EU-Japan Centre for Industrial Cooperation

Nuclear Decommissioning in Japan
-Opportunities for European Companies-

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Executive Summary

The decommissioning of nuclear power plants is currently gaining increased momentum in Japan. However, since decommissioning has in many cases only started after the Fukushima nuclear accidents, most projects are not yet very advanced. Several lingering uncertainties and unsolved problems, such as the method for the retrieval of the fuel debris from the damaged reactors of the Fukushima No. 1 nuclear power plant or the management of the radioactive waste, threaten to lead to serious delays and increased costs. Despite these issues, several new projects were announced in early 2015, while the future of other nuclear power plants remains uncertain. For these reasons, the market will likely see further growth in the future, which is expected to increase demand for foreign products and services. Therefore, now seems to be a good time for European companies to position themselves early on the market, despite the limited demand in the present, due to the early state of many such projects in Japan.

The reason for the current limited demand is due to several structural characteristics of the market in Japan: The close relationship between the utilities and the large industrial corporations and the preference of domestic companies as main contractors make it difficult for external companies to gain direct access to this market. This is especially the case in the field of robotics, where domestic companies have strong strategic business interests. The decommissioning projects are managed by the nuclear operators, but actual work is usually contracted to the major Japanese industrial corporations and construction companies, which in turn employ further subcontractors. This indirect access as a subcontractor of a Japanese company offers the best opportunities for European companies.

In order to be successful under these circumstances, European companies should consider to work together with Japanese partners seeking foreign technologies to complement their own technology. The area of R&D, in particular fundamental R&D, research into alternative technologies and technical feasibility studies, also seems to offer good opportunities for European activities. Many organisations in Japan are interested in the practical experiences gained in Europe. Applied R&D, especially for Fukushima, is more difficult to access, as Japanese companies with strong interests in this field have a significant stake in the organisation responsible for carrying out such projects. In any case, an excellent reputation in the industry and established business relations with Japanese companies are essential “ingredients” for the European companies with ambitions on this market. While SMEs in the nuclear industry, with their highly specialised product portfolio, could also find opportunities in the market for nuclear decommissioning in Japan, the start-ups are likely to face serious obstacles as they will often lack the all-important connections and means to support business in Japan.

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List of Abbreviations

General terms	
NPP	Nuclear power plant
D&D	Dismantling & deconstruction
JPY	Japanese Yen
JFY	Japanese Fiscal Year
Technical terms	
PCV	Primary Containment Vessel
RPV	Reactor Pressure Vessel
SFP	Spent-Fuel Pool
Magnox	Magnesium, non-oxidising
MOX fuel	Mixed-oxide fuel
PWR	Pressurised Water Reactor
BWR	Boiling Water Reactor
ABWR	Advanced Boiling Water Reactor
ATR	Advanced Thermal Reactor
FNR	Fast Neutron Reactor
JPDR	Japan Power Demonstration Reactor
MWe	Megawatt electrical
Rad-waste	Radioactive waste
LLW	Low-level radioactive waste
ILW	Intermediate-level radioactive waste
HLW	High-level radioactive waste
L1 waste	Relatively high-level radioactive waste
L2 waste	Relatively low-level radioactive waste
L3 waste	Very low-level radioactive waste
ALPS	Advanced Liquid Processing System
Bq	Becquerel
Sv	Sievert
H	Hydrogen (H-3: tritium)
C	Carbon
Cl	Chlorine
K	Potassium
Mn	Manganese
Fe	Iron
Co	Cobalt
Ni	Nickel
Zn	Zinc
Sr	Strontium
Nb	Niobium
Ru	Ruthenium
I	Iodine
Cs	Caesium
Eu	Europium
U	Uranium
Np	Neptunium

Pu	Plutonium
Am	Americium
Organisations	
LDP	Liberal Democratic Party
DP	Democratic Party
TEPCO	Tokyo Electric Power Company, Limited
Kansai EPCO, KEPCO, Kanden	Kansai Electric Power Company, Limited
JAPCO, Genden	Japan Atomic Power Company, Limited
Chugoku EPCO, CEPCO, Energia	Chugoku Electric Power Company, Limited
Hokkaido EPCO, HEPCO, Hokuden	Hokkaido Electric Power Company, Limited
Chubu EPCO, Chuden	Chubu Electric Power Company, Limited
Tohoku EPCO	Tohoku Electric Power Company, Limited
Hokuriku EPCO, Hokuden, Rikuden	Hokuriku Electric Power Company, Limited
Shikoku EPCO, Yonden	Shikoku Electric Power Company, Limited
Kyushu EPCO, Kyuden	Kyushu Electric Power Company, Limited
MHI	Mitsubishi Heavy Industries, Limited
JNFL	Japan Nuclear Fuel Limited
JAEA	Japan Atomic Energy Agency
JSME	Japan Society of Mechanical Engineers
Randec	Radwaste and Decommissioning Center
IAEA	International Atomic Energy Agency
METI	Ministry of Economy, Trade & Industry
MEXT	Ministry of Education, Culture, Sports & Technology
MOE	Ministry of the Environment
MLIT	Ministry of Land, Infrastructure, Transport & Tourism
EURATOM	European Atomic Energy Community
NUMO	Nuclear Waste Management Organisation of Japan
NDF	Nuclear Damage Compensation & Decommissioning Facilitation Corporation
IRID	International Research Institute for Nuclear Decommissioning
CLADS	Collaborative Laboratories for Advanced Decommissioning Science
TEPCO D&D Co.	Tokyo Electric Power Company Fukushima Dai-Ichi Deconstruction & Dismantling Engineering Company
NRA	Nuclear Regulation Authority
NSC	Nuclear Safety Commission
NISA	Nuclear & Industrial Safety Agency
JNES	Japan Nuclear Energy Safety Organisation
AEC	Atomic Energy Commission
NSIC	Nuclear Safety Investigation Commission
NDA	Nuclear Decommissioning Authority
CEA	French Alternative Energies and Atomic Energy Commission
JST	Japan Science and Technology Agency
ANR	French National Research Agency
EPSRC	Engineering and Physical Sciences Research Council

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Introduction

The Fukushima accidents in March 2011 have been a turning point for the nuclear industry of Japan. Before Fukushima, Japan intended to vastly expand its construction program for new nuclear power plants (NPP) and to increase the share of nuclear power to 60% of its total electricity generation capacity. The accidents raised fundamental questions about the safety and endurance of NPPs in the country while exposing that the regulatory and disaster response system was not adequate to deal with a nuclear emergency of this scale. Combined with strong popular opposition to nuclear power and several earlier scandals, which had eroded the reputation of the industry, the future of the Japanese NPPs seemed open. And even though nuclear power is now expected to remain a major source of electricity generation in Japan, the Fukushima accidents brought the decommissioning of NPPs into the spotlight: The four heavily damaged reactors needed to be decommissioned, doubling the number of reactors in decommissioning from four to eight. The reformed regulatory agency, the Nuclear Regulation Authority (NRA), introduced, together with stricter requirements for plant safety and disaster resilience, a 40-year maximum operational limit for NPPs, with the option of a single extension for another 20 years. The implementation of the updated safety regulations and the lengthy re-licensing process have meant that the Japanese NPPs remained shut-down for much longer than initially assumed, with only two plants restarted so far. The stricter safety regulations also made the operation of older reactors with low output increasingly unprofitable for their operators. Together with the two remaining reactors at the Fukushima No. 1 nuclear power plant (Fukushima I NPP), the announcement of the decommissioning of five old reactors in March 2015 has now brought the total number of reactors in decommissioning to 15.

While decommissioning has received increased attention after the Fukushima accidents, it is not a completely new phenomenon in Japan. Nuclear decommissioning, defined as the gradual removal of regulatory controls from a nuclear facility [1], began with the Japan Power Demonstration Reactor (JPDR), the first reactor in Japan. Until the Fukushima accidents, decommissioning activities continued with a relatively low profile and priority. Three commercial reactors and one experimental reactor entered decommissioning during this time. The explosion of the number of decommissioning projects since the Fukushima accidents is likely to increase demand for decommissioning-related products and services, both in Japan and abroad. Major European nuclear companies are already beginning to position themselves on the market in anticipation of this growing demand. At the same time, decommissioning in Japan has some peculiarities that sets it apart from practices in Europe. A small number of large Japanese industrial corporations maintain a very influential position on the market, preferring to grant subcontracts to their own subsidiaries and affiliates. At the same time, the number of plant

[1] Laraia 2012

operators is quite high. The disposal of decommissioning waste poses a serious problem, with existing disposal concepts currently relying on on-site solutions for most of the radioactive waste. Furthermore, the continued unavailability of the domestic reprocessing plant makes the management of spent fuel increasingly problematic. Many technical – and some regulatory – issues for the decommissioning of Fukushima I remain unsolved, particularly due to the still limited understanding of the situation inside the damaged reactors. Understanding these peculiarities is central for successful business in Japan.

This report is structured as follows: **Part I** provides a brief overview of decommissioning in Japan to familiarise the reader with the particularities of the Japanese approach to decommissioning, the regulatory framework, and relevant organisations. **Part II** discusses the current decommissioning projects in more detail. The part includes short characterisations of the individual decommissioning projects. **Part III** follows with an analysis of the market for nuclear decommissioning. This part describes the typical pattern of how foreign companies are currently involved in nuclear decommissioning in Japan and outlines the demand for specialised technologies in both conventional projects and the Fukushima I decommissioning project. **Part IV** briefly discusses strategies to enter the market for nuclear decommissioning in Japan. The report ends with **conclusions and recommendations**. Appendix A provides a list of Japanese organisations involved in the nuclear industry.

This report focuses on the decommissioning of commercial and experimental power reactors. The decommissioning of research reactors and other nuclear facilities, technical specifications for decommissioning-related products and the decontamination of off-site areas affected by the Fukushima nuclear accidents are not covered. Efforts have been made to keep this report within reasonable length and to provide the most relevant information in a concise manner. More detailed information on many aspects of decommissioning can be found in the cited references, which are recommended for further study. The data and content given in this report is based on interviews with experts familiar with the field, research papers, official publications, and a visit of the Fugen decommissioning project in April 2015. Great care has been taken to confirm the facts and data stated in this report, but no independent verification by third parties has been made so far. While the report is mainly targeted at companies and organisations active in the field of nuclear decommissioning, the author hopes that readers unfamiliar with the subject are also able to acquire a general understanding of nuclear decommissioning in Japan and the business opportunities for foreign companies on this market.

Part I: Decommissioning in Japan

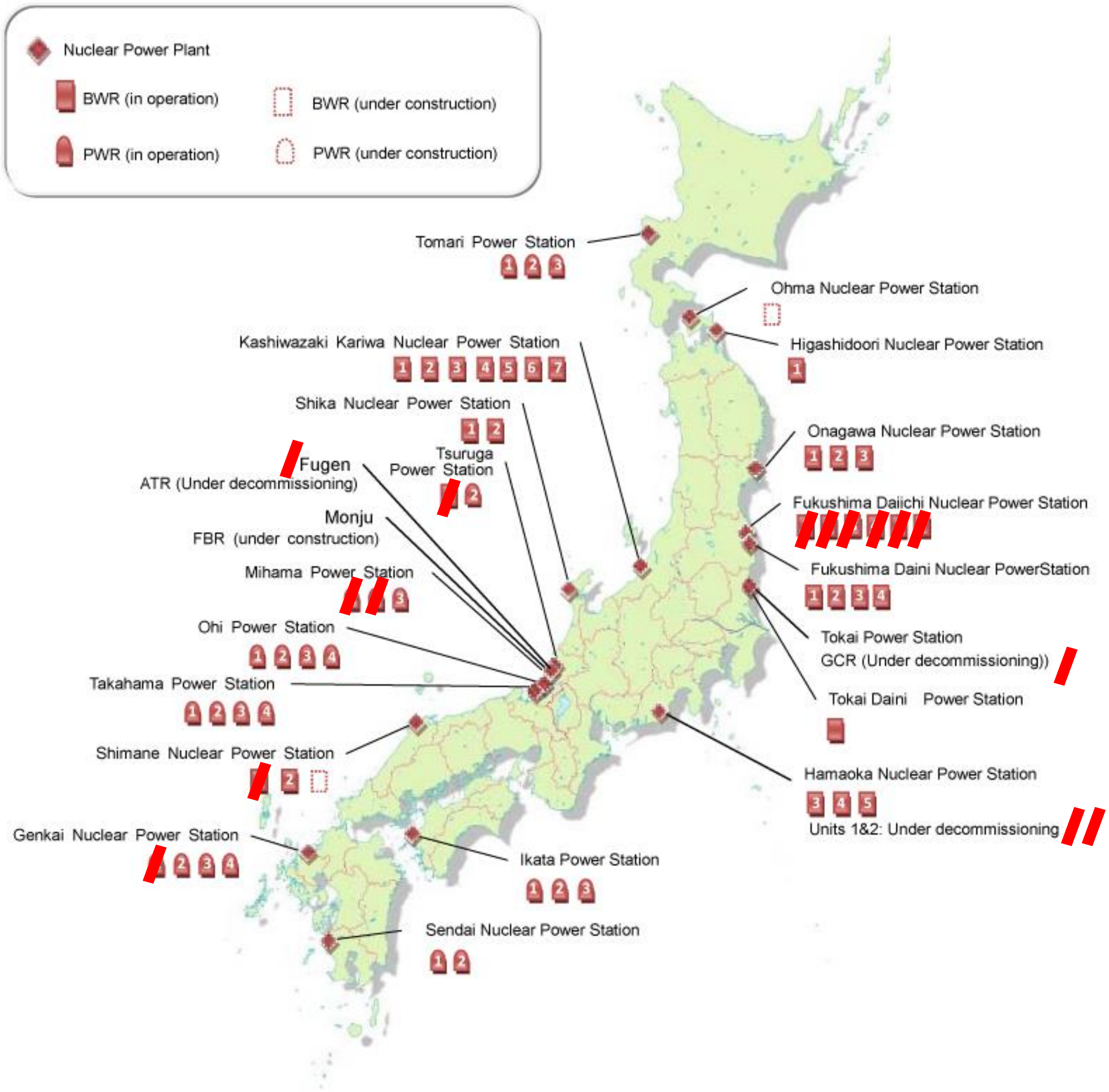
This chapter is mainly intended to familiarise the reader with decommissioning in Japan and its unique features. Section I.1 introduces nuclear power in Japan (section I.1), followed by a discussion of the basic decommissioning strategy in Japan (section I.2), and the regulatory framework (section I.3). Section I.4 provides an overview of waste management strategies in Japan, a major and highly problematic component of the decommissioning process (section I.4). The fifth section describes major organisations involved in decommissioning, primarily to help European companies to identify potential business partners and relevant organisations (section I.5). The discussed organisations are usually only the major organisations in the respective area. A more detailed list of organisations can be found in the appendix. The final section discusses the funding of decommissioning in Japan (section I.6).

I.1 The current situation of nuclear power in Japan

The use of nuclear power for electricity generation in Japan started in the 1950s with imported British and American reactor technology. The three large industrial corporations Mitsubishi Heavy Industries (MHI), Toshiba and Hitachi became involved in the construction of nuclear reactors and the first domestic reactor designs emerged. Next to the power plants themselves, a supporting industry for the operation of NPPs as well as the mining of uranium and the fabrication and transportation of nuclear fuel developed, again with strong involvement of the three industrial conglomerates, as well as major trading companies, steel makers and construction companies. Since then, Japanese companies have become world leaders in the construction of nuclear reactors, with about 400 domestic companies having business interests in the field[2]. The share of nuclear power in the domestic energy production steadily increased, culminating in the plan to raise the percentage to up to 60% of the total electricity generation capacity. 60 commercial and experimental power reactors have been built at 21 sites[3]. Map 1 shows the location of the Japanese power reactors. The largest number of reactors is concentrated in Fukui prefecture. A second cluster of nuclear reactors can be found in the neighbouring prefectures of Fukushima and Ibaraki. Aomori prefecture also hosts a number of nuclear facilities, including the Rokkasho reprocessing plant, but most of the facilities in the prefecture are not yet in operation.

[2] The nuclear divisions of the two primary builders of nuclear reactors in the Western world are now affiliated with Japanese industrial conglomerates – the joint venture GE-Hitachi Nuclear Energy, formed in 2007, and Westinghouse Electric Co., owned by Toshiba since 2006.

[3] Tsuruga NPP and Fugen NPP share the same location, as do the JPDR, Tokai I and Tokai II NPP. The decommissioning of the JPDR, a 12 MWe BWR, was completed in 1996.



Map 1: NPPs in Japan (in red: reactors in decommissioning)[4]

[4] Source: https://www.oecd-nea.org/news/2011/NEWS-02.html

The Fukushima accidents in March 2011 marked a turning point for nuclear power in Japan. All nuclear plants in operation were shut down in the aftermath of the accidents, initially mostly for regular maintenance. **Most reactors have remained shut down** ever since. The new regulatory agency, the NRA, implemented stricter safety regulations for commercial NPPs and mandated a lengthy re-licensing process to ensure compliance with the new regulations. Costly investments in safety-related upgrades and the lengthy re-licensing process have made it increasingly unattractive to operate small, older NPPs. For this reason, Japanese utilities announced that they will not seek to restart five old reactors. These reactors will now be decommissioned instead. The Fukushima II NPP, primarily for political reasons, might also not be restarted. Furthermore, the maximum operational limit for commercial nuclear reactors was set to 40 years of operation in order to opt out of nuclear power on a step-by-step basis. A nuclear operator can apply at the NRA for a one-time licence extension of another 20 years in exceptional cases. This sets a definite limit for the operational life of nuclear reactors and allows a forecast on the future development of the market for nuclear decommissioning in Japan. Table 1 shows the operational NPPs in Japan and how long they have been in operation. As can be seen, without lifetime extension, the operational licence of many reactors will expire within the next 15 years of operation.

This issue has recently gained new momentum when the NRA in principle approved the lifetime extension of reactor units 1 and 2 of the Takahama NPP, the two oldest reactors still in service. Under the current legislation, the final decision on this matter must be made by the NRA until July 2016. If the approval process is not completed by that time, the reactors will have to be decommissioned. The strict time limit for the completion of this process has raised some fears that the safety assessment of the reactors might be rushed in order to make the deadline. Even though lifetime extension was originally intended to be limited to exceptional cases, the legislation has remained quite vague on the conditions for eligibility[5]. Customary application for lifetime extension could make the limit basically meaningless in practice.

[5] Both the operational limit and the rules regarding lifetime extension can be found in the amended version of the Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors

as of March 2016

Nuclear Power Plant	Net Capacity (MWe)	Operator[6]	Type[7]	Prefecture	Application for Re-licencing	Operational Years			
Takahama NPP[8]	3220	Kansai EP	PWR (4)	Fukui	07/13 (units 3,4) 03/15 (units 1,2)	41	40	31	30
Mihama NPP	780	Kansai EP	PWR (1)	Fukui	03/15	39			
Ikata NPP[9]	1922	Shikoku EP	PWR (3)	Ehime	07/13 (unit 3)	38	34	21	
Tokai II NPP	1060	JAPCO	BWR (1)	Ibaraki	05/14	37			
Ohi NPP	4494	Kansai EP	PWR (4)	Fukui	07/13 (units 3, 4)	37	36	24	23
Genkai NPP	2783	Kyushu EP	PWR (3)	Saga	07/13 (units 3,4)	35	22	18	
Fukushima II NPP	4268	TEPCO	BWR (4)	Fukushima		33	32	30	28
Onagawa NPP	2090	Tohoku EP	BWR (3)	Miyagi	12/13 (unit 2)	31	20	14	
Sendai NPP	1692	Kyushu EP	PWR (2)	Kagoshima	07/13	31	30		
Kashiwazaki-Kariwa NPP	7965	TEPCO	BWR (5), ABWR (2)	Niigata	09/13 (units 6,7)	30 25	25 19	22 18	21
Tsuruga NPP	1110	JAPCO	PWR (1)	Fukui	11/15	29			
Hamaoka NPP	3473	Chubu EP	BWR (2), ABWR (1)	Shizuoka	02/14 (unit 4) 06/15 (unit 3)	28	22	11	
Shimane NPP	791	Chugoku EP	BWR (1)	Shimane	12/13 (unit 2)	27			
Tomari NPP	1966	Hokkaido EP	PWR (3)	Hokkaido	07/13	26	24	6	
Shika NPP	1809	Hokuriku EP	BWR (1), ABWR (1)	Ishikawa	08/14 (unit 2)	22	10		
Higashidori NPP	1067	Tohoku EP	BWR (1)	Aomori	06/14	10			
Monju NPP	280	JAEA[10]	FNR (1)	Fukui		20[11]			

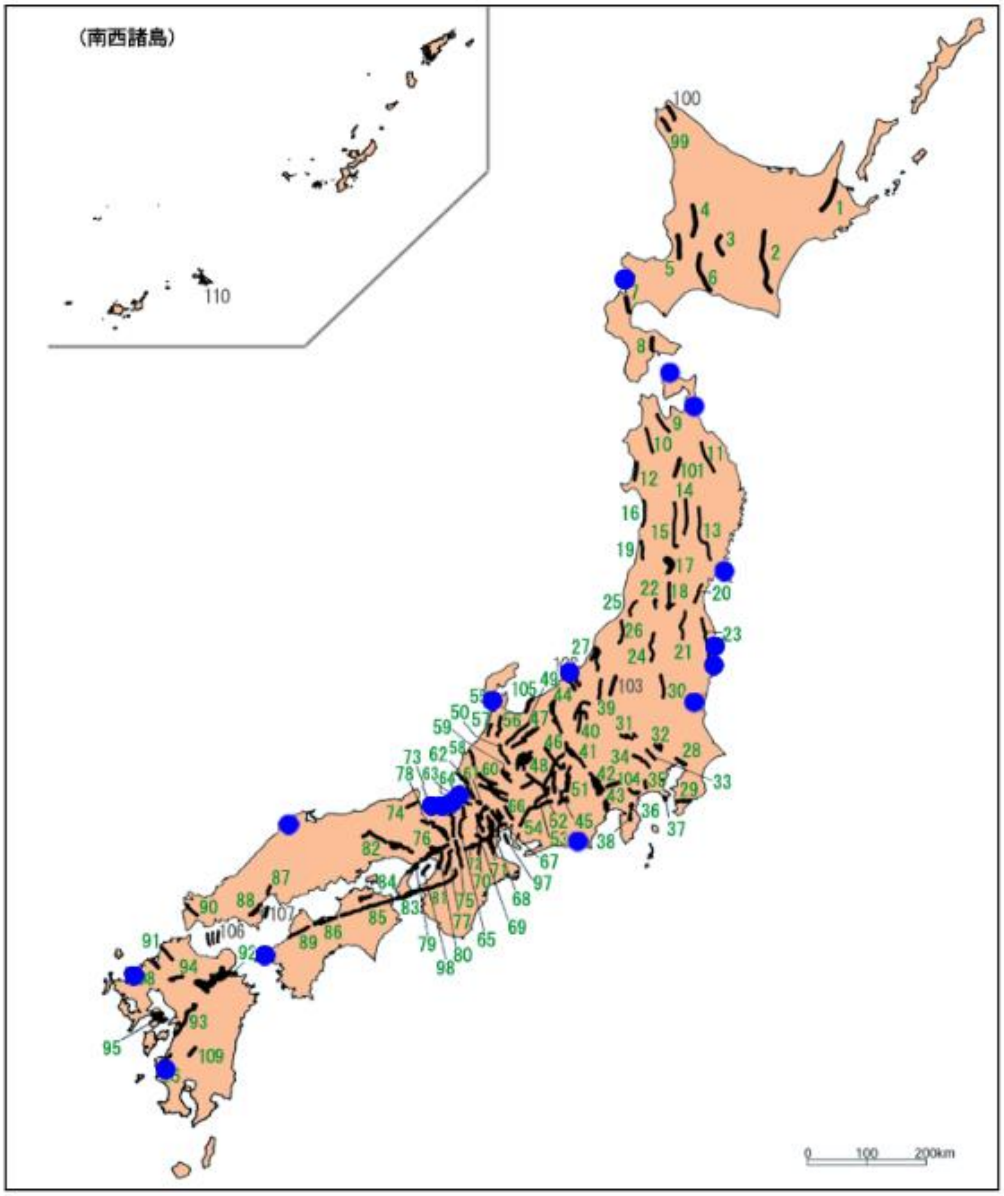
Table 1: Current operational commercial and experimental nuclear reactors in Japan[12]

Legend: Green = restarted reactors ・ Red = Reactors with 30 or more years of service ・ Blue = Reactors with less than 30 years of service ・ Orange = lifetime extension under consideration

In the changed public and political climate after the Fukushima accidents, it was even considered to completely opt out of nuclear power, similar to some European countries. However, this was reconsidered after the re-election of the Liberal Democratic Party (LDP) and Japan now seems to be set to continue the use of nuclear power, albeit at a reduced scale. According to the energy mix targets for 2030, announced in May 2015, nuclear power will make up 20 to 25% of the total electricity generation. To reach and maintain this target, Japan will likely have to build new NPPs in the future, but it is unclear whether the necessary support of local governments and the public can be secured and whether the utilities are willing to invest in new reactors. Even the restarting of the remaining reactors has been severely slowed down by protests, lawsuits and safety

[6] The utilities have a regional monopoly in their respective region. JAPCO (Japan Atomic Power Company) provides energy for all utilities. TEPCO stands for Tokyo Electric Power Company and serves the Kanto region.
[7] BWR: Boiling Water Reactor, ABWR: Advanced Boiling Water Reactor, PWR: Pressurised Water Reactor, FNR: Fast Neutron Reactor. The number in brackets indicate the number of operational reactors.
[8] Only Units 3 & 4. The Otsu District Court ordered the halt of operations on 9 March 2016
[9] Only Unit 3
[10] The operator of Monju is currently under review
[11] Actual operation: August 1995 – December 1995 and May 2010 – August 2010
[12] Source: http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan and own research

concerns. Scientists and regulators suspect active faults under many reactors, including Tsuruga NPP and Shika NPP (see Map 2). If the NRA upholds this assessment, these reactors cannot be restarted under the current legislation.



Map 2: Active fault lines and locations of NPPs[13]

To reduce Japan's dependence on fossil fuel imports, the new LDP-led administration, headed by Prime Minister Shinzo Abe, increased the pressure on the NRA to speed up the re-licensing

[13] NRA 2013

process. In August 2015, four years after the Fukushima nuclear accidents, the first restart of a commercial nuclear reactor was approved by the NRA and the stakeholders[14] and reactor unit 2 of Sendai NPP re-commenced commercial operation. Reactor unit 1 of the Sendai plant followed in October, while the NRA and local governments authorised the restart of unit 3 of Ikata NPP on Shikoku island in November, which is expected to re-commence commercial operations in early 2016. The NRA had also greenlighted the restart of reactor units 3 and 4 of Takahama NPP in Fukui prefecture, but a court in the prefecture issued an injunction to prevent this temporarily. This interdiction was reversed by the Fukui District Court in December 2015. Reactor unit 3 was restarted in late January 2016. Two incidents in quick succession delayed the restart of unit 4[15] and raised the question whether the restart approval was granted too fast. The Otsu District Court issued another temporary injunction against the operation of the two reactors on 9 March 2016.

Public opinion in Japan remains strongly anti-nuclear. Several scandals and incidents in the 1990s undermined public trust in the safety culture of the Japanese nuclear industry[16]. The accidents at the Fukushima I NPP have only reinforced this opinion, with many people expressing their wish to see nuclear power replaced by safe and environment-friendly renewables, similar to the *Energiewende* policy followed by Germany. Despite the popular opposition, the current LDP administration plans to retain nuclear power as an important pillar of domestic electricity generation.

While R&D in next-generation reactor technologies is continuing at some universities and research institutes in the country, the development of a domestic fast breeder reactor has been a history of disappointing setbacks. Monju, an experimental fast breeder reactor, has only operated for short times due to malfunctions and accidents. The latest setback came in November 2015, when the NRA, doubtful whether its operator, the Japan Atomic Energy Agency (JAEA), could ensure the safe operation of the plant, issued a recommendation to transfer the management of the facility to a new, not yet specified organisation. Since there is no other organisation in Japan with comparable expertise in the operation of fast breeder reactors, this move will likely put the operations at Monju on hold for the next years. More and more voices are therefore advocating for the decommissioning of the plant. Next to Monju, only two more reactors are currently under construction in Japan: Unit 3 of the Shimane NPP[17] and Unit 1 of

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[14] Principally the local and prefectural governments.

[15] A coolant leak on 20 January 2016 and an automatic shutdown after problems with a generator and transformer on 29 February 2016

[16] These accidents included a sodium leak at the Monju experimental reactor in 1996 and the 1999 criticality accident with two deaths at a fuel fabrication plant in Tokai.

[17] Construction of Shimane-3, a 1373 MWe ABWR, began in 2005, but was suspended after the Fukushima accidents. The METI approved the recommencing of construction in 2012, and the unit is scheduled to be completed in March 2016. The operator has not yet applied for an operational licence under the new safety regulations.

Ohma NPP[18] in Aomori prefecture. The development of a commercial reprocessing plant, underway since the late 1980s at the Rokkasho nuclear complex and centrepiece of the Japanese closed fuel cycle strategy, also remains unfinished, with new safety requirements recently pushing back the begin of commercial operations to 2018.

I.2 The basic decommissioning strategy

Decommissioning is the responsibility of the operator of a nuclear facility. The NRA defines the decommissioning of NPPs in Japan by the following four activities: Dismantling of the relevant reactor facilities (1), transfer of nuclear fuel (2), removal of irradiated material (3), and the disposal of radioactive waste (4)[19]. Within these boundaries, nuclear operators can design their own decommissioning strategies. The currently preferred approach for commercial NPPs in Japan combines immediate dismantling with deferred dismantling. Immediate dismantling is a strategy where dismantling begins immediately after the approval of the project, whereas in deferred dismantling, the reactor is first placed in safe storage for a number of years to reduce the radioactive inventory. The operators of commercial power reactors in Japan have opted for such safe storage periods, but the dismantling of secondary facilities will begin as soon as possible.

Like the decommissioning strategies of many other countries, the basic decommissioning strategy in Japan consists of **sequential stages**: Site preparation (including site characterisation, defueling and decontamination), safe storage, and deconstruction & dismantling (D&D) (see Figure 1). Waste management and disposal is also a part of the decommissioning process. The basic strategy envisions this as only becoming an issue during the D&D stage, but in practice waste from decommissioning also needs to be handled at earlier stages. While this is acknowledged in the individual decommissioning plans for Japanese reactors, lingering problems with waste management have led to delays in some ongoing decommissioning projects (see the description of the individual decommissioning projects in Part II and the discussion of waste management later in this chapter). The newest decommissioning plans also show a tendency for more prolonged safe storage periods.

[18] Ohma-1 is a 1383 MWe ABWR, built for J-Power since 2010. Construction was also suspended from 2011 to 2012. The plant is scheduled to be completed in 2022. J-Power applied for an operational licence under the new safety regulations on 16 December 2014

[19] This definition can be found in rule No. 119 for commercial NPPs and rule No. 114 for experimental NPPs

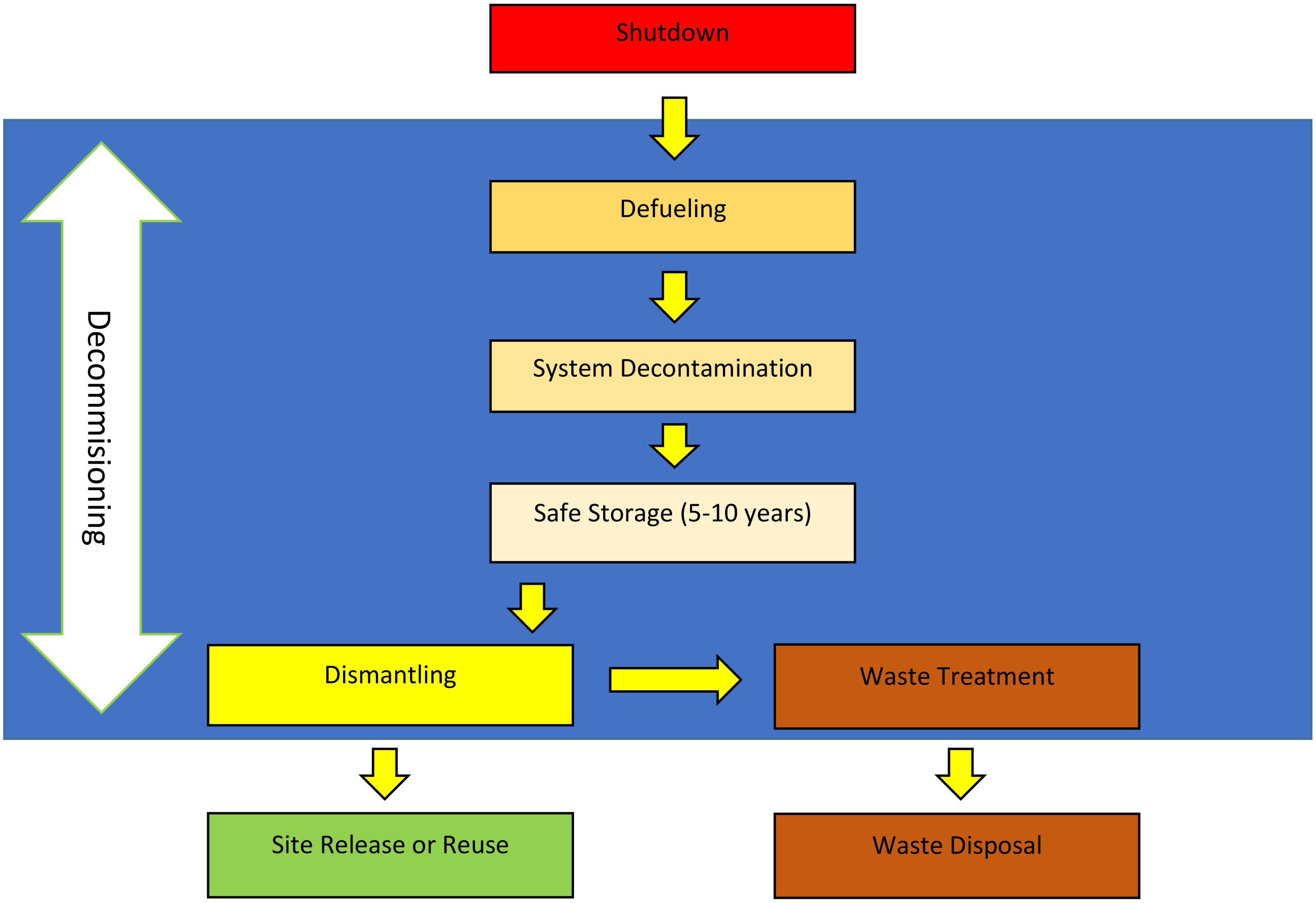

Figure 1: Basic decommissioning strategy in Japan[20]

In the first stage of the decommissioning project, the fuel in the reactor core and the spent fuel pool (SFP) is retrieved and transported to either a temporary storage site[21] or a reprocessing plant[22]. After a survey and characterisation of the radioactive inventory of the facility, systems and facilities are decontaminated to reduce the radioactive dose rates in the work spaces and to prepare the site for dismantling.

[20] Source: JAPCO & University of Fukui 2015

[21] JNFL has some storage capacity at its reprocessing plant at Rokkasho, and additional storage capacity for TEPCO and JAPCO spent fuel has been built at Mutsu near Rokkasho. Furthermore, the SFPs of other NPPs might also serve as makeshift temporary storage facilities. Several utilities are considering to build additional storage facilities

[22] Since the commercial reprocessing plant at Rokkasho is still under construction, most reprocessing so far has taken place in France or the UK

In the second stage, the reactor core is placed in safe storage, during which basic safety, monitoring and cooling systems are maintained. This stage is meant to reduce the radioactive inventory in the reactor through natural decay processes. The duration of this phase is usually around 10 years for physicochemical reasons, but a certain period of relative inactivity in the decommissioning process might also be necessary for some utilities to recover the financial losses from the premature or long-term shut-down of the reactor after the Fukushima accidents (see part I.6). The dismantling of non-essential and redundant systems and peripheral facilities also begins at this point.

The safe storage stage is followed by the D&D stage. During this phase, again in a number of sequential steps, the various components of the reactor are dismantled. This stage sees the highest demand for specialised equipment, particularly during the dismantling of the highly radioactive reactor pressure vessel (RPV) and its internals, where remote-controlled, submersible equipment is required for safety reasons. After the reactor has been dismantled, the reactor building and the remaining facilities are dismantled. Large quantities of waste, both radioactive and non-radioactive (see section I.4), are generated in this stage. The Japanese strategy envisions the implementation of strategies to reduce the amount of waste, through means such as a clearance system and the recycling of non-radioactive waste.

At the end of the decommissioning process an application for verification of completion is submitted to the NRA, which then assesses the final state of the site. If the measurable radioactive dose rates are within the legal limits and all targets of the decommissioning plan have been reached, the NRA formally terminates the licence of the operator and releases the site from regulatory control. The site of the former reactor can then be reused for new purposes. The current plan is to build new reactors on the sites of decommissioned reactors, due to difficulties in acquiring sites for new reactors and an expected unwillingness of the local population to develop the land of the former NPP for agricultural or residential purposes[23]. However, in light of strengthened safety regulations, stricter licensing criteria and growing opposition to the operation of NPPs in the surrounding communities and local governments, it is not yet known if this strategy will be economically and politically feasible.

I.3 Regulation

The Fukushima accidents have resulted in an overhaul of the legal and regulatory system for decommissioning. Before Fukushima, the main laws concerning the Japanese decommissioning strategy were the Atomic Energy Basic Law[24] and the Law for the Regulation of Nuclear Source

[23] Due to the remote location of almost all Japanese NPPs, industrial and commercial development is also rather unlikely.

[24] Law No. 186, 19 December 1955

Material, Nuclear Fuel Material and Reactors[25], both dating from the earliest days of the Japanese nuclear programme. Responsibility for supervising the decommissioning process was shared between the Ministry of Economy, Trade and Industry (METI) and the Ministry of Education, Culture, Sports and Technology (MEXT). The METI was responsible for commercial power reactors and reprocessing plants, while the MEXT would supervise the decommissioning of experimental and research facilities. The METI, with the attached Nuclear and Industrial Safety Agency (NISA), would also be responsible for safety-related regulation. The decommissioning of the nuclear facility was in any case the responsibility of the owner of the facility.

After Fukushima, the Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors was partially amended in the Act for Establishment of a Nuclear Regulation Authority in 2012[26]. The newly established Nuclear Regulation Authority (NRA) assumed responsibility for nuclear safety, including safety during the decommissioning process. The NRA was placed under the Ministry of the Environment (MOE) to separate safety regulation and economic interests. Nuclear operators, who remain responsible for the decommissioning of their facilities, were required to prepare decommissioning plans for their facilities as part of the re-licensing process.

After the end of commercial operation and the shut-down of the reactor, the operator of the facility submits his finalised decommissioning plan to the NRA. This plan is – in principle – unique for each project and includes plant parameters, service history, the radioactive inventory, the schedule of the project, a safety analysis, the estimated waste volume and the desired end state of the facility. A **Japanese-language outline** is disclosed to the public when the plan is submitted to the NRA[27]. The NRA assesses the compliance with the law and the safety regulations and approves the plan if all criteria are met.

After receiving the regulator's approval, the on-site work can start. The execution of the decommissioning plan has to strictly follow the schedule described in the approved decommissioning plan. Any change requires approval by the NRA. The completion of each stage also needs to be confirmed by the NRA before work on the next stage can continue. This can take considerable time. While the NRA is responsible for safety-related supervision and regulation, supervision of the facility owner remains the responsibility of the METI and the MEXT. The contractors carrying out decommissioning-related work are usually supervised by the METI.

Furthermore, The NRA has the responsibility to inspect the final state of the facility and decide whether the site can be released from regulatory control or not (see Figure 2). Since the NRA is currently dedicating most of its resources to the re-licensing and lifetime extension of the

[25] Law No. 166, 10 June 1957, as amended
[26] Law No. 47, July 2012
[27] The exception is the roadmap for the decommissioning of the Fukushima I NPP, for which the full text is publicly available in both Japanese and English. The outlines of the other projects can be accessed on the websites of the respective utilities

Japanese NPPs, decommissioning-related activities currently seem to be of rather low priority[28]. In the case of Fugen, NRA officials make a brief visit to the reactor three times per week and conduct a safety inspection every three months.

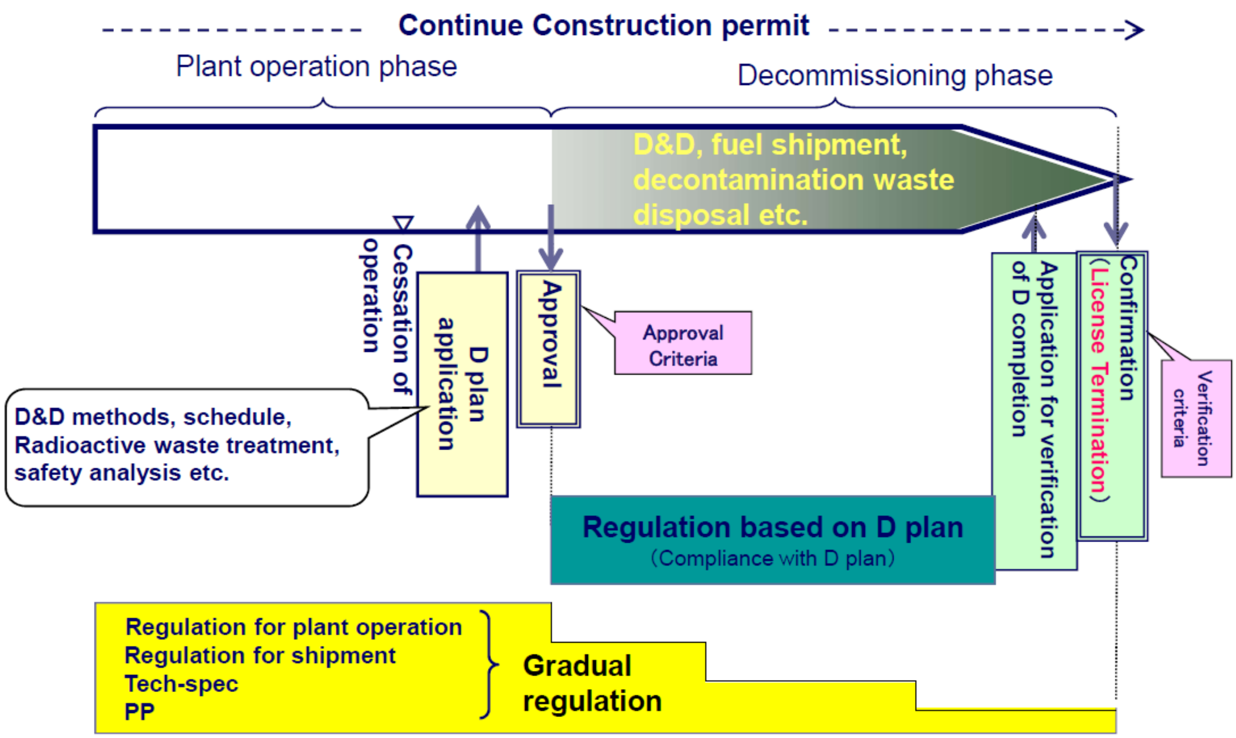

Figure 2: Safety regulation for decommissioning in Japan[29]

I.4 Waste management and disposal

One of the central problems and cost factors in nuclear decommissioning is the disposal of the accrued waste, especially the radioactive waste. Waste generated during decommissioning is made up of primary waste, waste originating from the reactor and its peripheral facilities, and secondary waste, waste generated during the decommissioning process. The radioactive waste is subject to specific regulations[30] and usually requires specially engineered, purpose-built repositories for disposal. Such a disposal site needs to be able to contain the material safely for an extended period of time, with limited or no interactions with the environment. Next to pure

[28] Especially in regard to conventional decommissioning projects

[29] Source: JAPCO & University of Fukui 2015

[30] While HLW-related regulation is mostly confined to a single law, the Law on Final Disposal of High-Level Radioactive Waste (Law No. 117, 7 June 2000), LLW-related regulation seems to be very convoluted, with applicable laws such as the Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors and the Law No. 157 (13 December 1999) as well as many ordinances for specific aspects.

technical and regulatory aspects, political and economic considerations as well as stakeholder influence also play a role in the selection and construction of a disposal facility. Due to problems with finding suitable sites under these circumstances, a number of disposal concepts have been developed in Japan (see the following sections). However, except for a local solution for low-level radioactive waste (LLW) in both the JPDR and the Tokai I NPP decommissioning projects, the question of **radioactive waste disposal remains largely unsolved** in Japan.

Radioactive waste management also involves conditioning, packaging and – in the case of an off-site repository – the transportation of the waste. Conditioning is done to change the waste into a form suitable for compact and safe storage and to minimise the release of radionuclides into the environment. The packaging in purpose-built containers further improves shielding, allowing the safe handling, transportation and disposal of the waste. The design of these containers is not standardised in Japan, but strict safety regulations are in place. There is also no exclusively licenced manufacturer for such containers. Design specifications and safety regulations for some types of waste containers, including the containers for the fuel debris from the damaged reactors of Fukushima I NPP, are not yet in place. Japanese authorities are currently investigating relevant safety standards of the International Atomic Energy Agency (IAEA), and the eventually adopted regulation will likely mirror these standards[31]. The transportation of radioactive waste requires special safety precautions. Experience in Europe has shown that the transportation of radioactive waste can attract demonstrations of anti-nuclear activist groups, significantly increasing the costs of such transports.

However, not all waste from a nuclear facility needs such extensive treatment and precautions. Activation through exposure to ionising radiation is usually confined to the RPV and the biological shield of the reactor. In other areas of the facility, for example the components of the primary cooling and heat exchange cycle, radioactive contamination might also be present, but this is often limited to surfaces. Whereas activated material usually needs to be disposed of as radioactive waste, contaminated surfaces can be decontaminated with chemical and mechanical technologies (see section III.1.2). Japan has introduced a clearance system to allow the unrestricted release of decontaminated material. Non-radioactive and clearance-level waste can be recycled or disposed of with conventional technologies[32]. Table 2 shows the expected amount of waste for a 1,100 MWe reactor in Japan. Since Japan currently does not have a repository for high-level waste and the disposal methods for other types of radioactive waste are also still not fully established, **waste minimisation strategies are currently receiving strong attention**.

[31] In particular IAEA GSR Part 5 and SSR-5

[32] For market opportunities in conventional waste management and recycling see Yolin 2015

Category	BWR		PWR	
	Unit: 1000t	Conditioned waste for disposal	Unit: 1000t	Conditioned waste for disposal
Relatively high-level waste	0.1 (0.02%)	100m^3	0.2 (0.04%)	260m^3
Relatively low-level waste	2 (0.4%)	1600m^3	3 (0.6%)	2400m^3
Very low-level waste	10 (1.8%)	7200m^3	3 (0.6%)	2800m^3
Less than clearance level	530 (96.4%)		490 (98%)	
Total	550	8900m^3	500	5460m^3

Table 2: Estimation of waste arising from the dismantling of a Reference NPP (1,100MWe)[33]

The IAEA divides radioactive waste into three principal categories: low-level waste (LLW), intermediary level waste (ILW) and high-level waste (HLW), each defined by the activity concentration and half-life of the radionuclides in the material[34]. Japan uses a somewhat different terminology, and only recognises two basic categories, LLW and HLW. LLW is further divided into **very low-level waste** (L3 waste), **relatively low-level waste** (L2 waste) and **relatively high-level waste** (L1 waste). Table 3 gives an overview of the categorisation of the three types of LLW and the clearance definition in Japan.

Category	Dose rate	Disposal
Relatively high-level β・γ waste	Upper limit Np-237: 1.3x10^{10} Bq/t, C-14: 5.2x10^{14} Bq/t etc.	Upper limit (L1 repository) Cl-36 : 1.0x10^{13} Bq/t, C-14 : 1.0x10^{16} Bq/t etc.
Relatively low-level waste	Upper limit Total α: 1.11x10^{9} Bq/t, Co-60: 1.1x10^{13} Bq/t etc.	Upper limit (L2 repository) Co-60: 1.0x10^{15} Bq/t, Cs-137: 1.0x10^{14} Bq/t etc.
Very low-level waste	Upper limit Total α: 1.7x10^{7} Bq/t, Co-60: 8.1x10^{9} Bq/t etc.	Upper limit (L3 repository) Co-60: 1.0x10^{10} Bq/t, Cs-137: 1.0x10^{8} Bq/t etc.
Cleared materials	ΣD/C<1 C (Co-60: 0.1 Bq/g, H-3: 100 Bq/g, C-14: 1 Bq/g, Pu-238 0.1 Bq/g etc.)	

Table 3: Categorisation of low-level waste in Japan[35]
Legend: D: Nuclide density, C: Nuclide clearance level

I.4.1 Low-level waste

33 Source: University of Fukui 2015
34 IAEA GSG-1
35 Source: University of Fukui 2015

Almost all radioactive waste from decommissioning except for the fuel is classified as LLW in Japan. Very low-level waste (L3 waste in Japan) consists of slightly radioactive waste. Most of the radioactive waste generated during decommissioning falls into this category, up to 60%, depending on the reactor type and other factors such as service life and operational history. L3 waste consists mainly of material from the biological shield of the reactor and some components of the cooling and heat-exchange cycle. A trench-like repository without engineered barriers just below ground is considered to be sufficient for this type of radioactive waste. After being backfilled with soil, periodic inspections of the facility are conducted to monitor its structural integrity and the dose rates in the surrounding area.

Relatively low-level waste (L2 waste) makes up about 36% of the radioactive waste from a decommissioning project. It consists of components such as parts of the steam generator and the central part of the RPV. The envisioned strategy for L2 waste disposal is similar to L3 waste, but the repository is constructed with concrete shielding and at slightly greater depth. After being filled with the waste, the storage areas are further stabilised by grouting for additional safety.

Around 4% of the radioactive waste is classified as relatively high-level waste (L1 waste), mainly the reactor internals in the direct vicinity of the fuel. According to the waste disposal concept for this type of waste, repositories will be engineered facilities similar to the L2 waste facilities, but built at a much greater depth (50 to 100m below ground) and with reinforced shielding.

A central LLW storage site exists at the Rokkasho nuclear complex (capacity: 800,000m^3), operated by Japan Nuclear Fuel Limited (JNFL) and intended for LLW generated during reprocessing and fuel fabrication in the nearby fuel cycle facilities. In principle this site could also host waste from decommissioning, but the operator currently does not accept such material. During the JPDR pilot decommissioning project, all radioactive decommissioning waste was disposed of in an on-site trench repository (in total 1,670t). The realised facility is a hybrid of the L3 and L2 waste disposal concepts: the waste is stored just below surface level, but the storage areas are backfilled with cement and protected by concrete walls. Such an on-site trench repository is also planned for the ongoing Tokai I decommissioning project (the JPDR and Tokai I share the same geographic location). On the other hand, the lack of a disposal site at Hamaoka NPP poses a serious problem for the progress of the decommissioning activities at the site. Fukushima prefecture has expressed its willingness to accept L3 waste from Fukushima I at an existing industrial waste disposal site in the prefecture. The waste there will likely also be stored in a trench-type repository. Local municipal governments and stakeholders have yet to give their approval for this plan. This highlights the problem that currently prevents a more widespread usage of this type of repository: **The procedures to establish such a facility are very complex** and depend on political support at the prefectural and municipal level. The result is a localised solution under an agreement between the local stakeholders and the nuclear operator. Local disposal sites are only used by one operator, so each operator has to find and secure its own disposal site. Furthermore, regulations to release a disposal site from regulatory control are not yet in place, meaning that those controls currently cannot be lifted even if the radioactivity had already decayed below the clearance level. If the hybrid trench repository becomes the standard practice for low-level radioactive waste disposal in Japan, dedicated facilities for L2 waste might not be constructed in favour of the hybrid facility that can accept both types of LLW. Another discussed strategy for LLW disposal proposes a trench-type on-site repository for L3 waste and the disposal of L2 waste at the Rokkasho LLW repository. L1 waste, which remains problematic in both scenarios, might be disposed of in an existing test facility in Aomori prefecture that could be re-designated as a final disposal site for this type of radioactive waste.

I.4.2 High-level waste

HLW is even more problematic than L1 waste. This material has very high radioactive dose rates and high concentrations of long-living radionuclides, requiring storage for hundreds of years. In Japan, this category is basically **reserved for spent fuel waste and waste from reprocessing**, in particular transuranic nuclides. Japan plans to build a deep geological repository for this type of radioactive waste and has begun several R&D programmes in this direction, mostly under the supervision of the JAEA. The Nuclear Waste Management Organisation of Japan (NUMO) is responsible for the development of the site, but the adopted approach of waiting for voluntary applications by Japanese municipalities to host such a site seems rather inefficient[36]. The Japanese government, having grown increasingly concerned about the slow pace of progress, announced in late 2015 that it would present a suitable candidate site until the end of 2016. The selection of the site is supposed to be primarily based on scientific criteria. In the meantime, spent fuel is temporarily stored in the SFPs of remaining NPPs[37] or at a storage facility near Rokkasho[38], where a new reprocessing plant is slated to commence operations in 2018[39]. In the past, spent fuel was also shipped to reprocessing plants in France and the UK[40]. This could resume in the future if the Rokkasho project sees further delays. A pilot reprocessing plant was also operated by the JAEA at Tokai in Ibaraki prefecture, but this facility was shut down in the

[36] NUMO 2007

[37] In 2012, a total of 14,460t spent fuel was stored at either the SFPs or available temporary storage facilities

[38] Japan Nuclear Fuel Limited (JNFL) has a storage capacity of 3000t at Rokkasho (occupancy rate 2951t in May 2014). The Recyclable-Fuel Storage Company, owned by TEPCO (80%) and JAPCO, has built a temporary storage facility at Mutsu with a capacity of 3000t in dry casks. The facility is intended to store spent fuel from TEPCO and JAPCO plants. Construction was finished in October 2013, but the safety inspection and site approval by the NRA is not yet finalised. It is currently expected that the facility will become operational in October 2016. See World Nuclear Association, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx

[39] The reprocessing plant is currently operated by JNFL. In February 2016, the Japanese government approved a bill to transfer the management of the reprocessing activities to a new “authorized organisation” and introduce a new system of funding, with contributions by the nuclear operators based on the amount of fuel they generate. Even in this new arrangement, the JNFL is expected to remain in charge of the Rokkasho plant, under commission of the new management organisation. The reform was stipulated due to concerns about the impact of the liberalisation of the electricity market on reprocessing. The new management organisation will likely be organisationally similar to the NDF and increase governmental control over the reprocessing activities in Japan

[40] Japan maintains a fleet of freighters purpose-built to transport spent fuel and MOX fuel. Shipping of spent fuel for reprocessing was abandoned in 2005

aftermath of the Fukushima accidents due to safety concerns and is now being decommissioned. The reprocessing plants at both Rokkasho and abroad are part of a wider waste reduction strategy for HLW. During reprocessing, the fission products generated during the burning of the fuel are separated from the remaining uranium (mainly the non-fissile U-238 nuclide) and the produced plutonium. While both the uranium residue (called depleted uranium due to the low percentage of fissile U-235) and the plutonium can be reused, the fission products are treated as HLW. Since more than 90% of the spent fuel can be reused for the fabrication of new fuel – usually in the form of **m**ixed **ox**ide (MOX) fuel consisting of natural uranium[41] and the produced plutonium – reprocessing significantly reduces the amount of HLW. The transuranic fission products and other waste generated during reprocessing are vitrified and molten into steel containers for compact and safe storage. The vitrified waste is stored at a temporary storage site at Rokkasho until the availability of a deep geological repository[42]. The HLW repository will mainly be used to store these vitrified fission products and – in a second step – the waste from spent MOX fuel once this is burned up in the future[43]. The issue of spent MOX fuel management has already become a problem in the Fugen decommissioning project, with no clear solution at the moment (see section II.1.3).

I.4.3 Other waste

A significant amount of non-radioactive waste is generated during decommissioning. This is in fact the vast majority of all waste, making up over 95% of the total waste volume. Non-radioactive waste is designated by reviewing documents such as the initial characterisation of the radioactive inventory of the facility. Measurements are taken on a periodical basis for confirmation, with the NRA auditing the process. This waste, mainly concrete and steel, but also electrical equipment, wiring and similar material, may be recycled or disposed of with conventional means. Since industrial waste repositories are in preciously short supply in Japan, the goal is to recycle as much of the material as possible. However, the success of this policy depends on the industry and the general public, since they need to accept and use the recycled material for new purposes. Gaining this support seems to be a problem in practice, since the usage of recycled material has been limited to niche applications such as shielding for a particle accelerator and some demonstration objects made for the Japan Atomic Power Company (JAPCO). A recent initiative by the University of Fukui and the Fukui prefectural government aims to raise awareness and acceptance for recycled material among local businesses and

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[41] Even though it is technically possible to use the depleted uranium gained through reprocessing, MOX fuel is usually made from natural, freshly mined uranium. Natural uranium – similar to the depleted uranium from the spent fuel- only has a very low percentage of U-235 (around 1%), so it needs to be enriched to produce fuel-grade uranium (around 5% U-235). With the addition of plutonium, this enrichment process is not necessary

[42] The facility at Rokkasho has a capacity of 2880 canisters (occupancy rate 1574 canisters in April 2015)

[43] Reprocessing of MOX fuel is technically possible and has been demonstrated experimentally, but the process is currently not economically feasible. The Rokkasho plant is not equipped to reprocess MOX fuel. Spent MOX fuel will therefore likely have to be disposed of in its entirety.

communities within Fukui prefecture in preparation for the dismantling of Fugen NPP, Tsuruga NPP unit 1 and Mihama NPP units 1 and 2, all located within the prefecture. The decommissioning of NPPs also generates other toxic substances that require special treatment and disposal, for example asbestos. For the disposal of this waste, conventional waste management strategies are available in Japan.

I.4.4 Decontamination and clearance

The problems with finding appropriate repositories and the complexity of radioactive waste disposal have made the reduction of the radioactive waste volume an attractive strategy for easier and less expensive waste disposal. Material with contaminated surfaces can be decontaminated to allow its subsequent unrestricted release. The clearance system was introduced during the decommissioning of Tokai I and follows IAEA standards[44]. The central clearance criterion for unrestricted release in Japan is a radionuclide concentration of less than 10 µSv/year. Waste cleared for unrestricted release can be disposed of in conventional waste streams. The extent of decontamination depends on technical limitations and economic feasibility, but the target volume is usually quite high, as can be seen in the estimated waste for the Fugen decommissioning project given in Table 4 below. Table 5 shows the clearance levels for major radionuclides.

(Unit: 10^3t)

Decontamination

Level of radioactive waste		**During operation**	**During decommissioning**	**Total**
Low-level waste	Level 1	0.2	0.3	0.5
	Level 2	3.0	1.4	4.4
	Level 3	-	45.5 → 5.4	5.4
Cleared non-radioactive		-	0.6 → 40.6	40.6
Originally non-radioactive		-	141.0	141.0
Non-contaminated underground structure (not included in the program)		-	170.0	170.0
Total		3.2	358.6	361.8

Table 4: Estimated waste volume of the Fugen decommissioning project[45]

[44] IAEA RS-G-1.7
[45] Source: JAEA 2015

Artificial origin					
Radionuclide	Activity concentration (Bq/g)	Half life	Radionuclide	Activity concentration (Bq/g)	Half life
H-3	100	12.32y	Ru-106	10	368.2d
C-14	1	5730y	I-131	10	8.04d
Mn-54	0.1	313d	Cs-137	0.1	30y
Fe-55	1000	2.7y	Cs-134	0.1	2.062y
Co-60	0.1	5.271y	Eu-152	0.1	13.33y
Ni-63	100	96y	Eu-154	0.1	8.8y
Nb-94	0.1	20300y	Pu-239	100	24065y
Zn-65	0.1	243.9d	Pu-241	10	14.4y
Sr-90	1	29.12y	Am-241	0.1	432.2y
Natural origin					
Radionuclide			Activity concentration (Bq/g)		
K-40			10		
All other radionuclides of natural origin			1		

Table 5: Clearance levels of major radionuclides[46]

The clearance system is currently mostly applied to metallic waste, which can be recycled and reused in many ways[47]. The system could also be applied to concrete waste in principle, but the lack of reuse perspectives and more difficult decontamination procedures are significant obstacles. It will however be impossible to reduce the amount of radioactive waste to the desired levels without establishing a clearance system for concrete waste. A model flow of the clearance system is shown in Figure 3 below.

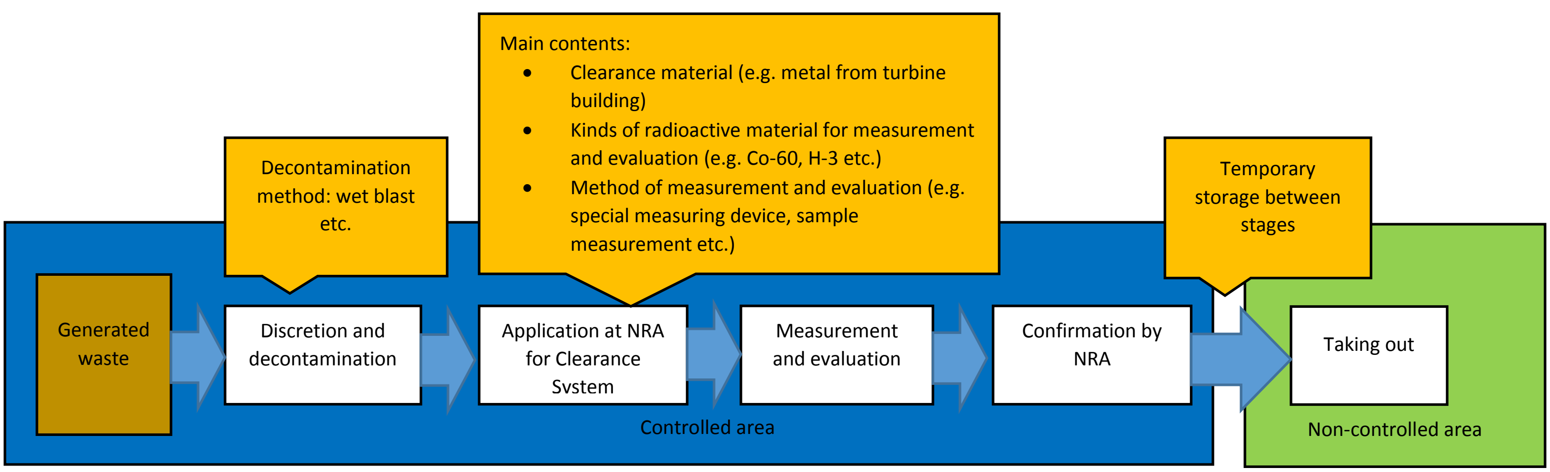

Figure 3: Model flow of the clearance system[48]

[46] University of Fukui 2015

[47] However, as described in the previous section, current applications are very limited and industrial acceptance remains low

[48] JAEA 2015

Decontamination technology is also used on a large-scale basis for the treatment of irradiated water at Fukushima I, with mixed results. While caesium, strontium and other unwanted nuclides and substances can be removed, there are currently no means to remove tritium from the water, making it impossible to release the treated water into the environment[49]. This has led to the construction of large tank farms to store the water on-site until a clearance system or disposal method becomes available (the total volume of stored water exceeds 700,000t). As shown in Table 6, this treatment also produces a sizable amount of secondary waste, which might lead to problems with available storage space in the future and may increase the pressure to find disposal solutions.

Type	Storage volume	Area-occupation rate
Waste sludge	597m³	85%
Concentrated waste fluid	9,292m³	46%
High-Integrity Containers	2900 containers	48%

Table 6: Secondary waste at Fukushima I NPP (as of 17 December 2015)[50]

Another waste reduction measure employed at Fukushima I is the attempt to reuse as much equipment as possible, since basically all equipment within the NPP will be considered radioactive waste after the completion of the project, thus further increasing the volume of secondary waste[51]. Such a waste reduction strategy might also be useful for other projects, but the large number of involved utilities (see next section) and the geographical distance between the NPPs might make this complicated in practice.

I.5 Important organisations

This section provides an overview of the organisational landscape in the field of nuclear decommissioning in Japan. The field is still very fragmented, despite some attempts at consolidation in the aftermath of the Fukushima accidents. This is in stark contrast to Europe, and may have some repercussions on decommissioning. The various organisations offer different potential as partners for joint-ventures or joint projects. Of particular interest for European companies should be the large industrial companies with overseas business activities, general contractors, trading companies and well-funded R&D organisations. The expected growth of

[49] Due to the comparatively short half-life of tritium, this problem will basically solve itself in the near future, provided that the necessary regulations to lift the regulatory controls are in place
[50] Source: TEPCO 2015
[51] Similar designations of equipment also occurred during the clean-up and mitigation efforts at Chernobyl, leading to complete vehicle and helicopter parks being abandoned in the restricted zone around the NPP

decommissioning-related R&D in the academic sector may provide additional opportunities. A more exhaustive list of relevant companies can be found in Appendix A.

I.5.1 Governmental organisations

The Atomic Energy Basic Law and the Law on the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors both mandate a governmental responsibility for the supervision of nuclear power in Japan. The Atomic Energy Council (AEC), a formerly influential council for nuclear strategy, is directly attached to the Cabinet Office, but its role was significantly reduced in the aftermath of the Fukushima accidents (see below). Two political parties dominate the political landscape, whose different views on nuclear power could affect nuclear decommissioning. The currently ruling Liberal Democratic Party (LDP) is generally pro-nuclear and at the moment actively encouraging the restart of the shut-down NPPs in the country. In contrast, the Democratic Party (DP), the main opposition party, toyed with the idea to opt out of nuclear power when in power during the Fukushima crisis. Such a policy would of course increase the number of decommissioning projects, and the increased burden on Japanese companies could translate into higher demand for foreign products. In any case, political considerations often play a larger role in the Japanese nuclear policy than purely economic considerations. This is evident in maintaining the accident-ridden Monju experimental fast breeder reactor and the decision to decommission the two remaining reactors of the Fukushima I NPP. Four ministries are involved in the supervision of decommissioning-related activities. The METI is responsible for the supervision of the operators of commercial reactors and the industrial corporations involved in decommissioning. The MEXT has a similar role for research facilities and is also responsible for the supervision of the Japan Atomic Energy Agency (see below). The METI supports the decommissioning activities at Fukushima I NPP with generous budgets, primarily for R&D projects. The MEXT funding for decommissioning-related activities is much more limited, but it has launched joint calls for Fukushima I-related R&D projects in collaboration with funding organisations in France and the UK (see chapter III.4). The MOE is responsible for the environmental impact and safety of the decommissioning process, primarily through supervision of the NRA and the Nuclear Safety Investigation Commission (NSIC). The MOE also provides funding for the off-site decontamination activities in areas contaminated during the Fukushima nuclear accidents. It is the newest ministry to assume responsibilities in decommissioning, which means it lacks the long-established connections of the other ministries. The last ministry with a significant role in decommissioning is the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), which is mainly responsible for the regulation of the transportation of radioactive material. Both the MLIT and the METI have very close connections to the Japanese industry.

I.5.2 Regulatory bodies

The Japanese regulatory system in the field of nuclear energy has long been extremely fractured. This has led to considerable problems during the Fukushima accidents, when the old system proved to be too unwieldy to quickly react and adapt to situations in which fast decision-making is necessary. The reforms in the aftermath of the Fukushima accidents unified the regulatory responsibility largely in a single organisation, the NRA. This organisation is now responsible for the licensing of NPPs, the setting and monitoring of safety standards and safeguards, the assessment of the resilience of NPPs against natural disasters, and the regulation of most aspects of the decommissioning process, including radioactive waste management and disposal. It was formed in September 2012 and incorporated the earlier Nuclear Safety Commission (NSC), affiliated with the Cabinet Office, and the Nuclear & Industrial Safety Agency (NISA), an agency of the METI. The agency furthermore includes the Radiation Council[52], a council for the establishment of technical standards for radiation protection and the measurement of radioactivity levels. The new agency was placed under the MOE to separate safety-related regulatory functions from the promotional functions of the METI. In 2014, the NRA also absorbed the Japan Nuclear Energy Safety Organisation (JNES), greatly expanding its manpower and capabilities.

However, even with this merger there remain some problems in the current regulatory setup. While the NRA became more independent from industry-backed interest groups and the policy targets of the METI, the migration to the MOE cut many existing connections and relationships between the old regulatory bodies and the nuclear industry. NRA officers are not permanently stationed at the NPPs. Together with personnel shortages this has led to complicated and prolonged regulatory procedures. The NRA tries to alleviate these problems with frequent visits and safety inspections of nuclear facilities, but this increases the strain on the manpower of the agency even more. The efficiency of these inspections and its impact on the safety culture in Japanese nuclear facilities seems to be mixed. The Integrated Regulatory Review Service mission of the IAEA, dispatched to review the efficiency of the reform of the Japanese nuclear regulatory system, recommended that inspections by the NRA should be further reinforced[53]. As the NRA is currently prioritising the re-starting of the Japanese NPPs, decommissioning-related regulation appears to receive less priority at the moment. Recently, the application for lifetime extension of the first two reactors of the Takahama NPP, which must be approved within strict time limits or the reactors will have to be decommissioned regardless of the NRA safety assessment, has bound further resources of the agency.

Beside the NRA, two more organisations with some regulatory functions exist: the Atomic Energy Commission (AEC), formerly an advisory body on national nuclear policy, and the Nuclear Safety Investigation Commission (NSIC). The role of the AEC was reduced in the post-Fukushima reforms

[52] This council was formerly associated with MEXT.
[53] World Nuclear News: http://www.world-nuclear-news.org/RS-IAEA-praises-reform-of-Japans-nuclear-regulator-2201164.html (accessed 22 January 2016)

to supervise national plutonium stocks and advise on nuclear waste. The NSIC is, like the NRA, a new creation and responsible for reviewing the NRA and examining nuclear accidents in the country. This organisation is also attached to the MOE.

I.5.3 Industrial corporations

As described above, the owner of a nuclear facility is in principle responsible for decommissioning. However, while the owner of a nuclear facility prepares the decommissioning plan and maintains overall responsibility for the project, most of the technical work is usually contracted to the large Japanese industrial companies who originally supplied the reactor. Toshiba and GE-Hitachi supplied boiling water reactors (BWR) and the Fugen advanced thermal reactor (ATR, supplied by Hitachi), while MHI supplied all pressurised water reactors (PWR)[54]. In terms of engineering capabilities and expertise, many experts view MHI as the leading Japanese company in this field. Toshiba became involved in a major accounting scandal in 2015. As part of the restructuring efforts of the company, the spin-off of the nuclear business is currently under consideration, making them a more uncertain partner at the moment.

Many utilities, especially the smaller ones, depend on the technical support of these companies to operate their reactors. **The dependence of the utilities on the services of the three corporations makes it incredibly unlikely that an external company can become the main contractor for a decommissioning project in Japan.** Beside the three reactor vendors, who are mainly involved in the technically complex dismantling of the reactor, many other contractors are involved in decommissioning, primarily for the dismantling of non-radioactive components and structures. There is a tendency that most contracts are obtained by large general contractors such as Kajima Corporation or Obayashi Corporation, who have long-established business connections with the utilities. These companies, both reactor vendors and general contractors, in turn employ many subcontractors for various specialised tasks and services. Heavy reliance on subcontracting to carry out construction-related work is quite widespread in Japan, sometimes involving multiple layers of subcontractors. In a bid to soften the impact of decommissioning on the local economy and to save costs, some operators also grant direct contracts for less technically complex tasks to local companies. Another important Japanese company in the field of decommissioning is ATOX Co., Ltd., a supplier of decontamination and measurement technology[55].

The larger, multinational companies are the most promising partners for joint-ventures or business partnerships due to their central role in D&D. Smaller construction companies often focus largely on the local market and might be more difficult to approach due to communication

[54] The oldest reactors and the initial reactor designs were supplied by American and British companies: GE (BWR), Westinghouse Electric (PWR), and GEC (Magnox)

[55] ATOX Co. Ltd. is also the only manufacturer involved in the IRID beside the three reactor vendors. Other than these manufacturers, the Japanese utilities also have a share in the organisation (including J-Power and JNFL)

problems. Most companies involved in nuclear decommissioning are not specialised in this field, but instead have very diverse business interests in the nuclear sector. This may make some companies more receptive to collaboration with European companies, especially if this collaboration does not affect the core business interests of the Japanese partner.

International procurement is often handled by trading companies affiliated with these corporations. The trading companies may be interesting business partners for companies solely interested in exporting their products to Japan. Some Japanese SMEs active in nuclear decommissioning have also taken steps to strengthen their business profile and increase their independence from the main contractors. Nagoya-based Nissin Kiko Co., Ltd. entered business agreements with a German SME and the nuclear operators to market a specific cutting technology used in the dismantling of a nuclear reactor, high-pressure abrasive water jet cutting. This approach is however very rare in Japan, with the large industrial corporations and the trading companies still dominating the business with foreign companies.

Industry associations play an important role in setting industrial standards in Japan. In the field of decommissioning-related manufacturing, an important association is the Japan Society of Mechanical Engineers (JSME).

I.5.4 Utilities

Nearly all utilities in Japan operate nuclear power plants. The two largest utilities are Tokyo Electric Power Co., Ltd. (TEPCO), focusing on the densely populated Kanto region in Eastern Japan and Kansai Electric Power Co., Ltd. (KEPCO or Kanden) in the central Kansai region. Next to these two major utilities, several other utilities with regional monopolies also operate NPPs. These are Chubu Electric Power Co., Ltd. (Chuden) for the area between Kansai and Kanto, Kyushu Electric Power Co., Ltd. (Kyuden) for the southern island of Kyushu, Shikoku Electric Power Co., Ltd. (Yonden) for the island of Shikoku, Chugoku Electric Power Co., Ltd. (CEPCO or Chuden, also operating under the name Energia) for the area west of Kansai, Hokuriku Electric Power Co., Ltd. (Hokuden or Rikuden) for the area north of Kansai, Tohoku Electric Power Co., Ltd. for the area north of Kanto, and Hokkaido Electric Power Co., Ltd. (HEPCO or Hokuden) for the northern island of Hokkaido. Only the small Okinawa Electric Power Co., Ltd. of the southern Ryukyu island chain does not operate a NPP. Table 7 provides more detailed information about these companies, and the number of their reactors in service and in decommissioning. Of these utilities, Hokuriku, Hokkaido and Shikoku Electric Power are comparatively small companies, with only small teams of nuclear engineers. This shortage of engineers, coupled with the dispersion of the decommissioning projects over many companies, might make it difficult for smaller utilities to successfully manage decommissioning projects. Many of the smaller utilities also focus solely on the domestic market and have little international experience.

The Japan Atomic Power Company (JAPCO or Genden) pioneered the use of nuclear power in Japan. It is a utility that only uses NPPs for electricity generation[56]. The decommissioning of its Tokai I NPP, in direct vicinity to the JAEA facilities at the same location, is the most advanced decommissioning project of a commercial NPP in Japan. Due to this edge in expertise and its sole focus on nuclear power, many smaller utilities plan to closely cooperate with JAPCO in their own decommissioning projects. This should help them to compensate for their lack of skilled personnel and might create synergies between the individual decommissioning projects. As such, **JAPCO has the potential to become a central organisation in future decommissioning projects**, especially for consulting and technical assistance services. At the moment, however, such collaboration still seems to be rather underdeveloped. The Fugen experimental reactor, operated by the JAEA, and unit 1 of Tsuruga NPP, operated by JAPCO, are both in decommissioning and located at the same site. Despite this, cooperation between the two organisations is currently limited to some joint meetings. This situation will likely change in the future. A last utility, Electric Power Development Co., Ltd., operating under the brand J-Power, is currently building a new NPP at Ohma in Aomori prefecture. The company is also involved in the clean-up and decommissioning efforts at Fukushima I.

Utility	Website (English)	Revenue in Mio. JPY (consolidated)	Personnel	Reactors	
				in Operation	in Decommissioning
TEPCO	www.tepco.co.jp/en/index-e.html	6,802,464 (FY2014)	33,853	11	6
Kansai EP	www.kepco.co.jp/english	34,060 (FY2014)	20,628	9	2
Chubu EP	www.chuden.co.jp/english	3,103,600 (FY2014)	17,782	3	2
Tohoku EP	www.tohoku-epco.co.jp/english/index.html	2,182,075 (FY2014)	12,731	4	0
Kyushu EP	www.kyuden.co.jp/en_index.html	1,873,467 (FY2014)	13,148	5	1
Chugoku EP	www.energia.co.jp/e/index.html	1,299,624 (FY2014)	14,149	1 (+1)	1
Shikoku EP	www.yonden.co.jp/english/index.html	664,286 (FY2014)	4,739	3	0
Hokkaido EP	www.hepco.co.jp/english/index.html	692,925 (FY2014)	5,709	3	0
Hokuriku EP	www.rikuden.co.jp/english/index.html	532,760 (FY2014)	4,956	2	0
Okinawa EP	www.okiden.co.jp/english/index.html	179,266 (FY 2013)	1,531	0	0
J-Power	www.jpower.co.jp/english	750,627 (FY 2014)	2,366	0 (+1)	0
JAPCO	www.japc.co.jp/english	131,894 (FY 2014)	1,200	2	2

Table 7: Utilities in Japan[57].

Legend: Light grey: Major utilities • grey: medium-sized utilities • dark grey: small utilities • violet: special utilities. Numbers in brackets indicate reactor units under construction.

[56] JAPCO supplies its electricity to the regional utilities. It is mostly controlled by the other utilities (the 9 regional utilities except for Okinawa Electric Power hold ca. 85% of its stock, with another 5% held by J-Power)

[57] All data has been taken from the business reports and data files available at the listed websites.

I.5.5 R&D organisations

The leading organisation in the field of decommissioning-related R&D is the JAEA, which has supervised the decommissioning of the JPDR and several nuclear research facilities (see Table 8). The decommissioning of the JPDR was used as a testbed, with many utilities in Japan sending observers to study the decommissioning process and gain expertise for their own future projects. The JAEA continues to be involved in the decommissioning of research facilities, including the Fugen experimental reactor (see section II.1.3). After the Fukushima accidents, the JAEA has also become active in many Fukushima I-related R&D activities. Two new research facilities, the Naraha Remote Technology Development Center close to the site of the Fukushima I NPP (opened in April 2015) and the Collaborative Laboratories for Advanced Decommissioning Science (CLADS, currently in establishment), were organised for this purpose with major contributions by the JAEA. The JAEA is also probably the Japanese R&D organisation with the strongest involvement in the global discourse on nuclear R&D, safety and decommissioning. As such, it plays an important role in introducing international standards and technological advancements into the domestic discourse. The good international connections of the JAEA make this organisation an interesting partner for joint R&D projects, but limited funding means that the extent of these projects is often narrow. Beside the JAEA, other notable Japanese R&D institutions include the Radwaste and Decommissioning Center (Randec), which was founded to preserve and share the experience gained during the decommissioning of the JPDR. In 2001, the organisation also began to research disposal strategies for low-level radioactive waste (LLW) from research facilities. The organisation further monitors international decommissioning projects, strategies and experiences, complementing the JAEA in this role. Furthermore, the Nuclear Waste Management Organisation of Japan (NUMO) was set up in 2000 in accordance with the Law on Final Disposal of High-Level Radioactive Waste[58]. Its task is the study and development of a final disposal site for HLW and transuranic waste. This organisation is authorised by the government, but funding comes solely from waste producers (primarily the reactor-operating utilities and the JAEA). The JAEA assists in this task with several research facilities for the deep geological disposal of HLW and transuranic waste. Research institutes affiliated with industrial corporations also conduct decommissioning-related R&D, often with a focus on the Fukushima I NPP. These private research institutes include Mitsubishi Research Institute and Toshiba Nuclear Technology Research Institute.

[58] Law No. 117, 7 June 2000

Facility	Type	Operation	Decommissioning
Japan Power Demonstration Reactor (JPDR)	Power Reactor	1963 - 1976	1986 - 1995
JAERI Reprocessing Test Facility (JRTF)	Reprocessing Test Facility	1968 - 1990	1996 – 2031 (planned)
Research Hot Laboratory	Research Facility		2003 – 2024 (planned)
Very High Temperature Reactor Critical Assembly (VHTRC)	Research Reactor		2006 - 2009
Japan Research Reactor No. 2 (JRR-2)	Research Reactor	1960 - 1996	2006 – 2034 (planned)
Ceramic Research Facility	Research Facility	1959 - 2006	2007 - 2008
Metallurgy Facility	Research Facility	1957 - 2001	2007 – 2009
Plutonium Research Building No. 2	Research Facility	1968 - 2006	2008 - 2009
Reprocessing Test Laboratory	Research Facility	1959 - 2001	2008 – 2009
Isotope Separation Research Facility	Research Facility	1959 - 2001	2008 - 2009
Mock-up Building	Research Facility		2010 – 2013
Liquid Waste Treatment Facility	Waste Treatment Facility		2010 – 2026 (planned)
Safeguards Technology Development Laboratory	Research Facility		2012 – 2014
Uranium Enrichment Laboratory	Research Facility		2012 - 2015

Table 8: Decommissioning projects under the supervision of the JAEA at Tokai Research and Development Center[59]

Beside the JAEA and private research institutes, important R&D services are also increasingly provided by Japanese universities and academic research institutes, including Kyoto University, Fukushima University, the University of Fukui and the Nagaoka University of Technology. In the concept for Fukushima I-related R&D, universities are expected to provide basic research (see Figure 4 in the next section). Still, most research and education on nuclear decommissioning at the universities and research institutions is a very recent development, often only really begun after the Fukushima accidents. As a result, the infrastructure for decommissioning-related R&D is still in development, both in regard to academic capacities and scientific expertise. Many Japanese universities and institutes have expressed their desire to rectify these shortcomings and to share the experience gained at Fukushima I with the international scientific community. The steady increase in the number of decommissioning projects and the uncertain future of the Japanese nuclear reactors might further increase academic interest in decommissioning, similar to developments in Germany after the decision to opt out of nuclear power. The field of academic R&D on nuclear decommissioning in Japan is therefore likely to see continued growth in the near future, with growing opportunities for international involvement in joint projects. Universities also play a central role in human resource management, as they, together with the JAEA, are in charge of training the next generation of nuclear engineers and technical experts. The Japanese government has authorised a long-term project designed to foster the training of new experts in the field. This has become an urgent issue, as **many senior experts in the nuclear sector are**

[59] Source: https://www.jaea.go.jp/english/04/ntokai/decommissioning/index_01.html (accessed 1 February 2016)

expected to retire in the coming years. Since the operating crews of the reactors and the experts involved in the first decommissioning projects are valuable sources of knowledge, the retirement of these experts could erode the knowledge base of decommissioning in Japan. A shortage of skilled engineers and technicians and difficulties in attracting domestic talent could lead to increased demand for foreign professional services in the mid-term future.

I.5.6 Fukushima I-related organisations

The unique challenges and characteristics of the Fukushima I decommissioning project have led to the establishment of several new organisations dedicated solely to the decommissioning efforts at the site (see Figure 4). The Japanese government has the ultimate responsibility for setting policy targets and approves the overall decommissioning plan (the Mid- and Long-Term roadmap). Three unique organisations, the International Research Institute for Nuclear Decommissioning (IRID), the Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF), and the TEPCO Fukushima Daiichi Deconstruction and Dismantling Engineering Company (TEPCO D&D Co.), were set up to facilitate the decommissioning of the damaged plant. The IRID was originally established to coordinate the R&D efforts and assist the government in the development of a decommissioning strategy for Fukushima I, but many observers were unhappy with its performance and its preferential treatment of affiliated companies. This issue was primarily attributed to the fact that IRID was controlled and made up of the nuclear utilities (including J-Power), the three nuclear manufacturers and ATOX[60].

To address these perceived shortcomings, the NDF eventually took over much of IRID's role in regard to strategy development and the coordination of international affairs. The NDF is a special organisation incorporated under the Nuclear Damage Compensation Facilitation Corporation Act[61], originally set up for the purpose of compensating victims of nuclear emergencies. It has a controlling interest in TEPCO since a government-backed bailout on 31 July 2012, when it acquired 50.11% of TEPCO's shares. Its current role in decommissioning was obtained in August 2014 with the enforcement of the Act on the Partial Revision of the Nuclear Damage Compensation Facilitation Corporation Act. **It is not yet clear to what extent this change in responsibilities will affect the opportunities for European companies** in the decommissioning of Fukushima I NPP. The NDF receives yearly contributions from the nuclear utilities and JNFL, with the option to receive additional capital through bonds issued by the Japanese government if the need arises[62]. The Cabinet Office approves the business plans of the corporation, making it effectively a vessel for governmental intervention into the decommissioning of Fukushima I NPP.

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[60] International tenders by the IRID have focused on feasibility and preliminary design studies, for example the Request for Proposals for a Feasibility Study of Essential Technologies for Internal RPV Investigation in 2014.
[61] Law No. 94, 10 August 2011
[62] Its capital of 14 billion JPY was also jointly invested by the Japanese government (7 billion JPY) and the nuclear operators (12 companies, 7 billion JPY)

MEXT and METI provide direct funding for Fukushima I-related R&D projects. IRID remains in charge of the implementation of R&D projects for Fukushima I and has developed a number of robots for the exploration and decontamination of the damaged reactor units 1 – 4. The TEPCO D&D Co. is responsible for conducting the actual decommissioning work on-site. It is one of the few dedicated organisations for nuclear decommissioning in Japan[63]. All of these organisations officially welcome international collaboration, especially in the field of R&D. However, as mentioned above, due to the membership structure of the IRID and close ties between the utilities and the nuclear manufacturers, the actual outcomes of this policy were quite underwhelming, both for the Japanese and foreign side. Open R&D tenders have so far mostly focused on fringe issues (alternative retrieval methods for the molten fuel) and technical feasibility studies. However, the new NDF management might offer more opportunities for European companies and R&D institutions, including stronger cooperation with supranational organisations such as EURATOM. Outside the field of R&D, the Fukushima I decommissioning project has so far seen limited involvement by the French companies Areva and Veolia as well as US companies, in particular in the field of water treatment and decontamination. The assessment of this involvement was mixed. As a result, Japanese authorities have become more careful and reluctant about the involvement of foreign companies, as exemplified by a statement of TEPCO's Chief Decommissioning Officer for the Fukushima I NPP that procurement for Fukushima will remain closed to ensure the continuity and reliability of procured equipment[64].

[63] A similar organisation exists for the Fugen decommissioning project with the Fugen Decommissioning Engineering Center

[64] Source: http://bigstory.ap.org/article/2f19d2613f584b998b341837a8614127/ap-interview-fukushima-chief-says-no-textbook-cleanup (accessed 16 December 2015)

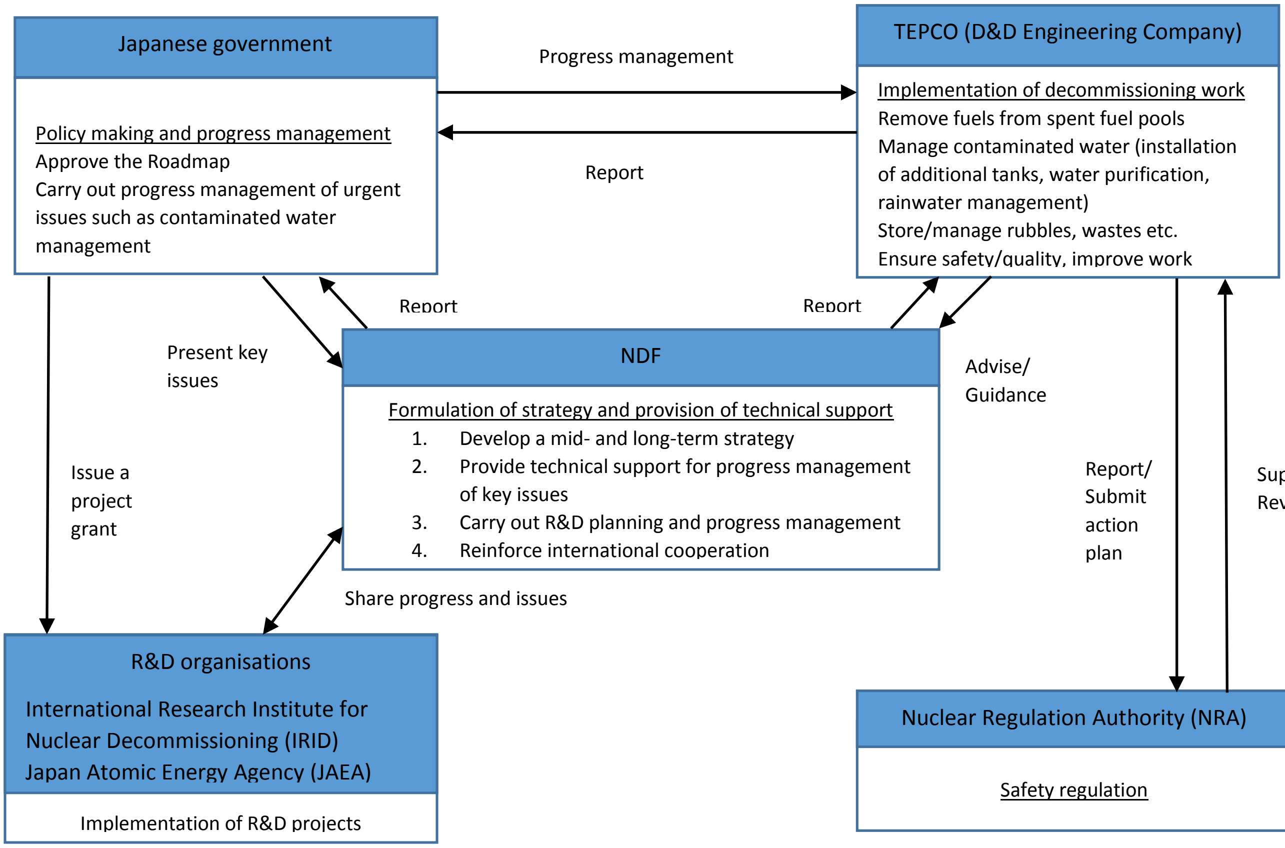

Figure 4: Organisational structure of the Fukushima I Decommissioning Project[65]

As has been mentioned in the section on R&D, the need to decommission the four damaged reactors at the plant have led to an expansion of decommissioning-related R&D projects. The NDF has made efforts to characterise the R&D system for Fukushima I and to clarify the role individual R&D institutions play in it (see Figure 5). In this multi-layered system, universities and research institutes provide the fundamental research, human resource development and basic R&D. The JAEA is involved in this stage as well, but also contributes to the practical development of equipment for Fukushima, which is otherwise mainly conducted by the IRID. TEPCO D&D Co. applies the developed technology and carries out the actual decommissioning work. This structure does not explicitly include foreign R&D institutions, but can accommodate them. Since the IRID remains controlled by the utilities and the three nuclear manufacturers, collaborating with R&D institutions on other layers of the R&D system should be considered. The NDF has concluded partnership agreements with major European nuclear organisations, including the Nuclear Decommissioning Authority (NDA) of the UK and the French Alternative Energies and Atomic Energy Commission (CEA), whereas TEPCO has signed its own agreements with the CEA

[65] Source: NDF 2015

and Sellafield, Ltd. These cooperation agreements might be a channel for more joint R&D projects in the future.

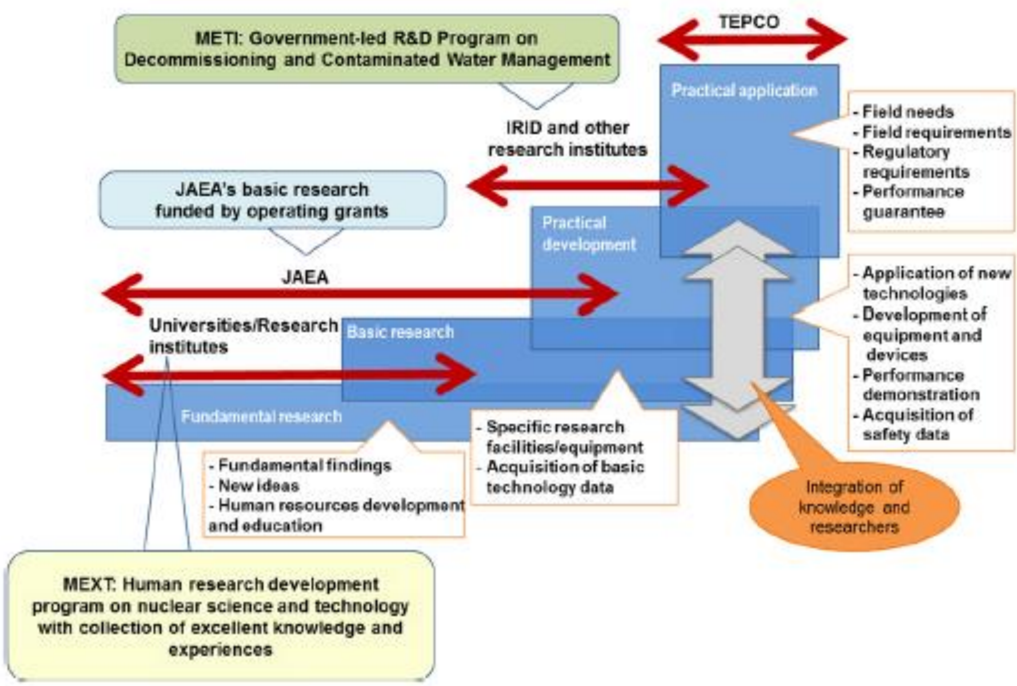

Figure 5: Multi-layered R&D system for the decommissioning of Fukushima I NPP[66]

I.6 Funding

The costs for decommissioning have to be covered by the operator of the nuclear facility. The funds earmarked for decommissioning are accumulated through surcharges on the retail prices for electricity. In the past, these surcharges were based on the output of the facility. The unusually long shut-down of all NPPs after the Fukushima accidents therefore had a negative effect on the accumulation of funds for decommissioning (see Figure 6). The shut-down and decommissioning of reactors before the end of their operational licence is another source for possible financial problems in this funding arrangement. As a reaction, fixed surcharges – independent from actual plant operation – were introduced. The funding gap caused by the shut-down after the Fukushima accidents is supposed to be recovered during the safe storage period, where surcharges are continued to be levied on electricity prices. If the funds accumulated through this method prove to be insufficient, the safe storage period might be extended. This underlines the importance of the efficient management of knowledge and human resources (see also chapter III.1.9). Increased competition and downward pressure on retail prices due to the

[66] Source: EU-Japan Centre for Industrial Cooperation 2016, NDF 2015

liberalisation of the retail market for electricity in April 2016 could make it more difficult to sustain this funding model in the future.

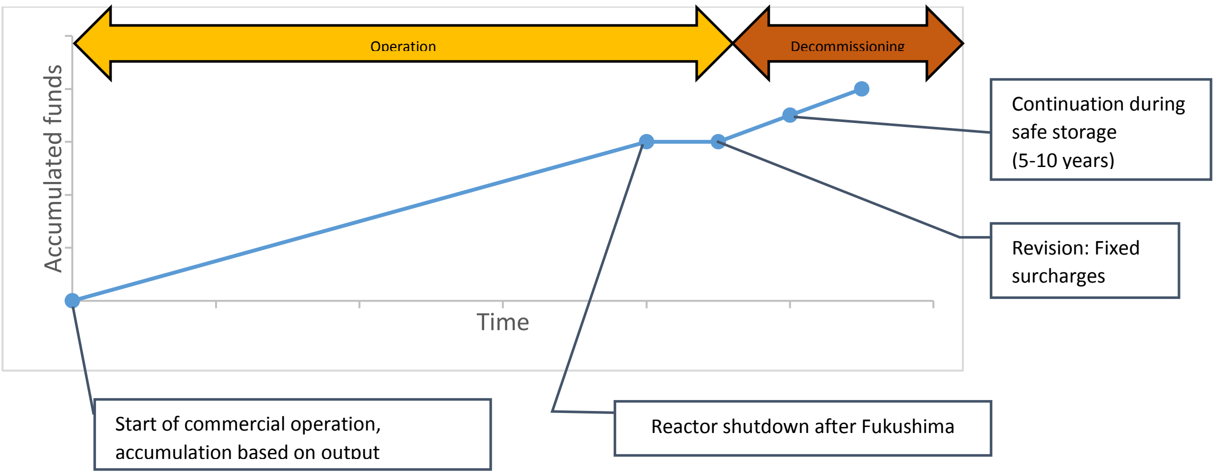

Figure 6: Financing of decommissioning in Japan[67]

The decommissioning of PWR-type reactors is expected to be less costly than BWR-type reactors (see Chart 1). However, the majority of the current projects, including all of the reactors of the Fukushima I NPP, are BWRs (see chapter II). Expenses related to waste management make up around one third of the total costs. This is the most uncertain cost factor in the estimation due to the largely unresolved question of radioactive waste disposal and spent-fuel management. PWRs produce a smaller total volume of radioactive waste (see Table 2), but the quantity of highly irradiated material is higher. This makes the clearance system less effective for a PWR-type reactor.

[67] Source: JAPCO 2015

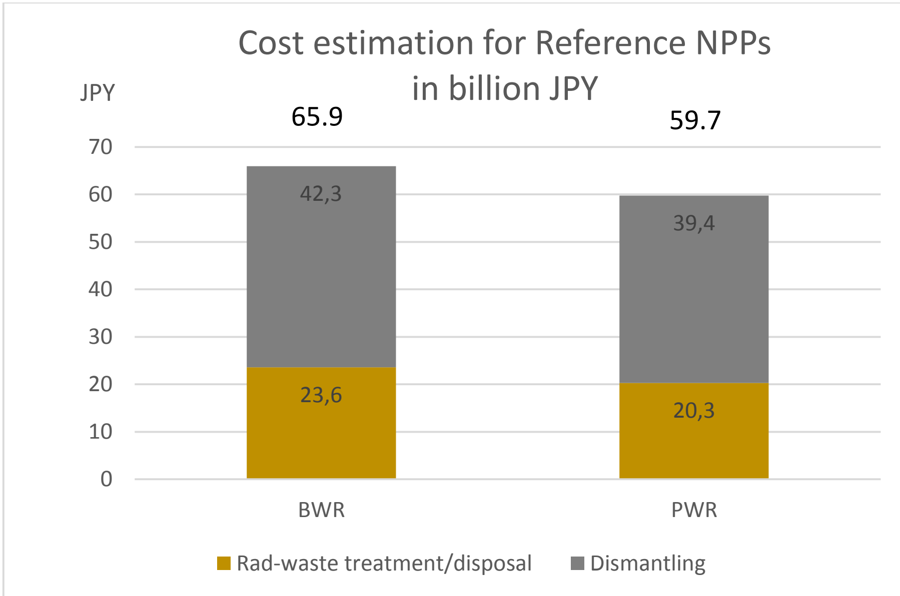

Chart 1: Cost estimation for Reference NPPs (1,100 MWe)[68]

Chart 2 shows the planned budgets of the current decommissioning projects. As can be seen, the budget of the Fukushima I NPP decommissioning projects dwarfs all other budgets, with only the TEPCO budget for the project making up nearly three quarters of the whole planned expenses on decommissioning. In addition to TEPCO, the METI and the MEXT directly fund R&D projects for the decommissioning of Fukushima I. The companies involved in decommissioning and the IRID also fund R&D projects related to Fukushima. The NDF finances many of the Fukushima I-related expenses, in particular expenses related to the compensation of disaster victims. This includes direct money grants to TEPCO[69]. The MEXT is also a major source of funding for the JAEA and largely responsible for the funding of the Fugen decommissioning project. The somewhat limited budget made available for this purpose by the MEXT have raised some concerns, both within the JAEA and the NRA, about the safety and feasibility of the project. The budget for the two reactors of the Hamaoka NPP is notably high, mainly due to problems with finding an appropriate waste disposal site (see chapter II). The unique technical challenges of the Tokai I NPP decommissioning project, primarily the treatment and disposal of the gas coolant, have also resulted in a comparably high budget.

[68] Including the 2007 cost revision. Source: University of Fukui 2015

[69] For example, TEPCO received a 56.7 billion yen grant from the NDF on 24 December 2015 to cover compensation payouts for the Fukushima nuclear accidents. Earlier funding from the NDF amounted to 5690.8 billion yen. Source: http://www.tepco.co.jp/en/press/corp-com/release/2015/1264851_6844.html. TEPCO expects that the total costs for Fukushima I will amount to 11.8 trillion JPY (6.2 trillion JPY for victim compensation, 2.5 trillion JPY for off-site decontamination, 2 trillion JPY for decommissioning and 1.1 trillion JPY for the construction of an interim storage facility for contaminated soil)

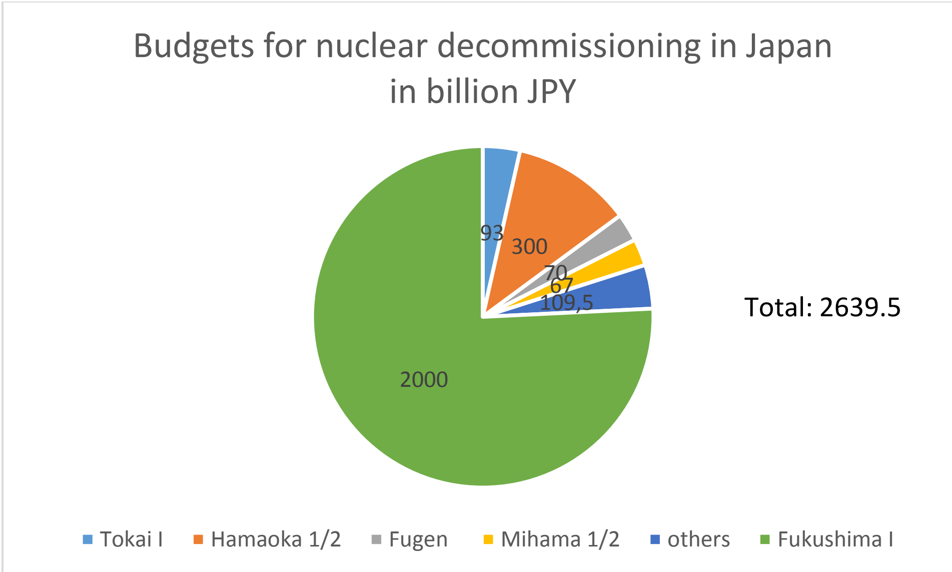

Chart 2: Budgets for ongoing decommissioning projects in Japan[70]

[70] Source: World Nuclear Association, http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx (accessed 8 February 2016), Japanese Wikipedia (data for Hamaoka 1&2), https://ja.wikipedia.org/wiki/%E6%B5%9C%E5%B2%A1%E5%8E%9F%E5%AD%90%E5%8A%9B%E7%99%BA%E9%9B%BB%E6%89%80 (accessed 8 February 2016), the Associated Press (data for Fukushima), http://bigstory.ap.org/article/2f19d2613f584b998b341837a8614127/ap-interview-fukushima-chief-says-no-textbook-cleanup (accessed 16 December 2015). The budget for Fukushima only includes the budget allocated by TEPCO for the decommissioning of the plant. It does not include governmental subsidies on decontamination efforts or R&D.

Part II: Current decommissioning projects in Japan

This chapter describes the ongoing decommissioning projects in Japan in more detail. It includes a brief discussion of the project progress and the respective decommissioning plan. The first chapter focuses on conventional decommissioning projects (chapter II.1), while the second chapter concentrates on the Fukushima I decommissioning project (chapter II.2).

II.1 Conventional decommissioning projects

Japan's first experience with the decommissioning of a large-scale nuclear facility was the decommissioning of the JPDR until 1996. This project was managed by the predecessor of the Japan Atomic Energy Agency (JAEA) and served as a testbed for decommissioning technologies. It also demonstrated the feasibility of the trench-type waste disposal facility. Since then, 15 new decommissioning projects of large-size power reactors were started, although none has been completed so far.

The projects are in various stages of progress, with the Tokai I project being the most advanced. Four reactors, the reactor of the Tokai I NPP, the experimental heavy water reactor Fugen and the first two reactors of the Hamaoka NPP, are in safe storage or preparatory stages. The dismantling of peripheral facilities has started at Tokai I and Fugen.

The largest and most complex project is by far the decommissioning of Fukushima I (six reactors), where four reactors suffered massive damage during and after a tsunami-earthquake in March 2011. The most pressing issues at the moment are the investigation of the interior of the reactors, the prevention of radioactive water leakage and the removal of the fuel assemblies in the SFPs of the damaged reactors. The on-site work is accompanied by extended R&D activities, carried out by various organisation (see chapter I.5.6). This project is expected to take the longest time of all the ongoing decommissioning projects.

In addition, due to changes in the nuclear regulation after the Fukushima accidents, five old reactors were also written off for decommissioning (Tsuruga 1, Mihama 1&2, Shimane 1, Genkai 1). The decommissioning plans for four reactors were submitted to the NRA in December 2015 and February 2016. The utilities are currently waiting for the approval of these plans. The decommissioning plan for Shimane 1 has not been submitted yet. Table 9 gives an overview of the current decommissioning projects in Japan. The following sections describe the projects in more detail.

Reactor unit	Shut-down	Operator	Location	Current status	Expected completion
Tokai I	3/98	JAPCO	Ibaraki	Safe storage, dismantling of peripheral facilities	2025
Hamaoka 1	1/09	Chubu EP	Shizuoka	Safe storage, dismantling of peripheral facilities about to begin	2036
Hamaoka 2					
Fugen	3/03	JAEA	Fukui	Decontamination, dismantling of peripheral facilities	2033
Tsuruga 1	1/11[71]	JAPCO	Fukui	Plan submitted, awaiting NRA approval	2039
Mihama 1	12/11[72]	Kansai EP	Fukui	Plan submitted, awaiting NRA approval	2045
Mihama 2					
Genkai 1	12/11[73]	Kyushu EP	Saga	Plan submitted, awaiting NRA approval	2043
Shimane 1	11/10[74]	Chugoku EP	Shimane	Shut-down	Not yet decided
Fukushima I-1	3/11	TEPCO	Fukushima	Site decontamination, reactor exploration, spent fuel retrieval	Unclear, the roadmap envisions a date around 2050
Fukushima I-2	3/11				
Fukushima I-3	3/11				
Fukushima I-4	11/10				
Fukushima I-5	1/11			Shut-down	
Fukushima I-6	8/10				

Table 9: Ongoing decommissioning projects in Japan[75]

II.1.1 Tokai I NPP

The reactor of the Tokai I NPP is the oldest reactor for commercial electricity generation in Japan. The reactor is a British Magnox design, which features a gas-cooled, graphite-moderated core with fuel rods made of a **mag**nesium-based, **n**on-**ox**idising alloy (hence the name). Like the British reactors of the same type, the Magnox reactor in Tokai is considered outdated and was shut-down in 1998 to prepare it for decommissioning. The reactor is now in safe storage. The dismantling of the peripheral facilities has begun, and the turbine and other auxiliary facilities are already removed. At the moment work is underway to dismantle the steam raising units. Due to design similarities and the technological expertise acquired during the ongoing decommissioning efforts for gas-cooled reactors in the United Kingdom and France, collaboration with British and French companies seems most promising in the case of Tokai I[76]. It is interesting

[71] Reactor No. 1 of Tsuruga NPP was originally shut-down for safety inspections and has not been restarted ever since. Decommissioning announced in 3/15.

[72] Reactor No. 1 was shut-down due to a leak of radioactive water, reactor No. 2 was shut-down due to regular safety inspections. Decommissioning announced in 3/15

[73] Reactor No. 1 was shut-down for regular safety inspections. Decommissioning announced in 3/15.

[74] Reactor No. 1 was shut- down for safety inspections. Decommissioning announced in 3/15.

[75] Source: http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Japan--Nuclear-Fuel-Cycle and own research

[76] France built 9 UNGG reactors at 4 sites, while Britain built 26 Magnox reactors at 11 sites. All of these reactors have been written off and are in decommissioning.

to note, though, that the pace of the Japanese Magnox decommissioning project is much faster than the pace of the British Magnox decommissioning projects. JAPCO intends to finish the decommissioning by 2026, whereas the decommissioning of the first British Magnox reactor is expected to be completed only in 2080. The decommissioning plan for Tokai I draws heavily on lessons learnt from the decommissioning of the nearby JPDR, using a similar waste disposal concept. This concept is built around disposing low-level radioactive waste in an on-site trench facility (see chapter I.4.1 for a more detailed discussion). In contrast to the JPDR, where all decommissioning waste could be disposed of in the disposal facility, the facility for Tokai I will likely only be used for L3 waste. The disposal methods for L2 and L1 waste have not been decided yet. The course of the Tokai I decommissioning project has also led to the development of the clearance system for decommissioning waste in Japan. The practical effectiveness of this system has so far been mixed (see chapter I.4). Recycled material from cleared waste has seen limited use in demonstration objects for JAPCO (benches and the like) and shielding for a particle accelerator operated by the JAEA.

Fact Sheet – Tokai I NPP unit 1	
Type	Magnox
Net Capacity MWe	137
Operator	JAPCO
Main Contractor	GEC/SC
Start of commercial operation	7/66
Shut-down	3/98
Start of decommissioning	12/01

Tokai I NPP (JAPCO)

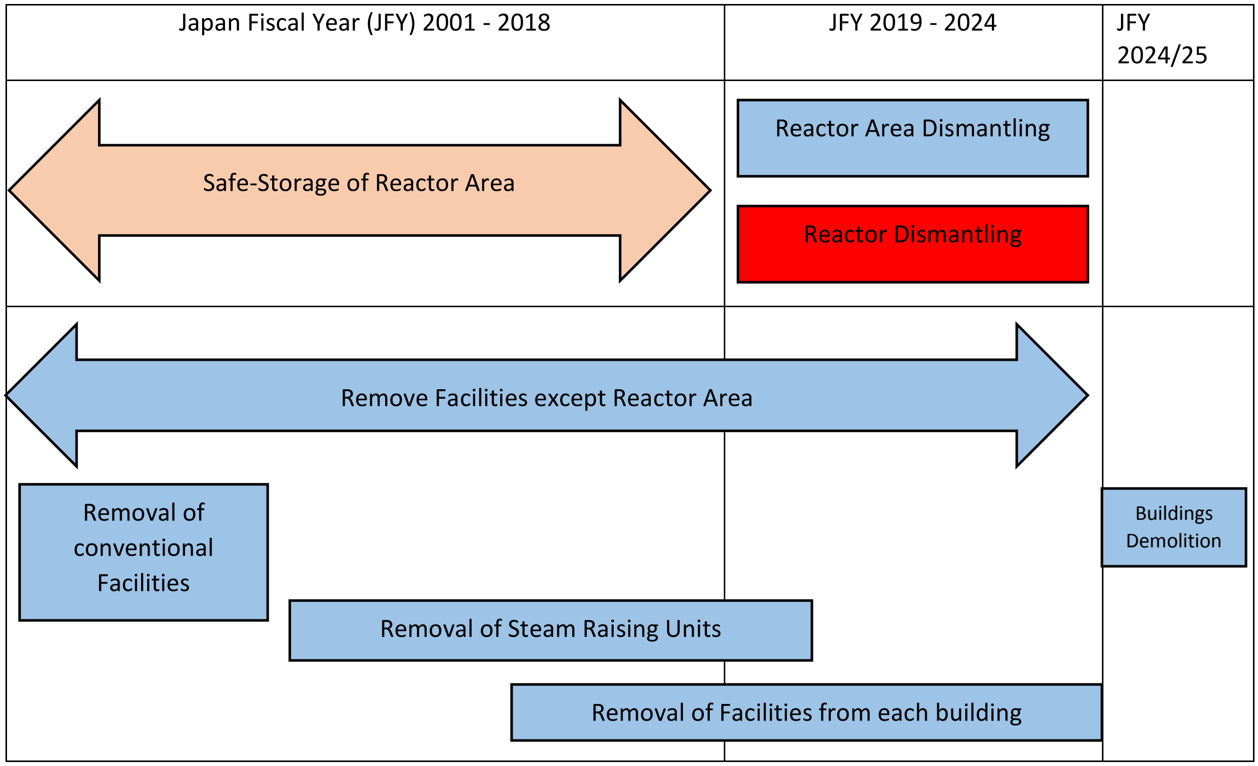

Figure 7: Tokai I Decommissioning Project[77]

II.1.2 Hamaoka NPP Units 1 – 2

The oldest two reactors of the Hamaoka NPP are BWRs, a common design for modern power reactors originating in the US. The plant started commercial operation in the late 1970s. In contrast to gas-cooled reactors like Tokai I, which are mostly limited to the UK and France, BWRs were built throughout the world to a number of different design specifications. BWRs are now considered to be more susceptible to accidents than PWRs and more difficult to upgrade, so BWRs are often among the first reactors to be decommissioned. Especially in Germany there is now considerable expertise with the decommissioning of BWR-type plants[78], and Japanese authorities show a growing interest in collaboration with the German and European companies involved in those projects. The reactors were originally shut down for safety upgrades. After an earthquake in 2007 it was decided not to restart them. Decommissioning officially began in 2009. A major problem for the decommissioning process is the unavailability of a waste disposal site, forcing the operator Chubu Electric Power to store the waste temporarily on-site. As waste disposal is part of the decommissioning process in Japan, the project cannot be completed before a viable waste management route has been found. For this reason, most observers assume that this project will take longer than planned. The retrieval of the fuel was completed in March 2015, and Chubu Electric Power applied at the NRA to begin with stage 2 of the project, in which the

[77] Source: JAPCO 2015
[78] The decommissioning of 4 BWR-type reactors was successfully completed in Germany.

reactor is placed in safe storage while peripheral facilities are dismantled. The NRA approved this in February 2016, almost one year after the completion of fuel retrieval. Dismantling of the peripheral facilities is about to begin. Chubu Electric Power originally planned to build new reactors on the site after the completion of the project, but it is not known if this can be realised.

Fact Sheet – Hamaoka NPP units 1 – 2	
Type	BWR
Net Capacity MWe	515 (Hamaoka 1) 806 (Hamaoka 2)
Operator	Chubu EP
Main Contractor	Toshiba (Hamaoka 1) Toshiba/Hitachi (Hamaoka 2)
Start of commercial operation	3/76 (Hamaoka 1) 11/78 (Hamaoka 2)
Shut-down	11/01 (Hamaoka 1) 2/04 (Hamaoka 2)
Start of decommissioning	1/09

Hamaoka NPP (Chubu)

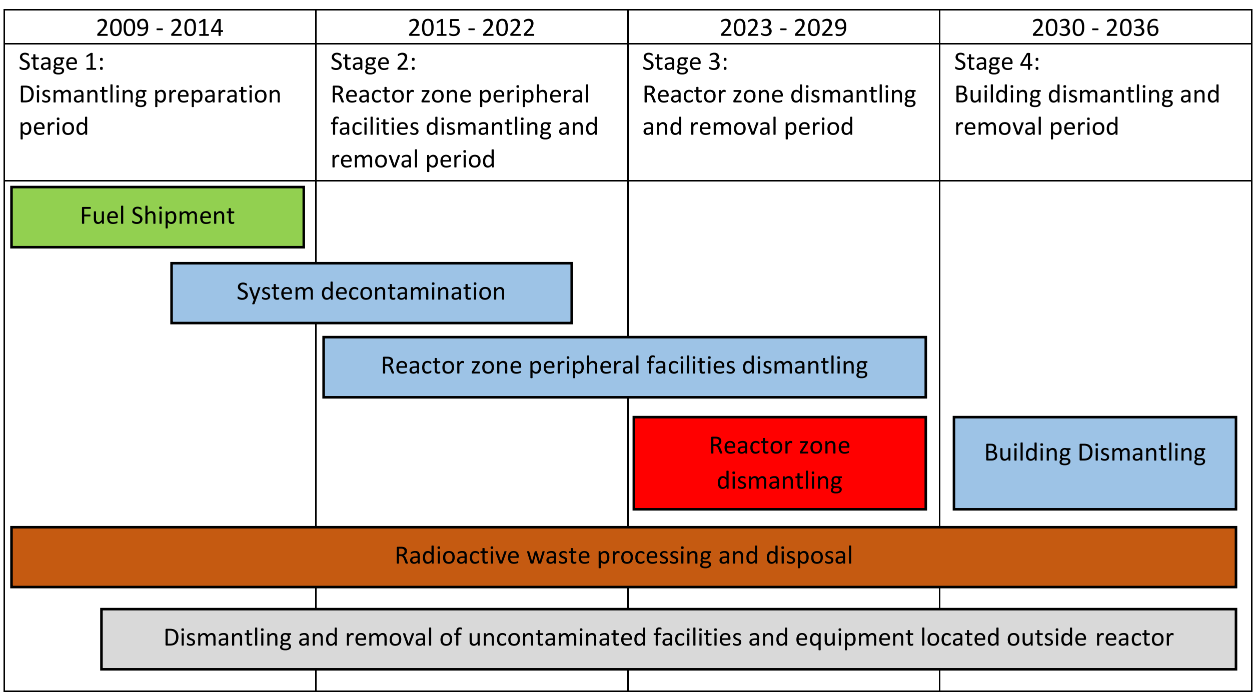

Figure 8: Hamaoka 1/2 Decommissioning Project[79]

[79] Source: JAPCO 2015

II.1.3 Fugen NPP

Fugen is an experimental reactor built to gain experience with MOX fuel. In contrast to the predominant PWR and BWR reactor designs, in which normal "light" water serves as both moderator and coolant, Fugen uses heavy water as moderator (light water is still being used as coolant). This project is managed by the JAEA and has some characteristics that sets it apart from the other decommissioning projects in Japan. It is the only project where no period of safe storage is planned. The JAEA has instead opted for the immediate dismantling of the reactor. Also in contrast to the other projects, the JAEA has not accumulated decommissioning funds during the operation of the reactor. The project is therefore dependent on funding by the MEXT. Both the team in charge of decommissioning and the NRA are concerned that the current budget might be too limited, which could make it difficult to ensure safety during the decommissioning process. Despite the need for cost minimisation, the decommissioning crew has managed to study a variety of technologies in the course of the project, including many imported products. Cooperation with JAPCO, who manages the decommissioning of reactor unit 1 of the neighbouring Tsuruga NPP, is still underdeveloped, despite the obvious advantages of such an approach for both sides. The dismantling of the condensers is currently underway and the removal of the tritium residue in the heavy water system is almost completed.

This project faces two principal problems: the transfer of spent fuel from the site and the dismantling of the reactor core.

As mentioned in chapter I.4.2, reprocessing of MOX fuel is currently impossible in Japan due to technical limitations. Originally it was planned to reprocess the spent fuel at the JAEA reprocessing plant in Tokai, but this is now out of question due to the decommissioning of that facility after the Fukushima accidents. At the moment, the operator hopes to reprocess the fuel in France, but there are strict international regulations on the transportation and handling of plutonium[80]. It is therefore not yet known if this method can be implemented. As a temporary measure, the decommissioning team plans to leave the fuel in the SFP while dismantling the reactor as planned. The fuel would then be removed from the SFP once a disposal method becomes available. This change to the original decommissioning plan requires NRA approval. The transfer of the spent fuel will therefore take longer than planned regardless of the eventually adopted strategy. Despite these problems, the operator hopes to complete the overall project in time until 2033.

The reactor core of Fugen is internally much more complex than conventional cores. The employed cutting equipment needs to be able to operate in very confined spaces and to cut from the inside of double tubes made of a flammable zirconium alloy. Various cutting technologies for this purpose are studied at the moment (see section III.3.5).

[80] Primarily due to the obligation for nuclear non-proliferation under international treaties, since plutonium can be used to construct nuclear weapons

The Fugen project aims to make heavy use of the clearance system to reduce the amount of radioactive waste (see Table 4). The clearance system for concrete waste is not yet established. Disposal methods for the radioactive waste are also not yet established, but it is planned to use an on-site repository for L3 waste. As a structurally similar reactor, the experiences of German and other European companies in the decommissioning of the Niederaichbach heavy water reactor, successfully completed in 1995, are attracting the interest of the organisations and companies involved in the decommissioning of Fugen. The site of Fugen is only leased from JAPCO and will be returned after decommissioning.

Fact Sheet – Fugen NPP unit 1	
Type	ATR[81]
Net Capacity MWe	148
Operator	JAEA[82]
Main Contractor	various[83]
Start of operation	3/79
Shut-down	3/03
Start of decommissioning	3/03[84]

Fugen NPP (IAEA)

[81] ATR: Advanced Thermal Reactor

[82] The original operator was the Japan Nuclear Fuel Cycle Development Institute (JNC), which became part of the JAEA in 2005

[83] See http://www.jaif.or.jp/en/npps/fugen-1/

[84] Preparatory work began immediately after shut-down, but the project was only approved in 2/08

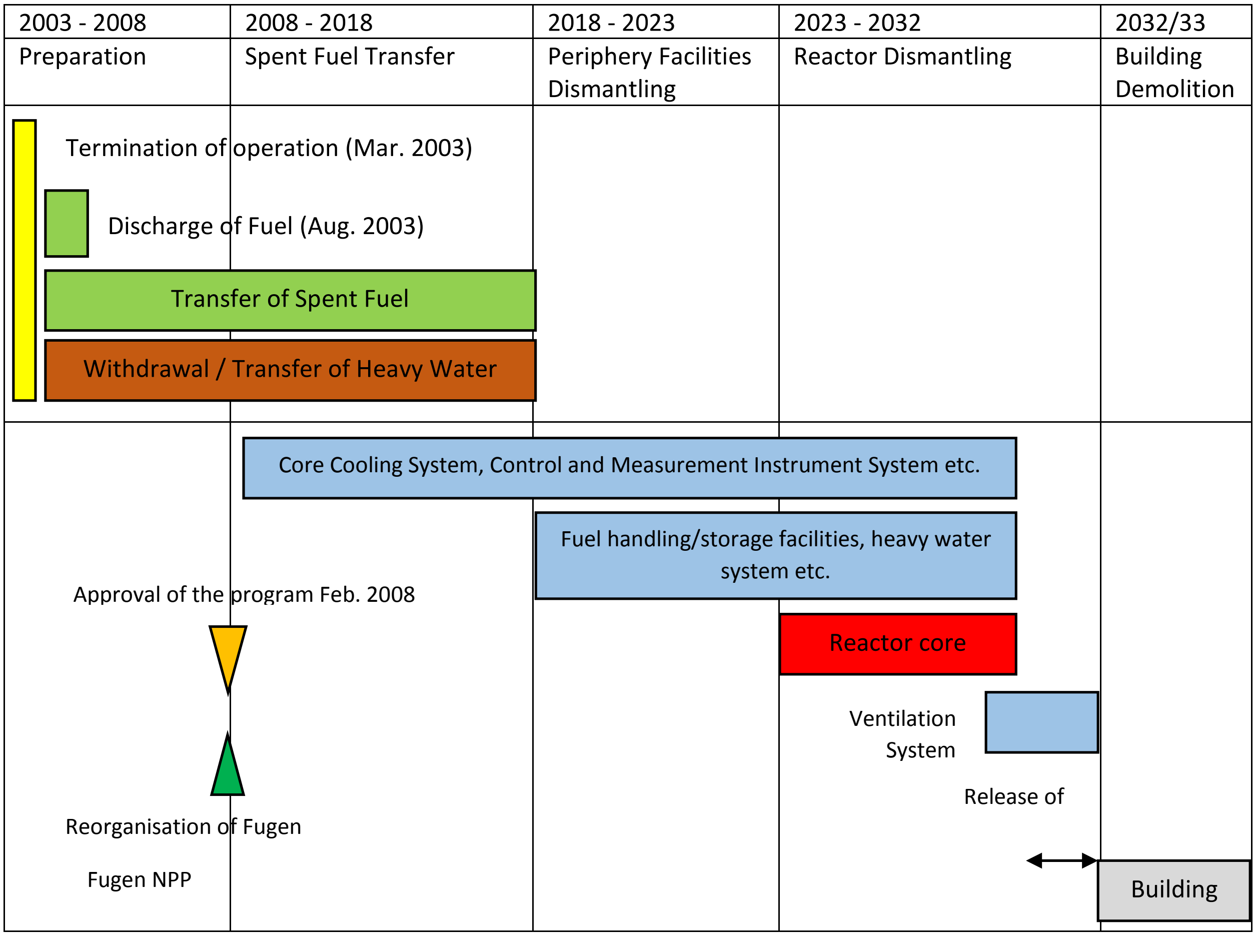

Figure 9: Fugen Decommissioning Project[85]

II.1.4 Tsuruga NPP Unit 1

Unit 1 of Tsuruga NPP is the oldest Japanese BWR, with a comparatively small electrical output of 357MWe. It is located in Fukui prefecture, on the same site as the Fugen reactor (see above) and close to the planned Mihama decommissioning project. Since this will be the second decommissioning project for the company, JAPCO can use the experience gained in the ongoing Tokai I project to facilitate the decommissioning of this plant. Furthermore, the proximity to several other reactors in decommissioning (albeit all under different operators and using different reactor technology) may allow the sharing of technology and expertise between the individual projects. Such cooperation has not materialised yet. JAPCO submitted the decommissioning plan for Tsuruga 1 to the NRA in February 2016.

[85] Source: JAEA 2015

Fact Sheet – Tsuruga NPP unit 1	
Type	BWR
Net Capacity MWe	341
Operator	JAPCO
Main Contractor	GE
Start of commercial operation	3/70
Shut-down	1/11
Written off for decommissioning	3/15

Tsuruga NPP unit 1 (JAPCO)

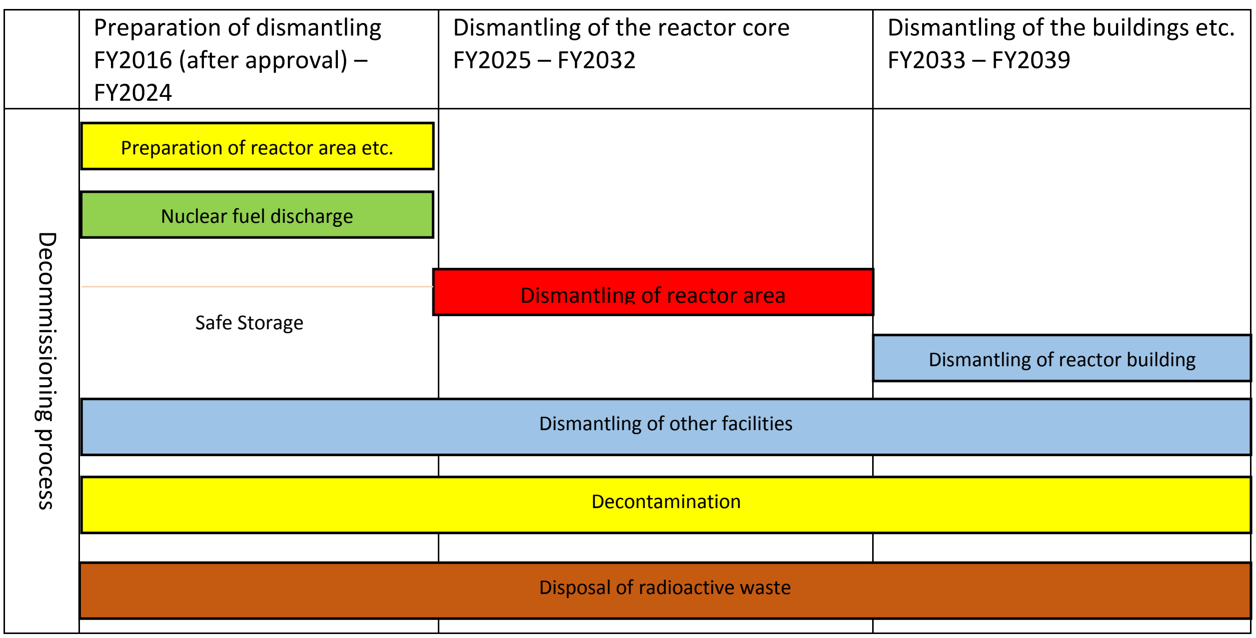

Figure 10: Tsuruga 1 Decommissioning Project (tentative)[86]

[86] Pending NRA approval. Source: JAPCO 2016

II.1.5 Mihama NPP Units 1 – 2

The two oldest units of the Mihama NPP are small, old reactors. In contrast to the aforementioned plant at Tsuruga, the Mihama reactors are PWRs. The plant is owned by Kansai Electric Power and will be the first decommissioning project for the company. This project will likely have the character of a pilot project to gain decommissioning expertise for subsequent decommissioning projects. As the reactors are also located in Fukui prefecture, close to the sites of both Fugen NPP and Tsuruga NPP, synergy effects from collaboration with other decommissioning projects in the region might improve the efficiency of the decommissioning project. Together with Genkai NPP unit 1, this project will be the first decommissioning of PWR-type reactor in Japan. Kansai Electric Power submitted the decommissioning plan for the two reactors to the NRA in February 2016. This plan already seems to take some of the risks mentioned in Chapter I into account. The long period of defueling is mostly due to the lack of storage space and reprocessing capacities in Japan, whereas the long safe storage period of 19 years might reflect the financial uncertainties caused by the shutdown of the Japanese NPPs and the anticipated impact of the full liberalisation of the electricity market in Japan.

Fact Sheet – Mihama NPP units 1 – 2	
Type	PWR
Net Capacity MWe	320 (Mihama 1) 470 (Mihama 2)
Operator	Kansai EP
Main Contractor	WE/MAPI (Mihama 1) MAPI (Mihama 2)
Start of commercial operation	11/70 (Mihama 1) 7/72 (Mihama 2)
Shut-down	12/11
Written off for decommissioning	3/15

Mihama NPP (IAEA)

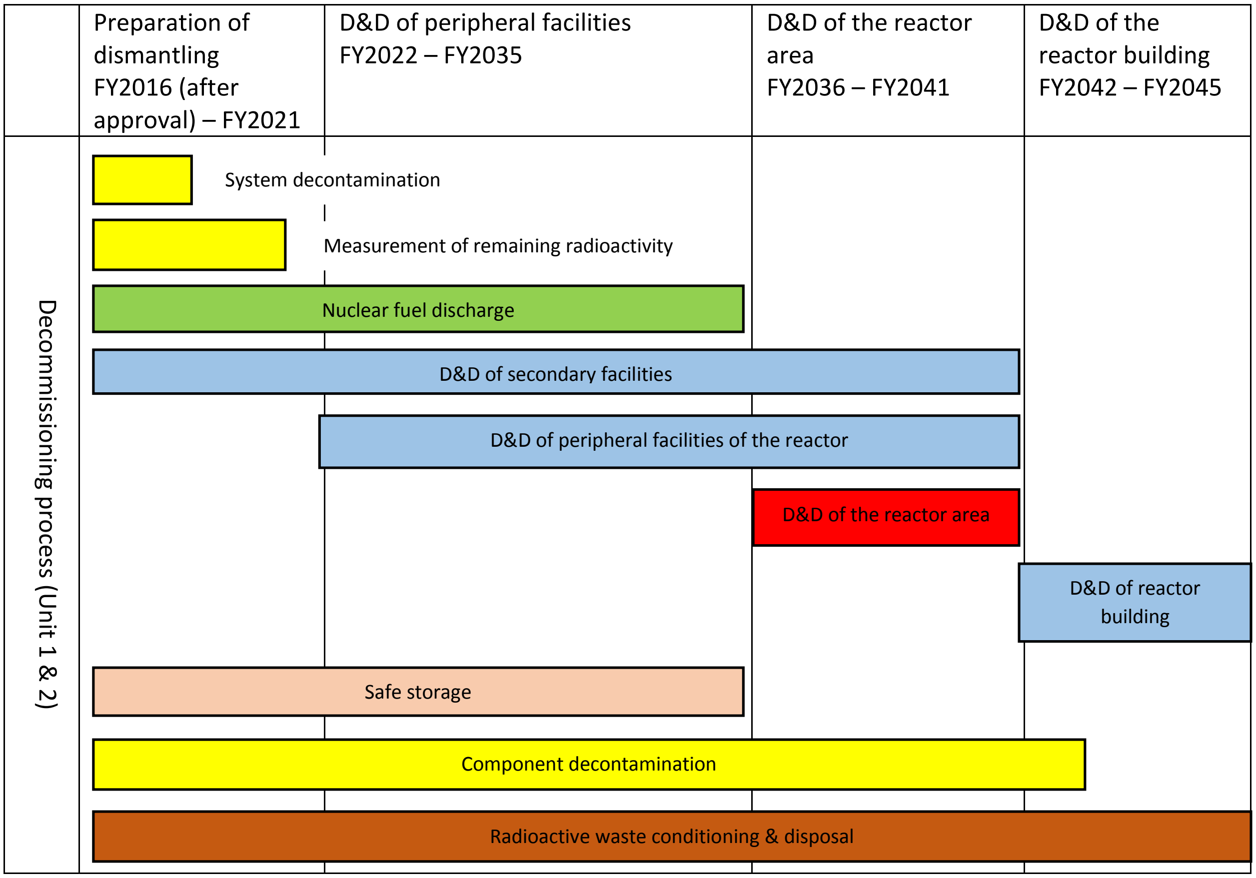

Figure 11: Mihama 1/2 Decommissioning Project (tentative)[87]

II.1.6 Shimane NPP Unit 1

Reactor unit 1 of Shimane NPP is a BWR and was the first reactor that was completely designed and built domestically in Japan. It is operated by Chugoku Electric Power and located in Shimane prefecture in western Japan, isolated from the other projects. Similar to Kansai Electric Power, Chugoku Electric Power lacks previous expertise in decommissioning. While JAPCO, JAEA, TEPCO and Kansai Electric Power are organisations with extensive expertise in the field of nuclear power, Chugoku Electric Power is a medium-sized regional utility and operates only two nuclear reactors. This means that this company may have to rely more heavily on the Japanese industrial companies for decommissioning-related services. Chugoku Electric Power has not yet submitted its decommissioning plan for the reactor.

[87] Pending NRA approval. Source: Kansai Electric Power 2016

Fact Sheet – Shimane NPP unit 1	
Type	BWR
Net Capacity MWe	439
Operator	Chugoku EP
Main Contractor	Hitachi
Start of commercial operation	3/74
Shut-down	11/10
Written off for decommissioning	3/15

Shimane NPP (IAEA)

II.1.7 Genkai NPP Unit 1

Genkai NPP's reactor unit 1 is a PWR and entered service in 1975. Its operator is Kyushu Electric Power, another medium-sized regional utility. The plant is located in Saga prefecture on Kyushu island, like Shimane 1 far away from the centres of decommissioning in Fukui prefecture and the neighbouring prefectures of Ibaraki and Fukushima. This decommissioning project is the first major decommissioning project for the operating company and one of the first PWR decommissioning projects in Japan. Kyushu Electric Power submitted its decommissioning plan to the NRA in December 2015. Like the decommissioning plan for the two Mihama reactors, the decommissioning plan features a comparatively long period for defueling and safe storage, reflecting some of the uncertainties in the decommissioning of nuclear facilities in Japan.

Fact Sheet – Genkai NPP unit 1	
Type	PWR
Net Capacity MWe	529
Operator	Kyushu EP
Main Contractor	MHI
Start of commercial operation	10/75
Shut-down	12/11
Written off for decommissioning	3/15

Genkai NPP (IAEA)

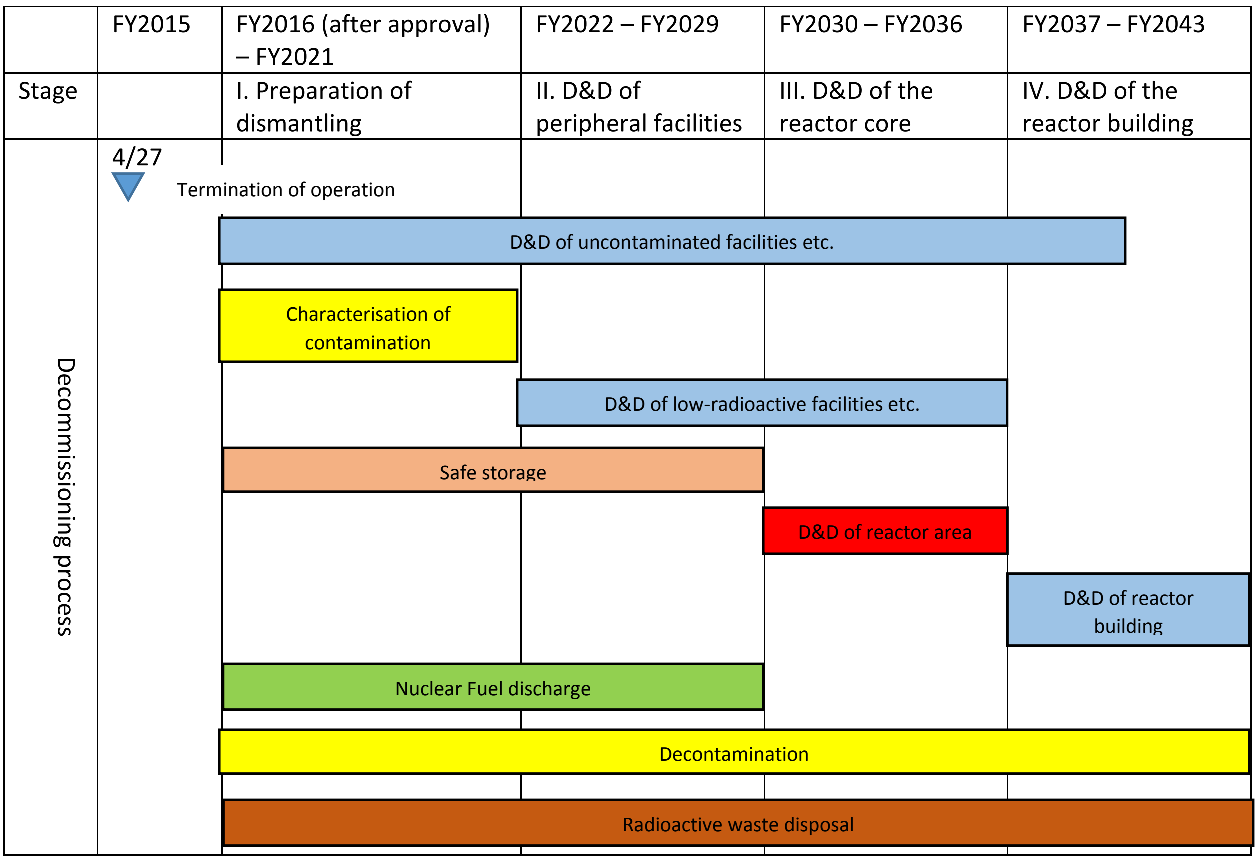

Figure 12: Genkai 1 Decommissioning Project (tentative)[88]

II.2 The Fukushima I NPP Decommissioning Project

All reactors described in the previous section can be decommissioned with conventional technologies. The decommissioning of Fukushima I NPP is a different case[89]. Owned by TEPCO and located in Fukushima prefecture in north-eastern Japan, the power plant was flooded and heavily damaged in a tsunami-earthquake in March 2011. The damage caused by the tsunami-earthquake resulted in the nearly total loss of power at the plant and the subsequent failure of the reactor cooling systems. Even though all of the reactors had automatically shut-down after the initial earthquake, the hot fuel in the reactor core still required cooling to prevent uncontrolled recriticality. The loss of power and coolant resulted in a fuel meltdown in three of

[88] Pending NRA approval. Source: Kyushu Electric Power 2015
[89] This is also reflected in the designation of Fukushima I NPP as a "Specified Nuclear Facility" under the new safety regulations

the six reactors and heavy damage to three reactor buildings due to hydrogen explosions. Large quantities of radioactive substances escaped from the plant. Even though the emission of radioactive substances and the damage to the individual reactors was lower than at Chernobyl, simultaneous accidents in four reactors were a new, unprecedented scale of disaster. It took TEPCO until December 2011 to announce that all damaged reactors had been stabilised in a state of cold shut-down.

While workers at the site were busy to stabilise the reactors and prevent the emission of more radioactive substances, the DPJ-led government decided to develop a strategy for the ultimate decommissioning of the first four reactors of the Fukushima I NPP. This decommissioning plan was termed the "*Mid- and Long-term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Units 1-4*" and was released on 21 December 2011. This plan envisioned a decommissioning project of around 30 to 40 years, to be completed in three stages: 1) Fuel retrieval from the SFPs, 2) Removal of the fuel debris in the reactor cores, and 3) Completion of the decommissioning.

This plan proved to be too ambitious and has since seen a number of delays and revisions. To calm the strong anti-nuclear sentiments in the Japanese population, the new LDP government of Prime Minister Shinzo Abe decided to include reactor units 5 and 6, which only sustained light damage during the tsunami-earthquake, in the decommissioning project. As a result, all reactors at the Fukushima I NPP will now be decommissioned. In spite of these changes, the Mid-to Long-term roadmap remained the basis for the planning process of the decommissioning project, seeing a number of revisions as more and more details about the status of the damaged reactors and the technical requirements for decommissioning became known. The last revision was made by the NDF, when this organisation assumed the role of directing the overall strategy for the decommissioning of Fukushima I NPP in 2014. This plan, titled *"Technical Strategic Plan 2015 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company – Towards Amendment of the Mid- and Long-Term Roadmap in 2015"*, was released on 30 April 2015. It re-examined the technical feasibility of the proposed strategies for the removal of the fuel debris and the R&D requirements for the decommissioning efforts. The NDF further established or strengthened five guiding principles for all work undertaken at Fukushima I: The principle of safety (1) mandates the reduction of risks posed by radioactive materials and promotes work safety, the principle of proven technology (2) calls for the adaptation of reliable and flexible technology, the principle of efficiency (3) requires the efficient utilisation of available resources, the principle of time (4) calls for awareness of the temporal dimension, and the principle of field-orientation (5) emphasises the importance of actual conditions at the site. The application of these principles might mean that European companies with proven technology and competitive prices can find more opportunities in the decommissioning of Fukushima I in the future.

The duration of the project was also extended to around 50 years. A schematic of the amended Mid- and Long-term roadmap is given in Figure 13 below. As the internal status of the damaged reactors and the location and chemical properties of the fuel debris are still largely unknown, **more delays or changes might occur in the future**. The following discussion of the Fukushima I decommissioning project as well as the later chapter on technology demand at Fukushima I (see Part III) is based on the NDF roadmap, except if explicitly noted otherwise.

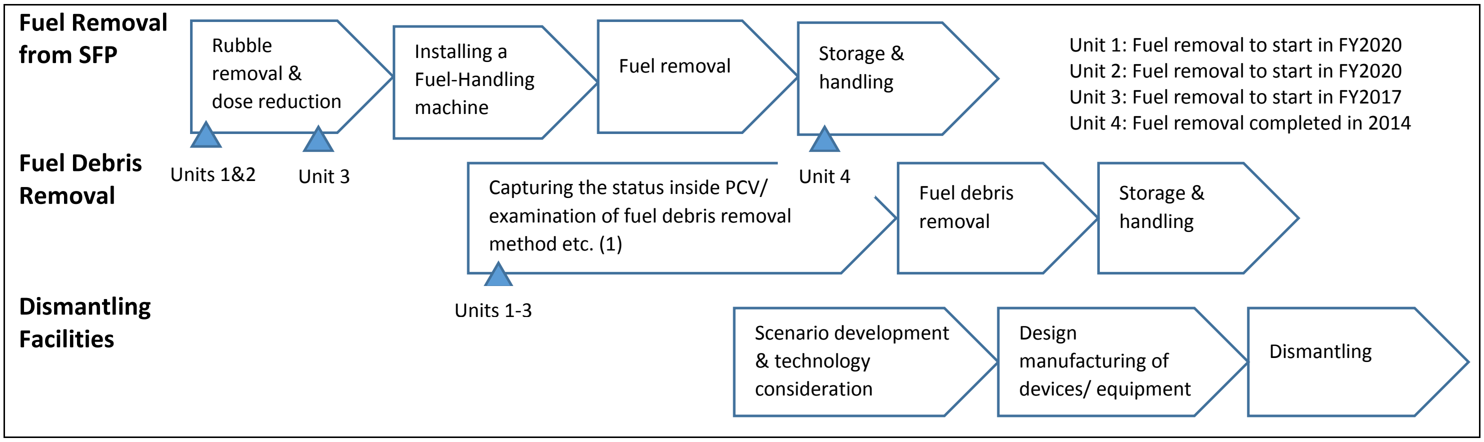

Figure 13: Roadmap for the Fukushima I Decommissioning Project[90]

(1) The fuel debris removal method for each unit will be decided two years after revising the Mid- and Long-term road map (June 2015). The method for the first unit will be confirmed in the first half of FY2018.

The lack of practical expertise with decommissioning and the unprecedented nature of the accidents have led to a number of technological experiments at the site, with mixed results. While the decontamination of the exterior is progressing, dose rates inside the reactor buildings remain high. This makes the exploration difficult, leading to a heavy reliance on remote-controlled and robotic devices. Many of these devices are purpose-built and require long development time before deployment. The current work, beside decontamination and water management, focuses on the retrieval of the spent fuel from the SFPs of the damaged reactor units and the exploration of the reactor interior (see Figure 14). TEPCO currently prepares the retrieval of spent fuel from the SFP of reactor unit 3. Retrieval from reactor units 4 – 6 is already completed. After completing this stage, the method for the removal of the so-called “corium” (highly-radioactive molten fuel and molten components of the reactor) from reactor units 1 – 3 will be decided and implemented. Several conceptual studies for this key issue of the decommissioning project are under consideration at the moment (see section III.4.5). The final third stage will see the dismantling of the reactors, starting with reactor units 5 and 6. These reactors are easier to dismantle than the damaged units and can provide valuable experience to TEPCO.

[90] Source: TEPCO 2015

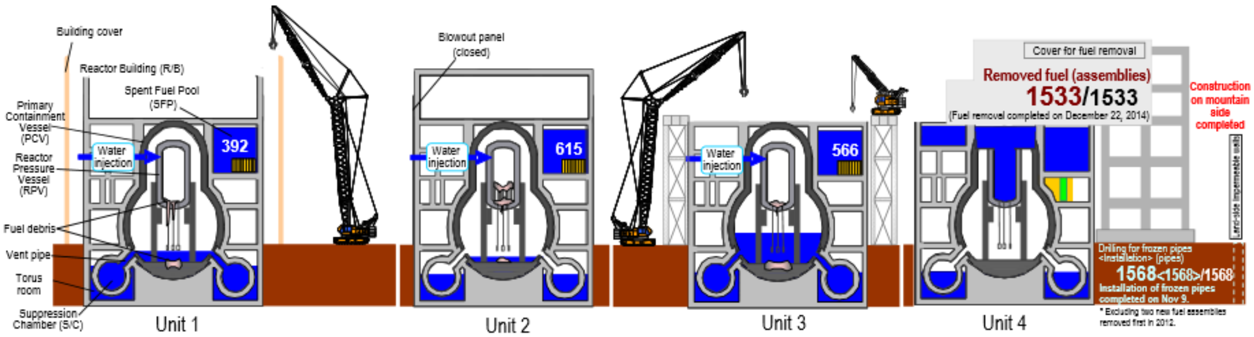

Figure 14: Current situation of the damaged reactors at Fukushima I NPP[91]

Fact Sheet – Fukushima NPP units 1 – 6							
Reactor	Type	Net Capacity MWe	Operator	Main Contractor	Start of commercial operation	Shut-down	Sustained damage 3/11
Fukushima I-1	BWR	439	TEPCO	GE	3/71	3/11	Core meltdown & hydrogen explosion
Fukushima I-2	BWR	760	TEPCO	GE/Toshiba	7/74	3/11	Core meltdown
Fukushima I-3	BWR	760	TEPCO	Toshiba	3/76	3/11	Core meltdown & hydrogen explosion
Fukushima I-4	BWR	760	TEPCO	Hitachi	10/78	11/10	Hydrogen explosion
Fukushima I-5	BWR	760	TEPCO	Toshiba	4/78	1/11	Minor damage
Fukushima I-6	BWR	1067	TEPCO	GE/Toshiba	10/79	8/10	Minor damage

Fukushima I NPP (AP)

[91] As of 24 December 2015, taken from TEPCO 2015

II.2.1 Fukushima I NPP Units 1 – 3

The reactors 1, 2 and 3 of the Fukushima I NPP suffered the most severe damage during the accidents. All three reactors were in commercial operation at the time of the accidents, and the hot fuel in the reactor cores required continuous cooling to prevent the fuel from overheating, even after the automatic shut-down after the earthquake. However, the earthquake and tsunami disrupted the power supply – both from external and emergency sources – to the reactors. Without power, the cooling systems stopped working one after another, and the temperature and pressure in the cores began to rise to critical levels. While pressure could be relieved by emergency venting, attempts to re-establish emergency cooling proved to be less successful. This resulted in core meltdowns with subsequent damage to the bottom of the Reactor Pressure Vessel (RPV) and possibly the Primary Containment Vessel (PCV) in all three units. Hydrogen generated in the core escaped into the reactor buildings, where it accumulated until it reached the threshold for spontaneous explosion. Hydrogen explosions occurred in units 1 and 3, causing significant damage to the reactor buildings. The structural damage to the reactor buildings and the debris of these explosions pose an additional challenge for the decommissioning activities, as the installed equipment for fuel retrieval in the reactor buildings is damaged or unusable and access routes[92] to the reactor cores blocked. Some pipes and other structurally weak parts of the containment also suffered damage during the accidents, the core meltdown and subsequent stabilisation efforts, e.g. material degradation caused by the salt of the seawater used in the early emergency cooling of the reactors. From these leaks, contaminated water continues to trickle into the reactor buildings (leaks are confirmed for units 1 and 3[93]). Furthermore, next to the fuel in the core, which is believed to have mostly melted and moved through the bottom of the RPV into the lower PCV, the reactor's SFPs also house a large quantity of spent fuel assemblies, which pose an additional safety risk[94]. Work is currently underway to prepare the three units for the retrieval of the spent fuel, which is expected to be begin in 2017 (unit 3) and 2020 (units 1&2). After the retrieval of the spent fuel, the third stage of the decommissioning activities will see the retrieval of the molten fuel from the reactor core. The method and feasibility of this operation is currently under consideration. Investigation robots have successfully entered and explored the reactor interior of unit 1 and 3 in 2015, marking an important step in the exploration of the reactors. Further exploration of the reactor interior will be necessary to identify the location of the fuel debris and to confirm the status of the PCV. Muon tomography scanning has confirmed that no large concentrations of fuel remain in the RPV, but the actual location or locations of the fuel debris remains unknown. Due to differences in the internal situation, the method and technology for fuel debris removal will likely have to be customised for each reactor.

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[92] The conventional access route for fuel retrieval is from the top, using a crane that is also used to change fuel assemblies during commercial operations. The explosions might have disabled this crane or the valves and motors of the access port.

[93] NDF 2015. More leaks are suspected.

[94] Unit 1: 392 fuel assemblies, unit 2: 615 fuel assemblies, unit 3: 566 fuel assemblies. TEPCO 2015

II.2.2 Fukushima I NPP Unit 4

Reactor unit 4 was not in operation at the time of the accidents, and no fuel was loaded into the core. However, the reactor building also experienced a hydrogen explosion, caused by hydrogen that wandered into the reactor building of unit 4 through shared piping with unit 3. Unit 4 housed a large number of spent fuel assemblies in its SFP, which caused serious safety concerns[95]. As a result, it was decided to remove the fuel assemblies of this unit first. The removal was successfully completed in December 2014. As the retrieval of molten fuel debris is not necessary in this unit, it is planned to begin the D&D stage for the four damaged reactors with this unit.

II.2.3 Fukushima I NPP Units 5 – 6

The other two reactors of the Fukushima I NPP were built later than the earlier units, at a slightly more elevated location. They are more modern designs with improved safety systems. At the time of the accidents, they were also shut down for maintenance, but fuel had already been loaded into the cores to conduct some preparatory tests for their planned restart. In contrast to the other units, where all power supply was lost, a single emergency generator remained operational and could be used to supply power to the emergency cooling systems of the two reactors. Therefore, the overheating and core meltdown that occurred in units 1 to 3 was successfully prevented and the reactors were quickly brought back under control. It was originally planned that these two reactors would re-commence commercial operation after the clean-up of the site, but due to popular resistance the government finally decided that all reactors of the Fukushima I plant would be decommissioned[96]. As the extent of damage to these reactors is rather low, these reactors can be largely dismantled with conventional technologies.

Part III: The market for decommissioning in Japan

This part focuses on the market for decommissioning-related products and services in Japan. Following the characteristics of this market (chapter III.1), a short section introduces the procurement system for such products and services (chapter III.2). As generic products and services will be mostly provided by domestic suppliers, the more interesting aspects are technologies for specific nuclear-related decommissioning activities. These technologies are

[95] Unit 4: 1533 fuel assemblies. Source: TEPCO 2015

[96] Undamaged reactors at the sites of other severe nuclear accidents, Chernobyl NPP and Three Mile Island NPP, also continued to be used for commercial purposes after the accidents.

discussed in the following chapter (chapter III.3). The last chapter of this part focuses exclusively on the unique demand of the Fukushima I decommissioning project (chapter III.4).

III.1 Characteristics of the market

The decommissioning of large-scale NPPs in Japan is only beginning in Japan, as shown in the two preceding parts. Therefore, even though the technological capabilities of the Japanese industry are quite advanced, practical experience with large-scale projects remains limited. Most technologies for decommissioning have only been tested and employed in an experimental environment during the decommissioning of the JPDR or in mock-up facilities.

Nevertheless, the market is already largely divided between the major industrial corporations and construction companies and their affiliates. In fact, most of these companies seemingly do not perceive the decommissioning of nuclear facilities as a separate market, but as a continuation of the construction and operation of the facility. As such, the companies on the market for nuclear decommissioning are often the same companies that were already involved at those earlier stages. The long-standing and close relationship with the utilities places these companies in a very influential position and gives them a decisive advantage. It is very unlikely that European companies, regardless of size or product portfolio, can gain a similar position on the market. As many utilities do not have large engineering teams or R&D capacities of their own, they rely heavily on the nuclear vendors and general contractors as the main contractors for decommissioning-related work (tier 1 contractors). These prime contractors in turn employ various subcontractors to supply manpower, services and products (tier 2 contractors). Figure 15 shows this arrangement in a schematic way. It is unlikely that this arrangement will change much in the near future.

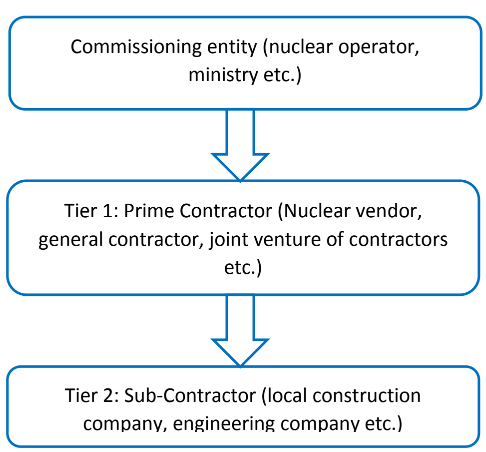

Figure 15: General work flow of decommissioning-related projects

Japanese companies are confident that they can readily supply the services and products needed for decommissioning. This is particularly true for general products and services, so **demand for general decommissioning equipment and services is expected to be very low**. Only European companies well-integrated into the Japanese market and with a representation in Japan might be able to find business opportunities in this area.

In respect to nuclear-related products, however, the basic design of many technologies seems to originate from overseas. Highly specialised parts and components are also imported and used in Japanese-manufactured devices and machines. Specialised nuclear-related technologies therefore offer the best opportunities for foreign companies. The demand for such equipment is expected to increase during the dismantling of the reactor area, when tools and machines for the cutting and segmentation of the reactor as well as the handling of large quantities of radioactive waste will become necessary. The first project is scheduled to enter this stage in 2019 (see Table 10). US companies seem to be the most active at the moment, but European companies also have a certain presence on the market. Several recently established joint-ventures between European and Japanese companies point to a growing interest in deepening mutual business relations in this field. Russian companies appear to be almost absent.

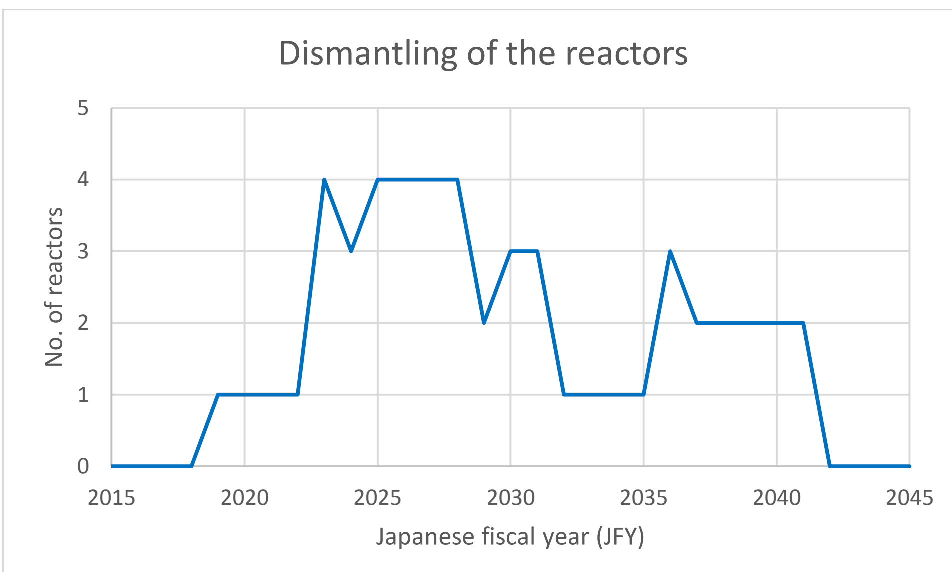

Table 10: Dismantling of the reactors (excluding the reactors of the Fukushima I NPP)

All foreign companies currently involved in nuclear decommissioning in Japan are established companies with a strong reputation and a long history of business in the nuclear industry. Many also offer a highly specialised product portfolio. The current situation shows a recurring pattern of how foreign companies are involved in nuclear decommissioning: They often provide the basic design or specialised components, whereas the adaptation, manufacturing and operation of the technology is done by a Japanese partner, usually one of the three reactor vendors (see Figure 16). Almost all companies involved so far **focus on products**, whereas decommissioning-related services provided by foreign companies are extremely rare at the moment.

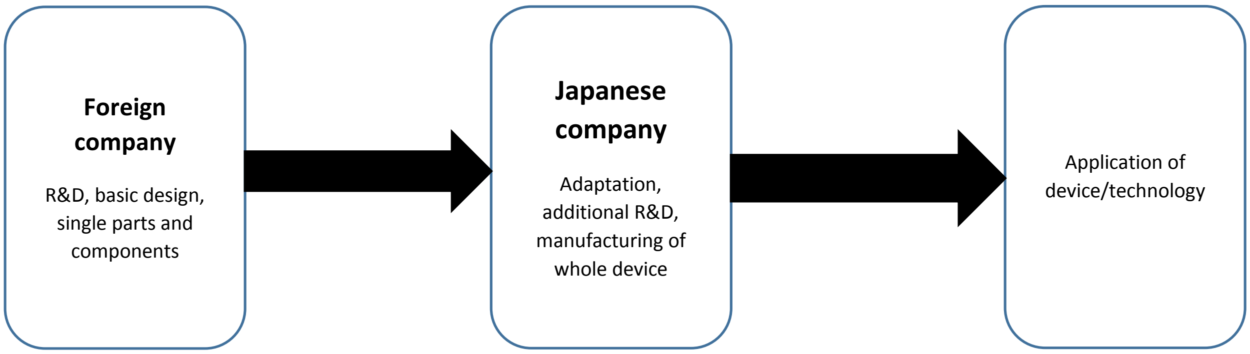

Figure 16: Pattern of foreign involvement in decommissioning

III.2 Procurement

Japanese corporations active in the nuclear sector, placing strong importance on trust and personal relationships, usually do not procure publicly for decommissioning-related services and products. Procurement by Japanese companies is usually a lengthy process with a strong emphasis on quality criteria. This can lead to meticulous questions about the product and may require product or facility inspections by the procuring entity. Companies with production plants and representations in Japan are therefore in an advantageous position. Equipment supplied by overseas companies is usually highly specialised, whereas general products and services are usually procured from domestic suppliers. This is reflected in Table 11, which shows recent nuclear-related procurement by Kansai Electric Power. Since most decommissioning-related activities are carried out by contractors, most products are not directly procured by the utilities managing the projects. Due to language barriers and risk-aversion, Japanese companies might also choose to not directly procure from foreign companies, instead using affiliated trading houses and other middlemen for product scouting and negotiations. This makes the process somewhat opaque. In fact, even the managers of the decommissioning projects seem to have some difficulty in tracing the country of origin and the original producer of some of the employed products and technologies.

Main items procured	Main items procured from suppliers outside Japan[97]
Reactor vessels & auxiliary system	Spent fuel storage device (spent fuel pit rack)
Turbines & generators and related system	Condenser system equipment (condenser tube cleaning system, Eddy filters for condenser tube)
Instrumentation & control equipment	Other related equipment
Circulation water pipes	
Trash screen	
Water treatment facilities	
Waste disposal system	
Cranes	
Radiation monitoring system	
Other related equipment	

Table 11: Procurement by Kansai Electric Power[98]

Government-financed projects, such as the decontamination of areas outside of the Fukushima I NPP or MEXT and METI R&D projects, are usually public tenders. Such tenders are announced in **Japanese language** in the official gazette of the Japanese government (called Kanpo), business newspapers and the websites of the relevant authority. The application process is quite complex and requires Japanese-language documentation. For more information about the public procurement system in Japan refer to the 2014 study on the subject by Lyckle Griek[99].

III.3 Specific technology demand in conventional decommissioning projects

The decommissioning of a nuclear facility involves technical tasks such as the monitoring of the radioactive dose rates and the characterisation of the radioactive inventory, the retrieval and transport of spent fuel, decontamination, dismantling of the facilities and the processing, treatment and disposal of waste. While many activities can be sufficiently completed with conventional equipment and machinery readily available in Japan, some tasks require specialised equipment. This applies especially to all the aspects of decommissioning that are directly related to the nuclear properties of the facility – facility characterisation, decontamination, fuel and waste management and the dismantling of the reactor. Next to this demand for products, non-technical services such as staff training, consulting services and knowledge management represent other fields with demand for specialised expertise. All of these areas also require supporting R&D capacities to develop the technologies and adapt them for the on-site conditions. This is especially true in Japan, where nuclear decommissioning is still a rather new phenomenon. The following sections introduce and discuss selected specialised technologies and their demand in Japan. An overview of specialised nuclear-related technologies is given in Figure 17.

[97] Includes procurement for both fossil-fired & nuclear power plants
[98] Taken from http://www.kepco.co.jp/english/corporate/info/procurement/formalities/index.html (accessed 16 February 2016)
[99] see Griek 2014 in the list of references

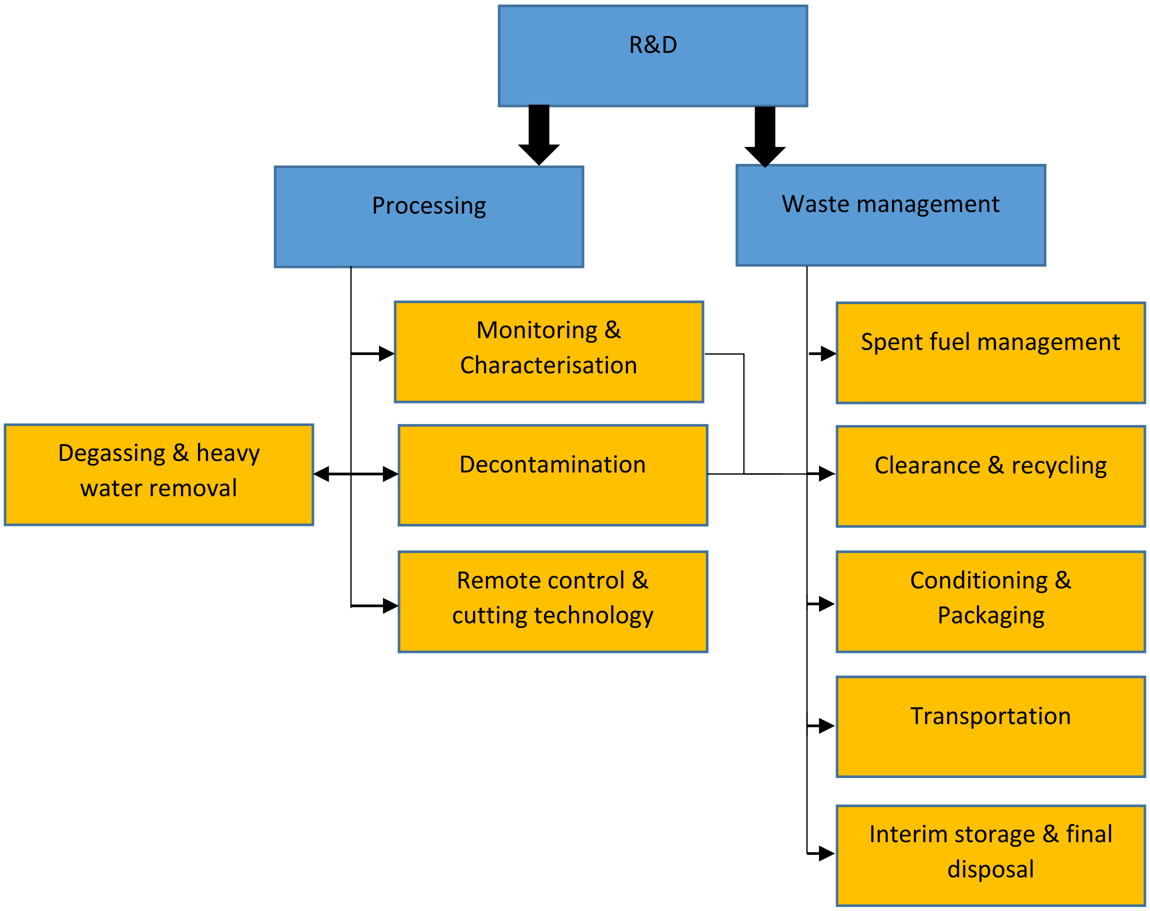

Figure 17: Demand for specialised technologies in nuclear decommissioning

III.3.1 Characterisation and measurement technologies

Precise knowledge about dose rates, nuclide concentration, the location of contamination, and the distribution of radionuclides in a nuclear facility allows to address the hazards associated with radioactivity as well as the categorisation of waste and the planning of a decontamination strategy. This data is usually acquired from multiple sources, including the operational record of the facility, a characterisation of the radioactive inventory at the beginning of the decommissioning process and computational simulations. This field therefore includes a range of different technologies, ranging from computer-based database and simulation programs to hand-held, fixed-position or remote-controlled measurement devices. As part of the JPDR pilot program, a very extensive survey of the radioactive inventory was produced during the decommissioning process, including the characterisation of the whole plant and the measurement of every dismantled part. This is a valuable database for comparison and simulation. Further advances in technology and application have been made during the Fukushima I NPP decommissioning project, particularly in the field of remote-controlled devices (see section III.4.1). Due to these factors, the domestic industry in Japan seems to be able to supply the technology necessary for large-scale decommissioning projects. European companies may be able to supply single parts and components for Japanese-manufactured devices. This field also receives strong attention in R&D, so further growth and technical advances are likely. The interest in R&D could lead to new collaborative R&D projects and other opportunities for European companies.

III.3.2 Decontamination technologies

Decontamination is usually done in two stages: A system decontamination at the beginning of the decommissioning project to reduce the exposure of the workers to radioactivity and the decontamination of single components in later stages of the project. This second stage is particularly useful for waste management, as treated material with radioactive dose rates below the clearance level of 10 µSv/h does not need to be disposed of as radioactive waste. Decontamination is usually limited to surface contamination, while the treatment of volume contamination is difficult to impossible. Depending on the purpose and the component, different technologies may be employed (see Table 12 below). In general, the inner surfaces of tubes and pipes are decontaminated by using chemical solutions (system decontamination), whereas the surfaces of equipment, components and structures are decontaminated with mechanical, chemical or thermal methods (component decontamination). The decontamination and clearance system in Japan currently focuses on metallic materials, whereas a treatment system for concrete waste is not yet established. The current concepts revolve around removing the entire surface layer and the subsequent incineration of the carbon due to the difficult separation of C-14. The application of decontamination technology generates secondary waste, so project managers need to find a balance between the waste reduction achieved through decontamination and the generation of new waste. Highly efficient decontamination strategies and technologies, especially for concrete waste, are therefore areas with strong potential for European companies.

Decontamination method	**Examples**	
Chemical	Chemical solutions (CAN-DECON, CITROX, CORD, LOMI etc.) Chemical gels, etc.	
Mechanical	Flushing with water Steam cleaning Abrasive cleaning Drilling and spalling	Vacuuming/wiping/scrubbing CO2-blasting Scarifying/scabbling/planning etc.
Other	Electro-polishing Ultrasonic cleaning Melting	
Emerging techniques	Supercritical fluid extraction Microwave scabbling etc.	

Table 12: Decontamination technologies[100]

[100] Source: University of Fukui 2015

III.3.3 Heavy Water Treatment

In contrast to all other Japanese nuclear reactors, which use normal "light" water as moderator and coolant, the Fugen experimental reactor used heavy water as moderator. This water is irradiated and needs to be removed from the facility. The JAEA shipped 274t of heavy water to Canada for this purpose, where the water will be re-used in the heavy water-moderated NPPs of the country. After completing these shipments in 2014, the remaining tritium, present in both the heavy water residue and the surface of the tubing, still needed to be removed. This is facilitated by air and vacuum drying, after which the tritium is removed from the system in gaseous form. The decontamination of the heavy water system is now almost complete, so there will be no opportunities for European companies in this area.

III.3.4 Fuel retrieval technologies

In the conventional approach to nuclear decommissioning, the remaining fuel in the reactor core and SFP is removed from the facility before the dismantling of the reactor. While the removal in itself is a standard operating procedure in a NPP and therefore does not require specialised technology, the subsequent transport in purpose-built containers and interim storage in temporary facilities requires specific technical and engineering solutions. There is currently no mandatory design or exclusively licenced producer for spent fuel or radioactive waste containers in Japan. The NRA has specified that interim storage of spent fuel should be in dry storage with convection cooling[101]. Adaptation of European designs for this purpose is therefore possible, but Europe-designed containers still need to comply with strict safety regulations and Japanese industrial standards. The need to pass extensive safety inspections and testing can make this a very expensive investment. Easier opportunities might be found in collaborating with Japanese institutions in R&D for such containers.

European experience has shown that a rapid succession of decommissioning projects will greatly increase the demand for containers and casks for radioactive material. The lengthy manufacturing and acceptance process for such containers might result in supply shortages. This may force Japanese decommissioning managers to look for alternatives elsewhere. However, this scenario depends on the course and progress of the individual projects. If the conventional projects continue to experience delays, this supply shortage may never materialise in practice.

Due to the mentioned difficulties with the temporary storage and reprocessing of spent fuel, some projects are considering to adjust the method for the handling of spent fuel. In the Fugen project, an alternative concept of leaving the spent fuel in the SFP during the dismantling of the reactor is under consideration. If implemented, the spent fuel would only be transferred from

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[101] See http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/japan-nuclear-fuel-cycle.aspx

the site *after* the dismantling of the reactor. Internal safety analyses have shown that such a strategy would not significantly increase the risk of an accidental release of radioactive substances during decommissioning. The recently submitted decommissioning plans for Mihama NPP units 1 and 2 and Genkai NPP unit 1 also take these problems into account by opting for very long durations for spent fuel removal.

III.3.5 Cutting tools and remote-controlled equipment

A modern nuclear reactor is shielded by a concrete PCV and an inner RPV made of high-grade steel. The internal structure of both PCV and RPV is very complex. Furthermore, the area around the fuel is the most irradiated part of the reactor. Even after the removal of the fuel, the activated reactor internals and the RPV are still potent sources of radioactivity, requiring special precautions to prevent accidents and the release of radioactive substances during dismantling. The dismantling of the reactor, including PCV, RPV and reactor internals, is therefore a central technical and engineering challenge in the decommissioning of a nuclear facility. Other structures and components of the reactor building can be mostly segmented and processed with conventional means, since the radioactive dose rates in these areas are usually negligible[102].

Even though the retrieval, transportation and disposal of the RPV in one piece has been successfully demonstrated in the US, waste reduction requirements and limitations in the available transportation capacities mean that the RPV usually needs to be segmented into smaller pieces for retrieval and processing. The internals also need to be cut for easier extraction and conditioning. During the cutting of reactor internals, the RPV is usually filled with water for safety reasons. The cutting equipment used in the RPV must therefore be remote-controlled, submersible and able to tolerate a relatively high radioactive dose rate. Various techniques for cutting, segmentation and demolition have been adopted for use in a nuclear reactor. Most were developed from available industrial cutting equipment. The technologies differ for steel and concrete components (see Table 13 below). Mechanical methods are very robust and produce only low quantities of secondary waste, but they require a strong handling machine and their size often makes them unsuitable for areas with complex geometries. Thermal methods have faster cutting speeds and are easier to adapt to a wide range of applications. They can produce significant amounts of secondary waste, however.

[102] In BWR-type reactors, the components of the primary cooling and heat exchange cycle outside of the reactor are also often contaminated, but far less than the interior of the reactor.

Method	Material	Type
Shears, Nibbling	all	Mechanical
Mechanical saws	all	Mechanical
Core drilling	Concrete	Mechanical
Band saws	all	Mechanical
Diamond wire saws, diamond chain saws	Concrete	Mechanical
Jackhammer	Concrete	Mechanical
Orbital cutters	Metallic	Mechanical
Abrasive water jet cutting	all	Mechanical
Ceramic cutting	all	Mechanical
Oxy-fuel cutting	Metallic	Thermal
Plasma arc cutting	Electrically-charged	Thermal
Laser cutting	all	Thermal
Contact arc metal cutting	Electrically-charged	Thermal
Electro discharge machining	all	Thermal
Electric arc water jet cutting	Electrically-charged	Thermal
Electric arc oxygen cutting	Metallic	Thermal
Microwaves	Concrete	Thermal
Explosives	all	Thermal, Demolition
Wrecking ball	Concrete	Demolition
Expansive grout	Concrete	Demolition

Table 13: Cutting and demolition equipment[103]

In the JPDR pilot project, underwater plasma-arc cutting, a thermal cutting method, was used to cut most reactor internals. This also seems to be the technology of choice in other decommissioning projects in Japan. The Fugen NPP is a special case. The reactor is internally highly complex, with many double tubes in the core, and the radioactive dose rates remain very high (30 – 200 Sv/h), so most of the more conventional cutting technologies are difficult to use. Several of the technologies studied at Fugen are imported from overseas, including abrasive water jet cutting technology from Germany and gasoline oxygen cutting technology from the UK. Abrasive water jet technology, used for the cutting of concrete components and also able to cut steel components, has been successfully employed in decommissioning projects in Germany. In the case of Fugen, this technology is supplied via a business agreement between a German SME and a Japanese SME. While it is a proven technology and usable in confined spaces, there are some concerns about its cutting speed. This technology also dirties the water in the vicinity, which makes it difficult for the operators to observe and remotely control the cutting process. Gasoline oxygen cutting on the other hand has a very good cutting performance, but the currently used equipment can only be operated manually. Other cutting technologies under consideration at Fugen are laser cutting and band saw cutting. Laser cutting is an advanced technology, but it is very new and expensive[104]. This method is currently investigated as a preferred technology.

[103] Source: University of Fukui 2015, Thierfeldt & Schartmann 2012

[104] The technology was also experimentally employed in the dismantling of the Greifswald NPP in Germany

Band saw cutting is interesting because it produces only negligible amounts of secondary waste, but its adaptation for the requirements of Fugen is expected to be costly and complex. It might be used to cut the thick upper plates of the reactor core[105]. The robotic handling machines for the cutting equipment are supplied by Mitsubishi.

Several other developments in the German decommissioning projects might also be interesting for Japanese companies, particularly measures to increase the efficiency of the cutting process. This includes a standardised scheme to convert experimental prototypes into serial production models and remote-controlled power manipulators with increased durability. Some of these power manipulators can be disassembled when cutting is completed and moved to the next decommissioning project, thus reducing costs and streamlining operational patterns. As electrical equipment is susceptible to radioactivity, a design for power manipulators from Germany has all electrical parts stored in a central equipment box near the base of the manipulator, whereas the powered arm of the manipulator only consists of mechanical and hydraulic parts. This greatly increases durability and reliability.

These technologies and methods might be very interesting for Japanese decommissioning managers, especially due to the fact that many projects are concentrated in two geographic locations. Moreover, most of this equipment can be imported and operated with minimal assistance by European manufacturers, making this a viable opportunity for European SMEs and Japanese companies with limited numbers of English-speaking staff.

Japanese-developed products are likely to benefit from further development impulses by Fukushima I-related R&D. Particularly in the field of remote-controlled power manipulators, or robots, Japanese companies are among the world leaders both in respect to manufacturing capabilities and R&D. This means that specialised cutting technology is easier to market to Japanese partners than remote-controlled or robotic equipment. In some respects, the Fukushima I NPP decommissioning project is used by Japanese companies as a showcase for their products, which is both a blessing (availability of advanced equipment, technical innovation) and a curse (ballooning costs, long development time) for the progress of the decommissioning project. However, since costs currently do not play a major role in the decommissioning of Fukushima I NPP, the positive effects of this approach currently outweigh the negative ones. In other decommissioning projects, where the budget is much more limited and financing not as secured (see chapter I.6), interest in reliable and cost-effective technology may be higher. The NDF-promoted focus on reliable technology might also translate into new opportunities in the Fukushima I project for European companies.

III.3.6 Waste management technologies

[105] These plates consists of two layers: The upper iron water shield (150mm steel-plate) and the Calandria tank upper tube plate (150mm stainless steel-plate)

The operation and decommissioning of NPPs produces a number of waste streams: Spent fuel, radioactive waste, general waste, and secondary waste accrued during the decommissioning activities. Waste with nuclide concentrations above the clearance level requires dedicated waste disposal concepts, as described in chapter I.4. A number of waste disposal concepts exists, the most promising being the on-site trench repository for L3 waste, but **many aspects of the disposal problem remain unsolved**. This includes in particular the final disposal of HLW and the reprocessing of spent fuel. These problems are not only technical in nature, but also caused by inconclusive political legislation and past attempts to leave waste disposal largely to the private sector. While a certain responsibility of the central government was confirmed in the Law on Final Disposal of High-Level Radioactive Waste, the responsibility for finding and developing a final disposal site rested with the NUMO, a private-sector organisation. So far, NUMO's work has not produced many tangible outcomes, so the government recently took some steps to become more involved and pro-active in this matter. This includes the plan to present a candidate site for the HLW repository by the end of 2016. Nevertheless, development of an eventual repository for HLW will likely require a considerable time. For reprocessing, a domestic facility is still under construction. The plant is currently scheduled to open in 2018. In the past, Japan shipped its spent fuel to France and the UK for reprocessing, but this has been stopped and the repatriation of the vitrified waste is currently ongoing. The ongoing accumulation of vitrified waste and spent fuel awaiting reprocessing has a strong potential to lead to storage space shortages. The spent MOX fuel of the Fugen reactor will remain in the facility for the time being, as there is neither temporary storage space nor reprocessing capacity available. It might eventually be sent to France for reprocessing. The French and British reprocessing plants might also recommence the reprocessing of Japanese spent fuel if the domestic facility faces further delays and complications[106]. The uncertainties of waste management could lead to a demand for consulting on waste management in the future.

Waste processing involves various techniques to condition waste for transportation and disposal. These techniques often involve size reduction, for example smelting of metallic waste for subsequent recycling, compaction for size reduction, evaporation and incineration, and vitrification or cementation to contain the radioactivity in the material. A vitrification plant for liquid radioactive waste from reprocessing is under construction at the Rokkasho complex. The plant uses both French and Japanese technology.

One technology for waste processing that might be interesting for Japanese decommissioning authorities is the radiologically controlled melting of metallic waste. This process is an alternative and extension of the clearance system, particularly for metallic waste where the verification of the clearance condition is difficult or where the nuclide concentration is slightly above the clearance limit. The process decontaminates the material by separating elements with a low

[106] Parts of the British facilities at Sellafield, including the plant for fabricating MOX fuel, are already shut down or scheduled for shutdown, however. An alternative would be reprocessing and MOX fuel fabrication in Russia. In any case, foreign reprocessing and shipping of nuclear material by ship is not a purely economic question, but would also require political action

boiling point (e.g. caesium) and alpha-emitters (e.g. plutonium, americium, curium and uranium) from the molten mass. Furthermore, remaining radionuclides are evenly distributed throughout the molten mass, reducing the overall dose rate through the self-absorption of the material. Metallic waste treated in this fashion can either be released from regulatory control after fulfilling the clearance condition or be used to make waste containers and other metallic components for use in radiologically controlled areas, thus reducing both the amount of radioactive waste and recycling some of the waste for reuse in nuclear waste repositories. Facilities for this process are available in Germany, Sweden and France. While the shipping of radioactive waste could be a challenge, British experiences with shipping boilers from their Magnox plants to Sweden for melting show that this approach is feasible in practice.

After conditioning, radioactive waste is stored in dedicated containers and casks and transported to the waste repository for disposal. There is currently no standardised waste container design for radioactive waste in Japan, so imports from overseas or the adaptation of European container designs is possible. However, imported designs would have to comply with the strict safety requirements of the NRA and Japanese industrial standards, similar to the situation discussed in the section on fuel retrieval.

While there are many potential uses for recycled metallic waste, envisioned usage for concrete waste is currently basically limited to road pavements and similar applications. Consulting on recycling strategies might offer some potential for experienced European companies.

III.3.7 Consultancy services

European companies have more practical experiences with large-scale decommissioning projects than their Japanese counterparts. Technical assistance, consultancy and other kinds of advisory services are therefore areas were European companies and organisations could provide significant support for the Japanese decommissioning projects. These services can be provided both by large companies and by smaller consultancies. The field of possible services is also very wide, ranging from consulting on management practices to the analysis of potential contingencies during decommissioning. Success will depend on the reputation of the company or organisation in question and its connections to Japanese business partners, as Japanese companies are reluctant to do business with unknown companies. Native Japanese speaking staff or translators and a willingness for many business trips to Japan to meet and support clients face-to-face will also be necessary.

This area is also linked to the expected retirement of many senior Japanese nuclear experts in the near future. External consultancy and technical assistance may help to alleviate the possible loss of experience and knowledge. In the case of Tokai I, a Magnox reactor, Japanese decommissioning managers are closely following the decommissioning process of similar Magnox plants in the UK, up to considering a similar waste minimisation strategy. Similar cooperation and synergies with experts and consultancies involved in the decommissioning of European reactors is a viable scenario for other plants and reactor types as well, especially for the pilot projects of the different reactor types. International experts also play a certain role in advising on decommissioning strategies for the damaged reactors of the Fukushima I NPP. However, as mentioned earlier in this report, European and US involvement in services remains at a very low level and this will likely not change much in the near future.

III.3.8 Fundamental R&D and technical feasibility studies

The field of R&D sees a strong Japanese interest in international cooperation, seen as a way to both learn from the experience gained overseas and to share domestic experiences with the international community. Japanese nuclear R&D organisations have long-running relationships with European R&D organisations, and universities are currently also expanding their international collaboration programs at an increasing pace. Japanese companies currently seem to prefer US companies as partners for R&D projects, but first joint-ventures and business alliances with European companies for decommissioning-related products and services may indicate a changing trend in the business community. Technical feasibility studies and preliminary R&D are areas where European companies already cooperate with Japanese partner companies. The number of decommissioning-related R&D projects has seen a dramatic increase after the Fukushima nuclear accidents. R&D for conventional decommissioning will likely remain a niche activity in Japan for the foreseeable future, as most of the available resources are devoted to Fukushima I (see the next part on Fukushima for a more detailed discussion). Talent and capacity shortages in the Japanese R&D organisations potentially open up opportunities for European organisations, but this will likely also remain limited in scale due to the lower priority of conventional projects. Japanese companies with business interests in the field have an advantage in obtaining contracts for applied R&D due to their close relations with the commissioning entities and the closed nature of many tenders. However, these companies may use subcontractors for parts of the contract, in particular for areas in which overseas experience and competence can be an important complementary factor. Close relations with Japanese companies and organisations are therefore important to acquire contracts in this area.

III.3.9 Knowledge management and IT technologies

Efficient planning of appropriate decommissioning strategies for individual reactors is strongly coupled with knowledge about the service history of the facility. Precise knowledge of the initial construction, later upgrades, and irregularities and incidents during operation helps with characterisation and reduces uncertainty. Such knowledge can be gained from a variety of sources. Besides the official records of the plant and construction-related documents, tacit knowledge of the operating crew is another valuable source of information about plant conditions. However, the retirement of senior engineers, a longer period of safe storage and staff layoffs after the termination of commercial operation might result in the loss of this knowledge if no steps are taken to preserve it. It is also important to make this knowledge available in an accessible way. For these reasons, technologies to collect, organise and maintain knowledge currently receive much attention in Japan. The preferred technologies are computer-based databank and virtual reality systems. Databanks also enable utilities to share knowledge and experience between different projects (or with other utilities) at little cost. Software solutions for this purpose could be supplied by or licenced from European SMEs, but due to the confidential nature of the information and the necessity to collect data in Japanese (beside service history records and plant parameters, it is also planned to include personal experiences and knowledge, which would be collected in interviews with the crew), it is more likely that in-house or domestic software solutions will be preferred by the utilities. A pilot project for a virtual reality system to simulate dismantling and provide easy access to the collected knowledge (VRdose) is currently under development for the Fugen decommissioning project, developed jointly by the JAEA and the University of Fukui. The software used in this project is developed in cooperation with a Norwegian research institute. It allows to view the radioactive dose rate distribution and history of selected components and simulates the dismantling of the component. A second augmented reality system to support decommissioning is being developed for the Fugen project by the JAEA, the University of Fukui and Kyoto University. This system allows to superimpose 3D-CAD models of dismantling scenarios on real images. It is not yet known if these systems will also be employed in other decommissioning projects in Japan.

III.4 Specific technology demand of the Fukushima I decommissioning project

The decommissioning of the damaged reactors at the Fukushima I NPP, particularly reactor units 1 – 4, will very likely be much more complex and technically demanding than conventional decommissioning projects. Furthermore, as each of the damaged reactors is in a different condition, the technology and method for dismantling needs to be customised accordingly. The technologies discussed in the previous chapter apply in principle to Fukushima I NPP as well, but the project faces additional challenges, in particular the retrieval of the fuel debris and the management of the radioactive waste from the plant. This creates demand for equipment and services specifically tailored to the unique requirements and condition of the plant and the individual reactors. **Much of this equipment is not yet developed**. This is not necessarily due to technological limitations or limited manufacturing capacities of the Japanese industry. Instead, the biggest obstacle at the moment is the still incomplete knowledge of the interior of the reactors and uncertainty about the feasibility of the currently adopted fuel retrieval strategy. The safety regulations for the handling, processing and disposal of the molten fuel debris are also not yet established. As domestic experiences and capacities are limited, Japanese organisations and companies are interested in foreign knowledge and expertise. While Toshiba seems to mainly cooperate with US companies for Fukushima I-related R&D, MHI has recently awarded a contract for four technical feasibility studies to a German company specialising in nuclear decommissioning. The contract covers the scanning and retrieval of fuel debris with the PCVs of the damaged reactors, cutting and dismantling technology for the biological shield, the remote installation of a rail system and a remote-controlled system for fuel-debris transportation[107]. Furthermore, three R&D calls by the MEXT and the Japan Science and Technology Agency (JST) specifically targeted European organisations: The Japan-UK joint calls for research on the removal of the fuel debris and environmental measures including measures for the management of radioactive waste[108] and the Japan-France joint call for research on remote operation in harsh environment such as robotics, remote distributed sensing, image processing and observing systems [109] . The establishment of cooperation agreements between European nuclear organisations and the NDF and TEPCO could offer further potential for joint R&D calls in the future (see chapter I.5.6).

Table 14 shows an overview of the R&D system for Fukushima I NPP. The following chapter reviews the current situation and the decommissioning strategy laid out in the mid-to long-term roadmap, as amended by the NDF in 2015.

		Development of remote-controlled reactor building decontamination technology
		Development of a comprehensive dose reduction program

[107] See also http://www.world-nuclear-news.org/WR-Fuel-removal-machine-for-Fukushima-Daiichi-3-1801164.html
[108] With EPSRC, calls closed on 7 July 2015
[109] With ANR, second stage of the call to be closed on 31 March 2016

Preparation for fuel debris retrieval	Containment examination & repair technology	Development of technology to identify containment leak locations
		Development of technology to repair containment leak locations/stop leakage
		Full-scale testing of technology to repair containment leak locations/stop leakage
	Fuel debris retrieval technology	Development of technology to examine the inside of the containment vessel
		Development of technology to examine the inside of the reactor pressure vessel
		Development of techniques and systems to retrieve fuel debris and core internals
		Development of technology to contain, retrieve and store fuel debris in the reactor
		Development of fuel debris criticality control technology
	Core/fuel debris evaluation technology	Getting information on reactor by improving accident development analysis technology
		Development of reactor fuel debris detection technology (MUON)
		Development of technology to determine the physical state of fuel debris and to treat fuel debris
		(Spent fuel pool management)
	Integrity evaluation technology	(Spent fuel pool management)
		Development of technology to evaluate the integrity of the reactor pressure vessel & the containment vessel
Spent fuel pool management		Development of a method for treating damaged fuel removed from the spent fuel pool
		Evaluation of the long-term integrity of fuel assemblies, etc. removed from the spent fuel pool
Radioactive waste treatment/disposal		Research and development on solid waste treatment and disposal

Table 14: R&D system for Fukushima I NPP[110]

III.4.1 Exploration and characterisation technologies

Stationary and mobile measurement and exploration equipment is important to track radioactive dose rates and contaminated areas on the site and inside the reactor buildings. Besides measuring the radioactive dose rates, the identification of the location of the molten fuel debris is instrumental for deciding and developing the method for fuel retrieval, in particular in regard to the question whether a top-entry or side-entry approach would be the most promising strategy. Getting a clear picture of the condition within the damaged reactors is therefore a key challenge to establish the dismantling strategy for the damaged reactor units. Observation equipment, especially mobile robotic devices that are durable enough to take and return samples, can also play an important role in the study of the chemical and physical characteristics of the fuel debris.

[110] NDF 2015b

While monitoring equipment for external spaces offers only limited opportunities, similar to the situation discussed in section III.3.1, the high technical requirements for devices to be used in the exploration of the reactor interior and the reactor buildings may offer more opportunities for European companies. The devices have to be compact enough to fit through the narrow access ports into the interior of the reactor, they must be submersible and remote-controlled, and able to resist high radioactive dose rates. Further requirements are advanced observation capabilities through sensors and cameras and the capability to take and return samples. Since it is unlikely that a single device will be able to satisfy all of these requirements, several devices built to different mission requirements will likely be deployed[111]. However, especially for devices that are supposed to return from their mission, for example robots taking material samples, the interchangeability of parts and a common design platform would be useful to reduce costs, simplify operations and allow for the reuse of parts of the equipment. This is especially important from the viewpoint of waste reduction, as basically all equipment used in the reactor buildings of the damaged reactors at Fukushima I NPP will be considered as secondary waste.

Since data and information about the interior of the reactors is urgently needed and a wide range of possible applications needs to be covered, European companies may find opportunities in the area of R&D for such devices. It is also worthwhile to note that a previous engagement in nuclear services or decommissioning might be of less importance in this area if the company or R&D institution has an otherwise excellent track record in robotics, optics, artificial intelligence or related fields. In the field of manufacturing complete devices, however, opportunities for European companies are currently limited. This is due to political reasons and the procurement strategy of TEPCO. Robotic technology was identified as a core technology for the growth of the Japanese economy, and the decommissioning of Fukushima I NPP offers the opportunity to showcase domestic products and boost domestic manufacturing capabilities. Among the biggest and most advanced producers of such devices are incidentally Mitsubishi Heavy Industries, Hitachi and Toshiba, the same companies that are also very influential in the nuclear industry and the IRID. These companies therefore obtain most contracts for the development of robotic devices for Fukushima I. Some experts argue that this practice frequently leads to over-engineered solutions that could also be acquired for lower costs and with less development time overseas, but the close connection to the national growth strategy and a desire for continuity on the side of TEPCO makes changes in this policy unlikely at the moment. While **the manufacturing of robotic devices will therefore remain confined to Japanese corporations**, opportunities may be found in supplying specialised components and sensors for such devices.

Due to the difficulties of entering the highly radioactive reactor interior, technology development has also focused on developing technologies for the investigation of the reactor interior from the outside. The principal technology developed for this purpose is the muon tomography technology. This technology is used for two purposes: the analysis of the reactor interior and the search for the fuel debris. So far, the technology has confirmed that no large bodies of fuel remain in the

[111] The devices deployed so far have completely focused on exploration and were purpose-built for each reactor.

reactor cores of the damaged reactors, but it has not yet identified where the fuel has moved. This technology is already very advanced and does not offer many opportunities for European companies.

III.4.2 Filtering and decontamination equipment

Due to the failure of the cooling system, a replacement system had to be installed to stabilise the damaged reactors. While this system is able to keep the Fukushima reactors in a state of cold shutdown[112], it produces a large amount of irradiated water during operation. Since this water cannot simply be released into the environment, it needs to be treated for reuse and release. To this end, irradiated water from the reactors 1 – 4 is directed into two streams (see Figure 18). Both streams first pass a facility where caesium and strontium is removed from the water[113] and continue to a desalination plant. After desalination, the two streams separate: one stream flows back to the damaged reactors, to be used as new coolant. The second stream continues to the filtering and treatment system. Several systems have been installed at Fukushima for this purpose since the accidents. However, the performance of the earliest systems, provided by French companies, was hampered by reliability problems. The underwhelming results of these devices have made TEPCO more reluctant to procure from overseas companies. The currently used equipment, the Advanced Liquid Processing System (ALPS) is a domestic development, with some parts supplied by US companies. It is technically very advanced, but cannot remove all radionuclides from the water, in particular tritium[114]. The tritium concentration makes it impossible to release the water even after the aforementioned treatment, so all treated water is currently stored on-site in gigantic tank farms. As TEPCO currently considers it impossible to remove the tritium from the water, European solutions may not attract the interest of the Japanese side.

[112] Some experts argue that the cooling of the reactor units is no longer necessary due to the long shutdown of the reactors. TEPCO continues to operate the system as of now.

[113] The two devices for this purpose were supplied by US-based Kurion and Toshiba

[114] A functional tritium removal device is used in the Fugen decommissioning project, but this device is used to remove residual heavy water from the heavy water system.

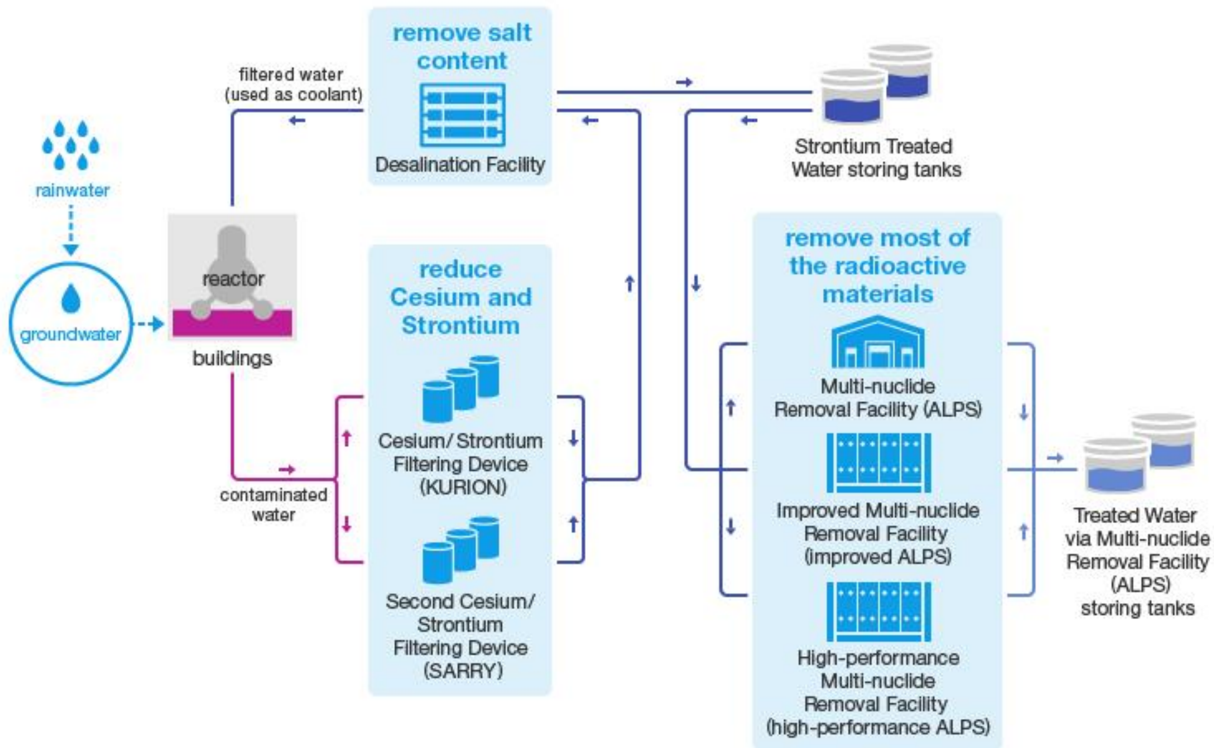

Figure 18: Water treatment flow diagram for units 1 – 4 of Fukushima I NPP[115]

Beside the treatment of irradiated water, the decontamination of the site, the working spaces in the reactor buildings, and the surrounding environment is also a matter of concern. Site and working space decontamination promotes and increases work safety and is a requirement for fuel retrieval and dismantling. Due to high radioactivity levels and the damage in the reactor buildings robotic and remote-controlled decontamination devices are necessary for much of the initial work. This field thus offers similar opportunities to the preceding section on monitoring and characterisation technologies: European companies can participate in R&D, whereas manufacturing will likely be done by Japanese companies. Water treatment, due to the already advanced state of the technology, is unlikely to offer many opportunities for European companies.

III.4.3 Repairing of the PCV

Even though the ultimate goal is to completely dismantle the reactors of the Fukushima I NPP, it will be necessary to first repair the damaged PCVs to a certain extent. Repairing and restoring the integrity of the PCV will reduce the exposure of the workers to radioactivity, prevent the leakage of irradiated water, and protect the reactor in the case of another strong earthquake. A

[115] Source: http://www.tepco.co.jp/en/decommision/planaction/alps/index-e.html

waterproof PCV, at least up to a certain height, would also make underwater fuel retrieval possible (see also the following section on fuel retrieval). Due to the excessive radioactivity levels prevailing in the vicinity of the reactor, this work will also likely have to be conducted by robotic or remote-controlled equipment. Such repairs require precise damage characterisation, which links this issue to the monitoring and characterisation activities discussed in section III.4.1 and the section on knowledge management (section III.3.7). Initial exploration has already identified several leaks, but further damage investigation is difficult due to the prevailing radioactive dose rates and the limited accessibility of the interior of the reactor building. The technical challenges and uncertainties in this area are considerable and it is unknown if the repairs can be realised at reasonable costs and with the available technology. European companies may find opportunities in R&D for precise guidance and control systems for remote-controlled devices and technologies for the repairing and sealing of the PCV. Further demand can be expected in R&D for methods to verify and evaluate successful repairs and the integrity of the PCV.

III.4.4 Neutron absorbers and criticality prevention

Measurements confirm stable temperatures and pressure in the reactors, so it is assumed that the fuel debris is no longer critical, with the new cooling system being sufficient (or not even necessary anymore) to maintain this state. However, there are some fears that changes to the current environment within the PCV, as would happen during fuel retrieval, might trigger the recriticality of the material. This constitutes a threat to the safety of the workers and might also lead to the emission of more radioactive particles into the environment. The standard measure in nuclear decommissioning to prevent recriticality and ensure operational safety is the underwater retrieval of the fuel, with the water acting as a neutron absorber. However, in the case of Fukushima, this may not be possible due to the extent of damage to the PCV. After the meltdown, the nuclear fuel debris breached the lower bottom of the RPV and moved into the lower PCV, where it is supposed to have cooled down and solidified. Underwater fuel retrieval thus necessitates a water-filled PCV, which in turn requires the PCV to be sealed and waterproof. If the damage turns out to be too severe (or if the molten fuel has penetrated the PCV bottom and moved into the reactor building below it), an alternative method for criticality prevention and other neutron absorbers may need to be considered. European companies may be contracted to investigate alternative scenarios and methods for this purpose. Research in this direction is currently in its early stages and further progress depends heavily on the results of the PCV investigation.

III.4.5 Fuel retrieval technologies

In addition to the issue of the transportation and disposal of the spent nuclear fuel as described in section III.3.3, the retrieval of the fuel from the reactor itself becomes a central issue in the case of the damaged reactors of the Fukushima I NPP. There are two types of nuclear fuel that need to be removed: The spent fuel in the SFPs and the remains of the fuel that was in the reactor core at the time of the accidents (this applies only to reactor units 1 – 3). The removal of the fuel in the SFPs is well underway in early 2016, with the SFP of reactor unit 4 already successfully emptied. While the fuel in the SFPs did not melt after the accidents, some fuel assemblies might have been damaged in the course of the accidents. The technology for conditioning and packaging needs to be adapted accordingly and disposal methods for damaged assemblies need to be investigated. Furthermore, the tsunami and hydrogen explosions caused damage to the reactor buildings, cranes and electrical equipment. Replacement machinery for fuel retrieval therefore needs to be developed and installed in the damaged reactor buildings. Toshiba provided a new fuel retrieval machine for reactor unit 3 in January 2016. The equipment will be installed in the reactor building during 2016, with fuel retrieval slated to begin in 2017. While the removal of fuel assemblies is so far only complete for unit 4 – 6, it seems as if Japanese companies are able to supply the technology for the safe and efficient removal of the fuel in the SFPs[116]. Depending on the extent of the damage, the handling and disposal of damaged spent fuel assemblies could offer some opportunities for European companies.

On the other hand, **the question of how to remove the molten fuel inside the reactor cores is still unsolved**. As the actual extent of damage to the PCV, as well as the location and chemical properties of the molten fuel – also called corium – are not known at the moment, it is not yet possible to develop a retrieval strategy. In particular, it is not yet known how to remove and extract the corium from its unknown location[117]. Similarly, methods for the conditioning, packaging, and transportation of the fuel debris are not decided yet.

For fuel retrieval, three basic methods are discussed: Fully submerged retrieval, partial submerged retrieval and dry retrieval. Fully submerged retrieval requires the complete restoration of the structural integrity of the PCV, which is then filled to the top with water. Remote-controlled robots would retrieve the fuel debris. In contrast, in partial submerged retrieval the PCV is only repaired up to a level where the fuel debris can be completely covered with water. This approach is expected to be faster and more cost-effective, since the amount of repairs is more limited. As the most extensive damage to the PCV is likely in its lower part, the required repairs would still be significant and complex. Furthermore, the fuel debris would be moved through two different environments on the way out of the reactor: First through water and then air. It is not known how the corium will react to this difference. Alternatively, the corium

[116] For more information about the fuel retrieval machine see World Nuclear News (18 January 2016) http://www.world-nuclear-news.org/WR-Fuel-removal-machine-for-Fukushima-Daiichi-3-1801164.html

[117] As the corium is thought to consist of molten fuel and components of the reactor, including the concrete of the PCV, extraction of the material is likely very complex. Different nuclide concentrations within the material must also be taken into account. During extraction, some of the radioactivity currently contained by the outer layers of the corium could be re-exposed to the surface and have an adverse effect on the extraction equipment

could already be packed in the submerged area, but this would require extremely complex robotic devices. This method also requires precise knowledge of the location of the corium to decide the level to which the structural integrity of the PCV needs to be restored. The last method, dry retrieval, envisions fuel retrieval completely without water. This is unprecedented and considered to be very difficult. It might however be the only viable scenario if the PCV repairs turn out to be too complex. In this scenario, the issue of alternative methods for recriticality prevention discussed in the previous section would become most urgent.

Similarly to different retrieval methods, three different access routes into the reactor are being discussed. The fuel debris is, as mentioned earlier, believed to be mainly in the lower PCV, with some fuel possibly remaining in the RPV and in all areas between the two locations. The discussed access routes are top-access, side-access and bottom-access. Access from the top is the standard practice in most NPPs, including the reactors of the Fukushima I NPP. The PCV and RPV are structurally prepared for access from this direction, with large access ports available. However, damage during the accidents might have damaged the electrical motors, valves and other equipment needed to open them. It might therefore be impossible to use this route without extensive repairs. Moreover, access from the top means access at the farthest point from the assumed location of the majority of the fuel debris, complicating retrieval operations. Structurally, the internals of the RPV are also in the way of a direct access route to the lower PCV, so they would need to be cut before the route can be fully established (in standard practice, the fuel in the reactor core is removed before the cutting of the reactor internals). The PCVs of the reactors of Fukushima I NPP are also structurally prepared for access from the side, in the form of two smaller hatches[118]. This access route would place the access port closer to the fuel debris, but the size of the hatches would impose stricter limits on the size of the usable equipment. Furthermore, in order to get to the bottom of the PCV, the structures in the lower PCV would need to be cut. Too high water levels in the PCV also complicate access from this route, so this access route would work best with partial submersion or dry retrieval. Access from the bottom enables direct access to the fuel debris, but the PCV is not structurally prepared for this route. A new access port would therefore have to be established, possibly further degrading the structural stability and containment function of the PCV. This method would likely require a dry retrieval approach.

From these considerations, the NDF has derived three preferred scenarios for fuel retrieval: The top-access-full submersion method, the top-access-partial submersion method and the side-access-partial submersion method. Each would require PCV repairs and remote-controlled cutting equipment. However, due to the uncertainties about the feasibility of these methods, R&D in the other methods is also encouraged. This includes international tenders for R&D into alternative technologies[119]. Besides the method of fuel retrieval, the necessary equipment and devices also need to be developed, for which European companies with experience in the

[118] Equipment hatch and CRD hatch

[119] IRID, RFP for Innovative Approach for Fuel Debris Retrieval, 17 December 2013. See http://irid.or.jp/fd/

decommissioning efforts at Chernobyl could provide important technologies. R&D in regard to long-distance remote-control, resistance to radioactivity, guidance systems, and mechanical power to extract and transport solid fuel debris may offer further opportunities for European companies in the future.

III.4.6 Waste management technologies

The disaster mitigation after the Fukushima nuclear accidents and the dismantling of the Fukushima I NPP is a herculean effort, involving tens of thousands of workers and equal numbers of machines, tools and material. Accordingly, large amounts of waste are produced during the decommissioning activities – discarded protective clothing, contaminated tools, debris from the accidents, leaves and earth removed for decontamination purposes, irradiated water used in the cooling cycle for the damaged reactors and more. As off-site transport is difficult due to safety concerns and the lack of alternative waste disposal sites[120], almost all waste is currently stored on-site, but space is limited. The above-ground storage of radioactive waste, with the necessary safety measures and monitoring, is also a drain on financial resources and a source for work-related risks and hazards[121]. Therefore, strategies and technologies for the reduction and minimisation of waste are very important. A measure for size reduction is the installation of an incinerator to burn discarded clothing and trees[122]. Moreover, the NDF has announced the goal of reusing and recycling as much equipment as possible to limit the introduction of new equipment into the site. It is not yet clear what impact these new goals will have on the Fukushima I decommissioning project. Nevertheless, due to the mounting problems associated with waste management at the Fukushima I NPP, further growth in this field is anticipated for the future. European companies might find some opportunities, similar to the discussion for waste management technologies in conventional decommissioning projects in section III.3.6.

Technology for waste treatment, as well as methods and technologies for the processing, conditioning, transportation and disposal of the fuel debris also needs to be developed. Even though the fuel debris is thought to be solid and relatively stable at the moment, it needs to be transformed into a form that is stable enough for final disposal and able to contain the radioactivity of the material as effective as possible. Containers with appropriate shielding and capacity need to be developed for the transportation to the disposal site. However, as with other kinds of radioactive waste, this final disposal site is not yet available. Since safety regulations cannot be established without a detailed understanding of the radioactive and chemical characteristics of the material, the necessary regulatory standards and rules for the handling of the fuel debris are also not yet established. As in the related fields of PCV preparation and fuel

[120] This might change in the near future, as Fukushima prefecture has announced its intention to accept very Low-level nuclear waste at an existing industrial waste disposal site in the prefecture.
[121] For example, workers have died during accidents at the storage tanks for irradiated water (NDF 2015)
[122] see TEPCO 2015

debris retrieval, R&D into these issues is in early stages and will offer more opportunities when more details about the internal situation of the reactor become available.

The recent NDF review of the decommissioning strategy for the Fukushima I NPP raises **concerns about the domestic capacities for waste management**. It states that current manpower, manufacturing and R&D resources are inadequate for the expected challenges. This seems to refer in particular to the lack of waste repositories, a shortage of domestic experts in the field (both within the scientific community, the companies and the regulatory bodies) and the low profile of waste management-related R&D projects, both for conventional decommissioning projects and the Fukushima I project. These capacity shortages may translate into stronger demand for European products and services in the future.

Part IV: Business strategies

This part will introduce several strategies for business on the market for nuclear decommissioning in Japan. The structure of the nuclear industry in Japan and the closed procurement preferred by the utilities means that the most promising business opportunities for European companies are found in the area of subcontracting. It is unlikely that the general pattern of how contracts are awarded in Japan will change much in the foreseeable future. For example, TEPCO has explicitly confirmed its intention to maintain the current system. Japanese corporations are mainly interested in technology design and single components or machines**.** For more extensive involvement in nuclear decommissioning in Japan, it will almost always be necessary to establish a permanent representation in Japan due to the strong emphasis on personal meetings and legal accountability within Japan.

Business partnerships and joint-ventures can make business considerably easier for foreign companies, but they require a specialised product portfolio and a good relationship with the partner company. Personal relationships and mutual economic ties play an important role in the Japanese economy, and the nuclear sector is no exception. Perhaps even more than in other sectors of the Japanese economy, mutual trust between the involved companies and organisations is incredibly important for conducting business in this field. This originates from the need to ensure the safety and continuity of the long-running decommissioning projects, in particular the Fukushima I project, and the desire to avoid the disclosure of sensitive information to outsiders. Establishing these networks may take some time, meaning that the strategy for entering the Japanese market should follow a mid- to long-term strategy. Frequent business trips to Japan, attendance of professional conferences, and meetings with potential partner companies are ways to build up such networks. **Endurance and patience are necessary to be successful** on the market for decommissioning in Japan.

Many European companies in the nuclear sector already maintain business relationships with relevant Japanese companies. The notion of trust means that **it will be difficult for newcomers to enter this market** without connections to the established organisations. The current system favours large companies, since they can more easily afford the business trips to Japan and other supporting services such as translation and legal advice. SMEs will face more challenges, but they might use their product portfolio to their advantage. Start-ups will likely often lack both the manpower and reputation necessary for gaining the interest of the Japanese side. In some cases, looking among other European companies for potential business partners may be a worthwhile strategy for indirect access to the Japanese market for nuclear decommissioning, in particular for smaller SMEs without the means to support extensive business activities within Japan. It is also important to carefully consider which Japanese company would be the most promising partner. In general, large multinationals and prime contractors may be easier to approach than companies with a strong domestic focus, but attention should be paid whether such cooperation would result in conflicting interests or competition with other Japanese companies, which will nearly always be in an advantageous competitive position. It is therefore a good idea to market products and services as **complementary solutions** rather than as a replacement for domestic alternatives. Cooperation with smaller companies with a domestic focus might be accompanied by communication problems. Since the decommissioning projects are distributed over many regions of Japan, including Kyushu and the Hokuriku region, looking for partners outside of the Tokyo metropolitan area is also an option.

Current demand in Japan largely concentrates on products. Services have a much lower chance of being successfully marketed, except by companies with a branch in Japan. There is however a certain chance that this might change in the future, due to possible talent shortages and the slow progress in developing waste repositories. When marketing a product to Japanese partners, it is important to **emphasise the unique features and advantages** of the technology. As Japanese procurement officers are mostly interested in acquiring proven technology, being able to show examples how the technology in question was successfully applied in past decommissioning projects is a valuable asset. Since the regulatory and industrial standards are different to Europe, relevant regulations and standards, in particular the JSME standards, should also be researched during the development of a business strategy for Japan. As foreign involvement is often limited to the export of single components and technology designs, questions of IP protection also need to be considered. Furthermore, the business strategy should also take the persisting risks of decommissioning in Japan into account, such as project delays, regulatory changes and funding shortages.

Conclusions

The decommissioning of commercial and large-sized nuclear reactors is still in its infancy in Japan, with only one smaller pilot project successfully completed. Nuclear decommissioning in Japan is a multi-stage project consisting of site decontamination, spent fuel removal, D&D and waste management. The projects are managed by the operators themselves, which might lead to problems in the case of smaller utilities.

Currently, Japan is decommissioning three commercial reactors and one experimental reactor. The decommissioning of Tokai I is advanced, especially in comparison to the British reactors of the same design. Fugen is largely an experimental project and suffers from budgetary constraints and problems with spent fuel management, which threatens to delay the project. The dismantling of secondary facilities is underway at both reactors. Defueling of the Hamaoka reactors has been completed and the operator is starting with the dismantling of secondary facilities at the two reactors. The utilities have written off five more reactors for future decommissioning. Three utilities have submitted the decommissioning plans for their reactors and will begin the decommissioning once the NRA has approved these plans. The operator of one reactor, Chugoku Electric Power, has not submitted a decommissioning plan yet. Furthermore, all six reactor units of the damaged Fukushima I NPP are in decommissioning. Extensive work is conducted on the site to mitigate the impact of the accidents and to prepare the damaged reactor units 1 – 3 for the retrieval of the spent fuel assemblies from the SFPs. Among the decommissioning projects, the priority lies on the Fukushima I NPP decommissioning project, with 2 trillion JPY readied by TEPCO to facilitate the decommissioning of the plant. The budgets of the other projects amount to around 640 billion JPY[123]. These numbers reflect a considerable market size, but most of the projects have only begun after the Fukushima accidents in 2011 and are therefore not yet very advanced. The Fukushima accidents have also created new problems for nuclear decommissioning. The NRA, responsible for the regulation of the decommissioning process, currently focuses on the restarting of the Japanese NPPs. The resulting long procedures to obtain regulatory approval is a source for uncertainty and threatens to delay the progress of some projects. The accumulation of capital for nuclear decommissioning depended on the output of the reactors, which has caused funding gaps due to the unexpectedly long or premature shutdown of the NPPs after the Fukushima accidents. Furthermore, the domestic reprocessing plant is still not completed because of stricter licencing criteria, meaning that spent fuel assemblies are occupying more and more storage space without a real perspective for reprocessing in the near future. The most recent projects try to alleviate these problems with relatively long safe storage periods and a change to fixed surcharges for capital accumulation. This may allow the utilities to recover losses resulting from the premature shut-down of the reactors and effectively defers the retrieval of the spent fuel to a later date, giving the utilities more time to either wait for the completion of the Rokkasho reprocessing plant or an alternative disposal concept.

[123] This is equivalent to about 15.4 billion Euro and 4.9 billion Euro at December 2015 exchange rates

The overall assessment by both European and Japanese experts familiar with the matter is that the market for nuclear decommissioning in Japan is still emerging. Demand for foreign products is likely to rise when the dismantling of the first reactors begins and the method for fuel retrieval has been established for the Fukushima I NPP. Furthermore, the number of decommissioning projects in Japan will very likely continue to grow due to the uncertainties surrounding the restart of some Japanese NPPs, including the Fukushima II NPP, Tsuruga NPP, Shika NPP and the experimental reactor Monju, as well as the advanced age of many reactors.

The decommissioning projects are all managed by different organisations (except for Tokai I and Tsuruga NPP unit 1, both managed by JAPCO), whereas nuclear services in Japan are virtually limited to three large industrial corporations and their affiliates. These corporations are also the main contractors for the dismantling of the reactors. The dismantling and deconstruction of the non-radioactive facilities is largely contracted to a number of large general construction companies. JAPCO also has the potential to serve as a support platform for smaller utilities in the future. Japanese authorities hope that this will help smaller utilities to successfully manage their projects and increase the overall efficiency of decommissioning. However, so far inter-organisational cooperation in decommissioning seems to remain rather weak. The resulting piecemeal approach to decommissioning could actually increase demand for European products, whereas stronger concentration and cooperation between the operators could reduce demand in the long run, as more equipment is reused and shared between the individual projects. The focus on Fukushima I might also create capacity shortages in conventional projects, which – depending on the plans of the utility in charge of the project – might influence demand for foreign products and services. Most utilities lack expertise in large-scale decommissioning projects. The reactor technology of the individual projects is very diverse, requiring different technical solutions and approaches. This could increase demand for products and services from European companies involved in the decommissioning of similar reactors in Europe. Companies involved in the decommissioning of the Niederaichbach heavy water reactor might attract the interest of the similar Fugen decommissioning project, whereas British and French companies involved in the ongoing decommissioning of gas-cooled reactors may find opportunities in the decommissioning of Japan’s Tokai I gas-cooled reactor. The experiences made during the decommissioning of several BWRs in Germany may also attract the interest of Japanese companies, as BWRs make up the largest number of reactors in decommissioning. Lastly, European companies involved in the decommissioning efforts at the damaged reactor at Chernobyl may be able to contribute significantly to the decommissioning of the damaged reactors at Fukushima I NPP.

While the decommissioning of nuclear facilities generates a demand for advanced technology – especially in the case of the Fukushima I NPP – demand for foreign expertise and technology currently remains limited as many projects are not yet very advanced. The direct marketing of European products for conventional decommissioning projects is – barring effects from capacity shortages – difficult in most areas due to the high technological level of the Japanese industry and the close relationship between the utilities and the large industrial corporations. This will nearly always give them a competitive advantage over external competitors, particularly in fields where these corporations themselves have strong economic interests, such as robotics. This applies in particular to general products and services that are unrelated to the radioactive properties of the facility. The provision of highly specialised parts and components and R&D for nuclear-related products and services by European companies as subcontractors of a Japanese contractor is the most promising way to be successful under these circumstances. The importation of various European cutting edge technologies, such as abrasive water jet cutting technology from a German SME and gasoline oxygen cutting technology from a British company, offers a practical example. Other examples of European involvement include water treatment technology for contaminated water at the Fukushima I NPP, and technology for reprocessing, both supplied by French companies. In the past, British and French companies also reprocessed spent fuel and fabricated MOX fuel assemblies for Japanese utilities. This might start again due to the problems and technical limitations of the domestic reprocessing plant at Rokkasho. Since the Japanese nuclear industry shows a certain reluctance and distrust towards outside companies, a strong track record in the nuclear industry and long-standing business relationships will be very helpful to successfully facilitate business on this market. This basically means that business opportunities are mostly limited to established companies. Start-ups can only be successful if they have good personal contacts to the Japanese nuclear industry.

Better opportunities than in manufacturing can be found in the field of R&D, since decommissioning-related expertise remains limited in Japan. As many R&D organisations are currently expanding their decommissioning-related research projects, in particular in regard to the decommissioning of Fukushima I NPP, there is a growing interest in cooperation and joint R&D programmes with foreign R&D institutions and companies. Examples include a call for joint research on remote operation in harsh environment such as robotics, remote distributed sensing, image processing and observing systems (Japan-France joint call by MEXT/JST and ANR) and the calls for joint research on removal on fuel debris and environmental measures including measures for the management of radioactive waste (Japan-UK joint call by MEXT/JST and EPSRC). Agreements between the NDF and the NDA and the CEA as well as between TEPCO and the CEA and Sellafield, Ltd. could pave the road for more Fukushima I-related joint R&D projects in the future. Most of these projects currently seem to focus on basic technology, proof of concept and research in alternative scenarios for the decommissioning of the damaged reactors at the Fukushima I NPP. The reactor vendors also use European companies as subcontractors for decommissioning-related R&D, including feasibility studies on the scanning and removal of fuel debris, the cutting of the biological shield, the remote installation of a rail system and a remote-controlled transportation system for fuel debris. These studies are carried out for MHI by a German company specialising in nuclear decommissioning. Interested European companies and R&D organisations may find additional opportunities in areas where domestic R&D capacities are not very developed, for example in the area of waste management.

Many crucial technical aspects of the Fukushima I decommissioning project are still unresolved, in particular the extraction of the fuel debris from the damaged reactors and the management of the radioactive waste from the facility. These challenges could also offer many opportunities for European companies, including R&D in resistance to radioactivity, precise guidance systems, power manipulator systems, artificial intelligence, and the conditioning and packaging of damaged fuel assemblies and fuel debris. The experiences made by European companies in the decommissioning of the damaged reactor of the Chernobyl plant may be extremely useful for some of these issues. Manufacturing of the decommissioning equipment for Fukushima I will likely follow a pattern similar to conventional decommissioning projects.

A further business field where European companies with an excellent track record and high expertise could provide meaningful services is the area of consultancy, technical assistance and training. However, the potential in this field is limited by a number of structural barriers, including communication problems, reluctance of Japanese companies to share confidential information with outsiders, the preference of trusted business partners and the considerable efforts needed to support such an endeavour. The marketing of services is therefore considered to be much more difficult than the marketing of products.

A major issue that can seriously impact the progress of nuclear decommissioning in Japan – both for conventional projects and Fukushima – is the largely unsolved question of waste management and disposal. Waste repositories and domestic reprocessing capabilities are either not yet available or very limited. Further problems arise from the fragmented nature of the current waste disposal system, where repositories for radioactive waste are dependent on local political support. The only existing central LLW repository in Japan currently does not accept waste from decommissioning. As a special case, the reprocessing of the spent MOX fuel from the Fugen reactor also faces serious problems, since the originally intended reprocessing plant became unavailable after the Fukushima accidents. In the case of Fukushima I, further problems for waste disposal arise due to sheer volume (in the case of contaminated soil and water) and unknown chemical and physical characteristics (in the case of the molten fuel debris). The clearance system was adopted as a method to reduce the amount of waste that needs to be disposed of as radioactive waste. The system is already well established for metallic waste, whereas the clearance system for concrete waste remains a concept study. European companies can provide reprocessing, advanced smelting and recycling solutions to support the volume reduction of radioactive waste. Furthermore, some European countries have made strong progress in developing repositories for radioactive waste, in particular Finland and Sweden. These experiences may also be interesting for the Japanese side. The complete lack of a disposal strategy for the fuel debris and damaged spent fuel assemblies from the damaged reactors at the Fukushima I NPP may offer additional opportunities for European involvement in the future.

Recommendations

The business environment for European companies interested in nuclear decommissioning in Japan is currently rather difficult. At the same time, there is still some time before demand is expected to rise, so **now is a good time for positioning on the market**. Since successful business in this field revolves around reputation and the business connections to relevant organisations, it is advisable to strengthen the business relations with relevant Japanese companies and organisations. Attendance at industry fairs, conferences and frequent meetings with Japanese partners to build personal relationships are some ways to achieve this.

Now it is the right time to **form partnerships and joint-ventures** with Japanese companies. These joint-ventures can be very useful for both sides: the European partner profits from the business connections and reputation of the Japanese partner, whereas the Japanese partner gains access to products that might otherwise be expensive to produce or procure. This strategy is therefore most useful for companies with a highly specialised portfolio of proven and reliable technology. The partner should also be considered carefully. MHI, GE-Hitachi Nuclear and Toshiba are the most influential companies and involved in all aspects of decommissioning where nuclear-related competence is required. Recently established decommissioning-related joint-ventures all involved these corporations as the Japanese partners. Furthermore, the character of these corporations as multi-national conglomerates with extensive business interests throughout the world can make it easier to approach them and may reduce communication problems.

The reactor vendors will be the main contractors for the decommissioning of the reactors, making it difficult for European companies to directly obtain contracts from the utilities and the commissioning entities. Instead, it is more advisable to **look for opportunities as a subcontractor** of the main contractors. Information is the key for finding such opportunities, underlining again the importance of relationships with relevant Japanese companies.

Since practical experience with large-scale decommissioning projects is still underdeveloped in Japan and much of the research in this field has only started after Fukushima, a **focus on R&D** is another very recommendable strategy for European companies. There is a great interest in Japan to learn from the experiences in Europe and to apply European decommissioning knowledge in Japan. Recent news in the media suggest that the number of joint R&D projects is on the rise. This field is therefore a fertile ground for cooperation and should – in particular due to the expected rise in Fukushima I-related R&D demand in the future – provide ample business opportunities. It is necessary, however, to carefully consider where to look for opportunities in this area. Collaborative fundamental R&D and projects into alternative methods for fuel retrieval, PCV repair and waste disposal should have good perspectives, whereas applied R&D for robotic devices will be a much more difficult field due to the advanced capabilities of the Japanese manufacturers.

Many parts of the Japanese decommissioning strategy remain conceptual, with only limited practical experience. At the same time, problems with waste management and the premature shutdown of many reactors in decommissioning threaten to drastically increase the costs for decommissioning. This opens **opportunities in the field of consulting** to keep costs within reasonable limits and to develop new waste disposal strategies. A number of challenges should be considered in this field, though, ranging from language barriers to the reluctance of the nuclear sector to do business with outsiders. A strong reputation and long history in the nuclear industry, ideally combined with existing business relations with Japanese companies, are likely necessary to overcome these challenges.

When planning a business strategy for Japan, the European companies should carefully analyse whether a product can be successfully marketed in Japan. This question involves not only technical and economic considerations, but should also consider applicable Japanese laws, regulations and industrial standards. A **strong commitment and endurance** is necessary to attract the interest of Japanese partners. This may include frequent business trips to Japan and intensive product support. Since Japanese companies are mostly interested in designs and single components rather than in foreign manufacturing or the on-site operation of complete devices and technology by foreign companies, IP protection should also be taken into account.

Since the work flow of a nuclear decommissioning project in Japan is made up of Japanese main contractors and many subcontractors with intricate mutual relations, it is also important to choose an appropriate marketing strategy. Attempting to market European products as a replacement for Japanese technology will very likely not lead to successful outcomes. Instead, it is recommendable to stress the complementary character of the technology. **Complementary technology** may also help to reduce the wariness of Japanese partners.

Many aspects of nuclear decommissioning, in particular in regard to waste management, are not yet completely established. Over the next years, further political and regulatory action might lead to significant changes in the decommissioning strategy and the flow of the individual projects, for example by designating candidate sites for waste repositories or opening the Rokkasho LLW repository for decommissioning waste. Other important questions of the near future are the results of the investigation of the interior of the damaged reactors at Fukushima I and the subsequent decision of the retrieval method for the fuel debris. This means that companies with ambitions on the Japanese market for decommissioning should continue to closely **monitor the latest news and developments** on this market.

List of References

- Matsumoto, H., *Present status of R&D activities in support of Decommissioning of Fukushima Reactors*, EU-Japan Centre for Industrial Cooperation, 15 March 2016
- Kansai Electric Power Company, Limited, 美浜発電所１，２号機 廃止措置計画認可申請書の概要, 12 February 2016

- Japan Electric Power Company, Limited, 敦賀発電所１号機 廃止措置計画認可申請書の概要について, 12 February 2016
- TEPCO, Secretariat of the Team for Countermeasures for Decommissioning and Contaminated Water Treatment, *Summary of Decommissioning and Contaminated Water Management*, Tokyo, 24 December 2015
- Kyushu Electric Power Company, Limited, 玄海原子力発電所１号機 廃止措置計画の概要について, 22 December 2015
- Yanagihara, S., *Nuclear Decommissioning*, University of Fukui, 2 December 2015
- Iguchi, Y., *Decommissioning Project of the Fugen Nuclear Power Station*, Fugen Decommissioning Engineering Center, Japan Atomic Energy Agency, 18 November 2015
- Yolin, C., *Waste Management and Recycling in Japan – Opportunities for European Companies (SMEs focus)*, EU-Japan Centre for Industrial Cooperation, Tokyo, September 2015
- Nuclear Damage Compensation and Decommissioning Facilitation Corporation, *Technical Strategic Plan 2015 for Decommissioning of the Fukushima Daiichi Nuclear Power Station of Tokyo Electric Power Company – Towards Amendment of the Mid- and Long-Term Roadmap in 2015*, Tokyo, 30 April 2015
- Nuclear Damage Compensation and Decommissioning Facilitation Corporation, *Activities of Nuclear Damage Compensation & Decommissioning Facilitation Corporation (NDF) and Outline of the "Strategic Plan for Decommissioning of Fukushima Daiichi NPS"*, presentation at 2nd Japan-U.S. Decommissioning and Remediation Fukushima Recovery Forum, Tokyo, 9 April 2015
- Japan Atomic Power Co., Kansai Electric Power Co. Ltd., *Decommissioning situation of Nuclear Power Plant in Japan*, presentation at 2nd Japan-U.S. Decommissioning and Remediation Fukushima Recovery Forum, Tokyo, April 2015
- Griek, L., *Government Procurement in Japan – Obstacles and opportunities for European SMEs*, EU-Japan Centre of Industrial Cooperation, March 2014
- Nuclear Regulation Authority, *Post-Fukushima Assessment and Actions*, presentation by NRA commissioner Kenzo Oshima at ENSREG, Brussels, 11 June 2013
- Thierfeldt, S. & Schartmann, F., *Stilllegung und Rückbau kerntechnischer Anlagen – Erfahrungen und Perspektiven*, Brenk Systemplanung, 4. Neu bearbeitete Auflage, September 2012
- Act for Establishment of a Nuclear Regulation Authority (Law No. 47, July 2012)
- Laraia, M. (ed.), *Nuclear decommissioning – Planning, execution and international experience*, Woodhead Publishing Series in Energy: No. 36, Woodhead Publishing, 2012
- Nuclear Emergency Response Headquarters, Government and TEPCO's Mid-to-Long Term Countermeasure Meeting, *Mid-and-long-Term Roadmap towards the Decommissioning of Fukushima Daiichi Nuclear Power Station Units 1-4, TEPCO*, Tokyo, 21 December 2011

- Nuclear Damage Compensation Facilitation Corporation Act (Law No. 94, 10 August 2011)
- Act on Special Measures concerning the Handling of Environment Pollution by Radioactive Materials Discharged by the NPS Accident Associated with the Tohoku District – Off the Pacific Ocean Earthquake That Occurred on March 11, 2011 (August 2011)
- International Atomic Energy Agency, *Disposal of Radioactive Waste – Specific Safety Requirements*, IAEA Safety Standards Series No. SSR-5, Vienna 2011
- International Atomic Energy Agency, *Predisposal Management of Radioactive Waste – General Safety Requirements*, IAEA Safety Standards Series No. GSR Part 5, Vienna 2009
- International Atomic Energy Agency, *Classification of Radioactive Waste – General Safety Guide*, IAEA Safety Standards Series No. GSG-1, Vienna 2009
- Nuclear Waste Management Organization of Japan, *The NUMO Structured Approach to HLW Disposal in Japan – Staged Project Implementation at Volunteer Sites Utilising a Requirements Management System*, Tokyo, July 2007
- Japan Atomic Energy Commission, *Framework for Nuclear Energy Policy (Tentative Translation)*, Tokyo, 11 October 2005
- International Atomic Energy Agency, *Application of the Concept of Exclusion, Exemption and Clearance – Safety Guide*, IAEA Safety Standards Series No. RS-G-1.7, Vienna 2004
- Law on Final Disposal of High-Level Radioactive Waste (Law No. 117, 7 June 2000)
- Law No. 157, 13 December 1999
- Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors (Law No. 166, 10 June 1957, as amended)
- Atomic Energy Basic Law (Law No. 186, 19 December 1955)

Appendix A: List of organisations

The list is based on the membership list of the JAIF (www.jaif.or.jp/about/member/list, in Japanese). Only Japanese organisations with websites are listed. The list includes subsidiaries and parent companies. Not all listed organisations are necessarily engaged in nuclear decommissioning.

Organisation	URL

Utilities	
Chubu Electric Power Co., Ltd.	www.chuden.co.jp/english
Chugoku Electric Power Co., Ltd.	www.energia.co.jp/e/index.html
Electric Power Development Co., Ltd.	www.jpower.co.jp/english
Hokkaido Electric Power Co., Ltd.	www.hepco.co.jp/english/index.html
Hokuriku Electric Power Co., Ltd.	www.rikuden.co.jp/english/index.html
Japan Atomic Power Company	www.japc.co.jp/english
Kansai Electric Power Co., Ltd.	www.kepco.co.jp/english
Kyushu Electric Power Co., Ltd.	www.kyuden.co.jp/en_index.html
Shikoku Electric Power Co., Ltd.	www.yonden.co.jp/english/index.html
Tohoku Electric Power Co., Ltd.	www.tohoku-epco.co.jp/english/index.html
Tokyo Electric Power Co., Ltd.	www.tepco.co.jp/en/index-e.html
Reactor vendors	
Hitachi-GE Nuclear Energy, Ltd.	www.hitachi-hgne.co.jp/en
Mitsubishi Heavy Industries Ltd., Nuclear Energy Systems	www.mhi-global.com
Toshiba Corporation, Nuclear Energy Systems & Services Division	www.toshiba.co.jp/nuclearenergy/english
General contractors	
Chiyoda Corporation	www.chiyoda-corp.com/en/index.html
Daiho Corporation	www.daiho.co.jp/english/index.html
Dai Nippon Construction	www.dnc.co.jp/en/index.html
Fukuda Corporation	www.fkd.co.jp/index.html
Fujita Corporation	www.fujita.com
Hazama Ando Corporation	www.ad-hzm.co.jp/english/index.html
Iwata Chizaki Inc.	www.iwata-gr.co.jp (in Japanese)
Kajima Corporation	www.kajima.co.jp/english
Konoike Construction Co., Ltd.	www.konoike.co.jp/e_konoike/index.html
Kumagaigumi Co., Ltd.	www.kumagaigumi.co.jp/english/index.html
Maeda Corporation	www.maeda.co.jp/english.html
Nishimatsu Construction Co., Ltd.	www.nishimatsu.co.jp/eng/index.html
Obayashi Corporation	www.obayashi.co.jp/english
Okumura Corporation	www.okumuragumi.co.jp/en
Penta-Ocean Construction Co., Ltd.	www.penta-ocean.co.jp/english/index.html
Seibu Construction Co., Ltd.	www.seibu-group.co.jp/kensetsu (in Japanese)
Shimizu Corporation	www.shimz.co.jp/english/index.html
Shinryo Corporation	www.shinryo.com/en/index.html
Sumitomo Mitsui Construction Co., Ltd.	www.smcon.co.jp/english
Takada Corporation	www.takada.co.jp (in Japanese)
Takenaka Corporation	www.takenaka.co.jp/takenaka_e
Taihei Dengyo Kaisha, Ltd.	www.taihei-dengyo.co.jp/english/index.html
Taisei Corporation	www.taisei.co.jp/english/index.html
Tekken Corporation	www.tekken.co.jp (in Japanese)
Toa Corporation	www.toa-const.co.jp/eng
Tobishima Corporation	www.tobishima.co.jp/english/index.html
Toda Corporation	www.toda.co.jp/english/index.html
Tokyu Construction	www.tokyu-cnst.co.jp/english
Watahan & Co., Ltd.	http://watahan.co.jp/en/
Zenitaka Corporation	www.zenitaka.co.jp/indextop_eng.html
General Trading companies	
Itochu Corporation	www.itochu.co.jp/en

Kanematsu Corporation	www.kanematsu.co.jp/en
Marubeni Corporation	www.marubeni.com
Mitsubishi Corporation	www.mitsubishicorp.com/jp/en/index.html
Mitsui & Co., Ltd.	www.mitsui.com/jp/en/index.html
Sojitz Corporation	www.sojitz.com/en
Sumitomo Corporation	www.sumitomocorp.co.jp/english
Toyota Tsusho Corporation	www.toyota-tsusho.com/english
Other companies	
3R Corporation	www.3r-net.com (in Japanese)
Aichi Kinzoku Kogyo Co., Ltd.	www.aikin.co.jp (in Japanese)
Asatsu-DK Inc.	www.adk.jp/en
Ascend Co., Ltd.	www.ascend.co.jp (in Japanese)
Ask Sanshin Engineering Corporation, Ltd.	www.askcorp.co.jp (in Japanese)
ADPLEX Co., Ltd.	www.adplex.co.jp (in Japanese)
Advanced Fusion Technology Co., Ltd.	www.adfutec.com (in Japanese)
Atom Transport Service Ltd.	www.ats-ltd.co.jp (in Japanese)
ATOX Co., Ltd.	www.atox.co.jp/english
BGE Corporation	www.bge.co.jp (in Japanese)
BWR Operator Training Center Corporation	www.btc.co.jp/index_e.html
CBS Corporation	www.group-c.co.jp/en/service/index.html
CERES, Inc.	www.ceresco.jp (in Japanese)
Chiyoda Kosan Co., Ltd.	www.cknet.co.jp (in Japanese)
Chiyoda Maintenance Co., Ltd.	www.cmaint.co.jp (in Japanese)
Chiyoda Technol Corporation	www.c-technol.co.jp/eng
Choetsu Kaken	www.choetsu.co.jp (in Japanese)
Chubu Techno Co., Ltd.	www.c-techno.co.jp/?page_id=104
Chubu Plant & Service Co.	www.chubuplant.co.jp (in Japanese)
Chuden Kankyo Technos Co., Ltd.	www.e-ckt.jp (in Japanese)
Chudenko Corporation	www.chudenko.co.jp (in Japanese)
Chuden Plant Co., Ltd.	www.chuden-plant.co.jp (in Japanese)
Chuo Kaihatsu Corporation	www.ckcnet.co.jp (in Japanese)
Computer Simulation & Analysis Japan Co., Ltd.	www.csaj.co.jp/index_eng.html
Cornes Technologies Ltd.	www.cornestech.co.jp/en
C-Tech Corporation	www.ctechcorp.co.jp (in Japanese)
Dai-Ichi Cutter Kogyo Co., Ltd.	www.daiichi-cutter.co.jp (in Japanese)
Daiichi Kougeisha Co., Ltd.	www.d1-kougei.co.jp (in Japanese)
Daido Steel Co., Ltd.	www.daido.co.jp/en/index.html
Dainichi Machine and Engineering Co., Ltd.	www.dainichikikai.co.jp/en/index.E.html
Dainippon Plastics Co., Ltd.	www.daipla.co.jp/company/com_03.html (in Japanese)
D-CLUE Technologies Co., Ltd.	www.d-clue.com/en
DIA Consultants Co., Ltd.	www.diaconsult.co.jp/english/index.html
Dowa Eco-System Co., Ltd.	www.dowa-eco.co.jp/en
Eastern Car Liner, Ltd.	www.ecl.co.jp/top_e.html
Ebara Corporation	www.ebara.co.jp/en
Ebara Industrial Cleaning Co., Ltd.	www.eicc.co.jp/index.html (in Japanese)
E&E Techno Service Co., Ltd.	www.e-ets.co.jp (in Japanese)
Enginemaintenance Co., Ltd.	www.emc-jps.com (in Japanese)
Energis Co., Ltd.	www.energis.co.jp/en/index.html
ES Toshiba Engineering Corporation	www.ete.co.jp/ete (in Japanese)
FBR Engineering Co., Ltd.	www.fbec.co.jp (in Japanese)

FBR Technology Engineering Services Company	www.ftecnet.com/html/ftec-top.html (in Japanese)
Fuji Electric Co., Ltd.	www.fujielectric.com
Fujikin, Inc.	http://www-ng.fujikin.co.jp/fujikinhp_e
Fujikura Ltd.	www.fujikura.co.jp/eng
Fujitsu Ltd.	www.fujitsu.com/global
Fukushima Daiichi D&D Engineering Company	www.tepco.co.jp/en/decommission/index-e.html
Garlock Valqua Japan, Inc.	www.garlock-valqua.co.jp (in Japanese)
General Environmental Technos Co., Ltd.	www.kanso.co.jp/eng/index.html
Global Nuclear Fuel – Japan Co., Ltd.	www.jnf.co.jp/english/company/index.html
Hakuhodo Inc.	www.hakuhodo.jp
Hanwa Co., Ltd.	www.kk-hanwa.co.jp (in Japanese)
Hirata Valve Industry Co., Ltd.	www.hvi.co.jp (in Japanese)
Hitachi Aloka Medical, Ltd.	www.hitachi-aloka.co.jp/english
Hitachi, Ltd.	www.hitachi.com
Hitachi Metals, Ltd.	www.hitachi-metals.co.jp/e/index.html
Hitachi Plant Construction, Ltd.	www.hitachi-plant-construction.co.jp (in Japanese)
Hitachi Power Solutions Co., Ltd.	www.hitachi-power-solutions.com (in Japanese)
Hitachi Transport System, Ltd.	www.hitachi-hb.co.jp/english
Hitachi Zosen Corporation	www.hitachizosen.co.jp/english
HNK Co., Ltd.	www.hnk-i.co.jp (in Japanese)
Hoei Industries, Ltd.	http://ns.hoeikogyo.co.jp/index1.html (in Japanese)
Hokkaido Electric Meter Industry Co., Inc.	www.keikou.co.jp (in Japanese)
Hokkaido Power Engineering Co., Inc.	www.hpec.jp (in Japanese)
Hokkaido Records Management Co., Inc.	www.hrm.jp/index.html (in Japanese)
Hokuden Sangyo Co., Ltd.	www.hs-k.co.jp (in Japanese)
Hokuden Sogo Sekkei Corporation	www.hokuss.co.jp (in Japanese)
Hokuriku Electric Construction Company	www.rikudenko.co.jp (in Japanese)
Hokuriku Plant Services Co., Ltd.	www.hokuhatsu.co.jp (in Japanese)
Idemitsu Kosan Co., Ltd.	www.idemitsu.com/?sscl=head05
IHI Corporation	www.ihi.co.jp/en
IHI Instrumentation & Inspection Co., Ltd.	www.iic-hq.co.jp/english/index.html
Inoue Electric Co., Ltd.	www.inouedenki.co.jp/index_e.html
International Creative Co., Ltd.	www.incre.co.jp (in Japanese)
Inspection Development Co., Ltd.	www.kensakaihatsu.co.jp (in Japanese)
Itochu Techno-Solutions Corporation	www.ctc-g.co.jp/en/index.html
Itoki Corporation	www.itoki.jp/english
Japan Environmental Research Co., Ltd.	http://jer.co.jp (in Japanese)
Japan Industrial Testing Co., Ltd.	www.nikkoken.com (in Japanese)
Japan Nuclear Fuel Ltd.	www.jnfl.co.jp/english
Japan Nuclear Security System Co., Ltd.	www.jnss.co.jp (in Japanese)
Japan NUS Co., Ltd.	www.janus.co.jp/eng/tabid/92/Default.aspx
Japan Power Engineering and Inspection Corporation	www.japeic.or.jp/english/e_index.htm
Japan Radiation Engineering Co., Ltd.	www.jrec.cc/index.html (in Japanese)
Japan Research Institute, Ltd.	www.jri.co.jp/english
Japan Steel Works, Ltd.	www.jsw.co.jp/en/index.html
JFE Engineering Corporation	www.jfe-eng.co.jp/en
JFE Steel Corporation	www.jfe-steel.co.jp/en/index.html
JP Business Service Corporation	www.jpbs.co.jp (in Japanese)
JP Design Co., Ltd.	www.jpde.co.jp (in Japanese)

JPec Co., Ltd.	www.jpec.co.jp (in Japanese)
JP Hytec Co., Ltd.	www.jphytec.co.jp (in Japanese)
JX Holdings, Inc.	www.hd.jx-group.co.jp/english
Kamigumi Co., Ltd.	www.kamigumi.co.jp/english/index.html
Kanden Engineering Corporation	www.kanden-eng.co.jp (limited English)
Kandenko	www.kandenko.co.jp (limited English)
Kanden Plant Corporation	www.kanden-plant.co.jp (in Japanese)
Kanden Power-Tech Corporation	www.kanden-pt.co.jp (in Japanese)
Kanden Services Co., Inc.	www.kandensv.co.jp (in Japanese)
Kanden System Solutions Co., Inc.	www.ks-sol.com
Kaneka Corporation	www.kaneka.co.jp/kaneka-e/
Kansui Pump Co., Ltd.	www.kansui.com (in Japanese)
Karikyo Corporation	www.karikyo.co.jp (in Japanese)
Kawasaki Heavy Industries Ltd., Plant & Infrastructure Company	https://global.kawasaki.com/en/corp/profile/division/plant_infrastructure
KEC Corporation	www.kec.co.jp/english/index.html
Keihin Corporation	http://keihin-c.co.jp/home (in Japanese)
Kimura Chemical Plants Co., Ltd.	www.kcpc.co.jp/en
Kitanihon Electric Cable Co., Ltd.	www.kitaniti-td.co.jp (in Japanese)
KJK Co., Ltd.	www.kjk-jp.com (in Japanese)
Kobe Steel, Ltd.	www.kobelco.co.jp/english
Kokugo	www.kokugo.co.jp/company/top1_e.asp
Kondoh Industries, Ltd.	www.cambridgefilter.com/e/E_Welcome.htm
Koyo Electric Co., Ltd.	www.koyoelec.co.jp (in Japanese)
Kurihalant Co., Ltd.	www.kurihalant.co.jp/en/index.html
Kurita Water Industries Ltd.	www.kurita.co.jp/english/index.html
Kyuden Sangyo Co., Inc.	www.kyudensangyo.co.jp (in Japanese)
Marubeni Utility Services, Ltd.	www.mus.co.jp/en
Mayekawa Manufacturing Co., Ltd.	www.mayekawa.com
Meidensha Corporation	www.meidensha.com/index.html
Metal Technology Co., Ltd.	www.kinzoku.co.jp (in Japanese)
MHI Nuclear Systems and Solution Engineering Co., Ltd.	www.mhi-nseng.co.jp/en/index.html
Mitsubishi Cable Industries, Ltd.	www.mitsubishi-cable.co.jp/en/index.html
Mitsubishi Corporation Power Systems, Inc.	www.mcpower.co.jp/english
Mitsubishi Electric Corporation	www.mitsubishielectric.com/worldwide/index.html
Mitsubishi FBR Systems, Inc.	www.mfbr.co.jp (in Japanese)
Mitsubishi Hitachi Power Systems, Ltd.	www.mhps.com/en/index.html
Mitsubishi Materials Corporation	www.mmc.co.jp/corporate/en
Mitsubishi Materials Techno Co.	www.mmtec.co.jp/en/index.html
Mitsubishi Nuclear Fuel Co., Ltd.	www.mnf.co.jp/en
Mitsubishi Research Institute, Inc.	www.mri.co.jp/english/index.html
Mitsui Engineering & Shipbuilding Co.	www.mes.co.jp/english
Mitsui Global Strategic Studies Institute	http://mitsui.mgssi.com (in Japanese)
Mitsui O.S.K. Lines	www.mol.co.jp/en/index.html
Nagaki Seiki Co., Ltd.	www.ngk-nagaki.com (in Japanese)
Nagase Landauer, Ltd.	www.nagase-landauer.co.jp/english/index.html
Nakakita Seisakusho Co., Ltd.	www.nakakita-s.co.jp/en
Nakanihon Engineering Consultants Co., Ltd.	www.nakanihon.co.jp (in Japanese)
NEC Corporation	http://jpn.nec.com/index.html (in Japanese)
NEWJEC Inc.	www.newjec.co.jp/english/index.html

NGK Insulators, Ltd.	www.ngk.co.jp/english/index.html
NHV Corporation	www.nhv.jp/en/index.html
Nichias Corporation	www.nichias.co.jp/nichias-E
Nihon Axis Co., Ltd.	www.n-axis.xo.jp (in Japanese)
Nihon Kensetsu Kogyo Co., Ltd.	www.nikkenko.co.jp (in Japanese)
Nihon Matai Co., Ltd.	www.matai.co.jp/english
Nihon Shiken Kensa Co., Ltd.	http://nihonshikenkensa.co.jp (in Japanese)
Niigata Power Systems Co., Ltd.	www.niigata-power.com/english/index.html
Nippon Advanced Technology Co., Ltd.	www.nat-web.com/EN
Nippon Express	www.nipponexpress.com/?link=top
Nippon Gear Co., Ltd.	www.nippon-gear.jp/english/index.html
Nippon Light Metal Company, Ltd.	www.nikkeikin.com
Nippon Muki Co., Ltd.	www.nipponmuki.co.jp/e
Nippon Nuclear Fuel Development Co., Ltd.	www.nfd.jp (limited English)
Nippon Steel & Sumitomo Metal Corporation	www.nssmc.com
Nishimu Electronics Industries Co., Ltd.	www.nishimu.co.jp/index-e.html
Nishinippon Plant Engineering and Construction Co., Ltd.	www.npc21.jp/english.html
Nissin Kiko Co., Ltd.	www.nissinkiko.com/English/top.htm
Nohmi Bosai Ltd.	www.nohmi.co.jp/english/index.html
Nomura Research Institute, Ltd.	www.nri.com/global
Non-Destructive Inspection Co., Ltd.	www.hihakaikensa.co.jp/english/index.html
NRM Nippon Records Management Co., Ltd.	www.nrm.co.jp/index.html (in Japanese)
NS United Naiko Kaiun Kaisha, Ltd.	www.nsu-naiko.co.jp (in Japanese)
Nuclear Development Corporation	www.ndc-tokai.co.jp (in Japanese)
Nuclear Engineering and Services Company	www.gnesc.co.jp (in Japanese)
Nuclear Engineering Co., Ltd.	www.neco-net.co.jp (in Japanese)
Nuclear Engineering, Ltd.	www.neltd.co.jp/index_eng.html
Nuclear Fuel Industries, Ltd.	www.nfi.co.jp/e
Nuclear Fuel Transport Co., Ltd.	www.nft.co.jp/english/index.html
Nuclear Plant Service Engineering Co., Ltd.	www.nusec.co.jp (in Japanese)
Nuclear Power Training Center, Ltd.	www.jntc.co.jp/en/index.html
NYK Line	www.nykline.com/ecom/CUP_HOM_3000.do?redir=Y
OCL Corporation	www.ocl-corp.co.jp/en/index.html
Ohyo Koken Kogyo Co., Ltd.	www.oken.co.jp/web_oken/indexen.htm
Okamura Corporation	www.okamura.co.jp (in Japanese)
Okano Valve Manufacturing Co., Ltd.	www.okano-valve.co.jp/english
Organo Corporation	www.organo.co.jp/english/index.html
Otec Electric Corporation	www.otec-elec.co.jp (in Japanese)
Panasonic Corporation	www.panasonic.com/global/home.html
PESCO Co., Ltd.	www.pesco.co.jp (in Japanese)
Radia Industry Co., Ltd.	www.radia-ind.co.jp (in Japanese)
Recyclable-Fuel Storage Company	www.rfsco.co.jp (in Japanese)
Sadenko	www.sadenko.co.jp (in Japanese)
Sanesu Co., Ltd.	www.sanesu-k.jp (in Japanese)
Sangyo Kagaku Co., Ltd.	www.sangyo-kagaku.co.jp (in Japanese)
Sanko Group	www.skgr.co.jp/en
Sankyu Inc.	www.sankyu.co.jp/en
Sato Kogyo Co., Ltd.	www.satokogyo.co.jp (in Japanese)
Seiko EG&G Co., Ltd.	www.sii.co.jp/jp/segg (in Japanese)

Shihen Technical Corporation	www.shihen.co.jp (in Japanese)
Shikoku Instrumentation Co., Ltd.	www.yonkei.co.jp/en
Shimadzu Corporation	www.shimadzu.com
Shin-Etsu Chemical Co., Ltd.	www.shinetsu.co.jp/en
Shin Nippon Air Technologies Co., Ltd.	www.snk.co.jp (in Japanese)
Shin-Nippon Nondestructive Inspection Co., Ltd.	www.shk-k.co.jp (in Japanese)
Sota Iron Works Co., Ltd.	www.sota-tekko.com (in Japanese)
Sugino Machine Ltd.	www.sugino.com/index-e.html
Sukegawa Electric Co., Ltd.	www.sukegawadenki.co.jp/english/index.html
Sumitomo Electric Industries, Ltd.	http://global-sei.com
Sumitomo Metal Mining Co., Ltd.	www.smm.co.jp/E
Taiheiyo Consultant	www.taiheiyo-c.co.jp (in Japanese)
Takasago Thermal Engineering Co., Ltd.	www.tte-net.co.jp/english/index.html
Tatsumi Shokai Co., Ltd.	www.tatsumi-cs.co.jp/English/index.html
TechnoChubu Co., Ltd.	www.techno-chubu.co.jp (in Japanese)
Technoflex Corporation	www.technoflex.co.jp/en/index.html
Teikoku Sen-i Co., Ltd.	www.teisen.co.jp/english/index.html
TEPCO Systems Corporation	www.tepsys.co.jp (in Japanese)
Thirdwave Corporation	www.twave.co.jp/english/index.html
TOA Valve Engineering Inc.	www.toavalve.co.jp/english
Toenec Corporation	www.toenec.co.jp/english
Tohoku Electric Power Engineering & Construction Co., Inc.	www.tohatu.co.jp (in Japanese)
Tohoku Ryokka Kankyohozen	www.tohoku-aep.co.jp (in Japanese)
TOiNX	www.toinx.co.jp (in Japanese)
Tokokikaikogyo	www.tohkou.co.jp (in Japanese)
Tokyo Bosai Setsubi Co., Ltd.	www.tokyo-bosai-setsubi.co.jp/tbs/index_eng.html
Tokyo Electric Power Services Co., Ltd.	www.tepsco.co.jp/english/index.html
Tokyo Energy & Systems Inc.	www.qtes.co.jp/english/index.html
Tokyo Nuclear Services Co., Ltd.	www.tokyo-nucl.co.jp (in Japanese)
Tokyo Power Technology Ltd.	www.tokyo-pt.co.jp (in Japanese)
Tokyo Sangyo Co., Ltd.	www.tscom.co.jp/tscom/english
Tomiyama Pure Chemical Industries, Ltd.	www.tomypure.co.jp/english/eng-top.html
Toppan Printing Co., Ltd.	www.toppan.co.jp/english
Toray Industries, Inc.	www.toray.com
Toshiba Logistics Corporation	www.toshiba.co.jp/logi/en/index.html
Toshiba Nuclear Engineering Services Corporation	www.toshiba.co.jp/tnes (in Japanese)
Toshiba Plant Systems & Services Corporation	www.toshiba-tpsc.co.jp/english/index.html
Toshiba Power Systems Inspection Services Co., Ltd.	www.toshiba.co.jp/tisc/eng/index_j.html
Towa Elex Co., Ltd.	www.towaelex.co.jp (in Japanese)
Toyo Tanso Co., Ltd.	www.toyotanso.co.jp (in Japanese)
Transnuclear Tokyo, Ltd.	www.tntokyo.co.jp/en/index.html
Utoc Corporation	www.utoc.co.jp/english
Utsue Valve Service Co., Ltd.	www.utevs.co.jp (in Japanese)
West Japan Engineering Consultants, Inc.	www.wjec.co.jp/root/english
Yano Research Institute Ltd.	www.yanoresearch.com
Yokogawa Electric Corporation / Yokogawa Solution Service Corporation	www.yokogawa.co.jp (in Japanese)
YONE Yonden Engineering Co., Inc.	www.yon-e.co.jp (in Japanese)

Yoshizawa LA Co.	www.yoshizawa-la.co.jp (in Japanese)
Yurtec Co., Inc.	www.yurtec.co.jp (in Japanese)
Other organisations	
Agency for Natural Resources and Energy (ANRE)	www.enecho.meti.go.jp/en
Association for Nuclear Decommissioning Study (ANDES)	www.decomikon.org (in Japanese)
Central Research Institute of Electric Power Industry (CRIEPI)	http://criepi.denken.or.jp/en/index.html
Engineering Advancement Association of Japan (ENAA)	www.enaa.or.jp/EN
Federation of Electric Power Companies of Japan (FEPC)	www.fepc.or.jp/english
Institute of Applied Energy (IAE)	www.iae.or.jp/e
Institute of Energy Economics, Japan (IEE)	http://eneken.ieej.or.jp/en
Institute of Environmental Sciences (IES)	www.ies.or.jp/index_e.html
Institute of Nuclear Safety System, Inc.	www.inss.co.jp/e/index.htm
Institute of Radiation Measurements	www.irm.or.jp (in Japanese)
International Research Institute for Nuclear Decommissioning (IRID)	http://irid.or.jp/en English-language RFI/RFP: http://irid.or.jp/en/rfi_rfp/
Japan Atomic Energy Agency (JAEA)	https://www.jaea.go.jp/english
Japan Atomic Energy Commission (AEC)	www.aec.go.jp/jist/NC/eng/index.htm
Japan Atomic Industrial Forum, Inc. (JAIF)	www.jaif.or.jp/en
Japan Chemical Analysis Center (JCAC)	www.jcac.or.jp (limited English)
Japan Electrical Manufacturers' Association (JEMA)	www.jema-net.or.jp/English
Japan Electric Association (EJA)	www.denki.or.jp (in Japanese)
Japan Electric Power Information Center (JEPIC)	https://www.jepic.or.jp/en
Japan Energy Law Institute (JELI)	www.jeli.gr.jp (in Japanese)
Japan Federation of Construction Contractors (JFCC)	www.nikkenren.com (in Japanese)
Japan Nuclear Safety Institute	www.genanshin.jp/english/index.html
Japan Radioisotope Association (JRIA)	www.jrias.or.jp/e/index.html
Japan Society of Mechanical Engineers (JSME)	www.jsme.or.jp/English
Kansai Atomic Conference	www.kangenkon.org (in Japanese)
Marine Ecology Research Institute	www.kaiseiken.or.jp/english/index.html
Ministry of Economy, Trade and Industry (METI)	www.meti.go.jp/english
Ministry of Education, Culture, Sports, Science and Technology (MEXT)	www.mext.go.jp/english
Ministry of the Environment (MOE)	https://www.env.go.jp/en
National Institute for Materials Science (NIMS)	www.nims.go.jp/eng
National Institute of Advanced Industrial Science and Technology (AIST)	www.aist.go.jp/index_en.html
National Institute of Radiological Sciences (NIRS)	www.nirs.go.jp/ENG
National Institute of Science and Technology Policy (NISTEP)	www.nistep.go.jp/en
National Institute of Technology and Evaluation (NITE)	www.nite.go.jp/index-e.html
Nuclear Damage Compensation and Decommissioning Facilitation Corporation (NDF)	www.ndf.go.jp (limited English)
Nuclear Material Control Center	www.jnmcc.or.jp (in Japanese)
Nuclear Regulation Authority (NRA)	www.nsr.go.jp/english

Nuclear Safety Technology Center	www.nustec.or.jp (in Japanese)
Nuclear Waste Management Organization of Japan (NUMO)	www.numo.or.jp/en
Osaka Science & Technology Center	www.ostec.or.jp (in Japanese)
Overseas Reprocessing Committee	www.orc.or.jp (in Japanese)
Radiation Application Development Association (RADA)	www.rada.or.jp (in Japanese)
Radiation Effects Association (REA)	www.rea.or.jp (in Japanese)
Radioactive Waste Management Funding and Research Center (RWMC)	www.rwmc.or.jp/english
Radwaste and Decommissioning Center	www.randec.or.jp (limited English)
Research Organization for Information Science and Technology (RIST)	www.rist.or.jp (in Japanese)
Thermal and Nuclear Power Engineering Society	https://www.tenpes.or.jp/e_index.html
Wakasa-wan Energy Research Center (WERC)	www.werc.or.jp (in Japanese) Fukui International Human Resources Development Center for Atomic Energy (FIHRDC): https://fihrdc.werc.or.jp