Annex 3

DOSE ASSESSMENT FOR PUBLIC BY PACKAGES SHIPPING RADIOACTIVE MATERIALS HYPOTHETICALLY SUNK ON THE CONTINENTAL SHELF

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Abstract

Radioactive materials such as spent fuel (SF), PuO_2 powder, high level wastes (HLW) and fresh mixed oxide (MOX) fuel have been transported on sea between Europe and Japan. Dose assessments for public have been performed in the past when the packages shipping radioactive materials hypothetically sunk on the continental shelf. These studies employed various conditions and methods in their assessments and the results were not always the same. In this study, the dose assessment for these packages was performed under the same conditions and by the same methods. The effective dose equivalents of radiation exposure to the public for all materials become smaller than the previous evaluations due to more realistic assumption in this study. These evaluated results are far less than the effective dose equivalent limit (1 mSv $year^{-1}$) by the ICRP recommendation.

INTRODUCTION

There is a special safety standard called INF Code at International Maritime Organization (IMO) about structure and systems of transport ship of radioactive materials. On the other hand, for transport of radioactive materials, there is a safety standard stipulated in "Regulations for the Safe Transport of Radioactive Material" issued by International Atomic Energy Agency (IAEA). Transport of radioactive materials has been carried out safely under these standards and regulations. Therefore, there is little possibility for the ship to collide with other ship resulting in abnormal incident such as shipwreck.

However, dose assessment for public by packages shipping various radioactive materials hypothetically sunk into the sea was carried out in the past 20 years for the public acceptance of safe transport of radioactive materials through case studies developing assessment methods by Central Research Institute of Electric Power Industry (CRIEPI) (spent fuel (SF) [(1)], PuO_2 powder[(2)], high level wastes (HLW)[(3)], high burn-up spent fuel[(4)], fresh mixed oxide (MOX) fuel [(5)]). These studies employed various conditions and methods in their assessments and the results were not always consistent. It is necessary to make evaluation under the same condition and by the same method.

On the other hand, similar dose assessments have been performed in other countries[(6)(7)]. It is informative to make comparison between our study and their studies.

DOSE ASSESSMENT IN CRIEPI

Scenario of assessment

When a package might be sunk at a 200 m depth which is equivalent to the mean depth of the continental shelf, it would not be collapsed and would keep its integrity. Because the package meets the requirement for the 200 m water submersion test to the package that

contains more than 10^5A_2 as shown in the IAEA transport regulation (1996Edition). Since it would be possible to salvage the package from a 200 m depth [8], a 200 m depth was conservatively assumed for the assessment in case of submergence near shore. The effect of submergence at the depth more than 200 m would become smaller. As a result, the depth of the supposed location of submergence was 200 m near shore.

Figure 1 shows the sequence of the assessment. The barrier effect scenario that the presence of the package reduces the release rate of nuclides to the ocean was employed. The one dimensional flow field was evaluated by using the statistical data for 30 years of Japan Ocean Data Center [9]. Nuclide concentration was evaluated calculating three- dimensional diffusion equation in consideration of nuclides decay and scavenging (nuclides removed from seawater by phenomena that nuclides absorb suspended materials in seawater and settle down the seabed) by the finite differences method. The internal effective dose equivalent from ingestion of fish in the area of calculation and the external dose by marine operations were calculated.

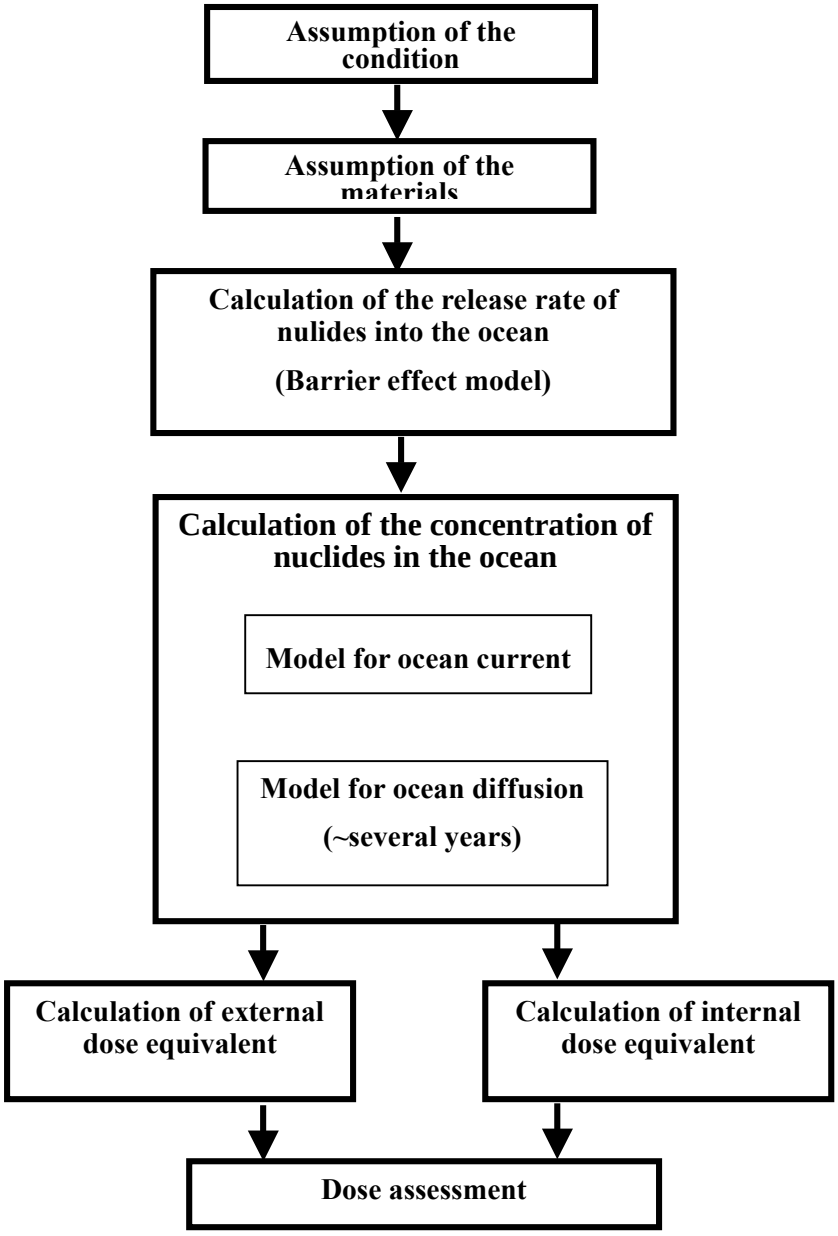


Figure 1. Sequence of dose assessment.

Conditions for evaluations

Location of submergence

The supposed location of submergence was a 200 m depth area 7 km off Shimokita peninsula (Figure 2).

Outlines of the packages

Table 1 shows type, weight and dimension of the packages and form, weight, inner container and activity of the packages for assessment [10]. Here after, the assessment was carried out per package. In this study, the dose assessments for these packages of SF, PuO_2 powder and HLW are performed under the same conditions and by the same methods.

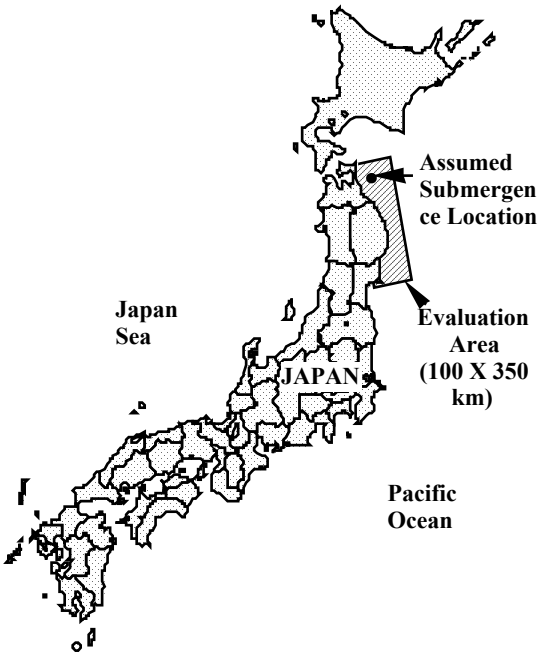


Figure 2. Assessment Area in north-eastern Japan.

TABLE 1. PACKAGES FOR ASSESSMENT [8]

		SF	PuO2	HLW
Packaging	Type	HZ-75T(PWR)	FS-47	TN-28VT
	Weight	70ton	1.5ton	100ton
	Size	ϕ 2.3m × 5.9m	ϕ 0.8m × 2m	ϕ 2.5m × 6.6m
Radioactine Material	Form	Pellet	Powder	Vitrified Residue
	Weight	3.2tU	14.5kg	400kg × 28
	Inner Container	Fuel Assembly × 7	Can × 4	Canister × 28
	Activity	81.5PBq × 7	5.2PBq	25.5PBq × 28

Scenario of nuclides release into the sea

The following conservative scenario was considered.
(1) The package is submerged on the seabed at the depth of 200 m.
(2) After submergence, sealing function is lost by a functional disorder of O-ring immediately.
(3) Seawater enters into the cavity of the package.
(4) All fuel pellets expose to the seawater.
(5) Nuclides leaches into the seawater in the cavity of the package.
(6) The solution of nuclides is released to the ocean through the seal gap.

Outline of the barrier effect model

Release rate of nuclides from the package to the ocean was calculated by the barrier effect model. Outline of the barrier effect model is shown in figure 3. The nuclides would leach into the seawater in the cavity of the package at the leaching rate R_c (Bq year^{-1}) and the solution of nuclides would be released into the sea through the gap at the release rate R_o (Bq year^{-1}). When the leaching rate R_c is larger than release rate R_o, the amount of nuclides into the sea is regulated by the release rate R_o, not by the leaching rate R_c. When the concentration of nuclides in the cavity of package is saturated, nuclides will leach into the seawater that entered the package through the gap with the certain rate. Accordingly, the leach rate would be controlled under this condition. Here after, this effect is called as barrier effect.

Parameters of the barrier effect model

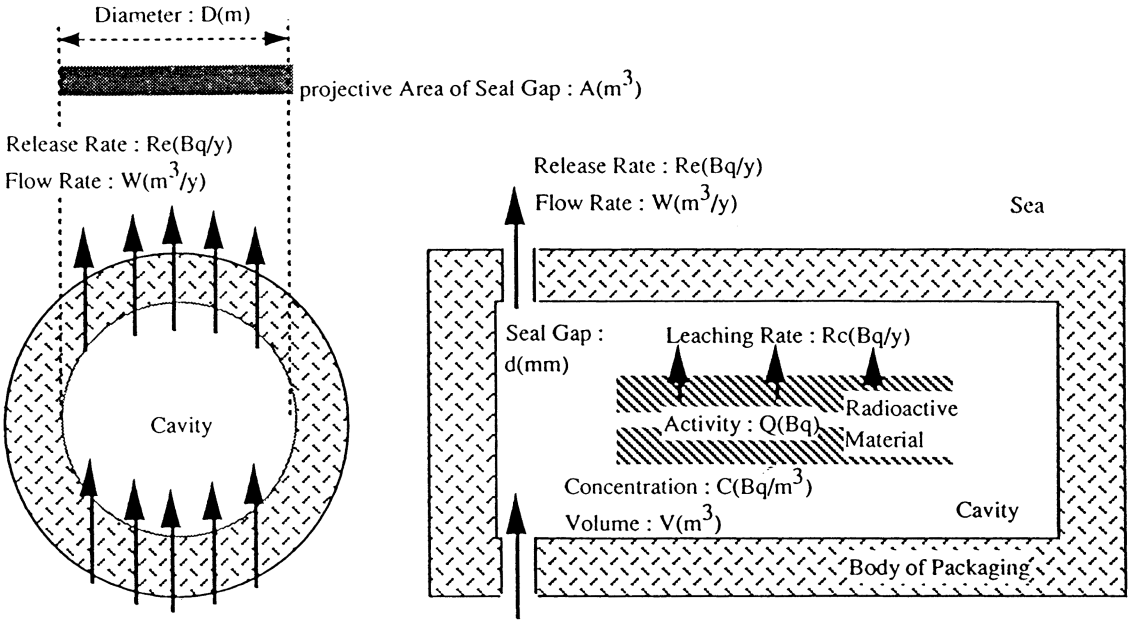
Temperature of seawater in the cavity of package was conservatively assumed to be $200\,°C$ for all materials in this assessment. The value for the HLW package was employed because data of heat value for the entire package were not available. This value is considered conservative for each package.

Table 2 shows the saturated concentration of elements and glass. Insoluble elements such as Np, Pu, Am and Cm are dissolved at a constant rate until the concentration of each element would be saturated. The soluble elements are dissolved into the seawater infinitely. However the soluble elements in the high level wastes were considered to be dissolved into the seawater until the concentration of the vitrified glass to the seawater would be saturated from previous study [3]. Taking account of the temperature dependence, the 100 times values of the saturated concentration at the room temperature were employed. From the solubility values for the elements, solubility of isotope (nuclides) were obtained in accordance with the weight ratio.

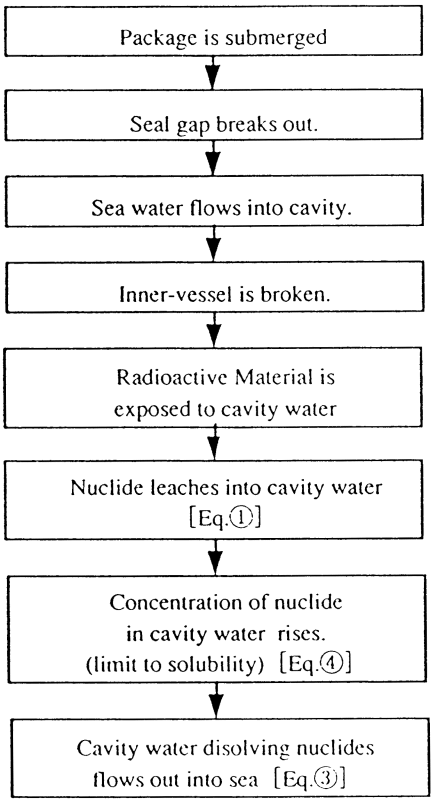
TABLE 2. SOLUBILITY OF NUCLIDES

Group	Element or Material	Solubility [1] (mole/L)	Adoption to Packages [*1]
Insoluble Nuclides	Np	5.5E-07	Spent Fuel,
	Pu	5.3E-04	High Level Wastes,
	Am	3.1E-05	PuO2 Powder
	Cm	3.1E-05	
Soluble Nuclides	Vitrified Glass (SiO2)	8.5E-01	High Level Wastes
	Pellet	Not given	Spent Fuel

[*1] For insoluble nuclides, these solubility are used for all packages.
Soluble nuclides in High Level Wastes are dissolved in concert with Vitrified Glass.
Soluble nuclides in Spent Fuel are not limited to be dissolved .
In PuO_2 Powder, there is no soluble nuclide .



Scinario of Release



Equation

①Leaching Rate of Nuclide into Cavity Water

$Rc = Rp\ \mu\ Q$

②Activity of Radioactive Material

$Q' = Q - (Rc + B\ Q)dt$

③Release Rate into Sea

$Re = C\ W$

④Concentration of Nuclide in Cavity Water

$C' = C + (Rc/V - Re/V - B\ C)\ dt$

For Unsoluble Nuclide and Glass $C' \leqq Cs$

Variables

Rc : Release Rate into Cavity Water (Bq/y)

Rp : Laching Rate ($g/cm^2/y$)

μ : Surface/Weight Ratio of Radioactive Material (cm^2/g)

Q : Activity of Radioactive Material(Bq)

Q' : Activity of Radioactive Material (after dt) (Bq)

B : Decay Constant (1/y)

dt : Differential Time (y)

Re : Release Rate into Sea (Bq/y)

C : Concentaration in Cavity Water (Bq/m^3)

C' : Concentaration in Cavity Water (aftre dt) (Bq/m^3)

Cs : Solubility of Unsoluble Nuclides (Bq/m^3)

W : Fow Rate throgh Seal Gap (m^3/y)

V : Volume of Cavity (m^3)

FIG. 3. Release scenario and process of calculating release rate.

The leaching rate of nuclides from pellet (SF) and powder(PuO_2 powder) in seawater was conservatively assumed to be 1×10^{-6} g cm^{-2} d^{-1} by referring to the hot experimental results [1][2]. The leaching rate of nuclides vitrified waste (HLW) in seawater was conservatively assumed to be 1×10^{-4} g cm^{-2} d^{-1} by referring to the hot experimental results [3].

Results of release rate

Release rates of radioactive nuclide of spent fuel, PuO_2 powder and high level wastes are shown in Table 3, 4 and 5, respectively. These results varied with time by barrier effect and nuclide decay.

TABLE 3. RELEASE RATE OF NUCLIDES (SPENT FUEL)

Nuclides	Solubility		Release	Release Rate
	For Elements	For Nuclides	Flow Rate	(per Package)
	[*1]	[*2]	[*3]	(at 20 yr)
	Cso	Cs	w	r
	(mol/L)	(Bq/m3)	(m3/s)	(Bq/y)
Sr-90	-	-	9.5E-10	2.8E+13
Y-90	-	-		2.8E+13
Sb-125	-	-		3.4E+10
Te-125m	-	-		1.4E+10
Cs-134	-	-		1.8E+11
Cs-137	-	-		4.0E+13
Ba-137m	-	-		3.7E+13
Pm-147	-	-		3.3E+11
Sm-151	-	-		6.0E+11
Eu-154	-	-		8.4E+11
Eu-155	-	-		2.4E+11
Pu-238	5.3E-04	1.6E+12		4.9E+10
Pu-241		5.9E+13		1.8E+12
Am-241	3.1E-05	8.9E+11		2.7E+10
Cm-244	3.1E-05	1.9E+13		5.8E+11

[*1] Solubolity is at 200℃. For solubule nuclides (Sr, . .,Eu) , solubolity is not given.

[*2] Solubility for an unsoluble element is distributed to each nuclide in accordance with its weig

[*3]Release flow rate is for 200℃ of cavity water and 0.01mm of seal gap.

[*4] This table shows release rate of nuclides at 20 yr after submergence when dose rate becomes

TABLE 4. RELEASE RATE OF NUCLIDES (PUO_2 POWDER)

Nuclides	Solubility		Release	Release Rate
	For Elements	For Nuclides	Flow Rate	(per Package)
	[*1]	[*2]	[*3]	(at 0 yr)
	Cso	Cs	w	r
	(mol/L)	(Bq/m3)	(m3/s)	(Bq/y)
Pu-238	5.3E-04	1.6E+12	9.5E-10	4.7E+10
Pu-239		1.9E+11		5.7E+09
Pu-240		2.7E+11		8.2E+09
Pu-241		5.2E+13		1.6E+12
Pu-242		7.3E+07		2.2E+06
Am-241	3.1E-05	8.9E+11		2.7E+10

[*1] Solubolity is at 200 ℃. For solubule nuclides (Sr, . .,Eu) , solubolity is not given.

[*2] Solubility for an unsoluble element is distributed to each nuclide in accordance with its weight.

[*3]Release flow rate is for 200℃ of cavity water and 0.01mm of seal gap.

[*4] This table shows release rate of nuclides at 0 yr after submergence.

TABLE 5. RELEASE RATE OF NUCLIDES (HIGH LEVEL WASTE)

Nuclides	Solubility		Release	Release Rate
	For Elements	For Nuclides	Flow Rate	(per Package)
	[*1]	[*2]	[*3]	(at 5 yr)
	Cso	Cs	w	r
	(mol/L)	(Bq/m3)	(m3/s)	(Bq/y)
Sr-90	8.5E-01	5.3E+14	9.5E-10	1.6E+13
Y-90	(for Glass)	5.3E+14		1.6E+13
Ru-106		6.2E+13		8.9E+11
Rh-106		6.2E+13		8.9E+11
Cs-134		1.5E+14		4.6E+12
Cs-137		7.6E+14		2.3E+13
Ba-137m		7.2E+14		2.2E+13
Eu-154		4.5E+13		1.4E+12
Pu-238	5.3E-04	1.4E+12		1.6E+10
Am-241	3.1E-05	7.2E+11		2.2E+10
Cm-243	3.1E-05	2.9E+11		8.7E+09
Cm-244		2.2E+13		6.7E+11

[*1] Solubolity is at 200 ℃. For solubule nuclides , solubolity is not given.
For solubule nuclides, solubolity for vitrified glass is given.

[*2] Solubility for an unsoluble element or glass is distributed to each nuclide in accordance with its weig

[*3]Release flow rate is for 200℃ of cavity water and 0.01mm of seal gap.

[*4] This table shows release rate of nuclides at 5 yr after submergence when dose rate becomes maximur

Method of calculation of nuclides concentration in the seawater

Nuclide concentration near shore was evaluated by calculating three dimensional diffusion equation with the finite differences method under the following boundary conditions. The followings show the assessment model, the three-dimensional diffusion equation, the assessment parameters, etc.

Assessment model

The mesh size of the assessment model was a few kilometers in the horizontal (X, Y) direction and tens meters in the depth (Z) direction. The seabed of the offshore of the Tohoku region of Pacific Ocean and its shore have been modeled as steps and straight line, respectively (Figure 4).

The basic equation was the three dimensional diffusion equation (Equation 1) in consideration of advection, ocean diffusion, absorption to suspended particles and sedimentation of nuclides (called scavenging), and nuclides decay.

$$\frac{\partial C}{\partial t} = \underbrace{-U\frac{\partial C}{\partial x} - V\frac{\partial C}{\partial y} - W\frac{\partial C}{\partial z}}_{\text{(Advection)}} + \underbrace{D_x\frac{\partial^2 C}{\partial x^2} + D_y\frac{\partial^2 C}{\partial y^2} + D_z\frac{\partial^2 C}{\partial z^2}}_{\text{(diffusion)}} \underbrace{-K_d\rho_s w_s\frac{\partial C}{\partial z}}_{\text{(scavenging)}} \underbrace{-\lambda C}_{\text{(decay)}} \quad (1)$$

where, C_I is radionuclide concentration (Bq m^{-3}), t is times (s), x, y and z are geographical coordinatess (m), U, V and W are advective velocities (m s^{-1}), D_x, D_y and D_z are ocean diffusion coefficienta (m^2s^{-1}) , λ is decay constant of nuclides (s^{-1}) , K_d is distribution coefficient of nuclides(m^3g^{-1}), ρ_s is concentration of suspension (g m^{-3}) and w_s is the sedimentation velocity of suspension (m s^{-1})

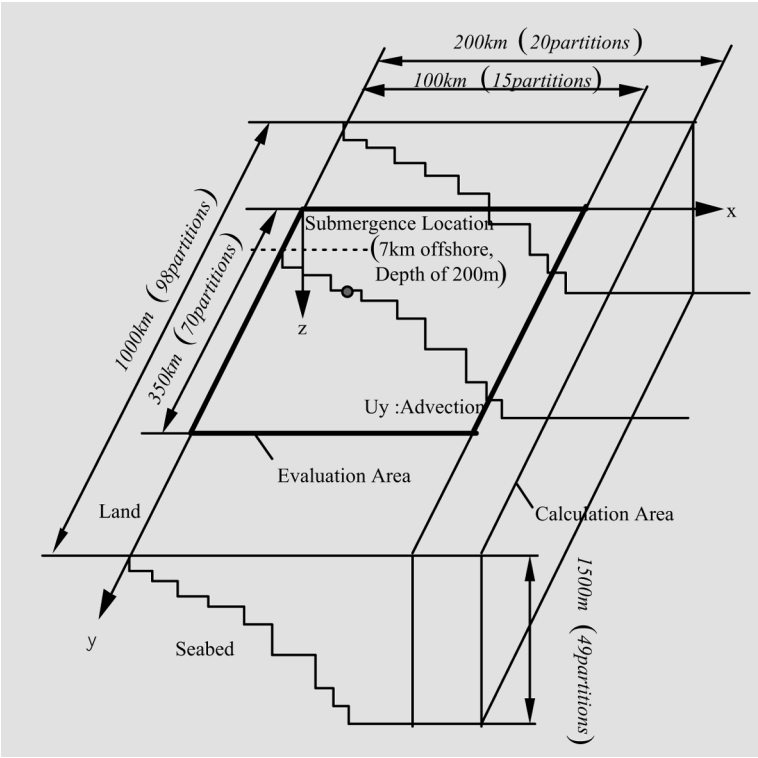


Figure 4. Model of Waters to Calculate Concentration.

Input conditions [3]

The advective velocity for the principal component of each season on the surface of the sea from 1905 to 1989 at 55 locations [9] was used. Within the sea area of calculation the flow was assumed to be uniform. The advective velocity was assumed to be uniform in the depth (Z) direction. The annual means Y directional velocity was 12cm s^{-1}. The diffusion coefficients in the horizontal direction were assumed to be $10^5 cm^2 s^{-1}$ in the offshore direction (perpendicular to shoreline) and $10^6 cm^2 s^{-1}$ along the coast (parallel to shoreline), that was based on Richardson's four third-power law on condition that the order of diffusion [11] in the horizontal scale was tens km. For Z (depth) direction it was assumed to be $10 cm^2 s^{-1}$ [12]. The values of distribution coefficient of element was employed from the safety series No.78 of IAEA [13]. Sedimentation velocity of suspended materials and its concentration in the seawater were determined with reference to published paper [14].

Calculation results of nuclides concentration

The nuclides concentration to be calculated in the ocean were assumed to be the maximum value in the different surfaces and time at the surface layer (0-100 m depth) which is the habitant of fishes ingested. Table 6 shows the concentrations for all nuclides under the condition that the release rate was 1 Bq $year^{-1}$. The difference of distribution coefficient and decay constant were considered in this calculation. The smaller the distribution factor was, the larger the concentration of radionuclide was. And the smaller decay constant was, the smaller the concentration was. The difference of two orders of magnitude was shown in calculated results by the difference of nuclides. The concentration of nuclides in the ocean from the different package was obtained by multiplying these calculated results per 1Bq $year^{-1}$ and the results of release rate into the ocean.

The effective dose equivalent of radiation exposure to the public

Calculation method for the effective dose equivalent of radiation exposure to the public

The internal exposure route was quoted from guideline of the calculation model for evaluating the effective dose equivalent around a nuclear site during the basic planning stage [15]. It was assumed that internal exposure would be caused by seafood ingestion. As to the values for ingested fishes in which the radionuclides are concentrated, the established values for a reference man per day in the guideline for effective dose equivalent evaluation in Japan were employed. The external exposure route was quoted from the case of the evaluation effective dose equivalent of liquid waste [16] for the safety examination of a nuclear power station. The parameters based on the evaluation of effective dose equivalent of liquid waste were employed. Table 7 shows the condition of calculating individual doses.

Result of the effective dose equivalent of radiation exposure to the public

The results of the effective dose equivalent of radiation exposure to the public are shown in Table 8, 9 and 10 in the cases of SF, PuO_2 powder and HLW. The values in table are maximum value in 50 years that is calculated period.

The result of the effective dose equivalent at the case of SF shows the maximum value of 4.1×10^{-4} mSv $year^{-1}$ in 20 years after submergence. This result is 500 times smaller than the previous result in 1976 [1]. The change of the results is mainly caused by the employment of barrier effect model and the consideration of ocean flow to calculate the concentration of nuclides in the ocean. The result at the case of PuO_2 powder shows the maximum value of 1.4×10^{-5} mSv $year^{-1}$ immediately after submergence. This result becomes 2 times smaller than the previous result in 1992 [2]. The difference is not so large because the effect of barrier

effect and the change of submerged depth from 500 m to 200 m were canceled out. The result at the case of HLW shows the maximum value of 3.1×10^{-4} mSv $year^{-1}$ in 2 years after submergence. This result become a little smaller than the previous result in 1996 [3] due to the consideration of weight ratio of isotope in a element for the calculation of solubility of isotopes (nuclides).

TABLE 6. CONCENTRATION OF NUCLIDES IN SEA WATER
(PER 1Bq/Y OF RELEASE)

Distribution Factor [12]	Half-Life Time	Adaptation for Nuclides			Maximum Concentration
Kd	Tr	Spent Fuel	PuO2	High Level	C
	(y)		Powder	Wastes	(Bq/m3)
≦ 1E+4	≦ 0.3	Sr-89, Ru-103, Rh-103m, Te-127m (Te-127)	-		1.9E-15
	0.3 ~ 3	Ru-106 (Rh-106), Sn-123, Cs-134	-	Ru-106 (Rh-106), Cs-134	2.1E-14
	≧ 3	Sr-90 (Y-90), Sb-125 (Te-125m), Cs-137 (Ba-137m)	-	Sr-90 (Y-90), Sb-125 (Te-125m), Cs-137 (Ba-137m), Np-237	2.7E-14
1E+4 ~ 1E+6	≦ 0.3	Zr-95 (Nb-95m), Nb-95	-	Zr-95	1.5E-15
	0.3 ~ 3	-	-	Sn-123	1.7E-14
	≧ 3	Pu-238, Pu-239, Pu-240, Pu-241	Pu-238, Pu-239, Pu-240, Pu-241, Pu-242	Pu-238, Pu-239, Pu-240, Pu-241, Pu-242	2.2E-14
≧ 1E+6	≦ 0.3	Y-91,Ce-141	-	Ce-141	4.2E-16
	0.3 ~ 3	Ce-144 (Pr-144), Pm-147, Cm-242	-	Ce-144 (Pr-144), Pm-147, Cm-242	4.5E-15
	≧ 3	Y-91, Sm-151, Eu-154, Eu-155, Am-241, Cm-244	Am-241	Sm-151, Eu-155, Am-241, Am-243, Cm-243, Cm-244	5.8E-15

TABLE 7. CONDITION AND PARAMETERS FOR ESTIMATION OF INDIVIDUAL DOSE

Item		Condition or Parameters		
Model		ICRP Pub.30		
Dose to Estimate		Effective Dose Equivalent for Individual		
Internal Dose	Ingestion of Seafood	Comsumption (g/d)	Fish	200
			Invertebrade	20
			Seaweed	40
External Dose	Working on Shipboad	Working Period (d/y)		120
	Swimming			4
	Working at Beach			20
	Operation of Fishery Net			80

TABLE 8. INDIVIDUAL DOSE EQUIVALENT (SPENT FUEL)

Nuclides	Internal Dose	Extenal Dose				Total
	Ingestion of Seafood Dw (mSv/y)	Working on Boad D1 (mSv/y)	Swimming D2 (mSv/y)	Working at Seashore D3 (mSv/y)	Handling of Fihing-Net D4 (mSv/y)	(per Package) (at 1 yr) Dtotal (mSv/y)
Sr-90	1.3E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	1.3E-05
Y-90	5.7E-05	2.4E-14	2.4E-15	1.3E-12	2.0E-12	5.7E-05
Sb-125	1.3E-08	2.4E-10	1.7E-11	3.8E-08	1.4E-08	6.6E-08
Te-125m	2.3E-07	1.8E-12	1.2E-13	8.1E-11	1.2E-10	2.3E-07
Cs-134	3.3E-07	4.8E-09	3.2E-10	7.4E-07	2.7E-07	1.4E-06
Cs-137	5.6E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	5.6E-05
Ba-137m	0.0E+00	4.0E-07	2.8E-08	6.4E-05	2.3E-05	8.8E-05
Pm-147	3.4E-08	3.8E-15	2.5E-16	4.4E-13	1.9E-13	3.4E-08
Sm-151	2.6E-08	2.6E-15	2.0E-16	1.1E-13	2.0E-13	2.6E-08
Eu-154	9.8E-07	4.0E-09	2.7E-10	6.4E-07	2.4E-07	1.9E-06
Eu-155	4.1E-08	4.4E-11	3.1E-12	4.3E-09	2.4E-09	4.8E-08
Pu-238	1.5E-05	4.2E-14	3.8E-15	2.6E-12	3.2E-12	1.5E-05
Pu-241	1.1E-05	7.5E-23	4.9E-24	1.2E-20	4.4E-21	1.1E-05
Am-241	1.2E-05	2.0E-12	1.4E-13	1.4E-10	1.1E-10	1.2E-05
Cm-244	1.5E-04	1.5E-13	1.3E-14	1.2E-11	1.1E-11	1.5E-04
TOTAL	3.2E-04	4.1E-07	2.9E-08	6.6E-05	2.4E-05	4.1E-04

Notes : Annual dose eqivalent at 20 yr after submergence is shown, when the value becomes maximum.

TABLE 9. INDIVIDUAL DOSE EQUIVALENT (PUO_2 POWDER)

Nuclides	Internal Dose	Extenal Dose				Total
	Ingestion of Seafood Dw (mSv/y)	Working on Boad D1 (mSv/y)	Swimming D2 (mSv/y)	Working at Seashore D3 (mSv/y)	Handling of Fihing-Net D4 (mSv/y)	(per Package) (at 1 yr) Dtotal (mSv/y)
Pu-238	4.6E-06	1.4E-14	1.2E-15	8.2E-13	1.0E-12	4.6E-06
Pu-239	6.4E-07	1.9E-15	1.4E-16	2.1E-13	1.2E-13	6.4E-07
Pu-240	9.2E-07	2.7E-15	2.4E-16	1.8E-13	1.9E-13	9.2E-07
Pu-241	3.3E-06	2.2E-23	1.4E-24	3.4E-21	1.3E-21	3.3E-06
Pu-242	2.3E-10	1.3E-18	9.7E-20	1.5E-16	8.2E-17	2.3E-10
Am-241	4.0E-06	6.7E-13	4.5E-14	4.5E-11	3.5E-11	4.0E-06
TOTAL	1.4E-05	6.9E-13	4.6E-14	4.6E-11	3.6E-11	1.4E-05

Notes : Annual dose eqivalent at 1 yr after submergence is shown, when the value becomes maximum.

TABLE 10. INDIVIDUAL DOSE EQUIVALENT (HIGH LEVEL WASTE)

Nuclides	Internal Dose	Extenal Dose				Total
	Ingestion of Seafood Dw (mSv/y)	Working on Boad D1 (mSv/y)	Swimming D2 (mSv/y)	Working at Seashore D3 (mSv/y)	Handling of Fihing-Net D4 (mSv/y)	(per Package) (at 5 yr) Dtotal (mSv/y)
Sr-90	7.3E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	7.3E-06
Y-90	3.3E-05	1.4E-14	1.4E-15	7.4E-15	1.2E-12	3.3E-05
Ru-106	4.2E-06	0.0E+00	0.0E+00	0.0E+00	0.0E+00	4.2E-06
Rh-106	0.0E+00	2.6E-09	1.7E-10	4.1E-07	1.5E-07	5.6E-07
Cs-134	8.4E-06	1.2E-07	8.0E-09	1.9E-06	7.0E-06	1.7E-05
Cs-137	3.2E-05	0.0E+00	0.0E+00	0.0E+00	0.0E+00	3.2E-05
Ba-137m	0.0E+00	2.4E-07	1.6E-08	3.8E-06	1.4E-05	1.8E-05
Eu-154	1.6E-06	6.6E-09	4.5E-10	1.1E-06	3.9E-07	3.1E-06
Am-241	1.0E-05	1.7E-12	1.1E-13	1.1E-10	8.6E-11	1.0E-05
Am-243	1.3E-07	4.9E-14	3.3E-15	4.1E-12	2.5E-12	1.3E-07
Cm-243	2.8E-06	4.4E-12	3.0E-13	5.9E-10	2.3E-10	2.8E-06
Cm-244	1.7E-04	1.7E-13	1.5E-14	1.4E-11	1.3E-11	1.7E-04
Total	2.8E-04	3.7E-07	2.5E-08	7.6E-06	2.1E-05	3.1E-04

Notes : Annual dose eqivalent at 5 yr after submergence is shown, when the value becomes maximum.

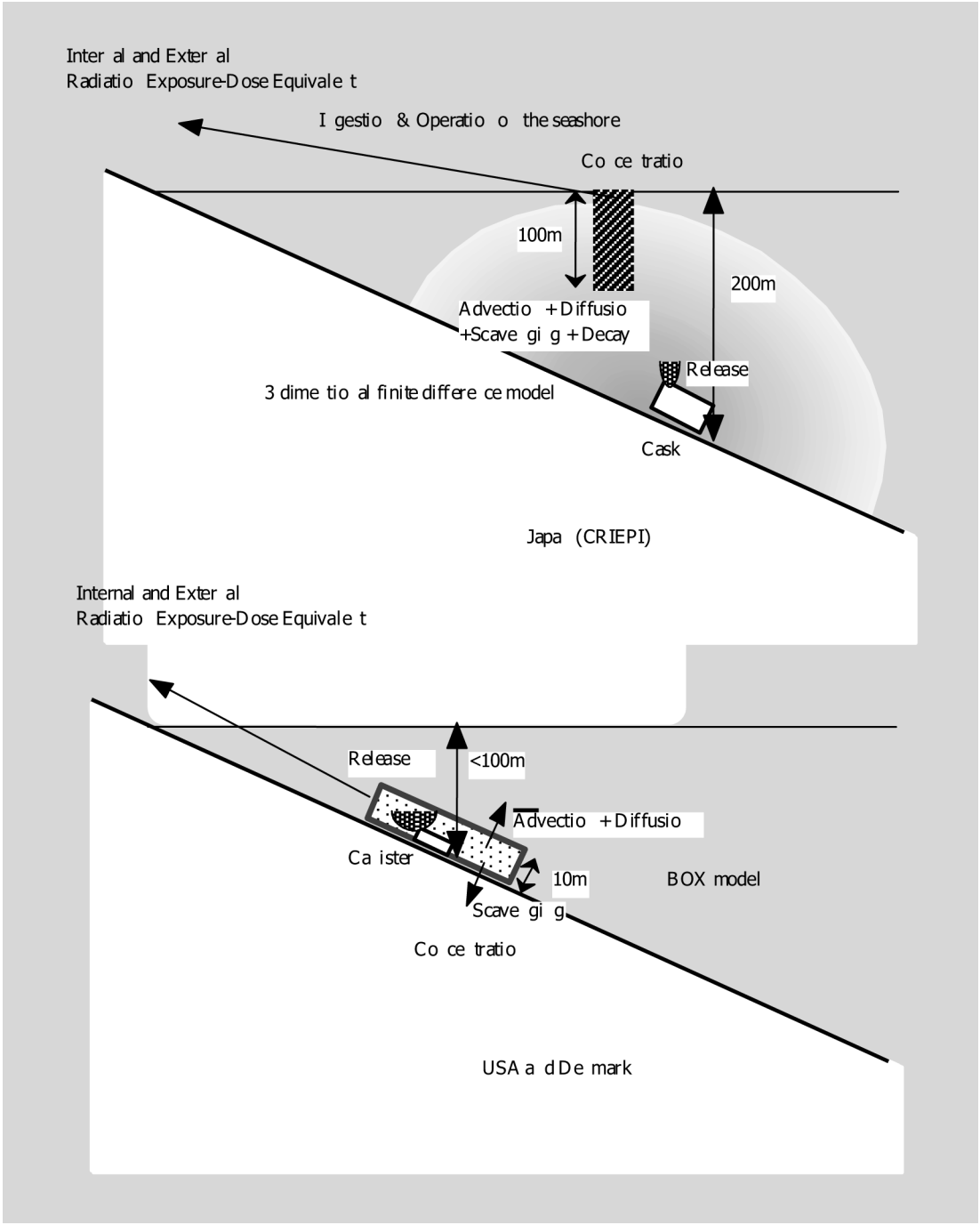


Figure 5. Schematic Drawing of the Sequence of the Assessment.

TABLE 11. THE OUTLINES OF DOSE ASSESSMENTS FOR PUBLIC AT THE SEA TRANSPORT ACCIDENTS NEAR SHORE BY CRIEPI

Country (Organisation)	Nuclear fuel material	Amount	Published year	Submerged area	Scenario of nuclides release into the sea	Flow field	Model to calculate the concentration of nuclides in the sea	Individual dose equivalent
USA (Klett, SNL)[5]	High level wastes	1 canister	1988	Middle Atlantic Bight (< 100 m)	Leaching	Box model (3 boxes) for coastal zone		0.01 mSv/year
Denmark (Neilsen) [6]	Spent fuel	1Tbq	1996	Europian sea (<100 m)	Immediate release	Box model for Europian sea		0.04 mSv/1Tbq release
Japan (CRIEPI)[1]	High level wastes [1]	1 cask (28 canisters)	1995	Off Shimokita 200 m depth	Barrier effect model	One dimensional advection supposed from observed data	Three dimentional finite differences method model	5.9×10^{-4} mSv/year
Japan (CRIEPI)[16]	High burn up spent fuel	1 cask (PWR × 12)	1997					2.3×10^{-3} mSv/year
Japan (CRIEPI)	**High level wastes**	**1 cask (28 canisters)**	**1998**		**Modified barrier effect model**			**3.1×10^{-4} mSv/year**
Japan (CRIEPI)	**PuO2 powder**	**1 cask (14.5 kg)**	**1998**					**1.4×10^{-5} mSv/year**
Japan (CRIEPI)	**Spent fuel**	**1 cask (PWR × 7)**	**1998**					**4.1×10^{-4} mSv/year**

COMPARISON OF OTHER RESULTS

The outlines of dose assessments for public at the sea transport accident by Klett [6], Nielsen [7] and CRIEPI (Japan) are shown in Table 11. In addition, the result of assessment at the case of high burn up spent fuel [4] is also shown in Table 11. This result is larger than the result at the case of conventional spent fuel due to the employment of large cask and its high burn up. In addition, as a recent estimated result, the result of assessment at the case of fresh MOX fuel [5] is also shown in Table 11.

The scenario and method of assessment by Klett and Nielsen are different from that by CRIEPI. The major difference is supposed depth of submergence. The supposed depth of submergence by Klett and Nielsen is several tens meters. Even for the case of submergence of cask to the several tens meters in depth, release of radionuclides by hypothetical reasons were supposed. On the other hand, in CRIEPI, the package would not be collapsed and would keep its integrity at 200 m depth. Because the package meets the requirement for a 200 m water submersion test applied to the package that contains more than 10^5 A_2 value according to the IAEA transport regulation [8]. Since it would be possible to salvage the package from 200 m depth. The submergence of the package at less than 200 m depth is not necessary for assessment. Schematic drawing of the difference of these assessments is shown in Figure 5. In CRIEPI's study, the concentration of nuclides at the surface (0-100 m depth) where almost of the marine product would be taken is used for dose calculation. On the other hand, in the studies of Klett and Nielsen, the concentration of nuclides near the submerged package is used for dose assessment so that the concentration near package contributes to exposure dose. The release of nuclides from package would not be properly assumed because it would be possible to salvage the package from several tens meters in depth. Although, they described in their papers that the possibility of the release of nuclides into ocean would be extremely small.

CONCLUSIONS

The evaluations for spent fuel, PuO_2 powder and high level wastes under the same conditions and by the same methods were carried out. The result of the effective dose equivalent at the case of spent fuel shows the maximum value of 4.1×10^{-4} mSv year^{-1} in 20 years after submergence. The result at the case of PuO_2 powder shows the maximum value of 1.4×10^{-5} mS year^{-1} immediately after submergence. The result at the case of high level wastes shows the maximum value of 3.1×10^{-4} mSv year^{-1} in 2 years after submergence. All results are smaller than previous results. The effective dose equivalents of radiation exposure to the public for all the materials per package are far less than the effective dose equivalent limit (1 mSv year^{-1}) by the ICRP recommendation.

The comparison among the studies in Klett (USA), Nielsen (Europe) and CRIEPI (Japan) was made. The major differences are the supposed depth of submergence, scenario of release of nuclides from package and numerical model for the evaluation of concentration of nuclide. The assumptions for assessment by CRIEPI (Japan) are considered to be more realistic than the other studies in Klett (USA) and Nielsen (Europe).

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