A PCMI Analysis for a DB-PWR Fuel Rod with TRISO-SiC pellets

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1. Introduction

The deep burn-pressurized water reactor (DB-PWR) converts the transuranic (TRU) radionuclides, recovered from spent light water reactor (LWR) fuel, into shorter-lived fission products (FPs). It can reduce the long-term storage requirements for the high-level waste generated from currently operating nuclear power plants.

The TRU recovered from the LWR spent fuel is manufactured as a kernel which is the innermost constituent of a coated fuel particle of a high temperature gas cooled reactor (HTGR). In a DB-PWR, some fuel rods contain SiC pellets in which a large number of tri-isotropic coated fuel particles (TRISOs) are embedded, instead of usual UO_2 pellets. The high conversion of TRUs requires the high burnup of the DB-PWR fuels. The high burnup increases the possibility of a pellet and cladding mechanical interaction (PCMI) which may break mechanically the cladding.

It is expected that there will be no PCMI between a TRISO-SiC pellet and a Zircaloy cladding during the life time of a DB-PWR fuel rod because the operation temperature in a DB-PWR is much lower than that in a HTGR. This study treats the quantitative analysis of a PCMI between a TRISO-SiC pellet and a Zircaloy cladding at high burnup.

2. A Thermomechanical Modeling for a PCMI

A two-dimensional axisymmetric finite element geometrical model has been applied to a half of the pellet and the surrounding cladding, as shown in Fig. 1. The pellet was assumed to move freely in the axial direction. By using the symmetry conditions, it was assumed that the radial center of the pellet and the axial center of the pellet and the cladding were not displaced. Helium is filled in a gap between the pellet and the cladding. The pressure of helium gas acts on the pellet surface and the inner surface of cladding. The coolant pressure acts on the outer surface of cladding. The external load acts on the top surface of cladding [1]. The TRISO-SiC pellet is assumed to experience thermal expansion and elastic deformation, and the Zircaloy cladding was assumed to experience thermal expansion, elastic deformation and plastic deformation.

3. Calculation Results

Table 1 gives the thicknesses and densities of layers in a TRISO. The major kernel materials of a DB-PWR TRISO are UO_2, NbO_2, $PuO_{1.8}$ and SiC. Table 2 shows the dimensions and pressures for a pellet and cladding geometry. The thermomechanical material properties were extracted from published literatures [2-5]. It has been assumed that the SiC matrix and the TRISOs were homogenously mixed in the pellet. The apparent material properties of a TRISO were estimated by summing the multiplication of material property and weight fraction of a layer in a TRISO.

The packing fractions (PFs) considered are 10, 39 and 45 %. The coolant temperature is 270 ^oC and the heat conductance between a cladding wall and a coolant is 15000 $W/(m^2\ K)$. Two linear heat generation rates (LHGRs) of 26 and 60 kW/m are considered for typical operation and accident conditions, respectively. A high burnup of 45 GWd/MTHM has been assumed in order to simulate severe bad conditions deteriorating the fuel rod materials. Fig. 2 shows the temperature distribution within a pellet and a cladding. The maximum fuel temperature is between 500 and 540 ^oC at a LHGR of 26 kW/m. The fuel temperature increases with a packing fraction, but the effect is not large. At a LHGR of 26 kW/m, the fuel temperature approaches 900 ^oC. These temperatures are much lower than 1250 ^oC, the usual normal operation temperature of a HTGR fuel. The TRISOs in a TRISO-SiC pellet are judged to maintain their integrity during their lifetimes in the DB-PWR. Fig. 3 presents the variation of gap thickness with a packing fraction. The gap between a pellet and a cladding decreases with a packing fraction. At a LHGR of 60 kW/m, it largely decreases, but the contact of a pellet and a cladding does not occur.

Table 1 Thicknesses and Densities of Layers in a TRISO

Layers	Thickness, μm	Density, g/cm^3
OPyC	40	1.900
SiC	35	3.180
IPyC	35	1.900
Buffer	100	1.050
Kernel	500*	9.461

* Diameter.

Table 2 Dimensions and Pressures for a Pellet and Cladding Geometrical Model

Parameters	Values
Pellet height/diameter, mm	12.7/10.8694
Dish depth of a pellet, mm	0.3429
Dish spherical radius of a pellet, mm	25.3390
Gap thickness, mm	0.0199
Radius of inner surface of cladding, mm	5.4546
Cladding thickness, mm	0.9398
Gas and gas pressure (MPa) in a gap	He, 0.101
Coolant pressure, MPa	7.15
Pressure acting on the top surface of a cladding, MPa	25.9837

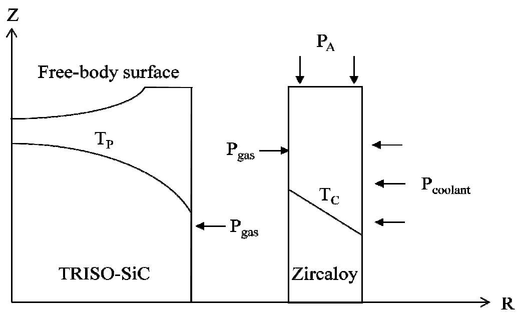

Fig. 1 Thermal and Pressure Loads in a Pellet and a Cladding

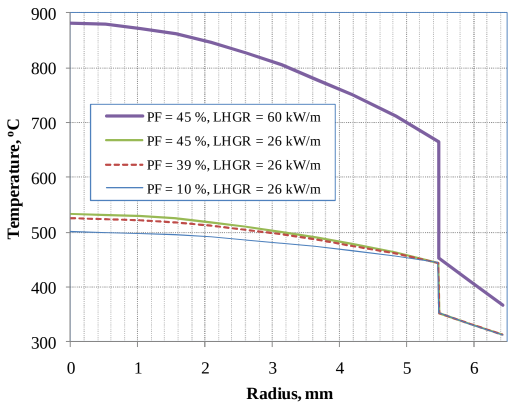

Fig. 2 Temperature Distribution within a pellet and a cladding at a burnup of 45 GWd/MTHM

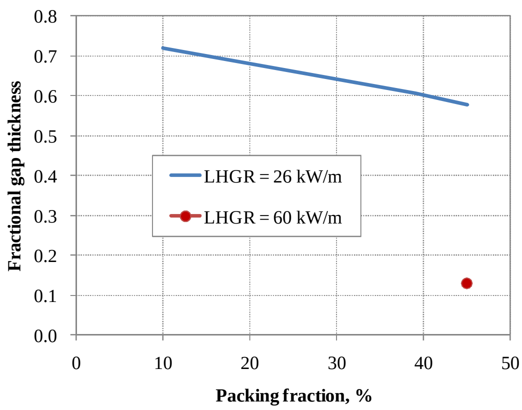

Fig. 3 Variation of Gap Thickness with a Packing Fraction at a burnup of 45 GWd/MTHM

4. Summary

A PCMI analysis has been performed for a DB-PWR fuel rod which contains TRISO-SiC pellets. The following conclusions are drawn through the analysis.

- The maximum fuel temperature in a DB-PWR fuel rod is much lower than the usual operation temperature of a HTGR fuel. It means that the failure of TRISOs does not happen in a DB-PWR.

- Any PCMI between a TRISO-SiC pellet and a Zircaloy cladding does not occurs even at an accident condition of a DB-PWR which causes high temperature in the fuel rod.

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