Transactions of the Korean Nuclear Society Spring Meeting
Gwangju, Korea, May 30-31, 2013

A Novel Plate Fuel Concept Based on Coated Particle for Research Reactor

Rully Hidayatullah and Yonghee Kim*
Korea Advanced Institute of Science and Technology
291 Daehak-ro, Yuseong-gu, Daejeon, Korea, 305-701
Corresponding author: yongheekim@kaist.ac.kr

1. Introduction

The safety characteristics of research reactors are largely governed by the fuel type used. Nowadays, most research reactors use a U_3Si_2 dispersion fuel in which U_3Si_2 fuel particles are dispersed in an Al matrix. Recently, to increase the U inventory, UMo dispersion fuel is under development [1]. Regardless of the fuel types, plate-type fuels are most popularly used in research reactors. The fuel meat thickness should be thin so that the fuel temperature is relatively low and the plate size is rather limited to ensure its mechanical integrity. This work proposes a novel plate fuel based on coated particle fuel (CPF) which can improve both the fuel temperature coefficient and fuel integrity.

2. New Fuel Concept and Core design

In order to enhance the Doppler effect of the plate-type fuel, the fuel temperature should increase more with the power level than in the case of the conventional one. In the widely used U_3Si_2 plate fuels, the low fuel temperature is achieved by using a very thin fuel meat and cladding. To achieve high temperature, one of the ways is to use low thermal conductivity fuel. For this reason, UO_2 or UC can be better candidates than other metallic fuels. Taking into account the goals of the new plate fuel concept, we came up with a plate fuel containing coated particle fuel (CPF) shown in Fig. 1. In the new plate fuel, CPFs are randomly dispersed in the Al matrix as in the conventional plate-type fuel. For the CPF, the fuel kernel is first coated with a thin carbon buffer layer and then a thin metallic Zr layer, if necessary. The fuel kernel can be either UO_2 or UC. In this work, a UO_2 kernel is used due to its good performance in the high temperature environment and achievable high burnup. A UC kernel can be used for a much higher U loading.

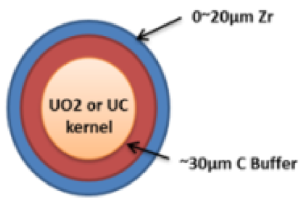

Fig.1 Concept of the coated particle fuel

The size of the kernel needs to be maximized to achieve a high U inventory. The kernel diameter can be 500~700 μm. The targeted thickness of the fuel plate is 2~4 mm, while it is usually about 1 mm in the typical plate fuel. The much thicker fuel plate actually results in a much higher fuel fraction in the fuel assembly than in the conventional plate fuel. The buffer layer thickness can be estimated by accounting for swelling behavior in the UO_2. A thin buffer ~30μm can be adopted in order to accommodate high burnup [2]. The fission gas release in the kernel is also very limited for the temperature lower than 400^{o}C [2]. Accounting for the robust configuration of the new fuel plate, the fuel volume fraction in the fuel meat is set to 50% in this study. Table 1 shows the uranium density of the new fuel concept for several configurations of the design parameters. It is clear that the U density of the fuel can be very high if the fuel kernel is over 600 μm and Zr layer is not used. It is worthwhile to note that the U density can be as high as in the UMo fuel in case of a large UC kernel.

Table 1. Uranium density in fuel meat of the new fuel

Kernel diameter/buffer layer/Zr layer	UO2 (g/cm^3)	UC (g/cm^3)
600 μm, Buf=30 μm/ 20 μm	3.38	4.56
650 μm, Buf=30 μm/ 0 μm	3.51	4.74
700 μm, Buf=30 μm/ 0 μm	4.46	6.02

A 20 MWth pool-type reactor is considered to investigate the neutronic potential of the new fuel concept. Figure 2 shows the radial configuration of the research reactor. The core is comprised of 8 fuel assemblies. The fuel assembly is a 13 cm x 13 cm box type assembly. Each fuel assembly consists of 20 fuel plates and 2 Al side-plates. Each fuel plate is made of 2 mm thick fuel meat and 0.34 mm of Al cladding. In this model design, the UO_2 kernel diameter is assumed to be 600 μm and the buffer and Zr thickness are 30 μm and 20 μm, respectively. The fuel enrichment is 19.75%.

The core is surrounded by beryllium reflectors. One large irradiation hole is located in the core center and 16 others are located in the reflector region. In this work, Er is used as the burnable absorber in a unique way: 0.5 wt% Er is alloyed in the Al matrix, cladding and side plates. Note that Er is not loaded into the CPF. The active core height is 60 cm. The core inlet coolant temperature is assumed to be 40^{o}C, the outlet core temperature is set to 50^{o}C and the average coolant speed is calculated to be ~6.4 m/s. The coolant speed is also one of the concerns in the box-type fuel assembly. In order to avoid the instability, the coolant speed should be well below the critical speed [3]. The calculated critical speed is ~17m/s. The average coolant speed of the model core is significantly below the critical velocity and it is expected that the fuel assembly design will be acceptable in terms of the hydraulic instability.

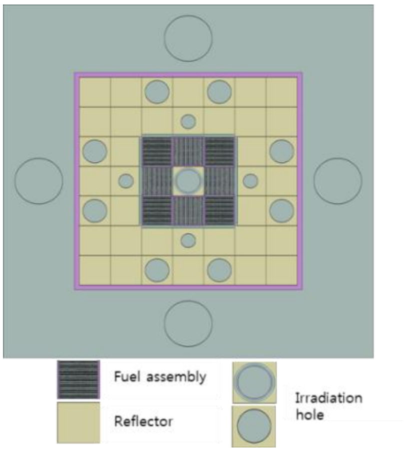

Fig. 2. Radial configuration of the research reactor

3. Analysis Results and Discussion

The thermal hydraulic analysis is done to investigate the fuel temperature in the core. To do the thermal hydraulic analysis for core average coolant channel, a simple one dimensional heat flow of a solid plate type fuel [4] is used to calculate the temperature profile. Figure 3 shows the core averaged axial temperature profiles in the core. Figure 3 shows that the peak fuel temperature is about 130°C in the average fuel channel. The average coolant, cladding and fuel temperature for the calculations are calculated to be 44.89°C, 75.80°C and 89.56°C.

The higher temperature can lead to the enhancement of the fuel Doppler effect, thereby enhancing safety. In order to see the impacts of the new fuel design on the safety parameters, the power defect was calculated for the core. The power defect is defined as reactivity difference between hot zero power and the hot full power conditions. The power defect is usually decomposed into two main components, contribution from the coolant and fuel. Table 2 shows the two components of the power defect of the model reactor.

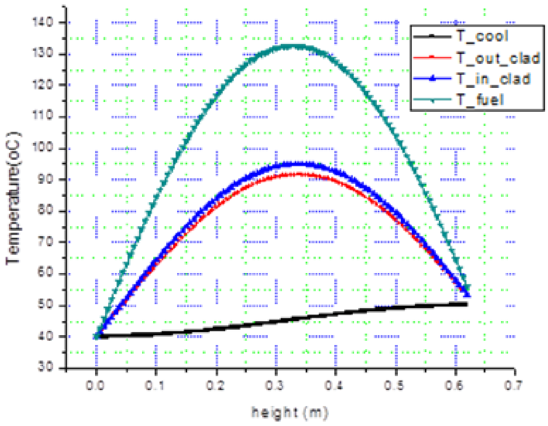

Fig 3. Axial temperature profiles in the average coolant channel

From Table 2, it is clear that the reactivity change due to the coolant temperature change is slightly positive, while the fuel provides a clearly negative reactivity feedback for 100% power change. The positive reactivity due to coolant temperature rise is mainly ascribed to a relatively high coolant volume fraction of about 54% and the Be reflector.

Table 2. Components of Power Defect

Power defect component	Reactivity (pcm)
Coolant temperature	16.74± 2.8
Fuel temperature	-123.75±2.8

For an equilibrium cycle established with a 4-batch fuel management, the unperturbed maximum thermal neutron flux in the central irradiation hole is calculated to be around 6.6×10^{14} n/cm^{2}s. This peak thermal neutron flux is considered to be quite high. In the 20 MWth FRM-II [5] research reactor, which is one of the high performance research reactors in the world, the peak thermal neutron flux is around 8×10^{14} n/cm^{2}s. It should be noted that most high-flux reactors such as FRM-II use costly fuel types such as involute fuel design requiring a very high coolant speed exceeding 10 m/sec.

4. Conclusions

A new plate fuel concept based on CPF has been proposed to improved the negative reactivity feedback from the fuel temperature and to enhance the mechanical integrity. The neutronic feasibility and potential have been demonstrated by considering a small 20 MWth research reactor. It has been shown that the Doppler feedback can be greatly enhanced with the new fuel concept and a very high thermal flux can be achieved by using a simple box-type fuel assembly design. In addition, a very high U loading can be achieved with the new fuel. It is concluded that the newly proposed fuel concept deserves more detailed R&D efforts and has a very high potential as a high-performance and ultra-safe research reactor fuel.

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