Mechanical Dimensioning of the Canister Insert for PWR Spent Fuels

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1. Introduction

KAERI is developing a Korean Reference Disposal System for the high-level radioactive wastes. The spent fuels from the nuclear power plants will be directly disposed of in the repository based upon the current design concept. It is planned to store PWR spent fuels in the interim storage facility more than 40 years before the final disposal, during which we expect most of short-lived radionuclides might decay.

Several kinds of disposal canisters for the high-level radioactive wastes have been proposed by the authors. The canisters consist of two parts. One is an outer shell for the corrosion resistance and the other is an insert for the mechanical strength. This kind of double layered canister was introduced in the countries such as Sweden [1] and Finland [2] in which the lifetime of the canister was required to be more than 100,000 years. It is thought that the radioactivity in the spent fuel will decay to the level of uranium mine during the period.

The main function of the canister is the containment of the radionuclides during the specified period. Thus, the canister is designed with an outer layer of copper for corrosion protection, and the canister is supported by the pressure-bearing insert. This paper focused on the design of canister insert. The nodular cast iron was selected as material for the insert because it shows the best properties [3].

The determination of the canister diameter is very important in the design of the repository. The previous study [4] showed the diameter and height of the Korean Disposal Canister (KDC) were 122 cm and 483 cm, respectively. The pre-conceptual design of Korean Reference Disposal System was based on the KDC. The diameter of the KDC was so large that the weight of the canister was too heavy to handle in the repository. The canister size was determined mainly by the diameter of the insert, and the diameter of the insert is determined through the structural analysis. The insert has to be designed to withstand the hydrostatic pressure and the swelling pressure from the bentonite buffer.

The structural analysis of the canister insert was the most important activity in design. NISA computer program was used for the structural analysis of the insert. A new heat source term from PWR spent fuels and boundary conditions were applied to design the insert for PWR spent fuels. The results of the calculation were compared with the safety factor of 2.0.

The main purpose of this study is to develop a new canister insert for PWR spent fuels. The optimum size of the canister insert was determined based on the structural analysis. With the new design of the insert we calculate the gains from the reduction of the canister size in terms of the volume of excavation of deposition holes and the volume of bentonite buffer.

2. Canister insert

Several requirements for the canister design were prepared by KAERI since no regulations on the design of the canister were prepared by the regulatory body in Korea. Table 1 shows the requirements compared with those in Finland. Among the lists described in Table 1, the insert was related to the load (pressure) condition. The canister insert should be designed to withstand the thermal stress from the decay heat of spent fuels, the hydrostatic pressure at 500 m below the surface, and the swelling pressure from the bentonite buffer.

Table 1. Canister design requirements

	KAERI	Finland
Duration of corrosion resistant	1,000 years or 100,000 years	100,000 years
Maximum exposure rates	0.5 Gy/y	1 Gy/y
Criticality	$K_{eff} < 0.95$	subcritical
Temperature at the canister surface	< 100°C	< 100°C
Load (Pressure) condition	Qualitatively stated	7 MPa + 7 MPa
Drop test condition	2.0 m	Not mentioned
Handling	Qualitatively mentioned	Strength of copper
Remaining	Initial defects less than 0.1 %	Gap between outer shell and insert: <5%

3. Structural analysis

The heat source from the PWR spent fuels was newly calculated with the computer program, ORIGEN-2. Figure 1 showed the result of the calculation. From the figure 1, the heat generation rate was obtained as follows:

$$q(50) = 1476.29\, W / m^3 \qquad (1)$$

This value was used to calculate the thermal stress from the PWR spent fuels.

Two cases of hydrostatic pressure and swelling pressure were considered in the paper. One is for the extreme case and another for the normal case. The safety factor of 2.0 was used for the extreme case and the normal case.

The diameter of the canister was 122 cm in the previous study [4]. Five cases were compared for the optimization of the canister insert. The results of the calculation were shown in Table 2. As shown in Table 2, the smallest canister with the diameter of 102 cm meets the safety factor of 2.0 for both the extreme load condition and the normal load condition. The distribution of von-Mises stress for the extreme load condition was given in Figure 2.

Table 2. Results of the structural analysis

		102 cm	107 cm	112 cm	117 cm	122 cm
Load Case-1 (extreme)	Max. von Mises stress (MPa)	80.5	77.5	74.7	72.3	70.0
	Safety factor	2.5	2.6	2.7	2.8	2.8
	Max. Deform (mm)	2.7	2.7	2.7	2.7	2.7
Load Case-2 (normal)	Max. von Mises stress (MPa)	65.8	62.24	61.74	61.41	57.36
	Safety factor	3.0	3.2	3.2	3.3	3.5
	Max. Deform (mm)	2.6	2.6	2.6	2.6	2.6

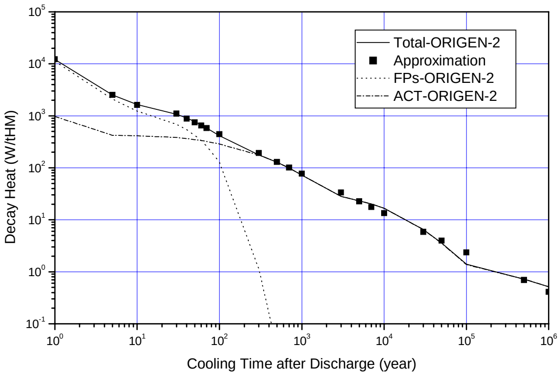

Figure 1. Result of new calculation of heat source from PWR spent fuels.

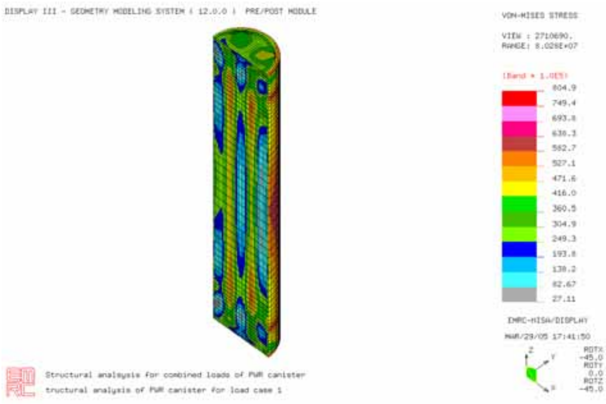

Figure 2. Result of the structural analysis of the canister insert for load case 1.

4. Calculation of buffer volume

The diameter of the canister was determined to be 102 cm according to the structural analysis. The diameter was reduced by 20 cm compared with the previous study. Thus, the weight of canister, the volume of deposition holes and the volume of buffer material could be reduced with the new canister insert. The comparison was given in Table 3. The current design of HLW repository needs 11,375 deposition holes for PWR spent fuels.

Table 3. Comparison of three cases

	A	B	C
Diameter of canister (m)	1.22	1.07	1.02
Diameter of insert (m)	1.12	0.97	0.92
Weight of a canister (ton)	37.3	27.8	24.9
Volume of one hole (m^3)	30.84	26.8	25.6
Volume of 11,375 holes (m^3)	3.51×10^5	3.05×10^5	2.91×10^5
Difference (m^3) (A-B, A-C)	-	4.54×10^4	**5.98×10^4**
Volume of buffer in one hole (m^3)	24.1	21.5	20.6
Volume of buffer in 11,375 holes (m^3)	2.74×10^5	2.44×10^5	2.35×10^5
Difference (A-B, A-C)	-	2.98×10^4	**3.94×10^4**

5. Conclusion

The diameter of the canister insert for PWR spent fuels was determined based upon the structural analysis. The calculation shows that 102 cm canister meets the safety factor of 2.0 for both extreme and normal load conditions. The volume of buffer material necessary for the PWR spent fuel deposition holes could be reduced by about 3.94×10^4 m^3 compared with the previous study.

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