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Decay Heat Analysis of a 200MWth VHTR Core with the HELIOS/ORIGNE-2 Code

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1. Introduction

Recently, a Very High Temperature gas-cooled Reactor(VHTR), which is one of the Gen-IV reactor concepts, has been developed to generate hydrogen in the future[1]. Verififcation of a decay heat model of a nuclear fuel is necessary for the transient analysis of a core and for determining the heating load in fuel pools, shipping casks, reprocessing plants, and waste repositories. The ORIGEN-2[2] code is widely used for a decay heat calculation of a nuclear fuel. However, there is no neutron cross-section library for a VHTR fuel in the ORIGEN-2 code.

In this study, the HELIOS[3] code was used to generate 1-group neutron cross-sections for a VHTR nuclear fuel and a decay heat emission from a VHTR core was preliminary evaluated with the ORIGEN-2 code to verify the decay heat characteristics of a VHTR core.

2. Methods and Results

2.1. Decay Heat Calculation Procedure

Figure 1 shows the layout of the calculation procedure of the decay heat of a VHTR core with the HELIOS and the ORIGEN-2 code.

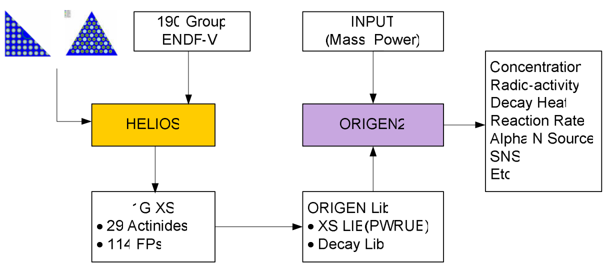


Fig. 1. Decay Heat Calculation Procedure with HELIOS/ORIGEN.

The ORIGEN-2 code is a versatile point-depletion and radioactive-decay computer code for use in simulating nuclear fuel cycles and calculating the nuclide compositions and characteristics of materials contained therein. The HELIOS code, which is a two-dimensional neutron transport calculation code, was used to prepare 1-group homogenized micro cross-sections of a VHTR fuel from the ORIGEN-2 code. Among the neutron cross-section libraries contained in the ORIGEN-2 code, PWRUE was modified and adjusted to the VHTR core conditions. PWRUE is the last version of a neutron cross-section library to support a high burnup of PWRs based on the ENDF-V data-base files.

2.2. Validation of HELIOS/ORIGEN-2 Procedure

According to the ORIGEN-2 library, PWRUE, which uses a 4.15w/o enriched UO_2 fuel with 3 cycles to achieve a extended fuel burnup of 50 GWd/tHM in a LWR, the cross-sections of the uranium isotopes do not depend on the fuel burnup. On the contrary, the cross-sections of the plutonium isotopes vary significantly with the fuel burnup rate. Table 1 shows the cross section data of the major uranium and plutonium isotopes from the PWRUE library and from the HELIOS calculation of a Korea Standard Nuclear Power Plant(KSNP) fuel assembly. Most of the neutron cross-sections from the HELIOS calculation are smaller in the uranium isotope and larger in the plutonium isotopes when compared with those of the ORIGNE-2 library.

Table 1. Neutron cross-sections of an ORIGEN-2 library and a HELIOS calculation

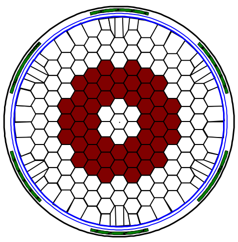
	ORIGEN-2 0/14GWd/tHM	HELIOS* 0/14GWd/tHM	Relative Error(%)**
U-235 (σ_c) U-235 (σ_f)	8.91 3.78E+1	8.05 3.49E+1	-9.65 -7.67
U-238 (σ_c) U-238 (σ_f)	8.55E-1 9.69E-2	7.51E-1 1.08E-1	-12.2 11.5
Pu-239 (σ_c) Pu-239 (σ_f)	57.5/35.1 99.2/63.8	59.5/45.7 105.2/80.8	3.5/30.2 6.0/26.6
Pu-240 (σ_c)	213.5/41.3	213.6/144.8	0.04/250.6
Pu-241 (σ_c) Pu-241 (σ_f)	33.6/24.8 101.3/78.3	36.8/28.8 108.7/85.7	9.5/16.1 7.3/9.5

* : Calculation of the KNSP fuel assembly with 4.15w/o UO_2.
** : (HELIOS-ORIGEN-2)/ORIGEN-2*100

As a result of the ORIGEN-2 calculations, the decay heat generations are similar to each other with a 1.1% difference although the neutron cross-sections of the major fission nuclides are very different. However, the difference increases with the cooling time and it is 7% at 1000 years of the decay time. The increasing discrepancy between the two libraries is induced by the actinides of the Pu-239 and Pu-240 isotopes which are the main decay heat contributors in the actinides. As shown in table 1, the capture cross-sections of the plutonium isotopes are very different between the two libraries. On the contrary, the decay heat generation from the fission products does not depend on the neutron cross-section. It means that the HELIOS/ORIGEN-2 coupled procedure for a decay heat calculation of a nuclear fuel is reasonable for a short-term cooling period until several hundreds of years.

2.3. 1-Group Cross-Section Generation of PMR200

A PMR200 VHTR core used in this study is a scale-down core from 600MWth of a Gas Turbine Modular Helium Reactor(GT-MHR).[4] The core configuration and design parameters are shown in Fig. 2. The PMR200 core contains 92 tons of graphite in the fuel block and the inner and the outer reflector and 1.59 ton of heavy metal uranium. The structure materials are not considered in this study for a simplification. The discharged fuel burnup of the PMR200 core is 120GWd/tHM using a 15.5w/o enriched UO_2 fuel. The specific power is 132.17W/g which is three times higher than that of a conventional LWR.



- Thermal Power 200 MWth
- Inlet/outlet helium temp. 490/950C
- Eq. core inner/outer radius 50/140 cm
- Effective core height 555 cm
- Outer reflector thickness 100 cm
- Avg. power density 6.69 W/cc
- U-235 enrichment 15.5%
- Avg. discharged burnup 120 GWd/tHM

Fig. 2. PMR200 Core Design & Parameters.

1-group neuron cross-sections for the PMR200 were prepared by a HELIOS single assembly calculation. The neutron cross-sections of U-235 and Pu-239 in the PMR200 fuel assembly are much higher than those of a conventional LWR fuel. The fission cross section of U-235 and Pu-239 at a zero burnup are 69.9 and 278 barn respectively. The neutron cross-sections of the actinides in the ORIGEN-2 source program and the PWRUE library were replaced by new one from the HELIOS calculation. The cross-sections of the fission products and activation products were not changed in the PWRUE library.

2.4 Calculation Results and Discussions

The decay heat fractions per total power of the PMR200 core are shown in Fig. 3 as a function of the burnup. The decay heat generation sharply increases with the burnup until 5GWd/tHM(38EFPD), and then it decreases slowly because the fission products accumulated in the core decay during a fuel depletion. The decay heat fraction of the fission products is over 95% during the burnup period. Since most strong gamma emitters have a short half-life time, the mass of them is small and slightly decreases with a burnup because of their precursors decaying with time. However, the total mass of fission products and actinides increase with burnup. The maximum decay heat fraction of the PMR200 core is 6.13% at the 5GWd/tHM burnup point.

The decay heat regression curves with the cooling time are depicted in Fig. 4. The decay heat generation per ton of heavy metal of the PMR200 core is three times higher than that of the KSNP fuel which will be a burden for a spent fuel management. This is due to the high power density in the PMR200 core.

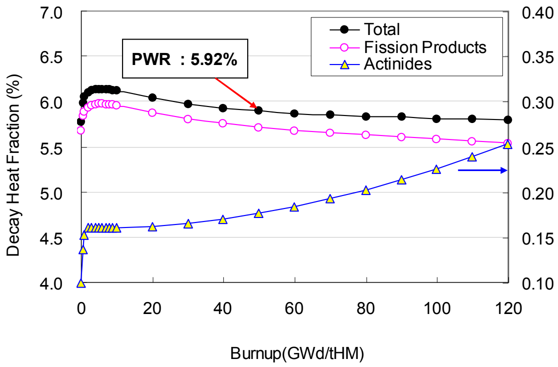


Fig. 3. Decay heat fraction vs. burnup.

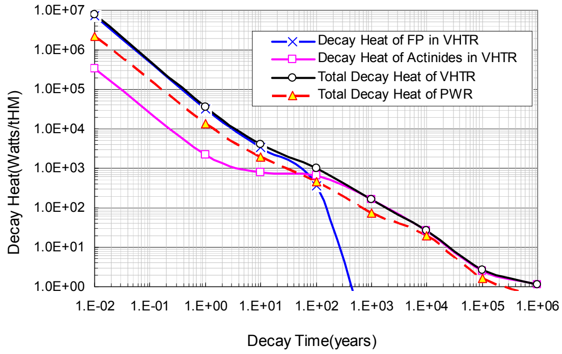


Fig. 4. Decay heat vs. cooling time.

3. Conclusion

Simulation of a decay heat calculation was performed based on the HELIOS/ORIGEN-2 coupled system for the preliminary 200MWth VHTR core. The decay heat fraction of the core was varied with the burnup and the maximum decay heat fraction was shown at the 5GWd/tHM burnup point as 6.13%. The decay heat generation per ton of heavy metal was three times higher than that of a LWR core which will be a burden for a spent fuel storage tank, reprocessing and repository facility.

REFERENCES

[1] A Technology Roadmap for Generation IV Nuclear Energy Systems, GIF-002-00, USDOE Nuclear Energy Advisory Committee and the Generation IV International Forum, December, 2002.
[2] A. G. CROFF, ORIGEN-2: A Versatile Computer Code for Calculating the Nuclide Compositions and Characteristics of Nuclear Materials, *J. Nucl. Technol.*, **62**, 335, 1983.
[3] R.STAMMLER et al., User's Manual for HELIOS, Scandpower, 1994.
[4] N.Kodochigov et al., Neutronic Features of the GT-MHR reactor, *J. Nucl. Eng. Design,* **222**, 161, 2002.