Estimation of the Cross-sectional Temperature in a Capsule for the Irradiation of TRISO-coated Fuel Particles

Kim Young Min, B.G. Kim, C.S. Lee, M.S. Cho, H.M. Kim and Y.W. Lee
Korea Atomic Energy Research Institute
P.O. Box 105, Yuseong-gu, Daejeon, 305-600, Republic of Korea
E-mail: nymkim@kaeri.re.kr

1. Introduction

The irradiation tests for the fuel and materials of a Very High Temperature Gas-Cooled Reactor (VHTR) support the development of a fuel process, the qualification of a fuel for normal operating conditions, and the development and validation of the models and computer codes for a fuel performance and a fission product transport. They also produce irradiated fuel and materials for a post-irradiation examination and a high-temperature furnace safety testing [1].

HTR Fuel Technology Development Division in KAERI (Korea Atomic Energy Research Institute) will irradiate the TRISO-coated fuel particles in the HANARO reactor by using a non-instrumented capsule [2]. For an optimum design of the capsule, it is necessary to determine the structural materials and estimate the temperature distribution within the capsule. This study provides details on the selection and configuration of the capsule material and an estimation of the temperature in the capsule.

2. Irradiation Capsule

The capsule is a cylindrical tube containing a graphite rod. Figure 1 shows the typical capsule and the graphite rod. The length and diameter of the graphite rod are 50 and 8.35 mm, respectively. There are nine holes inside the rod and every hole contains 50 TRISO-coated fuel particles. The characteristics of the TRISO particle are given in Table 1. A gap exists between the rod and the outer tube. The holes and gap contain helium gas. The outer tube has two layers that are separated by a helium or neon gap between them. The temperature at the graphite rod increases with the outer gas gap size.

The candidate materials of the tube are zircaloy, stainless steel, inconel, tungsten, and molybdenum. It was concluded that zircaloy and inconel were difficult to purchase. The stainless steel will severely deform at an elevated temperature (The target irradiation temperature is 1250 ℃ which is the operation temperature of the VHTR). The molybdenum and tungsten will not greatly expand at a high temperature. These two materials are being used in various foreign irradiation capsules. To begin with, the molybdenum was selected as a tube material for the present capsule (The performance of the tungsten will be estimated).

The capsule will be inserted into the OR5 test hole in the HANARO reactor. As a result of MCNP [3] calculations for the fuel in Table 1, the anticipated average power, effective full power days, and burnup are 0.652 watts per particle, 180 days, and 100 GWd/MTU, respectively.

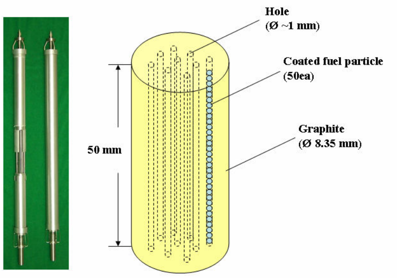


Figure 1 Capsule and graphite rod.

Table 1 Characteristics of a TRISO-coated Fuel Particle

	Kernel	Buffer	IPyC	SiC	OPyC
Material	UO_2	PyC	PyC	SiC	PyC
Enrichment (wt% U^{235})	12	-	-	-	-
Diameter (μm)	500	-	-	-	-
Thickness (μm)	-	95	40	35	40
Density (g/cm³)	10.5	1.0	1.9	3.2	1.85
Weight (×10^{-4} g)	6.8722	1.0656	1.2736	2.2816	1.8015

3. Estimation of the Temperature in a Capsule

Figure 2 represents the geometric finite element model for the temperature estimation of the capsule. The size of the neon gas gap was increased from 0.1 mm until the maximum temperature at the center of the graphite rod approached the target temperature. The material properties necessary for the thermal analysis of the capsule are the thermal conductivity, specific heat, and density and the related data was taken from the literatures [4,5]. The specific heats generated by the gamma heating of the capsule materials were calculated with the MCNP code.

The thermal analyses were performed with ABAQUS [6] and COPA-TEMTR [7] for the cases of an outer gap size of 0.1, 0.2, 0.3, and 0.4 mm. Figure 3 shows the temperature distribution within the irradiation capsule when the size of the outer gas gap is 0.4 mm. The maximum temperature in the graphite is 991.7 ℃. The temperature of the inner molybdenum tube is 890~900 ℃ and the temperature of the outer molybdenum tube is 45~65 ℃. Figure 4 displays the temperature distribution of a TRISO particle in the center of the graphite rod. The maximum temperature is 1290 ℃ when the thermal conductivity of the buffer layer is 0.5 W/(m·K) and 1152 ℃ when the thermal conductivity is 2 W/(m·K). The thermal conductivity of the buffer in the literatures showed a scatter.

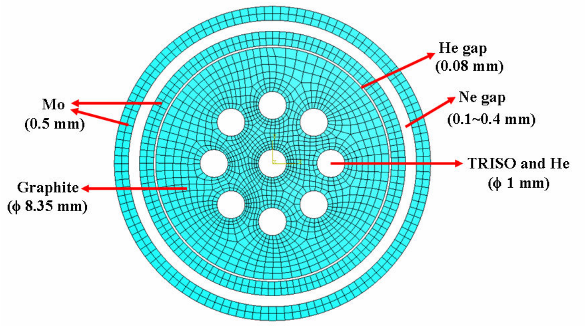
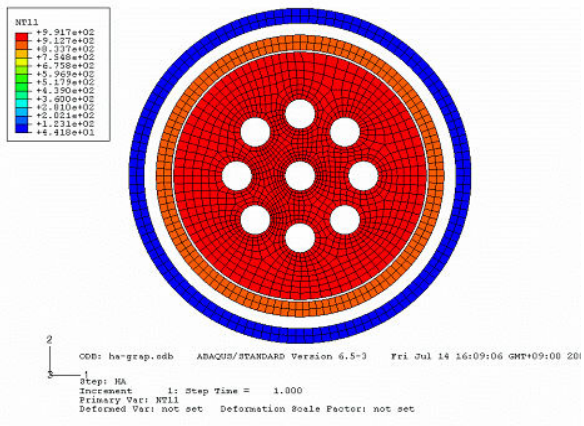


Figure 2 Geometric model for temperature estimation of a capsule.



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ODB: ha-grap.odb    ABAQUS/STANDARD Version 6.5-3    Fri Jul 14 16:09:06 GMT+09:00 20
Step: HA
Increment      1: Step Time =    1.000
Primary Var: NT11
Deformed Var: not set   Deformation Scale Factor: not set
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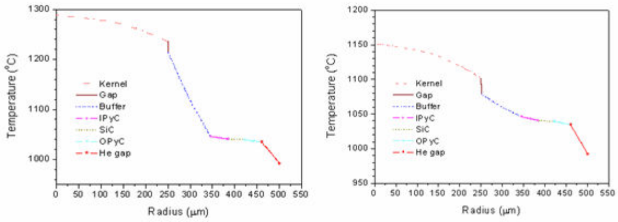
Figure 3 Temperature distribution in an irradiation capsule.



(a) k_B = 0.5 W/(mK)   (b) k_B = 2.0 W/(mK)

Figure 4 Temperature distribution of TRISO-coated fuel particle in the center of graphite rod (k_B = thermal conductivity of a buffer).

4. Conclusion

Double-layer irradiation capsule for the irradiation of TRISO-coated fuel particles was designed. The capsule consisted of a graphite rod (ϕ 8.35 mm) with nine holes (ϕ 1 mm) in it and two molybdenum tubes (each tube thickness is 0.5 mm). Every hole can contain 50 TRISO particles. The size of the inner helium gap was 0.08 mm. When the size of the outer neon gap was 0.4 mm, the maximum temperature of the TRISO particles in the center of the graphite was 1152~1290 ℃ which is near the target irradiation temperature of 1250 ℃. The temperature of the inner molybdenum tube was found to be under a high temperature, 890~900 ℃. The thermal deformation of the capsule should be estimated.

Acknowledgement

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REFERENCES

[1] Next Generation Nuclear Plant Research and Development Program Plan, INEEL/EXT-05-02581, 2005.
[2] Kim, Y.M. and B.G. Kim, Preliminary Calculations of Temperature in a capsule for irradiation of TRISO-coated Fuel particles, NHDD-KA06-FU-001-00, 2006.
[3] MCNP4C: Monte Carlo N-particle Transport Code System, CCC-700/MCNP4C, Oak Ridge National Laboratory, 2000.
[4] NP-MHTGR Material Models of Pyrocarbon and Pyrolytic Silicon Carbide, CEGA-002820, Rev. 1 (1993).
[5] Perry, R.H. and D. Green, Perry's Chemical Engineers' Handbook, Sixth Ed., McGraw-Hill Book Co., 1984.
[6] ABAQUS, Ver. 6.5-3, ABAQUS, Inc., U.S.A. (1998).
[7] Kim, Y.M., D.H. Kim, Y.Y. Yang, and J.H. Chang, “A Thermal Analysis of a TRISO-coated Fuel Particle,” Transactions of the Korean Nuclear Society Spring Meeting, Jeju, Korea, May 2005.