Increased complexity of radioactive waste disposal issues in Japan after Fukushima Daiichi accident

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Abstract: Almost seven years have passed since Fukushima Daiichi accident in 2011, and these days the radioactive waste disposal issue is affecting on the future of nuclear power in Japan. In this paper, the appearing dilemma of nuclear policy in Japan is discussed from the aspect of increased complexity of radioactive waste disposal issues.

The governmental target of more increase of restarting nuclear power to meet with the current Japanese energy plan 2030 for saving higher energy cost with more reduction of global warming gas emission is facing the difficulty to attain. It is because the number of nuclear power plants to restart is not so enough while the number of nuclear power facilities to be decommissioned has suddenly surpassed after Fukushima Daiichi accident. The sudden increase of decommissioned light water reactors brings the urgent necessity of finding places for disposal of low level radioactive waste with unexpected long time and costs which had not well planned before Fukushima Daiichi accident.

The high level radioactive waste disposal issue becomes no simple issue to find a proper underground disposal site in Japan for burial of small amount of vitrified wastes discharged from the reprocessing plant in future. The crucial change of high level radioactive waste disposal issue in Japan after Fukushima Daiichi accident is brought about the delay of commercial operation of reprocessing plant in Rokkasho-mura and the recent governmental decision of decommissioning a prototype fast reactor Monju in Tsuruga. The prerequisite of Japanese nuclear policy for establishing nuclear fuel cycle technology for processing all spent fuels from commercial light water reactor and using Plutonium for fast reactor with vitrified high level radioactive waste in deep geological disposal site all facing the difficulties of realization.

Keywords: Fukushima Daiichi accident; radioactive waste disposal; decommissioning; nuclear fuel cycle; social acceptance; risk communication

1 Introduction

Six years have already passed since Fukushima Daiichi accident in March 2011. This article is one of the special articles to memorize the six year after Fukushima Daiichi accident, and the major subject is problems on radioactive waste processing and disposal.

In Japan, the traditional policy of processing and disposal of radioactive wastes by nuclear power industry is that low level radioactive wastes from all nuclear power plants in Japan are conveyed to Japan Nuclear Fuel Limited (JNFL) in Rokkasho-mura, Aomori Prefecture, and are disposed in the burial center of low level radioactive waste. On the other hand of low level radioactive waste, it has been believed that the spent nuclear fuels from all the nuclear power plants are shipped to the large spent fuel pools of the reprocessing plant in JNFL and they will be reprocessed in the reprocessing plant (now under test prior to commercial operation) to separate them into reusable nuclear fuel materials of Uranium and Plutonium (A) and high level radioactive wastes (B). For A, both Uranium and Plutonium will be used as mixed oxide (MOX) fuels for both PWR and BWR of light water reactor and for fast reactor Monju. For B, high level radioactive wastes are vitrified and cooled for several tens of years in a storage facility in JNFL before final underground disposal of high level radioactive waste (HLW). This final disposal of vitrified HLWs will be made by a responsible company called the Nuclear Waste Management Organization of Japan (NUMO) and the call for the final disposal site had started for all local towns in Japan since the start of NUMO in 2000. (Until now,

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no application from any local town in Japan has appeared for the final HLW disposal site in Japan.)

However, the traditional nuclear policy in Japan has not been proceeded as stated in the above. These days almost seven years after Fukushima Daiichi accident, the radioactive waste disposal issues have been increasing the difficulty of the future of nuclear power in Japan. In Chapter 2, the whole picture of the complicated radioactive waste processing and disposal will be first described, then decommissioning of old light water reactors in Chapter 3, and uncertain future of high level radioactive waste disposal in Chapter4, before the concluding remarks in Chapter 5.

2 Whole picture of complicated radioactive waste issues

2.1 History of nuclear power development in Japan before Fukushima Daiichi accident

Nuclear power development in Japan had started in the period of 1960s as the national policy with the corporation of government and industry, especially electric power industry. The basic policy had been to establish the nuclear power technology and nuclear fuel cycle technology for the effective utilization of nuclear fuel material resource of Uranium-Plutonium series as substantially domestic resource. Wherein the following assignment setting had been made:

(1) Introduce light water reactor technologies (BWR and PWR) from U.S.A. for domestication,
(2) Develop and establish Uranium enrichment plant and the technology for nuclear fuel fabrication in Japan so that it can produce and procure low enriched Uranium fuels necessary for light water reactors by importing natural Uranium resources from overseas,
(3) Develop and validate the construction and operation technology of reprocessing plant, fabrication technology of mixed oxide fuel of Uranium and Plutonium series, and new power reactors other than light water reactors (both advanced thermal reactor and fast reactor), so that the spent nuclear fuels from light water reactors are all reprocessed, and the recovered Uranium and Plutonium resources are reused as nuclear fuels in both light water reactors and fast reactors, and
(4) Construct disposal facility for low level radioactive wastes produced by the operation of nuclear power plants, Uranium enriched plant and reprocessing plant, and establish the geological disposal technology of high level radioactive wastes which are left after the reprocessing of spent nuclear fuels in reprocessing plant.

These have been the basic direction of nuclear power development policy in Japan, and there are already attained subjects, altered ones, tried but changed ones, and not yet tried ones. However, the nuclear power development in Japan had been firmly progressed by the support of majority people in Japan prior to the Fukushima Daiichi accident in March 2011. At the time total number of light water reactors in operation were 54 units with producing ca. 30 % of whole electricity generation in Japan. Japan was the third largest nuclear power generation country after U.S.A. and France.

On the other hand of nuclear power generation, the stage of establishing nuclear fuel cycle technology had been summarized as below;

(1) At JNFL in Rokkasho-mura, Aomori prefecture, commercial Uranium enrichment plant had been constructed and operated, and the burial center of surface disposal facility was already constructed and operated to accept and dispose low level radioactive wastes from all nuclear power plants in Japan. The reprocessing plant had been constructed and had been being prepared to accept spent fuels from nuclear power plants with the final testing stage of the reprocessing process,
(2) The construction and operation of advanced thermal reactor prototype plant Fugen had been successfully progressed by Power Reactors and Nuclear Fuel Development Corporation (PNC) at Tsuruga- Fukui Prefecture. However, the construction project of Demonstration plant of advanced thermal reactor at Ohma-Cho, Aomori by J-Power was canceled by the objection of electric power industry by the reason of high construction cost. Therefore, J-Power chose to construct Full MOX fuel advanced BWR (ABWR) plant instead, and the PNC had decided to close the 28 years' operation of Fugen plant

in 1995 and since then the decommissioned Fugen plant has been utilized for the development of decommission technology,

(3) Construction of Fast Reactor Prototype Monju plant in Tsuruga, Fukui by PNC had progressed smoothly and had started test operation in the middle of 1995. But during the test, the operation had suspended by the sodium leakage accident which happened in December 1995. After the long pause for repair, Monju had restarted the operation in 2010 but soon stopped again by the failure of fuel transfer operation and then met the Fukushima Daiichi accident, and

(4) The technology development for final disposal of vitrified waste as the high level radioactive waste had been developed by PNC, and the responsible company called NUMO was established by the law of final disposal of vitrified HLWs in 2000. Then, the NUMO had started the call for all local towns in Japan to examine the geographical suitability of the town for the final disposal site, but no local town has not yet appeared to apply for this call.

2.2 Kinds of radioactive waste and the processing methods

As related with the subject of this paper, the kinds and the processing methods of various radioactive wastes are as shown in **Table 1**. The recognition of this classification in Japan is not changed from prior to after Fukushima Daiichi accident.

Table 1 Kinds of radioactive waste and the processing methods.

Kinds of radioactive waste			Examples of radioactive wastes	Generated places	Examples of processing methods
Low level radioactive waste	Wastes from power plant	Very low level radioactive waste	Concrete, metal, *etc.*	Nuclear power plant	Trench disposal
		Comparative low level radioactive waste	Solidified liquid waste, filter, and consumables		Pit disposal
		Comparatively high level radioactive waste	Control rods and in core structures		Sub-surface Disposal
	Uranium waste		Consumables, sludge, waste goods	Uranium enrichment, fuel processing facility	Pit disposal, Sub-surface Disposal and in cases geological disposal
	Radioactive waste which includes trans-uranium nuclide (TRU waste)		Parts, liquid waste and filter of nuclear fuel rods	Reprocessing facilities, MOX fuel fabrication facilities	Geological disposal, Sub-surface Disposal Pit disposal,
High level radioactive waste			vitrified radioactive waste	Reprocessing facilities,	Geological disposal,
Waste lower than clearance level			Most of demolition waste of nuclear power plant	All generation places shown above	Reuse or disposition as general goods

2.3 Influence of Fukushima Daiichi accident on basic energy plan of Japanese government

The basic energy plan of Japan is regulated in every three years by government. According to the basic energy plan just prior to Fukushima Daiichi accident in 2011, it was intended to increase both nuclear and renewable energy to suppress the fraction of fossil energy. Especially the target of nuclear energy at the time was 40 % of total electric generation. But the Fukushima Daiichi accident completely changed the Japanese energy policy. The Democratic Party of Japan (DPJ), ruling party at the time, had changed the direction towards nuclear phase out. Especially, the past nuclear regulation framework had completely changed in 2012 by DPJ to reorganize as Nuclear Regulation Authority (NRA) which should be independent from nuclear industry. However, the defeat of DLJ by the general election in December 2012 changed the ruling party to Liberal Democratic Party (LDP). The LDP had reconsidered the nuclear policy, and the revised basic energy plan in 2016 published by the present Prime Minister Shinzo Abe set the nuclear energy as the important base electric source by modifying the target ratio of nuclear energy 20-22 % and renewable energy 22-24 % in 2030.

In August 1, 2017 the present cabinet had started the revision of the basic energy plan with maintaining the present ratios of nuclear energy and renewable energy. However, it is said very difficult to attain the both targets of nuclear energy and renewable energy in 2030 when you consider the present environment surrounding the energy in Japan.

First for renewable energy, its ratio was ca. 15 % in 2015 although the introduction of strong incentive of feed-in tariff (FIT). Second for nuclear energy, it will be very difficult to construct new plants and add units under the present headwind to nuclear. The ratio of nuclear energy in 2030 is said to be as low as 15 % with the extension of operation life of existing plants from 40 years to 60 years without any replace or new constructed plants. Therefore, it will be necessary to implement new mechanisms to improve those two energy source; otherwise the basic energy plan in 2030 might be soon revised.

2.4 Present state of light water reactors in Japan

By Fukushima Daiichi accident, the past framework of nuclear safety regulation in Japan had completely changed in 2012, and the nuclear safety standard set by the NRA had completely revised in 2014. Until then all nuclear power plants had already stopped operation.

The new LDP cabinet under Prime Minister Shinzo Abe changed the nuclear policy from that of DPJ so that the government approves the restart of nuclear power plant with the approvals of both the nuclear regulatory commission and the local government. But since it is impossible to start plant operation unless the operators apply and pass the NRA's examination by the new regulation standard, Japan became no nuclear country until there appears a plant which passes the examination by the NRA.

On the part of plant operators who wish to restart the plant, they had to reinforce the plant facilities by taking long time with not a small investment to meet with the strengthened standard, submit the application for the NRA and take a long month to respond to the NRA's examination before its permission. In fact, there are only 5 PWR plants as of December 2017 in operation. A few plants of almost 40 years after operation were admitted to prolong 20 years, but there are already 11 plants to abandon restart and decided to decommission by considering the heavy burden and cost to pass the regulatory examination.

Concerning the public opinion, the percentage of anti-restart amounts to 60 % at the present time almost seven years after Fukushima Daiichi accident. In addition, some plants got the order of lower court to stop operation by the appeal of anti-nuclear local citizen, although they already passed the Prime Minister Shinzo Abe's three conditions of licensing examination, the approvals of local government and central government. Under those situations there are no prospect of new plant construction nor addition of new units in the near future.

The present status of all nuclear power plants in Japan is indicated in **Table 2**.

On the other hand of nuclear power plants, the nuclear fuel cycle facilities in Rokkasho-mura are under licensing examination except for the Uranium enrichment plant and the burial center of low level radioactive waste which are already approved to operate. Therefore, the only commercial reprocessing plant is still not operated. (The pilot reprocessing plant of JAEA in Tokai was already decided to decommission.)

Table 2 Status of nuclear power facilities in Japan (as of December, 2017).

Operating company	Name of facility	Kind of facility	Present state of facility				
			To be decommissioned	Not yet decided	Under licensing	Operation approved by regulation	Under commercial operation
Hokkaido Electric Power Co., Inc.	Tomari No.1	PWR			+		
	Tomari No.2				+		
	Tomari No.3				+		
J-POWER	Ohma	BWR			+		
Japan Nuclear Fuel Limited,	Rokkasho	Nuclear fuel			+		
Tohoku Electric Power Co., Inc.	Onagawa No.1	BWR		+			
	Onagawa No.2				+		
	Onagawa No.3			+			
	Higashi□dori				+		
Tokyo Electric Power Company Holdings, Inc.	Kashiwazaki-Kariwa No.1	BWR		+			
	Kashiwazaki-Kariwa No.2			+			
	Kashiwazaki-Kariwa No.3			+			
	Kashiwazaki-Kariwa No.4			+			
	Kashiwazaki-Kariwa No.5			+			
	Kashiwazaki-Kariwa No.6	ABWR				+	
	Kashiwazaki-Kariwa No.7					+	
	Fukushima Daini No.1	BWR		+			
	Fukushima Daini No.2			+			
	Fukushima Daini No.3			+			
	Fukushima Daini No.4			+			
Japan Atomic Power Co.□□□□	Tokai No.1	GCR	+				
	Tokai No.2	BWR			+		
	Tsuruga No.1	BWR	+				
	Tsuruga No.2	PWR			+		
Hokuriku Electric Power Company	Shika No.1	BWR		+			
	Shika No.2				+		
CHUBU Electric Power Co.,Inc.	Hamaoka No.1	BWR	+				
	Hamaoka No.2		+				
	Hamaoka No.3				+		
	Hamaoka No.4				+		
	Hamaoka No.5	ABWR		+			
Kansai Electric Power Co.,Inc.	Mihama No.1	PWR	+				
	Mihama No.2		+				
	Mihama No.3					+	
	Ohi No.1		+				
	Ohi No.2		+				
	Ohi No.3					+	
	Ohi No.4					+	
	Takahama No.1					+	
	Takahama No.2					+	

	Takahama No.3						+
	Takahama No.4						+
The Chugoku Electric Power Company, Incorporated.	Shimane No.1	BWR	+				
	Shimane No.2				+		
	Shimane No.3	ABWR		+			
Shikoku Electric Power Co.,Inc	Ikata No.1	PWR	+				
	Ikata No.2			+			
	Ikata No.3						+
Kyushu Electric Power Co.,Inc.	Genkai No.1	PWR	+				
	Genkai No.2			+			
	Genkai No.3					+	
	Genkai No.4					+	
	Sendai No.1						+
	Sendai No.2						+
Total			11	16	12	9	5

As for the restart of Kashiwazaki Kariwa Nos. 6 and 7 (ABWR), eligibility of Tokyo Electric Power Co. ltd (TEPCO) who had committed Fukushima Daiichi accident, was examined by NRA, and in December 27, 2017 the both plants were officially admitted to operate by reflecting the concern of eligibility by NRA in the description of the safety provisions. However, whether or not able to restart the both plants will solely rest on the approval of Niigata Prefecture. The present Governor of Niigata Prefecture was elected in October 2016, with the public promise on the decision of the restart of the both plants by the conclusion of the following three investigation committees independently set by Niigata Prefecture. [1].

(i) Thorough validation on the cause of Fukushima Daiichi accident,
(ii) Thorough validation of the effects of nuclear accident on the residents' health and life, and
(iii) Thorough validation of safe evacuation method when serious accident would happen.

The three investigating committees have been engaged in the assigned tasks vigorously, and the governor said that it will take 3 to 4 years to reach the conclusion. In fact, it may be a long way for the both plants to reach the conclusion whether or not to restart, but this was the first case of the NRA's permission of restarting BWR plants. There would be other BWRs to restart faster than Kashiwazaki Kariwa Nos.6 and 7, probably within a couple of years.

On the other hand of Kashiwazaki Kariwa plants, the accident caused Fukushima Daiichi's Nos. 1 to 5 of Tokyo Electric Power Company had been assigned as "specific reactor facilities" by NRA. The specific reactor facilities are nuclear reactors which committed serious accident so that they are managed by the Japanese government for a long period spanning 30 to 40 years.

By assigning Fukushima Daiichi plant as specific reactor facilities, the NRA first ordered TEPCO to submit the executive plan of the whole Fukushima Daiichi plant which describes the methods and procedures for monitoring the damaged reactors and other facilities, proper storage of nuclear fuels, and processing of contaminated water and radiation dose of workers. Then the NRA investigated the appropriateness of the TEPCO's submitted executive plan by inviting outside specialists on the matters. The NRA approved the executive plan of TEPCO on August 2013 with special request to do with the prompt countermeasures against leakage of contaminated water to the sea. The government established the investigation committee on monitoring and evaluating the specific reactor facilities which will oversee the designated activities by TEPCO.

At this point the prospect of the nuclear power in Japan is described for the period after 2030. As already mentioned in **2.3**, there is a trial estimate that the number of nuclear power plant in 2030 is 30 units with the ratio 15 % of total electric power source under the assumption that the all existing units will restart with the extension of plant life from 40 to 60 years with no replace nor new constructed units. But as you see in **Table 1**, the whole number of the units is 26 units with under examination, approved to operate and now in operation. If no further restart of more units, the ratio of 20-22% of nuclear in basic energy plan in 2030 will not be attained. Even if all units can restart, the ratio of 20-22 % in 2030 will not maintained because there will be retired units appeared by the limit of 40 years' operation. Construction of new units will not be in time for 2030, if you take into account of the lead time of at least 20 years in Japan even before Fukushima Daiichi accident. To sum up, the future of nuclear power in Japan would be better to assume natural decay of unit numbers.

2.5 Complicated problems of radioactive waste processing and disposal

Concretely speaking there are three complicated problems for the radioactive waste processing and disposal after Fukushima Daiichi accident in Japan. Those three problems are briefly summarized in the subsequent sub-sections.

2.5.1 Problem A: Decommissioning of old power reactors

The premise of disassembling old reactors for decommission is that all spent fuels should be completely taken out of reactor vessel and spent fuel pool of the decommissioned nuclear power plant. During the process of this disassembling the reactor various kinds of radioactive wastes are produced but those radioactive wastes cannot be shipped to the burial center in Rokkasho-mura in Aomori. For the process of decommissioning old reactors, the operator will first meet the problem of where to keep the spent nuclear fuels before disassembling the reactor. The detail of the problem A will be mentioned in Chapter 3.

2.5.2 Problem B: Complicated situation surrounding high level radioactive waste disposal

Prior to Fukushima Daiichi accident in 2011, high level radioactive waste (HLW) from nuclear power was generally recognized as vitrified waste produced by reprocessing plant in Rokkasho-mura. But after Fukushima Daiichi accident, this common sense of "HLW = vitrified waste" should be altered by considering the following three factors of completely changed complex situation surrounding the nuclear power development in seven years after Fukushima Daiichi accident:

(i) No prospect of finding underground HLW disposal site for these seventeen years,
(ii) Delay of the operation of commercial reprocessing plant in Rokkasho-mura and decommission decision in 2017 of fast reactor Monju in Tsuruga, and
(iii) Too many stock of Plutonium with no prospect of consumption.

The detailed background of the problem B will be explained in Chapter 4.

2.5.3 Problem C: Disassembling of damaged Fukushima Daiichi plants

The reactors Units Nos. 1, 2 and 3 of Fukushima Daiichi nuclear power station of TEPCO had committed core melt accident. It is believed by nuclear experts that the molten fuel materials of those reactors reacted with the structural materials such as fuel claddings and reactor vessel and converted to the substances of complex composition and shape. These are generally called "fuel debris". In case when fuel debris stay within reactor vessel they are called "reactor core debris". Whereas when they penetrate through the bottom of the reactor vessel, they would have reaction with concrete materials of the containment base mat and to form furthermore fuel debris of complicated chemical configuration and shape. In this stage the fuel debris are called "molten core concrete interaction (MCCI) debris". It is estimated that the total quantity of core debris is ca. 120 ton while MCCI debris ca. 740 tons. [2]

The accident committed reactors of Fukushima Daiichi nuclear power station cannot start the decommission work in so short time, because it is not possible to set to decommission work unless all fuel debris are removed from the reactors. As of December, 2017, there is no clear prospect of when and how to remove the debris from reactors, no prospect of what to do with the debris even if they are removed, nor any fixed idea of what to do with the disassembling of whole reactor building.

For conducting the ultimate decommission of damaged Fukushima Daiichi plant, it is essential to remove those fuel debris from the damaged reactors where human activities will be restricted because of strong radioactive environment. Therefore, it will be important to develop new remote operation technologies such as robotics as the representative one. In April, 2016, Naraha Remote Technology Development Center was constructed in Fukushima prefecture, as the core of the related technological development where the following three research and development have been progressing to prepare for the decommissioning of Fukushima Daiichi plant in future. [3]

(i) Provision and maintenance of validation test field with various test facilities in order to simulate the actual environment of accident committed nuclear reactors where various types of robots will be remotely operated,

(ii) System development which will serve to design the specification, environmental data of remote operated robots, conduct test and train the robots and the handling by operators, by full utilization of advanced computational science such as virtual reality and high level simulation technique, and

(iii) Development of test method for the performance of robots and operators' skill.

3 Rush of decommissioning old nuclear power reactors and nuclear fuel cycle facilities

3.1 What is decommission of nuclear facilities

According to the history of the decommissioning of nuclear facilities in Japan since the start of nuclear research and development in 1960s, there are a lot of experience; many research reactors which had constructed and operated by Japan Atomic Energy Research Institute (JAERI; now JAEA) , national and private universities and private companies, a nuclear ship Mutsu and a demonstration nuclear power reactor called Japan Power Demonstration Reactor (JPDR) which had constructed and operated by respective national institutes, and a gas cooled reactor (GCR) plant imported from UK and operated by Japan Atomic Power Co.ltd. In addition, there is Advanced Thermal Reactor (ATR) called Fugen in the process of decommissioning in Tsuruga by JAEA. Therefore, it has been believed in Japan that Japan has enough experience for the decommissioning of nuclear reactors. Then, there appears a rush of decomminioning plan of light water reactor power plants after Fukushima Daiichi accident in Japan. In addition, the decommission plan of a pilot reprocess plant in Tokai owned by JAEA was admitted in 2017 and then in December 2017 the decommissioning of the fast reactor prototype Monju also owned by JAEA was decided by Government. The both have different technical characters from those of the nuclear reactor facilities in the past.

According to the NRA in Japan, safety regulation of operation, decommissioning and use of vacated land of nuclear facilities will be processed as illustrated in **Fig.1.**

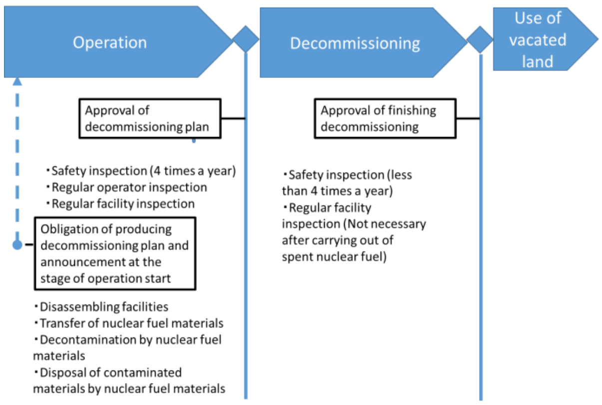

Fig. 1 Safety regulation of operation, decommissioning and use of vacated land.

In **Fig. 3**, the safety regulation by NRA will intervene in each stage and transition between the stages. Four conditions as indicated below should be satisfied so that the NRA will admit the application of decommission of the existing nuclear power reactors.

(i)Condition 1: All spent fuels are taken out from the reactor core,

(ii)Condition 2: Appropriate management and transfer of the nuclear fuel are performed,

(iii)Condition 3: Nuclear fuel materials and the contaminated things by them are properly managed, processed and disposed, and

(iv)Condition 4: Decommission is properly performed from the viewpoint of disaster prevention.

Therefore, decommission of the nuclear facilities cannot be started unless the above conditions are all satisfied. In case of Fukushima Daiichi nuclear power station, it cannot start decommission because it does not satisfy even Condition 1. In fact, Fukushima Daiichi nuclear power station is already specified as specific nuclear facility by NRA. The list of all nuclear facilities of which decommission were already admitted by NRA is shown in **Table 3**.

As seen in **Table 3** there are total nine units of light water reactors which were applied for decommission and admitted by government after Fukushima Daiichi accident. Those reactors are all old reactors of both PWR and BWR with almost 40 years' operation with rather small output electricity less than 1000 MWe. However, in December 2017, Kansai Electric Power, Co.ltd., decided to decommission Ohi Unit Nos. 1 and 2, two PWR units of 1,180 MWe each unit. This is because the strengthened safety standard by NRA forces the reactor operator to reconsider after Fukushima Daiichi accident by weighing the investment needed for restart plus decommission with the profit gained by additional 20 years' operation in future.

Table 3 List of nuclear facilities of which decommission plan were approved by nuclear regulation in Japan (as of December 2017).

Name and type of nuclear facility	Application for decommissioning	Approved time by regulation
Tokai No.1 (GCR)	May 2006	June 2006
Fugen (ATR)	November 2006	February 2008
Hamaoka Nos. 1, 2 (BWR)	June 2009	November 2009
Genkai No.1 (PWR)	December 2015	April 2017
Tsuruga No.1 (BWR)	February 2016	April 2017
Mihama Nos. 1, 2 (PWR)	February 2016	April 2017
Shimane No.1 (BWR)	July 2016	April 2017
Ikata No.1 (PWR)	December 2016	June 2017

On the other hand of initiating the decommission process, on what state the reactor decommission will be considered to finish? According to NRA, the following four conditions are the threshold standard to judge as the end of decommission by law:
(i)Condition 1: Deliver of all nuclear fuels is completed,
(ii)Condition 2: Soils in the site and the remaining facilities are not necessary to conduct preventive measures against radiation hazard,
(iii)Condition 3: Disposal of nuclear fuels and the contaminated matters are finished, and
(iv)Condition 4: All records of radiation management should be all transferred to the appropriate organization specified by NRA.

In view of the present situation of Fukushima prefecture where the decontamination of land, forests, buildings, *etc.*, should be cleaned for the evacuated residents to return the home town, this is also difficult problem to decide in future.

3.2 How the disposals of radioactive wastes are processed?

According to the Regulation Law of Nuclear Reactors and Others, the method of burial disposal of radioactive wastes as “the business of waste disposal” is classified into two categories of “burial disposal of the 1st kind” and “that of the 2nd kind”, in accordance with the radioactive concentration of the radioactive waste. The stage of radioactive materials prior to the final disposal by burial disposal will be either stored outside of the facility or process as the form suited for storage or final disposal, and this stage is called as “waste management”. The whole scope of radioactive waste disposals related with decommissioning of nuclear facilities is depicted in **Fig. 2**.

The disposal of low level radioactive waste by pit disposal has been already realized at the burial center of JNFL in Rokkasho-mura, Aomori Prefecture, but this facility is only for the disposal of low level radioactive waste generated by all operating nuclear power plants (both BWR and PWR). The low level radioactive waste generated by the disassembling of the decommissioning reactors are not processed there.

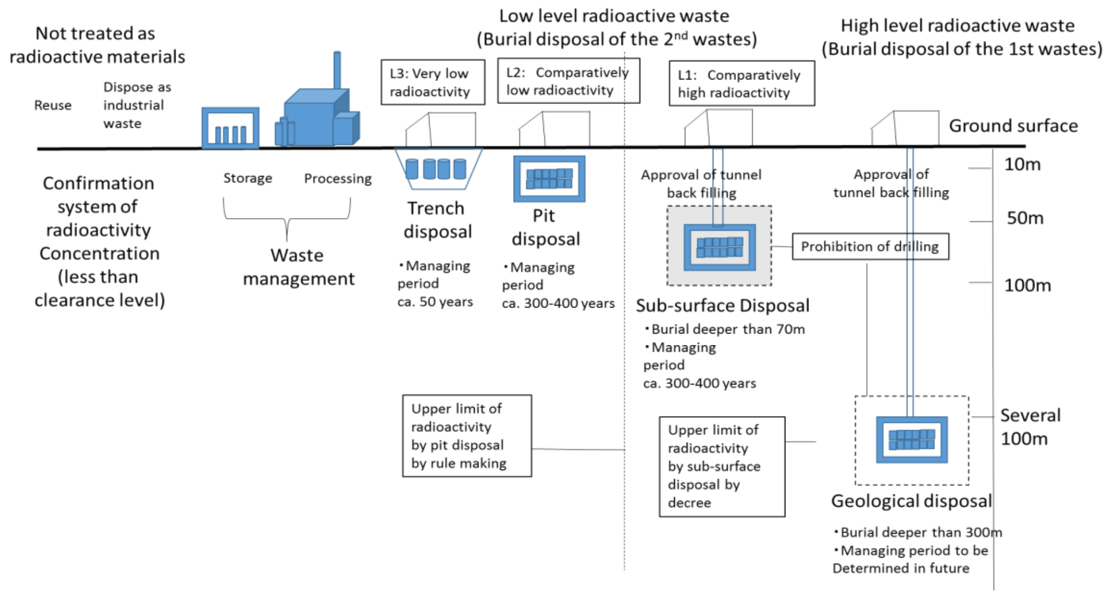

Fig. 2 Whole scope of radioactive waste disposals related with decommissioning of nuclear facilities.

The estimate given by the Federation of Electric Power Companies of Japan is shown in **Table 4** for the generated quantity of waste in ton by decommissioning all 57 nuclear power plants in Japan which include Tokai No.1 and Hamaoka Nos. 1 and 2.

Table 4 Generated quantity of waste in ton by decommissioning all 57 nuclear power plants in Japan which include Tokai No.1 and Hamaoka Nos. 1 and 2.

Category	Quantity of waste in ton	
L1	ca. 8,000	LLW Total ca.450,000 (ca.2%)
L2	ca.63,000	
L3	ca.380,000	
CL	ca.890,000	CL ca.5%
NR	ca.18,500,000	NR ca.93%
Total	ca.20,000,000	Total 100%

3.3 Situation and problems of decommissioning of nuclear facilities in Japan

In conjunction with the decommissioning of nuclear facilities, the present situation and problem in Japan are summarized as below.

(1) Almost seven years after Fukushima Daiichi accident, the reformed nuclear regulatory body of nuclear regulatory authority (NRA) seems too eager to strengthen the safety standard for light water reactor, fast reactor, and nuclear fuel cycle facilities. Nuclear power operators in Japan tend to select the business policy so that their old nuclear power plants almost 40 years to decommission rather than to invest for the restart. There is no clear vision to build new plants these days. Both the government-owned fast reactor prototype Monju in Tsuruga and reprocessing pilot plant in Tokai were decided to decommission. In addition, commercial operation of the reprocessing plant in Rokkasho-mura has been delaying so long time. These trend in nuclear power gives the impression that Japan is going to phase out of nuclear

(2) These days the decommissioning is the boom in nuclear industry. NRA is busy with studying how to regulate the process of the decommissioning every nuclear facility "safely" by the same manner as that of safety regulation of the operation of nuclear facilities. To this tendency, the nuclear operators requested to NRA that effective risk reduction by "graded approach" should be taken rather than zero risk regulation for the probate of clearance matters and the judgment of no risky waste.

(3) For the nuclear power operators, it becomes necessary to find and ensure new disposal sites for the low level radioactive wastes from the disassembled nuclear reactors to be decommissioned because the burial center of JNFL in Rokkasho-mura is for the low level radioactive wastes from the operating light water reactors.

(4) To be compared with the actual achievement of the decommissioning in foreign countries, the

time and cost estimate by Japanese operators are too costly. Especially the cost estimate by JAEA for decommissioning fast reactor Monju and Tokai reprocessing plant are both very enormous ones (ca. 300 Billion Japanese Yen for each).

4 Complicated situation surrounding high level radioactive waste disposal

In Japan, it had been no disputable practice of nuclear fuel cycle policy to reprocess all spent fuels from light water reactors to recover the nuclear fissile elements (Uranium and Plutonium). The residual high level radioactive liquid in the reprocess plant are converted to vitrified wastes and the vitrified waste are contained in the metallic cask which is made of stainless steel in order that the high level radioactive wastes become physically and chemically stable form. The casks which contain vitrified wastes with high radioactivity and high heat generation will be stored on surface ground for 30 to 50 years to cool down, and then dispose in underground burial site deep into 300 meters.

On the basis of above-mentioned technical process, the final disposal law was enacted in the Japanese Diet in 2000, in order to establish the government-industry cooperated organization called NUMO for conducting the final disposal business of vitrified HLW wastes. However the selection of the final disposal site had not been completely proceeded notwithstanding the official institution operated by NUMO started in 2000.

After Fukushima Daiichi accident in March 2011, along with the elevated national dispute to reconsider nuclear policy in general, a new political movement has been arising about the uncertain site selection of high level radioactive waste for these six years.

In this chapter, the historical progress on the dispute of HLW disposal issue in Japan will be summarized in the subsequent sections.

4.1 Traditional policy for underground disposal of high level radioactive waste in Japan

By the reprocessing of the spent fuel from the light water reactor, 95% of the original spent fuel will be extracted as uranium and plutonium, and it will be used in existing light water reactors as mixed oxide (MOX) fuel. Most of MOX fuel had been originally planned to utilize in fast reactor, but due to decision of decommissioning fast reactor proto type plant Monju in December 21, 2017, there will be no possibility of using MOX fuel in fast reactor in Japan in the near future.

The rest 5 % of the reprocessed spent fuel is high level radioactive waste solvent, and it is mixed with molten glass to produce vitrified waste in cylindrical solid form (1.3 m high, 40 cm in diameter, ca. 500 kg in weight). By this way of making solid vitrified waste, quantity of waste is decreased one fourth of the quantity by direct disposal of spent fuel. The period of radioactive decay of the vitrified waste to the radioactivity of natural uranium in ca. 8 thousand years. This is shorter than that of 100 thousand years by direct disposal of spent fuel.

When the light water reactor plant of 1 million KWe is operated for one year, spent fuel of ca. 27 ton is generated, and by the reprocessing of the spent fuel, ca. 26 bins of vitrified waste is generated. In Japan, there are 2,176 bins of vitrified waste in high level radioactive waste storage center of JNFL, in Rokkasho-mura, and 272 bins in the reprocessing plant of JAEA, in Tokai-mura. Therefore, total 2448 bins of vitrified waste are stored in Japan. On the other hand, when all the spent fuels from th light water reactor plants in Japan is assumed to reprocessed, then total 25,000 bins of vitrified waste should be disposed in future [4]

The system formation of HLW underground disposal in Japan had been proposed by Atomic Energy Commission in 1998 where not only technical aspect but also social aspect of HLW disposal policy were taken into account. On the basis of this proposal, Final Disposal Law was resolved at the Diet in June 2000. The essential point of this law is summarized by the following four points.

(1) Establish Nuclear Waste Management Organization of Japan (NUMO) as the leading business entity.
(2) Site of final disposal facility is determined by three step investigation (literature investigation, overall investigation, and accurate investigation).
(3) Formation of basic principle of final disposal and the final disposal planning.
(4) Every electric power company will contribute to the cost of disposal every year in proportion to the electricity generation.

For (2), the detailed process of site selection by NUMO will be:
(i) Area selection of overall investigation by literature investigation will take ca. two years,
(ii) Area selection of accurate investigation from the area of overall investigation will take ca. three years, and
(iii) Site selection of final disposal site from the area selection of accurate investigation will take ca. 15 years. So it will take ca. 30 years in total. It is also assumed that NUMO will observe the opinion of the area (mayor and governor) at each step, and if any objection then it will not go forward.

NUMO assumed to construct one facility which is able to accommodate 40 thousand bins of vitrified wastes, and had started the open call-for-application for the literature investigation to all local cities and towns in December 2002. After then official application had been made by the mayor of a town in Kochi Prefecture in January 2007. But the citizen and congress of the town opposed to the mayor who applied for NUMO. The mayor resigned and resort to the re-election of the mayor, but the candidate by the opposition group won the election, and the new elected mayor dropped the application to NUMO. Since then there had been no local town to apply for NUMO.

4.2 The Atomic Energy Commission asked the advice to Science Council of Japan

To see the situation as such, the Atomic Energy Commission asked officially to Science Council of Japan in September 2010 for the advice on how to explain the public on high level radioactive disposal and the related information service.

Science Council of Japan gave the answer to the Atomic Energy Commission in September 2012 by saying "During the discussion in the council, East Japan Earthquake hit the nuclear power facilities and Fukushima Daiichi accident happened. This big event affected the course of our discussion on the HLW disposal issue: the discussion had been made from the fundamental question whether or not it can be possible to assure the safety of the facility for a very long time span in which the probability of the big disaster would be heightened by the occurrence of large scale abnormal natural phenomena". The major points of the answers of Science Council of Japan are summarized as follows;
(1) Since there is no adequate consensus on the safety of underground disposal among the specialists on the matter, it should be necessary to discuss thoroughly by the group of scientists who keeps autonomy and independence.
(2) For that purpose, it is necessary to secure enough time for discussion. In order to adopt more scientifically superior measures to take, HLWs should be temporarily stored during several tens to several hundreds of years. (Provisional custody)
(3) In order to avoid the limitless increase of HLW, it is necessary to determine the upper limit of the HLW generation in advance. (Gross quantity control)
(4) It is necessary to improve the procedure of site selection such as the priority of reflecting the scientific knowledge, multi-stage consensus formation by the participation of diverse stakeholders.

The answer of Science Council of Japan is to conclude that the fact of no application to accept the disposal site does not merely show the problem of NUMO's explanation and information service. Rather the safety of disposal itself cannot be assured on the basis of the recognition that the modern scientists cannot assure the safety of high level radioactive waste which is calculated to take several ten thousand years for the radioactivity to decay the level of no harm to human body. Therefore, it can be said that Science Council of

Japan criticizes the traditional assertion of the technical safety of underground disposal by the government.

To respond the statement by Science Council of Japan, the Atomic Energy Commission issued the responsive statement where the commission stressed the importance of underground disposal and further pointed out several necessary provisions such as

(i) establishment of regular re-confirmation of the safety of disposal by third-party organization,

(ii) reversibility of policy and planning as well as the necessity of materializing technical recovery of waste,

(iii) not only the executive body of NUMO and recipient of local community but also the central government should take the front line to the selecting process of waste disposal site.

4.3 Policy of scientific promising area for the selection of vitrified waste disposal site-announcement of scientific character map

The discussion on the reconsideration of HLW waste disposal policy had initiated coincidentally after Fukushima Daiichi accident as mentioned in 4.2. Also the discussion on the same problem had become earnest in the Ministry of Economy, Trade and Industry (METI), the competent government agency on nuclear power, around 2013 under Prime Minister Abe Shinzo, after the change of ruling party by general election in December 2012. PM Abe Shinzo's cabinet decided the 4th basic energy plan in April 2014 to replace the 3rd basic energy plan (October 2010) by DPJ. In the 4th basic energy plan, the policy of high level radioactive waste disposal was altered so that the government should take the initiative to select the final disposal site. As the result, METI set up the specialists committee on the requirement and standard for scientific promising area for the selection of vitrified waste disposal site in order to promote the understanding of the local area to accept the construction of the underground site for final disposal. In May 2015, the METI decided to propose local communities to accept for the literature investigation by showing the scientific promising area on the basis of the recommendation by the specialists committee. And in July 28, 2017, scientific character map was officially announced by METI. [5]

The basic idea of requirement and standard for scientific promising land for high level radioactive disposal and the classification of areas are illustrated in **Fig.3**.

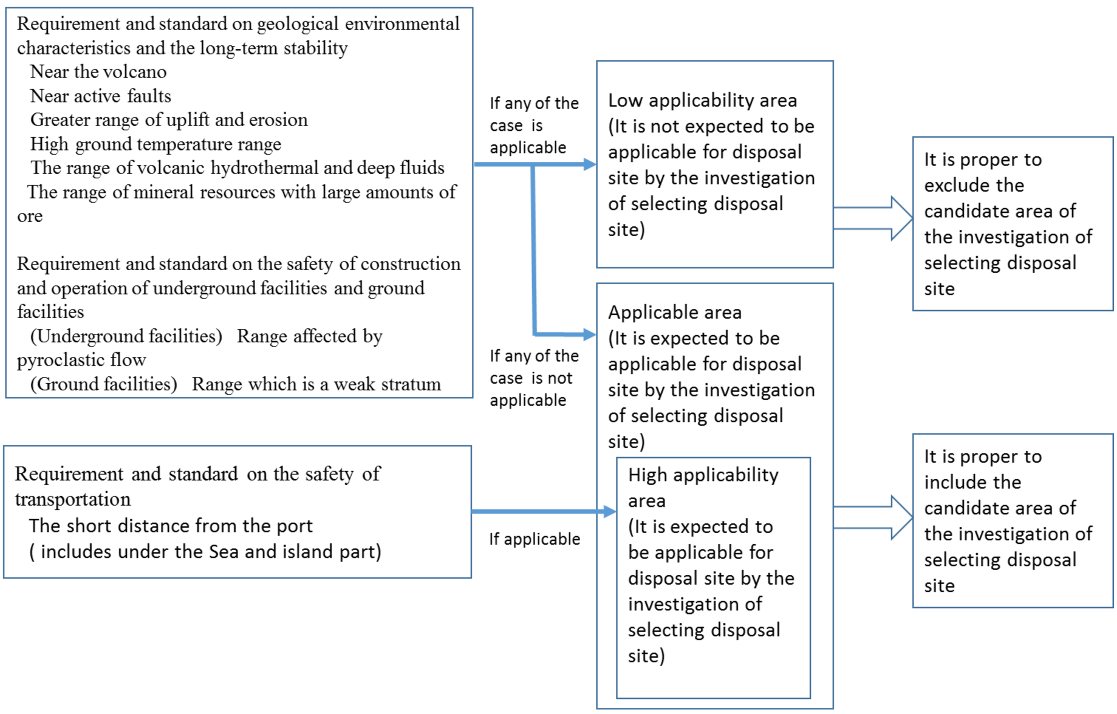

Fig. 3 Basic idea of requirement and standard for scientifically promising land for high level radioactive disposal and the classification of areas in Japan.

As the procedure in selecting the candidate areas for final disposal, the proposal to the promising areas by government will be made before the three steps procedure processed by NUMO as explained in **4.1.** Briefing sessions of this government initiative explanation of the promising areas have started block wise in Japan from October 2017.

4.4 Will the selection of HLW disposal site proceed smoothly?

Now will the new initiative of policy of scientific promising area solve the site selection of HLW disposal which has been no progress by NUMO for these 15 years? Around the time of establishing NUMO, there had been several cases in Japan that several mayors of local town would raise hands for NUMO's call-for-application for HLW investigation. But all cases had resulted in failure by the prompt rises of anti-campaign of local citizen in the town.

Around that time of turmoil, the authors of this paper had conducted on some sociological studies in 2006-2008 by assuming there exist some problem of risk communication of underground HLW disposal to the citizen. Concretely, the authors had developed web tool to support mutual discussion on the technical safety of HLW disposal, conducted on computer-aided debate among students of high school and colleges to collect the debaters' verbal records to analyze them by text mining. [6, 7] As the result of the authors study, it was pointed out that the reasons of opposing to accept for the HLW disposal site are roughly classified into the following types of opinions at the time:

(1) I do not want to invite the facility in my living town, although I understand it is necessary to build the facility. This is so to speak NIMBY (Not In My Back Yard) attitude.
(2) It is scientifically impossible to assure the safety for 10, 000 years in future.
(3) It is to turn the bill of present generation to the future generation. This is based on the notion of inter-generation environmental ethics.

Almost seven years have passed since Fukushima Daiichi accident. METI initiated recent policy of scientific promising area is that the MITI will lead the initiative of solving the 15 years' long stop of deciding the HLW disposal site by showing the scientific character map to the general public and then inviting plausible local towns to apply for the three step procedure provided by NUMO. However, Shunji Matsuoka recently pointed out that the METI's scientific character map by itself will not remove the high barrier of public acceptance by considering the views made by the interactions between Atomic Energy Commission and Science Counsel of Japan issued after Fukushima Daiichi accident. [8]

He argues that the present HLW disposal policy by METI has the drawbacks in any aspects of technical acceptance, institutional aspect, commercial market aspect, and local communities' aspect so that there will be no prospect of proceeding the site selection for the HLW final disposal, because the local community will not accept even if the METI persuades them on the front line.

To recall back from 1990s, it has been pointed out by social psychologists in Japan that persuasive risk communication (specialists enlighten right scientific knowledge of risk to general public who lacks scientific knowledge) not effective so that bi-directional risk communication (both specialist and general public think together with the equal position about problem solving) is necessary for improving the social acceptance of nuclear policy. In fact, right bi-directional risk communication will promote the understanding of general public about the substance of the problem.
However, even if bi-directional risk communication, it will not assure that the problem solving will proceed as the specialist expect and it takes lots of time and cost to reach the consensus.

The traditional nuclear power policy of Japan seems to exhibit many contradictions these days as the result of Fukushima Daiichi accident. As for HLW disposal issue, it will need to reconsider by the bi-directional risk communication from the broad context that the HLW disposal is not merely the matter of NUMO disposing vitrified waste in a certain underground depository somewhere in Japan.

5 Concluding remarks

The reality of complicated radioactive waste disposals in Japan after Fukushima Daiichi accident is reviewed in this paper.

Japan after Fukushima Daiichi accident has to increase the number of nuclear power plants in order to attain the objective ratio of nuclear in 2030 (20-22%) set by basic energy plan. But if the number of nuclear power plant will be increased by the restart of stopped reactors after Fukushima Daiichi accident, then Japan will soon meet the difficulty of too many spent fuels which cannot be transported to reprocessing plant in Rokkasho-mura. There are two reasons for this difficulty: one is that the commercial operation of the reprocessing plant at JNFL in Rokkasho-mura is not expected in near future, and the other is even if the reprocessing plant can be operated successfully there are no prospect of utilizing produced Plutonium in fast reactor prototype Monju because of the recent decision by the Japanese Government.

After Fukushima Daiichi accident, there have been many old light water reactors decided to decommission. And this makes it the urgent issue to find places and dispose low level radioactive wastes by the disassembling of those reactors.

As for HLW disposal, it also does not seem a mere problem that there is no prospect of finding the place of underground depository to dispose vitrified waste from the reprocessing plant. When number of restart plant increases then number of spent fuels increases. And if spent fuels will bde reprocessed then stock of Plutonium will increase because no fast reactor Monju to consume for the near future. This is also a matter of reconsidering the nuclear policy whether nuclear fuel cycle or direct disposal of spent fuel from light water reactors. Also there is the problem of what to do with the fuel debris from core melt Fukushima Daiichi reactors in future.

As the current trend it may well be inevitable that Japanese nuclear power will follow the road of nuclear phase out gradually. But even if decided to phase out, the problem of complicated radioactive waste disposal by Fukushima Daiichi accident will not disappear so easily. Moreover, without nuclear it will not satisfy the current basic energy plan for fulfilling Japanese duty of global warming prevention in 2030.

Lastly, the authors of this paper wish that the Japanese society would recognize the hard reality of the radioactive waste disposal issues as discussed in this paper in order to adjust the nuclear policy more wisely than to shift towards the either extreme of prompt nuclear phase out or return to the old road of nuclear-based country.

List of acronyms

ABWR:	Advanced Boiling Water Reactor
ATR:	Advanced Thermal Reactor
BWR:	Boiling Water Reactor
DPJ:	The Democratic Party of Japan
FIT:	Feed-in Tariff
GCR:	Gas Cooled Reactor
HLW:	High Level Radioactive Waste
JAEA:	Japan Atomic Energy Agency
JAERI:	Japan Atomic Energy Research Institute (Presently JAEA)
JNFL:	Japan Nuclear Fuel Limited
MCCI:	Molten Core Concrete Interaction
METI:	Ministry of Economy, Trade, and Industry
MOX:	Mixed Oxide
LDP:	Liberal Democratic Party
LWR:	Light Water Reactor
NIMBY:	Not in my back yard
NRA:	Nuclear Regulation Authority
NUMO:	The Nuclear Management Organization of Japan
PNC:	Power reactors and Nuclear Fuel Development Corporation (Presently JAEA)
PWR:	Pressurized Water Reactor
TEPCP:	Tokyo Electric Power Company
TRU:	Trans-uranium

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