Effects of Radial Failure Distribution on Fission Product Release in an FCM Fuel

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1. Introduction

A coated fuel particle (CFP) with a uranium mononitride (UN) kernel has been recently considered as an advanced fuel option, such as in fully ceramic micro-encapsulated (FCM) replacement fuel for pressurized water reactors (PWRs). In FCM fuel, a large number of tri-isotropic coated fuel particles (TRISOs) are embedded in a silicon carbide (SiC) matrix. A TRISO in FCM fuel consists of a kernel at its central region and four coating layers surrounding the kernel such as buffer, inner pyrocarbon (IPyC), silicon carbide (SiC), and outer pyrocarbon (OPyC).

The CFPs could mechanically break during reactor operation. One of the major factors causing CFP failure is an irradiation-induced dimensional change (IIDC) of an IPyC. At high levels of fast neutron fluence, the IPyC layer pushes the SiC layer outward and finally breaks it. The PyC IIDC increases as its temperature decreases. The FCM pellet has a temperature distribution. Accordingly, the failure fraction of CFPs within the FCM pellet is not radially uniform. For simplicity or conservativeness, the fission product (FP) release has been estimated using a maximum failure fraction. This approach should, however, be justified through a comparison with the estimation of FP release using the radial distribution of the failure fraction.

This study calculates the FPRs using both uniform and radially-distributed failure fractions, and compares the two results.

2. An FCM Fuel Pellet

A TRISO in FCM fuel consists of a kernel at its central region and four coating layers surrounding the kernel. The kernel material is UN. Table I shows the layers of the TRISO used in an FCM fuel and their thicknesses and densities. Both the matrix material of an FCM pellet and the cladding material are nano-infiltration and transient eutectic-phase (NITE) SiC. The radius and height pellet are 6.08 and 10 mm, respectively. The cladding thickness is 1.00 mm. The thickness of the gap between pellet and cladding is 0.32 mm. Helium gas is filled in the gap and its initial pressure is 2.62 MPa. The outer surface of the cladding faces water coolant. The coolant temperature is assumed to be 300 ^{o}C.

3. Calculation Results

The COPA code [1] is used to calculate the temperature, failure fraction, and fission product release in an FCM fuel rod. The failure of TRISOs started to occur at a fluence of 8.705×10^{21} n/cm^2 (E_n > 0.18 MeV) when a Monte Carlo statistical analysis was applied to 10^5 TRISOs. The related material properties are given in Ref. 2. Fig. 1 presents the radial distribution of failure fractions of TRISOs in an FCM pellet and the temperature distribution within the pellet. Fig. 2 shows the variation of failure fractions. The failure fraction is higher in the outer part than the inner part of the pellet. The volume-averaged temperature is 839 ^{o}C. The temperatures of the pellet are 758 and 922 ^{o}C at its surface and center, respectively. Figs. 3 through 6 display the variation of fractional releases of ^{137}Cs, ^{110m}Ag, ^{90}Sr, and ^{85}Kr. Both the fractional releases based on the uniform failure fraction at maximum temperature and the radially-distributed failure fraction are nearly the same over a fluence of 9.699 ×10^{21} n/cm^2 (E_n > 0.18 MeV).

Table I: Thicknesses and Densities of Layers in a TRISO

Layers	Thickness, μm	Density, g/cm^3
OPyC	20	1.90
SiC	35	3.18
IPyC	35	1.90
Buffer	50	1.05
UN kernel	[a] 700	14.32

[a] This figure means kernel diameter.

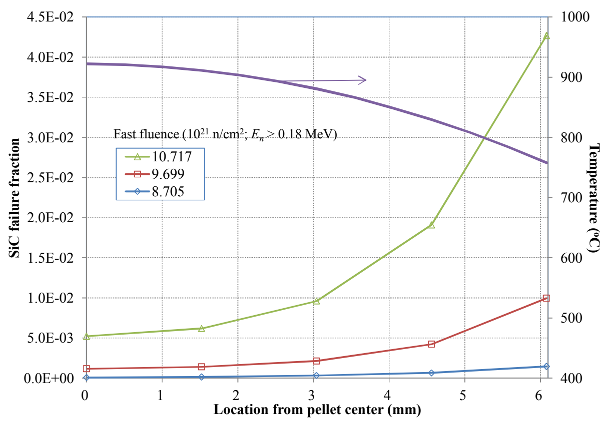

Fig. 1. Radial distribution of failure fraction in an FCM pellet.

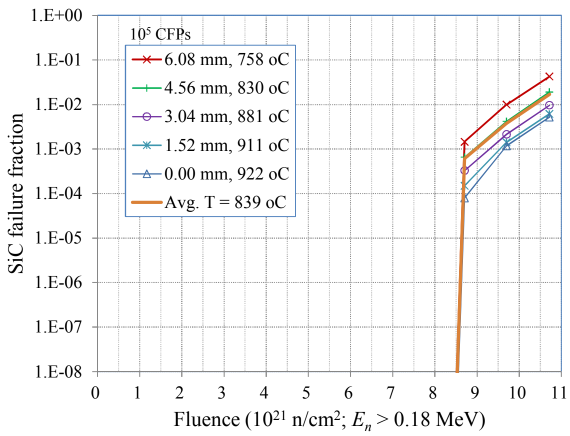

Fig. 2. Variation of failure fraction.

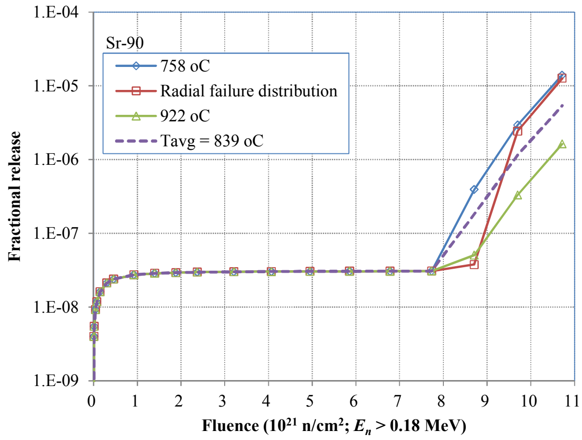

Fig. 5 Variation of Sr-90 Fractional Release

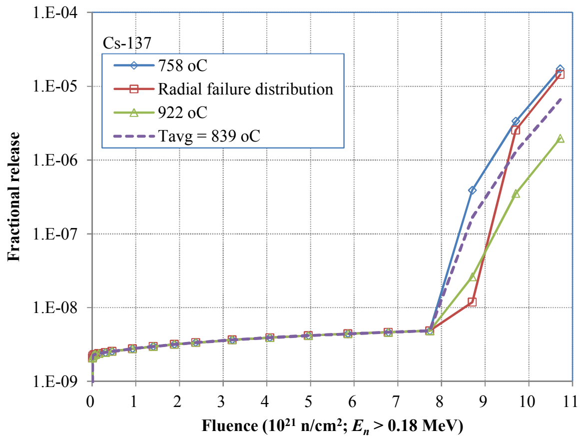

Fig. 3. Variation of Cs-137 fractional release.

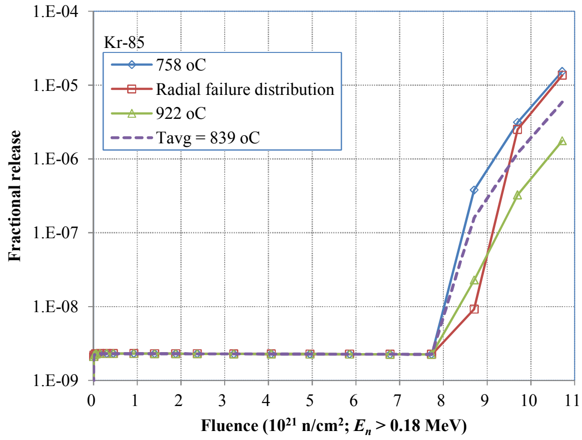

Fig. 6. Variation of Kr-85 fractional release.

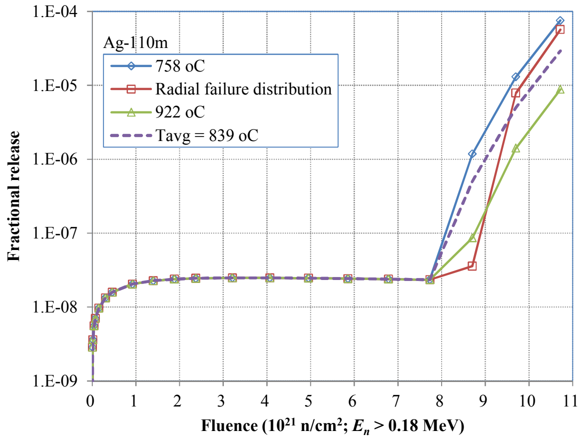

Fig. 4. Variation of Ag-110m fractional release.

4. Summary

The radially-distributed failure fractions of CFPs in an FCM pellet have been estimated on the basis of the temperature distribution in the pellet. The failure fractions are higher in the outer region than the inner region because the temperature decreases in outer direction and the PyC IIDC increases as its temperature decreases. When FP release is estimated at a high failure fraction, a uniform failure fraction based on the maximum temperature is applicable instead of the radially-distributed failure fraction.

REFERENCES

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[2] Kim, Y.M., Jo, C.K., Lee, W.J. and Venneri, F., 2013. A Fuel Performance Analysis for an FCM Fuel under LWR Conditions. Paper KF168. In: Proceedings of International Conference on Advanced Power Plants (ICAPP), Jeju, Korea, 14-28 April.