Development of supporting system for emergency response to maritime transport accidents involving radioactive material

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ABSTRACT

National Maritime Research Institute has developed a supporting system for emergency response of competent authority to maritime transport accidents involving radioactive material. The supporting system for emergency response has functions of radiation shielding calculation, marine diffusion simulation, air diffusion simulation and radiological impact evaluation to grasp potential hazard of radiation. Loss of shielding performance accident and loss of sealing ability accident were postulated and impact of the accidents was evaluated based on the postulated accident scenario. Procedures for responding to emergency were examined by the present simulation results.

1. INTRODUCTION

Most of nuclear fuel materials used at nuclear power plants are transported by general cargo ships from abroad while spent fuels are transported to nuclear fuel reprocessing plants in Japan and abroad by shipping vessels in exclusive use. Although the spent fuel (SF) have been transported to a reprocessing plant at Tokai-mura and reprocessing plants in UK and France from each nuclear power station by exclusive shipping vessels, sea transport of spent fuels to domestic reprocessing plants from each nuclear power station would take lead from now on because receipt of spent fuel at a storage facility in the reprocessing plant of Japan Nuclear Fuel Ltd. (JNFL) located at Rokkasyo-mura has been started since 1998. The low level radioactive wastes (LLW) has been transported to the LLW burial site of JNFL located at Rokkasyo-mura. As described above sea transport of radioactive material has played an important role in the nuclear fuel cycle in Japan. Due to recent increase of transported radioactive material and diversification of transport form with enlargement of nuclear research, development, and utilization, safety securement for sea transport of radioactive material is one of important subjects in the nuclear fuel cycle.

In the case of maritime transport accidents involving radioactive material, Ministry of Land, Infrastructure and Transport (MLIT) should give responsible companies an instruction of emergency response and recovery. The calculating system of accident scale, environmental impact and effect to public health is required for a prompt and efficient instruction. Procedures for responding to emergency could be examined by the simulation results of the supporting system and IAEA’s safety guide, “Planning and Preparing for Emergency Response to Transport Accidents Involving Radioactive Material”, TS-G-1.2 [1].

2. SUPPORTING SYSTEM FOR EMERGENCY RESPONSE

The supporting system for emergency response is composed of the radiation shielding calculation code, marine diffusion simulation code, air diffusion simulation code and database as shown in Fig. 1.

The radiation shielding calculation code can assess dose distribution inboard the shipping vessels both at normal condition and at accident condition by means of Monte-Carlo simulation method. The assessed radioactive contents are spent fuel (SF), high level wastes (HLW), fresh mixed oxide (MOX), fresh uranium fuel (FF), UO_2 powder, natural uranium hexafluoride (HEX) , enriched uranium hexafluoride and low level wastes (LLW). These are main packages in Japanese maritime transport. The assessed vessels are the exclusive shipping vessels, container vessels and normal cargo vessels.

The air diffusion simulation code can assess nuclide concentration distributions in air due to release from the package. The calculation models are the plume model and the puff model, which are based on the safety assessment guidance of Japanese Nuclear Safety Commission. These models have functions of subsidence due to gravitation and of deposition due to rainfall.

The marine diffusion simulation code can assess nuclide concentration distributions in ocean due to release from the sunken package. The release models are as follows. One is so called barrier effect model [2], which is on the basis of scenario that the presence of the package reduces the release rate of nuclides to the ocean, and another is non-barrier effect model, which is on the basis of scenario that nuclides leaches from radioactive material not taking into account presence of packaging. The marine diffusion calculations are calculus of finite differences, which is based on three-dimensional diffusion equation in consideration of nuclides decay and scavenging and calculation using simple method, which analyze the diffusion factors with no advection current. Scavenging means that nuclides removed from seawater by phenomena that nuclides absorb suspended materials in seawater and settle down the seabed. The simulation code can also assess effective dose and dose equivalent due to external and internal exposure. The internal dose is from ingestion of fish in the area of calculation, and the external dose is by marine operations (e.g. handing of fishing-net). The targets of assessment are public and emergency responder.

Integrated system has visualization of the simulation results and database. The databases consist of input data set for accident assessment such as nuclide composition of each transport packages as well as information on transport packages and transport vessels.

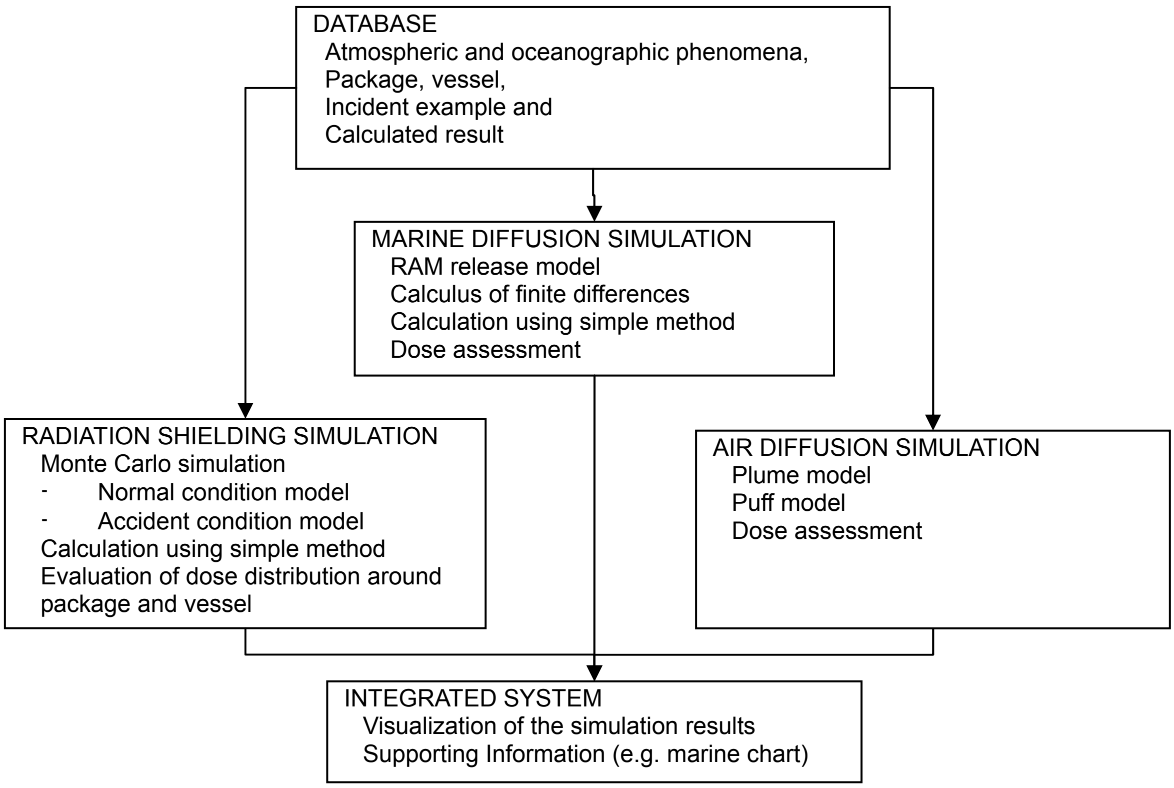

Fig.1. Overview of supporting system for emergency response to maritime transport accidents involving radioactive material.

3. VERIFICATION OF SUPPORTING SYSTEM

For verification of the developed supporting system for emergency response to maritime transport accidents involving radioactive material, evaluated results obtained by the developed supporting system are compared with the study of IAEA. This paper reports result of the marine diffusion calculation using the simple calculation method. The simple calculation method is useful because quick response is required.

(1) IAEA-TECDOC-1231

"Severity, probability and risk of accidents during maritime transport of radioactive material", TECDOC-1231 [3] was developed at the co-ordinated research project (CRP) on the severity of accidents in the maritime transport of radioactive material involved participants from five countries and extended over a period of approximately five years. Annex 3 of this TECDOC is “Dose assessment for public by packages shipping radioactive materials hypothetically sunk on the continental shelf”, the study of Central Research Institute of Electric Power Industry [2]. The target packages are spent fuel (SF), PuO_2 powder, high level wastes (HLW). The supposed location of submergence was a 200m depth.

(2) MARINE DIFFUSION SIMULATION USING SIMPLE METHOD

The developed marine diffusion simulation code system consists of two different models as marine diffusion model: one is a method to solve three-dimensional diffusion equation by means of the finite difference method, and another is a simple calculation method to obtain an analytical solution of the three-dimensional diffusion equation by only taking into account vertical diffusion as shown in Eq. 1,

$$\frac{\partial C}{\partial t} = Dx \cdot \frac{\partial^2 C}{\partial y^2} + Dy \cdot \frac{\partial^2 C}{\partial y^2} + Dz \cdot \frac{\partial^2 C}{\partial y^2} - \lambda \cdot C, \qquad \text{(Eq. 1)}$$

where C = radionuclide concentration (Bq m^{-3}),
t = time after sink of package (s),
x, y and z = geographical coordinates (m),
Dx and Dy = ocean diffusion coefficients at horizontal direction (1000 m^2s^{-1}),
Dz = ocean diffusion coefficient at vertical direction (0.02 m^2s^{-1}).
λ = decay constant of nuclides (s^{-1}).

The simple calculation model does not consider an advection current, a nuclide transition from coast, bottom and surface, nuclide concentration of background. The release rate of radioactive nuclide of SF, PuO_2 powder and HLW is same as IAEA study.

(3) COMPARISON OF RESULTS

Marine diffusion simulation using simple calculation method was carried out at the same condition shown in TECDOC-1231. By using the radionuclide concentration calculated by the simple calculation method, effective dose due to internal and external exposure was evaluated considering appropriate exposure route taken from the safety assessment guidance of Japanese Nuclear Safety Commission. The present results are shown in Table 1, Table 2 and Table 3 together with results in TECDOC-1231.

The present results by simple calculation method are little higher than those in TECDOC-1231. Reasons would be as follows. The model of simple method considers no advection current and scavenging. Advection current leads nuclide to spread so that the model of simple method is more conservative than that of TECDOC-1231. Not taking into account the scavenging effect in the present model also leads conservative results. Though TECDOC-1231 is excellent for safety assessment, the developed supporting system would be useful for emergency judgement which requires immediate response, because the simple model could very quickly obtain results.

Table 1. Individual dose equivalent due to release of radioactive material from spent fuel (SF) at 200m depth sea.

	Simple calculation method	TECDOC-1231
Internal Dose	5.0×10^{-4} mSv/year	3.2×10^{-4} mSv/year
External Dose	1.0×10^{-4} mSv/year	0.9×10^{-4} mSv/year
Total (per Package)	6.0×10^{-4} mSv/year	4.1×10^{-4} mSv/year

Table 2. Individual dose equivalent due to release of radioactive material from PuO_2 powder at 200m depth sea.

	Simple calculation method	TECDOC-1231
Internal Dose	5.0×10^{-5} mSv/year	1.4×10^{-5} mSv/year
External Dose	5.0×10^{-7} mSv/year	9.2×10^{-11} mSv/year
Total (per Package)	5.0×10^{-5} mSv/year	1.4×10^{-5} mSv/year

Table 3. Individual dose equivalent due to release of radioactive material from high level waste (HLW) at 200m depth sea.

	Simple calculation method	TECDOC-1231
Internal Dose	5.0×10^{-4} mSv/year	2.8×10^{-4} mSv/year
External Dose	3.0×10^{-4} mSv/year	0.3×10^{-4} mSv/year
Total (per Package)	8.0×10^{-4} mSv/year	3.1×10^{-4} mSv/year

4. EXAMINATION OF RESPONDING TO EMERGENCY

IAEA Regulations for the Safe Transport of Radioactive Material (TS-R-1) [4] set severe accidents (e. g. 30 minutes - 800 degree fire, 9 m drop and 200 m immersion for accident conditions of transport). And the packages are required to retain sufficient shielding and to restrict the accumulated loss of radioactive contents at accident conditions. As for examination of procedures for responding to emergency, the radiological effects were evaluated at such accident condition with the developed supporting system. From the examined results, operation plan of the supporting system for emergency response was established.

(1) DOSE LIMIT FOR RADIATION PROTECTION

It is important to revisit dose limit for radiation protection to discuss emergency response. The International Commission on Radiological Protection (ICRP) recommends a limit of effective dose of 20 mSv per year, averaged over 5 years (100 mSv in 5 years) for occupational exposure, with the further provision that the effective dose should not exceed 50 mSv in any single year. And for intervention after accidents the commission recommended as follows. Occupational exposures of emergency teams during emergency and remedial action can be limited by operational controls. Some relaxation of the controls for normal situations can be permitted in serious accidents without lowering the long-term level of protection. This relaxation should not permit the exposures in the control of the accident and in the immediate and urgent remedial work to give effective doses of more than about 0.5 except for life-saving actions, which can rarely be limited by dosimetric assessments. The equivalent dose to skin should not be allowed to exceed about 5 Sv. Once the immediate emergency is under control, remedial work should be treated as part of the occupational exposure incurred in a practice [5].

(2) HYPOTHETICAL ACCIDENT

Requirements of packages at accident conditions on TS-R-1 are shown in Table 4. Effective dose at 1 m from the surface of the package is set 10 mSv/h as hypothetical accidents for the radiation shielding simulation. Accumulated loss of radioactive contents in period of one week is set 10 A_2 of ^{85}Kr as hypothetical accidents for air diffusion simulation. Krypton-85 is gaseous and it is hard to image other radionuclide become aerosol, so that

Table 4. Requirement for package at the accident condition.

	Requirements
Shielding performance	Retain sufficient shielding to ensure that the radiation level at 1 m form the surface of the package would not exceed 10 mSv/h with the maximum radioactive contents which the package is designed to contain
Sealing ability	Restrict the accumulated loss of radioactive contents in a period of one week to not more than 10 A_2 for ^{85}Kr and not more than A_2 for all other radionuclide.

krypton-85 is set for air diffusion simulation.

a. RADIATION SHIELDING SIMULATION

Dose distribution at accommodation area was evaluated in the case that effective dose at 1 m from the surface of a package is set 10 mSv/h. Calculation model is shown in Fig. 1. In the spent fuel shipping vessel, 8 casks containing spent fuels of PWR plants are loaded. Only one cask which is the most close to the accommodation area was set to the accident condition. Dose distribution at accommodation area and engine room was calculated by a radiation shielding calculation code implemented in the supporting system. As shown in Table 5, effective dose rate in accommodation area is 3.0 μSv/h and in that in engine room is 58 μSv/h. For assessment of radiation level in the case of accident, it was assumed that crew in the shipping vessel could evacuate within 48 hours. Staying at the engine room for 48 hours results in exposure of effective dose of 2.8 mSv that is far smaller than the dose limit for occupational exposure recommended in ICRP Pub.60 [5]. For a case that crew stay in accommodation area for 48 hours, effective dose is 142 μSv. This result indicates that staying at accommodation area could reduce exposure less than dose limit for general public, 1 mSv, and evacuation into the accommodation area is one of effective procedures as emergency response for crew.

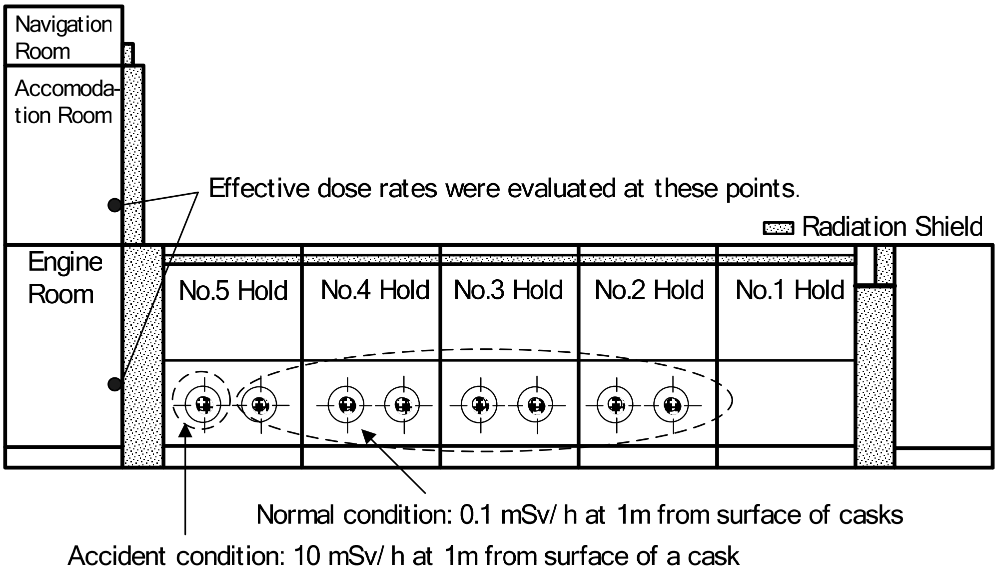

Fig. 2. A calculation model of shipping vessel for radiation shielding simulation.

Table 5 Result of Radiation Shielding Simulation

	Effective dose
Accommodation area	3.0 μSv/h
Engine room	58 μSv/h

b. AIR DIFFUSION SIMULATION

Individual effective dose was evaluated at the distance downwind in the case that accumulated loss of radioactive contents in period of one week is set 10 A_2 of ^{85}Kr with a plume model in the developed supporting system. The environmental condition is that wind velocity is 1 m/s, height of release point is 0 m and stability of atmosphere is the most stable condition, “F”.

The results of air diffusion simulation are as Table 6. This effective dose means exposure per hour when someone stays at the distance downwind. As described in Section 4.(2) a, RADIATION SHIELDING SIMULATION, assuming that it takes 48 hours for evacuation, effective dose at 100 m downwind is 14 mSv. This result indicates that effective dose in the case of severe accident is less than a dose limit of ICRP recommendation for occupational exposure.

c. MARINE DIFFUSION SIMULATION

Nuclide concentration are evaluated at the average between 0 - 100 m depth in the case that accumulated loss of radioactive contents in period of one week is set A_2 of ^{137}Cs, ^{90}Sr or ^{239}Pu from the package sunk at a 200 m depth with the simple calculation method of the marine diffusion simulation in the developed supporting system.

The results of marine diffusion simulation are as Table 7. The calculated radionuclide concentration is far smaller than background.

Table 6. Result of air diffusion simulation.

Distance downwind	Individual effective dose
100 m	0.3 mSv/h
200 m	0.1 mSv/h
300 m	0.06 mSv/h
400 m	0.04 mSv/h
500 m	0.02 mSv/h

Table 7. Result of marine diffusion simulation.

Radionuclide	Calculated Concentration	Background[5]
^{137}Cs	2.7×10^{-3} Bq/m^3	0.1 - 1000 Bq/m^3
^{90}Sr	1.4×10^{-3} Bq/m^3	0.1 - 1000 Bq/m^3
^{239}Pu	4.6×10^{-6} Bq/m^3	0.001 - 10 Bq/m^3

(2) RESPONSE WITH THE DEVELOPED SUPPORTING SYSTEM

It is possible to evaluate radiological effect on the basis of the potential hazard of packages using the developed supporting system. Dose distributions around package and vessel could be evaluated in the case of loss of shielding performance accident. Nuclide concentrations and individual effective dose could be evaluated at the distance downwind in the case of loss of sealing ability accident on the vessel. Nuclide concentrations and individual dose equivalent are evaluated in the case of sinking accident.

Immediately after the accident happens, correspondence policy could be made for radiological effect on basis of the evaluation results using the developed supporting system. The correspondence policy should be modified when the responsible officer gets in-depth data of radiation measurement, information on crew members refuge and etc. It is also effective for planning emergency working procedures for accident measure supporting staffs by using the developed supporting system.

As shown in Section 4.(2) HYPOTHETICAL ACCIDENT, radiological impact is considerably small even in the case of severe accident if packages meet requirements for the accident conditions in IAEA TS-R-1. Therefore, it can be said that an accident correspondence might be on the basis of same management as other vessel accident, such as lifesaving priority.

It is also possible to evaluate radiological effect to emergency responders, such as salvaging shipping vessel or package, using the developed supporting system. For example, individual effective dose was evaluated for emergency responders in the case that accumulated loss of radioactive contents in period of one week is set A_2 of ^{137}Cs from the package sunk at a 200 m depth (See Table 8). Effective dose for emergency responders due to radionuclide released into sea water is very small even taking into account possible maximum working time and also far smaller than a dose limit for radiation worker. In the evaluation of the effective dose for the emergency responder, radiation exposure from cask itself is not considered because salvage of shipping vessel or package would be carried out after some appropriate measure to reduce radiation level is taken or after becoming radiation level is low enough. Evaluation of radiation level around submerged shipping vessel and package can be carried using the developed supporting system. The developed supporting system will be also useful for planning for emergency response.

Table 8. Effective dose for emergency responders.

	Individual effective dose
Worker on shipboard	3.0×10^{-15} mSv/h
Diver	1.0×10^{-13} mSv/h

5. CONCLUSION

Supporting system for emergency response to maritime transport accidents involving radioactive material was developed aiming support of accident response of Ministry of Land, Infrastructure and Transport, Japan, in case of the accident during maritime transport radioactive material. In this paper, basic functions of the supporting system were described and evaluation results applied to a hypothetical accident. The results indicated that the supporting system can carry out required simulation for emergency response very quickly with good enough accuracy.

As an example for application of the developed supporting system, a hypothetical accident assuming loss of shielding performance and sealing ability was postulated considering accident condition of IAEA transport regulations. Procedures for emergency response were discussed using evaluated results by the developed supporting system for the postulated hypothetical accident. The present results indicated that there is almost no radiological impact for individual and environment in maritime transport of radioactive material even in severe accident. It is also concluded that accident correspondence might be on the basis of same management as other vessel accident, such as lifesaving priority.

Discussion in this paper indicates that the developed supporting system is very useful for planning for emergency response. The developed supporting system for emergency response will be used for (1) check of the sufficiency of the planning and preparing for emergency response based on simulation for hypothetical accidents, and (2) support of the competent authority at the time of the occurrence of accident by evaluation of impact of the accident. National Maritime Research Institute will conduct maintenance and operation of the supporting system for emergency response to maritime transport accidents involving radioactive material to secure transport safety of radioactive material during maritime transportation.

ACKNOWLEDGMENT

This study was conducted under a contract research “Development of accident assessment system for maritime transpor of radioactive material” with Ministry of Land, Infrastructure and Transport, Japan.

REFERENCES

[1] International Atomic Energy Agency, “ Planning and Preparing for Emergency Response to Transport Accidents Involving Radioactive Material, Safety Guide” , IAEA Safety Standards Series No. TS-G-1.2 (ST-3)、(2002).

[2] D. Tsumune, H. Suzuki, T. Saegusa, N. Watabe, H. Asano, K. Maruyama and Y. Kinehara, “Dose Assessment for Public by Packages Shipping Radioactive Materials Hypothetically Sunk on the Continental Shelf”, pp. 91, Annex 3, IAEA-TECDOC-1231, 2001.

[3] International Atomic Energy Agency, “Severity, Probability and Risk of Accidents during Maritime Transport of Radioactive Material”, IAEA-TECDOC-1231, 2001.

[4] International Atomic Energy Agency, “Regulations for the Safe Transport of Radioactive Material 1996 Edition (As Amended 2003)”, IAEA Safety Standards Series No. TS-R-1, (2003).

[5] International Commission on Radiological Protection, “Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals of the ICRP 21 (1-3), Pergamon Press (1991).

[6] M. Aoyama, K. Hirose, T.Miyao and H. Igarashi, http://www.mri-jma.go.jp/Dep/ge/dbhead.html, HAM database version U, Historical Artificial Radionuclides in the Pacific Ocean and Marginal Seas database, Artificial Radionuclide Databases (2001).