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Failure Probability of TRISO-Coated Fuel Particles under a Normal Operation

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1. Introduction

The integrity of the fuel in a very high temperature reactor (VHTR) is essential for the safety of the VHTR under normal and accident conditions. Failure fraction of the VHTR fuel must be lower than some safety design limits. Failure fraction limits at a fabrication and during an operation are set up through the safety design limits. It is very important to predict the failure fraction of the VHTR fuel during an operation.

This study details the development of a fuel failure analysis module, COPA-FAIL, and the failure probability calculated for benchmark cases 9 through 14 of IAEA-CRP-6 [1].

2. Development of COPA-FAIL

The fuel failure mechanisms are a pressure vessel failure, chemical attack, and thermal decomposition. The pressure vessel failure describes the failure of the fuel coatings due to the fission gas and CO gas pressure produced in a kernel. The chemical attack means a thinning of the SiC layer due to the Pd-Si reaction. The SiC layer becomes weakened at a high temperature. Only the pressure vessel failure is presently considered in the COPA-FAIL.

A mechanical analysis must be preceded in order to describe the pressure vessel failure. A computational module, COPA-MECH, has already been developed [2]. The COPA-FAIL uses a Monte Carlo method through a random particle sampling in which a sample is equivalent to a TRISO-coated fuel particle. The particle has different dimensional sizes, material properties, and fracture strengths of the coating layers through the Monte Carlo sampling. Kernel diameter, thicknesses of a buffer and the coating layers, and the densities of the kernel, buffer and the coating layers show the standard normal distribution. The strengths of the SiC and PyC layers display the Weibull distribution.

There are eight failure modes of a TRISO-coated fuel particle during an operation as in Table 1. The eighth failure mode in Table 1 is called a through-coating failure. The SiC failure has been considered as a particle failure. The calculational flow of the failure fraction is shown in Figure 1.

Table 1. Failure modes of the coating layers

Failure modes	IPyC	SiC	OPyC
1	intact	intact	intact
2	intact	intact	failure
3	intact	failure	intact
4	intact	failure	failure
5	failure	intact	intact
6	failure	intact	failure
7	failure	failure	intact
8	failure	failure	failure

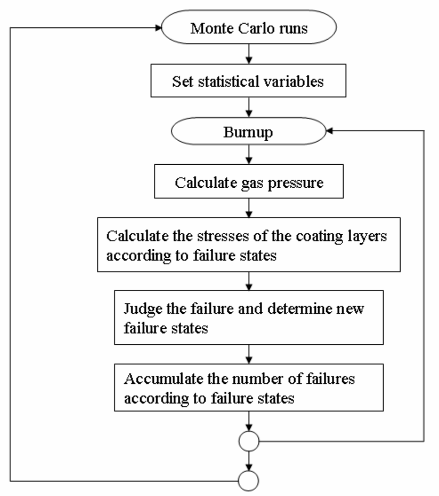

Figure 1. Calculational flow of failure fraction.

3. Benchmark cases 9 through 14 of IAEA-CRP-6

The IAEA CRP-6 benchmark Cases 9 through 12 characterize the fuel particles from past irradiation experiments. These include the HRB-22 experiment of Japanese (Case 9), the HFR-K3 experiment of German (Case 10), the HFR-P4 experiment of German (Case 11), and the NPR-1 experiment of the USA (Case 12). Parameters for these cases are listed in reference 1.

Case 13 and 14 characterize the fuel particles from irradiation experiments to be completed in the future. These include the HFR EU-1 (Case 13) and the HFR EU-2 (Case 14). Parameters for Cases 13 and 14 are also listed in reference 1.

4. Results

Table 2 shows the failure fraction calculated by the COPA-FAIL and PARFUME [3]. The total number of Monte Carlo runs for each case in the COPA-FAIL is 10,000,000. The failure fractions of the IPyC layer are higher in COPA-FAIL than in the PARFUME. The failure fractions of the SiC layer in the COPA-FAIL are similar to those in the PARFUME. It is proposed that the differences in the failure fractions of the benchmark cases are due to the failure mechanisms included. The PARFUME uses various failure mechanisms including a pressure vessel failure.

Table 2. Failure fraction of IAEA-CRP-6 cases 9 through 14

Case	Experiment	COPA		PARFUME	
		IPyC	SiC	IPyC	SiC
9	HRB-22	0.1086	0	0.026	1.3e-10
10	HFR-K3	0.1033	0	7.2e-4	3.7e-16
11	HFR-P4	0.1197	0	1.7e-3	1.1e-4
12	NPR-1	0.8779	0.0686	0.31	0
13	HFR EU-1	0.4193	0.1050e-4	1.4e-3	4.9e-3
14	HFR EU-2	0.1259	0	4.2e-4	2.4e-7

5. Conclusion

From the benchmark calculations of IAEA-CRP-6 cases 9 through 14 for a TRISO-coated fuel particle, the following conclusions are made:

1. The fuel failure analysis module, COPA-FAIL, calculates the failure fraction of the TRISO-coated fuel during a reactor operation according to eight failure modes.
2. Pressure vessel failure only is currently considered in the COPA-FAIL. The other failure mechanisms must be included in the COPA-FAIL.
3. Comparison of the benchmark results of the COPA-FAIL and the PARFUME requires more verification of the COPA-FAIL results.

Acknowledgement

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REFERENCES

[1] Maki, J.T. and G.K. Miller, "TRISO-Coated Particle Fuel Performance Benchmark Cases," INL, 2005.
[2] Kim, Y.M., Y.W. Lee, and J.H. Chang, "Calculations of IAEA-CRP-6 Benchmark Case 1 through 7 for a TRISO-Coated Fuel Particle," Transactions of the Korean Nuclear Society Autumn Meeting, Busan, Korea, October 2005.
[3] Miller, G.K., J.T. Maki, D.L. Knudson, and D.A. Petti, "Current Capabilities of the Fuel Performance Modeling Code PARFUME," 2nd International Topical Meeting on High Temperature Reactor Technology, Beijing, China, September 22-24, 2004.