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# Development of Collision Accident Scenario during Nuclear Spent Fuel Maritime Transportation

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## 1. Introduction

Remaining capacity of nuclear spent fuel of South Korea is running out. Whether the last process of the spent fuel is permanent disposal or reprocess, they need to be transported from power plants to interim storage facility, disposal area or reprocessing facility. Population density of South Korea is much higher than the other countries, and it is peninsula. Therefore, it is expected that major means of transportation of the spent fuel will be maritime transportation rather than overland transportation. Korea Maritime safety Tribunal (KMST) categorized various maritime accident, see table I [1].

**Table 1 KMST maritime accident categorization**

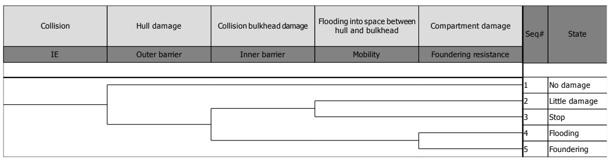
| Accident category | Definition |
|---|---|
| Collision | touch or hit with other ship |
| Contact | touch or hit with external object except other ship and the sea floor |
| Grounding | a hit/run on the sea floor or a wreck |
| Listing/Capsize | listing or capsize((not followed by collision or ground) |
| Fire/Explosion | fire or explosion as the first accident (not followed by collision or capsize) |
| Foundering | a foundering caused by flooding with bad weather or hull defect (not followed by collision or explosion) |
| Machinery | machinery damage of main engine, auxiliary boiler or auxiliary equipment |
| Injury/Fatality | injury, disappearance or fatality related with ship structure, facility or operation |
| Safety hindrance | loss of mobility caused by coiling of floating matter (such as fishing net, lope) to the propeller |
| Sailing hindrance | loss of mobility caused by running on a sand bar or the others without damage |
| Etc. | appurtenance damage, facility damage, propeller damage, rudder damage, water pollution and so on |

Among them, collision accident is one of the most important and complicated accident from Probabilistic Safety Analysis (PSA) point of view. We will show what will happen if the transportation ship is struck by other ship, how to calculate collision energy and probability of the branches on ship-ship collision with Event Tree Analysis (ETA) method.

## 2. Event tree of collision

Spent fuel transportation ship is assumed to have double hull structure. Outer hull is the outer most barrier of the ship and the next barrier is inner hull (collision bulkhead). If there's no damage on outer hull, there will be no damage on the ship. If collision energy is high enough to break outer hull, there is probability of fracture of inner hull and it depends on collision energy. Even if it is not high enough to break inner hull, water is flooded to the space between outer and inner hull. If it is too much ship will lose its mobility, if not, the accident remains just little damage to the ship. If collision energy is high enough to make fracture of inner hull, water will be flooded into the ship. The ship has compartment structure, it resist foundering. If it succeed to resist, it is flooding, if not, the ship is going to be foundered. See figure 1, event tree of ship-ship collision.

**Figure 1 Collision event tree**



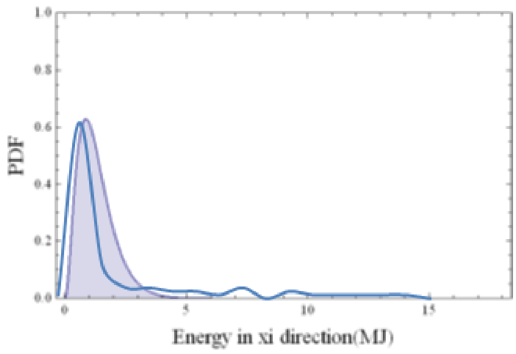

## 3. Collision energy

Collision energy can be calculated with equation 1 [2].

$$E_{\xi} = \frac{1}{2}\frac{1}{D_{\xi}+D_{\eta}}(1-e^{2})[\dot{\xi}(0)]^{2} \qquad (1)$$

$\xi$ is a normal direction to the struck ship from the collision point between two ships. D_ξ and D_η are functions of ship size, mass, collision velocity and angle, and they can be found previous studies and statistics [1,3,4]. Striking ship mass, collision angle and velocity follows probabilistic distribution. Then, with equation 1 gives collision energy PDF (probabilistic density function) like figure 2.

**Figure 2 Collision energy distribution**

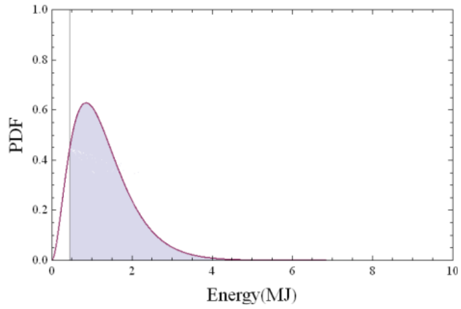



X axis of figure 2 is energy released in ξ direction. Blue line is real data and colored area is approximated pdf, that is, gamma distribution (3, 0.43).

### 4. Hull fracture probability

Collision energy distribution is figured out. To calculate branch probability of figure 1, we need to know hull fracture criteria energy for the first step. Experiment about double hull and collision energy is done in 2013 [5]. It uses design of ConRo 220 class German Ro-Ro ship as a struck ship. We assumed our struck transportation ship to have double hull structure but its exact model or detailed specification is not defined. When the assumed striking object to be rigid material, collision energy of outer hull rupture was about 0.45MJ, and inner hull's was about 1.15MJ. We used this number to calculate branch probabilities.

**Figure 3 Collision energy distribution and hull rupture criteria**



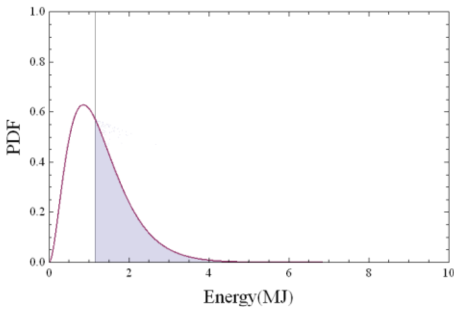




Figure 3 shows rupture probability of inner and outer hull. Outer hull rupture probability on collision is 91.1% and inner hull rupture probability on collision is 50.0%.

### 5. Conclusion

We selected and re-categorized maritime accident that KMST categorized for ship-ship collision analysis of spent fuel transportation ship. Event tree is constructed and collision energy distribution is derived from statistics and equation. And outer and inner hull fracture probabilities are calculated. If outer hull is broken but inner hull is fine, water will be flooded into the space between outer and inner hull. It will decrease mobility of the ship.

If inner hull is fractured, water will be flooded into the ship inside. The ship has compartment structure to resist from foundering. Loss of mobility and compartment damage (ultimately it ends with sink) mechanism need to be analyzed to complete transportation ship collision event tree.

### REFERENCES

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