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IMPROVEMENT OF ATMOSPHERIC AND OCEAN DISPERSION MODEL IN SUPPORTING SYSTEM FOR EMERGENCY RESPONSE TO MARITIME TRANSPORT ACCIDENT INVOLVING RADIOACTIVE MATERIAL

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ABSTRACT

National Maritime Research Institute 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, atmospheric and ocean dispersion simulation, and radiological impact evaluation to grasp potential hazard of radiation. To supply valuable information during operation in case of accident, the system contains various type of database and also has a function to visualize simulation results effectively. 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. To enhance functions of the supporting system for emergency response including measures to nuclear terrorism, feasibility of improvement of the current atmospheric and ocean dispersion model is discussed in this paper.

INTRODUCTION

In Japan, 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 by shipping vessels in exclusive use. Although the spent fuel 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 took lead 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 amount 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. To support

MLIT in the case of accident, the calculation system has been developed by National Maritime Research Institute.

OVERVIEW OF SUPPPORTING SYSTEM FOR EMERGENCY RESPONSE

The supporting system for emergency response is composed of the radiation shielding calculation code, ocean dispersion simulation code, atmospheric dispersion simulation code and database as shown in Figure 1.

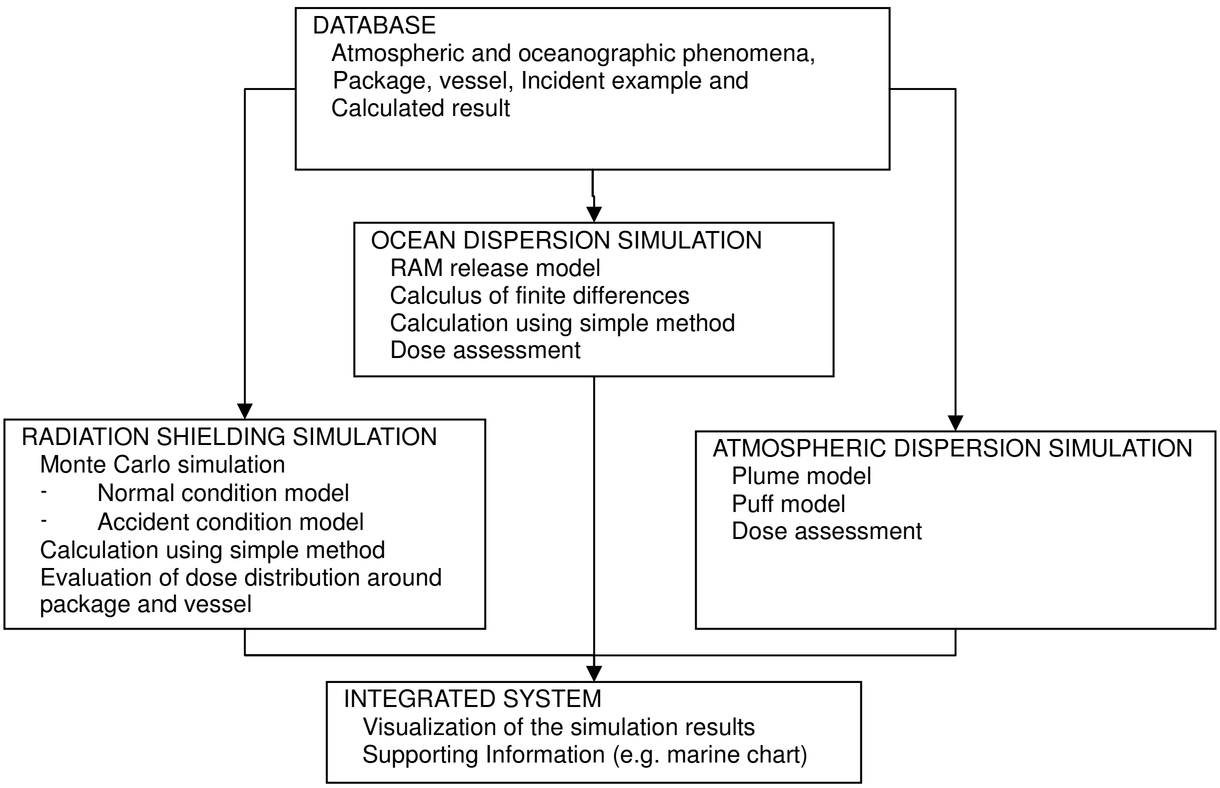

Figure 1. Overview of supporting system for emergency response to maritime transport accidents involving radioactive material

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, high level wastes, fresh mixed oxide (MOX), fresh uranium fuel, UO_2 powder, natural uranium hexafluoride (UF_6), enriched uranium hexafluoride and low level wastes (LLW). These are main packages in Japanese maritime transport. Shielding calculation models for the exclusive shipping vessels, container vessels and normal cargo vessels were prepared.

The atmospheric dispersion simulation code can assess nuclide concentration distributions in air due to release of radioactive materials 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 ocean dispersion simulation code can assess nuclide concentration distributions in ocean due to release of radioactive materials from the sunken packages. The release models are as follows. One is so called barrier effect model [1], 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 ocean dispersion 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 without 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 caused by ingestion of fish in the area of calculation, and the external dose is by marine operations (e.g. handling of fishing-net). The targets of environmental impact assessment of the system are public and emergency responder.

Integrated system has a function of visualization of the simulation results and databases. 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.

EVALUATION RESULTS FOR HYPOTHETICAL ACCIDENT USING CURRENT SUPPORTINNG SYSTEM

IAEA Regulations for the Safe Transport of Radioactive Material (TS-R-1) [2] sets 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 impacts were evaluated at such accident condition with the developed supporting system.

Requirements of packages at accident conditions on TS-R-1 are shown in Table 1. 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 atmospheric dispersion simulation. Krypton-85 is gaseous and it is hard to image other radionuclide become aerosol, so that ^{85}Kr was selected as a nuclide for the atmospheric dispersion simulation.

Table 1. 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.

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. The calculation model is shown in Figure 2. 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. The effective dose rate in accommodation area was 3.0 μSv/h and in that in engine room was 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 [3]. 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.

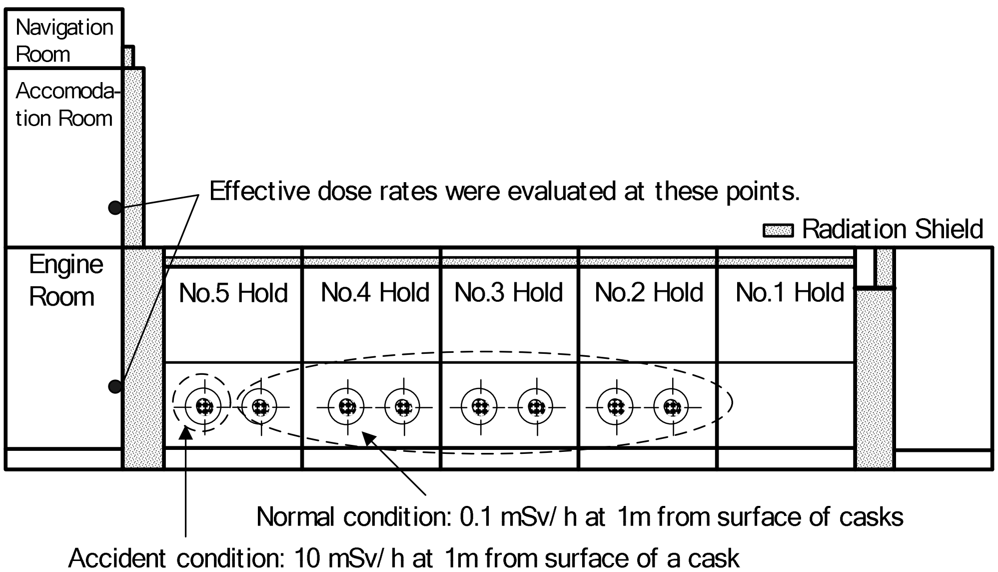

Figure 2. A calculation model of shipping vessel for radiation shielding simulation

Atmospheric Dispersion 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 A2 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 atmospheric dispersion simulation are as Table 2. This effective dose means exposure per hour when someone stays at the distance downwind. As described in the previous section 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.

Table 2. 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

Ocean Dispersion 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 A2 of ^{137}Cs, ^{90}Sr or ^{239}Pu from the package sunk at a 200 m depth with the simple calculation method of the ocean dispersion simulation in the developed supporting system.

The results of ocean dispersion simulation are as Table 3. The calculated radionuclide concentration is far smaller than background.

Table 3. Result of marine diffusion simulation

Radionuclide	Calculated Concentration	Background [4]
^{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

Response with the 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 indicated by evaluation for the 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 A2 of ^{137}Cs from the package sunk at a 200 m depth as shown in Table 4. 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 4. Effective dose for emergency responders

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

IMPROVEMENT OF SUPPPORTING SYSTEM FOR EMERGENCY RESPONSE

The atmospheric dispersion simulation code can assess nuclide concentration distributions in air due to release of radioactive materials from the package. The calculation models in the current supporting system 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. Though the current models give conservative results, models should be improved for realistic evaluation taking into account geographical data and plume fumigation (Figure 3) that occurs when an elevated onshore radioactive material plume intersects a growing thermal internal boundary layer contained within offshore air flow coming onshore.

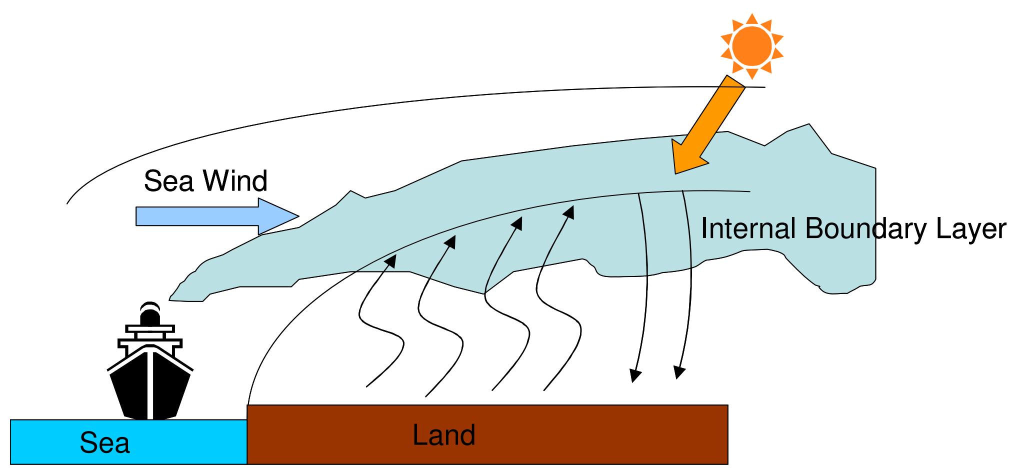

Figure 3. Image of plume fumigation.

It is also necessary to take into account geographical data of land. In the current atmospheric dispersion model dose not consider geographic data. Most of ports where radioactive materials are transported are closed to mountain excluding Tokyo Bay. For the improvement RAMS/HYPACT model would be implemented to the current system. HYPACT (HYbrid PArticle and Concentration Transport Model), which was developed by Mission Research Corporation [5], can predict the dispersion of air pollutants in 3-D, time dependent wind and turbulence fields. HYPACT allows assessment of the impact of one or multiple sources emitted into highly complex local weather regimes, including mountain/valley and complex terrain flows, land/sea breezes. Atmospheric dispersion model adopted in the HYPACT code is grid-based Eulerian dispersion methodologies with Lagrangian particle dispersion modeling. The 3-D wind and turbulence fields are provided by RAMS (Regional Atmospheric Modeling System). Daily operational weather forecasting data, which is called Grid Point Values (GPV), provided by the Japan Meteorological Agency, can be used for RAMS.

The ocean dispersion simulation code can assess nuclide concentration distributions in ocean due to release of radioactive materials from the sunken package. The current ocean dispersion model for detailed evaluation is based on three-dimensional diffusion equation in consideration of nuclides decay and scavenging. The simulation code can assess effective dose 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 current dispersion model can only apply for specific costal area where many radioactive packages are transported. To cover all costal region of Japan, it is necessary to update database of ocean geographical data, ocean flow data available from Japan Oceanographic Data Center. Update is planed in next fiscal year 2008.

CONCLUSIONS

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 summarized and evaluation results applied to a hypothetical accident were shown. The results indicated that the supporting system can carry out required simulation for emergency response very quickly with good enough accuracy.

Though the system can provide good enough accuracy for emergency response, evaluation results with higher accuracy makes possible more realistic measures for accident mitigation and environment impact assessment. For planning evacuation measures for incident of terrorism, it is essential to have capabilities to evaluate all coastal regions in nation. For that purpose, in this paper, improvement of atmospheric and ocean dispersion model were discussed. Performance of ocean dispersion simulation would be accomplished by updating information of oceanographic data such as ocean geographic data and ocean flow to cover all coastal region of Japan. For the atmospheric dispersion model, it is necessary to modify implemented model to apply complex geographical situation and realistic weather condition.

Accomplishment of the improvements presented in this paper might make the supporting system more power full tool for emergency response of transport accident and terrorists attack involving radioactive materials by competent authority.

ACKNOWLEDGMENTS

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