# Blister-threshold temperature of U-7Mo/Al-5Si dispersion fuel irradiated in HAMP-3 test

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## 1. Introduction

U-7wt.%Mo/Al-5wt.%Si dispersion fuel (hereafter referred to as U-7Mo/Al-5Si) has been selected as the fuel for Kijang research reactor (KJRR) and has undergone a series of irradiation tests for fuel qualification. Among these tests, the HAMP-1, HAMP-2, and HAMP-3 irradiation tests were conducted in the High-flux Advanced Neutron Application Reactor (HANARO) at Korea Atomic Energy Research Institute (KAERI) since 2014. The HAMP-3 irradiation test employed four fuel plates with reduced-width/full-length dimensions relative to KJRR fuel plates and was successfully completed in February 2024, achieving a local peak burnup of approximately 90 at.%U-235 depletion.

Post irradiation examinations (PIEs) were performed on the four irradiated fuel plates. The non-destructive examinations revealed no abnormal behavior, such as surface deformation or significant increases in plate thickness from all plates [1]. Among the four plates, KJF-8032 with local peak burnup, was subjected to destructive examination for microstructural characterization of fuel meat where U-Mo fuel particles are dispersion in Al matrix. The remaining three fuel plates (KJF-8031, -8034, and -8035) were used for blister threshold testing to determine whether significant surface deformation by localized swelling would occur under elevated temperature conditions.

The blister threshold test followed the conventional procedure in which an irradiated fuel plate is placed in a furnace and exposed to a specified elevated temperature to determine whether blisters form on the plate surface as a result of the accumulation and coalescence of gaseous fission products.

In this study, the results of the blister threshold tests performed on three HAMP-3 fuel plates are presented and analyzed in relation to the local burnup at the locations where blisters were observed. In addition, blister threshold test results from other irradiation tests are compiled and compared to investigate the overall trend in blister threshold temperature as a function of fuel burnup. Furthermore, the measured temperatures were compared with those predicted as a function of burnup using the model developed in a previous study [2]. This comparison was performed to access whether the blister threshold behavior observed for the HAMP-3 fuel plates are agreeable within the range predicted by the model.

## 2. Blister threshold temperature test

### *2.1 HAMP-3 fuel plates*

The dimensions and burnup values of the HAMP-3 fuel plates are summarized in Table 1. The plate and fuel meat dimensions were identical to those of the KJRR fuel plate except for the reduced plate width. The fuel meat was fabricated with a uranium loading of 8.0 g-U/cm$^3$, which is also same value specified for the KJRR fuel. As-run analysis indicated that both the local peak burnup and plate-average burnup were at nearly the same levels among the four fuel plates. Three fuel plates excluding KJF-8032 were selected for the blister threshold tests.

Table 1 Dimensions and burnup values of the HAMP-3 fuel plates.

| Plate ID | Dimensions of fuel meat and plate (W × T × L, mm) | Local peak burnup (at.%U-235 depletion) | Avg. burnup (at.%U-235 depletion) |
|---|---|---|---|
| KJF-8031 | 25 × 0.51 × 600 / 35 × 1.27 × 640 | 89.6 | 81.2 |
| KJF-8032 | | 89.8 | 81.6 |
| KJF-8034 | | 89.1 | 80.4 |
| KJF-8035 | | 89.0 | 80.2 |

### *2.2 Test Procedure*

For HAMP-3 plates, the test protocol was set up as follows:

a) A fuel plate is installed on a plate holder (see Fig. 1), and it is inserted in a furnace. A furnace is heated up until the furnace temperature reaches up to a specified temperature.
b) The fuel plate is exposed at the elevated temperature for a period of time (20 minutes). After the period of time, the plate is withdrawn from the furnace for the visual inspection.
c) This process is repeated with increasing the target temperature until the formation of any blisters is confirmed. The target temperature is specified from 350 ℃ to 550 ℃ with increasing temperature by 25 ℃ at each repetition of the process.

A schematic of the furnace and thermocouples (TC) arrangement used for the test is shown in Fig. 2. The furnace temperature was controlled using K-type TCs. During the test, five TCs positioned within the furnace were used to monitor the temperature distribution along the fuel plate in length direction, and the heating element power was controlled to maintain a uniform temperature distribution over the plate.



Fig. 1 A test plate with a holder.

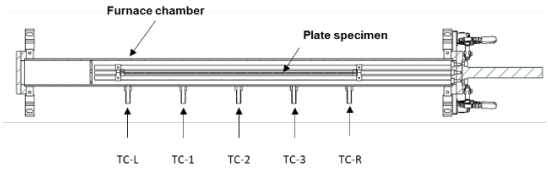



Fig. 2 A schematic of furnace and thermocouples for the blister-threshold temperature test.

## 3. Results

The results of the blister-threshold temperature tests are summarized in Table 2. For fuel plate KJF-8035, blisters were observed after holding the plate at 425 ℃ for 20 min. For the other two fuel plates (KJF-8031, KJF-8034), blisters were observed after holding at 400 ℃ for 20 min.

Table 2 Summary of blister-threshold temperature test.

| Plate ID | Blister-threshold temperature (℃) | Local burnup range at the region where blisters formed (%U-235 depletion) |
|---|---|---|
| KJF-8031 | 400 | 86.6 ~ 88.7 |
| KJF-8034 | 400 | 82.8 ~ 89.1 |
| KJF-8035 | 425 | 84.4 ~ 89.0 |

As shown in the photographs of the blistered regions in Fig. 3, blistering occurred locally rather than overt the entire plate surface. The blisters were primarily observed near the side edge regions of the plate in the width direction, corresponding to the fuel meat/cladding interface. These locations are associated with power peaking during irradiation, and As-run analysis confirmed that the local burnup at these regions was relatively higher than that in the central region along the plate width.

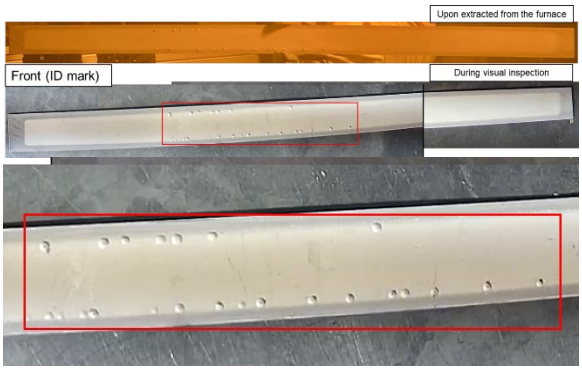



Fig. 3 A surface of KJF-8035 after the test at 425 ℃.

## 4. Discussion

### *4.1 Comparison with blister-threshold test*

The blister-threshold temperature found from the plates from HAMP-3 up to the plate-averaged burnup of 81.2 %U-235 (equivalent to fission density of $6.2\times10^{21}$ fission/cm$^3$-fuel) is agreeable to the tendency reported in literature available elsewhere [3]-[5] as shown in Fig. 4. It implies that no abnormal behaviors related to the blister formation were found.

Compared with monolithic U-Mo fuel, in which the fuel zone consists of a single-composition U-Mo foil (upper-triangle symbols in Fig. 4), U-Mo/Al-Si dispersion fuel (circle symbols in Fig. 4) generally exhibits higher blister-threshold temperatures at comparable burnup levels. This tendency indicates that U-Mo dispersion fuel has a greater resistance to blister formation than monolithic type fuel. However, the difference in blister resistance between two fuel types becomes less pronounced with increasing burnup.

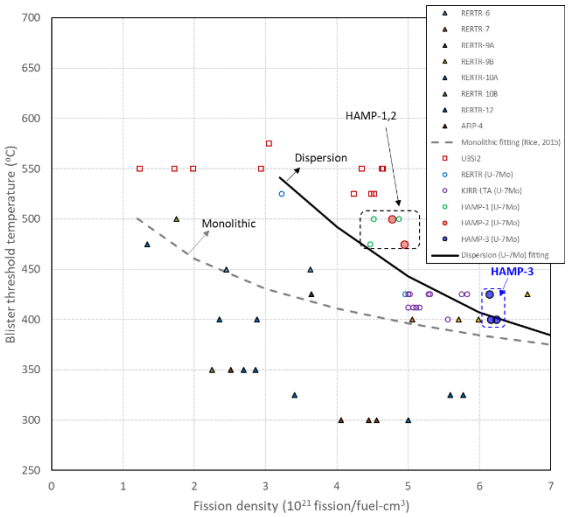



Fig. 4 Comparison of blister-threshold temperature observed in HAMP-3 with data from other irradiation tests for U-Mo fuel including monolithic type plate.

### *4.2 Comparison with model prediction*

The method described in Ref. [2] is used for predicting the blister-threshold temperature based on the fission history of the fuel. In this model, pressurization caused by fission gas agglomeration is considered, and the blister-threshold temperature is defined as the temperature at which the fission gas pressure during the blister test becomes equal to the yield strength of the Al-alloy cladding. Two threshold boundaries are predicted: Region I, based on the unirradiated cladding yield strength, and Region II, based on the cladding yield strength accounting for irradiation hardening.

When the HAMP-3 test results are compared with these predicted boundaries, most of the data fall within Region II. This behavior may be attributed to the higher

neutron fluence by longer irradiation period of HAMP-3 compared with the KJRR-LTA irradiation test, which could have resulted in higher extent of irradiation hardening of the cladding. Accordingly, HAMP-3 fuel plates exhibited blister-resistant behavior at temperature of 400 ℃, broadly consistent with the model prediction.

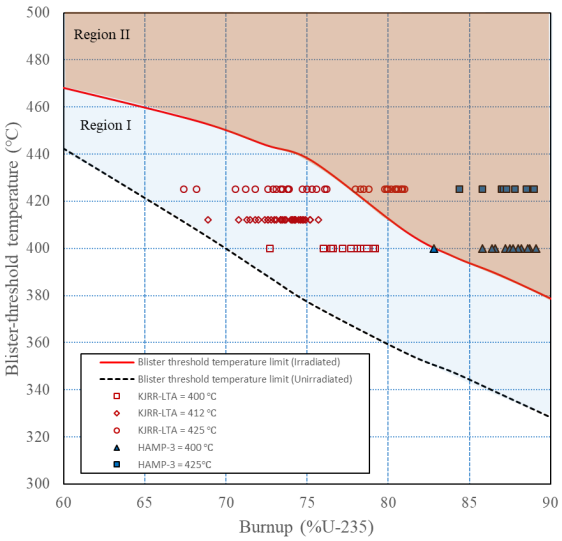



Fig. 5 Comparison between blister-threshold temperature limits and test data from KJRR-LTA and HAMP-3.

## 5. Conclusions

The HAMP-3 irradiation test was successfully completed without abnormal fuel behaviors up to the local peak burnup of 89.8 %U-235 depletion, and blister threshold temperature tests were subsequently performed on three irradiated fuel plates. The test results showed a blister-threshold temperature of 400 ℃ at a local peak burnup of 89.6 %U-235 depletion, corresponding to a plate-average burnup of 81.2 %U-235 depletion. Comparison with previously reported blister-threshold data and model predictions showed that the HAMP-3 results were in reasonable agreement with both. These results demonstrate that U-7Mo/Al-5Si dispersion fuel retains substantial resistance to blister formation up to approximately 90 %U-235 depletion burnup, with the blister-threshold temperature remaining at approximately 400 ℃.

## REFERENCES

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