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Development of High-density U_3Si_2/Al Dispersion Fuel in KAERI

Tae Won Cho*, Sung Hwan Kim, Hwa Young Song, Kyeong Min Park, Yong Jin Jeong
Research Reactor Fuel Division, Korea Atomic Energy Research Institute (KAERI), 111, Daedeok-daero 989beon-gil, Yuseong-gu, Daejeon, 34057, Korea
**Corresponding author: twcho@kaeri.re.kr*

1. Introduction

As an international non-proliferation policy, RERTR (Reduced Enrichment for Research and Test Reactors) program has been initiated to convert Highly Enriched Uranium (HEU) fuels into Low Enriched Uranium (LEU). Most HEU fuels were converted to LEU fuels using the pulverized U_3Si_2 dispersion fuel. However, some high-power research reactors (RRs) including ATR, HFRI, BR2, and others are still using the HEU fuels since the maximum uranium density of the pulverized U3Si2 dispersion fuel is about 4.8 gU/cm^3, which is relatively insufficient for the high-power RRs.

A few years ago, US government has announced stopping the supply of HEU to civilian RRs after 2023. As a result, a high-density U_3Si_2 fuel has been suggested as an alternative for some high-power RRs. KAERI has well-established plate-type fuel fabrication facilities and atomization technology. Using the atomized U_3Si_2 powder, KAERI successfully developed a high-density U_3Si_2 dispersion fuel with a uranium density of 5.6 gU/cm^3 [1]. KAERI initiated an irradiation test of the atomized powder-based high-density U_3Si_2 fuel plate in BR2 reactor in Belgium. It is expected that this international scale of fuel demonstration enables KAERI to enter the RR fuel export market by obtaining fuel supplier qualification and securing the export base [2].

In this study, the fabrication of the high-density U_3Si_2 fuel and the design analysis for irradiation test in BR2 reactor will be described. Based on the fabrication data, the irradiation conditions such as core configuration and requirements were determined so that the irradiation test can achieve the target burnup and heat flux successfully. Since the irradiation test is in progress, it is expected that the irradiation results including post-irradiation examinations will be obtained in 2023.

2. Fabrication of High-density U3Si2/Al Fuel

2.1 Fuel Fabrication

Using atomized U_3Si_2 powder, 5.3 gU/cm^3 of high-density fuel plates were fabricated by adopting a typical fabrication procedure including mixing and blending, compaction, assembling, hot-rolling, cold-rolling, and leveling. The fuel size was set as 970 mm in length, 61 mm in width, and 1.27 mm in thickness, which is narrower and longer compared to that of the KJRR fuel plate. In general, the narrower and longer the fuel is, the harder it becomes to fabricate. We successfully optimized all fabrication conditions such as atomization, powder mixing, compact condition, hot-rolling, and others. 5 fuel plates satisfying all design criteria were successfully manufactured as seen in Fig. 1.

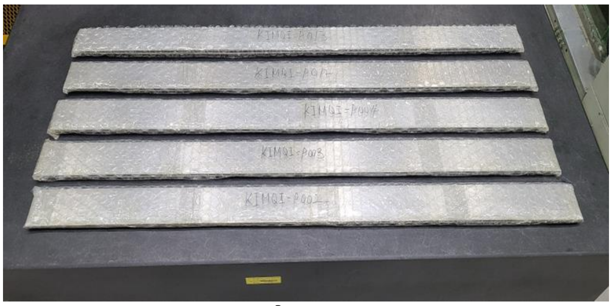

Fig. 1. Images of 5.3 gU/cm^3 of high-density U_3Si_2 dispersion fuel plates for irradiation test.

2.2 Inspection

The U_3Si_2 dispersion fuels were inspected by non-destructive and destructive examinations. First, the fuel meat size and location, and homogeneity were inspected by radiographic test (RT) as seen in Fig. 2.

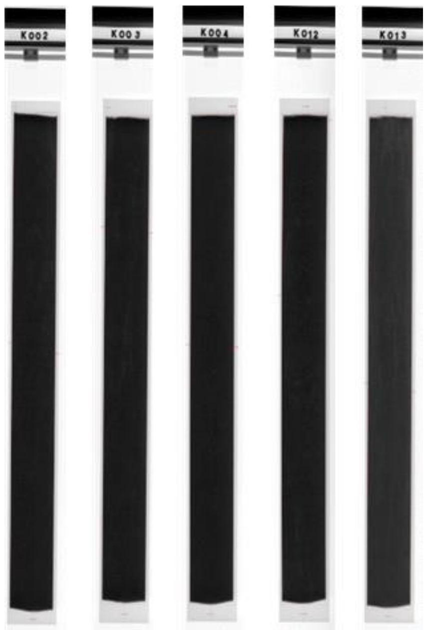

Fig. 2. Radiographic test images of 5.3 gU/cm^3 of high-density U_3Si_2 dispersion fuel plates for irradiation test.

Next, the fuel plates were inspected by ultrasonic test (UT) to identify any flaws or de-bonding, which can cause blistering. Last, one of the fuel plates in the same batch was cut and its cladding thickness was measured to ensure that the fuels have enough cladding thickness as seen in Fig. 3.

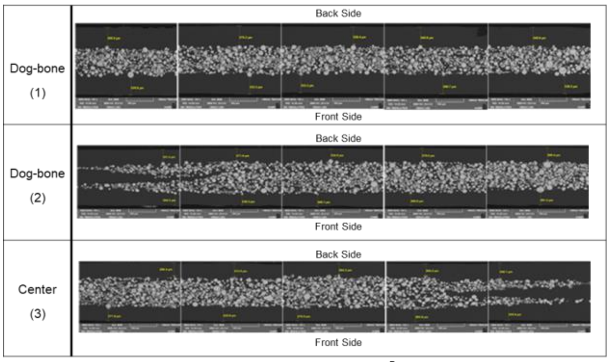

Fig. 3. Cladding thickness of 5.3 gU/cm^3 of high-density U_3Si_2 dispersion fuel plate measured by SEM.

3. Design of Irradiation Test

The irradiation test was designed to meet the general fuel qualification conditions for high-power research reactors. In this irradiation, the followings are targeted:

- Peak heat flux (edge): 470 W/cm^2 at 1st cycle BOC
- Minimum peak Burnup: ≥ 70% U-235

The BR2 configuration of the irradiation test cycle is determined as seen in Fig 4 and BR2 is planned to be operated at 52 MW power with a cycle length of 34 days. The fuel plates will be loaded into the FUTURE-5 basket (Fig. 4) and the basket with fuel plates will be loaded into channel C281 in Fig 3.

Heat flux and burnup distributions were calculated by utilizing the MCNP 6.2 code, in conjunction with the MCNPDATA cross-section library. In this calculation, both heat flux and burnup were only estimated in length and width direction. It was assumed that there will be no thickness difference since it is less than 0.5 mm [2].

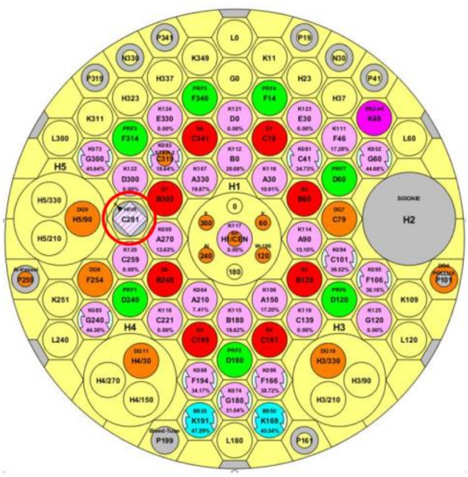

Fig. 4. Configurations of the core loading: BR2 cycle 07/2021.

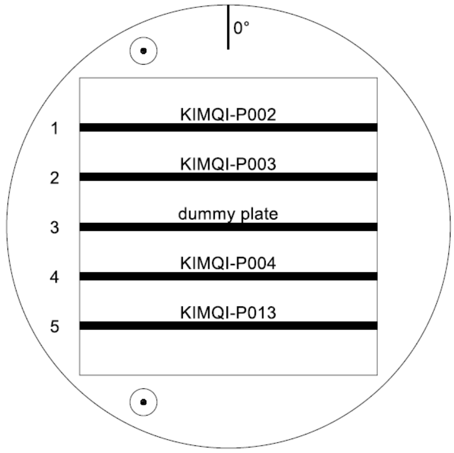

Fig. 5. A schematic of FUTURE-5 basket loaded with high-density U_3Si_2 dispersion fuel plates.

A summary of the results of the heat flux at the beginning of cycle (BOC) and the ^{235}U burnup at the end of the first irradiation cycle (EOC1) is given in Table 1. First, the minimum peak heat flux is 464 W/cm^2 of the KIMQI-013 plate, which is slightly lower than the target heat flux. However, the real heat flux will be higher than the target heat flux since the estimation is conservative. Next, it seems that the target burnup can be achieved after the second or third cycle.

Table 1. Heat flux and Burnup estimation results.

Plate ID	Heat Flux* (W/cm^2)	^{235}U Burnup† (%)	
	Peak	Avg.	Peak
KIMQI-002	470	29.5	46.4
KIMQI-003	479	28.8	43.0
KIMQI-004	475	30.3	47.7
KIMQI-013	464	30.5	45.8

* Heat flux evaluated at BOC (t=0 days)
† Burnup estimated at EOC (cycle 1)

4. Conclusions

KAERI successfully fabricated high-density U_3Si_2 dispersion fuel plates using atomized powder, which is applicable high-power research reactors. The fuel plates are planned to be irradiated in the BR2 reactor to verify their fuel performances, which enables the fuel plates to meet the general fuel qualification requirements. The fuel performance results will be obtained after the second or third cycle of irradiation in 2023.

REFERENCES

[1] Y. J. Jeong et al., "Development of High-density LEU U3Si2 Plate-type Fuel with Atomized Powder", RRFM 2019, JORDAN, 2019

[2] T. W. Cho et al., "Irradiation Design Report of the High-density U3Si2 Fuel Plate at BR2", KAERI/TR-9040/2021