A Study on CASK Design for HANARO Transportation Suitable for Material Capsule through Shielding Calculation

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1. Introduction

HANARO, the only neutron irradiation test facility in Korea, has been serving as an infrastructure for national medium-long term nuclear research and development projects and basic research since 1995 by conducting various neutron irradiation tests requested from users of the industry, universities, and institutes. Among the devices used for neutron irradiation testing, an irradiation test capsule is used to evaluate the neutron irradiation effects of a reactor pressure vessel, the core material, and the nuclear fuel, which are essential for a nuclear power plant, and is a device for reproducing the use environment of a nuclear power plant. The capsule is divided into a material capsule and a fuel capsule depending on the substance to be irradiated. The irradiated capsule (Fuel/Material Capsule) and the irradiation device are stored in the reactor water tank, and after having a certain period of radiation cooling, they are cut into a transport size and transported to the Irradiated Materials Examination Facility (IMEF) in the transportation CASK. However, unlike foreign research reactors, the domestic research reactor is not connected to the IMEF and the Irradiation Test Facility underwater. So the capsules are transported using the CASK for transportation. Originally, CASK was designed to transport HANARO nuclear fuel, but it is also used to transport irradiated capsules, and thus the CASK specifications are designed to meet the transport dose standard of HANARO nuclear fuel. However, although the irradiation test capsule has a lower dose than the HANARO nuclear fuel during the post-irradiation treatment, unnecessary factors such as labor, time and vehicle support are the same as in HANARO nuclear fuel processing. Therefore, the necessity of the design of CASK for transport suitable for the irradiation test capsule has been devised. In this paper, the material capsule (SA 508 Gr. 4N Irradiation test, 11M-25K) was selected as the pressure vessel model, and the radioactivity and gamma spectrum were calculated from the irradiation test capsule irradiated in HANARO using the ORIGEN2.2 Code. Based on this, the CASK for transport is modeled using the MCNP6 Code, and a shielding calculation is performed. Therefore, we compared and analyzed the dose of the existing CASK and the designed CASK. Based on the results of this calculation, it will be possible to reduce the volume and weight of the designed CASK for transport, such that it will be a more rapid and efficient post-irradiation examination treatment work [1].

2. Specifications of CASK for Transport

2.1 Specifications and Structure

CASK is a transport container designed/manufactured to transport combusted fuel irradiated in HANARO. It was designed to transport 36 HANARO fuel rods with 120,000 MWD/MTU, for a 1 month cooling period and 1.3 kW of decay heat. The outside of CASK is made of STS, and the inside is made of lead and Si for shielding, and it weighs about 6.6337 tons. Table 1 shows the specifications of the CASK, and Figure 1 shows the CASK design and modeled figure using the MCNP Code [1].

Table 1. Specifications and Standards of CASK

	Standard	Density
CASK(S.S316) Outer Diameter/Height	771 mm/ 2030 mm	8.03 g/cc
Lead Outer Diameter/Height (Gamma Shielding)	605 mm/ 1553mm	11.3 g/cc
Silicon Mixture Outer Diameter/Height (Neutron Shielding)	755 mm/ 1598.5 mm	1.45 g/cc
Center Hole	123mm/ 1,075mm	-

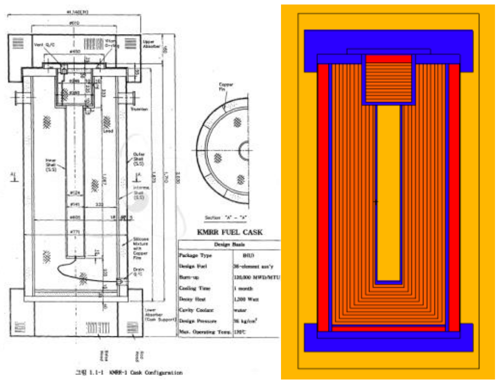

Fig. 1 Design and Geometry of CASK

2.2 Transport Dose Standard

According to the HANARO transport technology standards, the radiation dose rate at 10cm and 2m from the surface of the container are not to exceed 10 mSv/hr and 0.1 mSv/hr, respectively [2].

2.3 Transfer Procedure of Irradiated Capsule

After the irradiation test, capsules and the like, which have been tested in HANARO, are stored in a reactor working tank. After cooling for a certain period, the capsule body with specimen is cut into the CASK size, and the cut capsule is placed into a CASK and transferred to the IMEF by truck [2].

3. Selection of Representative Capsule

3.1 Material Capsule (11M-25K)

11M-25K has been used in an irradiation test to evaluate the irradiation characteristics of high strength RPV low alloy steels utilizing standard instrument capsule technology. The main design of the capsule was designed for the basic design of a standard material instrument capsule that has been conducted to irradiation tests on a CT (Centric Hole) of 30 MW output. A ten cycle test was assumed to calculate the maximum activation of the capsule, and the average neutron flux of the CT hole was calculated at 6× $\mathbf{10^{14} n/cm^2 \cdot s}$. The 11M-25K capsule is equipped with a specimen SA 508 of high strength RPV low alloy steel, which is a reactor pressure vessel model alloy. The diameter is 56 mm and the height is 960 mm. Figure 2 shows the design of the 11M-25K and the modeled figure using the MCNP6 Code [3].

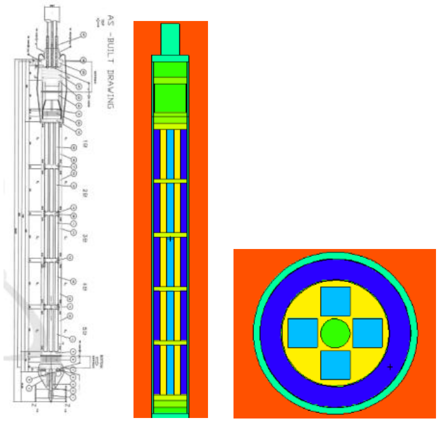

Fig. 2 Design and Geometry of 11M-25K

4. Computer Code

4.1 ORIGEN2.2

ORIGEN2.2 is a code for calculating the reduction of the fissile material through the fission, generation, and decay of radioactive isotopes and radioactive material. It mainly calculates the fuel cycle and related changes in the fuel composition and characteristics according to the degree of combustion, the gamma dose per unit weight of the fuel, and the content of the radioactive isotope in the fuel.

4.2 MCNP6

The MCNP6 Code is a transport code for neutrons, photons and electrons, and is widely used in radiation shielding, radiation dose measurement, and criticality calculation. In addition, geometries can be simulated in three-dimensions of reactor structures composed of various types of surfaces.

4.3 ORIGEN2.2/MCNP6

First, the mass calculation of the major elements of the capsule is performed. The ORIGEN2.2 Code is used to calculate the radioactivity after the irradiation test. After selecting the major nuclides, the energy-specific gamma spectrum is calculated, and the calculated spectrum is used as the input values in the MCNP6 code. MCNP6 modeling is performed based on the design data of the capsule and CASK, and a shielding calculation is conducted using the MCNP6 Code.

4.4 Calculation of Source

To conduct an accurate and reliable shielding calculation using the MCNP6 Code, it is most important to construct a source of the input data. Therefore, based on the design data, the mass value of each element of the correct capsule was calculated and the HANARO (CT Hole) exclusive cross-section library was constructed from the ORIGEN2.2 Code. It is also important to select gamma nuclides to calculate the energy-specific gamma spectrum. Therefore, the following Table 2 shows the calculation results of the total radioactivity amount assuming ten cycles of testing to calculate the maximum capsule activation. And Figure 3 shows a graph of the above. The calculation period was ten cycles (1 cycle is 28 days), and the maintenance period was 2 weeks (14 days). The results of the irradiation period and the cooling period repeatedly indicate the shape of the rise and fall.

Table 2. Results of Calculation of Radioactivity of Capsule

Status	Day	Cycle	Activity(Ci) HANARO CT hole
Irradiation	56	2	1.854e+05
Decay	84		2.536e+04
Irradiation	140	4	1.920e+05
Decay	168		2.990e+04
Irradiation	224	6	1.935e+05
Decay	252		3.175e+04
Irradiation	308	8	1.942e+05
Decay	336		3.316e+04
Irradiation	392	10	1.947e+05
Decay	422		3.317e+04
Decay	452		2.013e+04

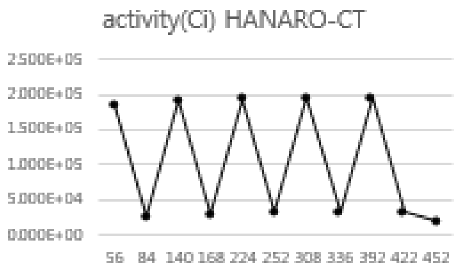

Fig. 3 Graph of Radioactivity of Capsule

The following Table 3 shows the radioactivity of each radionuclide calculated by the ORIGEN2.2 Code. Among them, the nuclides were selected as the representative values except for the radionuclide, which decreased significantly after 1 or 2 cooling periods. Table 4 shows the energy-specific gamma spectrum, which is applied to the MCNP6 input data.

Table 3. Gamma Nuclide Radioactivity with Irradiation and Cooling Period using ORIGEN2.2 Code

	Post-irradiation (Ci)	30day Cooling (Ci)	60day Cooling (Ci)
Na24	2.430e+01	8.632e-14	3.067e-28
P32	8.016e+01	1.872e+01	4.374e+00
Sc48	3.902e-03	4.401e-08	4.963e-13
Cr51	4.970e+04	2.347e+04	1.108e+04
Mn54	7.768e+02	7.268e+02	6.800e+02
Fe55	7.598e+03	7.434e+03	7.273e+03
Fe59	1.014e+03	6.385e+02	4.023e+02
Co58	9.889e+02	7.372e+02	5.495e+02
Co60	2.295e+01	2.271e+01	2.246e+01
Cu66	3.722e+00	9.674e-07	1.039e-10
Cu67	1.137e-05	3.566e-09	1.118e-12
Zn65	7.496e-04	6.883e-04	6.320e-04
Zr89	1.837e-03	3.171e-06	5.478e-09
Zr95	1.399e-04	1.010e-04	7.301e-05
Nb92	1.349e-01	1.743e-02	2.251e-03
Nb95	8.605e-04	5.287e-04	3.306e-04
Mo93	4.920e-04	4.920e-04	4.920e-04
Mo99	2.279e+01	1.185e-02	6.162e-06
Ru103	5.970e-04	3.516e-04	2.071e-04

Table 4. Energy-Specific Gamma Spectrum of Capsule

Energy (MeV)	Activity (Photons/sec)
0.015	2.8823e+14
0.02	2.9334e+06
0.04	9.1344e+03
0.05	4.8574e+04
0.15	2.4333e+11
0.2	7.3472e+11
0.3	8.5424e+13
0.4	4.7297e+04
0.5	8.1447e+12
0.6	1.3790e+08
0.8	5.4207e+13
1.0	1.4210e+13
1.5	1.1193e+13

5. Evaluation of dose according to CASK Change

5.1 Change of Size

The numerical change of the existing CASK was performed to calculate the optimal CASK corresponding to the transport dose standard.

5.2 Application of the Size Change

Figure 4 shows a model of the material capsule (11M-25K) stored in a CASK. The source spectrum of the material capsules was calculated using the ORIGEN2.2 Code, and the shielding calculation was performed based on the MCNP6 Code. Tables 5 and 6 show the CASK size change parameters and the calculation results. As a result, the diameter of CASK can be reduced by about 42%, the height by about 38%, and the weight by about 70%.

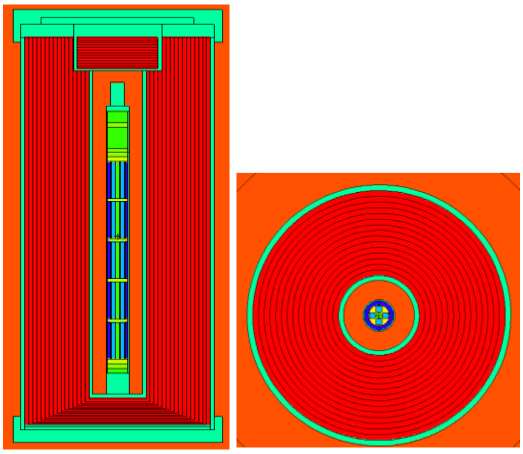

Fig. 4 Geometry of 11M-25K stored in CASK

Table 5. Size Change parameter of Material Capsule CASK (Units: mm)

	Preexistence	Rev01	Rev02	Rev03
Side Lead	-	-	-	-
Thickness	218.5	110	140	150
Height	1553.5	1123.5	1123.5	1123.5
Total	-		-	-
Diameter	771	360	430	450
Height	2030	1260	1260	1260

Table 6. Calculation Result according to Size Change of Material Capsule CASK (Units: mSv/hr)

	Preexistence	Rev01	Rev02	Rev03
Surface	8.8982e-03	49.434	5.8336	3.0957
10cm	5.1967e-03	20.778	2.9388	1.6046
2m	3.3649e-04	0.7341	0.1057	0.06496
Weight	6.6337 ton	1.31 ton	1.86 ton	2.0 ton

6. Conclusion

The CASK for transport currently being used as a means of transporting an irradiation test capsule in HANARO was originally designed to transport HANARO nuclear fuel. However, unlike foreign research reactors, the domestic research reactor is not connected to the IMEF and the Irradiation Test Facility underwater. So the capsules are transported using the CASK for transportation. Therefore, the transport dose standard is also designed to meet the standards of nuclear fuel. In addition, because of its large weight and volume, there are unnecessary factors in the operation of transferring a low dose capsule. Therefore, the necessity of the design of CASK for transport suitable for an irradiation test capsule has been devised.

First, in this paper, the material capsule (11M-25K) was selected, and the radioactivity and gamma spectrum were calculated from the irradiation test capsule irradiated by HANARO using the ORIGEN2.2 Code. Based on this, the CASK for transportation is modeled according to the transfer dose standard using the MCNP Code, and a shielding calculation was conducted. Unlike the conventional CASK, the designed CASK reduced the weight and volume. The CASK diameter was calculated to be reduced by about 42%, the height by about 38%, and the weight by about 70%.

As future studies, research is planned based on various conditions such as the size, weight, material, shape, and source, with a plan to use it at HANARO, as well as the CASK design for a nuclear fuel capsule, allowing a more rapid and efficient post-irradiation examination treatment to be conducted.

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