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Preliminary Radiation Safety Assessment for Engineering Barrier of HANARO Spent Fuel Disposal System

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1. Introduction

This research aims the radiation safety confirmation of HANARO spent fuel disposal system. For this purpose, this article will characterize HANARO spent fuel, calculate its amount, calculate radiation source intensity by making its own cross-section library, analyze its disposal system and components, make MCNP models of the system and finally perform radiation safety evaluations of the system.

2. Methods and Results

Fig. 1 shows a conceptual disposal system of HANARO spent fuel with each components briefly.

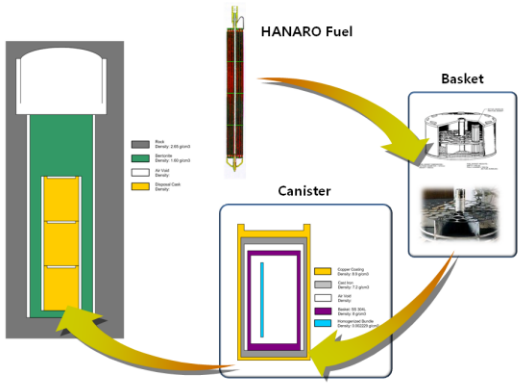

Fig. 1. Conceptual diagram for HANARO spent fuel disposal system.

2.1 HANARO fuel

HANARO fuel material is U_3Si and these high density U_3Si particles (61.4 wt%) are dispersed in high purity alumina matrix (38.6 wt%). Highly enriched (95 wt%) fuel has been used in the past to raise neutron flux by operating the reactor with high specific power, but recently lowly enriched (19.75 wt%) fuel which is the maximum limit for low enrichment is loaded for nonproliferation reason. This high specific power operation leads to high decay heat per unit uranium mass and high discharge burnup around 100,000 MWd/MtU. Reactor operation runs 23~28 days as one cycle, and aims 9 cycle management per a year. Two 18-pin spent fuels and three 36-pin fuels are reloaded every operating cycle and therefore, 45 spent fuels are produced every year. As of November 2007, 194 assemblies of 36-pin type and 106 assemblies of 18-pin type are stored in reactor pool and total uranium mass is 559 kg. The time of storage pool saturation is anticipated as 2022 with assuming that above operation cycle and spent fuel production rate are applied. Direct disposal of HANARO spent fuels after this pool storage is currently considered[1].

2.2 Radiation source

To evaluate HANARO spent fuel radiation source, this research used ORIGEN-ARP code. Cross-section library is most important for this purpose, but ORIGEN-ARP does not serve HANARO library and so this research performed producing its cross-section library with SAS2 in SCALE code system[2]. HANARO library only needs 1 initial enrichment case (19.75 wt%) with various burnup level up to 100,000 MWd/MtU. By using ARPLIB module, total 12 libraries were produced for 36-pin fuel assembly. For simplicity and conservatism, only 36-pin type was considered for library producing and radiation calculating here after. The irradiation history for a fuel assembly consisted of 7 cycles which include the irradiation time of 28 days with 510.2 W/gU specific power and the downtime of 7 days. This irradiation history could reach the 100,000 MWd/MtU for each fuel assembly. By applying this cross-section library to ORIGEN-ARP, radiation changes with time(Fig. 2) could be obtained for a million year that is recently considered as an important time boundary for the final disposal.

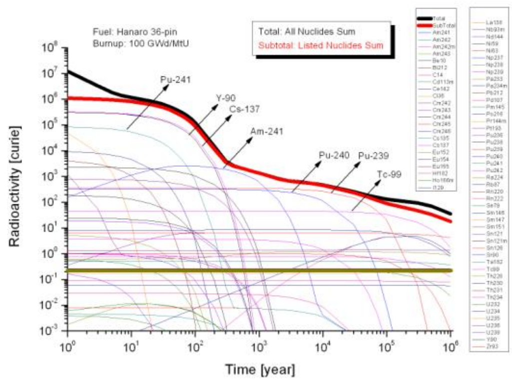

Fig. 2. Radioactivity changes along time up to 1 M year.

2.3 Disposal System

HANARO disposal system consists of spent fuel, basket, canister, and engineering barrier system(EBS). A basket could contain 60 36-pin fuel and it is made of stainless steel (SA240 Type 304L) with diameter as 106.7 cm, height as 102.2 cm, thickness of top & lateral side as 0.85 cm, and thickness of bottom as 1.91 cm. A canister which consists of cast iron inside wall and copper outside wall could contain a basket and perform radiation shielding. Cast iron is for structural material with 18 cm thickness in top & bottom and 9.5 cm thickness in lateral side. Copper coating with 3 cm thickness at the top and bottom and 1 cm thickness at the lateral region is added in order to prevent corrosion in the disposal environment. Engineering barrier system is similar with KRS-V1 disposal barrier system. This consists of bentonite blocks as buffer around the disposal canister, a vertical disposal hole, disposal tunnel and bedrock in the outer region.

2.4 MCNP modeling

For the MCNP calculation input, it is important to get the density and the composition fraction of the homogenized (fuel, cladding, and air) source material. For simplicity, a fuel assembly was modeled in a cylinder shape and these homogenizing procedures are followings:

- Analyzing nuclides and its composition fraction in fuel which has 3.15 g/cm^3 density; uranium 58.3, silicon 2.2, and aluminum 39.5 wt%.
- Analyzing nuclides and its composition fraction in cladding(Al AA1060) which has 2.7 g/cm^3 density; iron 0.35, manganese 0.03, silicon 0.25, copper 0.05, zinc 0.05, aluminum 99.27 wt%.
- Volumetric calculation for fuel and cladding results in fuel occupation value as 65%. This updated its homogenized composition fraction of each nuclide.
- Volumetric calculation for assembly(fuel and cladding) and open space(air) results in assembly occupation value as 42%.

The other components including basket, canister, disposal hole and tunnel were also modeled into MCNP program to calculate the radiation effect.

2.5 Dose calculation

Total photon and neutron rate for one canister of HANARO spent fuel had been calculated as 1.508 x 10^{15} (photons/sec) and 1.85 x 10^6 (neutrons/sec) in total for the 44 energy groups by using ORIGEN-ARP 5.0. Flux-to-Dose conversion factor of ICRP-74 recommendation was used for dose conversion. Tallies were set to top, bottom and lateral side of a canister with 10 cm distance. Dose calculation results for each direction are shown in Table 1. Dose result of canister bottom was higher than one of top and this is probably caused by 1 cm copper thickness of bottom area compared to 3 cm of top area. There are 3 canisters in a disposal hole vertically. Contrary to the dose calculation of a canister, absorbed dose is usually used for engineering barrier like bentonite or bedrock in order to estimate how the barrier could not help but absorb the radiation energy from the waste. Usually, 1 Gy/hr value is the recommended limit for the bentonite engineering barrier[3] because the higher radiation energy than this could cause radiolysis of bentonite. Absorbed dose of engineering barrier system from 3 canisters has been calculated for the most inner 1 cm bentonite layer conservatively. Absorbed dose result in Table 1 shows that engineering barrier system of HANARO spent fuel disposal system has enough margins for radiolysis threshold limit. This result is expected to be very useful to the engineering barrier system performance assessment.

Table 1: Dose calculation result for HANARO disposal system

Item	Location	Dose			Unit
		Gamma	Neutron	Total	
Canister	Top	1.06E-01	4.54E-04	1.06E-1	
	Side	3.58E+01	1.40E-03	3.58E+01	rem/hr
	Bottom	1.13E+03	2.98E-03	1.13E+03	
EBS		0.59E+00	5.56E-07	0.60E+00	Gy/hr

3. Conclusions

This research reviewed the major characteristics of HANARO fuel, suggested its disposal system conceptually, made MCNP modeling of it, and performed preliminary radiation safety evaluations of the disposal system quantitatively. For this work, the unique cross-section library of HANARO was made and successfully applied to ORIGEN-ARP and MCNP calculation. This research concluded that HANARO disposal system has enough margins for radiation safety based on the above calculation results.

REFERENCES

[1] Jongyoul Lee et al., Concept of a Korean reference disposal system for spent fuels, Journal of Nuclear Science and Technology, Vol. 44, No. 12, p.1565-1573, 2007
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