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TRISO Fuel Performances of a Very High Temperature System under Reactivity-Initiated Accident Conditions

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1. Introduction

The very high temperature system (VHTS) is a block-type high-temperature gas-cooled reactor (HTGR) that can supply the heat necessary for hydrogen production through 1500 EFPD of very high temperature operation at 950 °C [1]. The thermal output is 350 MW. There are axially nine fuel blocks in which a large number of compacts are loaded. A compact is a cylindrical mixture of matrix graphite and tri-structural isotropic coated fuel particle (TRISO). A TRISO consists of a spherical kernel at the center, a buffer surrounding the kernel and three concentric coating layers such as an inner high-density pyrocarbon (IPyC) layer, a silicon carbide (SiC) layer, and an outer high-density pyrocarbon (OPyC) layer. The kernel material is UO_2.

A reactivity-initiated accident (RIA) is one of accidents that can be occurred during the operation of a VHTS. The RIA can cause the change in the fuel performance of a VHTS. The study analyzes a TRISO fuel performance of a VHTS in which an RIA occurs during the operation.

2. Reactivity-initiated accidents

A continuous control rod withdrawal causes a rapid increase of reactor power and typically results in an automatic reactor shutdown. The amount of reactivity inserted depends on many factors, including the initial state of the reactor and the initial position of the control rods [2]. It is assumed that two control rod banks have been withdrawn at 1450 effective full-power days (EFPDs) and lasted for 300 seconds, followed by the pressurized conduction cooling (PCC) for 100 hours [3].

Fig.1 shows the block numbering for the 1/6 core of a VHTS. To evaluate the average fuel performance of the core under the accident conditions, nine evaluation points were selected throughout the whole core: positions 2 (bottom), 10 (middle), and 17 (top) in the z-axis direction, and positions 3 (inner), 5 (middle), and 11 (outer) in the radial direction. Figs. 2 and 3 show the TRISO power and coolant temperature, respectively, at the nine core locations of the VHTS under normal operation, RIA, and PCC conditions which were calculated by the GAMMA code [4].

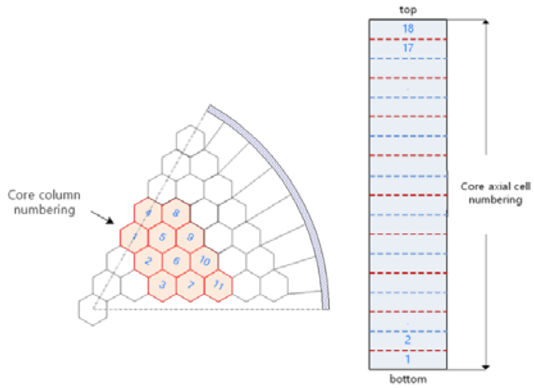

Fig. 1. Core numbering.

3. Fuel performances under normal operation, RIA, and PCC conditions

The fuel performances of fuel blocks at nine locations are analyzed using the COPA code [5]. Fig. 4 shows the total gas pressure in a TRISO at nine locations of the core. The gas pressures have the highest values in the initial stage of the RIA, and after dropping to the lowest values soon, they have a constant value. The highest gas pressure is about 65 MPa at the end of normal operation, and it increases to 80 MPa at 13 seconds after the RIA.

Fig. 5 shows the average failure fractions of 100 million TRISOs. The failure mechanisms considered are pressure vessel failure, fission product attack, and thermal decomposition. The seven failure types that a TRISO can have are occurred. The SiC layer starts to break at 900 EFPD, and its failure fraction is 11 % at the end of normal operation and 38 % during the RIA. The through-coatings failure starts to occur at 1200 EFPD. The failure fraction of the through-coatings failure is 2.25×10^{-5} at the end of normal operation, 3.82×10^{-4} during the RIA, and 4.11×10^{-4} during the PCC.

Fig. 6 shows the average releases of the fission products Cs-137, Ag-110m, Sr-90, and Kr-85 into the coolant. The release of the fission gas Kr-85 is negligible. The average fractional releases of Cs-137, Ag-110m, and Sr-90 are 1.52×10^{-3}, 9.12×10^{-2}, and 2.85×10^{-5}, respectively, at the end of normal operation and during the RIA. During the PCC, the metallic fission products Cs-137, Ag-110m, and Sr-90 are released in the fractions of 5.97×10^{-5}, 2.11×10^{-3}, and 6.55×10^{-13}, respectively, of the amount at the end of the RIA.

4. Summary

The fuel performance of a VHTS where an RIA has occurred at 1450 EFPD has been analyzed. The highest gas pressure in a TRISO is below 80 MPa. The seven failure modes that a TRISO can have occurred under normal operation and accident conditions. The SiC layer starts to break at 900 EFPD, and its failure fraction is 11 % at the end of normal operation and 38 % during the RIA. The through-coatings failure started to occur at 1200 EFPD and its fraction is 2.25×10^{-5} at the end of normal operation, and it is more than 10 times greater during the RIA and PCC. The high and early SiC or through-coatings failure is due to the increase of fission product attack under the prolonged operation at the elevated temperature and the gas pressure increase in a TRISO during the RIA. One remedy decreasing the SiC failure would be to include zirconium carbide, which is known to have better mechanical, thermal, and chemical-resistance properties than SiC, in the design of a coated fuel particle.

ACKNOWLEDGEMENTS

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REFERENCES

[1] Kim, Y.M., S. Yuk, H.S. Lim, and C.K. Jo, 2021. TRISO Fuel Performances under the Normal Operation and Core Heatup Accident Conditions of a Very High Temperature System. KAERI/TR-8909/2021.

[2] IAEA, 2008. Accident Analysis for Nuclear Power Plants with Modular High Temperature Gas Cooled Reactors. Safety Reports Series No. 54.

[3] Kim, Y.M., S. Yuk, H.S. Lim, and C.K. Jo, 2022. TRISO Fuel Performances of a Very High Temperature System under Normal Operation and Pressurized Conduction Cooling Conditions. In: *Transactions of the Korean Nuclear Society Spring Meeting*, Jeju, Korea, May 19-20, 2022.

[4] Lim, H.S., et al., 2021. GAMMA+2.0 Volume II: Theory Manual. KAERI/TR-8662/2021.

[5] Kim, Y.M. and Jo, C.K., 2019. COPA ver. 1.0: Theory Report. KAERI/TR-7945/2019.

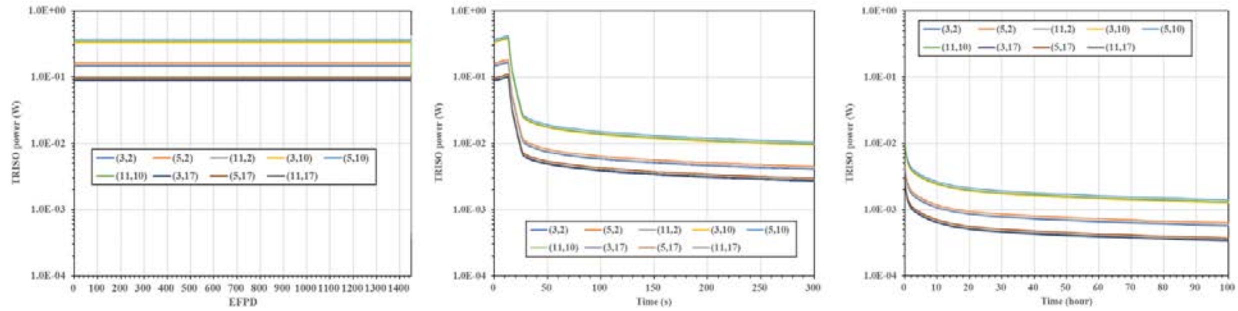

Fig. 2. TRISO power under normal operation, RIA, and PCC conditions.

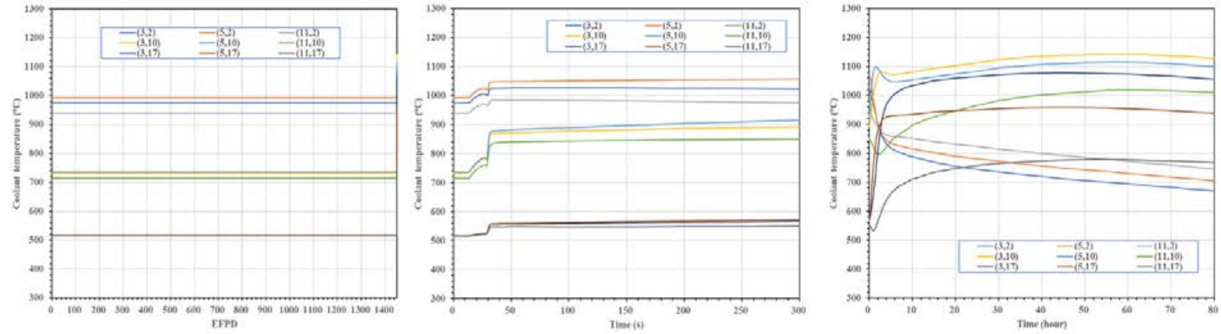

Fig. 3. Coolant temperature under normal operation, RIA, and PCC conditions.

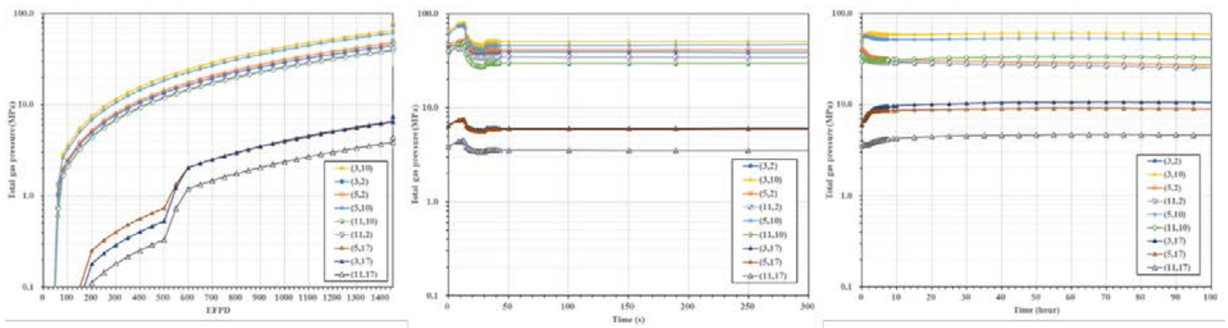

Fig. 4. Total gas pressures in a TRISO under normal operation, RIA, and PCC conditions.

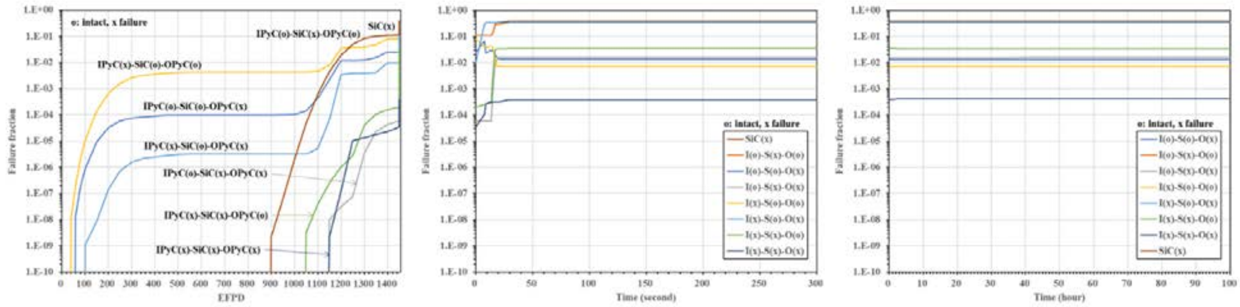

Fig. 5. TRISO failure fractions under normal operation, RIA, and PCC conditions.

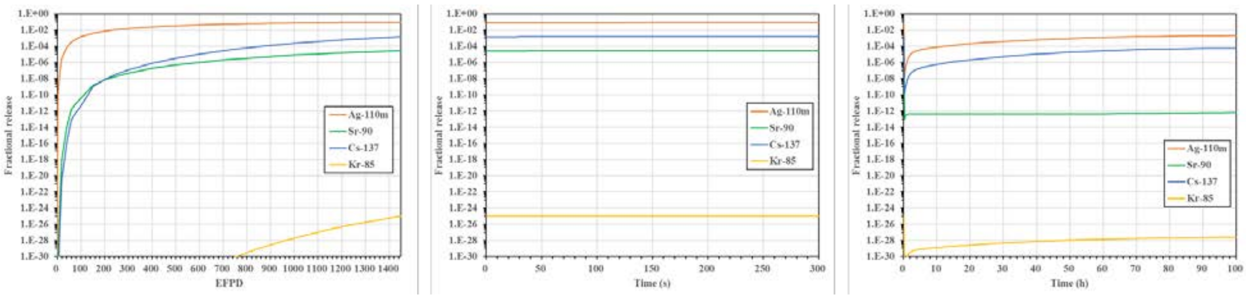

Fig. 6. Fission product releases under normal operation and PCC conditions.