Risk analysis of accident of released radioactive material during spent fuel cask transportation using ocean dispersion model and nodalization method

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Radioactive material can be released through many ways like from nuclear power plant accident, radioactive material processing procedures, and spent fuel transportation. Released radioactive material may be dispersed along with ocean current. In addition, dispersed radioactive material can be ingested by ocean biota and it will induce health effect. In this study, risk of radioactive material release was assessed by connecting concentration of radioactive material and cask damage probability. Nodalization method according to current direction was applied to calculation of probability of a transportation route. In further study, simplified food chain and annual consumption data will be applied for health effect analysis.

I. INTRODUCTION

After Fukushima accident, some people have thought that they are threatened by radioactivity from nuclear power plant (NPP) in various ways. Released radioactive material may have environmental impact for ocean or ocean biota. When human intakes contaminated ocean biota or water, they may affect human health. Despite of activity concentration of seawater had reached background level after several years according to several papers, there are anxiety about release of radioactive material from Korean NPPs[1-2]. Therefore, release accident during spent fuel transportation was assumed for this analysis among various release route since spent fuel will be transported in the future. In this study, risk of released radioactive material along with tidal movement, as a result of application of level three probabilistic safety assessment (Lv3 PSA), was assessed with nodalization method. In addition, Cs-137 was selected as target radioactive material because of its solubility about water.

II. METHODS

To analyze environmental impact of released Cs-137, probabilistic safety assessment (PSA) approach was applied to this study. Because environmental impact of Cs-137 is a result of level 3 PSA, level 1 and 2 PSA result is required. Level 1 PSA result was obtained from previous study while level 2 and 3 PSA result were calculated from the models.

Risk generally calculated following equation (1). Therefore, probability calculation is required to calculate risk. According to scenario, cask damage probability is calculated using equation (2).

$$Risk = Probability \times Consequence \tag{1}$$

$$Core\ damage\ probability = Collision\ probability \times Contact\ probability \tag{2}$$

II.A. Accident probability analysis

Ship collision accident with spent fuel transportation ship and general ship is assumed. A graphically processed statistical route map for general ships was used for collision probability calculation. Based on collision probability of each intersection point, ship collision probability for a route was calculated. The collision accident was divided to several subordinate accidents according to collision type and struck location. Based on division, event tree for maritime transportation was developed and shown in Fig. 1 [3]. Collision probability and contact probability can be calculated from previously invented software as shown in Fig.2 [4]. Detailed calculation methodology is explained in Ref 3 and 5.

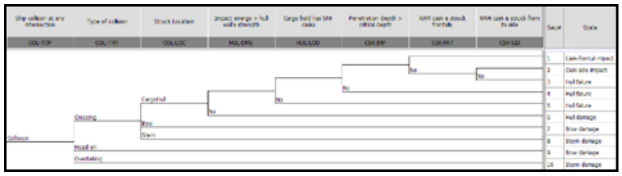

Fig. 1. Event tree for maritime transportation [3]

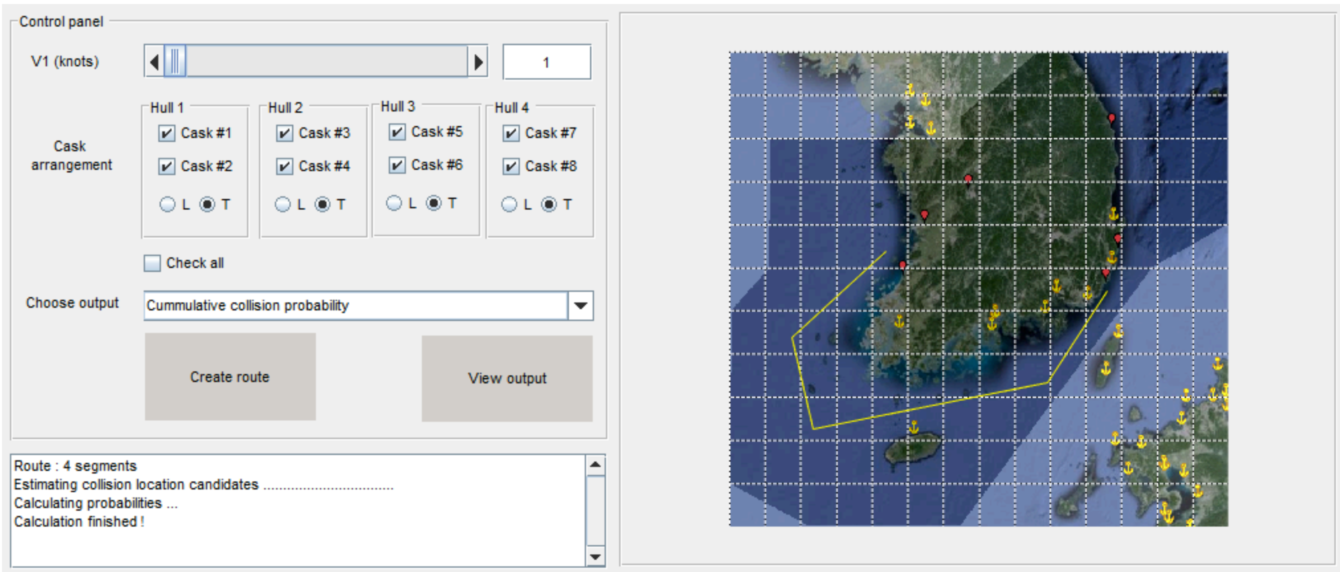

Fig. 2. Probability calculation software [4]

II.B. Concentration calculation from ocean dispersion model

Usually, ocean dispersion model is hard to be applied because lack of specific data such as meteorological data and geographical data. However, a specific model can be used for tidal dominant region like the West and South sea of Korea. Due to shallow depth, tidal condition of these area, and characteristics of target material, 2 dimensional tidal motion induced ocean dispersion simulation model, 2D ADCIRC (http://adcirc.org/), was applied for this analysis since targeted area is restricted to the West and South seas of Korea. From ADCIRC model, concentration of radioactive material will be calculated according to time as consequence.

ADCIRC model is tidal motion simulation based ocean dispersion calculating computer program. In tidal dominant region, ocean dispersion can be assessed regardless of wind speed and direction. From this model, dispersion of radioactive material was analyzed using tidal harmonic constants for open boundary. Generalized wave continuity equation was utilized in ADCIRC. Detailed description about continuity equation is explained in Ref. 6.

Input data of ADCIRC model were obtained from websites (NOAA, https://www.ngdc.noaa.gov/mgg/shorelines/ and GEBCO, http://www.gebco.net/). Then, these input data were processed using BatTri (http://www-nml.dartmouth.edu/Software/battri/) and Triangle (http://www.cs.cmu.edu/afs/cs/project/quake/public/www/triangle.html). Detailed processing steps are explained in Fig.3. In addition, source term was calculated from ORIGEN-ARP code for specific cask condition [7]. Although various kinds of nuclides can be analyzed in ORIGEN-ARP, only Cs-137 data was used for risk calculation.

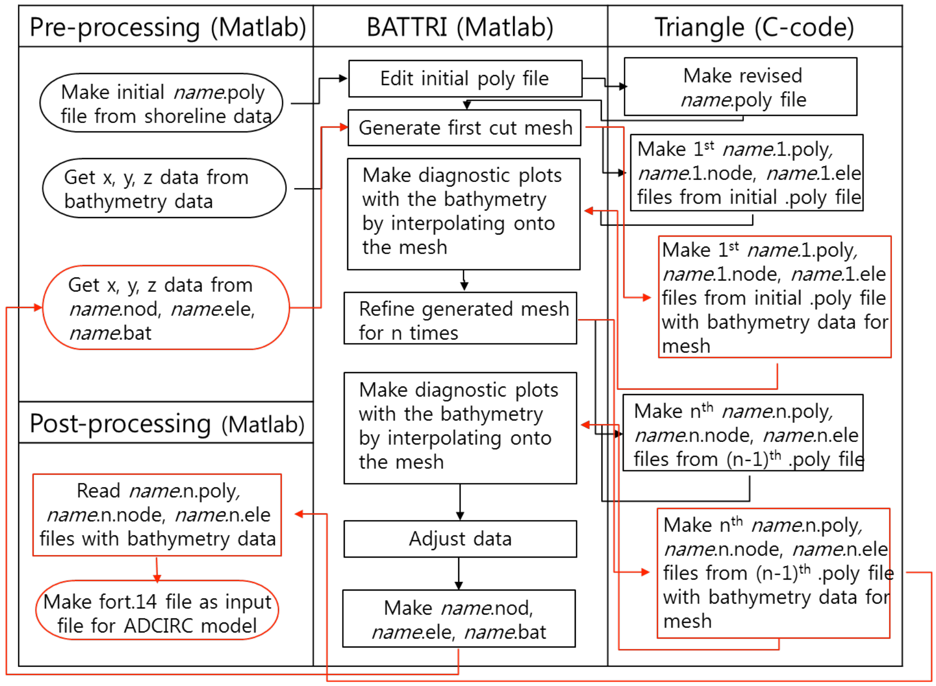

Fig. 3. Mesh generation process using BatTri and Triangle

II.C. Risk assessment with nodalization method

To calculate probability, nodalization method was used. As shown in Fig.4, a route was divided to several segments which have consistent consequences. In previous study, nodes were generated with same interval [8]. However, because target area of this study is large and there are various current changes, making nodes with consistent consequences may be suitable for this analysis. Since consequences are dependent on current direction, node location may be decided by current changing location. Each segment meets with other ship and then has intersection points (X) as shown in Fig.5. Because probability of X can be obtained from software that is explained before, probability of whole route can be calculated.

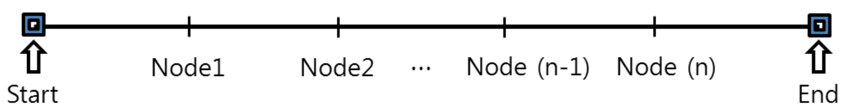

Fig. 4. Nodalization of a route for probability calculation

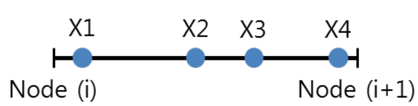

Fig. 5. Intersections within a segment

III. RESULTS

III.A. Accident probability analysis

Based on developed event tree, among classified accident, there was cask damage except OK states. Due to double hull structure of transportation ship, impact damage will be absorbed to structure instead of transferred to cask. Therefore, damage for specific location can be reduced. From a software, probability calculation can be easily managed.

Collision probability for a route was calculated using developed software. However, since it highly depends on accident condition, an example was used for this study. When a transportation ship carries 8 CE type casks which have 45,000 MWd/MTU burn-up, 4.5 wt% enrichment and 10 years cooling time with 3 knots velocity, the risk will be 3.23E-002 mSv per transportation.

III.B. Concentration calculation from ocean dispersion model

Radioactivity of Cs-137 from a cask is calculated from ORIGEN-ARP according to time. Simulation time was 10 years. Radioactivity is constant until around 30 days and decreased rapidly after 1 years. After 10 years from accident, radioactivity decreased 22 percent. Therefore, due to the simulation period is 14 days after accident, 6.60E+04 Curies of Cs-137 was used for model as source term. With source term calculation, release fraction is required to calculate the amount of released radioactive material. Release fraction of this study is conservatively assumed to 1. Release fraction can be calculated by mechanical impact analysis for accident scenario. However, because it takes lots of time and effort, it is conservatively assumed in this study.

Using BATTRI and Triangle, triangular mesh was generated on the ocean. There were 270,790 nodes and 488,973 elements as shown in Fig.6. Generated mesh was replotted with bathymetry data. Minimum depth was -150m while maximum depth was 0m. Output files of BATTRI is formatted as fort.14 file. ADCIRC model was run with fort.14 file. ADCIRC model running result will be shown in presentation.

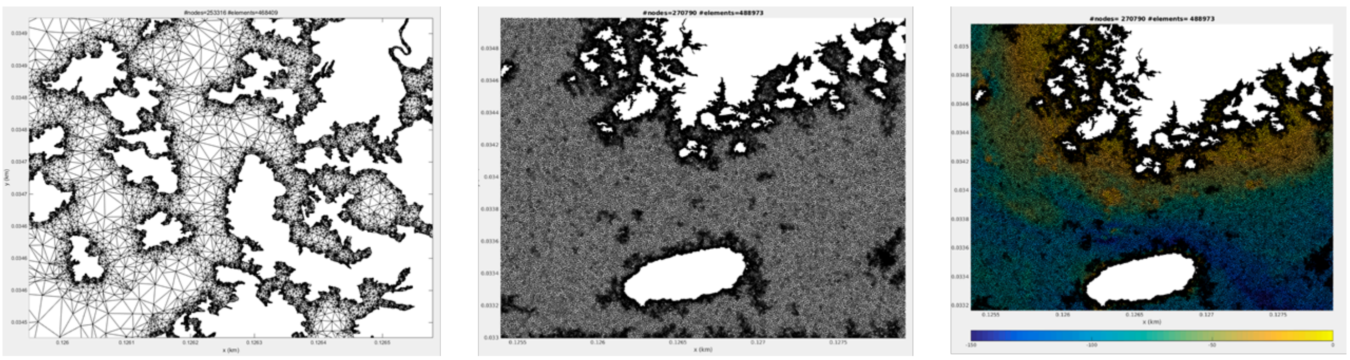

Fig. 6. Generated mesh from BATTRI and Triangle

IV. CONCLUSIONS

In this study, risk of released radioactive material from ship collision accident was assessed by proper modeling codes and methods. Developed accident scenario and calculated source term were used. With generated mesh, dispersion of radioactive material was simulated for 2 weeks. Then, calculated probability from route nodalization was connected with consequence for risk calculation. In further study, health effect from contaminated ocean biota will be analyzed using this result. Simplified food chain and annual consumption data will be applied for analysis in the future study.

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