Development of Domestic Maritime Transportation Scenario For Nuclear Spent Fuel

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Abstract: Spent fuel transportation of South Korea is to be conducted through near sea because it is able to ship a large amount of the spent fuel far from the public comparing to overland transportation. The maritime transportation is expected to be increased and its risk has to be assessed. For the risk assessment, this study utilizes the probabilistic safety assessment (PSA) method and the notions of the combined event. Risk assessment of maritime transportation of spent fuel is not well developed in comparison with overland transportation. For the assessment, first, the transportation scenario should be developed and categorized. Categories are assorted into accident type (routine, ship damage, cask damage), health effect type (direct external exposure and indirect internal exposure). This scenario will be exploited for the maritime transportation risk model which includes consequence and accident probability.

Keywords: PSA, Maritime transportation, Scenario, Spent fuel, Risk assessment.

1. INTRODUCTION

On August 25th, French cargo ship Mont-Louis which transported nuclear material collided with German ferry near Belgian and Dutch coast and sank. They refloated the casks and it is confirmed that little amount of uranium hexafluoride leaked. Although it is investigated that the radiation exposure was negligible, this accident give rise to a concern on the nuclear material transportation [1].

As nuclear spent fuel is increased, consequently, its transportation is supposed to be increased. 23 nuclear power plant units are in operation and are located in coastal sites in South Korea (Kori, Uljin, Wolsong, and Yeonggwang). Spent fuel policy of Korea is undecided yet whether it is to be disposal or reprocessing. Thus all spent fuels are stored in the plants temporarily until now. Within few years, onsite storage capacity will be full out of spent fuels. They will be transported to interim or permanent storage site where will be located near the plant site. Or it should be transported to other countries where have spent fuel disposal/reprocess facility such as Japan or France. Both domestic and foreign processing use maritime transportation mainly rather than overland or aerial transportation. For the safe transportation of the massive spent fuel, the risk of the transportation should be assessed to manage it.

The risk is defined as a collection of likelihoods and outcomes (consequences) of certain event [2]. The risk usually means product of the likelihood and the consequence or sum of them, it means expected value of the accident effect on human, economy or environment. The followings are the maritime transportation risk assessment and reduction of the risk procedure: (1) Accident data collection; (2) Accident type selection; (3) Scenario development and probability estimation; (4) Consequence computation; (5) Risk assessment; (6) Risk reduction; [3]. Some studies already researched maritime risk assessment. The risk of maritime transportation is studied with accident statistics [4]. This study contains risk of ship collision, grounding and foundering with structural failure. There are also various formal safety assessment in the paper. However it is not for the nuclear transportation and does not consider other accidents such as fire, explosion and so on. Other study introduced maritime quantitative risk assessment models [5]. It considered not only collision and grounding but also fire, explosion and the others using fault tree (FT), event tree (ET) and mathematical models. Probabilistic ship grounding model is well developed [6]. The study suggested various affecting factors on ship grounding and introduced five analytical models and five statistical models for the probabilistic modelling of the ship grounding. Although there is a study about hazardous and noxious substances risk assessment on

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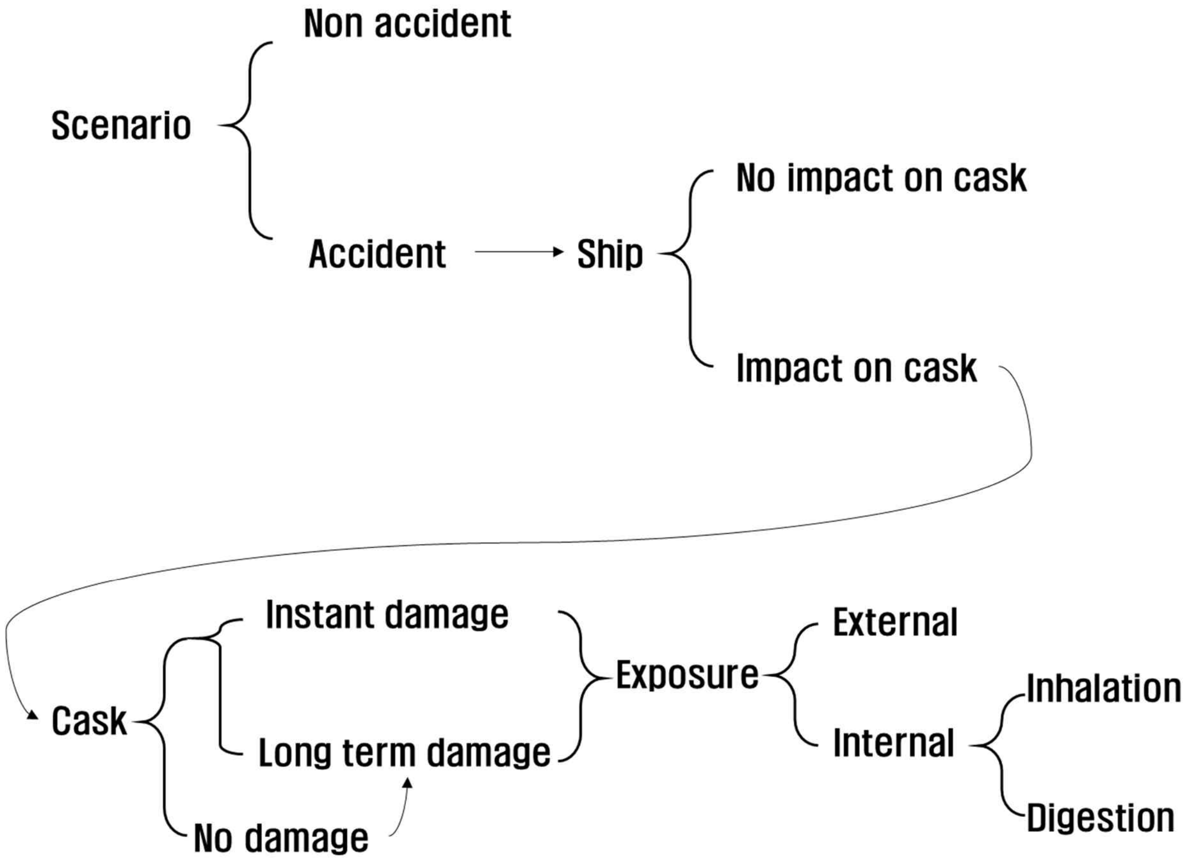
domestic maritime transportation, it developed too simple scenario and accident categorization is not applicable for the nuclear material transportation [3]. Studies of oil and gas industries handle leak and spread with scenarios and risk information [7, 8]. Even if a material they consider is not a spent fuel, basic risk, leak and spread models are applicable.

This paper will show a schematic of the maritime transportation scenario and selects meaningful accident categories among dozens of ship accident categories then combine chosen accidents to produce combined event such as explosion after collision.

2. DEVELOPMENT CONCEPT FOR THE MARITIME TRANSPORTATION SCENARIO

Figure 1: Schematic of the scenario development



The scenario is comprised of parts. First, it starts with non-accident scenario part and accidental scenario part. Accident means ship accident and it comes in two parts, no effect on cask and effect on cask. Effect on cask part does not mean damage on cask. Affected cask can be instantly damaged by the ship accident. Possibility that the others which have no damage during the ship accident will evolve to the long term damage state is increased as time goes on. Spent fuel material in the damaged cask will be leaked and distributed into the environment and people will be exposed to the radiation through air, water and food.

There was no maritime high level radioactive material transportation in Korea. There is only one intermediate and low level radioactive material transportation experience through sea. Japan, Sweden, France, United Kingdom and a few countries transports spent fuel via sea, there were just few small accidents. The accident data of the ship which transports nuclear spent fuel is impossible to collect and utilize. Thus general ship accident data will be used.

In this study, the scenario is developed based on the following assumption; the spent fuel will not be leaked unless the cask keeps its integrity and the cask will be safely secured as long as the ship does not meet with an accident. And the accident probability of the ship which transports nuclear spent fuel is same as general ship accident probability.

2.1. The Scenario for the ship Accident

Specific transporting ship is not yet decided, so general assessment on ship is needed. International Maritime Organization (IMO) enacted INF code which is "The International Code for the Safe Carriage of Packaged Irradiated Nuclear Fuel, Plutonium and High-Level Radioactive Wastes on Board Ships". The ship which transports nuclear spent fuel should apply INF code for the safe transportation. The ship which transports high level radioactive material such as uranium and plutonium should have intensified safety structure according to the INF code. It classifies ship into three classes. INF 1 ship carries "cargo with an aggregate activity less than 4,000 TBq". INF 2 ship carries "irradiated nuclear fuel or high-level radioactive wastes with an aggregate activity less than 2 x 106 TBq and ships which are certified to carry plutonium with an aggregate activity less than 2 x 105 TBq". INF 3 ship carries "irradiated nuclear fuel or high-level radioactive wastes and ships which are certified to carry plutonium with no restriction of the maximum aggregate activity of the materials". Ship which carries nuclear spent fuel is INF 3 ship. Table 1 is specification of INF 3 ships and Cheonjeongnuri that carried intermediate and low level radioactive material in Korea.

Table 1: Specification of ships

	Cheonjeongnuri	**Pacific Heron**	**Pacific Sandpiper**	**Kaiei Maru**	**Rokuei Maru**
Length(m)	78.6	104	104	100	100
Width(m)	15.8	17	16	16.5	16.5
Deadweight(t)	1,356	4,916	3,775	3,000	3,000
Displacement(t)	2,600	9,667	7,725	5,000	5,000
Engine	2 Diesel engines, each with 1632 hp	2 Diesel engines, each with 3600 hp	2 Diesel engines, each with 1900 hp		
Maximum velocity	12 knot				
Maximum capacity	190 flasks	20 casks	24 casks	12 spent fuel packages	24 spent fuel packages

Table 1 shows ship accident categorizations categorized by Korea Maritime Safety Tribunal (KMSF) and Marine Accident Investigation Branch (MAIB). KMSF defined their terms: (a) collision is a touch or hit with other ship in both case that the ship is at anchor and the ship is on the voyage except collision with a wreck under the sea; (b) contact is touch or hit with external object except other ship and the sea floor; (c) grounding is a hit/run on the sea floor or a wreck; (d) fire/explosion is accident occurred as initial event (not followed by collision or capsize); (e) foundering is a foundering caused by flooding with bad weather or hull defect (not followed by collision or explosion); (f) machinery is machinery damage of main engine, auxiliary boiler or auxiliary equipment; (g) injury/ fatality is human being is injured, disappeared or died in relation to ship structure, facility or management. They collected statistical data along the accident categorizations, ship size, ship type, accident time, sea area and so on.

Among them we selected suitable seven accident categories for the nuclear spent fuel transportation. They are collision, contact, grounding, fire/explosion, foundering, machinery and listing/capsize. Cargo handling failure is considered not to be happened during the voyage. Weather damage and hull defect are causes of other categories such as foundering and or listing/capsize. And hazardous incidents is not related to nuclear spent fuel transportation. Injury/fatality also important factor for the study. We define machinery as lose of mobility that causes temporary (a few hours ~ a few days) stop of the ship. Table 2, 3 and 4 show single and combined events of the selected accident categories. The probability to occur is too small with more than 3 events, combined events that has more than 3events are ignored.

Table 2: Accident categorization

Korea Maritime Safety Tribunal	Marine Accident Investigation Branch
Collision	Machinery
Contact	Fire/Explosion
Grounding	Injury/Fatality
Fire/Explosion	Grounding
Foundering	Collision/Contact
Machinery	Flooding/Foundering
Injury/Fatality	Listing/Capsize
Etc.	Cargo Handling Failure
	Weather Damage
	Hull Defects
	Hazardous Incidents

Table 3: Single accident events

Single event	Scenario number
Collision	1-1
Contact	1-2
Grounding	1-3
Fire/Explosion	1-4
Foundering	1-5
Machinery	1-6
Listing/capsize	1-7

Table 4: Double accident events

Double combined event		Scenario number
First event	*Second event*	
Collision	Contact	2-1
	Grounding	2-2
	Fire/Explosion	2-3
	Foundering	2-4
	Machinery	2-5
Contact	Collision	2-6
	Grounding	2-7
	Fire/Explosion	2-8
	Foundering	2-9
	Machinery	2-10
Grounding	Fire/Explosion	2-11
	Foundering	2-12
	Machinery	2-13
Fire/Explosion	Collision	2-14
	Contact	2-15
	Grounding	2-16
	Foundering	2-17
	Machinery	2-18

'Non-accident' scenario of the figure 1 means there is no accident of table 2 on ship. Routine radiation exposure on crew members should be considered though there is no accident. This assessment will be done by the method which is same method of overland transportation assessment [9]. In some scenarios cask might not be affected by the accident. That is 'no impact on cask' scenario. Even if the cask is not affected by the accident, a ship transports that cask slows down or stops with an accident. Then radiation from the cask will be exposed to crew members longer, total transport time will be increased and total risk of the transportation also will be increased.

Table 5: Triple accident events

Triple combined event		Scenario number
First event	*Sequent event*	
Collision	2-7	3-1-1
	2-8	3-1-2
	2-9	3-1-3
	2-10	3-1-4
	2-11	3-1-5
	2-12	3-1-6
	2-13	3-1-7
	2-14	3-1-8
	2-15	3-1-9
	2-16	3-1-10
	2-17	3-1-11
	2-18	3-1-12
Contact	2-2	3-2-1
	2-3	3-2-2
	2-4	3-2-3
	2-5	3-2-4
	2-11	3-2-5
	2-12	3-2-6
	2-13	3-2-7
	2-14	3-2-8
	2-15	3-2-9
	2-16	3-2-10
	2-17	3-2-11
	2-18	3-2-12
Grounding	2-14	3-3-1
	2-15	3-3-2
	2-17	3-3-3
	2-18	3-3-4
Fire/Explosion	2-1	3-4-1
	2-2	3-4-2
	2-4	3-4-3
	2-5	3-4-4
	2-6	3-4-5
	2-7	3-4-6
	2-9	3-4-7
	2-10	3-4-8
	2-12	3-4-9
	2-13	3-4-10

2.2. The Scenario for the cask

In the past, most nuclear spent fuels are transported from onsite spent fuel pool to offsite spent fuel pool for the reprocessing. Countries that needed to transport spent fuel developed and utilized spent fuel transportation cask. Since 1980, as demand for the transportation is increased, technology of the transportation cask is applied to the dry storage, then dual purpose canister is developed. BNG, NAC, NFT, PNTL and ACL developed commercial transportation casks. In Korea, Korea Atomic Energy Research Institute (KAERI) and Korea Hydro and Nuclear Power (KHNP) developed transport casks KSC-1, KSC-4, KN-12, KN-18.

According to an act of Korea (regulation for the radiation safety management), a cask for the transportation of radioactive material is classified L type, IP type, A type, B type, C type and a cask for material that fissions. Nuclear spent fuel is transported by B type cask. Specific transportation cask also not yet decided.

Damage on cask is occurred right after the ship accident (instant damage) or later (long term damage). Instant damage is caused by physical stress such as impact and high temperature of the ship accidents. Even if there are many ship accident scenarios defined above, impact and fire are root causes of the cask damage. NRC investigated overland transport casks (rail-steel, rail-lead and truck-DU) response to impact and fire using finite element analysis and simulation [9].

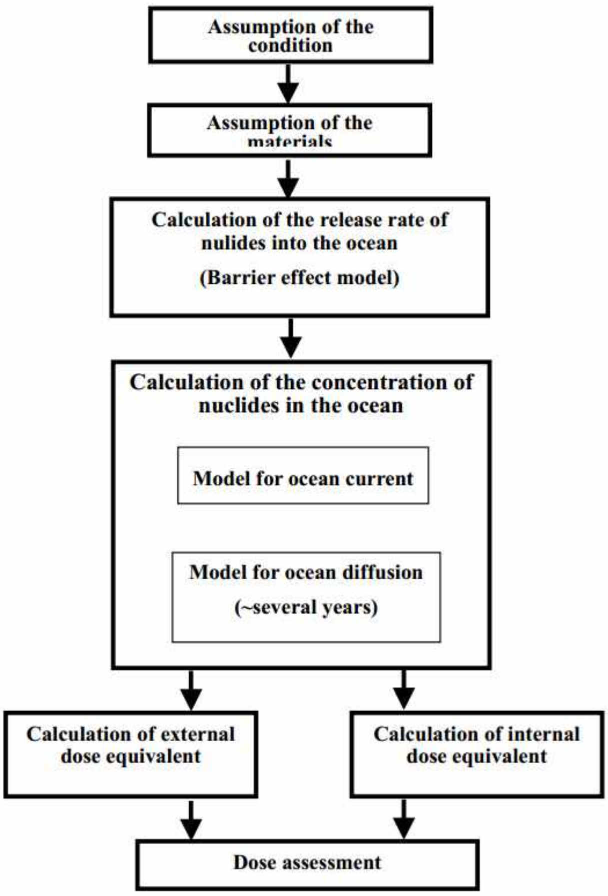
In the scenarios end with foundering or listing/capsize such as scenario number 2-2, 2-4, 2-7, 3-4-6 and so on, the cask might not be damaged. This 'no damage' scenario evolves to 'long term damage' scenario as time goes on. Pressure of the water, corrosion with salt water and aging of the cask are causes of the long term damage. If the cask is not be recovered after the accident, radioactive material probability to be leaked will be built up.

2.3. The Scenario for the exposure

Whatever, it is instant damage or long term damage of the cask, nuclear spent fuel material will be leaked into the environment. It will be spread via air or sea water. Assessment of the leakage into the air is no different than assessment on the ground. Assessment of the leakage into the sea water is different. Pathway of exposure divided into two part, direct exposure by diffusive convection of the sea water and indirect exposure by food chain of the marine ecosystem. Some of them will cause external radiation exposure to the people near the coast and some of radioactive materials will be accumulated in the marine ecosystem.

Central Research Institute of Electric Power Industry (CRIEPI) conducted assessment of radiation effect on maritime transportation with the transportation of spent fuel, plutonium oxide powder, high level waste and MOX nuclear fuel between Europe and Japan. Figure 2 shows the sequence of dose assessment [10].

Figure 2: Sequence of dose assessment conducted by CRIEPI



They assumed the accident and leakage condition, calculated the release rate of nuclides into the ocean using barrier effect model and calculated the concentration of nuclides in the ocean using model for ocean current and diffusion. Then internal exposure by ingestion of fishes and external exposure by marine activity are assessed.

Arctic Nuclear Waste Assessment Program (ANWAP) assessed the risk of the radioactive wastes that are deposited by the former Soviet Union for the public of Alaska [11]. They conducted radioactive source term assessment, investigation of major nuclide movement in the Arctic Ocean, bio concentration and radiation exposure by the digestion assessment.

3. CONCLUSION

This study developed the scenario for the maritime transportation of the nuclear spent fuel. The scenario consist of non-accident scenario and accident scenario. The accident scenario is composed of single ship accident categories and their combination. The ship accident scenarios can be classified according to whether or not the casks are affected by the accident. Non accident and no impact on cask scenario handles routine radiation exposure to the crew members. 'Impact on cask' Scenario also divided by two parts, instant damage and long term damage scenarios. If cask is damaged, the people are exposed through the external exposure via sea water movement, inhalation via the air and digestion of the sea foods. ET analysis and arrangement will be conducted for the above scenarios and consequence calculation. FT analysis of each ship accident will be conducted for the accident probability calculation.

The risk assessment of the nuclear spent fuel should include other fields in Korea. Spent fuel transportation plan is expected to include onsite overland transport and loading procedure at the port. Therefore, the risk of overland onsite transportation, loading at the port and in-port risk should be included for the complete risk assessment.

Acknowledgements

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