CASK Design for Material Capsule Transfer using MCNP6/ORIGEN2.2 Code

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1. Introduction

The irradiation capsules are devices that can reproduce the environment of NPPs, and thus are used to evaluate the irradiation effects of reactor materials and nuclear fuel in research reactors. And after irradiation test, the irradiated capsules 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). However, unlike foreign research reactors, the HANARO is not connected to the IMEF underwater. So the capsules are transported using a CASK. The CASK is a transport container manufactured to transport fuel irradiated in HANARO and it is also used to transport irradiated capsules. Because of its large weight and volume, there are unnecessary factors in the operation of transferring a low dose capsule. Therefore, the necessity of a new design of CASK for transport suitable for an irradiation capsule has been devised.

As a revised version of the previous paper [1], the material capsule was divided into 5 separate stages and stored in the new design of CASK. This has been able to increase efficiency in transporting the capsule by having a smaller size than the previous version.

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. 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 test treatment work.

2. Specifications of CASK for Transport

2.1 CASK

The CASK is a transport container manufactured to transport fuel irradiated in HANARO. and it is also used to transport irradiated capsules. 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 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 [2]. Figure 1 shows a schematic and actual photograph of the CASK.

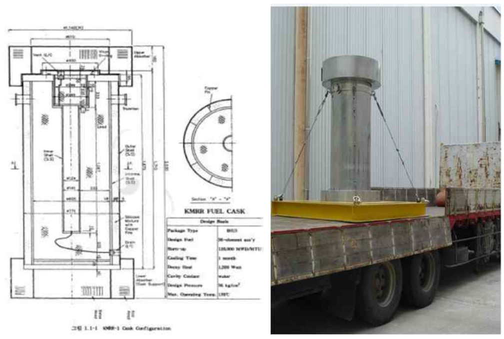

Fig 1. Schematic and Photograph of the CASK

2.2 Structure of CASK

The basic structural material of CASK is STS, and the inside is made of Pb for gamma shielding. CASK has a central hole with a diameter of 12.3cm and a height of 107.5cm, where the object to be transferred is inserted. The total diameter of CASK is 77.1cm, height 203cm and weight is about 6,630 kg [2].

2.3 Dose Standard of Transport Container

According to the HANARO transport technology standards, 2 mSv/hr from the surface of the container and the radiation dose rate at 2 m from the surface of the container is not to exceed 0.1 mSv/hr [3].

3. Calculation Method

3.1 ORIGEN2.2/MCNP6

In this paper, the mass calculation of the major elements of the capsule is performed. The ORIGEN2.2 code [4] 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 [5]. The capsule was divided into individual stages and contained in CASK. This shape was modeled and shielding calculations were performed using MCNP6 code [1].

3.2 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 HANAR (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 [1].

The following Table 1 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 ~ 2 cooling cycles. Table 2 shows the energy-specific gamma spectrum, which is applied to the MCNP6 input data.

Table 1. Radioactivity of Major Radionuclide Calculated by ORIGEN2.2 Code

	Post-Irradiation (Ci)	30-day Cooling (Ci)	60-day Cooling (Ci)
P-32	10.49	2.45	0.572
Cr-51	6673	3151	1488
Mn-54	908.2	849.7	795
Fe-55	8858	8666	8478
Fe-59	1184	745.7	469.7
Co-58	161.1	120.1	89.5
Co-60	10.04	9.937	9.83

Table 2. Energy-Specific Gamma Spectrum of Capsule

Energy (MeV)	Activity (Photons/sec)
0.015	1.0935×10^{14}
0.15	1.7900×10^{11}
0.2	5.4048×10^{11}
0.3	5.4572×10^{12}
0.5	9.8881×10^{11}
0.6	5.9328×10^{7}
0.8	3.2725×10^{13}
1.0	1.0199×10^{13}
1.5	7.8892×10^{12}

4. Evaluation of Dose according to Revised CASK

4.1 Modelling of CASK

The standard material capsule is composed of 5 stages. Therefore, to reduce the volume of CASK, each stage was divided and inserted into the CASK. The shape of CASK is rectangular parallelepiped model and the size of the storage space was 30.8 cm x 6 cm x 13.4 cm. The Pb was used as a gamma shielding material and the thickness was designed as 4.4cm to satisfy the dose standard. Also, Pb was calculated by dividing by 2mm to reduce the time of calculation. Figure 2 shows a CASK modelled with a capsule using MCNP6 code and Figure 3 shows it in 3D-geometry.

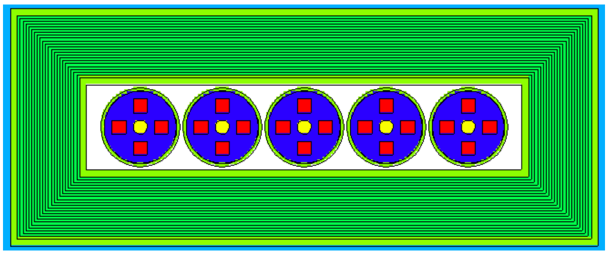

Fig 2. Geometry of Capsule stored in CASK

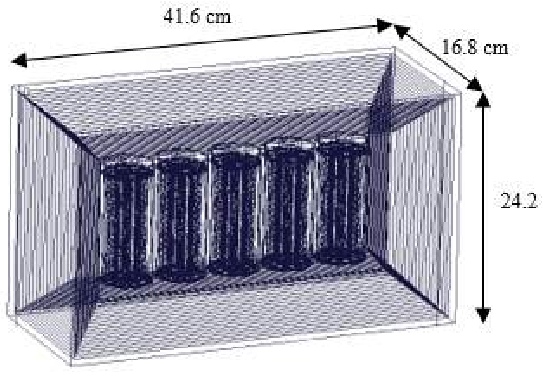

Fig 3. 3D-Geometry of CASK

4.2 Shielding Calculation of CASK

The shielding calculations were performed to confirm that the designed CASK was in compliance with the transport dose standard. The dose evaluation points were calculated at six locations (left, right, front, back, upper, bottom), 2m from the surface and surface of CASK. The calculation results are shown in Table 3.

As a results, it was satisfied with the dose standard, and it can be reduced to in volume (947,751 cm^3 → 16,912 cm^3), in height (203 cm → 24.2 cm), and in weight (6,630 kg → 150.86 kg).

Table 3. Calculation Results according to Designed CASK (Units: mSv/hr)

Surface of CASK : 2 mSv/hr (Standard)					
Left	Right	Front	Behind	Upper	Bottom
1.525	1.408	1.808	1.834	1.903	1.850
2 m from the surface of CASK : 0.1 mSv/hr (Standard)					
Left	Right	Front	Behind	Upper	Bottom
0.0042	0.0039	0.0124	0.0123	0.00733	0.00767

5. Conclusions

The CASK is a transport container manufactured to transport fuel irradiated in HANARO and it is also used to transport irradiated capsules. Because of its large weight and volume, there are unnecessary factors in the operation of transferring an irradiated capsule. Therefore, the necessity of a new design of CASK for transport suitable for an irradiation test capsule has been devised.

The radioactivity and gamma spectrum were calculated from the irradiation test capsule irradiated by HANARO using the ORIGEN2.2 code. Based on this, a new CASK is modeled by using the MCNP6 code according to the transport dose standard. As a results, the CASK was satisfied with the dose standard, and the size can be reduced in volume (947,751 cm^3 → 16,912 cm^3), in height (203 cm → 24.2 cm), and in weight (6,630 kg → 150.86 kg).

If the revised CASK is actually used in HANARO, it will be able to reduce unnecessary factors and efficient work can be performed.

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