but not for the older gas-cooled reactors)	10 (each prolongation)	10 (PWR, gas-cooled)	Yes, deferred dismantling is the main strategy used	85 (gas-cooled reactor)	10 (PWR), no information for gas cooled reactors	Bryers and Ashmead (2016), p.3;12;Dep. for Business, Energy & Industrial Strategy, 2016, p. 121; EDF Energy,2016 ; IEA/NEA, 2015, p.25; NDA, 2016b, p.30;Schneider et al.,2016, p.193
Ukraine	13.107	82.41 (56,5%)	30 (e.g. Rovno 1+2)	Yes	10-20	No information	Yes (Chernobyl)	No information	No information	IAEA, 2017a, p.19, Table 6; Schneider et al., 2016,p.21f., 233 (Annex 8), IAEA, 2016b,c; Kilochytska, 2009
USA	105.403	798 (19.5%)	40	Yes, 1(-2)x[34]	20	2 (or 1-5 dep. on source)	Yes	60 years: max. 50 years waiting time and 10 years dismantling duration	10	NRC, 2016a; Nuclear Energy Institute, 2016; OECD and NEA,2015, p.59; Reid and McGratz, 2016, p.2; Schneider et al., 2016, p.33; WNA, 2016p

*: This was deleted in 2011 from the law so that currently the Spanish government can decide on the operation duration.

**: Changed in 2014 to maintain national power supply in Belgium

***: Limitations for specific reactors are proposed by the Swiss government

****: 133TWh in 2010 before Fukushima

However, besides the listed criteria in Table 6, there are further national specific restrictions and constraints that are described in the following:

In the **USA**, the direct nuclear dismantling is pursued by governmental policy. But, if there is another operating reactor onsite, the direct dismantling of the shutdown reactor is delayed until

[33] „Design life was originally 20 years, but most run for at least twice that period." (WNA, 2016b)
[34] Proposals for 80 years of operation are already intended (NRC, 2017).

all active reactors on the site are shut down. If the dismantling of several reactors on a site is planned within 5 years, the reactor is assumed to remain in the shutdown/post-operational phase until the joint dismantling starts. Otherwise, a deferred dismantling is assumed for all shutdown reactors that are waiting for the shutdown of all reactors in operation on the same site. In the USA, deferred dismantling and direct dismantling have to be completed within 60 years after shutdown (Nuclear Energy Institute, 2016).

In **France**, the *Energy Transition for Green Growth Act* defines the energy policy of the coming years including the increased power of *Autorité de sûreté nucléaire* (ASN), the stricter regulation of reactors older than 35-40 years and more transparency (Schneider et al., 2016, p. 178). Initially, nuclear power capacity should be restricted to the current level and nuclear power generation share should have been reduced to 50 % by 2025 (Fischer, 2015). But, the new Macron administrative announced that this goal might not be reached by 2025 (Schneider et. al., 2017, p. 44). Although stricter regulation of old reactors is proclaimed, retrofits and prolongations of reactors' operational times seem probable (WNA, 2016f). Recent announcements from EDF and the IAEA indicate lifespan extensions of French nuclear 900 MW fleet up to 50 years (IAEA, 2017b). A recommendation from the ASN about possible lifetime expansions is expected to be given in 2020/2021 (reuters, 2018). In France, there is also the anomaly that the regulatory and technical ages of the reactors differ due to the regulatory approval process (Marignac, 2015). And, all reactors that have not been in operation for 2 years (in exceptions up to 5 years) are considered as shutdown reactors that have be dismantled (ASN, 2016, p. 459).

In **Japan**, the Fukushima accident changed the nuclear energy policy dramatically and currently 42 of 62 reactors (~70%) are in operation (IAEA PRIS). However, only five reactors (7.9%) actually provided power to the grid in 2017 (Schneider et al., 2016, p. 149; IAEA, 2016a, Schneider et al., 2017, p. 56), e.g. due to economic reasons and new and tightened safety regulations. 37 still await the political decision on re-start/operation versus decommissioning.

In **Russia**, five of 48 nuclear power reactors are in dismantling. Reactors are legally authorised for retrofits for a prolongation (status: 2016), but require considerable investments (WNA, 2016j; IAEA, 2015). The operation times are very reactor-specific – expected is be 45 years but some are already licensed for 60 years (Rosatom, 2014, p. 108). Especially when it comes to graphite reactors, a partly deferred dismantling is a viable way and has to be decided facility-wise (Izmestev, 2015). The prolongation times for Russian nuclear power reactors vary between 15 (BWR) and 30 years (PWR) (Nuclear Engineering International, 2016). For this study, the operation durations are assumed to be between 45-60 years (without a prolongation, status: 2016). Therefore, in the coming years, especially BWR have to be dismantled, before the decommission of a larger number of PWR. In Russia, only shutdown dates are known, but no national plans for nuclear decommissioning are published, yet.

In the **UK**, the government sees nuclear power generation as a main contribution to greenhouse gas emission mitigation and reduction by 2050. Consequently, the UK plans to decarbonise the energy sector by the installation of additional 16 GW_e of nuclear power by 2023 (IAEA, 2015) together with the prolongation of the operation times of existing reactors. In recent years, 30 nuclear reactors were shut down and are in different stages of decommissioning[35]. The remaining 15 commercial reactors will be shut down until 2030 (WNA, 2016o). However, the expected costs are more than five times higher than for light-water reactors due to the high masses of radioactive material (WNA, 2016b) and raise the pressure on radioactive waste storage in the UK.

In **Germany**, after the Fukushima incident in 2011 the German government decided the nuclear phase-out until 2022. Consequently, the remaining operating times and power volumes supplied by all German nuclear reactors are regulated. German reactors have originally been planned to operate for 60 years (Zink, 2013), but will be shut down at an average age of only 25.5 years (oldest reactor: 37 years). The dismantling phase is assumed to take place over

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[35] 4 reactors: direct dismantling; 16 reactors: deferred dismantling; 10 reactors: in shutdown (status: 2018).

several decades and very differing durations are assumed (Thierfeldt and Schartmann (2012), Wealer et al. (2015)).

In **South Korea** (similar to the UK), the future of energy supply is seen in nuclear power generation and an increase of installed nuclear electric capacity is planned in the coming years (Hyung, 2013; IAEA, 2004; Joo Hyun Moon, 2013; KHNP, 2016; Schneider et al., 2016).

In **Canada**, the *long term energy plan* (IAEA, 2015) prescribes the re-tubing/refurbishment of several reactors to prolong their operation times beyond the planned operation time of 25 years. For reactors that remained for over 30 years in the status of deferred dismantling, no information on their provisional dismantling start could be researched.

In **Sweden**, an energy production transition to 100% renewable energy in 2040 is pursued by the government, but a fixed nuclear shutdown date is not yet defined (WNN, 2016b). The decision on the prolongation of the operation times seems to be strongly linked to the profitability of the refurbishments/ investments and the availability of final storage capacity for radioactive waste. Except for two reactors, deferred dismantling of Swedish reactors is not envisioned. In Sweden, no dismantling will start before 2020 due to a lack of a final storage for radioactive waste (SSM, 2008; Barsebäck, 2016).

In **Spain**, the government aims at ending nuclear power generation and pursues investments in renewable energies (IAEA, 2015). They abolished the 40-years of reactors lifetime in 2011 (Schneider et al., 2016) and most operational licenses (6) end in 2020/2021 (WNA, 2016m; IAEA, 2004). The national strategy is the direct dismantling of the reactors[36], (European Commission, 2016b). Spain is a very attractive market, because by 2024 all reactors will be shut down. Since Spain is aiming for direct dismantling, this process will start in 2024 / 2025 (3 reactors each year) and 2028 (2 reactors) assuming a post-operational phase of 4 years like for Jose Cabrera 1.

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[36] except for reactor Jose Cabrera 1 that had been put into deferred dismantling in 1990 and will also be dismantled in 2028 (European Commission, 2016b).

In **Belgium**, the share of nuclear power generation is comparably high (37.5%) and the 7 operating reactors were intended to operate for 40 years at maximum. However, due to the legally decided phase-out in 2025 and potential blackouts, the government decided to increase the maximum operation time for three reactors by 10 years to secure national power supply (European Commission, 2016b; Kennes et al., 2008; WNN, 2014). The decommissioning market is rather small but the political decision provides planning security.

In **Lithuania**, **Bulgaria** and **Slovakia** nuclear reactors had to be partly shut down in the course of their EU accession and membership. In **Lithuania**, both reactors are already shut down, but a decommissioning approval is still pending. In **Bulgaria**, four reactors are already shut down and two will remain in operation until 2047 and 2051. In **Slovakia**, three reactors are already in the decommissioning process and two new reactors are under construction. Lithuania and Italy are both listed in Table 2 with 0 GW_e because their nuclear power reactors are shut down.

In **Switzerland**, only for the reactor Mühleberg plans for direct dismantling are available starting in 2019 (BWK, 2016). For the other power reactors, no plans are publicly available. Referendums declined an early leave of the nuclear power generation and confirmed an unlimited operating life of the reactors under the condition to adherence to safety regulations (Schindler, 2014; UVEK, 2017).

In **Taiwan**, after the Fukushima incident in 2011 the government decided to exit nuclear power generation by 2025, which was again confirmed in 2016 (Nuklearforum Schweiz, 2016) and approved by the Taiwanese parliament in 2017 (Anon, 2017).

5. The future nuclear dismantling markets

In total, Germany, Belgium, Taiwan, Spain, Italy, Lithuania, and Sweden decided on a nuclear phase-out. By 2047, 225 GW_e of todays' operating reactors power capacity in the considered countries will be in decommissioning and has to be substituted. The main nuclear decommissioning market potential in the next 10-30 years is located in the USA, Japan and

Germany with a high electrical capacity to be decommissioned (see Figure 6, Figure 8, Figure 9, annex Table B). In Figure 9, the shown status categories are grouped and their timely development between 2018 – 2047 can be seen from left to right per equally coloured bars[37].

In Germany, 17 reactors in operation and post-operational phase and the currently 13 reactors in dismantling phase will be dismantled completely in 2037 (capacity reduction by 9.5 GW_e, -100%). In Japan, a capacity reduction by 36 GW_e is projected (-91%). The Japanese market strongly depends on the political decisions to restart or decommission the pending reactors. In 2016 and 2017, only 2-3 political decisions were made annually (source: IAEA PRIS). In the USA, until 2047 55 nuclear reactors will be dismantled and from the currently 99 only 18 will remain in operation (capacity reduction by 86 GW_e, -81%). In the USA, a high and constant market potential is expected while in Germany a limited market volume and a high planning security is dominating.

Furthermore, Ukraine (15 reactors), Spain (7 reactors), Sweden (8 reactors) and Canada (11 reactors) are interesting smaller markets in the next years. Staring from 2030, market potential in Belgium (8 reactors) and Switzerland (5 reactors) is on the rise. Later starting from 2040, nuclear decommissioning will affect France. In France and the UK, there are no legally binding limits of operation durations, but periodical reviews by authorities (every 10 years) and prolongation proposals for a subsequent operation period (France: 20 years, UK: 10 years). This makes it difficult to assume expected reactors life times and to determine their decommissioning start.

[37] For underlying data for all countries see Annex, Table B.

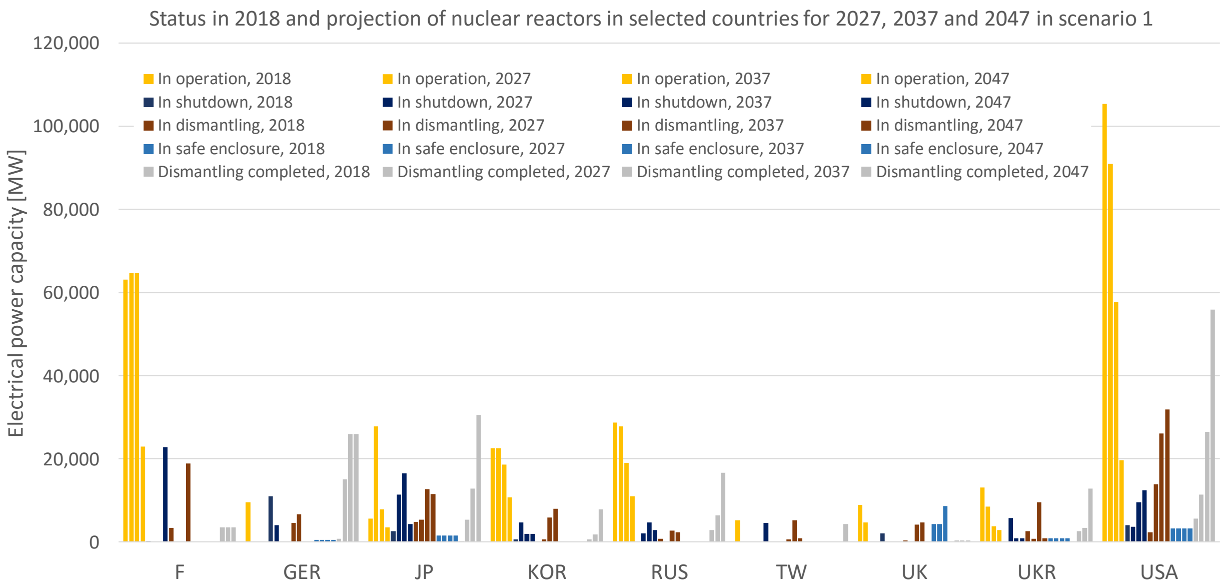

Figure 9: Current and projected status of nuclear power reactors in 2018, 2027, 2037 and 2047 according to Scenario 1 and shown for selected countries [electrical capacity in MW].

USA: In the USA, there is the highest market potential for nuclear decommissioning (IEA/NEA, 2015, p. 36). By 2027, there will be 17 reactors shut down and subsequently dismantled in the USA. The affected reactor types will be BWR (especially until 2026) and PWR. The highest numbers of nuclear power reactor shutdowns in the USA can be expected starting from 2023, if there won't be a considerable number of prolongations[38] of the operational times. Considering possible prolongations, in the next 10 years only 12 instead of 17 reactors will be shut down (baseline scenario). Nevertheless, the dismantling market in the USA is very attractive due to a low variability in reactor types (offering synergy effects) and an expected high continuity of shutdowns in the coming years and decades. Recent shutdowns and stable power generation shares showed that increased performances and upgrade are still able to compensate nuclear shutdowns (OECD and NEA, 2015, p. 59; Schneider et al., 2016, p. 126). In the future, only few new constructions are planned, but operation time prolongations up to

[38] The U.S. Nuclear Regulatory Commission (NRC) continues to prolong the operating times for 20 years to a total operating time of 60 years (81 approvals and 12 requests) and investigates about a total operating time of 80 years.

80 years are considered to avoid blackouts. Due to high competition in the energy sector in the USA, nuclear power plants face shutdowns due to economic reasons prior to their end licensed operation time. This affected recently[39] and will affect future shutdowns. But, market barriers have to be further investigated for a potential market entry.

Japan: High safety standards and pending political decisions on the future national energy policy and nuclear waste treatment and disposal are highly influencing the Japanese decommissioning market in the next years. In total, between 8 and 11 reactors will be shut down in the near future, amongst others Fugen, Fukushima-Daiichi 1-6, Genkai 1, Hamaoka 1+2, Mihama 1+2, Shimane 1, Tokai 1 and Tsuruga 1 (Plewnia, 2016, p. 15; Schmittem, 2016, p. 37). Furthermore, the technical efforts are higher, e.g. compared to French reactors, due to a comparably high variety of installed reactor types. The Japanese nuclear decommissioning market is young as decommissioning experiences only consist of experimental reactor JPDR and the nuclear hazard measures at Fukushima reactors. A market entry for highly specialised companies seems promising (Schmittem, 2016, p. 83).

Germany: In Germany, nuclear-phase out caused 10 reactors to be shut down and the remaining 7 operating reactors to be shut down by 2022 (11 PWR, 6 BWR). As the shutdown dates are already determined and legally binding, the dismantling can be clearly planned to start 5 years past the shutdown date (Laraia (2012)). This makes the German (and Swedish) nuclear decommissioning market very attractive[40], because the market conditions are predictable compared to other countries like Belgium, Japan or France where political decisions on retrofits, prolongations and nuclear decommissioning are still pendant.

[39] Recently shutdown US reactors are Fort Calhoune 1 in October 2016, Clinton in 2017, two reactors at Quad Cities in 2018 (Schneider et al., 2016, p. 131), FitzPatrick in January 2017, Pilgrim in May 2019, Oyster Creek in 2019 (U.S. Energy Information Administration, 2016), Diablo Canyon 1 and 2 in 2024 and 2025 (Schneider et al., 2016, p. 135) and Palisades in October 2018. Also reactors Ginna and Nine Mile Point 1 are on the verge of being uneconomic (Schneider et al., 2016, p. 133).

[40] See Thierfeldt and Schartmann (2012) as well as Wealer et al. (2015) for further analyses on the German market.

Important policy implication for the high number of reactor shutdowns and considerable reduction of base load power generation capacity in the next years and decades are the need for substitution by other power plants, power imports or energy savings. This will have great impact on national electricity markets. Here, the study results indicate the pace of substitution needed. Due to the large scale of reactor shutdowns by 2047, the results of this study implicate a need for technology innovations and large investments either in reactor refurbishments, alternative power plants or energy systems and infrastructure.

Also, this requires professional staff and expertise both in administration, national licensing authorities and industry to deal with the increasing number of decommissioning authorisations and permits in USA, Germany or Japan. Also, increasing decommissioning activities provide a growing market for jobs, business opportunities and margin supporting the respective national construction, demolition and recycling industries. Furthermore, specialised companies can take strategically advantage of different decommissioning markets, ongoing and increased research in the related fields of nuclear decommissioning technology and management.

During and after dismantling, there is a need for final storage of radioactive nuclear waste. Pending decisions on nuclear decommissioning (e.g. in Japan) and the waste treatment, disposal and final storage of increasing activated waste fractions from decommissioning projects are needed and already lead to delays in decommissioning (e.g. Sweden, Japan) or to costly intermediate storages. With the timely development of nuclear dismantling, the study shows the increasing pressure on governments to establish safe storage and sufficient container capacities for radioactive material.

Furthermore, management of stakeholders such as public, non-governmental organisations and local communities can early be included in final storage negotiations and preparation. And, governments and stakeholders can take strategically advantage of the study results by establishing strategic alliances to increase capacity utilisation, exchange expertise and shift resources. Also, documentation and exchange on best practices of current nuclear decommissioning projects could create a valuable experience database to reduce uncertainty in planning of future projects. This might enable governments to better project the timely development of expenses and investments in dismantling activities.

6. Conclusion

6.1 Summary

Nuclear decommissioning is increasing and raise questions on future energy supply, decommissioning management and final disposal capacities. Therefore, a detailed future projection on nuclear decommissioning is needed. But, no detailed projections on nuclear decommissioning markets are known to the authors. Thus, we extended the PRIS database by an extensive desk-based literature research to gain further insight regarding the decommissioning and dismantling status of nuclear reactors worldwide. Therefore, we investigated and analysed data for 540 reactors in 18 countries. Based on the extended dataset and a scenario analysis, we identified reactors that will be shut down, dismantled (directly or deferred) or put in safe enclosure until 2047. To do so, we used the earliest, the expected and the latest shutdown date per reactor, as well as country-specific post-operational and dismantling phase durations.

We found that in 2018, 36% of the reactors' capacity in "permanent shutdown" (PRIS) is in shutdown, 43% is already in dismantling, 16% is in safe enclosure and 5% is in preparation for it. By 2047, the currently installed and operating electrical capacity of nuclear reactors in the considered countries reduces considerably from ca. 339 GW_e[41] in 2018 to ca 80 GW_e. The expected market volume is rising in the next years until the mid-2030s from currently 25 GW_e to ca. annual 75-85 GW_e of nuclear reactors in dismantling. After 2045, a further increase in market volume is projected.

[41] incl. pending Japanese reactors

Main dismantling markets in the next decade are expected to be in the USA, Japan and Germany, later followed by France. In the USA, by 2047 55 nuclear reactors will be dismantled comprising a capacity reduction by 86 GW (-81%). In Japan, by 2047 a capacity reduction by 36 GW (-91%) is projected. In Germany, by 2037 a capacity reduction and dismantling by 9.5 GW (-100%, nuclear phase-out) is expected. In the next decade, Germany and USA offer a stable market potential. In Japan and France, the political decision on Japanese pending reactors and the prolongations of French reactors' operation life is strongly influencing the nuclear reactor retirements. The large market potential of France (capacity reduction by 40 GW, -64%) will unfold from 2040 onwards. Ukraine, Spain, Sweden and Canada and later Belgium and Switzerland are interesting smaller nuclear decommissioning markets in the next years.

The results of our reactor-based, detailed study are compared to existing coarse estimations and projections in literature. The most precise country-specific nuclear dismantling details and time frames were retrieved in the World Energy Outlook. Here, nuclear retirements of around 150 GW_e of nuclear capacity are expected by 2040 which is equivalent to 38% of the current capacity or 44% of the fleet (OECD/IEA 2014, p.388). The report roughly estimates the closure of almost 200 reactors for 8 countries/regions only by the reactors' age and indicates an acute need for capacity substitution in Europe (OECD/IEA, 2014, p. 27, 387f.). In this study, around 260 GW_e are expected to be retired until 2047. But, compared to the scenarios in the World Energy Outlook (IEA, 2014) the results of our study are plausible. Main future decommissioning and dismantling markets are similarly named by OECD/IEA (2014) and (IEA, 2014, p. 388, 395-399) particularly in the European Union, Russia, Japan and USA. However, the timely development of the dismantling market is estimated slightly different. In our study, the dismantling market volume highly increases between 2020 and 2030 and stagnates between 2030 and 2045 on a high level.

Policy implications focus on the country-specific establishment of sufficient regulation, expertise, equipment and authorities' infrastructures. Similarly, OECD/IEA indicates potential bottlenecks in expertise and dismantling equipment and potential dismantling strategy shifts to deferred dismantling (OECD/IEA, 2014, p. 388).

6.2 Discussion and critical appraisal

The presented study is considerably more detailed and actual than existing literature. It provides insights into the nuclear dismantling market development of 18 countries. However, it also has its limitations:

The study is limited to nuclear power reactors listed in PRIS of 18 considered countries. For a more comprehensive overview, all nuclear power generating countries and nuclear pilot and research facilities could have been included. However, since we focus on the nuclear dismantling market in the next 30 years and new/younger[42] reactors have expected life times between 40 and 60 years, only countries with nuclear phase-out policies or old and obsolete nuclear reactors are included. Also, we excluded research reactors and facilities due to their larger heterogeneity and due to their minor influence on energy supply, so that the projected market volume is higher than presented in the results.

In the calculated scenarios, we considered current legal regulations and economic conditions and disregarded larger interferences, such as Fukushima hazard, that led and might lead to abrupt policy changes in the future. Furthermore, possible delays in nuclear decommissioning have not been considered in this study yet, such as availability and shortages of containers, problems with onsite and offsite storage, future political decisions or other risks and changes that affect shutdown and dismantling strategies. Also, possible speed-up of nuclear

[42] The new construction concentrates on different countries, such as South Korea, India, China and Pakistan (see OECD/IEA, 2014, p.,388 and Schneider et al., 2016, p. 23 for the “China effect” in nuclear start-ups and worldwide shut downs of nuclear power reactors. However, only the new construction projects in South Korea are considered in this study. But as in China, India and Middle east no retirements are planned (OECD/IEA, 2014, p. 388), this limitation of our study is reasonable.

dismantling has not been included due to learning curves in companies and authorities, more precise planning data or reduced uncertainty.

In the USA, if there are several reactors on one site, obsolete reactors remain shut down until all reactors onsite are ready for decommissioning. This delay in dismantling is not considered in the study and might timely distort the projection results for USA and in total.

The manual search for reactor statuses might be error prone and remaining data gaps were filled by assumptions according to the countries' nuclear strategy and international average post-operational and dismantling durations. Also, as research in documents of native language was not possible in many countries, our research was restricted to German and English publications of researchers and international agencies.

The study also assumes the return to operation or shutdown of Japanese pending reactors by 2019. Compared to the current rate of official authority decisions on the pending reactors (ca. 3/year), it will probably take longer.

Furthermore, due to lacking data on expected dismantling project closures we assumed the completion of ongoing dismantling projects until 2019. This is a strong restriction that does not depict reality and distorts the projected dismantling figures in 2019. However, it does not affect the new retirements and shutdowns of reactors that have been the focus of this study. However, changes can occur due to shutdown delays, e.g. because of unclear storage or container shortages.

In sensitivity analyses, we varied the default durations of post-operational phase and dismantling phases of those countries were there was no country-specific value available. In Scenario 1, we varied the post-operational phase between 2.5 and 5.5 years and the dismantling phase between 10 and 12.5 years for taking into account the values reported in Thierfeldt and Schartmann (2012, p. 31). Compared to Figure 6, we see a slight increase of 5-10% in dismantling numbers especially after 2027. However, it shows only marginal influence and does not change trends. Also, when Scenario 1 is calculated with a post-operational phase duration of 6 years and a dismantling phase of 10 years the numbers only slightly vary with a difference from the initial case of 3-5% until 2031 and then increasing.

6.3 Outlook

Future research could address the impacts of new construction of reactors as well as focus on the timely development of the retrofit investments in prolongation of operating time of nuclear reactors. Furthermore, this study can be extended to all countries worldwide and all types of nuclear facilities. Moreover, for the markets with high decommissioning potential the market entry barriers can be investigated in detail to define competition within the markets.

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References

Ananiev, A.; Zimin, V.; Korneev, I. (2015): Planning for the decommissioning of Leningrad NNP units N 1, 2. Moskau. http://www.atomeco.org/mediafiles/u/files/2015/Materials/Zimin.pdf, last access: 13.12.2016.

Anon (ed.) (2017): Taiwan amends its Electricity Act, plans nuclear exit by 2025. https://www.enerdata.net/publications/daily-energy-news/taiwan-amends-its-electricity-act-plans-nuclear-exit-2025.html, (last access: 21.10.2017).

Anunti, A.; Larsson, H.; Edelborg, M. (2013): Decommissioning study of Forsmark NPP. http://www.skb.se/upload/publications/pdf/R-13-03.pdf, last access: 28.12.2016.

ASN, Autorité de sûreténucléaire (2016): ASN report on the state of nuclear safety and radiation protection in France in 2015. Chevet, Peirre-Franck. Montrouge. Online: www.french-nuclear-safety.fr/content/download/103003/758456/version/10/file/ASN+Report+on+the+state+of+nuclear+safety+and+radiation+protection+in+France+in+2015.pdf, last access: 28.11.2016.

Barsebäck (2016): Activities on the site. http://www.barsebackkraft.se/en/About-Barseback/Plant-service-and-other-activities/, last access: 28.12.2016

Bonnenberg, H.; Mischke, J. (1996): Allgemeiner Überblick über Stillegung und Rückbau kerntechnischer Anlagen. In: VDI-Gesellschaft Energietechnik (Hg.): Stillegung und Rückbau kerntechnischer Anlagen. Wirtschaftliche, rechtliche und politische Aspekte; Tagung Schwerin, 26. und 27. September 1996. Düsseldorf: VDI-Verl. (VDI-Berichte, 1268), S. 9–20.

Bruce Power (2016b): Life-Extension Program. http://www.brucepower.com/about-us/life-extension/, last access 27.12.2016.

Bryers, J.; Ashmead, S.: Preparation for Future Defueling and Decommissioning Works on EDF Energy's UK Fleet of Advanced Gas Cooled Reactors 2016. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/47/061/47061284.pdf, last access: 16.12.2016.

BWK (2016): Stilllegungsprojekt. Stilllegung des Kernkraftwerks Mühleberg. Hg. v. BWK Energie AG. Bern. https://bkw-portal-static.s3.amazonaws.com/Webcontent/bkw.ch/fileadmin/user_upload/19_KKM/Hauptbericht_-_Stilllegungsprojekt_v1.1.pdf, last access: 20.12.2016.

DAtF, Deutsches Atomforum e.V. (2016): Kernenergie in Zahlen 2016. http://www.kernenergie.de/kernenergie-wAssets/docs/service/621kernenergie-in-zahlen2016.pdf, last access: 20.11.2016.

Department for Business, Energy & Industrial Strategy (2016): Digest of United Kingdom Energy Statistics.

https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/577712/DUKES_2016_FINAL.pdf.

EDF, Électricité de France (2016): Pressedossier Das Kernkraftwerk Cattenom. https://www.edf.fr/sites/default/files/contrib/groupe-edf/producteur-industriel/carte-des-implantations/centrale-cattenom/presentation/Dossiers%20de%20presse/dossier_de_presse_2016_allemand_maj_15062016.pdf, last access: 30.11.2016.

European Court of Auditors (2016): EU nuclear decommissioning assistance programmes in Lithuania, Bulgaria and Slovakia: some progress made since 2011, but critical challenges ahead. Luxemburg, Publications Office of the European Union, 2016 (Special Report /, No. 22), ISBN 978-92-872-5467-2, ISSN 1977-5679. http://doi.org/10.2865/50913, https://www.eca.europa.eu/Lists/ECADocuments/SR16_22/SR_NUCLEAR_DECOMMISSIONING_EN.pdf (last access: 01.08.2018)

European Commission (2016a): Nuclear Illustrative Programme. SWD (2016) 102 final.Hg. v. European Commission. http://ec.europa.eu/transparency/regdoc/rep/1/2016/EN/1-2016-177-EN-F1-1.PDF.

European Commission (2016b): Nuclear Illustrative Programme presented under Article 40 of the Euratom Treaty for the opinion of the European Economic and Social Committee. Commission Staff Working Document.Hg. v. European Commission. https://ec.europa.eu/energy/sites/ener/files/documents/1_EN_autre_document_travail_service_part1_v10.pdf.

Fischer, S. (2015): Frankreich macht die Wende- Weniger Kernkraft, mehr Erneuerbare: Frankreichs neues energiepolitisches Programm ist ambitioniert. Aber wie ernst ist es gemeint?, DIE ZEIT, online, 24. July 2015, 17:32 pm, http://www.zeit.de/wirtschaft/2015-07/atomenergie-frankreich-energiewende?print, last access: 17.10.2017

Hyung Kook, K. (2015): Comparative Study of the Politics of Nuclear Decommissioning between Great Britain and South Korea. Department of Political Science and International Relations Chung AngUniversity, Korea. England.

https://www.psa.ac.uk/sites/default/files/conference/papers/2015/KIM%20hyung%20Decommissioning_btw%20GB%20and%20KOR.pdf.

IAEA (2004): Status of the decommissioning of nuclear facilities around the world. Vienna: International Atomic Energy Agency (STI/PUB, 1201). http://www-pub.iaea.org/MTCD/publications/PDF/Pub1201_web.pdf, last access 20.12.2016.

IAEA, International Atomic Energy Agency (2011): Policies and strategies for the decommissioning of nuclear and radiological facilities. IAEA Nuclear Energy Series No.NW-G-2.1.

IAEA, International Atomic Energy Agency (2015): Country nuclear power profiles. 2015 edition. Vienna: International Atomic Energy Agency. http://www-pub.iaea.org/MTCD/Publications/PDF/CNPP2015_CD/pages/index.htm, last access: 27.07.2018.

IAEA, International Atomic Energy Agency (2016a): Nuclear Power Reactors in the World, Reference data series No. 2, 2016 Edition, International Atomic Energy Agency, Vienna, ISBN 978–92–0–103716–9, http://www-pub.iaea.org/MTCD/Publications/PDF/RDS_2-36_web.pdf (last access: 06.10.2017)

IAEA, International Atomic Energy Agency (2016b): Country Nuclear Power Profiles – Ukraine (Updated 2016), https://cnpp.iaea.org/countryprofiles/Ukraine/Ukraine.htm, last access: 10.10.2017

IAEA, International Atomic Energy Agency (2017a): Nuclear Power Reactors in the World, Reference data series No. 2, 2017 Edition, International Atomic Energy Agency, Vienna, ISBN 978–92–0–104017–6, http://www-pub.iaea.org/MTCD/Publications/PDF/RDS_2-37_web.pdf (last access: 10.10.2017)

IAEA, International Atomic Energy Agency (2017b): Country Nuclear Power Profiles – France (Updated 2017), https://www-pub.iaea.org/MTCD/Publications/PDF/cnpp2017/countryprofiles/France/France.htm, last access: 02.04.2017

IEA (2014): World Energy Outlook, ISBN: 978-92-64-20805-6, Paris, http://www.worldenergyoutlook.org/weo2014/, last access: 10.10.2017

IEA/NEA (2015): Technology Roadmap Nuclear Energy, Edition 2015. https://www.iea.org/media/freepublications/technologyroadmaps/TechnologyRoadmapNuclearEnergy.pdf (last access: 06.10.2017).

Izmestev, A. (2015): Technical approaches and main challenges of U-graphite reactors decommissioning. Hg. v. Pocatom. http://www.atomeco.org/mediafiles/u/files/2015/Materials/Izmestiev.pdf, last access: 25.12.2016.

Joo Hyun Moon, G. (2013): Estimated decommissioning cost for the 23 opera-ting nuclear power reactors in Korea. In: ATW - Internationale Zeitschrift für Kernenergie 2013 (58 (7)), S. 420–422. http://www.kernenergie.de/kernenergie-wAssets/docs/fachzeitschrift-atw/2013/atw2013_07_moon-decommissioning.pdf.

Kennes, C.; Mommaert, C.; Schmidts, O. (2008): Bel V activities in the Belgian context of dismantling research reactor and fuel cycle facilities. (ed.)Eurosafe.https://www.eurosafe-forum.org/sites/default/files/Presentations2008/Seminar%203/Slides/3.3_Bel%20V_presentation_seminar_3.pdf,last access: 17.10.2017

Kilochytska, T. (2009): Decommissioning of nuclear facilities in Ukraine, State Nuclear Regulatory Committee of Ukraine, Annuale Forum for Regulators and Operators in the field of decommissioning, Nov 2-6, 2009, Vienna, Austria, https://www.iaea.org/OurWork/ST/NE/NEFW/documents/IDN/meeting2009/session1/Ukraine.pdf, last access: 10.10.2017

KHNP, Korea Hydro & Nuclear Power (2016): Nuclear | Continue Operation. http://cms.khnp.co.kr/eng/content/554/main.do?mnCd=EN030301, last access: 21.12.2016.

Laraia, M. (Ed.) (2012): Nuclear decommissioning. Planning, execution and inter-national experience. Philadelphia, Pa: Woodhead Pub (Woodhead Publishing series in energy, no. 36). http://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=683131.

Larsson, H.; Anunti, A.; Edelborg, M. (2013): Decommissioning Study of Oskarshamn NPP. http://www.skb.se/upload/publications/pdf/R-13-04.pdf, last access: 28.12.2016.

Marignac, Y. (2015): French Nuclear Reactors Reaching 40 Years. WISE Paris. http://nuris.org/wp-content/uploads/2015/04/Marignac_Problems-of-long-term-operation-of-french-nuclear-power-plants.pdf, last access: 28.11.2016.

NDA, Nuclear Decommissioning Authority (2016b): Strategy. Effective from April 2016. London: The Stationery Office. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/512836/Nuclear_Decommissioning_Authority_Strategy_effective_from_April_2016.pdf.

NRC, Nuclear Regulatory Commission (2016a): Backgrounder: Reactor License Renewal. http://www.nrc.gov/docs/ML0506/ML050680253.pdf, last access: 06.10.2017.

NRC, Nuclear Regulatory Commission (2017): Subsequent License Renewal, Guidance Schedule Milestones, https://www.nrc.gov/reactors/operating/licensing/renewal/subsequent-license-renewal.html#milestones (Page Last Reviewed/Updated Friday, July 21, 2017) (last access: 06.10.2017)

Nuclear Energy Institute (2016): Decommissioning Nuclear Power Plants. http://www.nei.org/Master-Document-Folder/Backgrounders/Fact-Sheets/Decommissioning-Nuclear-Energy-Facilities, last access: 14.11.2016.

Nuclear Engineering International (2016): Lessons in modernity - Nuclear Engineering International. http://www.neimagazine.com/features/featurelessons-in-modernity-4943402/, last access: 12.12.2016.

Nuklearforum Schweiz (2011): Taiwan will aus der Kernenergie aussteigen. http://www.nuklearforum.ch/de/aktuell/e-bulletin/taiwan-will-aus-der-kernenergie-aussteigen, last updated: 22.12.2016, last access: 22.12.2016.

Nuklearforum Schweiz (2016): Taiwan: neue Kernenergiepolitik vorgestellt. http://www.nuklearforum.ch/de/aktuell/e-bulletin/taiwan-neue-kernenergiepolitik-vorgestellt, last updated 22.12.2016, last access: 22.12.2016.

OCDE/IEA, 2017; Energy Technology Perspectives 2017, Catalysing Energy Technology Transformations, Executive Summary, https://www.iea.org/publications/freepublications/publication/EnergyTechnologyPerspectives2017ExecutiveSummaryGermanversion.pdf (last visit: 02.04.2018)

OECD/IEA, 2017, World Energy Outlook 2017, Executive Summary, https://www.iea.org/Textbase/npsum/weo2017SUM.pdf, last access: 02.04.2018

OECD/NEA (2015): Nuclear Development/ Développement de l'énergie nucléaire 2015, Nuclear Energy Data / Données sur l'énergie nucléaire 2015, NEA No. 7246, Nuclear Energy Agency (NEA), Organisation For Economic Co-Operation And Development (OECD), https://www.oecd-nea.org/ndd/pubs/2015/7246-ned-2015.pdf, last access: 05.04.2018).

OECD/NEA (2016): Nuclear Development/ Développement de l'énergie nucléaire 2016, Nuclear Energy Data / Données sur l'énergie nucléaire 2016, NEA No. 7300, Nuclear Energy Agency (NEA), Organisation For Economic Co-Operation And Development (OECD), https://www.oecd-nea.org/ndd/pubs/2016/7300-ned-2016.pdf, last access: 06.04.2018). s

OECD; NEA (2011a): Nuclear Legislation in OECD and NEA Countries - Japan. https://www.oecd-nea.org/law/legislation/japan.pdf, last access: 01.12.2016.

Oskarsson, M. (2016): Decommissioning of Nuclear Power Plants – what are the challenges? Magnus Oskarsson BU Nuclear Decommissioning. Hg. v. Vattenfall. https://www.chalmers.se/en/centres/snec/societyandindustry/snecday/snecday2016/Documents/05.%20Magnus%20Oskarsson%20-%20decommissioning%20challenges.pdf, last access: 28.12.2016.

Plewnia, N. M. (2016): Zielmarktanalyse Japan – KKW Rückbau und Modernisierung. Bundesministerium für Wirtschaft und Energie (BMWi) (ed.). Deutsche Industrie- und Handelskammer in Japan. Berlin. https://www.ixpos.de/IXPOS/Content/DE/Ihr-geschaeft-im-ausland/_SharedDocs/Downloads/bmwi-markterschliessungsprogramm-2016/bmwi-mep-marktstudie-japan-kernkraftwerk-rueckbau.pdf?v=2 (last access: 20.08.2017).

Reid, R.; McGratz, R. (2016): EPRI Guidance for Transition from Operations to Decommissioning. Hg. v. Electric Power Research Institute. https://www.oecd-nea.org/rwm/wpdd/predec2016/docs/S-1-5___FP_SNYDER.pdf.

Reuters (2018): UPDATE 2-French nuclear safety authority to rule on EDF reactor lifespan in 2020-21, Energy, November 8, 2017 / 1:43 PM, https://www.reuters.com/article/france-nuclearpower/update-2-french-nuclear-safety-authority-to-rule-on-edf-reactor-lifespan-in-2020-21-idUSL5N1NE3O7 (last access: 02.04.2018).

Rosatom (2014): Rosatom Annual Report 2014. http://www.rosatom.ru/upload/iblock/661/661e5b99fa4ad0eca00bfde76055b503.pdf, (last access: 12.12.2016).

RWE (2016): Mit ganzer Kraft - Pressemitteilungen. http://www.rwe.com/web/cms/de/2320/rwe-power-ag/presse-downloads/pressemitteilungen/pressemitteilungen/?pmid=4015287, (last access: 22.12.2016).

Schindler, F. (2014): Nationalrat sagt Nein zu Ausstiegsinitiative der Grünen. In: BernerZeitung, 09.12.2014. http://www.bernerzeitung.ch/schweiz/standard/England-baut-neue-AKW-mit-Subventionen-der-EU/story/10155878, (last access: 20.12.2016).

Schmittem, M. (2016): Nuclear Decommissioning in Japan. Opportunities for European Companies. http://cdnsite.eu-japan.eu/sites/default/files/publications/docs/2016-03-nuclear-decommissioning-japan-schmittem-min_0.pdf, last access: 03.12.2016.

Schneider, M.; Froggatt, A.; Hazemann, J.; Fairlie, I.; Katsuta, T.; Maltini, F.; Ramana, M. V. (2016): The World Nuclear Industry. Status Report 2016. http://www.worldnuclearreport.org/ (last access: 10.10.2017).

Schneider, M.; Froggatt, A.; Hazemann, J.; Katsuta, T.; Ramana, M. V.; Rodigues, J. C.; Rüdinger, A., Stienne, A. (2017): The World Nuclear Industry. Status Report 2017. https://www.worldnuclearreport.org/IMG/pdf/20170912wnisr2017-en-lr.pdf, (last access: 26.03.2018)

SOGIN (2016a): Caorso nuclear power plant – Piacenza. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/caorso-nuclear-power-plant-%E2%80%93-piacenza.html, zuletzt aktualisiert am 30.12.2016, zuletzt geprüft am 30.12.2016.

SOGIN (2016b): Garigliano nuclear power plant – Caserta. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/garigliano-nuclear-power-plant-%E2%80%93-caserta.html, last access: 30.12.2016.

SOGIN (2016c): Latina nuclear power plant – Latina. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/latina-nuclear-power-plant-%E2%80%93-latina.html, last access: 30.12.2016.

SOGIN (2016d): Trino nuclear power plant Vercelli. http://www.sogin.it/en/about-us/environmental-remediation-of-nuclear-sites/where-we-are/trino-nuclear-power-plant-vercelli.html, Last access: 30.12.2016.

SSM, Stralsäkerhetsmyndigheten (2008): The Swedish Radiation Safety Authority's Regulations on Planning before and during Decommissioning of Nuclear Facilities. http://www.stralsakerhetsmyndigheten.se/Global/Publikationer/Forfattning/Engelska/SSMFS-2008-19E.pdf, last access: 28.12.2016.

Taiwan Power Company (2014): Decommissioning Plan for Nuclear Power Plants in Taiwan 沒有投影片標題. (ed.). Taiwan Power Company. http://www.cieca.org.tw/ConferenceData.aspx?mrid=536, last access: 27.12.2016.

Ternon-Morin, F.; Degrave, C. (2012): Long Term Operation For EDF Nuclear Power Plants: Towards 60 years… IAEA.Frankreich. http://www.iaea.org/inis/collection/NCLCollectionStore/_Public/43/070/43070836.pdf, last access: 31.12.2016.

Thierfeldt, S.; Schartmann, F. (2012): Stilllegung und Rückbau kerntechnischer Anlagen. Erfahrungen und Perspektiven. 4. Aufl. https://www.ptka.kit.edu/downloads/ptka-wte-e/WTE-E-Entsorgungsforschung-Broschuere_Stilllegung-und-Rueckbau_BRENK.pdf.

U.S. Energy Information Administration (2016): Fort Calhoun becomes fifth U.S. nuclear plant to retire in past five years - Today in Energy - U.S. Energy Information Administration. http://www.eia.gov/todayinenergy/detail.php?id=28572, last access: 29.12.2016.

UVEK, Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK (2017): Energiestrategie 2050: Abstimmung zum Energiegesetz(last access: 02.04.2018), https://www.uvek.admin.ch/uvek/de/home/energie/energiestrategie-2050.html

VDI-Gesellschaft Energietechnik (ed.) (2002): Stillegung und Rückbau kerntechnischer Anlagen. Auswirkungen aktueller Regelungen und Randbedingungen; Tagung Bonn, 10. April 2002. Düsseldorf: VDI-Verl. (VDI-Berichte, 1671).

Wealer, B.; Gerbaulet, C.; Seidel, J. P.; von Hirschhausen, C. (2015): Stand und Perspektiven des Rückbaus von Kernkraftwerken in Deutschland. (ed.) Deutsches Institut für Wirtschaftsforschung. Berlin. https://www.diw.de/documents/publikationen/73/diw_01.c.519393.de/diw_datadoc_2015-081.pdf.

Wendling, R. (2002): Neue gesetzliche Regelungen. In: VDI-Gesellschaft Energietechnik (ed.): Stillegung und Rückbau kerntechnischer Anlagen. Auswirkungen aktueller Regelungen und Randbedingungen; Tagung Bonn, 10. April 2002. Düsseldorf: VDI-Verl. (VDI-Berichte, 1671), S. 1–8.

WNA, World Nuclear Association (2016b): Nuclear Development in the United Kingdom. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/appendices/nuclear-development-in-the-united-kingdom.aspx, last access: 16.12.2016.

WNA, World Nuclear Association (2016c): Nuclear Energy in Italy: Italian Nuclear Power. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/italy.aspx, last access: 30.07.2018.

WNA, World Nuclear Association (2016d): Nuclear Energy in Sweden. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/sweden.aspx, last access: 27.12.2016.

WNA, World Nuclear Association (2016f): Nuclear Power in France. http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx, last access: 28.11.2016.

WNA, World Nuclear Association (2016i): Nuclear Power in Lithuania. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/lithuania.aspx, last access: 27.12.2016.

WNA, World Nuclear Association (2016j): Nuclear Power in Russia. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/russia-nuclear-power.aspx, last access: 12.12.2016.

WNA, World Nuclear Association (2016k): Nuclear Power in Slovakia, Slovakia Nuclear Energy. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/slovakia.aspx, last access: 30.07.2018.

WNA, World Nuclear Association (2016m): Nuclear Power in Spain | Spanish Nuclear Energy. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/spain.aspx, last access: 30.12.2016.

WNA, World Nuclear Association (2016n): Nuclear Power in Switzerland. http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/switzerland.aspx, last access: 28.12.2016.

WNA, World Nuclear Association (2016o): Nuclear Power in the United Kingdom. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-kingdom.aspx, last access: 15.12.2016.

WNA, World Nuclear Association (2016p): Nuclear Power in the USA. http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/usa-nuclear-power.aspx, last access: 02.06.2017.

WNA, World Nuclear Association (2016q): Taiwan Nuclear Power. http://www.world-nuclear.org/information-library/country-profiles/others/nuclear-power-in-taiwan.aspx, last access: 22.12.2016.

WNN, World Nuclear News (2014): Belgian government approves life extensions. http://www.world-nuclear-news.org/NP-Belgian-government-approves-life-extensions-1912145.html, last access: 29.12.2016.

WNN, World Nuclear News (2016b): Sweden abolishes nuclear tax. http://www.world-nuclear-news.org/NP-Sweden-abolishes-nuclear-tax-1006169.html, last access: 27.12.2016

WNN, World Nuclear News (2017): Decommissioning Nuclear Facilities, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-wastes/decommissioning-nuclear-facilities.aspx, last updated: 8 September 2017, last access: 17.10.2017

Zink, M. (2013): Laufzeitverlängerungen deutscher Kernkraftwerke - Wie lange können Kernkraftwerke sicher betrieben werden? http://www.energie-fakten.de/html/laufzeitverlaengerung.html, last updated on 22.02.2013, last access: 19.12.2016.

Appendix

***Table A:** Extended nuclear reactor database (PRIS) by their incurred shutdown date, the expected shutdown start date and expected dismantling start date as well as the scenario results in baseline Scenario 1 for 2017, 2037 and 2047. The listed reactors are alphabetically sorted.*

Reactor name	Country	Reactor Type	Thermal capacity [MW]	Electrical capacity [MW]	Year of initial operation (Grid connection)	Status (April 2018)	Incurred shutdown date [year]	Expected shutdown start [year]	Expected dismantling start [year]	Scenario 1, 2027	Scenario 1, 2037	Scenario 1, 2047
AGESTA	SW	PHWR	80	12	1964	In safe enclosure	1974		2020	In safe enclosure	In safe enclosure	In safe enclosure
AKADEMIK LOMONOSOV-1	RUS	PWR	150	32		Under construction				In operation	In operation	In operation
AKADEMIK LOMONOSOV-2	RUS	PWR	150	32		Under construction				In operation	In operation	In operation
ALMARAZ-1	ES	PWR	2947	1011	1981	In operation		2020	2024	In shutdown	Dismantling completed	Dismantling completed
ALMARAZ-2	ES	PWR	2947	1006	1983	In operation		2020	2024	In shutdown	Dismantling completed	Dismantling completed
ANO-1	USA	PWR	2568	903	1974	In operation		2034	2040	In operation	In shutdown	Dismantling completed
ANO-2	USA	PWR	3026	1065	1978	In operation		2038	2040	In operation	In operation	In shutdown
APS-1 OBNINSK	RUS	LWGR	30	5	1954	In dismantling	2002	2002	2006	Dismantling completed	Dismantling completed	Dismantling completed
ASCO-1	ES	PWR	2954	995	1983	In operation		2021	2025	In shutdown	Dismantling completed	Dismantling completed
ASCO-2	ES	PWR	2941	997	1985	In operation		2021	2025	In shutdown	Dismantling completed	Dismantling completed
AVR JUELICH	GER	HTGR	46	13	1967	In dismantling	1989	1989	1994	Dismantling completed	Dismantling completed	Dismantling completed
BALAKOVO-1	RUS	PWR	3000	950	1985	In operation		2038	2042	In operation	In operation	Dismantling completed
BALAKOVO-2	RUS	PWR	3000	950	1987	In operation		2040	2044	In operation	In operation	In shutdown
BALAKOVO-3	RUS	PWR	3000	950	1988	In operation		2048	2052	In operation	In operation	In operation
BALAKOVO-4	RUS	PWR	3200	950	1993	In operation		2053	2057	In operation	In operation	In operation
BALTIC-1	RUS	PWR	3200	1109		Under construction				In operation	In operation	In operation
BARSEBACK-1	SW	BWR	1800	615	1975	In safe enclosure	1999	1999	2020	In safe enclosure	In safe enclosure	In safe enclosure
BARSEBACK-2	SW	BWR	1800	615	1977	In safe enclosure	2005	2005	2020	In safe enclosure	In safe enclosure	In safe enclosure
BEAVER VALLEY-1	USA	PWR	2900	959	1976	In operation		2036	2038	In operation	In shutdown	In shutdown
BEAVER VALLEY-2	USA	PWR	2900	958	1987	In operation		2047	2049	In operation	In operation	In operation

BELLEVILLE-1	F	PWR	3817	1310	1987	In operation		2047	2032	In operation	In operation	In operation
BELLEVILLE-2	F	PWR	3817	1310	1988	In operation		2048	2033	In operation	In operation	In operation
BELOYARSK-1	RUS	LWGR	286	102	1964	In dismantling	1983	1983	1987	Dismantling completed	Dismantling completed	Dismantling completed
BELOYARSK-2	RUS	LWGR	530	146	1967	In dismantling	1990	1990	1994	Dismantling completed	Dismantling completed	Dismantling completed
BELOYARSK-3	RUS	FBR	1470	560	1980	In operation		2033	2037	In operation	In shutdown	Dismantling completed
BELOYARSK-4	RUS	FBR	2100	789	2015	In operation		2060	2064	In operation	In operation	In operation
BERKELEY-1	UK	GCR	620	138	1962	Preparation for safe enclosure	1989			In safe enclosure	In safe enclosure	In safe enclosure
BERKELEY-2	UK	GCR	620	138	1962	Preparation for safe enclosure	1988			In safe enclosure	In safe enclosure	In safe enclosure
BEZNAU-1	CH	PWR	1130	365	1969	In operation		2029	2034	In operation	In shutdown	Dismantling completed
BEZNAU-2	CH	PWR	1130	365	1971	In operation		2031	2036	In operation	In shutdown	Dismantling completed
BIBLIS-A	GER	PWR	3517	1167	1974	In shutdown	2011		2018	Dismantling completed	Dismantling completed	Dismantling completed
BIBLIS-B	GER	PWR	3733	1240	1976	In shutdown	2011		2018	Dismantling completed	Dismantling completed	Dismantling completed
BIG ROCK POINT	USA	BWR	240	71	1962	Decommissioning completed	1997	1997	1999	Dismantling completed	Dismantling completed	Dismantling completed
BILIBINO-1	RUS	RBMK	62	11	1974	In operation		2027	2031	In operation	Dismantling completed	Dismantling completed
BILIBINO-2	RUS	RBMK	62	11	1974	In operation		2027	2031	In operation	Dismantling completed	Dismantling completed
BILIBINO-3	RUS	RBMK	62	11	1975	In operation		2028	2032	In operation	Dismantling completed	Dismantling completed
BILIBINO-4	RUS	RBMK	62	11	1976	In operation		2029	2033	In operation	In shutdown	Dismantling completed
BLAYAIS-1	F	PWR	2785	910	1981	In operation		2041	2026	In operation	In operation	In shutdown
BLAYAIS-2	F	PWR	2785	910	1982	In operation		2042	2027	In operation	In operation	In shutdown
BLAYAIS-3	F	PWR	2785	910	1983	In operation		2043	2028	In operation	In operation	In shutdown
BLAYAIS-4	F	PWR	2785	910	1983	In operation		2043	2028	In operation	In operation	In shutdown
BOHUNICE A1	SLO	HWGCR	560	93	1972	In dismantling	1977		1981	Dismantling completed	Dismantling completed	Dismantling completed
BOHUNICE-1	SLO	PWR	1375	408	1978	In dismantling	2006		2017	Dismantling completed	Dismantling completed	Dismantling completed
BOHUNICE-2	SLO	PWR	1375	408	1980	In dismantling	2008		2017	Dismantling completed	Dismantling completed	Dismantling completed
BOHUNICE-3	SLO	PWR	1471	471	1984	In operation		2024	2029	In shutdown	In shutdown	Dismantling completed
BOHUNICE-4	SLO	PWR	1471	471	1985	In operation		2025	2029	In shutdown	In shutdown	Dismantling completed
BONUS	USA	BWR	50	18	1964	In safe enclosure	1968	1968	1970	In safe enclosure	In safe enclosure	In safe enclosure
BR-3	BE	PWR	41	10	1962	In dismantling	1987		1989	Dismantling completed	Dismantling completed	Dismantling completed
BRADWELL-1	UK	GCR	481	123	1962	Preparation for safe enclosure	2002			In safe enclosure	In safe enclosure	In safe enclosure
BRADWELL-2	UK	GCR	481	123	1962	Preparation for safe enclosure	2002			In safe enclosure	In safe enclosure	In safe enclosure
BRAIDWOOD-1	USA	PWR	3645	1270	1987	In operation		2026	2029	In shutdown	In shutdown	Dismantling completed
BRAIDWOOD-2	USA	PWR	3645	1230	1988	In operation		2027	2029	In operation	In shutdown	Dismantling completed
BROKDORF	GER	PWR	3900	1410	1986	In operation		2021	2026	In shutdown	Dismantling completed	Dismantling completed
BROWNS FERRY-1	USA	BWR	3458	1155	1973	In operation		2033	2038	In operation	In shutdown	Dismantling completed

BROWNS FERRY-2	USA	BWR	3458	1155	1974	In operation		2034	2038	In operation	In shutdown	Dismantling completed
BROWNS FERRY-3	USA	BWR	3458	1155	1976	In operation		2036	2038	In operation	In shutdown	In shutdown
BRUCE-1	CAN	PHWR	2575	760	1977	In operation		2035	2035	In operation	In shutdown	Dismantling completed
BRUCE-2	CAN	PHWR	2456	730	1976	In operation		2035	2035	In operation	In shutdown	Dismantling completed
BRUCE-3	CAN	PHWR	2832	750	1977	In operation		2036	2036	In operation	In shutdown	Dismantling completed
BRUCE-4	CAN	PHWR	2832	750	1978	In operation		2036	2036	In operation	In shutdown	Dismantling completed
BRUCE-5	CAN	PHWR	2832	817	1984	In operation		2059	2059	In operation	In operation	In operation
BRUCE-6	CAN	PHWR	2690	817	1984	In operation		2053	2053	In operation	In operation	In operation
BRUCE-7	CAN	PHWR	2832	817	1986	In operation		2060	2060	In operation	In operation	In operation
BRUCE-8	CAN	PHWR	2690	817	1987	In operation		2063	2063	In operation	In operation	In operation
BRUNSBUETTEL	GER	BWR	2292	771	1976	In shutdown	2011	2011	2018	Dismantling completed	Dismantling completed	Dismantling completed
BRUNSWICK-1	USA	BWR	2923	990	1976	In operation		2036	2038	In operation	In shutdown	In shutdown
BRUNSWICK-2	USA	BWR	2923	960	1975	In operation		2034	2038	In operation	In shutdown	Dismantling completed
BUGEY-1	F	GCR	1954	540	1972	In dismantling	1994	1994	1999	Dismantling completed	Dismantling completed	Dismantling completed
BUGEY-2	F	PWR	2785	910	1978	In operation		2038	2027	In operation	In operation	In shutdown
BUGEY-3	F	PWR	2785	910	1978	In operation		2038	2023	In operation	In operation	In shutdown
BUGEY-4	F	PWR	2785	880	1979	In operation		2039	2028	In operation	In operation	In shutdown
BUGEY-5	F	PWR	2785	880	1979	In operation		2039	2024	In operation	In operation	In shutdown
BYRON-1	USA	PWR	3645	1242	1985	In operation		2024	2028	In shutdown	Dismantling completed	Dismantling completed
BYRON-2	USA	PWR	3645	1210	1987	In operation		2026	2028	In shutdown	In shutdown	Dismantling completed
CALDER HALL-1	UK	GCR	268	49	1956	Preparation for safe enclosure	2003			In safe enclosure	In safe enclosure	In safe enclosure
CALDER HALL-2	UK	GCR	268	49	1957	Preparation for safe enclosure	2003			In safe enclosure	In safe enclosure	In safe enclosure
CALDER HALL-3	UK	GCR	268	49	1958	Preparation for safe enclosure	2003			In safe enclosure	In safe enclosure	In safe enclosure
CALDER HALL-4	UK	GCR	268	49	1959	Preparation for safe enclosure	2003			In safe enclosure	In safe enclosure	In safe enclosure
CALLAWAY-1	USA	PWR	3565	1275	1984	In operation		2024	2026	In shutdown	Dismantling completed	Dismantling completed
CALVERT CLIFFS-1	USA	PWR	2737	918	1975	In operation		2034	2036	In operation	In shutdown	Dismantling completed
CALVERT CLIFFS-2	USA	PWR	2737	911	1976	In operation		2036	2038	In operation	In shutdown	In shutdown
CAORSO	IT	BWR	2651	860	1978	In dismantling	1990	1990	2004	Dismantling completed	Dismantling completed	Dismantling completed
CATAWBA-1	USA	PWR	3411	1188	1985	In operation		2043	2045	In operation	In operation	In shutdown
CATAWBA-2	USA	PWR	3411	1188	1986	In operation		2043	2045	In operation	In operation	In shutdown
CATTENOM-1	F	PWR	3817	1300	1986	In operation		2046	2031	In operation	In operation	In shutdown
CATTENOM-2	F	PWR	3817	1300	1987	In operation		2047	2032	In operation	In operation	In operation
CATTENOM-3	F	PWR	3817	1300	1990	In operation		2050	2035	In operation	In operation	In operation
CATTENOM-4	F	PWR	3817	1300	1991	In operation		2051	2036	In operation	In operation	In operation

CHAPELCROSS-1	UK	GCR	260	48	1959	In shutdown	2004			In safe enclosure	In safe enclosure	In safe enclosure
CHAPELCROSS-2	UK	GCR	260	48	1959	In shutdown	2004			In safe enclosure	In safe enclosure	In safe enclosure
CHAPELCROSS-3	UK	GCR	260	48	1959	In shutdown	2004			In safe enclosure	In safe enclosure	In safe enclosure
CHAPELCROSS-4	UK	GCR	260	48	1960	In shutdown	2004			In safe enclosure	In safe enclosure	In safe enclosure
CHERNOBYL-1	UKR	LWGR	3200	740	1977	In dismantling	1996	1996	2015	Dismantling completed	Dismantling completed	Dismantling completed
CHERNOBYL-2	UKR	LWGR	3200	925	1978	In dismantling	1991	1991	2015	Dismantling completed	Dismantling completed	Dismantling completed
CHERNOBYL-3	UKR	LWGR	3200	925	1981	In dismantling	2000	2000	2015	Dismantling completed	Dismantling completed	Dismantling completed
CHERNOBYL-4	UKR	LWGR	3200	925	1983	In safe enclosure	1986	1986	1992	In safe enclosure	In safe enclosure	In safe enclosure
CHINON A-1	F	GCR	300	70	1963	Partly decommissioned	1973	1973	1978	Teilweise Rückgebaut	Teilweise Rückgebaut	Teilweise Rückgebaut
CHINON A-2	F	GCR	800	180	1965	Partly decommissioned	1985	1985	1990	Teilweise Rückgebaut	Teilweise Rückgebaut	Teilweise Rückgebaut
CHINON A-3	F	GCR	1170	360	1966	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
CHINON B-1	F	PWR	2785	905	1982	In operation		2042	2027	In operation	In operation	In shutdown
CHINON B-2	F	PWR	2785	905	1983	In operation		2043	2028	In operation	In operation	In shutdown
CHINON B-3	F	PWR	2785	905	1986	In operation		2046	2031	In operation	In operation	In shutdown
CHINON B-4	F	PWR	2785	905	1987	In operation		2047	2032	In operation	In operation	In operation
CHINSHAN-1	TW	BWR	1840	636	1977	In operation	2018	2018	2027	In shutdown	In shutdown	Dismantling completed
CHINSHAN-2	TW	BWR	1840	636	1978	In operation	2019	2019	2027	In shutdown	In shutdown	Dismantling completed
CHOOZ B-1	F	PWR	4720	1500	1996	In operation		2056	2041	In operation	In operation	In operation
CHOOZ B-2	F	PWR	4720	1500	1997	In operation		2057	2042	In operation	In operation	In operation
CHOOZ-A (ARDENNES)	F	PWR	1040	305	1967	In dismantling	1991	1991	1996	Dismantling completed	Dismantling completed	Dismantling completed
CIVAUX-1	F	PWR	4720	1495	1997	In operation		2057	2042	In operation	In operation	In operation
CIVAUX-2	F	PWR	4720	1495	1999	In operation		2059	2044	In operation	In operation	In operation
CLINTON-1	USA	BWR	3473	1098	1987	In operation		2017	2019	In shutdown	Dismantling completed	Dismantling completed
COFRENTES	ES	BWR	3237	1064	1984	In operation		2021	2025	In shutdown	Dismantling completed	Dismantling completed
COLUMBIA	USA	BWR	3486	1190	1984	In operation		2043	2045	In operation	In operation	In shutdown
COMANCHE PEAK-1	USA	PWR	3612	1259	1990	In operation		2050	2055	In operation	In operation	In operation
COMANCHE PEAK-2	USA	PWR	3612	1250	1993	In operation		2053	2055	In operation	In operation	In operation
COOK-1	USA	PWR	3304	1100	1975	In operation		2034	2039	In operation	In shutdown	Dismantling completed
COOK-2	USA	PWR	3468	1151	1978	In operation		2037	2039	In operation	In operation	In shutdown
COOPER	USA	BWR	2419	801	1974	In operation		2034	2036	In operation	In shutdown	Dismantling completed
CRUAS-1	F	PWR	2785	915	1983	In operation		2043	2028	In operation	In operation	In shutdown
CRUAS-2	F	PWR	2785	915	1984	In operation		2044	2029	In operation	In operation	In shutdown
CRUAS-3	F	PWR	2785	915	1984	In operation		2044	2029	In operation	In operation	In shutdown
CRUAS-4	F	PWR	2785	915	1984	In operation		2044	2029	In operation	In operation	In shutdown

CRYSTAL RIVER-3	USA	PWR	2568	890	1977	In safe enclosure	2013			In safe enclosure	In safe enclosure	In safe enclosure
CVTR	USA	PHWR	65	19	1963	Decommissioning completed	1967	1967	1969	Dismantling completed	Dismantling completed	Dismantling completed
DAMPIERRE-1	F	PWR	2785	890	1980	In operation		2040	2025	In operation	In operation	In shutdown
DAMPIERRE-2	F	PWR	2785	890	1980	In operation		2040	2025	In operation	In operation	In shutdown
DAMPIERRE-3	F	PWR	2785	890	1981	In operation		2041	2026	In operation	In operation	In shutdown
DAMPIERRE-4	F	PWR	2785	890	1981	In operation		2041	2026	In operation	In operation	In shutdown
DARLINGTON-1	CAN	PHWR	2776	878	1990	In operation		2055	2055	In operation	In operation	In operation
DARLINGTON-2	CAN	PHWR	2776	878	1990	In operation		2055	2055	In operation	In operation	In operation
DARLINGTON-3	CAN	PHWR	2776	878	1992	In operation		2055	2055	In operation	In operation	In operation
DARLINGTON-4	CAN	PHWR	2776	878	1993	In operation		2055	2055	In operation	In operation	In operation
DAVIS BESSE-1	USA	PWR	2817	925	1977	In operation		2037	2039	In operation	In operation	In shutdown
DIABLO CANYON-1	USA	PWR	3411	1197	1984	In operation		2024	2027	In shutdown	Dismantling completed	Dismantling completed
DIABLO CANYON-2	USA	PWR	3411	1197	1985	In operation		2025	2027	In shutdown	Dismantling completed	Dismantling completed
DOEL-1	BE	PWR	1311	433	1974	In operation		2025	2030	In shutdown	In shutdown	Dismantling completed
DOEL-2	BE	PWR	1311	433	1975	In operation		2025	2030	In shutdown	In shutdown	Dismantling completed
DOEL-3	BE	PWR	3054	1006	1982	In operation		2022	2027	In shutdown	Dismantling completed	Dismantling completed
DOEL-4	BE	PWR	2988	1033	1985	In operation		2025	2030	In shutdown	In shutdown	Dismantling completed
DOUGLAS POINT	CAN	PHWR	704	206	1967	In safe enclosure	1984	1984	1984	In safe enclosure	In safe enclosure	In safe enclosure
DOUNREAY DFR	UK	FBR	60	11	1962	In dismantling	1977	1977	1987	Dismantling completed	Dismantling completed	Dismantling completed
DOUNREAY PFR	UK	FBR	600	234	1975	In dismantling	1994	1994	2004	Dismantling completed	Dismantling completed	Dismantling completed
DRESDEN-1	USA	BWR	700	207	1960	In safe enclosure	1978	1978	1980	In safe enclosure	In safe enclosure	In safe enclosure
DRESDEN-2	USA	BWR	2957	950	1970	In operation		2029	2033	In operation	In shutdown	Dismantling completed
DRESDEN-3	USA	BWR	2957	935	1971	In operation		2031	2033	In operation	In shutdown	Dismantling completed
DUANE ARNOLD-1	USA	BWR	1912	624	1974	In operation		2044	2036	In operation	In operation	In shutdown
DUNGENESS A-1	UK	GCR	840	225	1965	Preparation for safe enclosure	2006			In safe enclosure	In safe enclosure	In safe enclosure
DUNGENESS A-2	UK	GCR	840	225	1965	Preparation for safe enclosure	2006			In safe enclosure	In safe enclosure	In safe enclosure
DUNGENESS B-1	UK	GCR	1500	520	1983	In operation		2028	2038	In operation	Vorbereitung sicherer Einschluss	In shutdown
DUNGENESS B-2	UK	GCR	1500	520	1985	In operation		2028	2038	In operation	Vorbereitung sicherer Einschluss	In shutdown
EL-4 (MONTS D'ARREE)	F	HWGCR	250	70	1967	In dismantling	1985	1985	1990	Dismantling completed	Dismantling completed	Dismantling completed
ELK RIVER	USA	BWR	58	24	1963	Decommissioning completed	1968	1968	1970	Dismantling completed	Dismantling completed	Dismantling completed
EMSLAND	GER	PWR	3850	1335	1988	In operation		2022	2027	In shutdown	Dismantling completed	Dismantling completed
ENRICO FERMI	IT	PWR	870	260	1964	In dismantling	1990		1999	Dismantling completed	Dismantling completed	Dismantling completed
FARLEY-1	USA	PWR	2755	918	1977	In operation		2037	2043	In operation	In operation	In shutdown

FARLEY-2	USA	PWR	2755	928	1981	In operation		2041	2043	In operation	In operation	In shutdown
FERMI-1	USA	FBR	200	65	1966	In safe enclosure	1972			In safe enclosure	In safe enclosure	In safe enclosure
FERMI-2	USA	BWR	3486	1198	1986	In operation		2045	2047	In operation	In operation	In shutdown
FESSENHEIM-1	F	PWR	2785	880	1977	In operation		2037	2023	In operation	In operation	In shutdown
FESSENHEIM-2	F	PWR	2785	880	1977	In operation		2037	2023	In operation	In operation	In shutdown
FITZPATRICK	USA	BWR	2536	849	1975	In operation	2017	2017	2019	In shutdown	Dismantling completed	Dismantling completed
FLAMANVILLE-1	F	PWR	3817	1330	1985	In operation		2045	2030	In operation	In operation	In shutdown
FLAMANVILLE-2	F	PWR	3817	1330	1986	In operation		2046	2031	In operation	In operation	In shutdown
FLAMANVILLE-3	F	PWR	4300	1600		Under construction				In operation	In operation	In operation
FORSMARK-1	SW	BWR	2928	1022	1980	In operation		2040	2041	In operation	In operation	In shutdown
FORSMARK-2	SW	BWR	3253	1158	1981	In operation		2041	2042	In operation	In operation	In shutdown
FORSMARK-3	SW	BWR	3300	1203	1985	In operation		2045	2046	In operation	In operation	In shutdown
FORT CALHOUN-1	USA	PWR	1500	512	1973	In shutdown	2016		2018	In shutdown	Dismantling completed	Dismantling completed
FORT ST. VRAIN	USA	HTGR	842	342	1976	Decommissioning completed	1989	1989	1991	Dismantling completed	Dismantling completed	Dismantling completed
FUGEN ATR	JP	HWLWR	557	148	1978	In safe enclosure	2003	2003	2011	In safe enclosure	In safe enclosure	In safe enclosure
FUKUSHIMA-DAIICHI-1	JP	BWR-F	1380	439	1970	In dismantling	2011			Dismantling completed	Dismantling completed	Dismantling completed
FUKUSHIMA-DAIICHI-2	JP	BWR-F	2381	760	1973	In dismantling	2011			Dismantling completed	Dismantling completed	Dismantling completed
FUKUSHIMA-DAIICHI-3	JP	BWR-F	2381	760	1974	In dismantling	2011			Dismantling completed	Dismantling completed	Dismantling completed
FUKUSHIMA-DAIICHI-4	JP	BWR-F	2381	760	1978	In dismantling	2011			Dismantling completed	Dismantling completed	Dismantling completed
FUKUSHIMA-DAIICHI-5	JP	BWR-F	2381	760	1977	In dismantling	2013			Dismantling completed	Dismantling completed	Dismantling completed
FUKUSHIMA-DAIICHI-6	JP	BWR-F	3293	1067	1979	In dismantling	2013			Dismantling completed	Dismantling completed	Dismantling completed
FUKUSHIMA-DAINI-1	JP	BWR	3293	1067	1981	Ready-for-operation		2021	2029	In shutdown	Dismantling completed	Dismantling completed
FUKUSHIMA-DAINI-2	JP	BWR	3293	1067	1983	Ready-for-operation		2023	2031	In shutdown	In shutdown	Dismantling completed
FUKUSHIMA-DAINI-3	JP	BWR	3293	1067	1984	Ready-for-operation		2024	2032	In shutdown	In shutdown	Dismantling completed
FUKUSHIMA-DAINI-4	JP	BWR	3293	1067	1986	Ready-for-operation		2026	2034	In shutdown	In shutdown	Dismantling completed
G-2 (MARCOULE)	F	GCR	260	39	1959	In dismantling	1980	1980	1985	Dismantling completed	Dismantling completed	Dismantling completed
G-3 (MARCOULE)	F	GCR	260	40	1960	In dismantling	1984	1984	1989	Dismantling completed	Dismantling completed	Dismantling completed
GARIGLIANO	IT	BWR	506	150	1964	In dismantling	1982	1982	2000	Dismantling completed	Dismantling completed	Dismantling completed
GE VALLECITOS	USA	BWR	50	24	1957	In safe enclosure	1963	1963	1965	In safe enclosure	In safe enclosure	In safe enclosure
GENKAI-1	JP	PWR	1650	529	1975	In shutdown	2015			In shutdown	Dismantling completed	Dismantling completed
GENKAI-2	JP	PWR	1650	529	1980	Ready-for-operation		2020	2028	In shutdown	Dismantling completed	Dismantling completed
GENKAI-3	JP	PWR	3423	1127	1993	In operation		2033	2041	In operation	In shutdown	In shutdown
GENKAI-4	JP	PWR	3423	1127	1996	Ready-for-operation		2036	2044	In operation	In shutdown	In shutdown
GENTILLY-1	CAN	HWLWR	792	250	1971	In safe enclosure	1977	1977	1977	In safe enclosure	In safe enclosure	In safe enclosure

GENTILLY-2	CAN	PHWR	2165	635	1982	In safe enclosure	2012			In safe enclosure	In safe enclosure	In safe enclosure
GINNA	USA	PWR	1775	608	1969	In operation		2029	2031	In operation	In shutdown	Dismantling completed
GOESGEN	CH	PWR	3002	1010	1979	In operation		2029	2034	In operation	In shutdown	Dismantling completed
GOLFECH-1	F	PWR	3817	1310	1990	In operation		2050	2035	In operation	In operation	In operation
GOLFECH-2	F	PWR	3817	1310	1993	In operation		2053	2038	In operation	In operation	In operation
GRAFENRHEINFELD	GER	PWR	3765	1275	1981	In shutdown	2015		2018	In shutdown	Dismantling completed	Dismantling completed
GRAND GULF-1	USA	BWR	4408	1500	1984	In operation		2044	2046	In operation	In operation	In shutdown
GRAVELINES-1	F	PWR	2785	910	1980	In operation		2040	2025	In operation	In operation	In shutdown
GRAVELINES-2	F	PWR	2785	910	1980	In operation		2040	2025	In operation	In operation	In shutdown
GRAVELINES-3	F	PWR	2785	910	1980	In operation		2040	2025	In operation	In operation	In shutdown
GRAVELINES-4	F	PWR	2785	910	1981	In operation		2041	2026	In operation	In operation	In shutdown
GRAVELINES-5	F	PWR	2785	910	1984	In operation		2044	2029	In operation	In operation	In shutdown
GRAVELINES-6	F	PWR	2785	910	1985	In operation		2045	2030	In operation	In operation	In shutdown
GREIFSWALD-1	GER	PWR	1375	408	1973	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
GREIFSWALD-2	GER	PWR	1375	408	1974	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
GREIFSWALD-3	GER	PWR	1375	408	1977	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
GREIFSWALD-4	GER	PWR	1375	408	1979	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
GREIFSWALD-5	GER	PWR	1375	408	1989	In dismantling	1989	1989	1994	Dismantling completed	Dismantling completed	Dismantling completed
GROHNDE	GER	PWR	3900	1360	1984	In operation		2021	2026	In shutdown	Dismantling completed	Dismantling completed
GUNDREMMINGEN-A	GER	BWR	801	237	1966	In dismantling	1977	1977	1983	Dismantling completed	Dismantling completed	Dismantling completed
GUNDREMMINGEN-B	GER	BWR	3840	1284	1984	In shutdown	2017	2017	2022	Dismantling completed	Dismantling completed	Dismantling completed
GUNDREMMINGEN-C	GER	BWR	3840	1288	1984	In operation		2021	2026	In shutdown	Dismantling completed	Dismantling completed
HADDAM NECK	USA	PWR	1825	603	1967	Decommissioning completed	1996	1996	1998	Dismantling completed	Dismantling completed	Dismantling completed
HALLAM	USA	LWGR	256	84	1963	In safe enclosure	1964	1964	1966	In safe enclosure	In safe enclosure	In safe enclosure
HAMAOKA-1	JP	BWR	1593	515	1974	In safe enclosure	2009	2009	2017	In safe enclosure	In safe enclosure	In safe enclosure
HAMAOKA-2	JP	BWR	2463	806	1978	In safe enclosure	2009			In safe enclosure	In safe enclosure	In safe enclosure
HAMAOKA-3	JP	BWR	3293	1056	1987	Ready-for-operation		2027	2035	In operation	In shutdown	Dismantling completed
HAMAOKA-4	JP	BWR	3293	1092	1993	Ready-for-operation		2033	2041	In operation	In shutdown	In shutdown
HAMAOKA-5	JP	BWR	3926	1325	2004	Ready-for-operation		2044	2052	In operation	In operation	In shutdown
HANBIT-1	KOR	PWR	2787	997	1986	In operation		2026	2030	In shutdown	In shutdown	Dismantling completed
HANBIT-2	KOR	PWR	2787	984	1986	In operation		2026	2030	In shutdown	In shutdown	Dismantling completed
HANBIT-3	KOR	PWR	2825	994	1994	In operation		2034	2038	In operation	In shutdown	In shutdown
HANBIT-4	KOR	PWR	2825	980	1995	In operation		2035	2039	In operation	In shutdown	In shutdown
HANBIT-5	KOR	PWR	2825	994	2001	In operation		2041	2045	In operation	In operation	In shutdown

HANBIT-6	KOR	PWR	2825	993	2002	In operation		2042	2046	In operation	In operation	In shutdown
HANUL-1	KOR	PWR	2785	966	1988	In operation		2028	2032	In operation	In shutdown	Dismantling completed
HANUL-2	KOR	PWR	2775	967	1989	In operation		2029	2033	In operation	In shutdown	Dismantling completed
HANUL-3	KOR	PWR	2825	997	1998	In operation		2038	2042	In operation	In operation	In shutdown
HANUL-4	KOR	PWR	2825	999	1998	In operation		2038	2042	In operation	In operation	In shutdown
HANUL-5	KOR	PWR	2815	998	2003	In operation		2043	2047	In operation	In operation	In shutdown
HANUL-6	KOR	PWR	2825	997	2005	In operation		2045	2049	In operation	In operation	In shutdown
HARRIS-1	USA	PWR	2900	960	1987	In operation		2046	2048	In operation	In operation	In shutdown
HARTLEPOOL A-1	UK	GCR	1500	595	1983	In operation		2024	2034	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HARTLEPOOL A-2	UK	GCR	1500	585	1984	In operation		2024	2034	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HATCH-1	USA	BWR	2804	911	1974	In operation		2034	2040	In operation	In shutdown	Dismantling completed
HATCH-2	USA	BWR	2804	921	1978	In operation		2038	2040	In operation	In operation	In shutdown
HDR GROSSWELZHEIM	GER	BWR	100	25	1969	Decommissioning completed	1971	1983	1992	Dismantling completed	Dismantling completed	Dismantling completed
HEYSHAM A-1	UK	GCR	1500	580	1983	In operation		2024	2034	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HEYSHAM A-2	UK	GCR	1500	575	1984	In operation		2024	2034	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HEYSHAM B-1	UK	GCR	1550	610	1988	In operation		2030	2040	In operation	Vorbereitung sicherer Einschluss	In shutdown
HEYSHAM B-2	UK	GCR	1550	610	1988	In operation		2030	2040	In operation	Vorbereitung sicherer Einschluss	In shutdown
HIGASHI DORI-1 (TOHOKU)	JP	BWR	3293	1067	2005	Ready-for-operation		2045	2053	In operation	In operation	In shutdown
HINKLEY POINT A-1	UK	GCR	900	235	1965	Preparation for safe enclosure	2000			In safe enclosure	In safe enclosure	In safe enclosure
HINKLEY POINT A-2	UK	GCR	900	235	1965	Preparation for safe enclosure	2000			In safe enclosure	In safe enclosure	In safe enclosure
HINKLEY POINT B-1	UK	GCR	1494	475	1976	In operation		2023	2033	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HINKLEY POINT B-2	UK	GCR	1494	470	1976	In operation		2023	2033	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HOPE CREEK-1	USA	BWR	3840	1240	1986	In operation		2046	2048	In operation	In operation	In shutdown
HUMBOLDT BAY	USA	BWR	220	65	1963	In dismantling	1976	1976	1978	Dismantling completed	Dismantling completed	Dismantling completed
HUNTERSTON A-1	UK	GCR	595	150	1964	Preparation for safe enclosure	1990			In safe enclosure	In safe enclosure	In safe enclosure
HUNTERSTON A-2	UK	GCR	595	150	1964	Preparation for safe enclosure	1989			In safe enclosure	In safe enclosure	In safe enclosure
HUNTERSTON B-1	UK	GCR	1494	475	1976	In operation		2023	2033	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
HUNTERSTON B-2	UK	GCR	1494	485	1977	In operation		2023	2033	Vorbereitung sicherer Einschluss	In shutdown	In safe enclosure
IGNALINA-1	LIT	LWGR	4800	1185	1983	In dismantling	2004		2022	Dismantling completed	Dismantling completed	Dismantling completed

IGNALINA-2	LIT	LWGR	4800	1185	1987	In dismantling	2009		2022	Dismantling completed	Dismantling completed	Dismantling completed
IKATA-1	JP	PWR	1650	538	1977	Ready-for-operation		2017	2025	Dismantling completed	Dismantling completed	Dismantling completed
IKATA-2	JP	PWR	1650	538	1981	Ready-for-operation		2021	2029	In shutdown	Dismantling completed	Dismantling completed
IKATA-3	JP	PWR	2660	846	1994	Ready-for-operation		2034	2042	In operation	In shutdown	In shutdown
INDIAN POINT-1	USA	PWR	615	277	1962	In safe enclosure	1974			In safe enclosure	In safe enclosure	In safe enclosure
INDIAN POINT-2	USA	PWR	3216	1067	1973	In operation		2033	2037	In operation	In shutdown	Dismantling completed
INDIAN POINT-3	USA	PWR	3216	1085	1976	In operation		2035	2037	In operation	In shutdown	Dismantling completed
ISAR-1	GER	BWR	2575	878	1977	In shutdown	2011	2011	2017	Dismantling completed	Dismantling completed	Dismantling completed
ISAR-2	GER	PWR	3950	1410	1988	In operation		2022	2027	In shutdown	Dismantling completed	Dismantling completed
JOSE CABRERA-1	ES	PWR	510	141	1968	In dismantling	2006		2010	Dismantling completed	Dismantling completed	Dismantling completed
JPDR	JP	BWR	90	12	1963	Decommissioning completed	1976	1976	1986	Dismantling completed	Dismantling completed	Dismantling completed
KALININ-1	RUS	PWR	3000	950	1984	In operation		2044	2048	In operation	In operation	In shutdown
KALININ-2	RUS	PWR	3000	950	1986	In operation		2046	2050	In operation	In operation	In shutdown
KALININ-3	RUS	PWR	3200	950	2004	In operation		2049	2053	In operation	In operation	In operation
KALININ-4	RUS	PWR	3200	950	2011	In operation		2056	2060	In operation	In operation	In operation
KASHIWAZAKI KARIWA-1	JP	BWR	3293	1067	1985	Ready-for-operation		2025	2033	In shutdown	In shutdown	Dismantling completed
KASHIWAZAKI KARIWA-2	JP	BWR	3293	1067	1990	Ready-for-operation		2030	2038	In operation	In shutdown	Dismantling completed
KASHIWAZAKI KARIWA-3	JP	BWR	3293	1067	1992	Ready-for-operation		2032	2040	In operation	In shutdown	Dismantling completed
KASHIWAZAKI KARIWA-4	JP	BWR	3293	1067	1993	Ready-for-operation		2033	2041	In operation	In shutdown	In shutdown
KASHIWAZAKI KARIWA-5	JP	BWR	3293	1067	1989	Ready-for-operation		2029	2037	In operation	In shutdown	Dismantling completed
KASHIWAZAKI KARIWA-6	JP	BWR	3926	1315	1996	Ready-for-operation		2036	2044	In operation	In shutdown	In shutdown
KASHIWAZAKI KARIWA-7	JP	BWR	3926	1315	1996	Ready-for-operation		2036	2044	In operation	In shutdown	In shutdown
KEWAUNEE	USA	PWR	1772	595	1974	In shutdown	2013			Dismantling completed	Dismantling completed	Dismantling completed
KHMELNITSKI-1	UKR	PWR	3000	950	1987	In operation		2027	2033	In operation	In shutdown	Dismantling completed
KHMELNITSKI-2	UKR	PWR	3000	950	2007	In operation		2047	2053	In operation	In operation	In operation
KHMELNITSKI-3	UKR	PWR	3200	950		Under construction				In operation	In operation	In operation
KHMELNITSKI-4	UKR	PWR	3200	950		Under construction				In operation	In operation	In operation
KNK II	GER	FBR	58	17	1978	In dismantling	1991	1991	1996	Dismantling completed	Dismantling completed	Dismantling completed
KOLA-1	RUS	PWR	1375	411	1973	In operation		2026	2030	In shutdown	Dismantling completed	Dismantling completed
KOLA-2	RUS	PWR	1375	411	1974	In operation		2027	2031	In operation	Dismantling completed	Dismantling completed
KOLA-3	RUS	PWR	1375	411	1981	In operation		2034	2038	In operation	In shutdown	Dismantling completed
KOLA-4	RUS	PWR	1375	411	1984	In operation		2042	2046	In operation	In operation	In shutdown
KORI-1	KOR	PWR	1729	576	1977	In shutdown	2017	2017	2024	Dismantling completed	Dismantling completed	Dismantling completed
KORI-2	KOR	PWR	1882	640	1983	In operation		2023	2027	In shutdown	Dismantling completed	Dismantling completed

KORI-3	KOR	PWR	2912	1011	1985	In operation		2025	2029	In shutdown	In shutdown	Dismantling completed
KORI-4	KOR	PWR	2912	1012	1985	In operation		2025	2029	In shutdown	In shutdown	Dismantling completed
KOZLODUY-1	BUL	PWR	1375	408	1974	In dismantling	2002		2017	Dismantling completed	Dismantling completed	Dismantling completed
KOZLODUY-2	BUL	PWR	1375	408	1975	In dismantling	2002		2017	Dismantling completed	Dismantling completed	Dismantling completed
KOZLODUY-3	BUL	PWR	1375	408	1980	In dismantling	2006		2018	Dismantling completed	Dismantling completed	Dismantling completed
KOZLODUY-4	BUL	PWR	1375	408	1982	In dismantling	2006		2018	Dismantling completed	Dismantling completed	Dismantling completed
KOZLODUY-5	BUL	PWR	3000	963	1987	In operation		2047	2052	In operation	In operation	In operation
KOZLODUY-6	BUL	PWR	3000	963	1991	In operation		2051	2056	In operation	In operation	In operation
KRUEMMEL	GER	BWR	3690	1346	1983	In shutdown	2011		2019	Dismantling completed	Dismantling completed	Dismantling completed
KUOSHENG-1	TW	BWR	2894	1020	1981	In operation	2021	2021	2029	In shutdown	In shutdown	Dismantling completed
KUOSHENG-2	TW	BWR	2894	1020	1982	In operation	2022	2022	2030	In shutdown	In shutdown	Dismantling completed
KURSK-1	RUS	RBMK	3200	925	1976	In operation		2029	2033	In operation	In shutdown	Dismantling completed
KURSK-2	RUS	RBMK	3200	925	1979	In operation		2032	2036	In operation	In shutdown	Dismantling completed
KURSK-3	RUS	RBMK	3200	925	1983	In operation		2036	2040	In operation	In shutdown	Dismantling completed
KURSK-4	RUS	RBMK	3200	925	1985	In operation		2038	2042	In operation	In operation	Dismantling completed
LACROSSE	USA	BWR	165	55	1968	In dismantling	1987	1987	1989	Dismantling completed	Dismantling completed	Dismantling completed
LASALLE-1	USA	BWR	3546	1207	1982	In operation		2022	2025	In shutdown	Dismantling completed	Dismantling completed
LASALLE-2	USA	BWR	3546	1207	1984	In operation		2023	2025	In shutdown	Dismantling completed	Dismantling completed
LATINA	IT	GCR	660	153	1964	In dismantling	1987		2006	Dismantling completed	Dismantling completed	Dismantling completed
LEIBSTADT	CH	BWR	3600	1220	1984	In operation		2034	2039	In operation	In shutdown	In shutdown
LENINGRAD 2-1	RUS	PWR	3200	1085	2018	In operation				Dismantling completed	Dismantling completed	Dismantling completed
LENINGRAD 2-2	RUS	PWR	3200	1085		Under construction				In operation	In operation	In operation
LENINGRAD-1	RUS	RBMK	3200	925	1973	In operation		2026	2030	In shutdown	Dismantling completed	Dismantling completed
LENINGRAD-2	RUS	RBMK	3200	925	1975	In operation		2028	2032	In operation	Dismantling completed	Dismantling completed
LENINGRAD-3	RUS	RBMK	3200	925	1979	In operation		2032	2036	In operation	In shutdown	Dismantling completed
LENINGRAD-4	RUS	RBMK	3200	925	1981	In operation		2034	2038	In operation	In shutdown	Dismantling completed
LIMERICK-1	USA	BWR	3515	1194	1985	In operation		2024	2026	In shutdown	Dismantling completed	Dismantling completed
LIMERICK-2	USA	BWR	3515	1194	1989	In operation		2029	2031	In operation	In shutdown	Dismantling completed
LINGEN	GER	BWR	520	183	1968	In safe enclosure	1977	1977	1982	In safe enclosure	In safe enclosure	In safe enclosure
LUCENS	CH	HWGCR	28	6	1968	In safe enclosure	1969	1969	1974	In safe enclosure	In safe enclosure	In safe enclosure
LUNGMEN-1	TW	BWR	3926	1350		Under construction (discarded)						
LUNGMEN-2	TW	BWR	3926	1350		Under construction (discarded)						
MAANSHAN-1	TW	PWR	2822	951	1984	In operation	2024	2024	2032	In shutdown	In shutdown	Dismantling completed

MAANSHAN-2	TW	PWR	2822	951	1985	In operation	2025	2025	2033	In shutdown	In shutdown	In shutdown
MAINE YANKEE	USA	PWR	2630	900	1972	Decommissioning completed	1997	1997	1997	Dismantling completed	Dismantling completed	Dismantling completed
MCGUIRE-1	USA	PWR	3411	1215	1981	In operation		2041	2045	In operation	In operation	In shutdown
MCGUIRE-2	USA	PWR	3411	1215	1983	In operation		2043	2045	In operation	In operation	In shutdown
MIHAMA-1	JP	PWR	1031	320	1970	In shutdown	2015			In shutdown	Dismantling completed	Dismantling completed
MIHAMA-2	JP	PWR	1456	470	1972	In shutdown	2015			In shutdown	Dismantling completed	Dismantling completed
MIHAMA-3	JP	PWR	2440	780	1976	Ready-for-operation		2036	2044	In operation	In shutdown	In shutdown
MILLSTONE-1	USA	BWR	2011	684	1970	In safe enclosure	1998	1998	2000	In safe enclosure	In safe enclosure	In safe enclosure
MILLSTONE-2	USA	PWR	2700	918	1975	In operation		2035	2037	In operation	In shutdown	Dismantling completed
MILLSTONE-3	USA	PWR	3650	1280	1986	In operation		2045	2047	In operation	In operation	In shutdown
MOCHOVCE-1	SLO	PWR	1471	436	1998	In operation		2038	2042	In operation	In operation	In shutdown
MOCHOVCE-2	SLO	PWR	1471	436	1999	In operation		2039	2043	In operation	In operation	In shutdown
MOCHOVCE-3	SLO	PWR	1375	440		Under construction				In operation	In operation	In operation
MOCHOVCE-4	SLO	PWR	1375	440		Under construction				In operation	In operation	In operation
MONJU	JP	FBR	714	246	1995	In dismantling	1995	2022	2003	Dismantling completed	Dismantling completed	Dismantling completed
MONTICELLO	USA	BWR	2004	691	1971	In operation		2030	2032	In operation	In shutdown	Dismantling completed
MUEHLEBERG	CH	BWR	1097	373	1971	In operation		2019	2024	In shutdown	Dismantling completed	Dismantling completed
MUELHEIM-KAERLICH	GER	PWR	3760	1219	1986	In dismantling	1988	1988	1993	Dismantling completed	Dismantling completed	Dismantling completed
MZFR	GER	PHWR	200	52	1966	In dismantling	1984	1984	1989	Dismantling completed	Dismantling completed	Dismantling completed
NECKARWESTHEIM-1	GER	PWR	2497	785	1976	In shutdown	2011		2017	Dismantling completed	Dismantling completed	Dismantling completed
NECKARWESTHEIM-2	GER	PWR	3850	1310	1989	In operation		2022	2027	In shutdown	Dismantling completed	Dismantling completed
NIEDERAICHBACH	GER	HWGCR	321	100	1973	Decommissioning completed	1974	1974	1979	Dismantling completed	Dismantling completed	Dismantling completed
NINE MILE POINT-1	USA	BWR	1850	642	1969	In operation		2029	2031	In operation	In shutdown	Dismantling completed
NINE MILE POINT-2	USA	BWR	3988	1320	1987	In operation		2046	2048	In operation	In operation	In shutdown
NOGENT-1	F	PWR	3817	1310	1987	In operation		2047	2032	In operation	In operation	In operation
NOGENT-2	F	PWR	3817	1310	1988	In operation		2048	2033	In operation	In operation	In operation
NORTH ANNA-1	USA	PWR	2940	990	1978	In operation		2038	2042	In operation	In operation	In shutdown
NORTH ANNA-2	USA	PWR	2940	1011	1980	In operation		2040	2042	In operation	In operation	In shutdown
NOVOVORONEZH 2-1	RUS	PWR	3200	1114	2016	In operation		2076	2080	In operation	In operation	In operation
NOVOVORONEZH 2-2	RUS	PWR	3200	1114		Under construction				In operation	In operation	In operation
NOVOVORONEZH-1	RUS	PWR	760	197	1964	In dismantling	1988	1988	1992	Dismantling completed	Dismantling completed	Dismantling completed
NOVOVORONEZH-2	RUS	PWR	1320	336	1969	In dismantling	1990	1990	1994	Dismantling completed	Dismantling completed	Dismantling completed
NOVOVORONEZH-3	RUS	PWR	1375	385	1971	In operation		2024	2028	In shutdown	Dismantling completed	Dismantling completed
NOVOVORONEZH-4	RUS	PWR	1375	385	1972	In operation		2025	2029	In shutdown	Dismantling completed	Dismantling completed

NOVOVORONEZH-5	RUS	PWR	3000	950	1980	In operation		2035	2039	In operation	In shutdown	Dismantling completed
OBRIGHEIM	GER	PWR	1050	340	1968	In dismantling	2005	2005	2010	Dismantling completed	Dismantling completed	Dismantling completed
OCONEE-1	USA	PWR	2568	891	1973	In operation		2033	2036	In operation	In shutdown	Dismantling completed
OCONEE-2	USA	PWR	2568	891	1973	In operation		2033	2036	In operation	In shutdown	Dismantling completed
OCONEE-3	USA	PWR	2568	900	1974	In operation		2034	2036	In operation	In shutdown	Dismantling completed
OHI-1	JP	PWR	3423	1120	1977	Ready-for-operation		2017	2025	In shutdown	Dismantling completed	Dismantling completed
OHI-2	JP	PWR	3423	1120	1978	Ready-for-operation		2018	2026	In shutdown	Dismantling completed	Dismantling completed
OHI-3	JP	PWR	3423	1127	1991	In operation		2031	2039	In operation	In shutdown	Dismantling completed
OHI-4	JP	PWR	3423	1127	1992	Ready-for-operation		2032	2040	In operation	In shutdown	Dismantling completed
OHMA	JP	BWR	3926	1325		Under construction				In operation	In operation	In operation
OLDBURY A-1	UK	GCR	730	217	1967	In shutdown	2012			In safe enclosure	In safe enclosure	In safe enclosure
OLDBURY A-2	UK	GCR	660	217	1968	In shutdown	2011			In safe enclosure	In safe enclosure	In safe enclosure
ONAGAWA-1	JP	BWR	1593	498	1983	Ready-for-operation		2023	2031	In shutdown	In shutdown	Dismantling completed
ONAGAWA-2	JP	BWR	2436	796	1994	Ready-for-operation		2034	2042	In operation	In shutdown	In shutdown
ONAGAWA-3	JP	BWR	2436	796	2001	Ready-for-operation		2041	2049	In operation	In operation	In shutdown
OSKARSHAMN-1	SW	BWR	1375	492	1971	In shutdown	2017	2017	2020	Dismantling completed	Dismantling completed	Dismantling completed
OSKARSHAMN-2	SW	BWR	1800	661	1974	In shutdown	2015	2015	2020	Dismantling completed	Dismantling completed	Dismantling completed
OSKARSHAMN-3	SW	BWR	3900	1450	1985	In operation		2045	2046	In operation	In operation	In shutdown
OYSTER CREEK	USA	BWR	1930	652	1969	In operation		2019	2021	In shutdown	Dismantling completed	Dismantling completed
PALISADES	USA	PWR	2565	850	1971	In operation		2018	2020	In shutdown	Dismantling completed	Dismantling completed
PALO VERDE-1	USA	PWR	3990	1414	1985	In operation		2045	2049	In operation	In operation	In shutdown
PALO VERDE-2	USA	PWR	3990	1414	1986	In operation		2046	2049	In operation	In operation	In shutdown
PALO VERDE-3	USA	PWR	3990	1414	1987	In operation		2047	2049	In operation	In operation	In operation
PALUEL-1	F	PWR	3817	1330	1984	In operation		2044	2029	In operation	In operation	In shutdown
PALUEL-2	F	PWR	3817	1330	1984	In operation		2044	2029	In operation	In operation	In shutdown
PALUEL-3	F	PWR	3817	1330	1985	In operation		2045	2030	In operation	In operation	In shutdown
PALUEL-4	F	PWR	3817	1330	1986	In operation		2046	2031	In operation	In operation	In shutdown
PATHFINDER	USA	BWR	220	63	1966	Decommissioning completed	1967	1967	1991	Dismantling completed	Dismantling completed	Dismantling completed
PEACH BOTTOM-1	USA	HTGR	115	42	1967	In safe enclosure	1974	1974	1976	In safe enclosure	In safe enclosure	In safe enclosure
PEACH BOTTOM-2	USA	BWR	3514	1412	1974	In operation		2053	2056	In operation	In operation	In operation
PEACH BOTTOM-3	USA	BWR	3514	1412	1974	In operation		2054	2056	In operation	In operation	In operation
PENLY-1	F	PWR	3817	1330	1990	In operation		2050	2035	In operation	In operation	In operation
PENLY-2	F	PWR	3817	1330	1992	In operation		2052	2037	In operation	In operation	In operation
PERRY-1	USA	BWR	3758	1303	1986	In operation		2046	2048	In operation	In operation	In shutdown

PHENIX	F	FBR	345	130	1973	In shutdown	2010	2010	2015	Dismantling completed	Dismantling completed	Dismantling completed
PHILIPPSBURG-1	GER	BWR	2575	890	1979	In shutdown	2011	2011	2017	Dismantling completed	Dismantling completed	Dismantling completed
PHILIPPSBURG-2	GER	PWR	3950	1402	1984	In operation		2019	2024	In shutdown	Dismantling completed	Dismantling completed
PICKERING-1	CAN	PHWR	1744	515	1971	In operation		2022	2022	In shutdown	Dismantling completed	Dismantling completed
PICKERING-2	CAN	PHWR	1744	515	1971	In safe enclosure	2007			In safe enclosure	In safe enclosure	In safe enclosure
PICKERING-3	CAN	PHWR	1744	515	1972	In safe enclosure	2008			In safe enclosure	In safe enclosure	In safe enclosure
PICKERING-4	CAN	PHWR	1744	515	1973	In operation		2022	2022	In shutdown	Dismantling completed	Dismantling completed
PICKERING-5	CAN	PHWR	1744	516	1982	In operation		2024	2024	In shutdown	Dismantling completed	Dismantling completed
PICKERING-6	CAN	PHWR	1744	516	1983	In operation		2024	2024	In shutdown	Dismantling completed	Dismantling completed
PICKERING-7	CAN	PHWR	1744	516	1984	In operation		2024	2024	In shutdown	Dismantling completed	Dismantling completed
PICKERING-8	CAN	PHWR	1744	516	1986	In operation		2024	2024	In shutdown	Dismantling completed	Dismantling completed
PILGRIM-1	USA	BWR	2028	711	1972	In operation		2019	2021	In shutdown	Dismantling completed	Dismantling completed
PIQUA	USA	X	46	12	1963	In safe enclosure	1966	1966	1968	In safe enclosure	In safe enclosure	In safe enclosure
POINT BEACH-1	USA	PWR	1800	640	1970	In operation		2030	2035	In operation	In shutdown	Dismantling completed
POINT BEACH-2	USA	PWR	1800	640	1972	In operation		2033	2035	In operation	In shutdown	Dismantling completed
POINT LEPREAU	CAN	PHWR	2180	660	1982	In operation		2037	2037	In operation	In operation	Dismantling completed
PRAIRIE ISLAND-1	USA	PWR	1677	566	1973	In operation		2033	2036	In operation	In shutdown	Dismantling completed
PRAIRIE ISLAND-2	USA	PWR	1677	560	1974	In operation		2034	2036	In operation	In shutdown	Dismantling completed
QUAD CITIES-1	USA	BWR	2957	940	1972	In operation		2018	2020	In shutdown	Dismantling completed	Dismantling completed
QUAD CITIES-2	USA	BWR	2957	940	1972	In operation		2018	2020	In shutdown	Dismantling completed	Dismantling completed
RANCHO SECO-1	USA	PWR	2772	917	1974	Decommissioning completed	1989	1989	1991	Dismantling completed	Dismantling completed	Dismantling completed
RHEINSBERG	GER	PWR	265	62	1966	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
RINGHALS-1	SW	BWR	2540	910	1974	In operation		2020	2021	In shutdown	Dismantling completed	Dismantling completed
RINGHALS-2	SW	PWR	2652	963	1974	In operation		2019	2020	In shutdown	Dismantling completed	Dismantling completed
RINGHALS-3	SW	PWR	3135	1117	1980	In operation		2041	2042	In operation	In operation	In shutdown
RINGHALS-4	SW	PWR	3300	1171	1982	In operation		2043	2044	In operation	In operation	In shutdown
RIVER BEND-1	USA	BWR	3091	1016	1985	In operation		2045	2047	In operation	In operation	In shutdown
ROBINSON-2	USA	PWR	2339	780	1970	In operation		2030	2032	In operation	In shutdown	Dismantling completed
ROLPHTON NPD	CAN	PHWR	92	22	1962	In dismantling	1987	1987	1987	Dismantling completed	Dismantling completed	Dismantling completed
ROSTOV-1	RUS	PWR	3200	950	2001	In operation		2046	2050	In operation	In operation	In shutdown
ROSTOV-2	RUS	PWR	3200	950	2010	In operation		2055	2059	In operation	In operation	In operation
ROSTOV-3	RUS	PWR	3000	1011	2014	In operation		2059	2063	In operation	In operation	In operation
ROSTOV-4	RUS	PWR	3000	1011	2018	In operation				Dismantling completed	Dismantling completed	Dismantling completed
ROVNO-1	UKR	PWR	1375	381	1980	In operation		2020	2026	In shutdown	Dismantling completed	Dismantling completed

ROVNO-2	UKR	PWR	1375	376	1981	In operation		2021	2027	In shutdown	Dismantling completed	Dismantling completed
ROVNO-3	UKR	PWR	3000	950	1986	In operation		2026	2032	In shutdown	In shutdown	Dismantling completed
ROVNO-4	UKR	PWR	3000	950	2004	In operation		2044	2050	In operation	In operation	In shutdown
SALEM-1	USA	PWR	3459	1254	1976	In operation		2036	2038	In operation	In shutdown	In shutdown
SALEM-2	USA	PWR	3459	1200	1981	In operation		2040	2042	In operation	In operation	In shutdown
SAN ONOFRE-1	USA	PWR	1347	456	1967	Decommissioning completed	1992	1992	1994	Dismantling completed	Dismantling completed	Dismantling completed
SAN ONOFRE-2	USA	PWR	3438	1127	1982	In shutdown	2013		2019	Dismantling completed	Dismantling completed	Dismantling completed
SAN ONOFRE-3	USA	PWR	3438	1127	1983	In shutdown	2013		2019	Dismantling completed	Dismantling completed	Dismantling completed
SANTA MARIA DE GARONA	ES	BWR	1381	446	1971	In shutdown	2013	2013	2017	In shutdown	Dismantling completed	Dismantling completed
SAXTON	USA	PWR	24	3	1967	Decommissioning completed	1972	1972	1974	Dismantling completed	Dismantling completed	Dismantling completed
SEABROOK-1	USA	PWR	3648	1296	1990	In operation		2050	2052	In operation	In operation	In operation
SENDAI-1	JP	PWR	2660	846	1983	In operation		2023	2031	In shutdown	In shutdown	Dismantling completed
SENDAI-2	JP	PWR	2660	846	1985	In operation		2025	2033	In shutdown	In shutdown	Dismantling completed
SEQUOYAH-1	USA	PWR	3455	1221	1980	In operation		2040	2043	In operation	In operation	In shutdown
SEQUOYAH-2	USA	PWR	3455	1200	1981	In operation		2041	2043	In operation	In operation	In shutdown
SHIKA-1	JP	BWR	1593	505	1993	Ready-for-operation		2033	2041	In operation	In shutdown	In shutdown
SHIKA-2	JP	BWR	3926	1108	2005	Ready-for-operation		2045	2053	In operation	In operation	In shutdown
SHIMANE-1	JP	BWR	1380	439	1973	In shutdown	2015	2015	2023	In shutdown	Dismantling completed	Dismantling completed
SHIMANE-2	JP	BWR	2436	789	1988	Ready-for-operation		2028	2036	In operation	In shutdown	Dismantling completed
SHIMANE-3	JP	BWR	3926	1325		Under construction				In operation	In operation	In operation
SHIN-HANUL-1	KOR	PWR	3938	1340		Under construction				In operation	In operation	In operation
SHIN-HANUL-2	KOR	PWR	3983	1340		Under construction				In operation	In operation	In operation
SHIN-KORI-1	KOR	PWR	2825	999	2010	In operation		2050	2054	In operation	In operation	In operation
SHIN-KORI-2	KOR	PWR	2825	996	2012	In operation		2052	2056	In operation	In operation	In operation
SHIN-KORI-3	KOR	PWR	3983	1340	2016	In operation		2056	2060	In operation	In operation	In operation
SHIN-KORI-4	KOR	PWR	3938	1340		Under construction				In operation	In operation	In operation
SHIN-KORI-5	KOR	PWR	3983	1340		Unter construction				In operation	In operation	In operation
SHIN-WOLSONG-1	KOR	PWR	2825	997	2012	In operation		2052	2056	In operation	In operation	In operation
SHIN-WOLSONG-2	KOR	PWR	2825	993	2015	In operation		2055	2059	In operation	In operation	In operation
SHIPPINGPORT	USA	PWR	236	68	1957	Decommissioning completed	1982	1982	1985	Dismantling completed	Dismantling completed	Dismantling completed
SHOREHAM	USA	BWR	2436	849	1986	Decommissioning completed	1989	1989	1991	Dismantling completed	Dismantling completed	Dismantling completed
SIZEWELL A-1	UK	GCR	1010	210	1966	In shutdown	2006			In safe enclosure	In safe enclosure	In safe enclosure
SIZEWELL A-2	UK	GCR	1010	210	1966	In shutdown	2006			In safe enclosure	In safe enclosure	In safe enclosure

SIZEWELL B	UK	PWR	3425	1198	1995	In operation		2035	2045	In operation	Vorbereitung sicherer Einschluss	In shutdown
SMOLENSK-1	RUS	RBMK	3200	925	1982	In operation		2035	2039	In operation	In shutdown	Dismantling completed
SMOLENSK-2	RUS	RBMK	3200	925	1985	In operation		2038	2042	In operation	In operation	Dismantling completed
SMOLENSK-3	RUS	RBMK	3200	925	1990	In operation		2042	2046	In operation	In operation	In shutdown
SOUTH TEXAS-1	USA	PWR	3853	1354	1988	In operation		2047	2050	In operation	In operation	In operation
SOUTH TEXAS-2	USA	PWR	3853	1354	1989	In operation		2048	2050	In operation	In operation	In operation
SOUTH UKRAINE-1	UKR	PWR	3000	950	1982	In operation		2022	2028	In shutdown	In shutdown	Dismantling completed
SOUTH UKRAINE-2	UKR	PWR	3000	950	1985	In operation		2025	2031	In shutdown	In shutdown	Dismantling completed
SOUTH UKRAINE-3	UKR	PWR	3000	950	1989	In operation		2029	2035	In operation	In shutdown	Dismantling completed
ST. ALBAN-1	F	PWR	3817	1335	1985	In operation		2045	2030	In operation	In operation	In shutdown
ST. ALBAN-2	F	PWR	3817	1335	1986	In operation		2046	2031	In operation	In operation	In shutdown
ST. LAURENT A-1	F	GCR	1650	390	1969	In dismantling	1990	1990	1995	Dismantling completed	Dismantling completed	Dismantling completed
ST. LAURENT A-2	F	GCR	1475	465	1971	In dismantling	1992	1992	1997	Dismantling completed	Dismantling completed	Dismantling completed
ST. LAURENT B-1	F	PWR	2785	915	1981	In operation		2041	2026	In operation	In operation	In shutdown
ST. LAURENT B-2	F	PWR	2785	915	1981	In operation		2041	2026	In operation	In operation	In shutdown
ST. LUCIE-1	USA	PWR	3020	1045	1976	In operation		2036	2038	In operation	In shutdown	In shutdown
ST. LUCIE-2	USA	PWR	3020	1050	1983	In operation		2043	2045	In operation	In operation	In shutdown
STADE	GER	PWR	1900	640	1972	In dismantling	2003	2003	2008	Dismantling completed	Dismantling completed	Dismantling completed
SUMMER-1	USA	PWR	2900	1006	1982	In operation		2042	2044	In operation	In operation	In shutdown
SUMMER-2	USA	PWR		1250		Under construction (discarded)						
SUMMER-3	USA	PWR		1250		Under construction (discarded)						
SUPER-PHENIX	F	FBR	3000	1200	1986	In dismantling	1998	1998	2003	Dismantling completed	Dismantling completed	Dismantling completed
SURRY-1	USA	PWR	2587	890	1972	In operation		2052	2055	In operation	In operation	In operation
SURRY-2	USA	PWR	2587	890	1973	In operation		2053	2055	In operation	In operation	In operation
SUSQUEHANNA-1	USA	BWR	3952	1330	1982	In operation		2042	2046	In operation	In operation	In shutdown
SUSQUEHANNA-2	USA	BWR	3952	1330	1984	In operation		2044	2046	In operation	In operation	In shutdown
TAKAHAMA-1	JP	PWR	2440	780	1974	Ready-for-operation		2034	2042	In operation	In shutdown	In shutdown
TAKAHAMA-2	JP	PWR	2440	780	1975	Ready-for-operation		2035	2043	In operation	In shutdown	In shutdown
TAKAHAMA-3	JP	PWR	2660	830	1984	In operation		2024	2032	In shutdown	In shutdown	Dismantling completed
TAKAHAMA-4	JP	PWR	2660	830	1984	In operation		2024	2032	In shutdown	In shutdown	Dismantling completed
THREE MILE ISLAND-1	USA	PWR	2568	880	1974	In operation		2034	2036	In operation	In shutdown	Dismantling completed
THREE MILE ISLAND-2	USA	PWR	2772	959	1978	In safe enclosure	1979			In safe enclosure	In safe enclosure	In safe enclosure

THTR-300	GER	HTGR	760	296	1985	In safe enclosure	1988	1988	1993	In safe enclosure	In safe enclosure	In safe enclosure
TIHANGE-1	BE	PWR	2873	962	1975	In operation		2025	2030	In shutdown	In shutdown	Dismantling completed
TIHANGE-2	BE	PWR	3064	1008	1982	In operation		2023	2028	In shutdown	In shutdown	Dismantling completed
TIHANGE-3	BE	PWR	3000	1038	1985	In operation		2025	2030	In shutdown	In shutdown	Dismantling completed
TOKAI-1	JP	GCR	587	137	1965	In safe enclosure	1998			In safe enclosure	In safe enclosure	In safe enclosure
TOKAI-2	JP	BWR	3293	1060	1978	Ready-for-operation		2018	2026	In shutdown	Dismantling completed	Dismantling completed
TOMARI-1	JP	PWR	1650	550	1988	Ready-for-operation		2028	2036	In operation	In shutdown	Dismantling completed
TOMARI-2	JP	PWR	1650	550	1990	Ready-for-operation		2030	2038	In operation	In shutdown	Dismantling completed
TOMARI-3	JP	PWR	2660	866	2009	Ready-for-operation		2049	2057	In operation	In operation	In operation
TORNESS-1	UK	GCR	1623	590	1988	In operation		2030	2040	In operation	Vorbereitung sicherer Einschluss	In shutdown
TORNESS-2	UK	GCR	1623	595	1989	In operation		2030	2040	In operation	Vorbereitung sicherer Einschluss	In shutdown
TRAWSFYNYDD-1	UK	GCR	850	195	1965	Preparation for safe enclosure	1991			In safe enclosure	In safe enclosure	In safe enclosure
TRAWSFYNYDD-2	UK	GCR	850	195	1965	Preparation for safe enclosure	1991			In safe enclosure	In safe enclosure	In safe enclosure
TRICASTIN-1	F	PWR	2785	915	1980	In operation		2040	2025	In operation	In operation	In shutdown
TRICASTIN-2	F	PWR	2785	915	1980	In operation		2040	2026	In operation	In operation	In shutdown
TRICASTIN-3	F	PWR	2785	915	1981	In operation		2041	2026	In operation	In operation	In shutdown
TRICASTIN-4	F	PWR	2785	915	1981	In operation		2041	2026	In operation	In operation	In shutdown
TRILLO-1	ES	PWR	3010	1003	1988	In operation		2024	2028	In shutdown	In shutdown	Dismantling completed
TROJAN	USA	PWR	3411	1155	1975	Decommissioning completed	1992	1992	1993	Dismantling completed	Dismantling completed	Dismantling completed
TSURUGA-1	JP	BWR	1070	340	1969	In shutdown	2015	2015	2023	In shutdown	Dismantling completed	Dismantling completed
TSURUGA-2	JP	PWR	3411	1108	1986	Ready-for-operation		2026	2034	In shutdown	In shutdown	Dismantling completed
TURKEY POINT-3	USA	PWR	2644	829	1972	In operation		2032	2035	In operation	In shutdown	Dismantling completed
TURKEY POINT-4	USA	PWR	2644	829	1973	In operation		2033	2035	In operation	In shutdown	Dismantling completed
UNTERWESER	GER	PWR	3900	1345	1978	In shutdown	2011		2017	Dismantling completed	Dismantling completed	Dismantling completed
VAK KAHL	GER	BWR	60	15	1961	Decommissioning completed	1985	1985	1988	Dismantling completed	Dismantling completed	Dismantling completed
VANDELLOS-1	ES	GCR	1670	480	1972	In dismantling	1990		2028	Dismantling completed	Dismantling completed	Dismantling completed
VANDELLOS-2	ES	PWR	2941	1045	1987	In operation		2020	2024	In shutdown	Dismantling completed	Dismantling completed
VERMONT YANKEE	USA	BWR	1912	635	1972	In shutdown	2014	2014	2016	Dismantling completed	Dismantling completed	Dismantling completed
VOGTLE-1	USA	PWR	3626	1229	1987	In operation		2047	2051	In operation	In operation	In operation
VOGTLE-2	USA	PWR	3626	1229	1989	In operation		2049	2051	In operation	In operation	In operation
VOGTLE-3	USA	PWR		1250		Under construction				In operation	In operation	In operation
VOGTLE-4	USA	PWR		1250		Under construction				In operation	In operation	In operation
WATERFORD-3	USA	PWR	3716	1250	1985	In operation		2044	2046	In operation	In operation	In shutdown

WATTS BAR-1	USA	PWR	3459	1210	1996	In operation		2035	2037	In operation	In shutdown	Dismantling completed
WATTS BAR-2	USA	PWR	3411	1218	2016	In operation		2055	2057	In operation	In operation	In operation
WINDSCALE AGR	UK	GCR	120	24	1963	In dismantling	1981	1981	1991	Dismantling completed	Dismantling completed	Dismantling completed
WINFRITH SGHWR	UK	SGHWR	318	92	1967	In dismantling	1990	1990	2000	Dismantling completed	Dismantling completed	Dismantling completed
WOLF CREEK	USA	PWR	3565	1285	1985	In operation		2045	2047	In operation	In operation	In shutdown
WOLSONG-1	KOR	PHWR	2061	657	1982	In operation		2022	2026	In shutdown	Dismantling completed	Dismantling completed
WOLSONG-2	KOR	PHWR	2061	652	1997	In operation		2037	2041	In operation	In operation	In shutdown
WOLSONG-3	KOR	PHWR	2061	665	1998	In operation		2038	2042	In operation	In operation	In shutdown
WOLSONG-4	KOR	PHWR	2061	669	1999	In operation		2039	2043	In operation	In operation	In shutdown
WUERGASSEN	GER	BWR	1912	640	1971	Decommissioning completed	1994	1994	1997	Dismantling completed	Dismantling completed	Dismantling completed
WYLFA-1	UK	GCR	1650	490	1971	In shutdown	2015	2015	2025	In safe enclosure	In safe enclosure	In safe enclosure
WYLFA-2	UK	GCR	1920	490	1971	In shutdown	2012	2012	2022	In safe enclosure	In safe enclosure	In safe enclosure
YANKEE NPS	USA	PWR	600	180	1960	Decommissioning completed	1992	1992	1994	Dismantling completed	Dismantling completed	Dismantling completed
ZAPOROZHYE-1	UKR	PWR	3000	950	1984	In operation		2024	2030	In shutdown	In shutdown	Dismantling completed
ZAPOROZHYE-2	UKR	PWR	3000	950	1985	In operation		2025	2031	In shutdown	In shutdown	Dismantling completed
ZAPOROZHYE-3	UKR	PWR	3000	950	1986	In operation		2026	2032	In shutdown	In shutdown	Dismantling completed
ZAPOROZHYE-4	UKR	PWR	3000	950	1987	In operation		2027	2033	In operation	In shutdown	Dismantling completed
ZAPOROZHYE-5	UKR	PWR	3000	950	1989	In operation		2029	2035	In operation	In shutdown	Dismantling completed
ZAPOROZHYE-6	UKR	PWR	3000	950	1995	In operation		2035	2041	In operation	In shutdown	In shutdown
ZION-1	USA	PWR	3250	1085	1973	In dismantling	1998	1998	2000	Dismantling completed	Dismantling completed	Dismantling completed
ZION-2	USA	PWR	3250	1085	1973	In dismantling	1998	1998	2000	Dismantling completed	Dismantling completed	Dismantling completed

***Table B**: Aggregated status of countries' nuclear reactors according to Scenario 1 for 2017, 2037 and 2047 in [MW] (without discarded construction* and partly dismantled reactors**). The reactors' electrical capacity is summarized per country and per status. Database is the extended PRIS dataset shown in Table A in the annex.*

	In operation				In shutdown				In dismantling				In safe enclosure				Dismantling completed			
	2018	**2027**	**2037**	**2047**	**2018**	**2027**	**2037**	**2047**	**2018**	**2027**	**2037**	**2047**	**2018**	**2027**	**2037**	**2047**	**2018**	**2027**	**2037**	**2047**
BE	5913	0	0	0	0	5913	0	0	10	0	4907	0	0	0	0	0	0	10	1016	5923
BUL	1926	1926	1926	1926	0	0	0	0	1632	0	0	0	0	0	0	0	0	1632	1632	1632
CAN	13524	10430	7440	6780	0	0	0	0	22	3094	2990	0	2121	2121	2121	2121	0	22	3116	6766
CH	3333	2960	0	0	0	0	1220	0	0	373	1740	1220	6	6	6	6	0	0	373	2113
ES	7121	0	0	0	446	1003	0	0	621	6564	1003	0	0	0	0	0	0	621	7185	8188
F	63130	64730	64730	22915	130	0	0	22875	3409	0	0	18940	0	0	0	0	0	3539	3539	3539
GER	9515	0	0	0	10981	4055	0	0	4620	6735	0	0	479	479	479	479	780	15106	25896	25896
IT	0	0	0	0	0	0	0	0	1423	0	0	0	0	0	0	0	0	1423	1423	1423
JP	5606	27742	7812	3516	2636	11360	16468	4296	4792	5398	12688	11530	1606	1606	1606	1606	12	5342	12874	30500
KOR	22497	22556	18649	10685	576	4644	1974	1995	0	657	5937	7943	0	0	0	0	0	576	1873	7810
LIT	0	0	0	0	0	0	0	0	2370	0	0	0	0	0	0	0	0	2370	2370	2370
RUS	28653	27823	18972	11036	0	2106	4696	2850	786	0	2786	2286	0	0	0	0	0	2882	6357	16639
SLO	1814	1752	1752	880	0	942	0	0	909	0	942	872	0	0	0	0	0	909	909	1851
SW	8994	7121	7121	0	1153	0	0	0	0	1873	0	7121	1242	1242	1242	1242	0	1153	3026	3026
TW	5214	0	0	0	0	4578	0	0	0	636	5214	951	0	0	0	0	0	0	0	4263
UK	8883	4643	0	0	2026	0	0	0	361	0	4240	4643	0	4354	4354	8594	0	361	361	361
UKR	13107	8550	3800	2850	0	5700	950	950	2590	757	9500	950	925	925	925	925	0	2590	3347	12847
USA	105403	90864	57711	19665	3996	3677	9527	12430	2290	13874	26106	31930	3262	3262	3262	3262	5650	10339	25410	54729
Total	**304633**	**271097**	**189913**	**80253**	**21944**	**43978**	**34835**	**45396**	**25835**	**39961**	**78053**	**88386**	**9641**	**13995**	**13995**	**18235**	**304633**	**271097**	**189913**	**80253**

*: Status "Under construction (discarded)": 2700 MW in Taiwan (LUNGMEN-1, LUNGMEN-2) and 2500 MW in USA (SUMMER-2 and SUMMER-3) (in 2018, and assumed for 2017, 2037 and 2047 as well).

**: Status "Partly dismantled": 250 MW in CHINON A-1 and CHINON A-2 in France (in 2018, and assumed for 2017, 2037 and 2047 as well).

[a] Based on IAEA PRIS database and own research.
[b] Based on IAEA PRIS database and own research.
[c] Based on IAEA PRIS database and own research.
[d] Based on IAEA PRIS database and own research, see data in Annex, Table A.
[e] Based on PRIS IAEA database and own research.
[f] Based on PRIS IAEA database and own research.
[g] Based on research results depicted in Table 6.
[h] Based on IAEA PRIS database, https://www.iaea.org/pris/, last access: 10 April 2018.
[i] Based on own data in the in Annex, Table A.