Advantages of a Dual Cooled Annular Fuel for a Super Critical Water Reactor

Yong Sik Yang, Je Geon Bang, Tae Hyun Chun, Kun Woo Song
Korea Atomic Energy Research Institute, 1045, Daedeok-daero, Yuseong-gu, Daejeon, 305-303, Korea
yys@kaeri.re.kr

1. Introduction

A SCWR(Super Critical Water Reactor) is among the most promising advanced nuclear systems because of its high thermal efficiency(~45%) and considerable plant simplification. The reference design of a SCWR is a direct cycle, thermal spectrum, light-water-cooled and moderated reactor with an operating pressure of 25MPa and inlet/outlet temperature of 290/510℃[1].

Currently, in a water cooled reactor, UO_2 is the most popular fuel material but its low thermal conductivity is its weak point. From a thermal conductivity point of view, UC and UN have excellent properties but the application of UC and UN in a nuclear fuel requires further researches and experiences. Therefore, UO_2 is a representative candidate material for the current SCWR design.

Because the UO_2 thermal conductivity is very low and the SCWR operating temperature is higher than the current water cooled reactor condition, it is expected that the SCWR fuel temperature will be higher than the current water reactor's one. A higher fuel temperature can cause many fuel performance disadvantages during an irradiation.

The current SCWR fuel design is similar to a PWR type fuel. In this design, a lowering of the fuel temperature can be achieved by a reduction of the fuel diameter or an increase of the UO_2 thermal conductivity but the former can decrease the fuel mechanical integrity and the latter is limited to very small ranges. Therefore, a high temperature issue of the current design SCWR fuel is an inevitable problem.

Since 2007, a dual cooled annular fuel development project for a PWR application has been started by KAERI[2]. The most important characteristics of an annular fuel is a very low fuel temperature due to a double side cooling and thin fuel thickness. Cross-sectional view of solid and annular fuels is shown in Fig. 1.

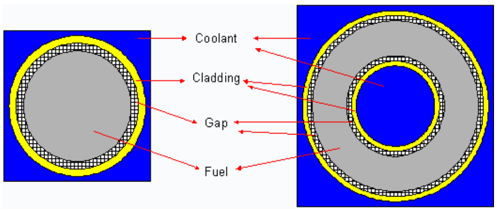

Fig. 1. Cross-sectional view of solid and annular fuel

In this study, we introduced an annular fuel concept for a SCWR fuel and the principal performance factors were analyzed. And the quantitative and qualitative analyses results are summarized in this paper.

2. Comparison of solid and annular type SCWR fuel behavior

The most important factor which is affected by the fuel temperature is the fission gas release. In addition, in the case of a SCWR fuel, I or Cs induced stress corrosion cracking(SCC) is an important factor which can threaten fuel integrity because the adopted SCWR fuel cladding is a stainless steel alloy. But, the SCC and fission gas release predictions are very complex and require appropriate performance models or code systems. So, a fuel temperature analysis was performed quantitatively, and the other performance factors were reviewed qualitatively.

2.1. Fuel temperature

The solid and annular type fuel temperatures under SCWR conditions were calculated by the FRAPCON-3[3] and DUO[4] programs respectively. Each fuel dimension and condition are summarized in Table. I.

Table. I. Input for the fuel temperature calculation

		Solid	Annular
Linear power rate	kW/m	39	39
Clad surface Temp.	℃	620	620
Rod O.D.	mm	9.5	15.9
Rod I.D.	mm	-	8.8
Pellet O.D.	mm	8.2	14.52
Pellet I.D.	mm	-	10.08
Outer/inner gap width	mm	0.07/-	0.07/0.07
Outer/inner clad Thick.	mm	0.55/-	0.62/0.57
Fill gas pressure	MPa	He / 7.3	

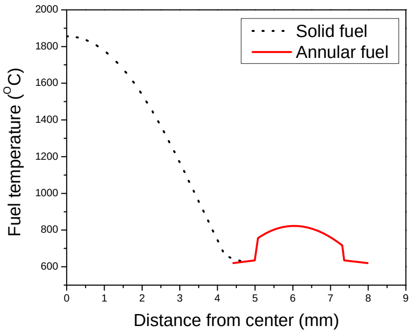

Fig. 2. Fuel temperature of the solid and annular fuel

Fig. 2 shows the fuel temperature calculation results for the solid and annular type SCWR fuels. As expected, the solid type fuel temperature is much higher than the annular fuel. The solid type maximum temperature reached up to 1857℃, whereas the maximum annular type temperature is 823℃.

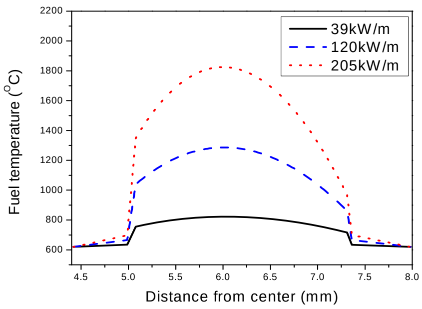

Fig. 3. Power level vs. annular fuel temperature

An annular type SCWR fuel temperature is presented in Fig. 3 as a function of rod power change. Under a 5 times larger power condition, the annular fuel shows the same fuel temperature as the solid type fuel. This result implies that the annular SCWR fuel can have a more flexible neutronic design capability because there is a large fuel temperature margin up to a fuel melting. And, in addition, a large power margin can be utilized for a power uprating of a SCWR.

2.2. Fission gas release

The fission gas release is greatly affected by fuel temperature. As can be seen in Fig. 4, a fission gas diffusion coefficient of the solid fuel temperature range is 10^4 times larger than the annular fuel one. Because a fission gas release rate is proportional to the root square of a diffusion coefficient, a solid type SCWR fuel fission gas release will be 100 times larger than annular type fuel one.

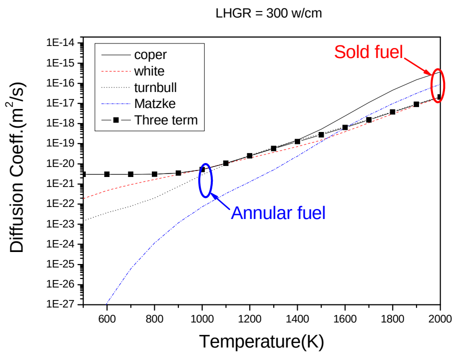

Fig. 4. Fission gas diffusion coefficient

A higher fission gas release, in the case of a solid type fuel, requires enough plenum volume to control the rod internal pressure. In other words, a solid type fuel must have a small fuel volume per rod due to a large plenum within a same core or reactor vessel volume.

2.3. Iodine Induced Stress Corrosion Cracking

Similar to the fission gas release, as can be seen in Fig. 5[5], the Iodine diffusion coefficient is affected by fuel temperature. Therefore, an annular type SCWR fuel can reduce a cladding SCC by a decrease of the Iodine inventory which is generated from a fuel pellet.

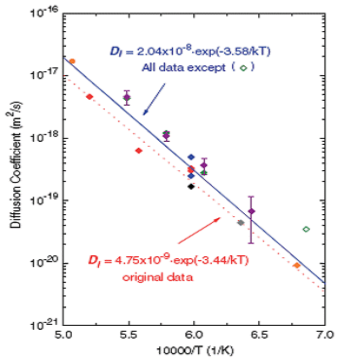

Fig. 5. Iodine diffusion coefficient as a function of Temp.

3. Results and Discussion

It is expected that a solid type SCWR fuel will have many fuel performance disadvantages due to its high temperature operation condition. In this study, we applied a dual cooled annular fuel concept to a SCWR because an annular fuel shows very low temperature characteristics.

Under the same conditions, the fuel temperature of a solid and an annular type fuel were compared. As expected the annular fuel showed about a 1,000℃ lower temperature and this larger temperature margin may contribute to a reactor power uprating or more flexible core design.

Based up on the temperature calculation result, the fission gas and the iodine release rates were examined. Because an annular type fuel will require a small plenum volume, its fuel loading can be increased when compared with the same volume of a solid type SCWR fuel. This effect will be helpful for a reactor and fuel economy.

From the SCC point of view, the annular fuel’s low temperature merit can decrease the iodine release from a pellet and it can reduce the fuel damage probability which is caused by the SCC.

REFERENCES

[1] Yoon Yeong Bae et al., “Preliminary Study on the High Efficiency Supercritical Pressure Water-Cooled Reactor for Electricity Generation”, KAERI/RR-2616/2004
[2] Y. S. Yang et al., "Conceptual Design of OPR-1000 Compatible Annular Fuel Assembly", ICAPP2007, France
[3] D. D. Lanning et al., "FRAPCON-3: Modifications to Fuel rod Material Properties and Performance models for High-Burnup Application", NUREG/CR-65345
[4] Y. S. Yang ea al., "Development of DUO_THERM Ver 1.0", Korea Nucl. Society Autumn Mtg. 2008
[5] M. Saidy et al. "Thermal diffusion of iodine in UO2 and UO2+x," Journal of Nuclear Materials 372 (2008) 405-415.