INTEGRATED APPROACH FOR ESTABLISHING OF DISPOSAL SYSTEMS FOR HIGHLY ACTIVATED WASTE

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ABSTRACT

The disposal method of highly activated wastes (HAW) is still under discussion in Japan**.** The preliminary results for the conceptual design of the disposal system for HAW were reported [1]. Three types of repository, tunnel type, underground silo type and opencut silo type, were designed. The safety analysis, the estimation of construction costs and the study of construction period of each designed repository were performed to investigate the safe and reasonable disposal system for HAW. The results indicate that HAW could be disposed of safely in all types of repository, and that especially the tunnel type repository with the large cross section would be the most preferable repository for the disposal of HAW.

INTRODUCTION

In Japan, fifty-one units of nuclear power plant (NPP) are operating and one unit was shut down in March 1998. It is predict that some of these NPPs will be decommissioned from the early stage of coming century, and that large amounts of radioactive waste will arise from the dismantling of NPPs.

Radioactive solid wastes arising from such as the utilization of nuclear energy as well as nuclear fuel cycle and application of radioisotopes have to be disposed of in terrestrial environment in Japan. Low level waste (LLW) arising from NPPs is being disposed of in near surface disposal facilities at Rokkasyo site under specified radioactivity concentration upper bounds. Whereas the disposal concept for highly activated wastes (HAW) such as core internals and control rods arising from dismantling and/or maintenance work of reactors, although categorized as LLW, is still under discussion in Japan, because the radioactivity concentrations of those wastes are exceeding the specified concentration upper bounds.

The Japan Atomic Energy Research Institute has investigated the disposal system for HAW under the contract with the Science and Technology Agency of Japan. At the WM '98, the preliminary results for the conceptual design and safety assessment of the disposal system for HAW including disposal containers and repositories were reported [1]. In this paper, the refined results of the conceptual design of disposal system for HAW, including disposal facilities, safety assessment, construction costs, operational aspects, are discussed. As a result, a preferable disposal system is recommended from the investigations

CONCEPTUAL DESIGN OF DISPOSAL FACILITIES FOR HAW

<u>Basic Data for Design</u>

The quantities and properties of radioactive wastes are the basic information for the designing of such as size and engineered barrier of disposal facilities and the safety assessment. On the other hand, the NPPs generating HAW vary in types, sizes and timing of decommissioning and dismantling, and as a result, the quantities and properties of HAW vary depending on those factors.

The quantities of HAW were estimated by assuming the complete dismantling of nineteen PWRs and twenty-three BWRs, which started their operations before 1993. The output of each NPP was assumed as 1.1GWe[1]. Control rods replaced in operational phase and stored onsite were contained in HAW. The estimated quantities of HAW are summarized in Table I.

TABLE I HAW DATA USED IN THE DESIGN AND EVALUATIONS

	PWR	BWR	total
Number of reactor decommissioned	**19**	**23**	**42**
Weight of HAW (ton)	**3,990**	**2,530**	**6,520**
Volume of HAW (m^3)	**512**	**324**	**836**
Total activities (Bq)	**3.8×10^{18}**	**5.8×10^{18}**	**9.6×10^{18}**

The radioactivity inventory of the HAW is an important property to carry out the design and the safety assessment of the disposal facilities. The inventories of main radionuclides contained in the HAW were estimated from the previous works [2-4]. The estimated radioactivity inventory in HAW is shown in Table II.

TABLE II RADIOACTIVITY CONCENTRATIONS (BQ/T) AND TOTAL ACTIVITIES (BQ) OF MAIN NUCLIDES IN HAW ARISING FROM 19PWRS AND 23BWRS AT SHUTDOWN

Nuclide	Radioactivity Concentration		Total Inventory	
	PWR	BWR	PWRs	BWRs
	Bq/ton	Bq/ton	Bq	Bq
^{14}C	6.5×10^{10}	3.4×10^{11}	2.6×10^{14}	4.3×10^{14}
^{36}Cl	1.3×10^{9}	7.5×10^{8}	5.3×10^{12}	9.4×10^{12}
^{60}Co	3.4×10^{14}	7.4×10^{14}	1.4×10^{18}	1.9×10^{18}
^{63}Ni	4.7×10^{13}	1.3×10^{14}	1.9×10^{17}	3.4×10^{17}
^{94}Nb	1.0×10^{9}	3.0×10^{8}	4.2×10^{12}	3.7×10^{12}
^{233}U	9.3×10^{5}	3.7×10^{6}	3.7×10^{9}	9.4×10^{10}
^{239}Pu	1.8×10^{7}	6.3×10^{7}	7.3×10^{10}	1.6×10^{11}

For facilitating the handling of HAW in disposal operations, such as transportation and emplacement in a repository, HAW should be packaged with appropriate containers taking account of gamma radiation shielding to reduce the exposure dose to workers and publics. From this viewpoint, above mentioned HAW were categorized into three groups, and packaging disposal containers for each group were designed. Total volume of disposal containers to be disposed of in a repository were estimated as Table III, which could provide a size of designing disposal facilities.

TABLE III SPECIFICATIONS OF DISPOSAL CONTAINERS AND ARISING VOLUME FROM PWR, BWR AND TOTAL

Type	External dimension (m)	Thicknes s of package wall (mm)	External Volume (m^3)	Arising Volume (m^3)		Total Arising Volume (m^3)
				PWR	BWR	
1	1.51x2.21x1.33	5 or 6	4.4	167	0	167
2	1.51x1.51x1.33	200	3.0	1,710	627	2,337
3	1.51x1.11x1.33	350	2.2	13,251	8,820	22,070

Design of Disposal Facilities

Comparing with the concentration upper bounds specified for LLW being disposed of in Japan, the radioactivity concentrations of main radionuclides in HAW, although categorized into LLW, are higher by one order or two orders on average, and two or three orders in maximum. The safe and reasonable disposal system for HAW will be achieved by carrying out the institutional control for a certain period and minimizing the possibility of human intrusion in the post-institutional control period for such HAW. The repositories constructed in underground deeper than those of Rokkasyo site that are constructed about eleven meters beneath the surface will be preferred for these reason. Therefore the Atomic Energy Commission of Japan suggests that the repository for HAW should be constructed in an enough depth in order not to restrict normal land use after the institutional control period, for example fifty or a hundred meters. Same consideration is taken into account in many other countries, for example, Finland is planning disposal facilities for decommissioning waste including HAW in the depth of 70 to 100 meters below the surface[5] ; and Switzerland is also planning the LILW disposal in the mountain. The repository will be located at 750 meters or more depth from the surface [6].

Three types of repositories for HAW were studied in taking account of the technical feasibility of the structure. The designed repositories are as follows;

- The tunnel type repository located in a few hundreds meters below earth's surface, (tunnel-type),
- The silo type repository located in a few hundreds meters below earth's surface, (underground silo-type),
- The opencut silo type repositories, which are excavated downward from surface and accessed directly, located in several tenth meters below earth's surface, (opencut silo-type),

In order to study the sensitive parameters for safety analysis and estimation of the disposal cost, two cases for each type having smaller and larger capacity for emplacement of HAW per a tunnel or a silo were designed. The specifications of the designed six repositories are shown in Table. IV. These repositories were composed of a vertical shaft or a spiral tunnel for access, disposal tunnels or silos, horizontal tunnels for working (construction and transportation), and shafts for service such as the ventilation shaft, the supplement shaft for worker's access, and so on.

Geological features of the disposal site were assumed to site-generic condition. Compressive strength of the rock in the site was set from 30 kgf/cm^2 to 130 kgf/cm^2 for soft rock, such as sedimentary rock, and from 450 to 2,000 kgf/cm^2 for hard rock, such as crystalline rock.

Bird's-eye view of Case 1 is shown in Fig.1. The facility has six disposal blocks that are composed of ten disposal tunnels and four working tunnels surrounding the block. Inner diameter of disposal tunnel is 2.5m. The repository in Case 2 is composed of two blocks, because inner diameter of disposal tunnel is 5.0m.

TABLE IV SPECIFICATIONS OF DESIGN OF REPOSITORIES

Case		1	2	3	4	5	6
Repository type		Tunnel-1	Tunnel-2	Under-ground silo-1	Under-ground silo-2	Opencut silo-1	Opencut silo-2
Depth of repository		100m,300m				50m	
Site condition		hard rock or soft rock				soft rock	
Specific-ations	Inner diameter of a tunnel or a silo	2.5m	5.0m	15m	24m	24m	30m
	Length or height of a tunnel or a silo	270m (length)	270m (length)	10m (height)	34m (height)	30m (height of waste layer)	30m (height of waste layer)
	Tunnels or silos per a disposal block	10	7 and 8	10 and 11	5	----	----
	Total number of a disposal block	6	2	4	1	12	5
	Total length of tunnels (total volume of silos)	16,200m	4,050m	74,200m^3	76,900m^3	163,000m^3	107,000m^3
	Access tunnel	shaft or spiral tunnel				----	
	Total length of working tunnel (transportation and construction tunnel)	2720m	940m	2650m	840m	----	

Bird's-eye view of case3 repository is shown in Fig.2. In this case, the repository has 42 silos assuming that all HAW arising from one reactor would be disposed of in one silo. The repository has four lines of disposal blocks. A block consists from ten or eleven silos and a working tunnel which connects these silos at the upper part. The tunnel is used for construction and access of silos. The two tunnels between two disposal blocks are used to put out excavated rocks to the outside.

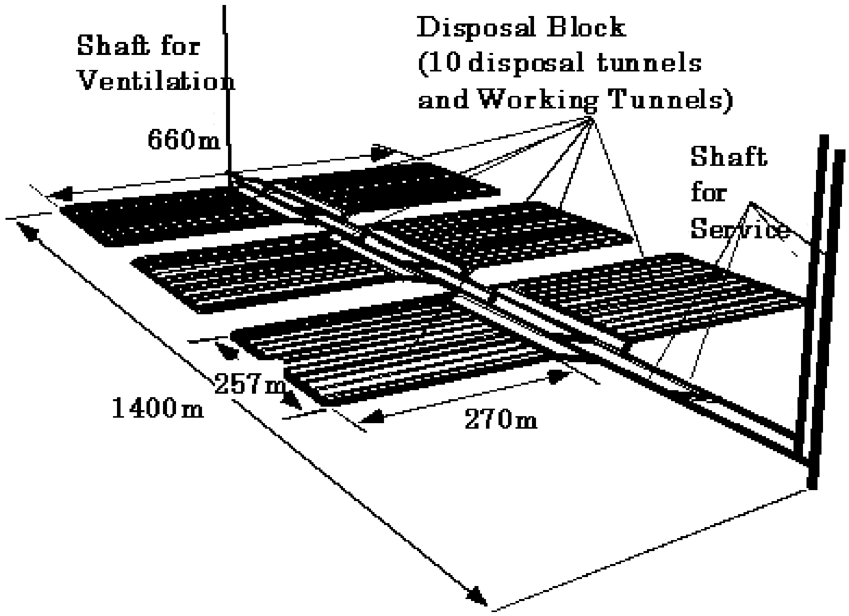

Fig. 1. Bird's-eye view of designed tunnel type repository (Case 1)

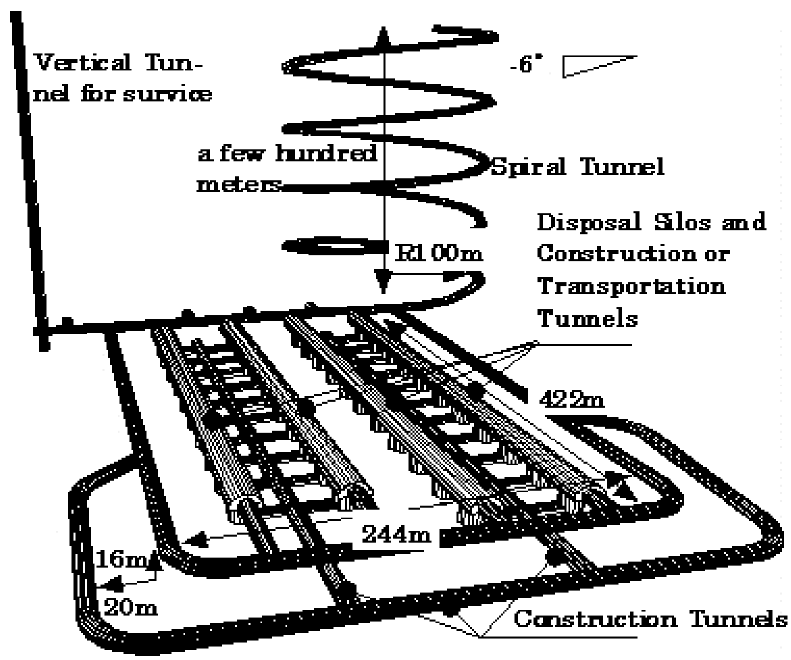

Fig. 2. Bird's-eye view of designed Underground silo type repository (Case 3)

Silos in case4 repository were designed to have larger sizes in both diameter and height than those of case3. Thus, total numbers of silo are five and these are arranged to a line of disposal block.

Opencut silo type repositories were designed as Case 5 and Case 6 in order to study the technical feasibility of the repository that are composed of the silos with large diameter constructed directly from earth's surface to several tenth meters below. The HAW waste packages would be emplaced up to the height of a few tenth meters from the bottom of the silo. The space between the disposal containers and the concrete structures of silos would be filled with cement mortar, bentonite, and soil, up to the earth's surface after emplacement of waste packages into the silo.

EVALUATIONS OF DESIGNED DISPOSAL SYSTEM FOR HAW

Disposal for HAW needs to be performed safely and reasonably from the viewpoint of the cost. The characteristics of a repository, such as the disposal capacity, the depth of repository, and the performance of engineered barriers, are important parameters to affect the safety and the cost of HAW disposal. The safety analysis and estimation of construction cost were done on the each designed repository, in order to study the important parameters on safety and the cost, and to discuss the preferable repository in the designed ones. The construction period of each repository were also done to consider the technical feasibility of the designed repository.

Safety Analysis of Designed Disposal Facilities

In radioactive waste disposal it needs to be evaluated that the exposure doses caused from the waste disposed of in a repository in post-institutional control period will not exceed the dose limit or criterion, such as 0.01mSv/a in Japan.

The safety analysis was performed to evaluate the safety of designed repositories and to identify the sensitive parameters on the safety of HAW disposal. The exposure doses were analyzed based on the specifications of each designed repository.

Exposure doses from drinking the water of river into which contaminated groundwater flowed were evaluated, though several exposure pathways to the public due to the disposed HAW were considered. The exposure doses due to groundwater drinking greatly depends on parameters of the disposal site. However, it is difficult to set the specific parameters because the site has not been decided yet in Japan. Therefore, the evaluation was done by assuming that the parameter values for the disposal site were set the representative values resulted from literature surveys [7],[8].

Groundwater flow and nuclide transfer in the geological media were simulated in the two-dimensional field that was vertical against earth's surface, by the finite element code. The assumptions used in the simulation are as follows:

- Depth of repositories below the earth's surface for Case 1 to Case 4 and from Case 5 and Case 6 are 100 m and 50 m, respectively,
- The distance between the river and the repositories are 500 m,.
- The HAW is solidified into disposal containers with cement mortar, but the containment of radionuclides by container is ignored. The radioactivity concentration are homogeneous in the container,

- The space between walls of repositories and the waste are filled with the pure bentonite to reduce the release rate of radionuclides from the repositories,
- The geological formations is homogeneous soft rock,
- The annual flow rate of the river is $3x10^8$ m^3.
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The parameter values used for the evaluation are shown in Table IV and Table V.

TABLE IV PARAMETERS USED IN SAFETY ANALYSIS

HAW conditions	Referred Table 1.1 and 1.2
Geological feature parameters (soft rock)	
Permeability	20m/a
Porosity ratio	0.15(-)
Density	$2.5g/cm^3$
Longitudinal dispersivity	x=5m
	z=1.5m
Engineered barrier(bentonite)	
Permeability	0.001m/a
Moisture content	0.1(-)
Density	$2.7g/cm^3$
Longitudinal dispersivity	0.1m
Hydraulic gradient	0.01(-)
Site parameters	
Groundwater flow rate	0.05 - 0.1m/a
Hydraulic gradient	0.005(-)
Distance from the repository to river	500m
River flow rate	$3.0x10^8m^3/a$
Annual intake of river water	$0.61m^3/a$

TABLE V PARAMETERS DEPENDENT ON NUCLIDE (ELEMENT)

nuclide		^{14}C	^{36}Cl	^{59}Ni	^{94}Nb	^{233}U	^{239}Pu
Diffusion coefficient [7] of concrete	m^2/a	4.4E-07	1.0E-06	8.5E-07	4.4E-06	1.0E-06	1.0E-06
Diffusion coefficient [7] of bentonite	m^2/a	5.2E-03	1.9E-02	3.8E-05	7.6E-05	1.4E-02	6.9E-04
Distribution coefficient of bentonite	m^3/kg	5.0E-05	5.0E-05	2.0E-04	1.0E-04	1.6E+00	3.5E+00
Diffusion coefficient of soft rock	m^2/a	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00	1.0E+00
Distribution coefficient of soft rock [8]	m^3/kg	0.0E+00	0.0E+00	2.0E-02	1.0E-01	5.0E-02	5.0E-01
Dose conversion coefficient(ingestion)	Sv/Bq	5.7E-10	8.2E-10	5.4E-11	1.4E-09	7.3E-08	9.8E-07

The estimated exposure doses by the river water drinking are shown in Fig.3. The exposure doses from each case are shown by relative values based on the peak doses in Case 6 which is the highest dose in all cases, but the peak dose not exceed 0.01mSv/a in this evaluation. It can be seen that the peak doses from Case 5 and Case 6 are higher than those from case1 to Case 4 because the depth of the latter repositories are deeper than that of the former repositories. The difference of the peak doses caused from Case 1 to Case 4 depends on the shape and volume of repositories. For example, the exposure dose from underground silo type repository of Case 3 indicates the lowest in that of all cases because radioactivity concentration was diluted into the large volume.

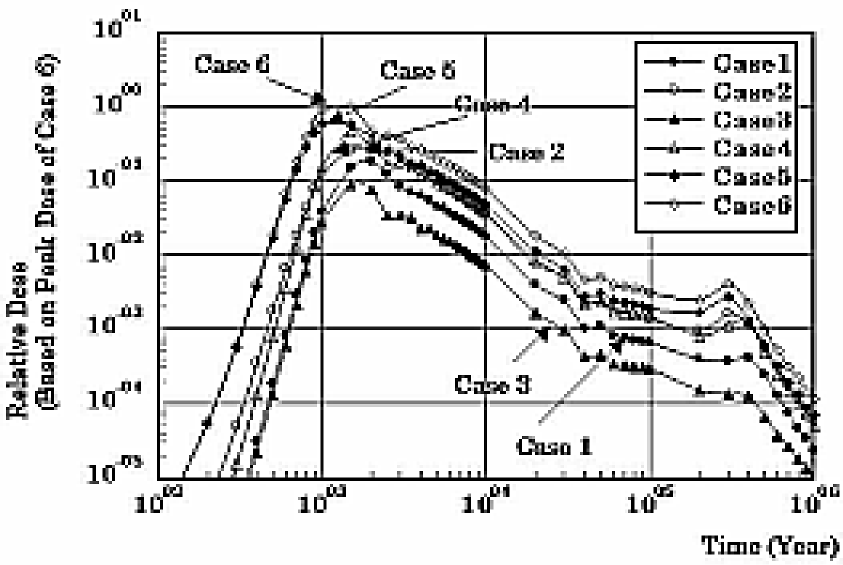

Fig. 3. Relative dose from contaminated river water at 500 m separate from each repository (The depth of the repositories of Case 1, 2, 3, 4 and Case 5 and 6 are 100 m and 50 m, respectively.)

Figure 4. shows comparison of exposure doses depending on the depth of 100m and 300m in Case1. These curves show exposure doses caused from C-14 because the doses due to C-14 are the highest of all the nuclides considered in this analysis. Figure 4 shows the peak dose in the case of 300m decreases by 1/10 below that of 100m. This analysis shows that the direction of groundwater flow is nearly horizontal to the earth's surface because the analysis is done on the site condition of homogeneous soft rock. In this analysis model, nuclides are transferred easily in the direction of groundwater flow by dispersion and diffusion, however, the transferred amount of nuclides in the other directions is small because the transfer at that direction is caused due to only diffusion. Accordingly, nuclides do not reach easily to the evaluation point at near surface when the repository was located at deep underground.

The thickness of bentonite surrounding the disposal containers as engineered barrier is considered as one of the effective parameters to retard the nuclide transfer. The variations of dose from Case 3 repository were evaluated with the difference of bentonite thickness. Figure 4 shows the exposure doses caused from C-14 in the pathway drinking the river water. It can be seen that the peak doses are decreased by about 1/2 when the thickness of bentonite increases from 0.5 m to 2 m because of the radionuclide decay of C-14.

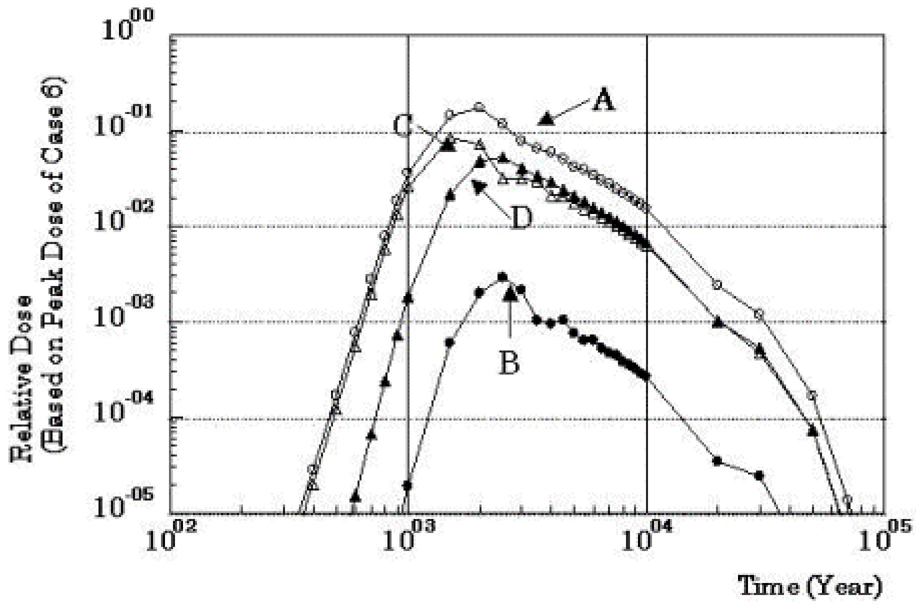

Fig. 4. Comparison of relative dose from C-14 due to the change of the parameters

A : The depth = 100 m, the thickness of the bentonite = 0.5 m (Case 1)
B : The depth = 300 m, the thickness of the bentonite = 0.5 m (Case 1)
C : The depth = 100 m, the thickness of the bentonite = 0.5 m (Case 3)
D : The depth = 100 m, the thickness of the bentonite = 2.0m (Case 3)

It is considered that there would be low possibility of the human intrusion below enough from the surface, e.g. fifty to a hundred meters or more. From this consideration, the human intrusion scenario would not be needed in case of the disposal of HAW at a few hundreds meters below the surface such as tunnel-type and underground silo-type repositories.

Estimation of Construction Costs

The cost of HAW disposal is desirable to be low considering the safety. The construction cost, a part of the cost of HAW disposal, was estimated for every type of repositories. The construction is broken down into several items as shown in Table VI. The estimation conditions were as follows;

- The depth of repositories: 100 m, (Case 1 to Case 4), 50 m (Case 5 and Case6)
- The geological feature in the construction site: hard rock (Case1 to Case 4), soft rock (Case 5, Case 6),
- The access tunnel: spiral tunnel, (Case1 – Case4),

Underground silo type repositories are provided with bentonite thickness of 2 m. The thickness of bentonite for opencut silo type repositories is set to 4 m based on the results of safety analysis.

The results of the cost estimation are shown in Table VII. The repository of the Case 2 could be constructed most economically of all repositories. Even though the depth of Case2 is deeper than that of opencut silo type repositories, the cost of Case 5 and Case 6 is estimated higher than that of Case2 due to the difficulty of excavation and maintenance of the silos. The Case 1 would be constructed most expensively, at about 2 .5 times higher than that of the Case 2.

TABLE VI ESTIMATION ITEMS FOR CONSTRUCTION COST AND PERIOD

Estimation items		Feature	Size	The thickness of concrete liner*1	The length of lock bolt *2	case
Auxiliary tunnels	Spiral tunnel for access	horseshoe type	8.5Wx4.5 H	0.20m	2m	1-4
	Shaft for access	cylinder	R=6m	0.5m	--	--
	Shaft for construction	cylinder	R=6m	0.5m	--	1-4
	Shaft for service	cylinder	R=4m	0.4m	--	1-4
	Construction or transportation tunnel	horseshoe type	8.5Wx4.5 H	0.20m	2m	1-4
		horseshoe type	5Wx4.5H	0.15m	2m	1,3,4
Disposal tunnels or silos	Disposal tunnel	cylinder	R=2.5m	0.5m	--	1
		horseshoe type	4.5mx4m H	0.15m	2m	2
	Construction or transportation tunnel at upper part of silo	half cylinder	19mWx8m H	0.30m	5m	3
		half cylinder	29mWx11 mH	0.35m	6m	4
	Silo	cylinder	15mRx10 mH	0.65m	4m	3
		cylinder	24mRx34 mH	0.9m	6m	4
	Opencut silo	cylinder	24mRx50 mH	2m	--	5
		cylinder	30mRx50 mH	2m	--	6
Backfilling material	Cement mortar	--	--	--	--	all
	Bentonite	--	--	--	--	all

*1,2: The reinforcement in case that the tunnels or silos are constructed in hard rock.

case	1	2	3	4	5	6
Thickness of bentonite	0.5m	1m	2m	2m	4m	4m

TABLE VII THE ESTIMATION OF CONSTRUCTION TERM, DISPOSAL DENSITY AND CONSTRUCT COST

Case	1	2	3	4	5	6
Repository type	Tunnel type-1	Tunnel type-2	Under-ground silo type - 1	Under-ground silo type - 2	Opencut silo type - 1	Opencut silo type-2
Construction period*1 (month)	75	59	72	105	144	108
Total volume of repository (m^3)	3.2E+5	2.4E+5	4.6E+5	2.6E+5	2.7E+5	2.1E+5
Disposal Density*2	0.05	0.11	0.06	0.10	0.10	0.13
Construction cost*3 (million dollars)	350	150	315	170	210	185

*1: The period from Case 1 to Case 4 is the value when the access tunnel is designed as spiral tunnel.
*2: The ratio of disposal container volume to total volume of repository
*3: The cost from case1 to Case 4 is the value when the access tunnel is designed as spiral tunnel.

Estimation of the Construction Period

It is important to study the workability for disposal operations when the technical feasibility of the designed repository is discussed. The construction period of repositories is one of the items of the workability and one of the basis for the technical feasibility. The rough estimation of the construction period of each repository was done. The estimation conditions were as follows;

- The depth of repository: 100 m (Case 1 – Case4), 50 m, (Case 5 and Case6),
- The geological feature in the construction site: soft rock (Case1,Case5,and Case6), hard rock (Case2, Case3, and Case4),
- The access tunnel: spiral tunnel: (Case1 – Case4)

The construction period depends on the specifications of repositories, such as the volume , the depth, the shape, the methods for excavation of tunnel or silo, the methods for reinforcement. Some of these items are shown in Table VI.

Table VII shows the estimated construction period for each type of repositories. The tunnel type repository of Case 2 could be constructed for the shortest period of approximately 59 months. Construction period for the silo type repository of Case 4 as well as opencut silo type repository of Case 5 and Case 6 is long-term though of total volume of them are not so larger than that of Case 2. The silos need to be reinforced firmly to maintain long-term stability as shown in Table VI. For example, Case 3 and Case 4, the mother rock of the silos need to be reinforced using the lock bolts of approximately 4 m and 6 m, respectively. The disposal density in Cases 3 is not high as shown in Table VII because the repository needs more construction tunnels.

CONCLUSION AND SUMMARY

Six cases of HAW repository were designed based on the properties of the waste and the specific conditions of the disposal containers. The disposal system for HAW needs to be established reasonably considering the safety, the cost, and the workability. The appropriateness of the designs were judged from the viewpoints of safety, construction cost and operational workability.

According to the results of safety analysis, the factors of the repository design that affect the exposure dose due to the groundwater scenarios are the depth and volume of repository and performance of engineered barrier.

The groundwater concentration of radionuclides released from large volume repository such as Case 1 and Case 3 would be lower than that released from small volume one because the quantities of groundwater passing through the large volume repositories are larger than those of small ones. The time of the peak dose will be retarded when the repository is constructed deeply below underground. The peak dose will be decreased if nuclide migration from the repository to earth's surface is controlled by diffusion of nuclide as shown in Fig. 3. The time of peak dose is delayed due to the bentonite thickened as shown in Fig. 4.

The cost and period for construction also depend on those above mentioned factors such as depth of repositories. Generally speaking, the construction period is longer and the cost is higher in constructing the repository with large volume. The same effect would arise on the cost and period in case of construction the repositories with large size of cavity, such as silo at Case 4 or Case 6. The silos have the technical difficulty of construction and maintenance in comparison with the tunnels. Moreover, the construction cost is higher as the thickness of the bentonite layer surrounding the waste packages increases. The cost of bentonite is relatively high compared with other backfilled materials.

In conclusion, the tunnel type repository with relatively large diameter would be the most preferable in six designed repositories according to the result from the estimation of both cost and period of construction. It is evaluated in the safety analysis that the exposure doses resulted from all six designed repositories are lower than the dose criterion in the post-institutional control period, i.e. 0.01mSv/y.

The system of HAW disposed of in underground-silo type repository would be expected as the available system. However, relatively large-scale silos would have the difficulty of construction and maintenance of structural stability and a possible construction size of the silo would depend on the geological features of the disposal site.

The construction cost of opencut silo type repository is evaluated to be economical, whereas, the safety of them would need to be improved.

The first commercial power plant (16.6Mwe, GCR) was permanently terminated its operation in March 1998. It is prospected that the number of the closed NPPs will increase in the future. Therefore, in Japan, the HAW disposal system needs to be decided as soon as possible.

The results described in this paper are useful to design and construct the disposal facility in the future.

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