# Preliminary Assessment of Radiation Effects on the Scenario for Transport of Spent Nuclear Fuel to Interim Storage Facilities

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## 1. Introduction

The saturation rates of the spent fuel (SF) wet storage at the Kori Nuclear Power Plant (NPP), Hanbit, and Hanul are 83.3%, 74.2%, and 80.8% as of the fourth quarter of 2021. The storages of Kori NPP and Hanbit NPP are expected to be saturated in 2031, and Hanul is expected to be saturated in 2032.

In this paper, firstly, radiological preliminary evaluation using NRC-RADTRAN ver. 1.0 in the process of sea transport of SF from the wet storage or independent SF storage installation (ISFSI) of the Hanbit NPP to the virtual interim storage facility is performed. Calculate the expected individual dose to the transport crew and the loading and unloading workers in the normal transport scenario. In addition, the collective dose of the general public in collision and fire accident scenarios is calculated and compared with the domestic legal standard.

The RADTRAN program [1] was developed by SNL (Sandia National Laboratories) of the United States as a program to calculate the radiation risk during the transport of radioactive materials. This program has been used as a calculation tool to perform radiation impact assessment on the movement of radioactive materials by means of transport including aircraft. It is used as a computer program that can be executed. [2]

## 2. Input data preparation

### *2.1 Transport Casks and Vessels*

For the transport cask, the specifications of ‘KORAD-21’ were used. And since there is no ship exclusively for SF in Korea yet, the specifications of the British ‘Pacific Grebe’ were used by investigating overseas ships for exclusive use of SF. The specifications of the transport vessels are shown in Table I.

Table I: Specifications of Overseas Shipping Vessels [3]

| Country | Name | Built (year) | INF | Length (m) | No. Cask | Ship. Capacity (t) | Purpose |
|---|---|---|---|---|---|---|---|
| U.K. | Pacific Heron | 2008 | 3 | 103.9 | 20 | 4850 | SF/HLW/MOX |
| U.K. | Pacific Egret | 2010 | 3 | 103.9 | 20 | 4408 | SF/HLW/MOX |
| U.K. | Pacific Grebe | 2010 | 3 | 103.9 | 20 | 4916 | SF/HLW/MOX |
| Sweden | M/S Sigrid | 2013 | 3 | 99.5 | 12 | 1600 | SF/ILW |
| Japan | Roduei maru | 1987 | 3 | 100 | 20 | 3000 | SF |
| Japan | Kaiei maru | 1985 | 3 | SF 100 | 12 | 3000 | |

### *2.2 Selection of regular SF and source term*

Since most of the nuclear fuel loaded in domestic NPPs exists within the enrichment level of 4.5 wt.% and the discharge burnup level of 45 GWD/MTU. The source term was selected accordingly to assessment [4].

Table II: Specification of the SF as waste contained in the transport container

| Item | Value |
|---|---|
| PWR SF | - |
| Enrichment (wt.%) | 4.51 |
| Average Burnup (MWD/MTU) | 45000 |
| Cooling time (yr) | 10 |

Table III: Average radioactivity of the SF in transportation container

| Radionuclides | Classification | Inventory (Ci) |
|---|---|---|
| $^{60}Co$ | Crud | 628 |
| $^{85}Kr$ | Gas | 2230 |
| $^{90}Sr$ | Particle | 27500 |
| $^{90}Y$ | Particle | 27300 |
| $^{106}Ru$ | Ruthenllum | 252 |
| $^{129}I$ | Particle | 0.0148 |
| $^{134}Cs$ | Cesium | 4850 |
| $^{137}Cs$ | Cesium | 38500 |
| $^{144}Ce$ | Particle | 90.1 |
| $^{238}Pu$ | Particle | 1360 |
| $^{239}Pu$ | Particle | 167 |
| $^{240}Pu$ | Particle | 206 |
| $^{241}Pu$ | Particle | 43200 |

### *2.3 Determination of transport routes and accident assessment input data*

The transport route was assumed to start from the Hanbit NPP and transported to optional interim storage facility in the East Sea coast. It was estimated considering the no-voyage zone for oil tankers, and it was assumed that the length of the vessel was 760 km, the ship speed was 24 km/hr, the number of crew members was 22, and there was no anchorage. For the population density along the route, 515 people/km2 was used using the Korean population density suggested by the National Statistical Office [5]. The accident rate represents an accident on one vessel while sailing 1 km. Using the current status of marine accident statistics in 2020 [6], the number of registered ships was calculated and inputted as the number of marine accidents. The accident assessment input data are represented in Table IV.

Table IV: Accident assessment input data

| Items | Value |
|---|---|
| Number of tankers and cargo ships | 826 |
| Number of accidents | 222 |
| Accident probability (%) | 3.39 E-04 |
| Collision, fire and explosion accident rates (%) | 40.5 |
| Probability of crashes, fires and explosions (%) | 0.1045 |
| Probability of death from collisions, fires and explosions (%) | 11.1 |

## 3. Conclusions

### *3.1. Normal transport scenario*

The individual dose of crew members is 3.26×10-3 mSv, and the individual dose of loading and unloading workers is 1.15×10-7 mSv. If crew members are not regarded as workers but as ordinary people, it is evaluated as 0.326% of the annual dose limit of 1 mSv. Since the annual dose limit for loading and unloading workers is 100 mSv for 5 years, when evaluating the amount of exposure for 5 years, it is evaluated as 5.75×10-7% which is significantly lower than domestic legal standard.

### *3.2. Accident scenario*

The collective dose for each radionuclide to the public in the event of collision, fire and explosion accidents is as follows in Table Ⅴ. The collective dose to the general public is 5.54×10-8 person-Sv, and the individual dose rate is 7.97×10-11 mSv, which is significantly lower than the individual dose limit of 1 mSv.

Table V: Collective dose of each radionuclide to general public

[unit: Sv]

| ISOTOPE | Inhaled | Resuspended | Cloud Shine | Ground Shine | TOTAL |
|---|---|---|---|---|---|
| $^{60}$Co | 3.00E-08 | 0.00E+00 | 1.15E-09 | 0.00E+00 | 3.12E-08 |
| $^{85}$Kr | 0.00E+00 | 0.00E+00 | 5.14E-10 | 0.00E+00 | 5.14E-10 |
| $^{90}$Sr | 1.76E-10 | 1.47E-12 | 1.12E-16 | 2.58E-15 | 1.77E-10 |
| $^{90}$Y | 6.81E-12 | 5.68E-14 | 2.80E-15 | 4.22E-14 | 6.91E-12 |
| $^{106}$Ru | 2.33E-12 | 0.00E+00 | 2.62E-15 | 0.00E+00 | 2.33E-12 |
| $^{129}$I | 3.95E-17 | 3.30E-19 | 3.04E-21 | 1.26E-19 | 4.00E-17 |
| $^{134}$Cs | 2.02E-10 | 0.00E+00 | 5.08E-12 | 0.00E+00 | 2.07E-10 |
| $^{137}$Cs | 1.71E-09 | 0.00E+00 | 1.46E-11 | 0.00E+00 | 1.72E-09 |
| $^{144}$Ce | 5.77E-13 | 4.82E-15 | 1.37E-16 | 1.75E-15 | 5.83E-13 |
| $^{238}$Pu | 1.11E-08 | 9.29E-11 | 3.59E-18 | 3.77E-16 | 1.12E-08 |
| $^{239}$Pu | 1.49E-09 | 1.24E-11 | 3.82E-19 | 2.02E-17 | 1.50E-09 |
| $^{240}$Pu | 1.83E-09 | 1.53E-11 | 5.29E-19 | 5.47E-17 | 1.85E-09 |
| $^{241}$Pu | 6.92E-09 | 5.78E-11 | 1.69E-18 | 2.75E-17 | 6.98E-09 |
| Total | 5.34E-08 | 1.80E-10 | 1.68E-09 | 4.70E-14 | 5.54E-08 |

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## 4. Conclusions

As a result of preliminary evaluation of radiation effects using NRC-RADTRAN, it is significantly lower than the domestic legal standard. However, there is no history of operating an exclusive vessel for SF transport in Korea yet. And it has not been decided which SF container to use. Above all, while the location of the intermediate storage facility has not yet been determined, it is necessary to evaluate and study the specific route after the the route is determined. In a future study, there is a plan to present a methodology for deriving an optimal scenario on the transport route using ‘Flexsim software’ and evaluating the radiation effect accordingly. In addition, when conducting the radiation impact assessment of the transport crew and loading and unloading workers, a study on the distance from the SF transport container and the rate of release of radioactive materials will be performed together.

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