

ON-GOING STATUS OF KJRR FUEL (U-7MO) QUALIFICATION

J.S.Yim, Y.W.Tahk, J.Y.Oh, H.J.Kim, E.H.Kong, B.H.Lee
Nuclear Fuel Design for Research Reactors, KAERI
zip305-353, 111 Daeduok Daero 989 Beon-gil, Yuseong-gu, Daejeon, KOREA
J.M.Park, Y.J.Jeong, K.H.Lee, S.H.Kim, C.T.Lee
Research Reactor Fuel Development, KAERI

A.A. Beasley, Y.J. Choi, D.S. Crawford, J.W Nielsen, N.E. Woolstenhulme
Nuclear Fuels and Materials Division, INL
Idaho National Laboratory, P.O. Box 1625 Idaho Falls, Idaho, 83415 USA

ABSTRACT

In order to cope with the global shortage of Mo-99 supplies and the growing demand of neutron transmutation doping, the KJRR construction plan was launched in April 2012 to provide self-sufficiency of domestic RI demand, and to extend the Si doping capacity for the power device market growth. Through comprehensive surveillance of the in-reactor behavior of fuel, KAERI has selected a fuel meat with a U-7%Mo dispersion in an aluminum matrix with 5wt%Si for KJRR fuel. As a part of the effort of fuel licensing and qualification of the KJRR fuel, an LTA irradiation test at the ATR started from November 2015, and was successfully completed by reaching 216.6 EFPD at the end of February 2017. Together with the results of HAMP-1, which already completed irradiation and PIE, the successful irradiation of the LTA also demonstrates the fuel integrity under more rigorous conditions than the KJRR operation conditions. This paper updates the current status of the KJRR U7Mo (8 g-U/cm³) LTA irradiation and PIE plan up to date as of February 2017.

1.0 INTRODUCTION

In 2012, KAERI launched a project to construct a new research reactor, in KiJang local provincial district near Kori PWR complex for a 5 year project [1-2]. After completion of a preliminary safety analysis of the reactor and various components including the fuel, a Preliminary Safety Analysis Report (PSAR) [3] was submitted to the Nuclear Safety and Security Commission (NSSC) in November 2015 together with other document sets to be reviewed by the KINS (Korea Institute of Nuclear Safety) which is an entity mandated to review the safety related documents by the NSSC.

Based on a comprehensive surveillance [4-17] of in-reactor behaviors of similar U-Mo fuel to the KJRR (KiJang Research Reactor), KAERI has chosen fuel meat of U-7wt%Mo/Al-5wt%Si dispersion with 8.0 g-U/cm³ for the driver fuel to achieve greater efficiency and a higher performance than U₃Si₂ fuel. A total of 22 fuel assemblies (FAs), 16 standard fuel assemblies, and six follower fuel assemblies will be loaded in the core. Both FAs consist of 19 interior plates with an uranium density of 8.0 g-U/cm³ and two exterior plates of 6.5 g-U/cm³ to lessen the radial peaking in an FA. The main parameters of the KJRR are listed in Table 1. The overall dimensions of the KJRR FA are 76.2x76.2x1010 mm, and the LTA is shown in Figure 1.

Because the KJRR fuel will be the first kind of engineering-scale application of U-Mo fuel for commercial utilization, it requires a license to be granted and a qualification of the fuel by demonstrating the mechanical integrity, geometric stability, acceptable dimensional changes, and assurance that the performances of the fuel meat and fuel assembly are stable and predictable during irradiation.

KAERI has plans for the licensing and qualification of the new fuel using the data acquisition

methods for the relevant irradiation properties: 1) 16 mini-plate irradiation in the High-flux Advanced Neutron Application Reactor (HANARO) and post-irradiation examinations at the KAERI site, 2) a lead test assembly (LTA) irradiation test at the Advanced Test Reactor (ATR) and PIEs at the INL site, and 3) using available irradiation and PIE data obtained from plate-wise irradiation and PIE programs, such as US-based RERTR and AFIP tests or European U-Mo development programs such as IRIS-3, IRIS-TUM, and E-FUTURES.

Apart from the irradiation tests, the FA properties will be provided using an out-of-pile flow test and mechanical tests such as a vibration test to yield the vibrational characteristics of a fuel plate and an FA. As-manufactured fuel properties will also be provided during the process of fuel licensing and fuel qualification.

All test results and fuel properties will be integrated and compiled to issue a qualification report that demonstrates that the fuel design is adequate, the manufacturing technology is acceptable, and the fuel performance is predictable under certain limits under reactor operation conditions.

As part of the fuel qualification program, three irradiation tests with mini-plates are scheduled to be performed at the HANARO reactor. HANARO located at the KAERI site has been operated successfully since 1995 with a variety of neutron utilization facilities and irradiation holes under 30MW of thermal power. The maximum thermal neutron flux achievable in the central hole is 5×10^{14} n/cm²-s. As the irradiation hole (OR-3, etc.) of the HANARO reactor is not sufficiently big to accommodate a full sized KJRR fuel plate or the FA, mini-plate irradiation tests designated as HAMP-1, 2, and 3 have been planned. These mini-plate irradiation tests will provide basic irradiation data including the fuel behavior depending on the level of fuel burnup, i.e., low burnup (about 60 % U235 depletion), fuel assembly average discharge burnup (about 70 %U235), and local maximum discharge burnup (about 85 % U235).

Among them, the HAMP-1 irradiation test up to the local peak burnup of 65% and PIEs with 8 mini-plates have been completed, results of which were presented already [18, 19]. These mini-plate irradiation data and properties will be added as a supplement to the LTA (Lead Test Assembly) test results for the fuel licensing and qualification.

Unfortunately, during the 20-year scheduled overall inspection of HANARO soon after the completion of the HAMP-1 irradiation, it was found that about 5 % of the HANARO building wall does not satisfy the seismic design limit (based on newly enforced construction law). In response to the request for wall bolstering, construction of the shore-up for the wall is almost complete as of the end of Feb. 2017, and HANARO will soon resume operation.

This paper focuses on an LTA irradiation test at the ATR in INL and a future plan of the PIE on the irradiated LTA.

Table 1 Main parameters of the KJRR [3]

Parameter	Design Result
Thermal Power	15 MW
Max. thermal neutron flux	3.37×10^{14} n/cm ² s
Heat Flux Nominal/Peak (W/cm ²)	41.5/137
Operation day per year	> 300 days
Reactor life	50 years
Average discharge burn-up	67.7 %U-235
Cycle length	> 50 days
Fission Mo production	2,300 Ci/week (6 targets)
NTD	200 ton/year
Number of FA in the Core	22(16 standard, 6 follower)

Fuel consumption/year	12 EA (9 SFAs, 3 FFAs)
Coolant flow velocity in flow gap (m/sec.)	Nominal 6.0

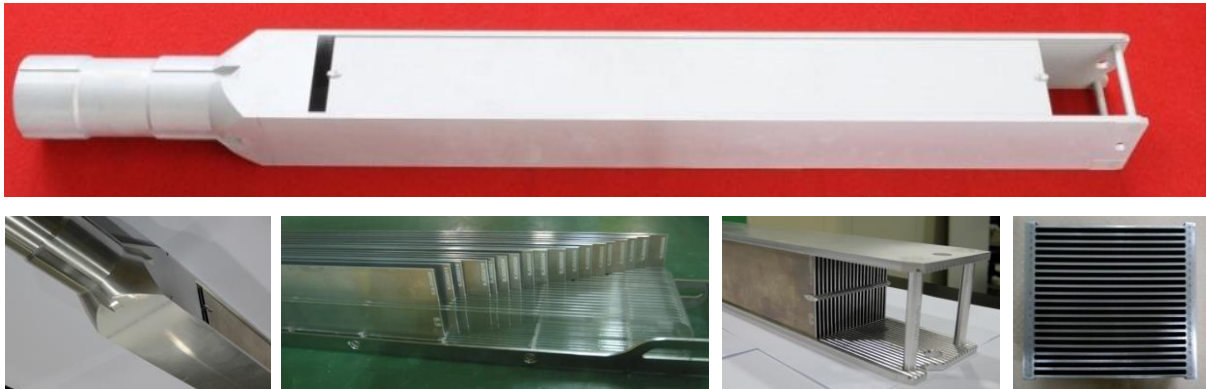


Figure 1 KJRR Lead Test Assembly (LTA)

2.0 CURRENT STATUS OF KJRR LTA IRRADIATION AND PIE

It is absolutely necessary to comprehensively demonstrate the structural integrity, fuel performance, and its stable and predictable behavior during irradiation under the KJRR operation conditions. In an attempt to demonstrate these aims, one LTA, a prototypical KJRR FA, has been irradiated since October 2015 in the ATR with a more rigorous operational environment [20, 21] than the KJRR up to target local peak burnup of about 85% U-235 depletion.

Prior to the LTA irradiation in the ATR, a low power test with one of the LTAs in the ATR-Critical facility was completed for evaluation and confirmation of the neutronics calculation [22]. A summary of the LTA irradiation is listed in Table 2.

Table 2 Summary of the LTA Irradiation Test at the ATR

Cycle	ATR Cycle	EFPD/ Cumulative	Irradiation Period	Peak Heat Flux W/cm ² (BE ^{*)})	Max. Temp. Meat/Clad (°C), (BE)	Peak Burnup (% U-235 depletion)
1	158A	52.2	26 Oct. 2015 -7. Nov. 2015	188	121.8/112.5	27.6
2	158B	51.4/103.6	6 Feb. 2016 -1 Apr. 2016	154	114.5/101	49.8
3	160A	52.9/156.5	17. Sept. 2016 - 7. Nov. 2016	137	120/97	68.8
4	160B	(60.1)/216.6	19. Dec. 2016 - 23. Feb.2017	<137	<114	83.1

*) BE: Best Estimated

2.1 KJRR LTA TEST REQUIREMENTS

To simulate the KJRR operation conditions while preserving the ATR safety requirements, test

conditions for the LTA were predetermined [21]. The requirements given are as follows: the maximum fuel temperature shall be less than 200°C, the maximum heat flux shall be less than 200 W/cm², and the oxide layer spallation on the fuel plates and blistering shall not be allowed. The target local peak burnup of a plate was set to be 79 to 84% at maximum. A nominal flow velocity of 7.2m/s was determined to satisfy the requirements, which was achieved by adjusting the orifice size of the LTA basket in the irradiation flux trap by applying a pressure drop flow test at KAERI [23] under NEFT flow environments using a dummy test FA and INL-designed inner and outer baskets.

2.2 KJRR LTA IRRADIATION

The LTA initially reached full power on 26th October, 2015, and irradiation continued till 7th November, 2015, reaching 52.2 EFPD [24] with the highest heat flux of 188 W/cm² during the first ATR cycle (158A). Since then, up to 23th February, 2017 irradiations with four ATR cycles were completed, successfully reaching a total of 216.6 EFPD. The heat flux history, plate temperature, and peak total plate swelling estimates by the as-run analysis by INL are shown in Figures 2 to 4 [25], and they will finally be updated in the KJRR-LTA irradiation summary report. In these figures, nominal estimates without an uncertainty factor as well as 40 % additional heat generation by including hot channel factors are depicted together. Plate peak swelling is estimated as less than 8% of volume increase when applying a 40% additional heat generation factor, as shown in Figure 4.

The plate peak burnup at plate 20 at the end of the irradiation was predicted to be about 83.1 % U-235 depletion, which is slightly lower than the required highest target burnup of 84%.

Figure 5 shows one of the footages of the LTA visual inspection after 4 cycle irradiation of the ATR

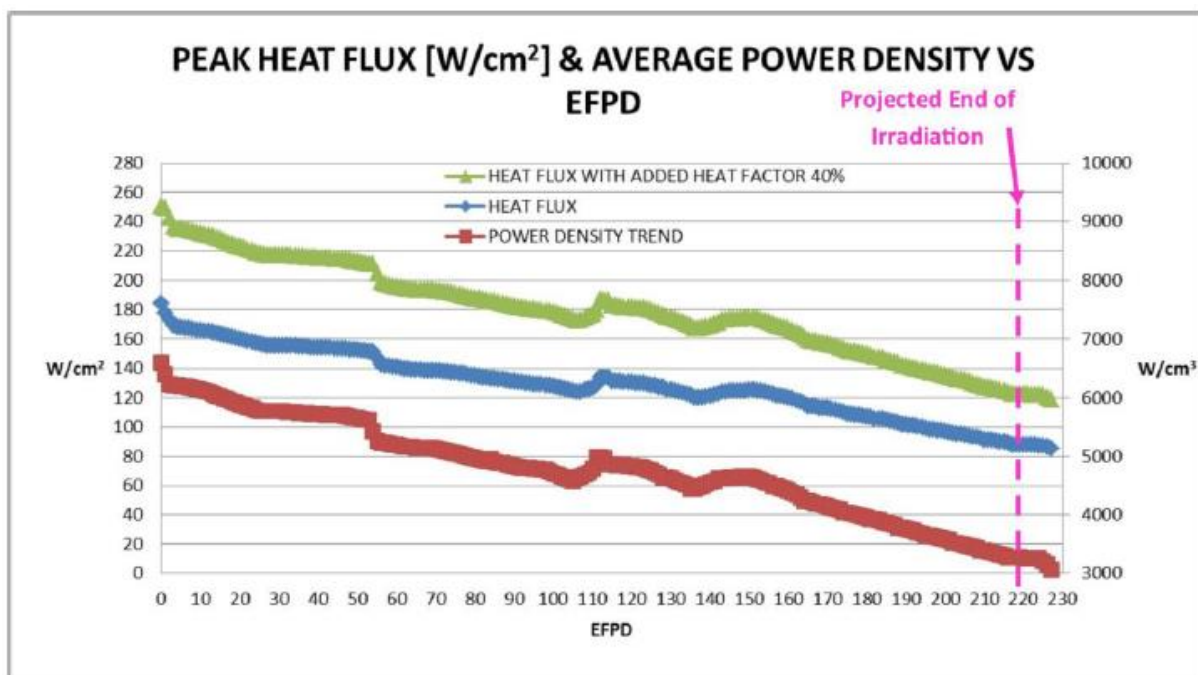


Figure 2 Peak Heat Flux and Average power density

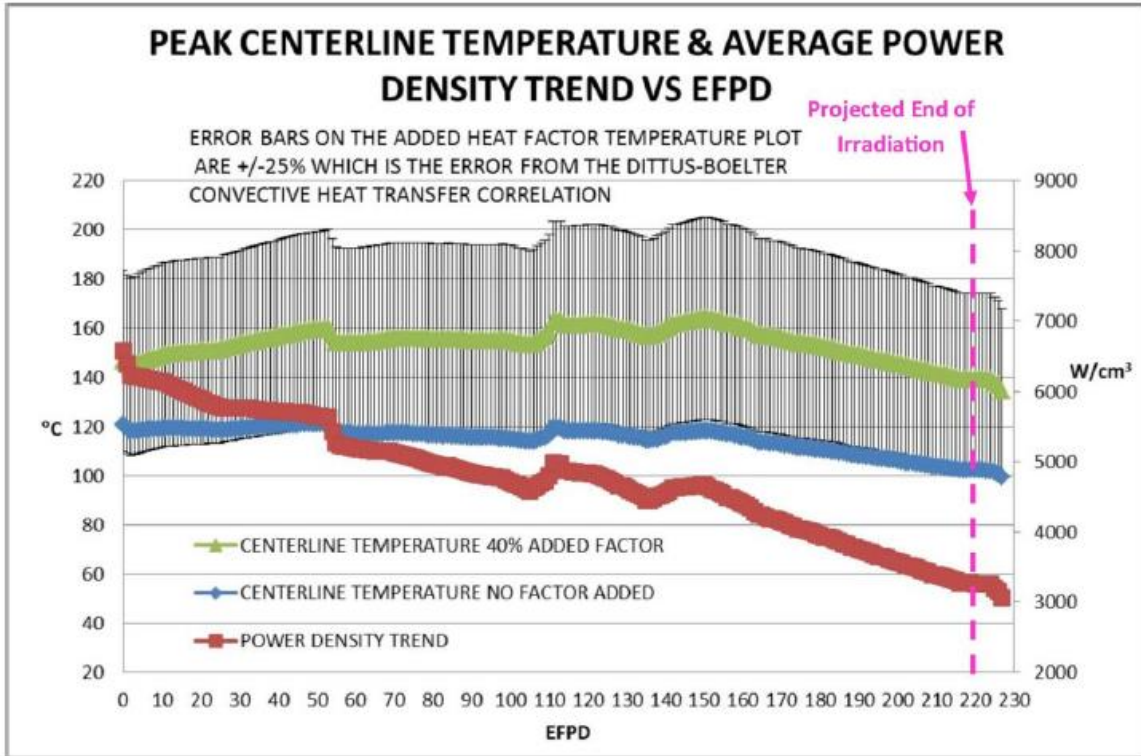


Figure 3 Peak centerline temperature and average power density

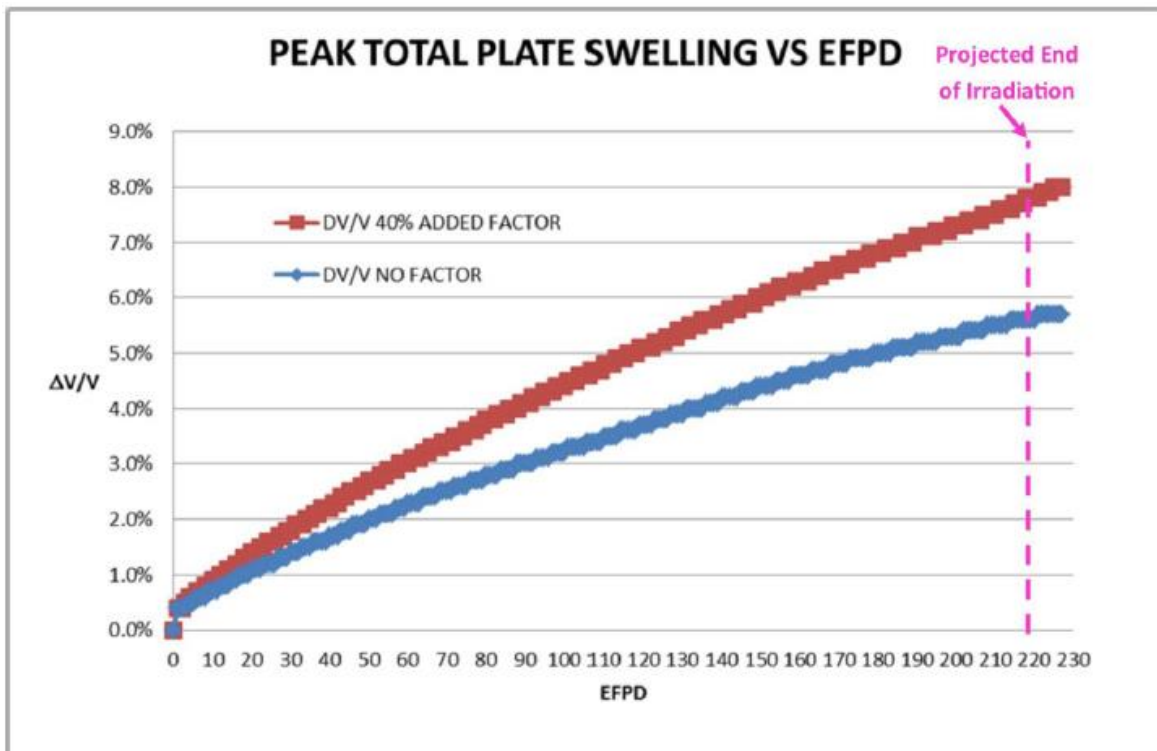


Figure 4 Peak total plate swelling



Figure 5 Visual inspection of the LTA after completion of 4 cycle irradiation

2.3 KJRR LTA PIE

Upon completion of the successful irradiation of the LTA, a typical PIE will follow [26] after cooling for several months to lower the fuel plate temperature below 300°C during the vacuum drying before transport from the ATR to the HFEF (Hot Fuel Examination Facility). Because the LTA was oriented in the ATR flux trap such that flux gradients caused plates 20 and 21, which were near and normal to the core center, to achieve a slightly higher burnup than plates 2 and 1, respectively. The inner plates will have less burnup owing to the plate-to-plate self-shielding, but they are to be used for blistering threshold temperature measurements depending on the burnup. PIE on the irradiated LTA will consist of a visual inspection, dimension measurements, and channel gap measurement. For fuel plate NDE, plate-wise visual inspection, plate-dimensional examination, fuel plate oxide layer examination, and fuel plate gamma scanning will be performed. A destructive examination of the fuel plates, blistering test for more than 10 plates, metallography, and isotopic analysis for burnup determination will be carried out. All PIE data will be summarized in a KJRR PIE summary report, which is expected to be issued at the end of 2018.

3.0 CONCLUDING REMARKS

In order to overcome the shortage of domestic RI production in KOREA, the KJRR construction project has been underway since April 2012. Through comprehensive

surveillances of the U-Mo fuel irradiation and PIE results, the fuel for the KJRR was selected to be U-7wt%Mo powder made by KAERI's own manufacturing technology, which is known as a centrifugal atomization process, and dispersed in an aluminum matrix with 5wt%Si.

Two LTAs were fabricated, one of which was irradiated up to 216.6 EFPD by 23th February 2017 at the ATR in INL. Through a successful irradiation test of the LTA, maintaining the FA structural integrity and fuel performance in a stable manner were demonstrated without any fuel breaches. After cooling for several months, various PIEs on the irradiated LTA will also add to the information of the fuel properties and behavior of the fuel during irradiation for the fuel licensing and qualification.

The existing irradiation and PIE data will also be used as complementary information for the fuel licensing and qualification of the KJRR fuel together with the results of HAMPs, LTA, and out of pile characteristic tests.

Acknowledgement

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