The Safety Assessment of Radioactive Material Transportation at Sea

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INTRODUCTION

Large quantities of low level wastes are prepared for transportastion by special use vessels from each power plant to the storage facility at Rokkasho-mura in Aomori Prefecture. Large quantities of reprocessed wastes are also planned for return by similar vessels to the same place from France and the UK. In this paper we describe the safety assessment in hypothetical accident conditions durig such mass transportation at sea. Although the possibilities of the sinking of the special use vessels as shown in figure 1 are considered to be very low on account of their double -hull structure, it is necessary to estimate the radiological risks of the transportation in order to obtain public acceptance. In this study, the following procedure is taken ;

i) Assumption of Accident
ii) Establishment of Safety Assessment Procedure
iii) Determination of Source Terms
iv) Diffusion Calculation of Radionuclide
v) Estimation of Radiation Exposure of the Public

Figure 2 shows the flow of this study.

SUMMARY OF RADIOACTIVE MATERIALS

The Following are the radioactive materials which are assumed to be the contents of the package in this study, and their typical compositions of radionuclide.
Reprocessed Wastes :

High Level	: Vitrified wastes of FP and TRU
Low & Intermediate Level	: Cement- or bitumen- solidified wastes of hull • endpiece or coprecipitation sludge

Low Level Wates : Cement- bitumen- or plastic-solidified wastes from each power plant in Japan

Characteristics of the source of the radionuclide
The sequence of radionuclide release from the package after sinking can be modeled as follows.

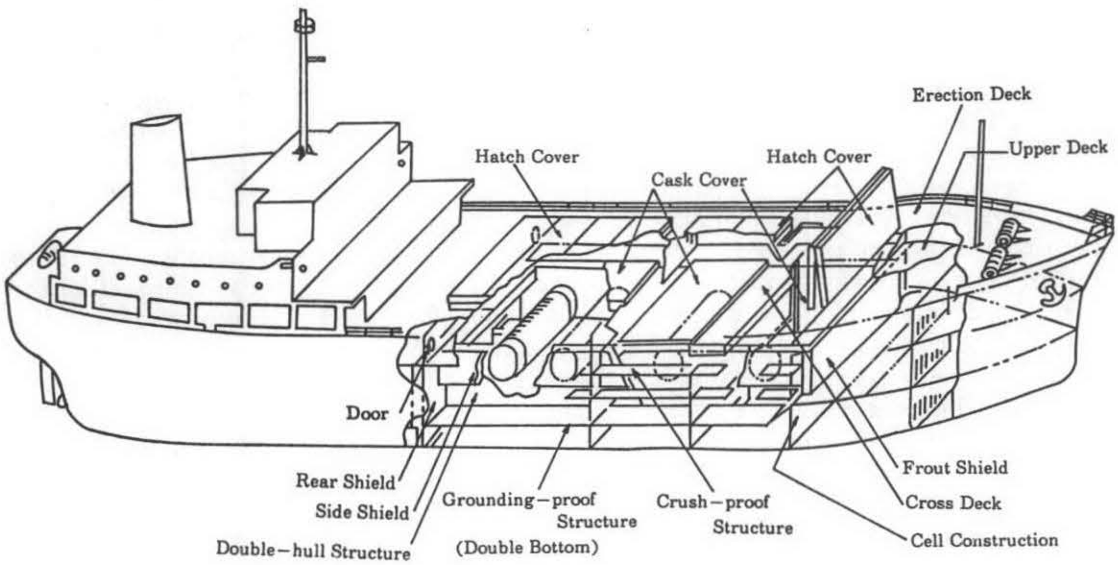

Fig. 1 General View of Special Use Vessel " Hinoura-maru"

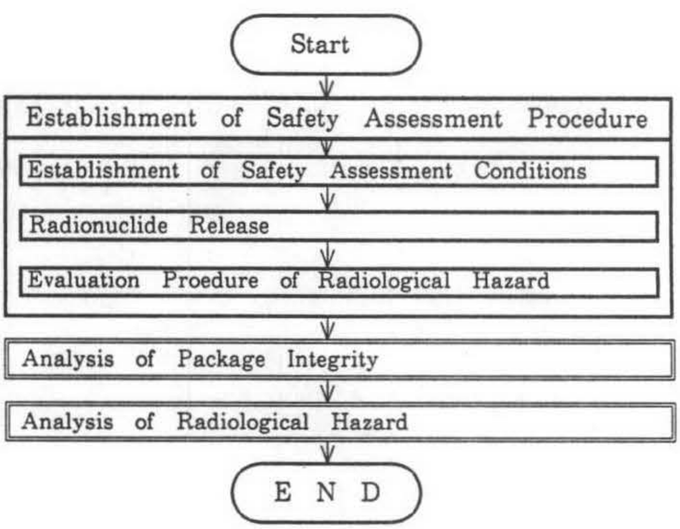

Fig. 2 Flowchart of Safety Assessment

i) Accident
ii) Loss of containment of the package
iii) Loss of containment of the contents (only if applicable)
iv) Radionuclide release

The period from the accident to the loss of the containment of the package is estimated considering the effect of corrosion by sea water if it keeps its integrity against outer pressure, thermal stress and the impact at sea bottom. The details of this corrosion *are described in Risk Evaluation Method During the Transportation at Sea, S. Ozaki* et al., CRIEPI, 1988. If the contents are expected to be contained, the period until loss of containment of the contents is estimated by the same procedure as above.
The source of radionuclide release from the package is determined after the evaluation of the period from the accident until the loss of containment of the package. Two patterns of release are assumed. One is release immediately after sinking, which is the model of the package having no containment or having lost its containment at the time of the accident. The other is the release after loss of containment of the package due to corrosion, which is the model of the package having containment.
These models are used according to the characteristics of the package and the contents. For example, the former model is applied for low level wastes and the latter model is for high level vitrified wastes. The surface area of wastes, which relates directly to the amount released, is assumed to increase 20 times, considering the existence of cracks. The possibility of salvage is also considered.

DIFFUSION CALCULATION OF RADIONUCLIDE

Accident points are assumed for waste along its route. Three different areas with two different depths are chosen for returned wastes and low level wastes respectively.

i) For returned wastes ;
Area A ; Depth 200m
B ; Depth 700m
C ; Depth 200m
ii) For low level wastes ;
Area A ; Depth 200m
D ; Depth 100m
E ; Depth 100m

The distribution of the concentration of radionuclide in the sea is calculated using the analytical solution of the following diffusion equation for the model as shown in figure 3.

$$\frac{\delta C}{\delta t} + V \cdot \frac{\delta C}{\delta y} = D_x \frac{\delta^2 C}{\delta x^2} + D_y \frac{\delta^2 C}{\delta y^2} + D_z \frac{\delta^2 C}{\delta z^2} - \lambda \cdot C$$

where,

H	; Representative depth (m)
λ	; Radioactive decay constant (1/sec)
V(x, y)	; Velocity of ocean current (m/sec)
C	; Concentration of radionuclide
t	; Time after sinking (sec)
(x, y, z)	; Sinking point
DX, Dy, DZ	; Diffusion Coefficient (msec)

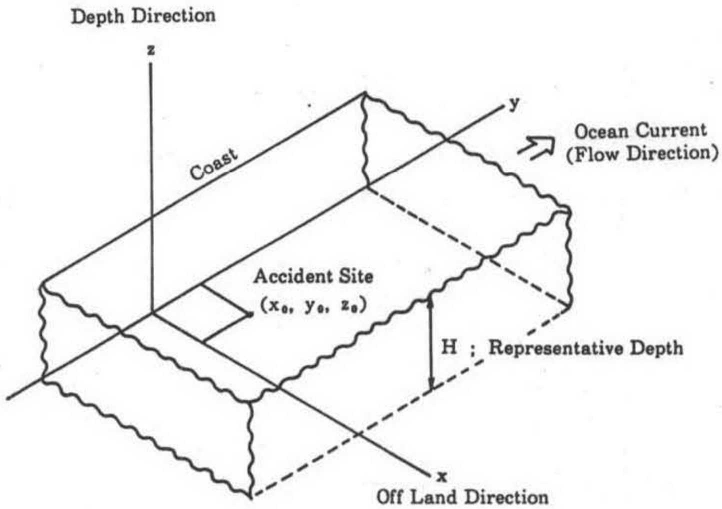

Fig. 3 Coordinate System of Diffusion Model in Ocean

ESTIMATION OF EXPOSURE DOSE

The dose which members of the public have been exposed to, including internal exposure caused by contaminated sea foods, is estimated assuming that the maximum concentration of radionuclide is to be representative of the concerned area of the sea. The following exposure passes are considered.

i) Internal exposure of critical organs caused by ingesting sea foods
ii) External whole−body exposure by radiation from radioactive materials on the shore

Internal exposure of critical organs is evaluated assuming that members of the public consume such sea foods as fish, mollusks and marine plants around the concerned are a of the sea The lung, the colon, the liver and the bone are considered as the critic al organs as well as the whole−body. Adults were chosen to represent the publr in this study. External whole−body exposure is evaluated assuming that radioactive materials diffused from packages drift to the shore and members of the public who wo rk on the shore are exposed to radiation. Figure 4 shows the calculated flow of inte rnal exposure of critical organs caused by consuming sea foods and figure 5 shows the external whole−body exposure by radiation from radiactive materials on the shore.
Table 1 below shows the dose limit of each organ based upon Recommendations of t he ICRP Publication 9.

Table 1 The dose Limit for Each Organ (for Public)

Organ	Dose Limit (mrem/Year)
Whole Body	500
Lung	1500
Colon	1500
Liver	1500
Bone	3000

SAFETY ASSESSMENT OF TRANSPORTATION

Safety assessments for the transportation of radioactive materials at sea are made for seven cases of assumed conditions as shown in above table 2 and table 3. Condition s that are not shown in the above tables are set as follows ;
The ocean current is assumed to be a constant flow in each area ;

Area A & B	: 0.3 m/sec
Area C	: 0.7 m/sec
Area D	: 0. m/sec
Area E	: 0.5 m/sec

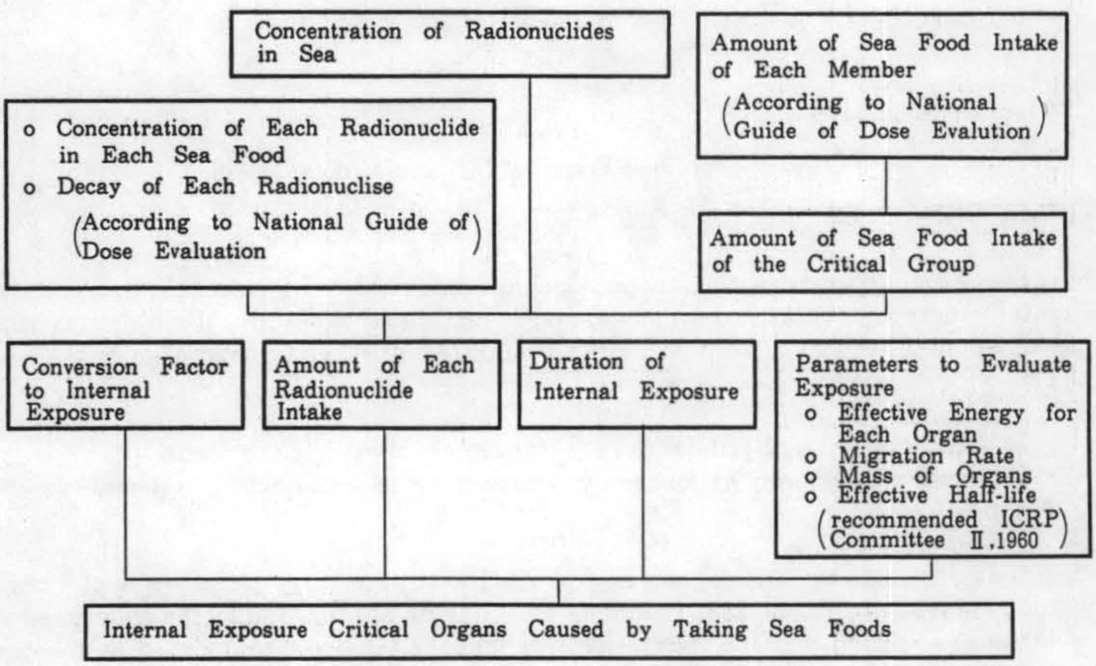

Figure 4 Calculation Flow of Internal Exposure of Critical Organs

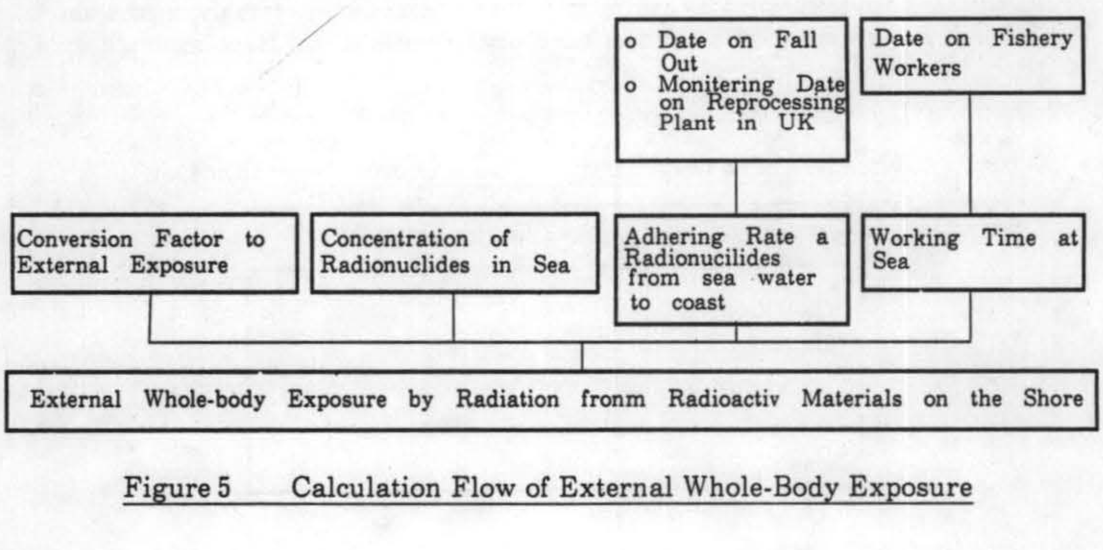

Figure 5 Calculation Flow of External Whole-Body Exposure

Table 2　Safty Assessment Cases for Reprocessed Wastes

				Case		
				1	2	3
			Site	A	B	C
			Depth	200m	700m	200m
Type of Wastes	Solidfication	Container of Contents	Packaging			
High Level (FP etc.)	Glass	Canister	Cask AH	○	○	○
Intermediate Level (Hulls/Ends)	Cement	Drum	Cask L1	○		
Intermediate Level (Co-precipitation sludges)	Bitumen		Cask L2	○		
Intermediate Level (Purification Resins)				○		
Low Level (α technological waste)	Cement	Asbestos Cement	Cask L3	○		
Low Level (non α technological waste)			Container	○		
High Level (FP etc.)	Glass	Canister	Cask BH	○		
Intermediate Level (Hulls)	Cement	Drum	Cask B1			
Intermediate Level (Centrifuge Cake Slurry)			Cask B2			
Intermediate Level (MEB Club) (Barium Carbonate Slurry)	Cement	Drum				
Low Level (Pu Contaminated Materials)		Drum	Cask B3			
Low Level (Solid wastes)		Drum	Cask B4 container			

Table 3　Safety Assessment Cases for Low Level Wastes from Power Plants

Site	A	A	D	E
Depth	200m	200m	100m	100m
Salvage	Impossible	After a year		
Radionuclide Composion Case1 with Low Leaching Rate	○			
Radionuclid Composion Case1 with High Leaching Rate	○	○	○	○
Radionuclide Composion Case2 with High Leaching Rate				○

Table 4 Results of Analysis for Package Integrity

	Hydro-pressure		Thermal Stress	Impact at Bottom	Corrosin			
	200m	700m			Lid	Body	Bottom	O-ring
Cask-AH	○	○	○	○	488Y	570Y	700Y	
Cask-L1	○	○	○	○	560Y	520Y	560Y	
Cask-L2	○	○	N.A	○	620Y	620Y	620Y	33Y
Cask-L3	○	×*1	N.A	○	400Y	100Y	100Y	
Cask-BH	○	○	○	○	700Y	540Y	700Y	
Canister	×*2	×*2	N.A	N.A	N.A			

○ : OK, × : Out

*1 : Strain will reach up to 15% at a depth of 400m by elastic and Plastic analysis

*2 : Bukling will occure at a depth of loom by bucking analysis

The Eddy diffusion coefficient is assumed to be 10^7 cm^2/sec for the horizontal direction and $200cm^2/sec$ for the vertical direction.

The integrity of packages for reprocessed wastes are examined when they are subjected to such conditions as hydropressure, impact at sea bottom, thermal stress and corrosion. The results of the above examinations are shown in table 4.

RESULTS AND CONCLUSION

Table 5 and table 6 show the results of the estimation for radiation exposure for members of the public. The internal exposure caused by reprocessed wastes is below the dose limit by two orders and the external exposure is one tenth of the internal exposure. As for low level wastes, the exposure of members of the public is below the dose limit by nine orders. This means that the exposure dose from radioactive wastes would be much less than that of the natural background level even if a serious accident happens and packages sink into the sea.

REFERENCE

S. Ozaki et al., *Risk Evaluation Methods during Transport at Sea*, from the Proceedings of the 1988 Annual Meeting of the Atomic Energy Society of Japan., (1988) .

Table 5 Results of Estimation of Radiation Exposure (Reprocessed wastes)

(mrem/year)

Site		A							B	C
Wastes		High Level	Hulls	Co-Sludge	Resin	α	Non-α	High Level	High Level	High Level
Depth(m)		200	200	200	200	200	200	200	700	200
Internal Exposure	Whole-Body	2E−01	3E−4	4E−07	1E−06	9E−06	8E−07	1E+00	7E−02	9E−02
	Lung	3E−02	4E−05	1E−07	4E−12	−	−	1E−01	8E−03	2E−02
	Colon	3E+00	4E−03	2E−06	3E−05	2E−04	2E−05	2E+01	1E+00	7E−01
	Liver	3E−01	3E−04	9E−07	5E−09	5E−10	4E−12	1E+00	1E−01	2E−01
	Bone	2E+00	3E−03	1E−06	2E−05	2E−04	1E−05	1E+01	7E−01	6E−01
Enternal Exposure	Whole-Body	3E−01	5E−04	9E−07	1E−07	2E−08	2E−09	1E+00	8E−02	2E−01

Table 6 Results of Estimation of Radiation Exposure (Low Level wastes Power Plants)

(mrem/year)

Site		A			D	E	
Depth(m)		200	200	200	200	100	100
Salvage		−	−	After a year	After a year	After a year	After a year
Leaching Rate		High	Low	High	High	High	High
Radionuclides Composition		Case1	Case1	Case1	Case1	Case1	Case2
Internal Exposure	Whole-Body	1E−08	9E−10	1E−08	8E−08	2E−08	1E−08
	Lung	1E−09	8E−11	1E−09	6E−09	1E−09	2E−10
	Colon	9E−07	6E−08	9E−07	5E−06	1E−06	6E−07
	Liver	1E−08	8E−10	1E−08	7E−08	2E−08	7E−09
	Bone	1E−07	7E−09	1E−07	5E−07	1E−07	7E−09
Enternal Exposure	Whole-Body	6E−08	4E−09	6E−08	3E−07	2E−07	1E−07