A Fuel Performance Analysis of a 600 MW_{th} DB-MHR Fuel

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1. Introduction

A deep burn-modular helium reactor (DB-MHR) burns the transuranic materials in spent fuels discharged from light water reactors (LWRs). The transuranic radionuclides are recovered from spent LWR fuels and converted into short-lived fission products (FPs) in a DB-MHR.

This paper treats the microanalysis for a 600 MW_{th} DB-MHR fuel. The analysis covers the gas buildup in a coated fuel particle (CFP) including a helium production, the failure probabilities of CPFs, and the FP transport in a CFP and a graphite. A fuel performance analysis code from KAERI, COPA, was used in the microanalysis of a DB-MHR fuel [1]. Fuel burnup and depletion were calculated by a McCARD code [2], and they were used as input data for the COPA code.

2. Microanalyses of a 600 MWth DB-MHR fuel

The thicknesses of the kernel, buffer, IPyC, SiC, and OPyC of a CFP are 200, 120, 35, 35, and 40 μm, respectively. This is one of the candidate designs for a DB-MHR CFP. The densities of the layers of a CFP, the composition in the kernel of a CFP, and the information on a compact and the design parameters of a prismatic DB-MHR are given by Ref. [3]. For the thicknesses and densities of the layers of a CFP, five and one percent of standard deviations of the stochastic variables have been assumed.

2.1. Gas buildup in the buffer of a CFP

The McCARD code generated the burnup and depletion data for a compact in a DB-MHR fuel. The final burnup and fluence are 750 GWd/tHM (71.98 %FIMA) and 7.086×10^{21} n/cm^2 (E > 0.1 MeV) at 1990.2 EFPD. The gas species considered were xenon, krypton, helium, and carbon monoxide. The fission yields of xenon and krypton and the inventory of helium were calculated using the depletion data generated by McCARD. A mass balance for the excess oxygen generated in a kernel is given as a function of burnup for a substoichiometric metal oxide (MO_{2-x}) or an oxycarbide (MC_xO_{2-x}) [4].

Fig. 1 displays the evolution of gas pressure in a buffer when the coolant temperature is 1000 °C and x is 0. The most significant contribution to gas pressure was carbon monoxide, and then xenon. Helium was produced more than the fission gas krypton, but the amounts of both species can be neglected compared to the total gas pressure.

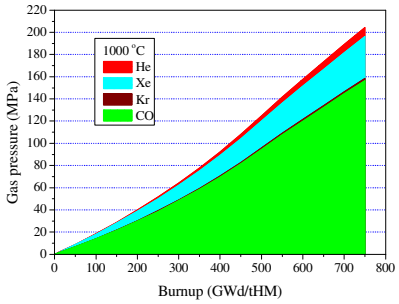

Fig. 1. Gas evolution in the buffer of a CFP.

2.2. Failure probabilities of a batch of CFPs

The COPA-FAIL calculates the failure fractions of a batch of CFPs under heating and reactor operation conditions. Only the pressure vessel failure was considered in the calculations of the failure probabilities. The ultimate tensile strengths (UTSs) for PyC and SiC are expressed as the Weibull distribution. The median UTS and Weibull modulus for SiC used in this analysis were 834 MPa and 8.0 before irradiation, and 687 MPa and 6.0 after irradiation. The median UTS and Weibull modulus for PyC is given by Ref. [5]. Fig. 2 shows the failure fraction of SiC layers for 10^7 CFPs. The failure fraction was near 1×10^{-4} at about 40 %FIMA. The failure fraction was judged to be too high.

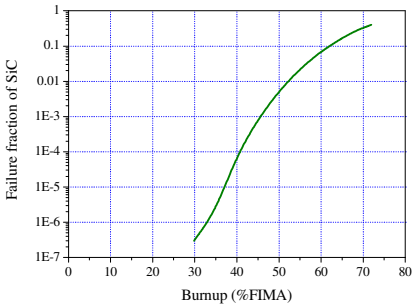

Fig. 2. Failure fraction of SiC when the number of Monte Carlo runs is 10^7.

2.2. Fission product transport from CFPs into a coolant

The COPA-FPREL analyzes the FP migration in a CFP and a fuel block under reactor operational

conditions, and during heating and irradiation tests. The FP migration mechanism in the layer was assumed to be diffusion only. FPs were generated through nuclear fissions of nuclear materials in the kernel and a heavy metal contamination of the coating layers. They were also generated from adjacent layers through recoil. Partition factors were assumed at the layer interfaces. It is assumed that no retention of FPs occurs in a failed coating layer.

Fig. 3 presents the fractional releases of ^{137}Cs, ^{90}Sr, ^{110m}Ag, and ^{85}Kr into a coolant under reactor operation conditions, when x is 0 and the coolant temperature is 1000 ^{o}C. For metallic FPs, the fractional releases were large in the order of silver, cesium, and strontium. The fractional releases of FPs were reasonably low, although how much FP releases are permissible should be determined through an environmental impact analysis. Table I shows the fractional retentions and release of fission products at the irradiation time of 1990 EFPD. Fractional release or retention means the ratio of the release or retention amount to the sum of release and all the retentions.

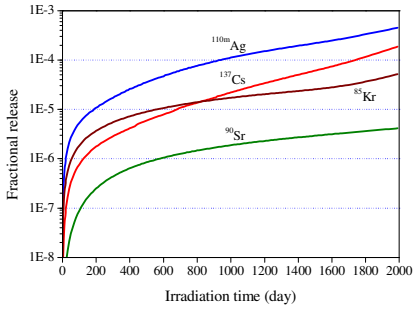

Fig. 3. Fractional release evolution of fission products into a coolant.

Table I: Fractional Distributions of Fission Products at 1990 days

	Intact CFP	Failed CFP	Compact	Graphite web	Release
Cs	8.13×10^{-1}	3.03×10^{-2}	1.56×10^{-1}	4.80×10^{-5}	1.86×10^{-4}
Sr	5.97×10^{-1}	3.66×10^{-1}	3.68×10^{-2}	1.97×10^{-6}	4.12×10^{-6}
Ag	7.46×10^{-1}	4.07×10^{-2}	2.12×10^{-1}	5.27×10^{-5}	4.48×10^{-4}
Kr	9.81×10^{-1}	1.92×10^{-2}	1.35×10^{-4}	5.82×10^{-8}	5.17×10^{-5}

3. Summary

Various fuel performance analyses were done for a 600 MW_{th} DB-MHR fuel: gas pressure buildup in a buffer of a CFP, failure fractions of a batch of CFPs, and FP releases into a coolant. The considered temperature was 1000 ^{o}C. The kernel diameter was 200 μm. Thicknesses of the buffer, IPyC, SiC, and OPyC were 120, 35, 35, and 40 μm, respectively.

The gas species that most significantly contributed to gas pressure was carbon monoxide. Helium was produced more than the fission gas krypton, but the amount can be neglected compared to the total gas pressure. The failure fraction was greater than 1×10^{-4} at about 40 %FIMA for CFPs. The failure fraction was too high. Within the operating temperature, the metallic FP releases were large in the order of silver, cesium, and strontium and were reasonably low. How much FP releases were permissible should be determined through an environmental impact analysis.

REFERENCES

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