A reconsideration on deep sea bed disposal of high level radiological wastes – a post-Fukushima reflection on sustainable nuclear energy in Japan

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Abstract: The ultimate disposal of high-level radioactive waste (HLW) is a common issue among all nuclear developing countries. However, this becomes especially a hard issue for sustainable nuclear energy in Japan after Fukushima Daiichi accident. In this paper, the difficulty of realizing underground HLW disposal in Japanese islands is first discussed from socio-political aspects. Then, revival of old idea of deep seabed disposal of HLW in Pacific Ocean is proposed as an alternative way of HLW disposal. Although this old idea had been abandoned in the past for the reason that it would violate London Convention which prohibits dumping radioactive wastes in public sea, the author will stress the merit of seabed disposal of HLW deep in Pacific Ocean not only from the view point of more safe and ultimate way of disposing HLWs (both vitrified and spent fuel) than by underground disposal, but also the emergence of new marine project by synergetic collaboration of rare-earth resource exploration from the deep sea floor in Pacific Ocean.
Keyword: high-level radioactive waste disposal; geological HLW disposal; seabed HLW disposal; rare-earth resource;

1 Introduction

The severe accident which happened in March 11, 2011 at Fukushima Daiichi nuclear power station has brought many hardships in Japan with respect to the environmental problem, energy supply issue, and economical difficulties. However, the author of this paper would like to limit the problem of high level radiological waste (HLW) disposal in Japan after Fukushima accident.

In Japan, a national nuclear policy had been strongly pushed forward by the Ministry of International Trade and Industry (MITI) by the recommendation of Atomic Energy Commission of Japan (AECJ) [1]. According to this, the AECJ recommended that ten more light water reactor (LWR) plants should be constructed than the total 53 LWR plants as of the year 2006 together while accomplishing closed nuclear fuel cycle. Reprocessing all spent fuels from all LWRs produces usable Uranium and Plutonium to be used as mixed oxide fuel in LWRs in a short time span while to be consumed in fast breeder reactors (FBRs) in future when FBR technologies are well established. This MITI's pro-nuclear energy policy had been supported by the majority of Japanese people before Fukushima Daiichi accident, in order to attain national energy security and to prevent global warming by CO_2 emission with the abundant use of fossil energy.

However as a matter of fact, the construction of more LWR plants has not been attained so easily as the energy policy of MITI intended. Concerning nuclear fuel cycle, although a lot of funds had been poured both from national budget and private sector, the commercial reprocessing plant constructed at Rokkasho-mura did not start for many years its commercial operation because of many troubles, and the fast breeder reactor prototype Monju in Tsuruga has been almost in dormant state since its sodium leakage accident during the plant power rise test in 1995.

On the other hand, increasing numbers of spent fuel from every LWR plants have been sent to the large pool of spent fuels at the reprocessing plant in Rokkasho-mura. According to the national policy of final disposal of HLW generated by nuclear power, all the spent fuels generated by nuclear power plants should be reprocessed after a number of years (ca. 30 years or so) of cooling time, and the remaining HLWs (long life radioactive fission products including

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trans-uranium elements) issued from spent nuclear fuel reprocessing as vitrified HLW to be disposed off in deep underground geological repository.

In accordance with the AECJ proposal, the MITI decided to select appropriate site for an underground HLW repository within Japan until 2020, and the union of electric power companies established a special company called Nuclear Waste Management of Japan (NUMO) in 2000 to initiate the construction of the HLW underground repository in Japan [2]. NUMO started in 2002 to call any local towns in Japan to apply for the 10-years preliminary investigation on whether or not the geological character of the town will be fitted as a potential candidate for the HLW final repository.

However, as of today, no town has applied for the site investigation, because of the strong objection of local citizens by saying that it is an ethical sin for the future generation to inherit the negative legacy of long time environmental risk for as many as 10,000 years, if the town be approved by NUMO to become the final HLW repository site.

As the result of Fukushima Daiichi accident, the problem of final disposal of HLW has become more serious issue in Japan than before because the amount of HLW to be processed and disposed has surely increased than before Fukushima accident. After Fukushima accident, in addition to the crushed nuclear fuels in the damaged Fukushima Daiichi plants which should be retrieved and processed after the decomposition of the plants, more nuclear power plants will be forced to phase out because of the danger of big earthquake foreseen in the future. There are significant amount of spent fuels in the spent fuel storages in such reactors even if they are not in operation. Therefore, even if all the reactors in Japan are shutdown, there will be the risk of radioactive release accidents in Japan where strong earthquakes may occur so frequently. Furthermore, it will be soon difficult to continue to store spent fuels in those pools because of the capacity limitation of spent fuel storage in the nuclear power plants. A temporary solution for spent fuel storage problem may be to construct many dry casks but they should be eventually processed and disposed in the final HLW disposal site.

Then what should they do with such serious HLW disposal issue in Japan? In this paper, the author will discuss on the difficulty of underground HLW disposal in Japanese islands and propose to re-consider the old idea of sea bed disposal of HLW deep in Pacific Ocean which had been studied in US until 1990s [3]. This old idea may violate London Convention which bans internationally radioactive waste disposal in public sea since 1986. But, the author would like to point out that the HLW disposal in seabed is not ocean dumping, and the sea-bed disposal of HLW deep in Pacific Ocean is not only a safer ultimate disposal of HLWs (both vitrified and spent fuel) than by underground disposal, but also it has the possibility of synergetic effect of rare-earth resource exploration in deep sea-beds [4].

In this paper, the author will first introduce the problem of HLW disposal in Japan, and then will proceed to re-consider the old idea of deep sea-bed disposal of HLWS, in order to resolve the difficult situation of Japan after Fukushima Daiichi accident. The author’s argument is based on the revisit of deep sea-bed disposal of HLW which was forgotten since 1990’s by the restriction of London Convention which had been already effective since 1972. The author’s argument in this paper also coincides with the advancement of knowledge about “earth science” which has been rapidly progressing after 1980’s, because it had not been considered at the time of deciding on underground HLW disposal not only in Japan but also in other nuclear developing countries around the world.

2 Problem of HLW disposal in Japan

2.1 Traditional concept of underground HLW disposal policy in Japan

According to the long-term nuclear development and utilization plan already decided by the Atomic Energy Commission of Japan (AECJ) in 1987, the Power Reactors and Nuclear Fuels Development Corporation (then PNC but nowadays altered as Japan Atomic Energy Research and Development Authority (JAEA), had been assigned as the core national organization of research and development for underground disposal of HLW in Japan. In this section, the fundamental notion of geological disposal of HLW is summarized from the paper by M. Yamakawa [5].

In Japan, “reprocess and recycle” have been taken as the fundamental policy of spent fuels from all nuclear power plants. Spent nuclear fuels are all reprocessed to reproduce fissionable materials (Uranium and Plutonium) to use as nuclear fuels again. Therefore, high level radioactive wastes (HLW) are residuals of spent fuels from the recycling process to separate useful fissionable materials. The spent fuel contains more than 99% of fission products as well as the long life decay nuclides such as *Np* and *Am*. A nuclear power station of one million kW output is said to produce about 30 tons of spent fuel after one year operation, and the reprocessing of 30 tons of spent fuel will produce about 30 canisters of vitrified HLW wastes of 100 liter [5].

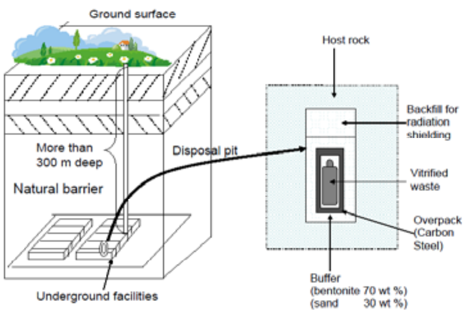

Fig.1 General concept of geological disposal of HLW.

That is, one ton of spent fuel generates one canister of vitrified HLW. The radioactive level of this vitrified HLW canister is ca. forty thousands **Ci** at its birth, while it will decrease ca one tenth after 100 years, one several thousands after 1000 years, and finally one twenty thousands after ten thousand years to become the same radiation level of natural uranium ore in natural environment. The heat generation by radiation at the birth of a vitrified canister is about 1.4 **kW**, and the heat will decay by the similar way as radioactivity decay. Therefore, it will take as many as 10,000 years for the vitrified HLW to become as safe as the natural uranium ore.

The vitrified canisters of HLW from the reprocessing plant have so strong radioactivity that they will be first stored in a ground surface facility for 30-50 years to cool down by natural air circulation, and then they will be disposed into the underground layers of several hundreds meters depth in order to safely isolate them from human and human living environment eternally or at least for ca. 10,000 years.

The basic concept to assure safety of the underground disposal consists of avoiding the two hazardous processes to human and human living environment: (A) Direct process by which the physical distance would be shortened between the vitrified HLW canisters and human and human living environment (Approaching scenario), and (B) Indirect process by which radioactive nuclides in the vitrified HLW canisters will be conveyed to human and human living environment by underground water flow (Underground water scenario). Concretely as shown in Fig.1, the multi barrier system by the combination of artificial barrier and natural barrier is the fundamental logical concept to assure the general public on the safety of geological disposal. For the appropriate selection for the geological disposal site of HLW, according to M. Yamakawa [5] it is necessary to prove scientifically that the safety of human and the human living environment will be assured against any conceivable scenarios of (A) and (B) for the long period of at least 10,000 years ahead, and it is also approved by social consensus.

The above concept of geological disposal of HLWs which includes not only vitrified HLW from reprocessing plant of spent fuels but also direct disposal of spent fuels from nuclear power plants has been common in all nuclear developing countries such as U.S.A. and many European countries since 1980's. However for such geological HLW disposal method, there had already a opinion letter presented by the National Research Council of U.S.A. in 1990, by criticizing "Such geological disposal method is completely opposite to the normal mining method to take out useful metal resources from underground mines, because it seems to restore and conserve the artificially manufactured metals back to the original underground mines. It is basically impossible to predict various uncertain geological phenomena over 10,000 years in future and to assure that the HLW disposal method is safe." [6].

There is a prevailing concern in Japan from the researchers of earth science based on the knowledge of plate tectonics theory which had been progressing since1980's; The Japanese islands where four plates (North American plate, Eurasia plate, Philippine plate and Pacific Ocean plate) collide with each other as seen in Fig.2, are just on the geologically varying zone where always persist frequent activities of earthquake and volcano. It is also difficult to predict and assure the intactness of multi barrier system of underground HLW disposal repository for the long future of 10,000 years or even 1,000 year. According to M. Yamakawa, he pointed out that further researches would be necessary for assuring the safety of underground HLW disposal repository by such way as natural analog study [5].

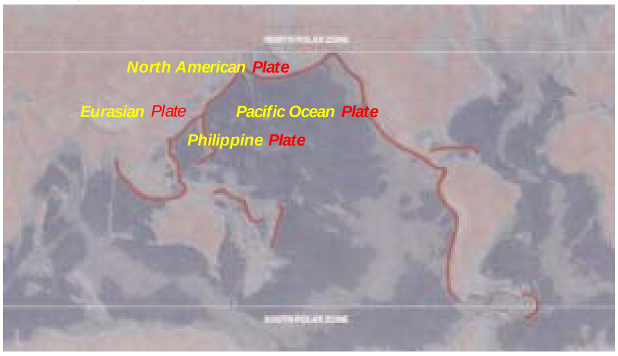

Fig.2 General picture of plate tectonics for Pacific Ocean region. (Modified from a picture in page 62 of Ref. [3])

2.2 Difficulty of finding disposal site

The governmental policy of HLW disposal in Japan has been originally deep underground disposal within Japanese islands. According to this policy, the Japanese government had set up a law in 2000 to proceed to geological HLW disposal in Japan. The name of the law is Specified Radioactive Waste Final Disposal Act authorized by the Ministry of Economy, Trade and Industry (METI). According to this law, electric power companies which operate nuclear power stations have the primary responsibility to find, construct and operate appropriate HLW disposal repository with the financial support of government. And then for this purpose, a special company called Nuclear Waste Management Organization of Japan (NUMO) had established in October 2000 [2]. Since then the NUMO invited many local towns as the future HLW disposal site to be started from 2020, but so far, no town has applied as potential candidate for HLW disposal site in Japan.

Concerning the HLW disposal issue, the AECJ in September 2010 asked the Science Council of Japan to give a recommendation of how to proceed smoothly underground HLW disposal in Japanese society by admitting that current promotion of underground HLW disposal project by NUMO had not be fully understood and accepted by Japanese society.

Therefore, HLW disposal had been already become a difficult issue in Japan, even though very aggressive policy of nuclear energy promotion was established in 2006 by Ministry of International Trade and Industry (MITI) to approve the AECJ's proposal that the ratio of nuclear energy should be increased up to 30-40 % in total energy supply and to establish the commercialization of fast breeder reactor in 2050 to meet with the national target of energy security as well as the reduction of 15% CO_2 emission in future[1].

2.3 After Fukushima Daiich accident

The severe accident that happened in March 11, 2011 at Fukushima Daiichi nuclear power station has brought many hardships in Japan with respect to the environmental issues, energy supply problem, and economical dilemma as described in Ref.[7]. The problem of high level radiological waste (HLW) disposal has become also serious after Fukushima accident. There are three problems as discussed below.

First, the HLWs to be disposed of are not only the vitrified high-level radiological wastes both coming back from reprocessing plants in foreign countries (ca. 2650 vitrified canisters of HLW deposited in UK and France) and those anticipated from the reprocessing plant in Rokkasho-mura after its commercial service (more than 24700 spent fuel sub-assemblies are already in there in total). As a matter of fact, whether or not full operation of the reprocessing plant is still uncertain because of many troubles happened during its test phase. Spent fuel pools in many nuclear power stations in Japan are going to be full of their capacities because of no prospect of transporting spent fuel to reprocessing plant in Rokkasho-mura.

Second, many spent fuels which reside in the stricken Fukushima Daiichi station and in many spent fuel pools of the other nuclear power stations to be decided for decommission after Fukushima accident should be considered as HLWs for final disposal without reprocessing. Table 1 shows the status of four units in Fukushima Daiichi nuclear power station after the accident.

Table 1. States of four units in Fukushima Daiichi nuclear power station after the accident

Unit No	No.1	No.2	No.3	No.4
State of nuclear fuel in the reactor	Almost all fuels molten down to reactor containment	More than half of fuels molten down to reactor containment.		No fuels in the reactor because of regular maintenance
Number of spent fuel assemblies in spent fuel pool	392	615	566	1533

Third, the day-by-day uproar of anti-nuclear power campaign after Fukushima Daiichi accident has been changing the Japanese nuclear policy towards nuclear phase-out until 2030s. Pressed by public sentiment against nuclear, the MITI recently announced that it would alter the law so that the spent fuels would be permitted to direct underground disposal.

The previous nuclear expansion policy of Japan has already bankrupted by Fukushima Daiichi accident even if some nuclear power stations would restart and maintain operation after the accident. Wherein three issues will become apparent by the following sequence: (i) decision on whether or not spent fuel reprocessing, (ii) how to cope with volumetric increase of various types of radiological wastes including HLW to be processed and disposed, while (iii) no prospect of finding underground HLM disposal site in Japan.

In September 11, 2012, the SCJ announced its recommendation on the problem of underground HLW disposal in Japan [8] to respond to the request made by AECJ in 2010.The major points of the recommendation by the SCJ are: (i) the underground HLW disposal technology adopted by AECJ is not the confirmed one to assure safety but uncertain and risky for a long time future, (ii) it is difficult to select final disposal site without the consensus building by the thoughtful discussions by many experts from different aspects and then the common understanding and share of the experts' conclusion in Japanese society, and it proposed that (iii) temporary storage of HLWs for several tens to several hundreds years to monitor and take out the stored HLW any time until the final HLW storage will be constructed, and that (iv)the total allowable amount of HLWs should be determined so that limitless spent fuels would not be generated by nuclear power operation.

The recommendation by the SCJ to the AECJ will certainly affect the alteration of the Japanese nuclear policy to be discussed in the Cabinet of the ruling party after the general election of National Diet at the end of the year 2012.

3 Seafloor disposal of HLW

In the preceding chapter, the author of this paper pointed out the difficulty of geological HLW disposal in Japan. In this chapter, the author will discuss on possibility of seabed disposal of HLW deep in Pacific Ocean.

3.1 Seafloor HLW disposal project by US [3]

In U.S.A. the Department of Energy (DOE) employs the policy of disposing both the spent fuels from commercial nuclear reactors and the enriched Uranium and Plutonium brought by disassembling nuclear weapons as HLWs. It has been a big issue since 1968 on how to dispose HLWs and where to select final disposal site of HLWs. Therefore in U.S.A. other than geological disposal of HLWs, a feasibility study of confirming the possibility of disposing HLW on the sea-bed had been conducted between 1976 and 1986 as an international research project which was called as "Seabed Working Group (SWG)". This SWG had conducted on the research project with 120 million U.S. Dollars by the support of U.S. government and OECD/NEA with the participation of 200 research institutions from ten countries. The activity conducted by the SWG was reported by Hollster, C.D. and Nadis, S., in Ref. [3]. The author of this paper would like to introduce this report in the subsequent paragraphs.

Inheriting precursory study conducted by Sandia National Laboratory, the SWG project had conducted on maritime studies travelling over Pacific Ocean by sea-bed drilling ship for exploring sea-bed oil well. The sea-bed drilling ship traveled many places in Pacific Ocean, stopped to collect many samples from the sediment layer with several hundreds meters into the sea floor as deep as more that 4000 meters. The researchers of SWG examined various physical, chemical and geological characters of sediment samples taken from many different places of sea-bed in Pacific Ocean, and based on those data simulating experiments were conducted to examine the diffusivity of Plutonium migration in sediment.

From those data analysis, the researchers of SWG reported that the sediment layers of deep sea-bed had been stable for 50 to 100 million years in the past. Regarding the possibility of sea-bed disposal of HLW, they pointed out that the sea-bed HLW disposal would be more favorable method than geological disposal because the HLW would be more stably maintained in the sediment of stable deep sea-bed than in underground repository.

They also remarked on the merit of deep sea-bed HLW disposal by the illustration of Pacific Ocean region as shown in Fig. 2, by saying there are no concerns as to find places for HLW disposal because the stable sea floor (part of dark blue color as shown in Fig.2) would expand to 20 % of whole surface of earth. However, those regions in Fig. 2 such as (i) plate boundaries (as shown in red color belt zones in Fig.2) and (ii) rather shallow sea-floor regions such as spots where plumes would pour out from mantle and many under-sea volcanoes line up in row, and (iii) the south and north polar zones (light blue color part in Fig.2) are classified as inappropriate place for sea-bed disposal because of the instability of the sea-bed layers.

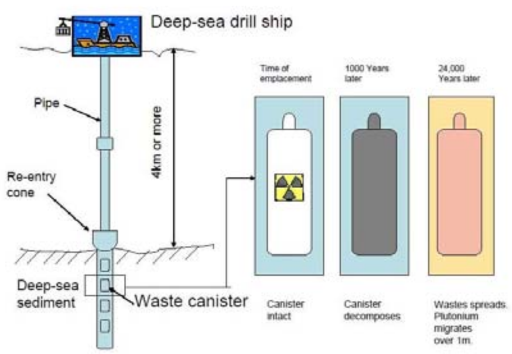

Fig.3 General concept of sea-bed disposal of HLW.

According to Hollister [3], the leader of the SWG, the essential points of how to do with deep sea-bed disposal of HLW are as depicted in Fig.3, and as illustrated in Fig.4, the detailed procedure to dispose HLW canisters in the hole of sediment in deep sea-bed is: (a) Drill lowered to ocean floor, (b) Re-entry cone dropped, (c) Hole drilled, (d) Waste canister emplaced, (e) Packed with sediment, (f) other canister added to fill in the re-entry cone, and finally (g) seal off the re-entry cone completely in the sea-bed so that no sea water should not intrude into the re-entry cone or any radioactive elements should not leak from the sealed re-entry cone.

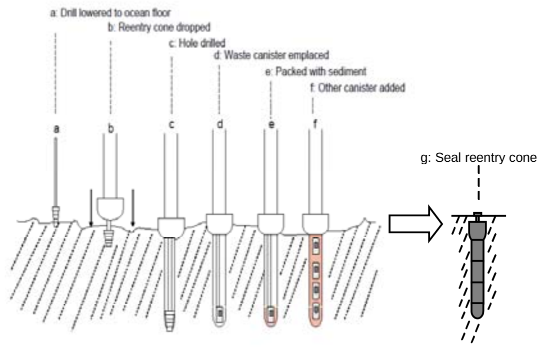

Fig.4 Detailed procedure to dispose HLW.

Although Hollister is optimistic that the disposal procedure by deep sea drill ship can be realized by the present sea-drill ship utilized in sea oil field exploring project by oil industry, the experimental validation should be made to prove the very mild migration of Plutonium of ca. one meter in the sediment even after 24,000 years after the waste canister decomposes in 1000 years. Also it is necessary to validate that the afore-mentioned whole process of HLW disposing into the sea-sediment layer as well as the safety maintenance of the HLW disposal in the sea-bed after the construction should be confirmed by some means of remote monitoring for the long years in order to repair the disposal area in case any problem. Also the confirmation will be necessary for maintaining the bio-diversity of deep seabed environment. These problems are further considered as the needed research subjects for the confirmation of the feasibility of deep sea-bed HLW disposal.

However, this SWG project was interrupted in 1986 by the U.S. government due to the choice of Yucca Mountain as the candidate site for HLW disposal repository which will start HLW disposal from 2015. (However, the actual construction of Yucca Mountain HLW repository has been cancelled because of long-time strong objection by Nevada state where the HLW repository has been assumed in U.S.A.)

Moreover in 1996, International Maritime Organization (IMO) made the resolution that the deep sea-bed disposal of HLW corresponding to ocean dumping is prohibited by London Dumping Convention. Since then and also because of the restriction of Basel Convention which became effective in 1992 to prohibit transport of harmful wastes over the national boundaries, the sea-bed HLW disposal has been forgotten, but only underground HLW disposal within each countries has been taken in nuclear developing countries for HLW disposal.（However according to Hollister, since the London Dumping Convention admits to re-evaluate the deep sea-bed disposal of HLW internationally after 25 years of IMO resolution, it is therefore possible to reconsider deep sea HLW disposal from 2021 internationally.)

Those activities of SWG group had been made in parallel with Deep Sea Drilling Project (DSDP) [9] between 1969~83 and Ocean Drilling Program (ODP) [10] between 1985~2002 to drill deep sea bed in many place of Pacific Ocean and Atlantic Ocean by travelling with deep seabed drilling ship. Both the DSDP and ODP are conducted as an international project on earth science to collect samples of rocks in seabed and mud sediments in order to explore and validate theories of plate tectonics, clarify the behavior of rapid climate change and recognize underground bio spheres. Those activities have been expanding to Integrated Ocean Drilling Program (IODP) [11] since 2003.

3.2 Proposal of HLW seabed disposal in Pacific Ocean

As already mentioned in Chapter 2, it had been already very difficult to find HLW repository site in Japan to start its constructing from 2020. The public opinion in Japan has been shifting more and more and day by day towards anti-nuclear after Fukushima Daiichi accident. It has also become more and more urgent issue how to deal with large amount of radioactive wastes including HLW. Before Fukushima Daiichi Accident, the vitrified HLWs in the canisters after reprocessing had been the target of underground disposal. But after the accident, many spent fuels from nuclear power plants and the fuel debris in the damaged plants in Fukushima are adding up for final disposal of HLWs in Japan.

Those different kinds of radioactive waste mentioned above should be appropriately collected and stored in the intermediate storage facilities to cool down for 30-40 years before final disposal as HLWs in a certain repository. This means it will be necessary to construct many additional intermediate storage facilities simply to store and cool down (radioactivity and heat) for so many years before final disposal of HLWs. At the moment, it would be the first difficulty to persuade many citizens who became emotionally sensitive to nuclear to understand and accept the necessity of constructing many intermediate storage facilities. Further in order for the citizens to accept constructing those intermediate facilities easily in many places in Japan, it is also necessary to resolve the prospect of final disposal of HLWs in future. For this solution, the traditional Japanese Governmental policy of “government simply dumps into the lap of nuclear industries to plan, persuade people and operate by themselves” will be no more admitted. The government should be responsible to resolve the issue. At this point at issue are what will be more socially and technically acceptable way of HLW disposal and more cost-efficient way of funding the construction of the HLW disposal repository in Japan whether continue nuclear power or nuclear phase-out in the near future.

The author of this paper would like to propose deep sea-bed disposal of HLW on the floor of Pacific Ocean whether (a) the HLW be vitrified HLW canister containing FPs and actinides after reprocessing, or (b) Plutonium and Uranium from nuclear weapon or damaged nuclear fuels taken out from Fukushima Daiichi reactors mixed with glass, or (c) direct processing as spent fuel sub-assemblies. Failed fuels and fuel debris extracted from Fukushima Daiichi plants will be molten by furnace to contain in the vitrified canister. In case of direct processing of spent fuel sub-assemblies, method of containing the sub-assemblies in the copper capsule as developed at Aespoo Hard Rock Laboratory in Sweden would be expected to endure long time corrosion in the sediment [12]. Of course it will be necessary to conduct research, develop and construct special facilities for the both purposes.

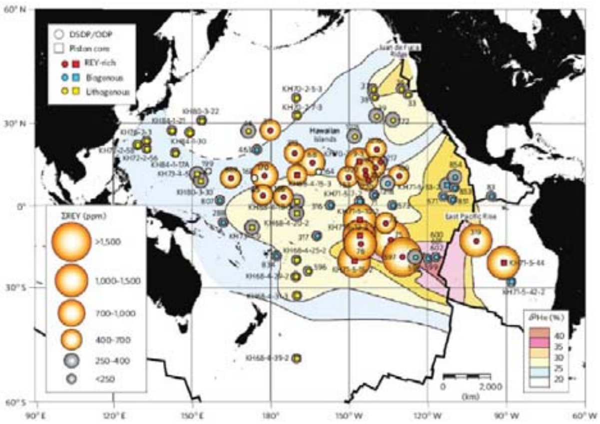

Fig.5 Possible distribution of rare-earth resource on sea-bed of Pacific Ocean. (Source: Ref. [4])

But where to dispose those HLWs? Recently, Y. Kato, et al., reported in Ref. [4] that there is the possibility of obtaining rare-earth resource and Yttrium which are indispensable materials for hi-tech products (such as to produce permanent magnets used in miniature size motors in PCs, hybrid cars, EV cars, etc.) from the sediment of deep sea-floor of Pacific Ocean . Kato showed by Fig. 5 that there are many places of getting rare-earth resource in the sediment in the see floor as deep as more than 4000 meters. (the larger the diameter of the circle, the larger percentage of 15 rare-earth elements and Yttrium in the sediment samples.)

According to Kato in his recently published book [13], the data of mass percentage of rare-earth elements as shown in Fig.5 were derived by conducting on elaborate mass spectroscopy of 15 rare-earth elements and Yttrium to “core samples” (mud samples) of deep sea-bed which were dug out at various places of Pacific Ocean by DSDP and ODP projects and have been preserved in Core Storage Center of Texas A&M University. It is also said in his book that this new resource of rare-earth sea-bed mud in the Pacific Ocean has the following favorable characters: (i) the resource volume will be 800 times larger than that of land resources, (ii) higher percentages of heavy rare-earth elements, (iii) no radioactive elements such as *U* and *Th* are contained, (iv) easy to detect, and (v) easy to extract rare-earth elements from mud. Kato also introduced a new submarine exploration project which has been initiated in Japan to reduce rare-earth resource from the sea floor in the exclusive economical water zone (EEZ) in the neighborhood of Minami-tori-shima island. (This island is a tiny island of Ogasahara islands in Pacific Ocean (9.1 km^2 with only 9 m high, located in 1800km apart from Honshu island). Kato considers the rare-earth resource explore system as depicted in Fig. 6, which consists of (i) land factory for extraction and refinery of rare-earth, (ii) conveyer ship and its port which will be constructed by using the residual mud from the land factory, (iii) special rare-earth drilling and lifting ship, (iv) sea bed module for condensing and selecting mud rich of rare-earth metals, and (v) support ship for positioning drilling spots with remote control of the sea bed module.

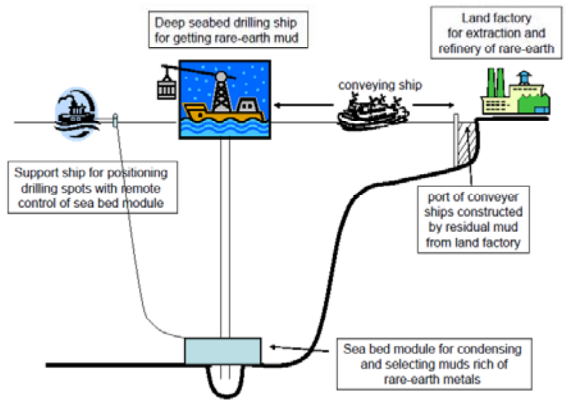

Fig.6 Rare-earth resource explore system.
(Modified from Fig.8-2 in Ref. [13])

From this Fig. 6 with the image of sea-bed HLW disposal in Fig.4, you can imagine the deep sea-bed HLW disposal repository system as shown in Fig.7, where (i) temporary storage of various types of HLW canisters conveyed from various nuclear facilities and also the re-entry cones fabricated in Japan, (ii) special sea-bed drilling ship, (iii) sea-bed module, and (iv) support ship to support the works of afore-mentioned sea-bed drilling ship and sea-bed module cooperatively, to dig the holes on the sea-bed, place the re-entry cone and then put canisters and fill in the sediment in turn from the bottom of the re-entry cone until its seal off from the sea bed.

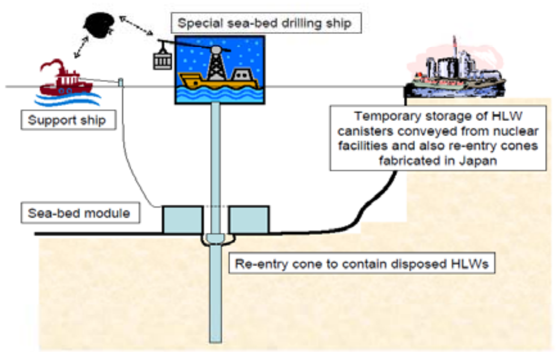

Fig. 7 Deep sea-bed HLW disposal repository system.

Of course, the above deep sea-bed HLW disposal repository system is a rough image on how this system will work together with the rare-earth explore system as the synergetic cooperative system in the neighborhood of Minami-tori-shima island. Future study to elaborate this idea is needed to elaborate the idea. Since the HLW disposal within EEZ does not violate the prohibition of radioactive waste dumping in the public ocean, the combination of rare-earth resource development and HLW disposal in deep sea-bed would be expected to a synergetic project to get high profit from rare-earth materials on one hand and to mitigate large public spending needed for the critical HLW disposal problem which is the negative legacy of nuclear energy utilization amplified by Fukushima Daiichi accident in Japan.

4 Concluding remarks

The ultimate disposal of high-level radioactive waste (HLW) is a common issue difficult to solve in social context among many nuclear developing countries. Especially in Japan, this becomes hard issue after Fukushima Daiichi accident. In this paper, the author discussed the difficulty of underground HLW disposal in Japanese islands and proposed to re-consider sea-bed disposal of HLW deep in Pacific Ocean. The merit of submarine disposal of HLW deep in Pacific Ocean is from the view of more safe and ultimate way of disposing HLW (both vitrified and spent fuel) than by underground disposal for a long term period spanning to 10,000 years in future.

It was recently reported in the international journal of geological science [4] that the mud taken from the deep seabed in the neighborhood of Minami-tori-shima islands in Pacific Ocean (within EEZ of Japan) contained rare-earth resource which become the raw material for high-tech industry. Getting rare-earth resource from deep seabed seems expensive in cost than by surface mining and processing of rare-earth production now conducted in China and Mongolia. But if this deep sea-bed resource development project would be conducted with the combination of the research and development of HLW disposal method in deep sea-bed, it will contribute to the resolution of final disposal of HLW which annoys not only for Japan but also for many other nuclear power developing countries already at present and in future.

List of Nomenclatures

AECJ	Atomic Energy Commission of Japan
DOE	Department of Energy
DSDP	Deep Sea Drilling Project
EEZ	Exclusive economical water zone
FP	Fission Product
HLW	High-Level radioactive Waste
IMO	International Maritime Organization
IODP	Integrated Ocean Drilling Program
JAERI	Japan Atomic Energy Research Institute
JAEA	Japan Atomic Energy Research and Development Authority
LWR	Light Water reactor
MITI	Ministry of International Trade and Industry
NUMO	Nuclear Waste Management of Japan
ODP	Ocean Drilling Program
PNC	Power Reactors and Nuclear Fuels Development Corporation
SCJ	Science Council of Japan
SWG	Seabed Working Group

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