Study on Method of Environmental Impact Assessment During Sea Transportation of Radioactive Materials

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Introduction

There is a special safety standard called INF Code at IMO (International Maritime Organization) for structure and systems of transport ships of high-level wastes. In Japan , there is a technical standard which is adopted from the INF Code by the Director-General of the Maritime Technology and Safety Bureau, Ministry of Transport. It is extremely difficult to assume that a ship will crash into another ship and a fire break out, and if it should happen, it is hard to predict that the ship will sink.

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 IAEA (International Atomic Energy Agency, 1986). In the regulations, a technical standard and quality assurance program of packaging, etc., are stipulated, and every country in the world which has activities of nuclear energy incorporates the regulations into its domestic legislation and has ensured the safety of the international transport of radioactive materials. In regard to environmental impact assessment, there are no requirements in the regulations.

Therefore, in this research, an environmental impact assessment has been made by assuming that a package might sink for unknown reasons. The sequence of the assessment is shown in Figure 1.

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Premise of Environmental Impact Assessment

Source term and the packaging for high-level waste

High-level wastes (the vitrified residue in a canister) are returned to Japan from BNFL (U.K.) and COGEMA (France). The specifications of these wastes are different from each other. In this assessment, the BNFL's specification, which has more radioactivity per canister than the COGEMA's, shall be employed.

The packaging for high-level waste is the type B. In this study, it was supposed that one package would sink into the sea for an unknown reason.

Supposed location of submerged package

As to locations that the package sinks into the seabed, two different areas, near shore and deep sea, will be supposed.

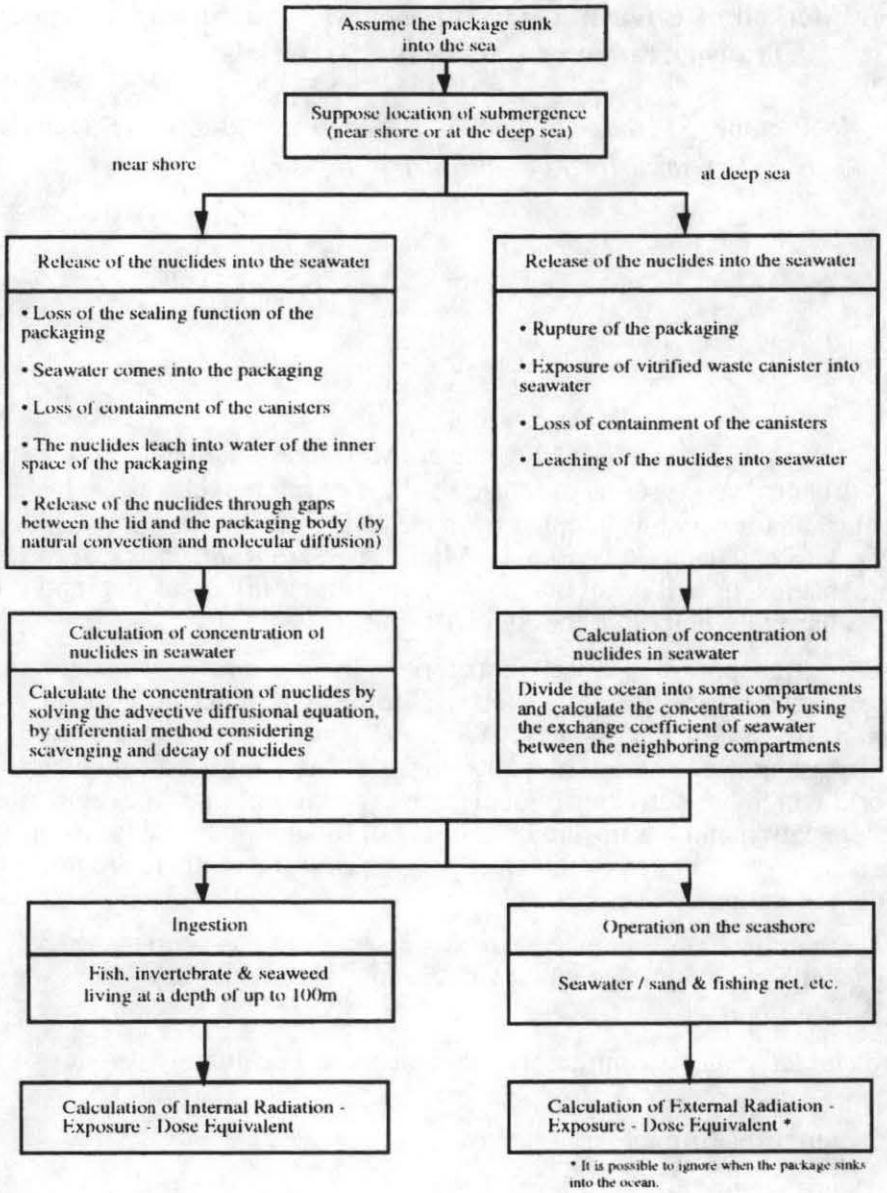

Fig .1 Sequence of the assessment

For assessment in the case where the package sinks near shore, the supposed location is on the Pacific side of eastern Japan (called Tohoku). Judging from the present technology, it is possible to salvage the package up to a depth of 200 m, so the submergence point is supposed at a depth of 200 m. For assessment in the deep sea, the supposed location is at the north Pacific Ocean near Japan.

Environmental Impact Assessment for Near Shore Sunk Case

Area of assessment

Area of the assessment for the near-shore case is north from Shimokita Peninsula on the Pacific in east Japan, south to Ojika Peninsula. The length of the area of the simulation is 350 km, and the 200 m depth point is 7 km off the shore.

Nuclides released into the sea

(1) Scenario

As the HLW packages complied with the IAEA's transport regulation and are extremely safe, it is apparent that should the package sink into the sea to 200 m, it would not be ruptured by the water pressure and would keep its integrity. Therefore, it would not be possible for seawater to get into the packaging and fill the inside. But in this research, a conservative scenario was supposed so that the nuclides of HLW might be released into the sea as follows.

1) After sunk, the O-ring at the lid loses its function, and seawater comes into the packaging.
2) Inner space of the packaging shall be filled with seawater, and the upper part of the canister will buckle and rupture by the pressure of seawater. Then the vitrified wastes are exposed to the seawater.
3) The radioactive nuclides are leached into the seawater of the inner space of the packaging, and the water in the packaging becomes a solution of the nuclides. The solution is released into the sea through the gap between the lid and the flange, as a result of natural convection caused by the difference of temperature in and out of the packaging and the molecular diffusion of the nuclides in the seawater.

(2) Contact area of the vitrified residue with seawater

At the melting and during cooling, irregularities and cracks arise on the surface of the vitrified waste. As a result, it has been reported that the surface area increases about 20 times at most (NAGRA 1983). So in this research it is assumed that the contact area of the vitrified waste becomes 20 times that of the geometric section area.

(3) Leaching ratio and saturated concentration

Based on the following mechanism, it was assumed that the nuclides were released from the vitrified waste to inside the packaging, then released to the seawater.

1) The nuclides in the vitrified waste are leached into the seawater at the contact area. The leaching rate was taken from NAGRA report (1983).
2) It is assumed that leaching-vitrified waste includes the nuclides in proportion to the weight ratio. In these nuclides, nuclides such as Cs and Ru are soluble and dissolved in the seawater at the above-mentioned rate until the concentration of the vitrified waste to the seawater was saturated. Insoluble nuclides such as Np and Cm are dissolved at the above-mentioned rate until the concentration of each element was saturated, but thereafter the concentration of the nuclides in the seawater is kept at the saturated value. The saturated concentration was acquired from the research data of Power Reactor and Nuclear Fuel Development Corporation (PNC 1992).
3) The leachate (seawater inside the package) shall be released to the outside of the package through the gap between the lid and the packaging body by the natural convection caused by the leachate's temperature rise and molecular diffusion phenomena.

Method of calculation of nuclides concentration in the seawater

Nuclides concentration near shore have been evaluated by calculating three-dimensional diffusion equation with the finite differences method. The following shows the assessment model, the three dimensional diffusion equation, the assessment parameters, etc.

(1) Model

The mesh size of the assessment model is a few kilometers in the horizontal (X, Y) direction and 10 meters in the depth (Z) direction. The seabed of the offshore of the Tohoku region of the Pacific Ocean and its shore have been modeled as steps and straight lines respectively. (cf. Fig.2)

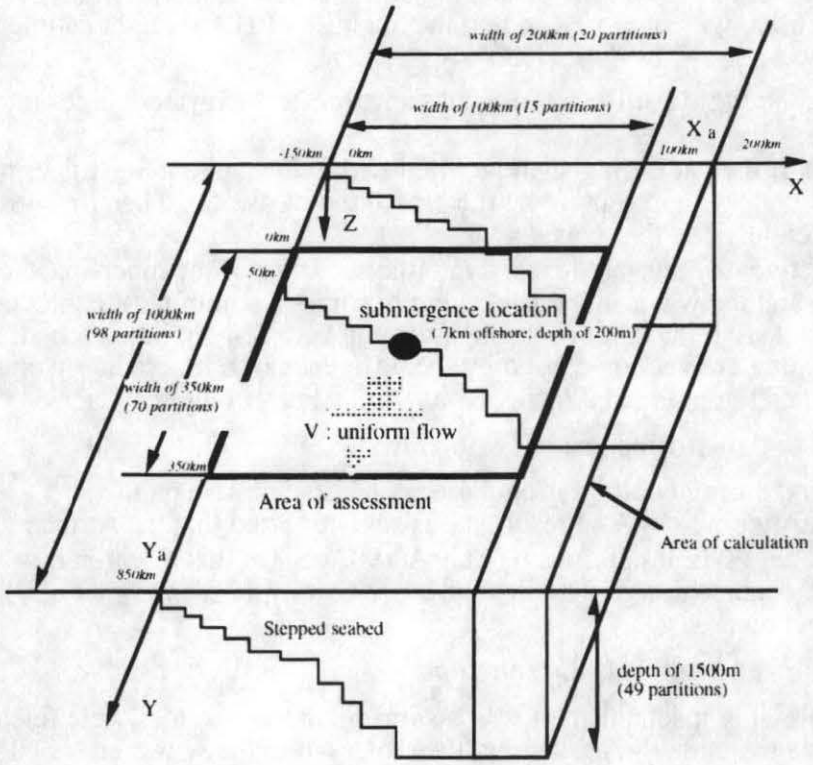

Fig. 2 Analysis model of the evaluation of the area near shore

(2) Basic equation

The basic equation is the three-dimensional diffusion equation (Eq.1) in consideration of advection, ocean diffusion, absorption of suspended particles and sedimentation of nuclides (called "scavenging"), and nuclides decay.

$$\frac{\partial C_i}{\partial t} = V\frac{\partial C_i}{\partial y} + D_x\frac{\partial^2 C_i}{\partial x^2} + D_y\frac{\partial^2 C_i}{\partial y^2} + D_z\frac{\partial^2 C_i}{\partial z^2} - K_d\rho_s w_s\frac{\partial C_i}{\partial z} - \lambda C_i \qquad \text{(Eq.1)}$$

(advection) (diffusion of x, y, z direction) (scavenging) (decay)

C_i: Radionuclide concentration (Bq/m^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)

(3) Input conditions

As for the basic equation, calculations have been made employing the following values.

1) Advective velocity

The advective velocity was estimated by the seasonal mean velocity at the sea surface on 55 points of the subject area from 1965 to 1989 using the JOCD's data (JODC 1991).

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.

2) Ocean diffusion coefficient

The diffusion coefficients in the horizontal direction were assumed to be $10^5 cm^2/sec$ in the offshore direction (perpendicular to shoreline) and $10^6 cm^2/sec$ along the coast (parallel to shoreline), that is based on Richardson's four third-power law (M. Hino 1991) on condition that the order of diffusion in the horizontal scale is 10 km. For Z (depth) direction it was assumed to be 10 cm^2/sec (A. Ohkubo 1977).

3) Distribution coefficient of element

The value distribution coefficient of elements is employed from the IAEA safety series No.78 (1986).

4) Sedimentation velocity of suspended materials and their concentration in the seawater

Referring to the SANDIA REPORT (1983), the values of the sedimentation velocity and the concentration of suspended materials in the seawater were assumed.

(4) Calculation of nuclides concentration

The nuclides concentration to be calculated in the ocean shall be the maximum of the average of the surface layer, which is the habitat of fishes that are ingested by the public. (0~100m deep)

Calculation method of the dose-equivalent by radiation exposure to the public

The internal dose-equivalent from ingesting the fishes from the area of calculation and the external dose by marine operation were calculated through the calculation methods in the following documents (quoting from the calculation model of effective dose-equivalent in ICRP Pub.30 (1977) and ICRP Pub.51 (1987)).

(1) Calculation of internal dose-equivalent

The exposure route was quoted from the guideline (Nuclear Safety Committee 1989a) of the calculation model for evaluating the dose-equivalent around a nuclear site during the stage of the basic plan. The released form to the environment is limited to leach into the ocean. It was assumed that internal exposure is caused by seafood ingestion.

As the values of ingested fishes in which the radionuclides are condensed, the values were employed for a referenced man per day as shown in the guideline for dose-equivalent evaluation in Japan (Nuclear Safety Committee 1989a).

(2) Calculation of external dose-equivalent

The exposure route was quoted from the case of the evaluation of dose-equivalent of liquid waste (Nuclear Safety Committee 1989b) for safety examination of nuclear power station.

The parameters based on the evaluation of dose-equivalent of liquid waste were employed.

Result

If the package should sink in the sea off the Tohoku region, the dose equivalent of radiation exposure to the public will be 5.9×10^{-4} mSv/year at maximum after 2 months

from submergence. This is far less than the dose-equivalent limit for the public (1 mSv / year) in the ICRP recommendations.

Environmental Impact Assessment in the Deep Sea

Environmental impact assessment was made supposing that the package sinks in the deep sea. The assessment follows the aforesaid case sunk near the shore basically, but the assessment model and accident scenarios are different.

Area of assessment

Area of assessment in the ocean is all of the Pacific Ocean in a case in which a package sinks to a depth of 2,500 m in the North Pacific Ocean near Japan.

Condition of nuclides released into the sea

As soon as the packaging reaches the seabed, it will collapse from the water-pressure and all of the vitrified waste shall be exposed instantly.

As for another condition (the increase of the contact area with the seawater, leaching ratio), it shall be based on the assessment in another case.

Method of calculation of nuclides concentration in the seawater

(1) Model

The assessment in the ocean employs the compartment model in consideration of the customary distribution of water mass which is reported by Wada (1992)

The conceptual sequence of the compartment model is shown in Fig.3. For the horizontal direction, the sea area of mainly the north Pacific Ocean is divided into 27 compartments as reported by Wada (1992) (The ocean near Japan is divided into small pieces , while the Atlantic Ocean, the Indian Ocean , the Arctic Ocean, and Antarctic Ocean surrounding the Pacific Ocean are divided into one, respectively). The horizontal compartments are shown in Fig.3. The vertical compartments are divided into 5 layers.

(2) Basic equations

The basic equations are derived from the advection diffusion equations (which are the same at another case) multiplied by compartment volumes to both sides. Instead of the advection velocity, the concept of the exchange flow between compartments is used. They are given as follows:

$$V_i \cdot \frac{\Delta C_i}{\Delta t} = \Sigma\ Q_{ji} C_j - \Sigma\ Q_{ij} C_i + \Sigma D A_{ij} (C_j - C_i) / L_{ij} + w_s A_{ij1} C_j^P - w_s A_{ij2} C_j^P - \lambda C_i V_i \quad \text{(Eq. 2)}$$

(advection) (diffusion) (scavenging) (decay)

$$C_i = C_i^W + C_i^P \quad \text{(Eq. 3)} \qquad C_i^P = C_i^W K_d \rho_{si} \quad \text{(Eq. 4)}$$

C_i: concentration of the nuclides on compartment i (g/m^3)

C_i^W: concentration of the nuclides dissolved in the seawater on compartment i (g/m^3)

C_i^P: concentration of the nuclides adsorbed by the suspending particles (g/m^3)

V_i: volume of the compartment i (m^3) Q_{ji}: exchange coefficient from compartments i to j (m^3/sec)

A_{ij}: contact area of compartments i and j (m^3) L_{ij}: mean distance of compartments i to j (m)

D: horizontal or vertical diffusion coefficient (m^2/sec)

ρ_{si}: concentration of the suspending particle of compartment i (g/m^3)

w_s: sedimentation velocity of the suspended material (m/sec)

K_d: distribution coefficient of the nuclides (m^3/g) λ: decay constant of the nuclides (1/sec)

t: time (sec) j: compartment neighboring compartment i

$j1, j2$: compartments above and below compartment i

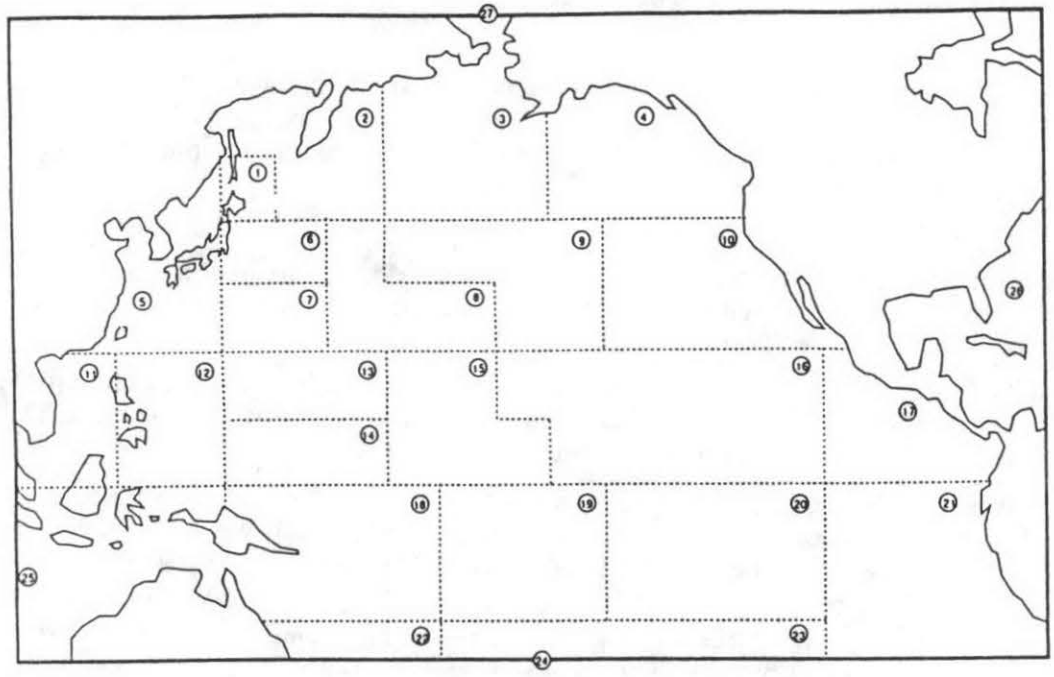

Fig.3 The horizontal compartments (A. Wada 1992)

(3) Conditions of input data

1) Exchange coefficient(Exchange flow) : Exchange flow for the advection velocity is referred to Wada (1992). As a reference it shows the method of solution as shown below.The exchange coefficients are determined by the following equations, the conservation laws of seawater, salt, and heat. The simultaneous equations of the conservation of seawater, salt and heat are solved to determine the exchange coefficient between the neighboring compartments. There are more variables than the number of simultaneous equations and there are an infinite number of solutions. So the basic equations were solved by using the Non-Linear Programming.

2) Ocean diffusion coefficient : Considering the diffusion scale, the horizontal ocean diffusion coefficient was assumed to be 1.0×10^7 cm^2/s, and the vertical to be 1.0 cm^2/s.

3) Distribution coefficient of element : It is assumed to be the same as the assessment at another case.

4) Concentration in the seawater and sedimentation velocity of suspended material : The sedimentation velocity is assumed to be the same for the coast. The concentration in the seawater is quoted from Sandia Report (1983).

(4) Calculation of the nuclides concentration

The concentration of the nuclides of each compartment can be calculated by substituting the determined exchange coefficient to equations (Eq.2, 3, 4).

The concentration of the nuclides used for evaluation of exposure are assumed to be the maximum value for 0 to 100 m deep in the surface compartments, the same as the

evaluation near shore.

Calculation method of the dose-equivalent by the radiation exposure to the public

The internal dose-equivalent from ingesting the fishes was calculated the same as the assessment in another case. For the external exposure, the submergence location is so far from the shore that the impact could be ignored.

Result

If the package should sink into the sea as mentioned above, the dose-equivalent of radiation exposure to the public will be 4.7×10^{-9} mSv/year at maximum 45 years after the submergence. This is far lower than the dose-equivalent limit for the public (1 mSv / year) in ICRP recommendations.

Summary

The environmental impact assessment (evaluation of the dose-equivalent by radiation exposure to the public) has been made for the package sunk near the shore and for that sunk in the deep sea, respectively.

The results of both cases are far lower than the dose-equivalent limit for the public in the ICRP recommendation (1 mSv/year). Particularly, the calculated dose for the package sunk in the deep sea is far lower than the case sunk near shore.

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