AN ENVIRONMENTAL IMPACT ASSESSMENT FOR SEA TRANSPORT OF SPENT FUEL

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SUMMARY

High burn-up spent fuel will be transported from each Japanese nuclear power station to the reprocessing facility of Japanese Nuclear Fuel Ltd. in Rokkasho-mura by the purpose built ship. Packagings of high burn-up spent fuels are manufactured strong and conformed to the IAEA Transport Regulations. This purpose built ship is much safer than other ordinary cargo ships because of its specially reinforced structure and navigation systems against collision with other ships, etc. Therefore, it is hardly supposed that high burn-up spent fuels would meet with any accident and that they would submerge into the sea. This paper presents a result of environmental impact assessment for a hypothetical submergence accident of high burn-up spent fuel during sea transport. In this assessment, calculation methods of nuclide and radiation dose, etc. are almost same as that employed by CRIEPI assessment for HLW (CRIEPI, 1995 and 1996).

PREMISE OF ENVIRONMENTAL IMPACT ASSESSMENT

This assessment consists of "Discussion of the hypothetical accident", "Establishment of the scenario of nuclide release to the environment", "Calculation of discharge rate", "Calculation of nuclide concentration in seawater" and "Dose estimation"(Fig. 1). One cask containing 14 high burn-up PWR-type fuel assemblies (average burn-up : 44,000 MWD/MTU) is the subject of this assessment. The package is filled with water during transportation. Nuclides composition was calculated by the ORIGEN2 code on the condition that 620 days have passed after extraction of the fuel assemblies. Major nuclides are as shown in Table 1.

The purpose built transport ship cruises near shore of Japanese four main islands. It is hard to suppose submergence of ship, because the ship is equipped with the prevention system against collision, double hull and sole structure, etc.. As a hypothetical accident, submergence of ship was assumed at the near shore of the Shimokita Peninsula in which the reprocessing plant of JNFL is under construction. This area is located at north-east part of Japan and faces onto the Pacific Ocean.

The package was assumed to be submerged onto the seabed of 200m depth, it was also assumed to loss the sealability of packaging as described below. This area has narrow

continental-shelf, then the submergence point is located at 7km off the seashore of the Shimokita Peninsula(Fig 2). The package does not rupture under the water pressure of 200m in accordance with the IAEA Transport Regulation. In addition, a similar type B package for High Level wastes was experimentally demonstrated to keep its containment under the water pressure of 3000m or more(Gomi et al.,1995). Based on the experiment and analysis, the containment of the package for the high burn-up spent fuels was shown by calculation to be kept for the water pressure of 3400m. Recovery of such package sunk at the depth of 200m would be possible (IAEA, 1997). Therefore, environmental impact assessment of a package sunk at the depth less than 200m would not be necessary. Based on these technical consideration, the package was assumed to be submerged onto the seabed of 200m depth.

Considering the packaging structure and the containment properties, the scenario of nuclides release from spent fuel rods into the ocean was assumed in this assessment. According to this scenario, the discharge rate to the ocean was separately calculated in each nuclide. Since a Type B packaging (i.e. metal made cask) is designed to withstand external pressure, it should not be damaged under the pressure of 200m depth. However, the conservative scenario was adopted in this assessment as follows (Fig.1 and 3)

1) ***The package sealability is lost and some gap is generated between the lid and the body.***
For a Type B package, O-rings made of elastomer are used at the interface of the packaging lid and body. In this assessment, O-rings are assumed to simultaneously lose the sealability with the submergence. Some gap, which equals to the surface roughness of interfaces of the lid and the body, is conservatively assumed to be generated. For the objective packaging, surface roughness of the lid and the body are controlled less than *Rz* 6.3 μ m (*Rz*:height of the profile irregularities in ten points) and *Rz* 3.2 μ m respectively in manufacturing. In this assessment, 10 μ m gap, i.e. 0.01mm gap, is assumed to exist uniformly around the whole circumference of interface (Fig. 4), although the real configuration is irregulated

2) ***Nuclides of spent fuel leach into water inside the cavity.***
Spent fuel pellets are sealed inside of a cladding tube, and the cladding tube has no possibility to be ruptured under the pressure of 200m depth. In this assessment, however, it is assumed that the spent fuel pellets would be exposed to water filled in the cavity. Then, nuclides leach into the water. Here, concentration of Pu, Am and Cm, i.e. insoluble nuclides, is limited with solubility of each nuclide. Leaching rate data were quoted from the report (CRIEPI, 1978) and solubility data were derived from the report (PNC, 1992). These leaching rate data were based on experiments with spent fuel pellets, while solubility data were theoretically calculated values.

3) ***The water with solved nuclides is released from the cavity to the surrounding ocean.***
The water in the cavity are warmed by the spent fuels and become warmer than the surrounding seawater of the packaging. The water with dissolved nuclides are released through the gap of sealed interface by buoyancy. Values of the flow rate at the sealed interface are taken from the report (CRIEPI, 1995).
The leaching rate of nuclides, the nuclides concentration in cavity and the nuclides release

rate from the packaging are related with the equations illustrated in Figure 3. Solving these equations by consideration of nuclide decay, the release rate was obtained in each nuclide.

CALCULATION OF NUCLIDE CONCENTRATION IN SEAWATER

Ocean current, diffusion, scavenging, nuclide decay and seabed topography were considered in the calculation model, and nuclide concentration in sea water were calculated with this model.

The three-dimensional conventional diffusional equation was solved by the method of finite difference. Scavenging and nuclide decay were considered at this time.

$$\frac{\partial C_i}{\partial t} = V\frac{\partial C_i}{\partial y} + Dx\frac{\partial^2 C_i}{\partial x^2} + Dy\frac{\partial^2 C_i}{\partial y^2} + Dz\frac{\partial^2 C_i}{\partial z^2} - Kd\,\rho_s w_s\frac{\partial C_i}{\partial z} - \lambda C_i \qquad \text{(Eq.1)}$$

advection　diffusion of x,y, z direction　scavenging　decay

C_i: Radionuclide concentration (Bq/cm^3)
x,y,z: Geographical coordinates (m)
D_x,D_y,D_z: Ocean diffusion coefficient (m^2/s)
K_d: Distribution coefficient of nuclides(m^3/g)
w_s: Sedimentation velocity of suspension (m/s)
t: Time (s)
V: Advective velocity (m/s)
λ : Decay constant of nuclides (1/s)
ρ_s: Concentration of suspension(g/m^3)

The assessment area is 320km north and south, 170km east and west, the seabed configurations are divided with mesh based on depth data derived from JODC(JODC, 1991). Each mesh size is horizontally divided in 5km regular intervals and vertically divided in minimum 10m.

0.1～0.3 knots southwards current to be parallel to the seashore is remarkable in this assessment area. The advective velocity in each mesh was estimated by seasonal mean velocity at the sea surface of subject area for 30 years using the JODC's data(JODC,1991). Since the vertical advective distribution was unknown, the flow was assumed to be uniform in the depth direction, then the compensation was executed so that the flow field would approximately keep the law of conservation of mass(JAERI, 1983).

The horizontal diffusion coefficients were assumed to be 10^5cm^2/sec, according to the Richardson's four-third power law. The vertical diffusion coefficients was assumed to be 10cm^2/sec. The concentration of suspension was employed from the larger value of 1.25g/m^3(SAND,1983), and the distribution coefficient value was employed from the recommendation value of IAEA safety series No.78(IAEA,1985).

CALCULATION METHOD OF THE DOSE-EQUIVALENT BY RADIATION EXPOSURE

The exposure path of internal dose-equivalent was quoted from the guideline for Japanese

nuclear sites by the Nuclear Safety Committee(ICRP, 1977 and NSCJ,rev.1989). The released form to the environment was assumed that internal exposure should be caused by marine products ingestion. As the values of ingested fishes in which the nuclides are taken and condensed, the values were employed for a referenced man per day as shown in the guideline for dose-equivalent evaluation in Japan (ICRP,1987 and NSCJ,rev.1989). The exposure path of external dose-equivalent was also quoted from the guideline for Japanese nuclear sites (NSCJ,rev.1989).

The dose reduced factors were quoted from ICRP Pub.30 data, and daily ingestion values of marine products were quoted from Japanese dose assessment study(NSCJ,1989), in which the values are 200g/day for fishes, 20g/day for invertebrates and 40g/day for seaweed. Concentration factor of each marine product was also quoted from the previous UCRL report(Thomson S.E.et al., 1972). The maximum annual concentration in the discussed area was adopted for the concentration which was used in the above dose calculations. This value is extremely conservative one so that people daily eat marine products fished in the maximum concentration point, and this value was estimated by averaging of surface to 100m depth concentration, considering the habitation depth of fishes and the external exposure path.

RESULTS

The public dose was estimated as the maximum value of 2.3×10^{-3}mSv/year for submergence of one package. This value is equivalent to one four hundredth of 1mSv/year which is the recommended value for public by ICRP. The public dose slowly increases right after the submergence, then it comes to the maximum value at 25th year, and it keeps the same level for a few decades(Fig.5). The release rate to the ocean slowly increases, because the leaching rate from pellet is extremely slow and the nuclide concentration of seawater in the cavity takes long time. The dominant nuclides of dose-equivalent were Pu-238, Cm-244, Ba-137, Cs-137, Y-90 and Pu-241. Ingestion of marine products was the dominant path so that it shares 90% of total dose-equivalent.

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Table 1 Major nuclides contained in one package

Nuclide	Half decay (y)	Activity* (Bq)	Nuclide	Half decay (y)	Activity* (Bq)
Sr-90	2.91E+01	1.76E+16	Eu-154	8.80E+00	3.07E+15
Y-90	7.31E-03	1.76E+16	Pu-238	8.77E+01	9.82E+14
Ru-106	1.01E+00	4.67E+16	Pu-239	2.41E+04	6.35E+13
Ru-106	9.48E-07	4.67E+16	Pu-240	6.54E+03	1.08E+14
Cs-134	2.06E+00	3.14E+16	Pu-241	1.44E+01	2.96E+16
Cs-137	3.00E+01	2.64E+16	Am-241	4.32E+02	1.14E+14
Ba-137m	4.86E-06	2.50E+16	Cm-244	1.81E+01	1.40E+15
Pr-144	3.29E-05	5.77E+16	——	——	——

* : This value was calculated by the ORIGEN2 code on the condition that 620 daye have passed after extraction of the fuel assemblies.

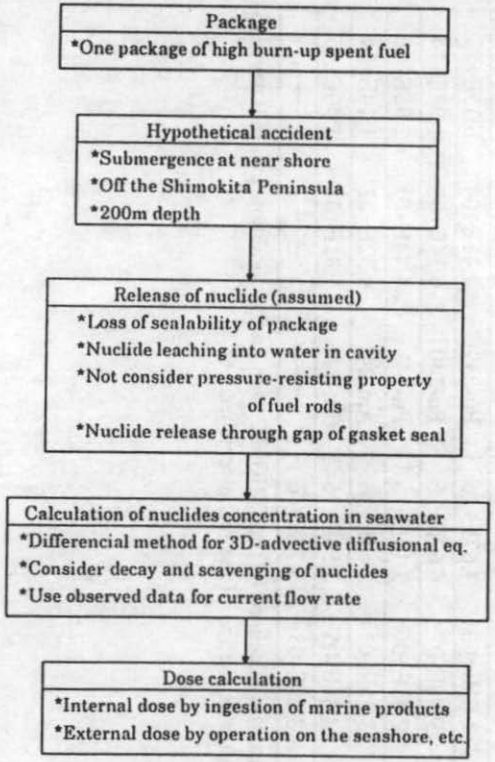


Fig.1 Schematic flow of assessment

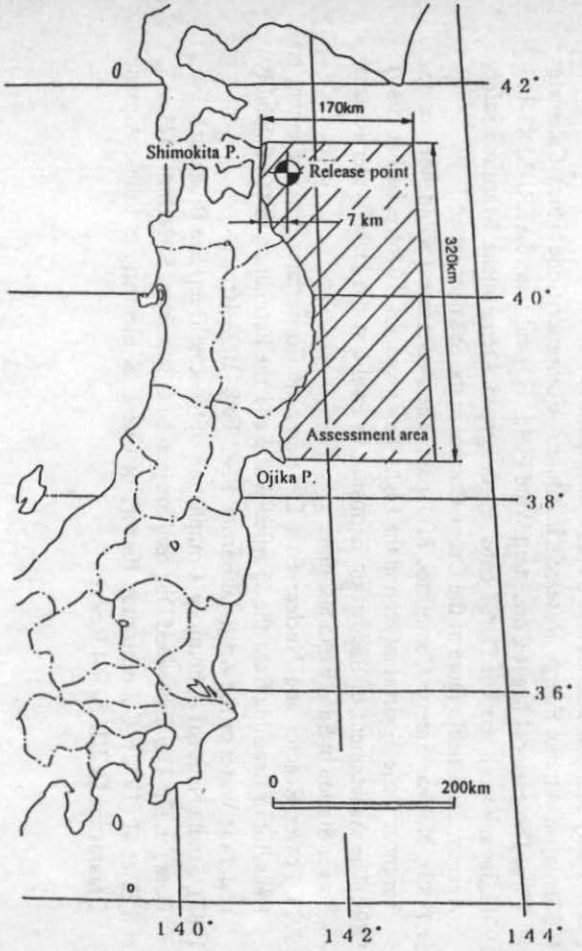
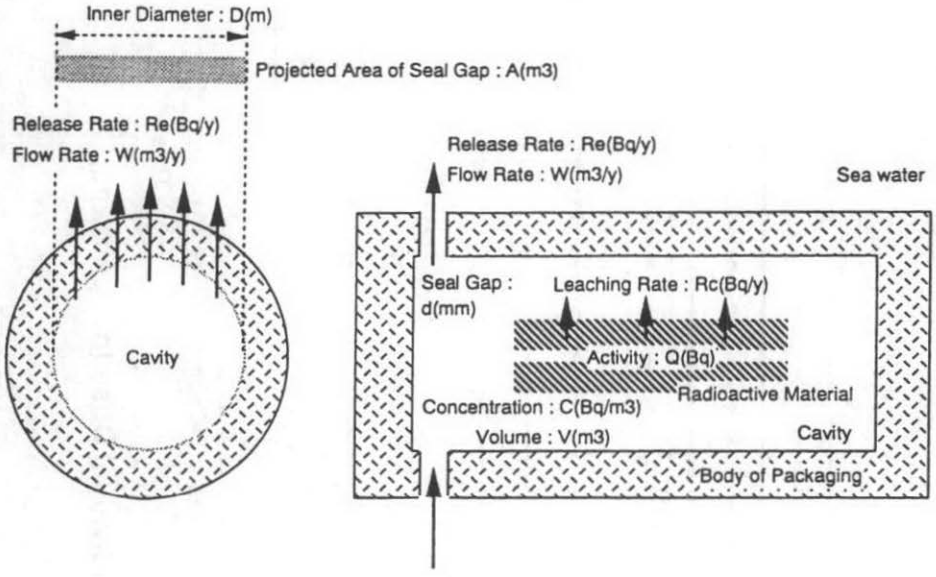


Fig.2 Assessment area



Scenario of Release

- Package is submerged
- Seal gap is generated.
- Sea water flows into cavity.
- Inner container is broken.
- Radioactive Material is exposed to cavity water.
- Nuclide leaches into cavity water [Eq.①]
- Concentration of nuclide in cavity water increases. (up to solubility) [Eq.④]
- Cavity water dissolving nuclides flows out into sea [Eq.③]

Equations

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 Insoluble Nuclide and Glass $C' \leqq Cs$

Variables

- Rc : Release Rate into Cavity Water (Bq/y)
- Rp : Leaching Rate (g/cm2/y)
- μ : Surface/Weight Ratio of Radioactive Material (cm2/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 : Concentration in Cavity Water (Bq/m3)
- C' : Concentration in Cavity Water (after dt) (Bq/m3)
- Cs : Solubility of Insoluble Nuclides (Bq/m3)
- W : Flow Rate through Seal Gap (m3/y)
- V : Volume of Cavity (m3)

Note : For Plutonium Dioxide, the concentration in cavity water would immediately reach to its solubility .

Fig.3 Release Scenario and Process of Calculating Release Rate

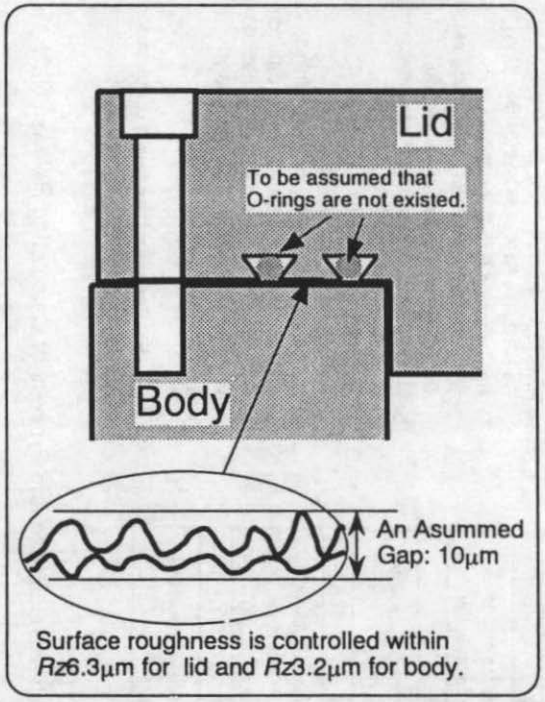


Fig. 4 Schematic view of seal gap

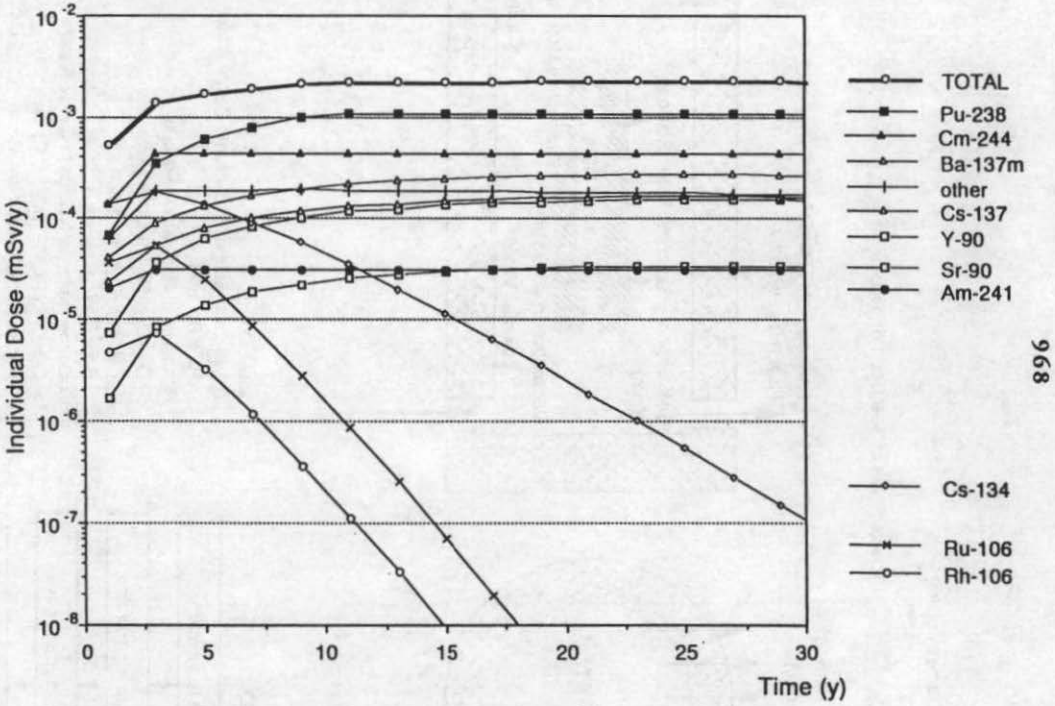


Fig. 5 Result of Individual Dose (per package)