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Irradiation Results of High-density Atomized U_3Si_2 Fuel Plates

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1. Introduction

U_3Si_2 dispersion fuel, with U_3Si_2 particles dispersed in an Al matrix, has been used as a general research reactor (RR) fuel plate all over the world. Currently, some high-power research reactors are still using highly enriched uranium (HEU) fuels. However, they have faced a fuel conversion problem since the US government announced stopping of the HEU supply after `23. As a result, some European countries have decided to develop a high-density U_3Si_2 dispersion fuel as an alternative to their high-power RR fuels.

KAERI has established plate fuel fabrication facilities and atomization technology. Based on these, KAERI successfully fabricated atomized U_3Si_2 powder and high-density U_3Si_2 dispersion fuels with a uranium density of 5.6 gU/cm^3 [1]. For the qualification of the high-density atomized U_3Si_2 dispersion fuel, KAERI initiated the KAERI high-density atoMized silicide fuel Qualification Irradiation (KIMQI) project with SCK·CEN to demonstrate fuel performances of the fuels in severe irradiation conditions. As its first step, some flat fuel plates with a uranium density of 5.3 gU/cm^3 are designed to be irradiated in the BR2 reactor in Belgium to examine their irradiation performances.

Currently, the irradiation of the KIMQI-FUTURE is completed and the fuels are under cooling for the post-irradiation examinations (PIEs). In this study, the irradiation results of the KIMQI-FUTURE experiment will be described.

2. KIMQI-FUTURE Irradiation Test

2.1 Specification of KIMQI-FUTURE fuel plates

Using atomized U_3Si_2 powder, 5.3 gU/cm^3 of high-density fuel plates were successfully fabricated as seen in Fig. 1 and they satisfied all design criteria required for the irradiation test.

Fig. 1. Images of 5.3 gU/cm3 of high-density U_3Si_2 dispersion fuel plates for KIMQI-FUTURE irradiation test.

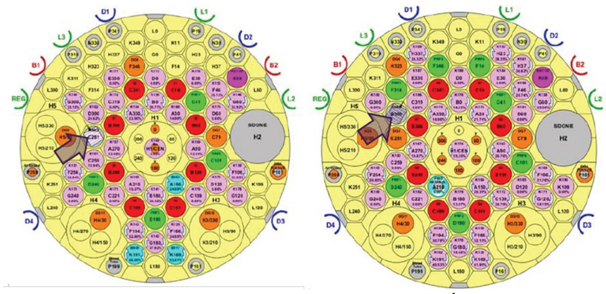
2.2 Irradiation of KIMQI-FUTURE fuel plates

The irradiation test was designed to meet the general fuel qualification conditions for high-power RRs. The target condition is as follows [2]:

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

Fig. 2 shows the BR2 configuration of core loadings for the first and second cycles respectively and key irradiation test results are given in Table 1. The irradiation test was completed in the second cycle and obtained the target burnup. For the first cycle, the fuels were loaded in the C281 slot for higher flux and burnup and they moved into the D300 slot for the second cycle.

The heat flux and burnup data for each fuel plate are given in Table 2 and Table 3. Both highest peak heat flux at the beginning of the cycle and highest peak burnup at the end of the cycle were obtained from the P004 plate. However, all fuel plates obtained similar heat flux and burnup ranges so it is expected that the fuels might show very similar irradiation behaviors.



(a) 1st Cycle (b) 2nd Cycle

Fig. 2. Configurations of the core loading for the KIMQI-FUTURE irradiation tests.

Table 1. Summary of the irradiation test results

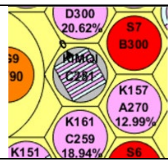
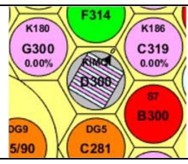
Cycle	1st	2nd
Basket Slot	C281	D300
Position Direction		
Duration	33	31
Average power (MW)	51.53	53.12
Peak ^{235}U Burnup EOC (%)	51.6 – 54.3	70.8 – 72.6

Table 2. Irradiation test results after 1st cycle

Plate ID	Avg. Heat Flux (W/cm^2)	Peak Heat Flux (W/cm^2)	Avg. ^{235}U Burnup EOC (%)	Peak ^{235}U Burnup EOC (%)
P002	280	464	31.7	52.5
P003	272	450	31.6	54.3
P004	281	473	31.6	51.6
P013	288	460	31.9	53.5

Table 3. Irradiation test results after 2nd cycle

Plate ID	Avg. Heat Flux (W/cm^2)	Peak Heat Flux (W/cm^2)	Avg. ^{235}U Burnup EOC (%)	Peak ^{235}U Burnup EOC (%)
P002	118	198	48.9	72.5
P003	118	219	48.6	72.3
P004	119	204	48.6	72.6
P013	128	215	48.9	70.8

2.3 Visual Inspection of KIMQI-FUTURE fuel plates

The visual inspections have been performed along the length direction and the regions are distinguished by TOP, MIDDLE, High Heat Flux region (HHF), and BOTTOM as seen in Fig 3. It is expected that peak heat flux and peak burnup are observed in the HHF region.

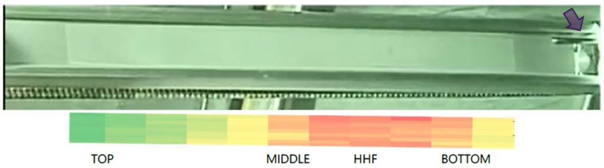


Fig. 3. Full-length images of P013 plate (ID side) indicating HHF region.

After the first cycle of irradiation, the surface images of the irradiated fuels were obtained and examined to detect any defects or deformations. In addition, the fuels were extracted from the basket and a wet shipping inspection was performed to detect any fission product released from the fuels. Fig. 4 shows the surface images of the irradiated fuels after the first cycle and its visual inspection results are summarized in Table 4. There were no meaningful defects observed from the images. Only minor shadings were observed in the HHF region except the P013 plate. The wet shipping inspection reported no detectable fission product release as well.

In the same manner, the irradiated fuels were examined after the second cycle of irradiation. Fig. 5 shows the surface images of the irradiated fuels after the second cycle and its visual inspection results are summarized in Table 5. All fuels still showed stable behaviors but the P013 plate showed minor shading at the HHF region likewise other plates. However, there were no meaningful observations even after the final irradiation and no fission product release.

Fig. 4. Visual images of irradiated fuels after 1st Cycle

Table 4. Summary of the visual inspection after 1st cycle

Plate ID	TOP	MID.	HHF	BOT.	Wet shipping inspection
P002	Clean	Clean	Minor Shading	Clean	No fission products detected
P003	Clean	Clean	Minor Shading	Clean	
P004	Clean	Clean	Minor Shading	Clean	
P013	Clean	Clean	Clean	Clean	

Fig. 5. Visual images of irradiated fuels after 2nd Cycle

Table 5. Summary of the visual inspection after 2nd cycle

Plate ID	TOP	MID.	HHF	BOT.	Wet shipping inspection
P002	Clean	Clean	Minor Shading	Clean	^{133}Xe 6.8 ^{131}I 1.6
P003	Clean	Clean	Minor Shading	Clean	
P004	Clean	Clean	Minor Shading	Clean	
P013	Clean	Clean	Minor Shading	Clean	

3. Conclusions

The KIMQI-FUTURE irradiation test was completed, which demonstrated that the high-density U_3Si_2 dispersion fuel fabricated by atomized U_3Si_2 powder showed stable irradiation behaviors even at the general high-power RR conditions without any noticeable changes. The visual observations revealed only slight discoloration or shading at the high heat flux zone. The plates were freely moved in and out of the basket, indicating the warping of the plates was non-existent or minor. In addition, there were no signs of abnormal fission product release detected after either cycle. These results indicate that the plates were subjected to the correct irradiation conditions and that no abnormal conditions were experienced.

Acknowledgment

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