Transactions of the Korean Nuclear Society Autumn Meeting
Busan, Korea, October 27-28, 2005

Feasibility Study of Double-Cooled Annular Fuel with KSNP (I)

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1. Introduction

One of the key components in any PWR affecting safety and economy is its nuclear fuel. The evolutionary improvements in fuel and cladding quality allowed a remarkable reduction in failure rate, and the fuel assembly design changes have allowed appreciable power density increase and performance improvement during irradiation. The first concept of internally and externally cooled annular fuel was proposed by Bujas[1] for high temperature gas cooled reactor fuel. High performance advanced fuel for PWR, which would allow a substantial increase of thermal margins and fuel safeties, is under consideration in NERI project.

2. Advantages of annular fuel

Internally and externally cooled annular fuel employs an internal cooling channel with its own cladding so that fuel is cooled from both the inside and outside. In contrast to solid pins where all the energy generated within the pin is transferred to the external open flow stream along the fuel pin array, power generated in the annular fuel is transferred to both the external coolant in the open fuel pin and to the coolant flowing through the inner channel. The MIT proposed 13×13 annular fuel assembly[2] and fuel radial temperature profile was compared with 17×17 commercial PWR fuel. At power of 45kW/m, the spot of the annular fuel rod is 1500℃ lower than the maximum fuel temperature in a typical solid fuel rod.

Moreover, very low fuel temperatures are retained even after substantial increase in fuel assembly power density (by 50%). This key advantage stems from two factors: (1) the relative fuel conduction thickness is reduced to about one half of its original value and (2) introduction of double sided cooling further reduces the effective conduction thickness to almost 25% of its original value.

2.1 Normal state

During normal operation condition, annular fuel has a various advantages in fuel thermal margin and safety. Introduction of annular fuel leads to a remarkable reduction of fuel temperature, and reduces the heat flux to the coolant and provides higher DNBR and possibility of substantial power uprate. Low fuel temperature means lower fission gas release(figure 1) and can reduce the rod internal pressure during and after the irradiation. Low heat flux, which is caused by double sided cooling, can increase plant reactor thermal margin. Increased thermal margin can increase fuel safety and can be used for power uprate.

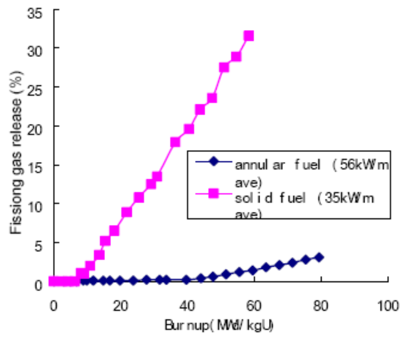


Figure 1. Fission gas release of solid and annular fuel

2.2 Accident state

Low fuel temperature reduces the stored energy and thus improves Loss Of Coolant Accident(LOCA) performance. The peak cladding temperatures for the solid fuel and the annular fuel at 100% power are compared in figure 2. It can be observed that the blowdown peak is eliminated for the annular fuel due to very small stored energy. Lower cladding temperature prior to the core heat up phase results in about 25℃ lower reflood peak temperature[3]. Sundaram[3] compared the maximum fuel temperature between solid fuel and annular fuel under rod ejection accident condition. As can be seen in figure 3, the maximum fuel temperatures for the annular fuel are significantly lower than that of the solid rod.

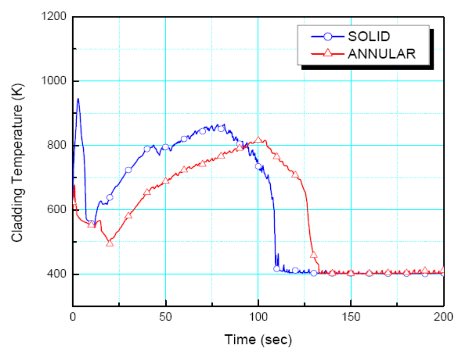
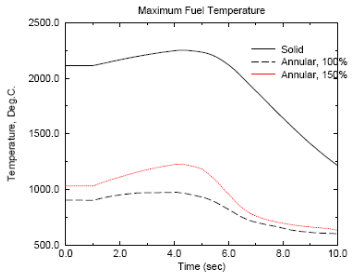


Figure 2. Peak cladding temperature during LB LOCA



.Figure 3. Peak fuel temperature during rod ejection accident

3. Application to KSNP

3.1 Neutonics

From the neutronics point of view, the amount of fissile material which is directly related to power density is the indispensable consideration condition. The designed annular fuel assembly contains small amount of UO2 than 16×16 solid assembly (~85%) and power density could increase due to the lack of fissile materials. But increase of fuel density (> 98% TD) and enrichment (~5%) can compensate for lack of fissile materials. Compatibility with reactor control rod is the most important condition for the application of annular fuel to existing reactor. The rectangular shape of 12×12 array is adopted and able to use the existing control rod system without modification.

3.2 Thermal hydraulics

In thermal hydraulic aspects, total flow area and DNBR analysis were performed. Because variety of total flow area can lead to the change of coolant velocity and core pressure drop. Total flow area of annular fuel assembly is identical with 16×16 solid fuel assembly. The DNBR is the key parameter of fuel safety and thermal margin. And the DNBR margin increase, which is caused by double-sided cooling, is the most important factor among the advantages of annular fuel. Detailed DNBR analysis results will be reported soon.

3.3 Fuel performance

The fuel pellet characteristics are very similar with commercial 16×16 solid UO_2 fuel with its composition, density and U-235 enrichment. The zirconium based alloy can be used as a fuel cladding and the total stack and plenum length are almost same with the 16×16 solid fuel rod. Figure 4 shows the calculated fuel radial temperature distribution by CFD-ACE[4]. As mentioned in chapter 2, annular fuel temperature is lower than solid fuel about 1000℃. According to the Zhao's results[5], annular fuels are superior to the reference solid fuels in vibration resistance even at a 50% increase in flow velocity. And, annular fuel assembly shows better structural performance than the solid fuel assembly due to its higher rigidity.

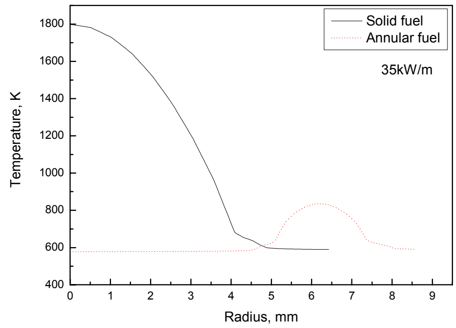


Figure 4. Fuel temperature distribution. (annular vs. solid)

3.4 Fabrication

Fabrication process of the annular pellet might be similar to that of commercial solid pellet. However, control of dimension tolerance of thin, annular fuel by conventional fabrication route will be difficult due to lack of reliable finishing technology (e.g., grinding excess fuel materials on OD/ID surfaces of sintered ring pellet). Therefore, it is necessary to develop the compaction and sintering process to ensure the dimensional uniformity in the sintered annular pellet. KAERI has studied on the fabrication process of the duplex fuel pellet. They developed the die and compaction process in order to precisely control the dimensions of a green and a sintered duplex pellet. This experience will be helpful to establish the fabrication process of the annular fuel pellet.

4. Conclusion

For the application of internally and externally cooled annular fuel to KSNP, feasibility study was performed and preliminary annular fuel rod/assembly was designed. When compared with 16×16 solid fuel assembly, annular fuel rod and assembly show the similar or superior neutronics and thermal hydraulics performance. In fuel performance aspects, many advantages are showed such as low fuel temperature, rod vibration resistance and structural rigidity.

5. References

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