Symposium on Solving Problems in Research Reactors
5th December, 2025

Development of U-Mo Fuel For Research Reactors and its Impact

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KAERI Korea Atomic Energy Research Institute

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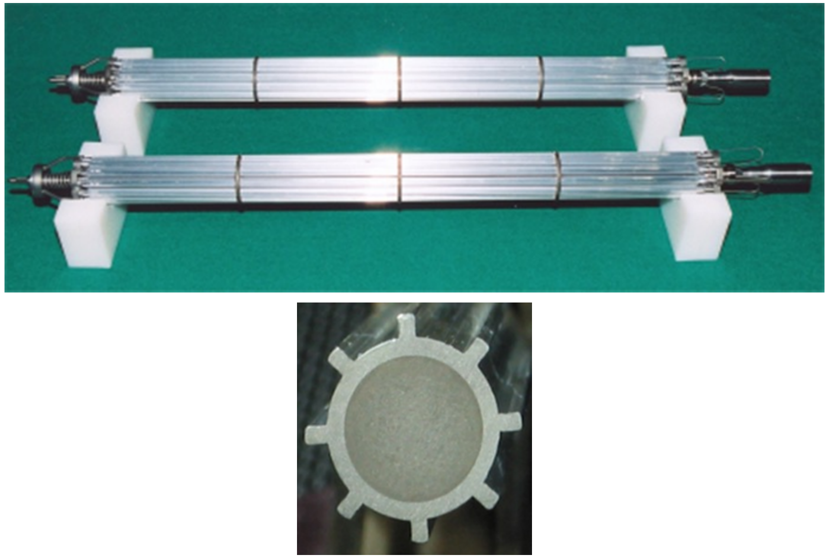
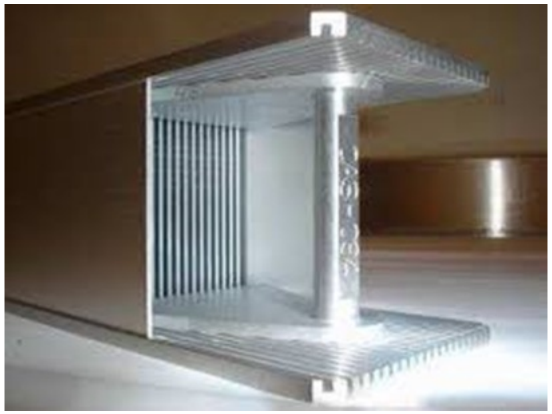
- History of RERTR (LEU Conversion)
- Performance of U_3Si_2-Al Dispersion Fuel
- U-Mo Fuel Development for HPRR
- Status of KJRR(U-Mo) Fuel Qualification
  - KJRR-LTA Irradiation Test
  - HAMP Irradiation Test
- Conclusion

RERTR Program
(LEU Conversion)

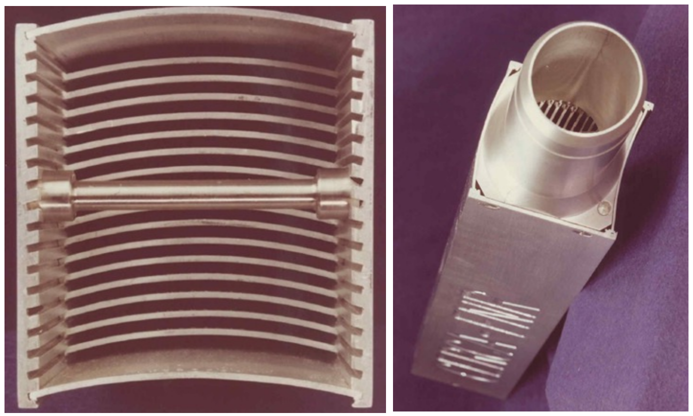
Research Reactor Fuels

Rod Type (HANARO)

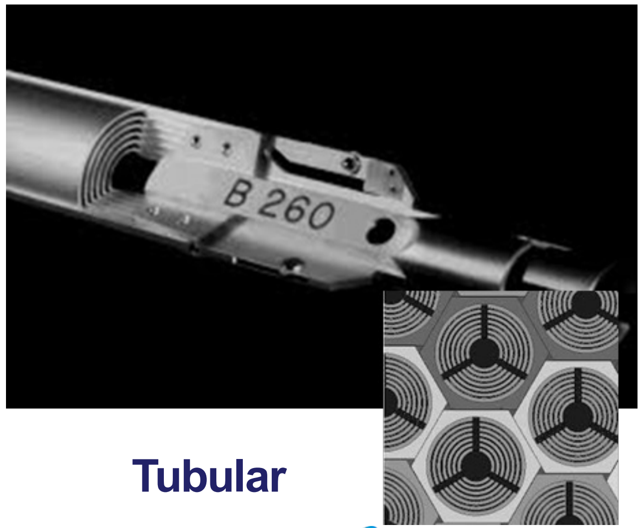




Flat Plates



Curved Plates



Tubular

RERTR Program

Reduced Enrichment for Research and Test Reactors

HEU (93%U-235) ➡ LEU (20%U-235)

The primary objective was to develop an LEU fuel to convert RR from HEU to LEU to minimize and eventually eliminate the use of HEU in civilian research reactors in the world.

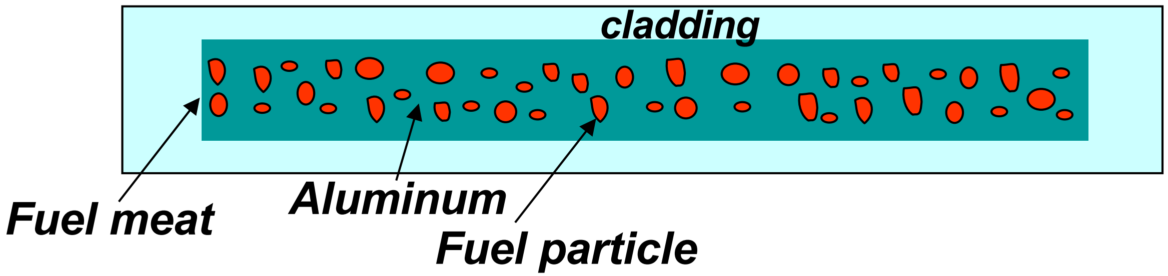
- **US civil HEU minimization policy**
- **Started in 1978 and still going**
- **Post-911, reappreciation of this program → GTRI**
- **Active international collaboration and cooperation critical**
- **Fuel development a cornerstone**

What are the difficulties and why are so much effort and time required?

Basic Requirement for LEU Fuel Development

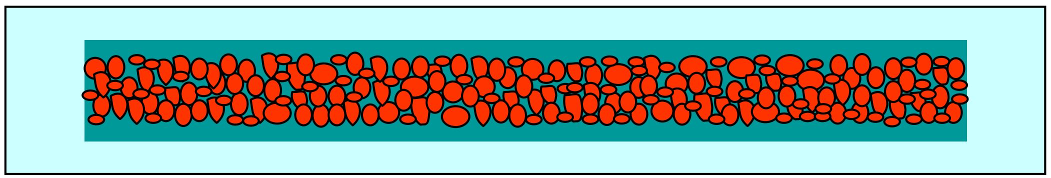
Conversion of a HEU dispersion fuel to LEU with the same fuel type

→ **Guarantee the absolute amount of U-235 loading unchanged**



HEU
~20 vol.%
fuel particles

HEU (93% U-235) → LEU (20% U-235)



LEU
~90 vol.%
fuel particles

This is no longer a viable dispersion fuel solution:

Find a fuel type with a much higher U-density

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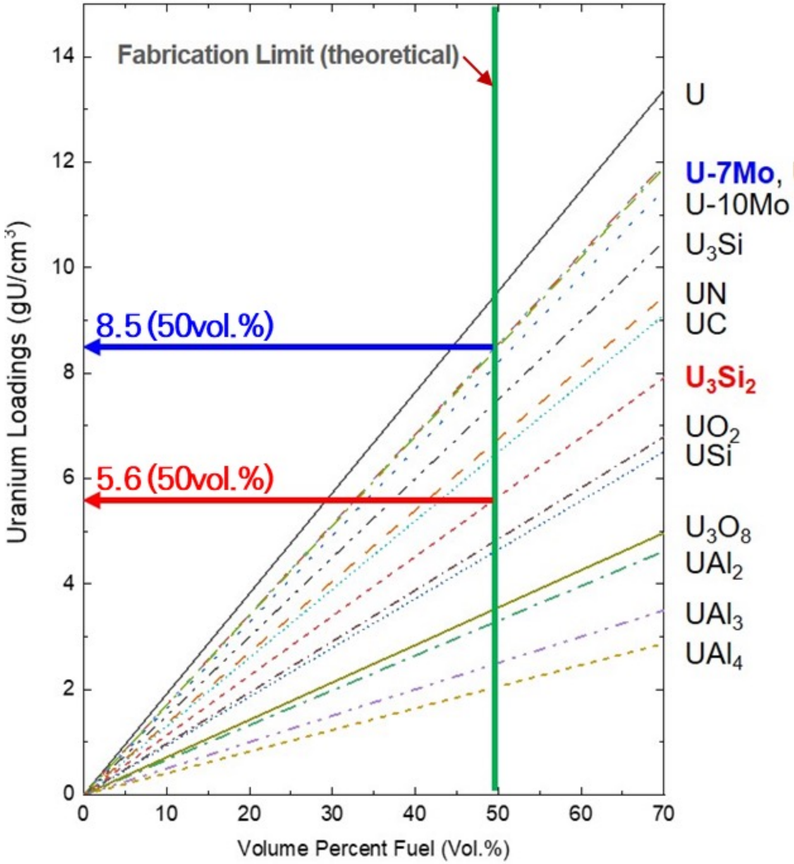
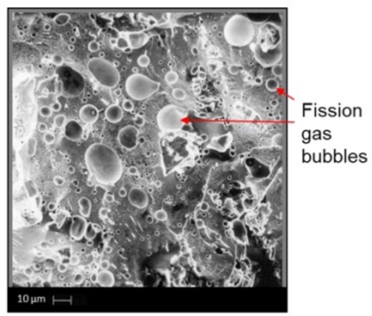
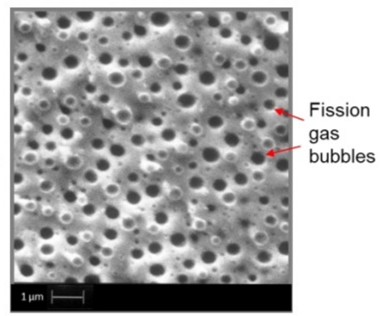
LEU Fuels

	Compound or Alloy	Density g/cm3	U-density g-U/cm3-fuel	Thermal neutron capture cross-section of 2nd element, barns
	UO_2*	**10.9**	**9.7**	**0.0003**
1st Generation	U_3O_8*	8.3	7.0	0.0003
	UAl_3*	**6.8**	**5.1**	**0.23**
	UC	**13.6**	**13.0**	**0.0032**
	UN	**14.3**	**13.5**	**1.91**
	U_3Si*	15.3	14.7	0.171
2nd Generation	**U_3Si_2***	**12.2**	**11.3**	**0.171**
	U_6Fe	**17.7**	**17.0**	**2.53**
	U_6Mn	**17.8**	**17.0**	**13.3**
	U_6Ni	**17.6**	**17.0**	**4.5**
	U-10 Mo	**17.0**	**15.3**	**2.55**
3rd Generation	**U-6 Mo**	**17.8**	**16.7**	**2.55**
	U-4 Mo	**18.1**	**17.4**	**2.55**
	U	**19.0**	**19.0**	**-**





a) U_3Si (90% LEU burnup)



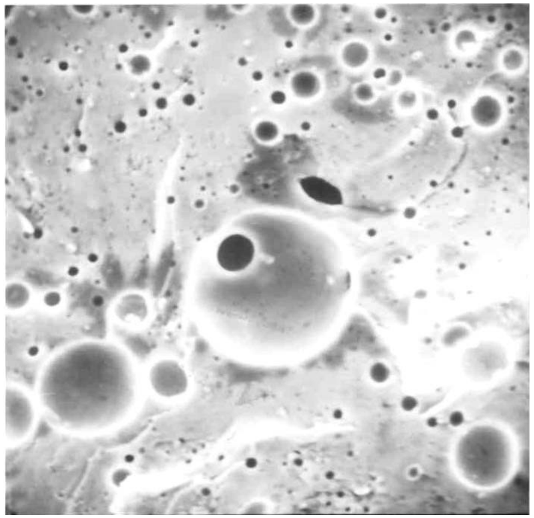
b) U_3Si_2 (90% LEU burnup)

Swelling Behavior of U-Silicide Fuels

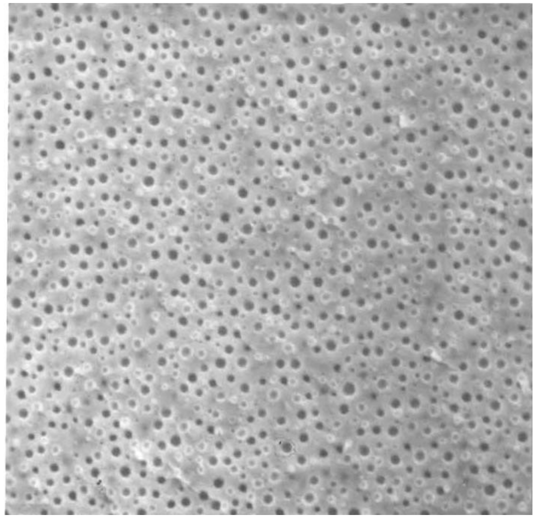
Both are amorphous, but different in Si/U ratio

→ U_3Si_2 has much lower free volume.

→ Acceptable stable swelling behavior



15 μm

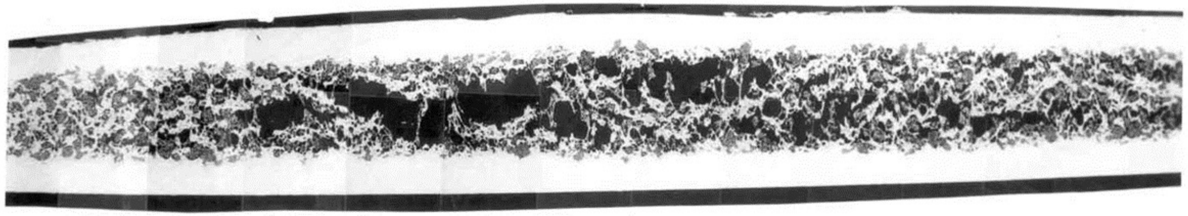


U_3Si	U_3Si_2
80% BU	90% BU
Low viscosity	High viscosity

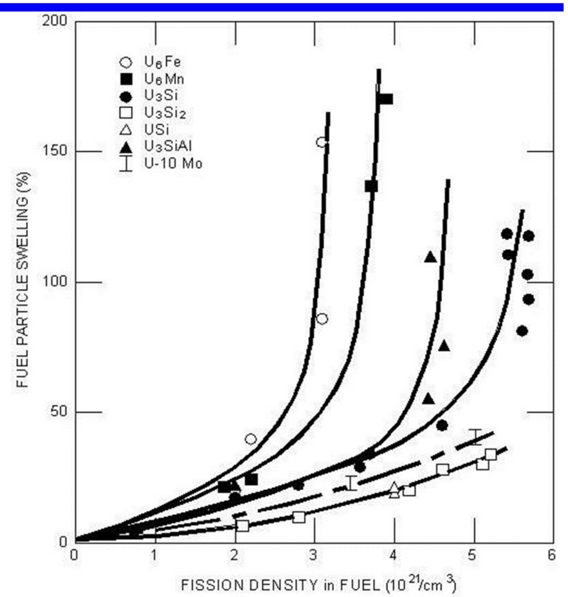
Fuel irradiation test result: Fuel swelling

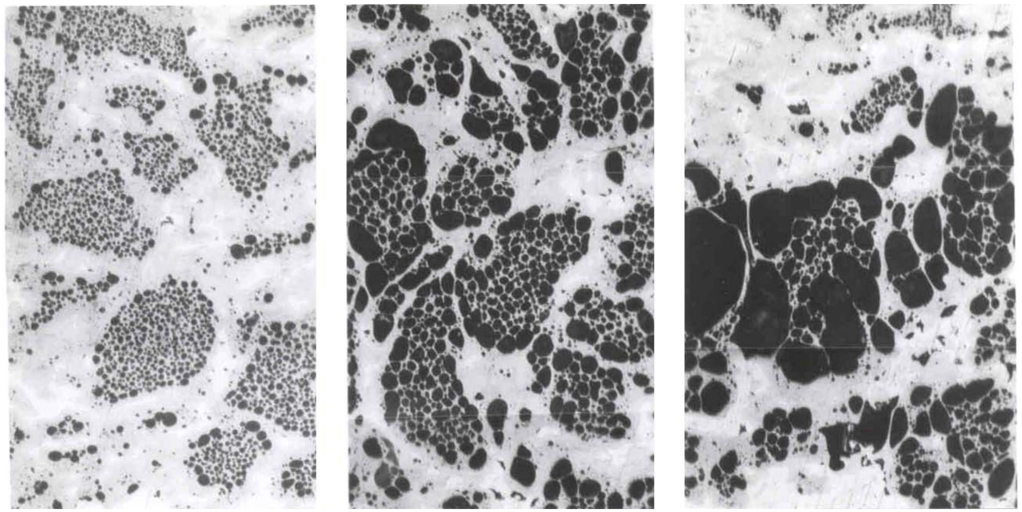
Fuel failure by excessive fuel swelling

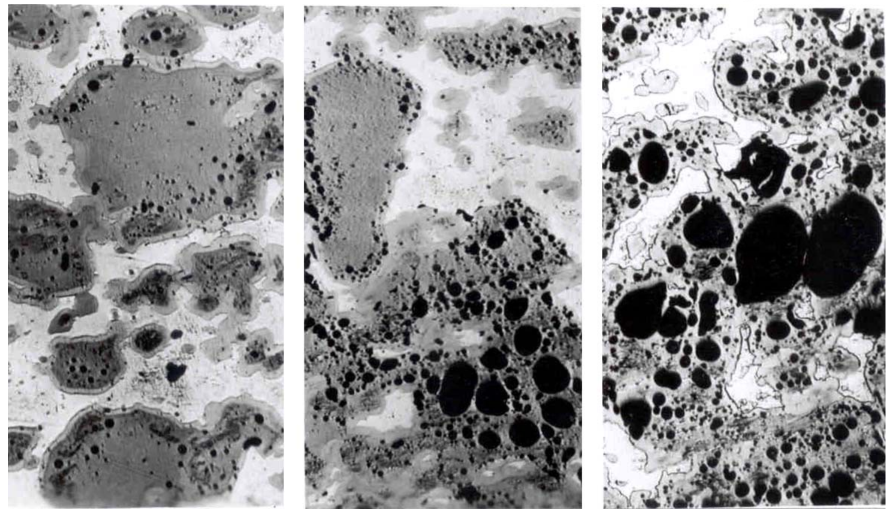
because of low viscosity in amorphous fuel



U_6Fe



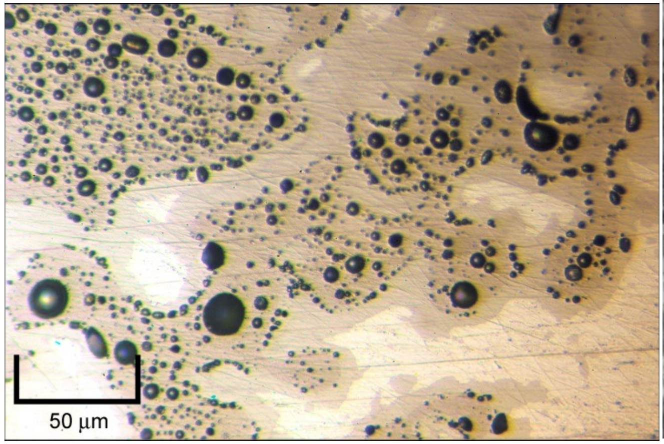


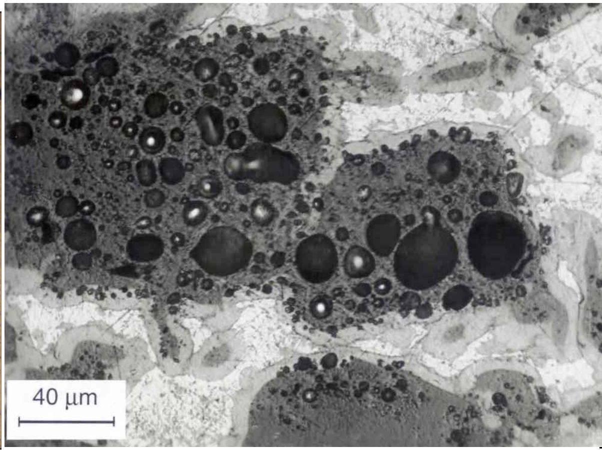


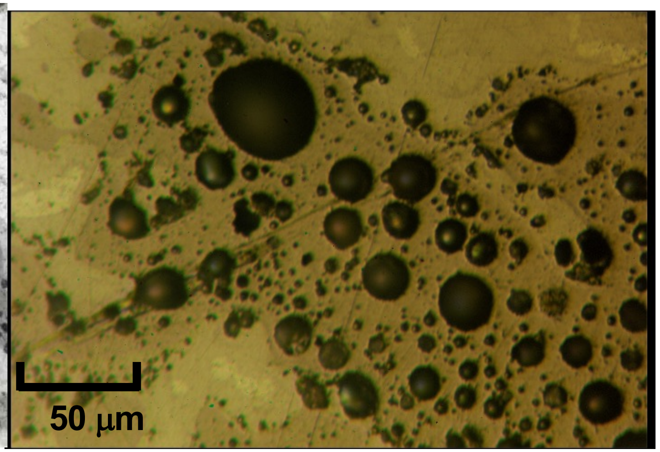
U_6Fe
Max Bu (40%)
4.5×10^{21} f/cm^3

U_3Si
Max Bu (85%)
5.3×10^{21} f/cm^3

U_3Si_2 fuel morphology comparison with U_3Si







U0R040 (U_3Si_2)
Hot side, (D,3)
FD=5.2x10^{21} f/cm^3
T=136°C
Bubble size = 20 µm

A105 (U_3Si)
U_3Si test in ORR
FD=5.3x10^{21} f/cm^3
T=100°C
Bubble size = 25 µm

U0R040 (U_3Si_2)
Additional section, (F,3)
FD=6.5x10^{21} f/cm^3
T=160°C
Bubble size = 38 µm

Fuel temperature and fission density appear to be the determining factors.

U_3Si_2 Fuel Performance

NUREG-1313

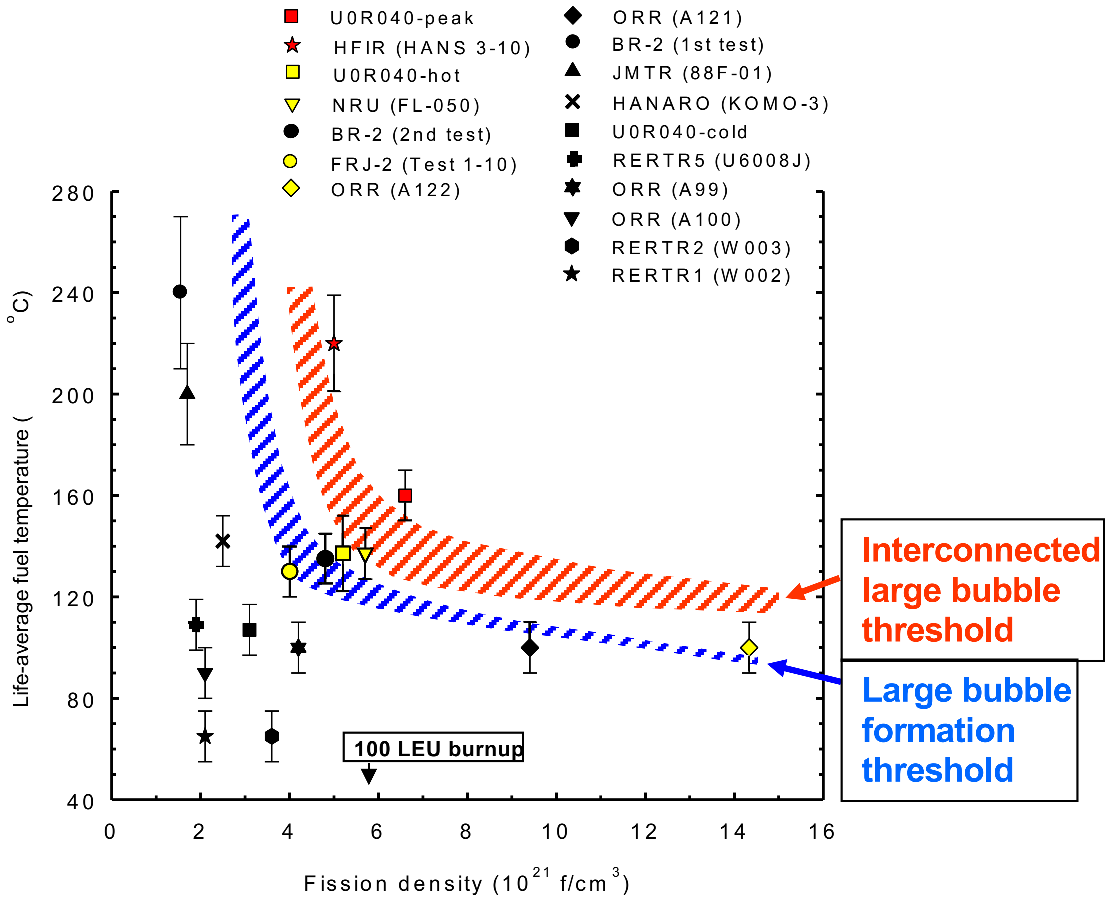
Ref. : Y.S. Kim, JNM 389(2009)443

U_3Si_2(4.8 g-U/cc) fuel was qualified and licensed at
- max. heat flux of 140 W/cm^2
- max. fuel temperature of 130^{o}C
- up to ~98% BU(~5.6 x 10^{21} fissions/cm^3)

Table. Life-average temperatures for formation of large bubbles and interconnected large bubbles for various fission densities in LEU U_3Si_2 fuel

Fission Density, 10^{21} x fiss/cm^3	Approximate LEU Burnup, %	Life-Average Temperature for Formation of	
		Large Bubbles, °C	Interconnected Large Bubbles, °C
2.5	50	>280	>280
3.1	60	180-270	>280
3.6	70	145-190	>280
3.9	75	130-170	>250
4.2	80	125-150	>200
4.6	85	120-140	170-240
4.9	90	120-135	150-205
5.8	100	115-125	135-165

Threshold curve



U_3Si_2/Al dispersion fuel enabled most low-to-intermediate power RR worldwide
However, this fuel is not applicable to HPRR

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U-Mo Fuel Development
For HPRR
(High Performance Research Reactor)

High-Density LEU-Mo Fuel Development

Two types of fuel plates under development (1996~)

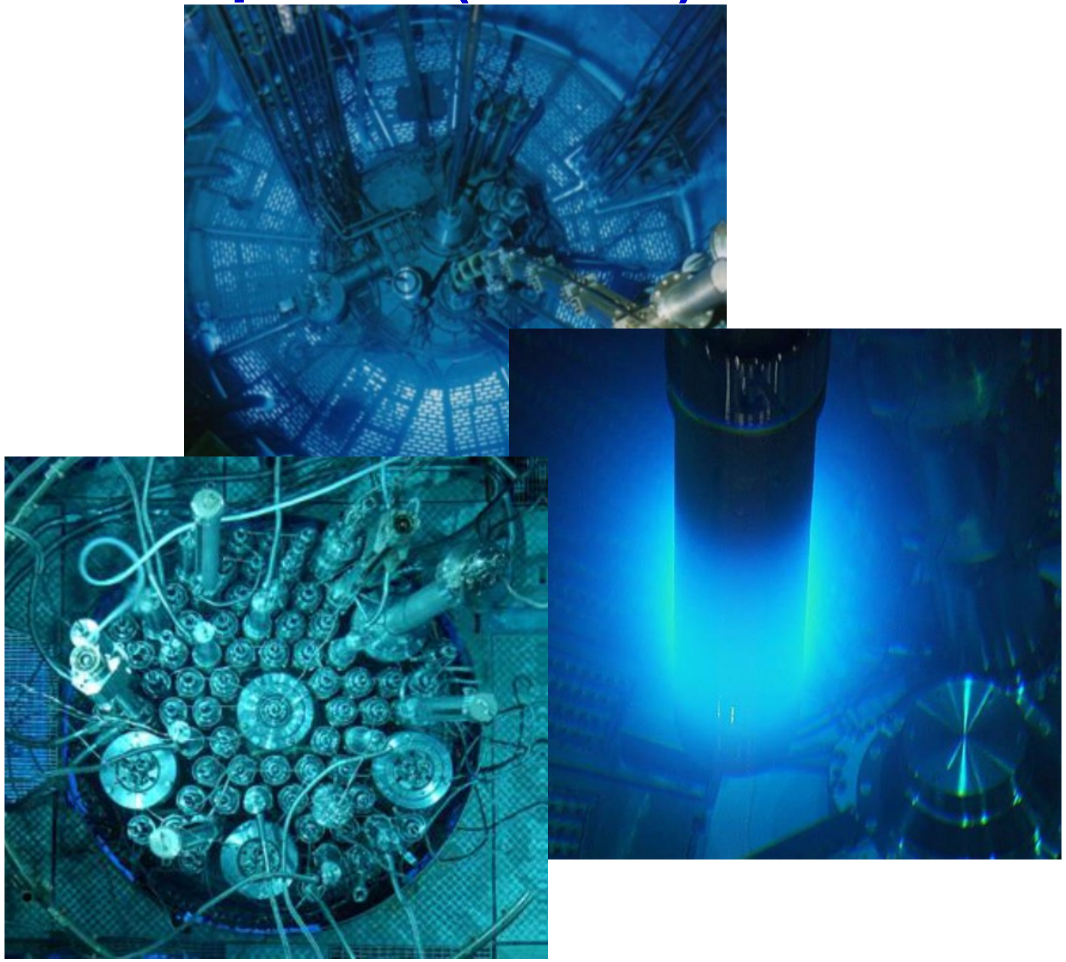
Goal is to convert

- ➢ **U-Mo dispersion fuel (8 g-U/cc)**

- BR2 (Belgium)
- RHF (France)
- JHR (France) – under construction
- Orphee (France)

- ➢ **U-Mo monolithic fuel (16 g-U/cc)**

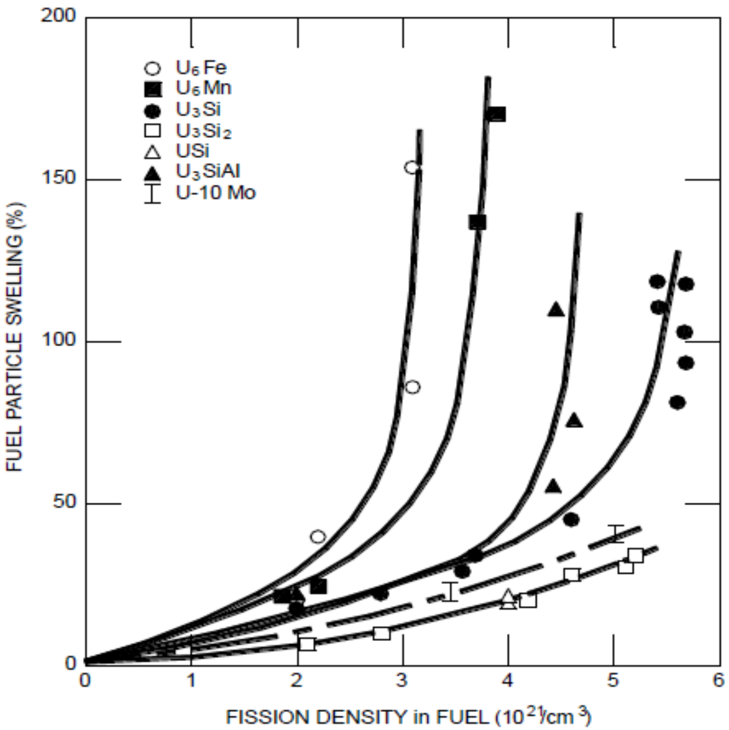
- FRM-II (Germany)
- US HPRR
  ATR, HFIR, MITR, MURR, NBSR

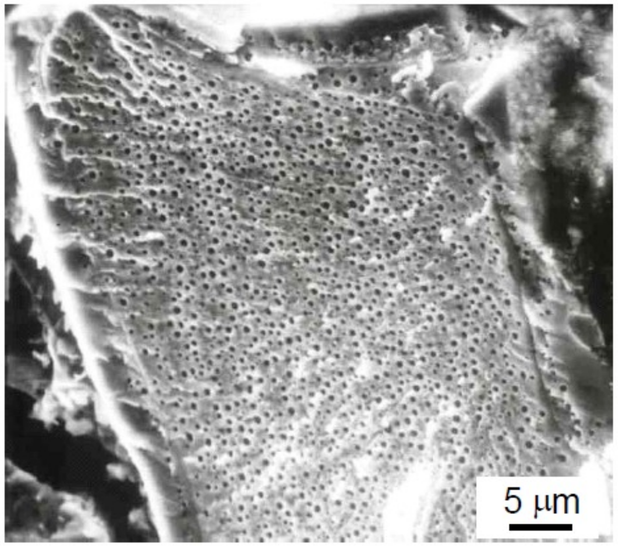


- All are High Flux Reactors
  - require very high density fuel systems able to withstand
    - ✓ High to very high heat flux (fission rate) ~470 W/cm^2
    - ✓ High burnup (fission density) ~80% BU
    - ✓ Very high coolant flows (potential for hydrodynamic challenges)

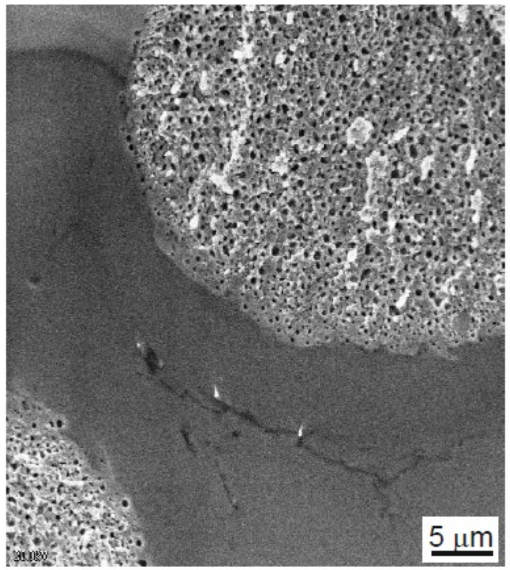
Intrinsic Nature of U-Mo Fuel

- **Excellent fuel performance**
  - **Stable and predictable swelling behavior (low T)**
  - **Similar to swelling of U_3Si_2**
  - **High uranium density**
  - **Studied as a candidate for fast reactor fuel (1950~1960)**





U_3Si_2
9.4×10^{21} f/cm^3



U-Mo
7.4×10^{21} f/cm^3

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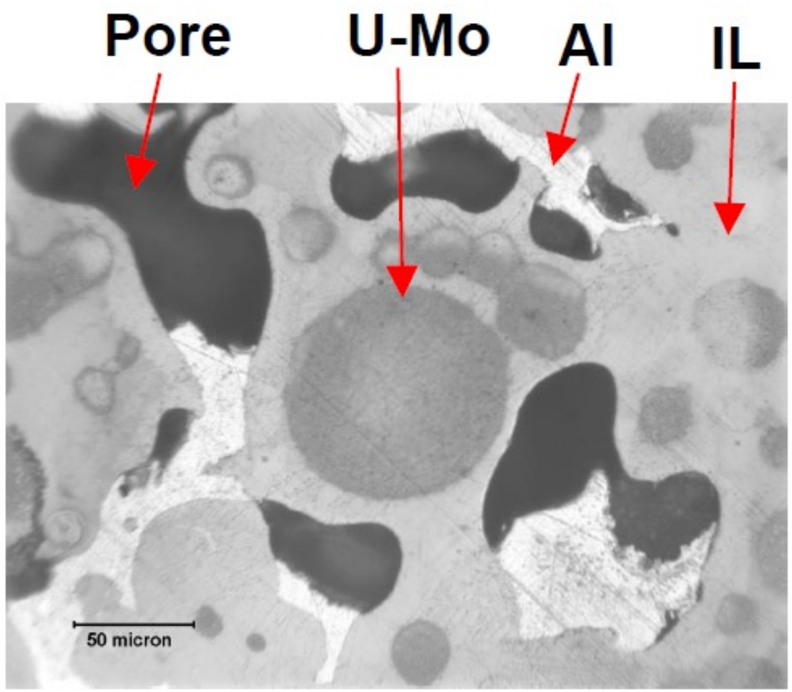
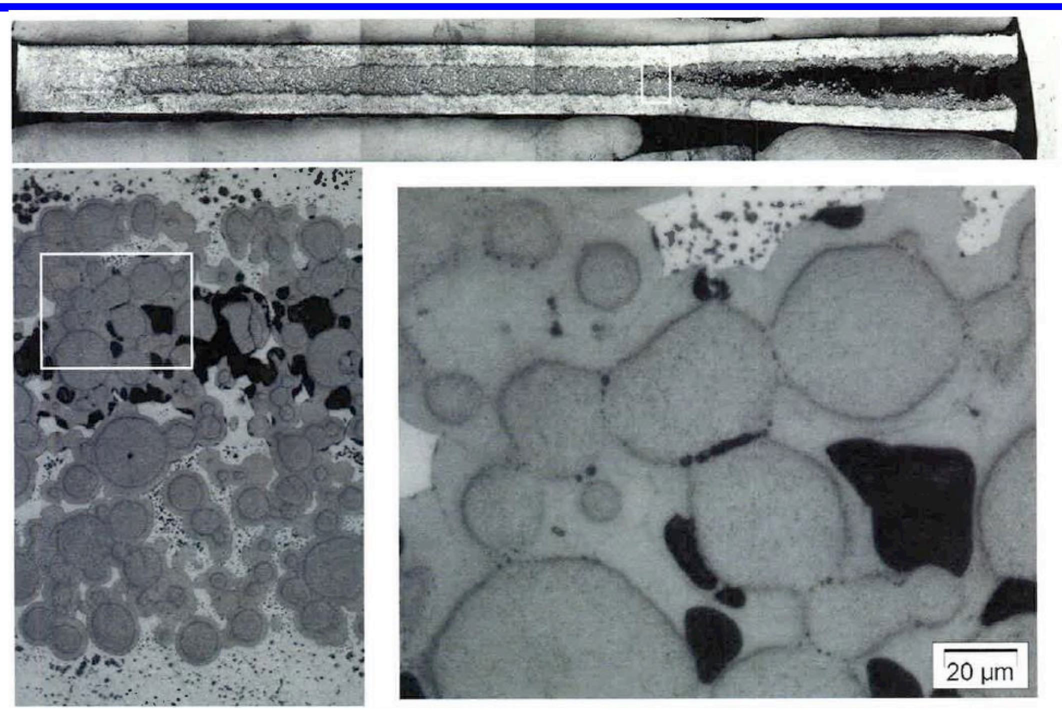
Porosity Problem with U-Mo/Al and Its Remedy



V6022M (RERTR-4)
U-Mo/Al 5.6×10^{21} f/cm^3(80% BU)
(Hofman and Kim, RERTR-2003)



U-Mo/Al failure by pillowing
IRIS-2 test result
(Huel, RRFM-2005)

however, the problem surfaced during 2002-2003
- at high T and high BU, U-Mo/Al fuel failed due to

- **excessive IL formation**
- **porosity formation in IL**

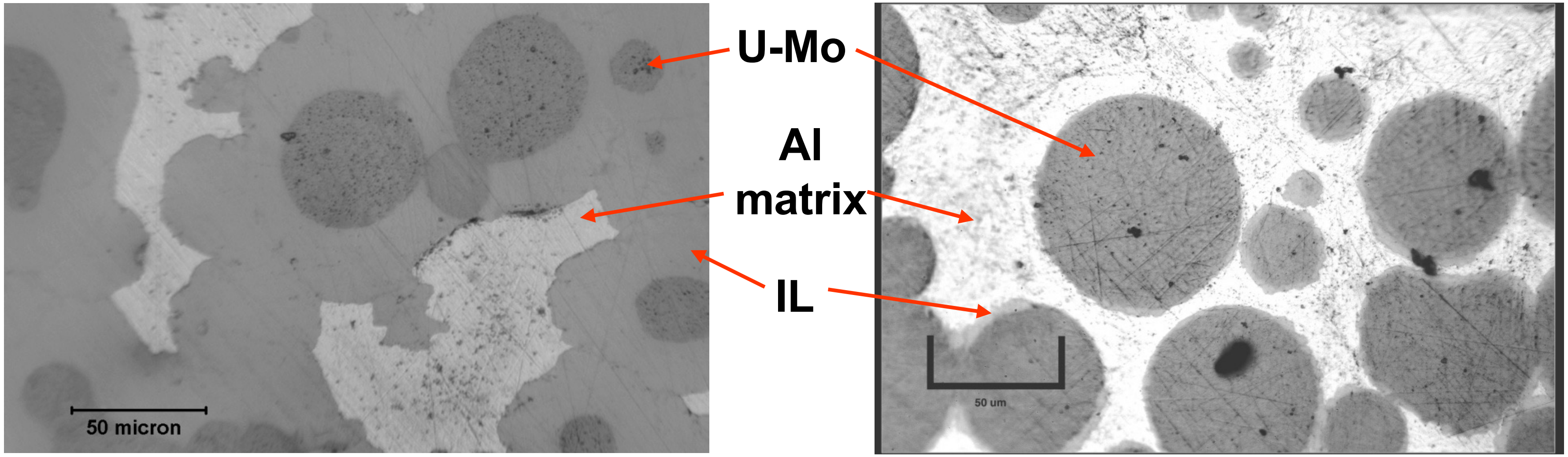
→ **Reduce IL growth**

Si addition to Al matrix-Remedy

Solution: Add 2-4 wt-% Si to Al matrix
(the U-Mo fuel particles are stable before and after silicon addition)

Before Si Addition

After Si Addition



Al matrix:

Large interaction layer (IL) weakens Al matrix, leading to potential fuel failure.

Al-2 wt% Si matrix:

Drastically suppresses interaction layer growth and stabilizes fuel plate.

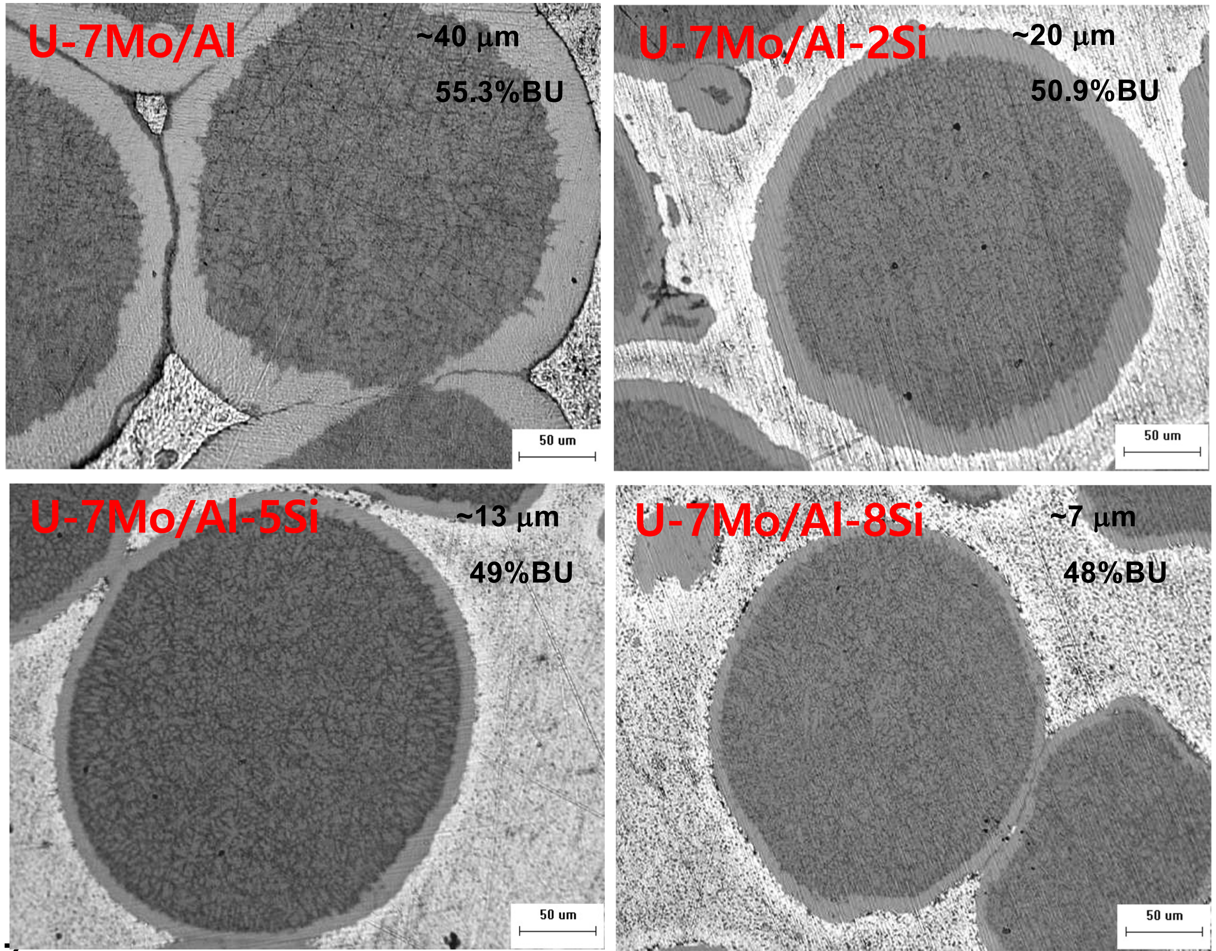
Si addition to Al matrix-Remedy

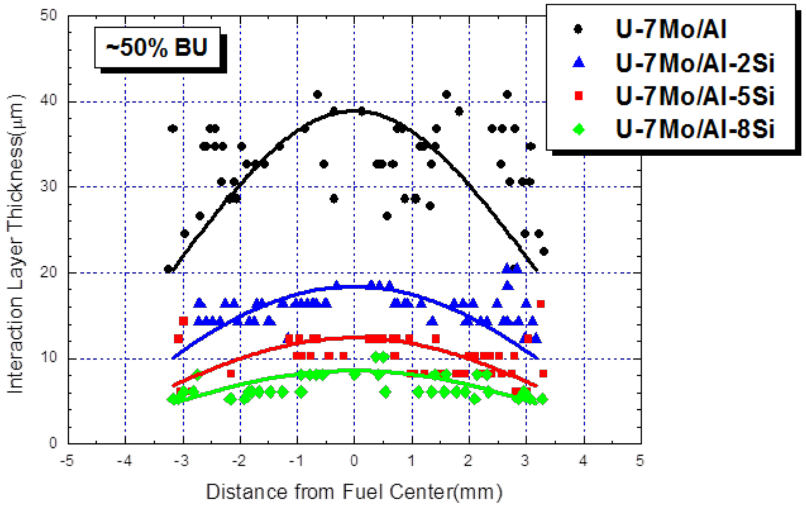
Find out the mechanism of Si effect on IL growth retardation

- **IL thickness in U-7Mo/Al-Si decreases progressively as Si content increases**

KOMO-4 Irr. Test (HANARO)   BOL : 105 kW/m, 200°C

J.M. Park, RERTR-2010





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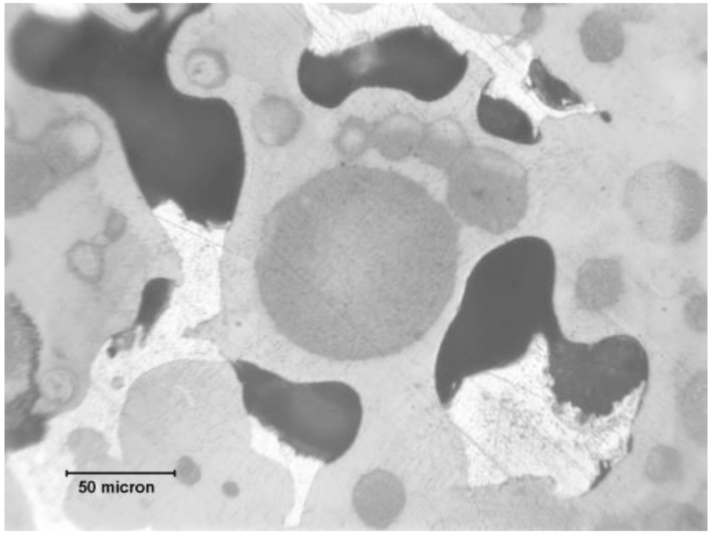
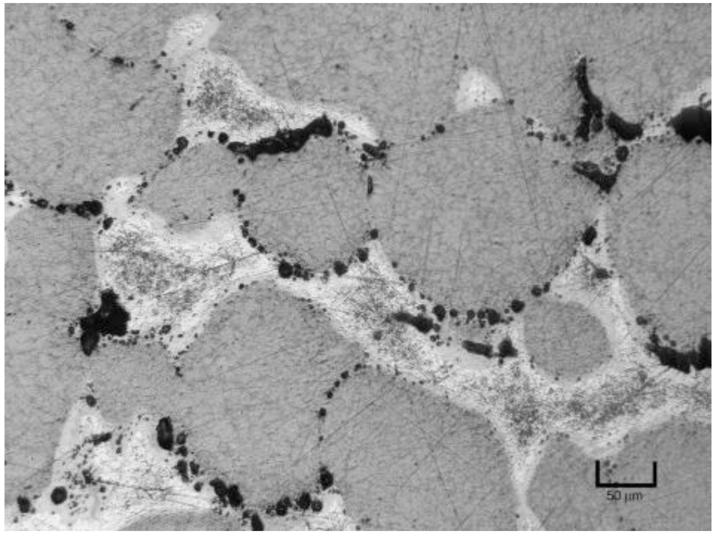
Si addition to Al matrix-Remedy

ATR mini-plate tests with q” < 350 W/cm^2



U-Mo/Al, Miniplate (80% BU)
2003 RERTR meeting
IL = 13 μm and massive pores



U-7Mo/Al-5Si, Miniplate (88% BU)
2007 RERTR meeting
IL = 4 μm and suppressed pores

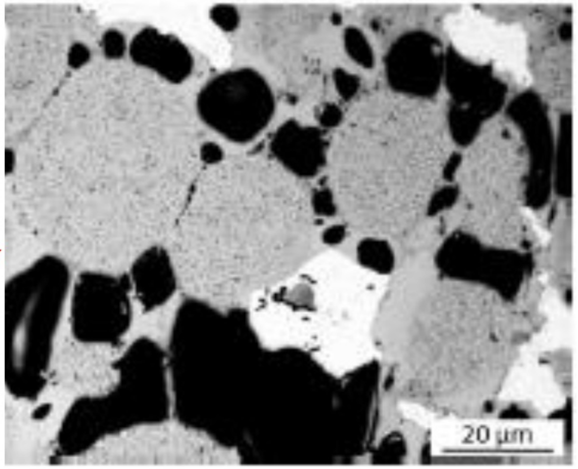
Si addition showed

encouraging results at medium power tests.

Si addition to Al matrix-Remedy

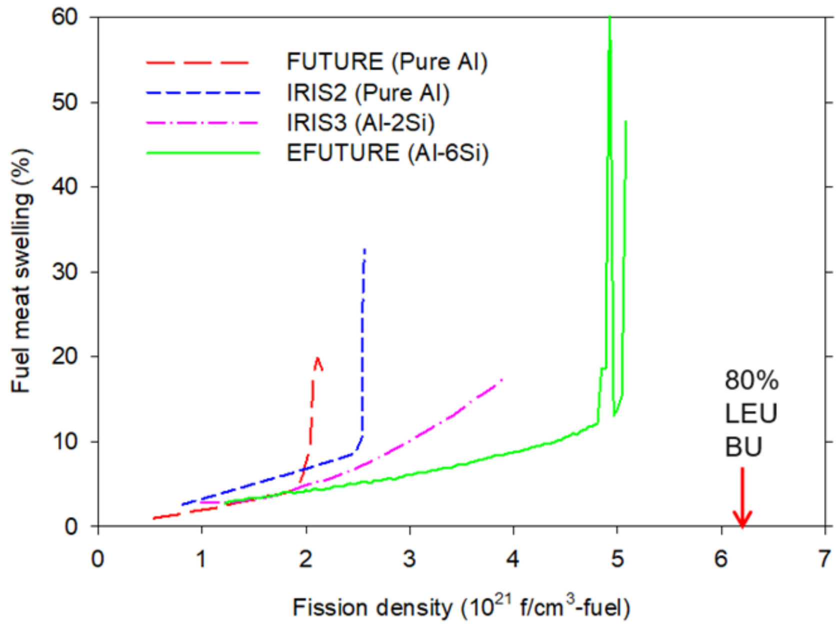
Si addition test in BR-2 with $q''_{max} = 470\ W/cm^2$

U-7Mo/Al-6Si



Full-size (E-FUTURE) (69% BU), 2011

Test	Reactor / Peak q"	Breakaway swelling (BS)	Cause for BS
FUTURE	BR2 / 340	Yes	Pores
IRIS2	OSIRIS / 240	Yes	Pores
IRIS3	OSIRIS / 200	No	
E-FUTURE	BR2 / 470	Yes	Pores



Note

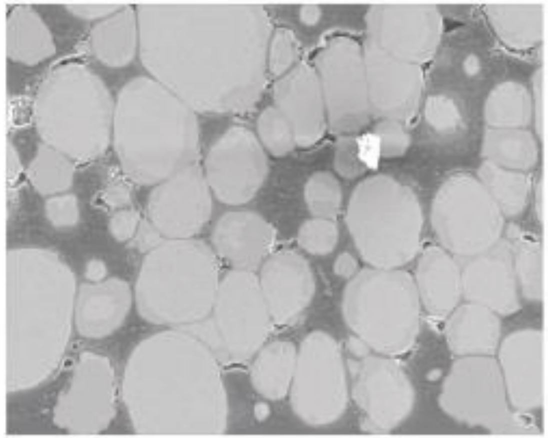
- Breakaway swelling occurred by big pores
- Si addition in Al matrix reduced IL growth, but appeared to be insufficient to reach 80% BU goal for EU HPRR conditions
- Coating on U-Mo particles was proposed at SCK-CEN

Coating on U-Mo particle-Remedy

SELENIUM irradiation test (q"max= 450 W/cm^2)

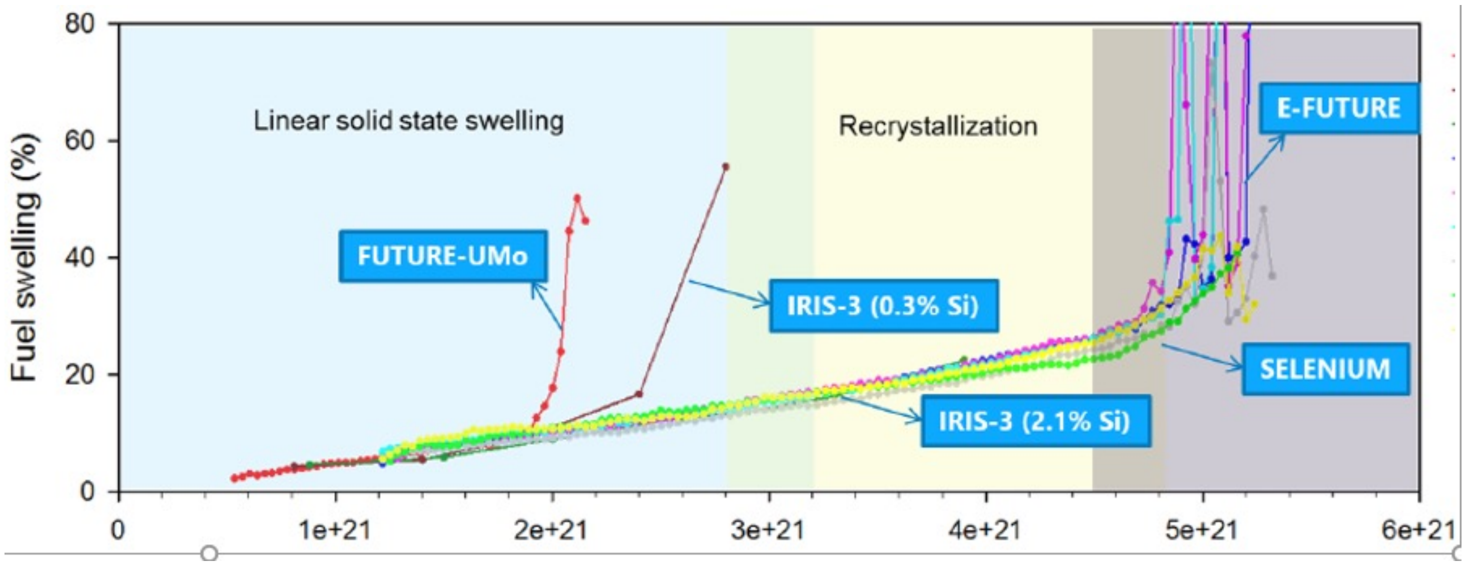
Si and ZrN coating(PVD) on U-Mo particle

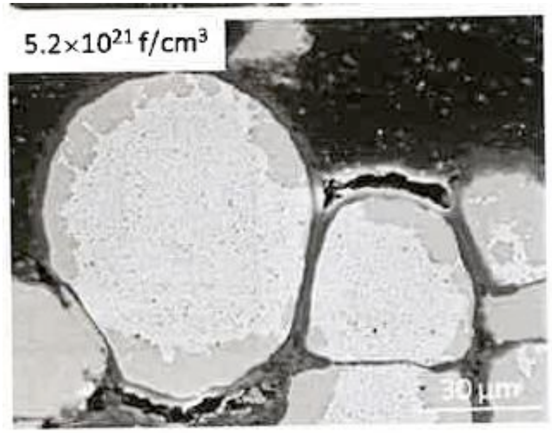
Van den Berghe, JNM, 2013.



showed promising performance to ~70% BU.

- No pillowing
- Indication of the initial stage of breakaway swelling at EOL problem
- Needs to demonstrate sound performance to BU of ~80%.



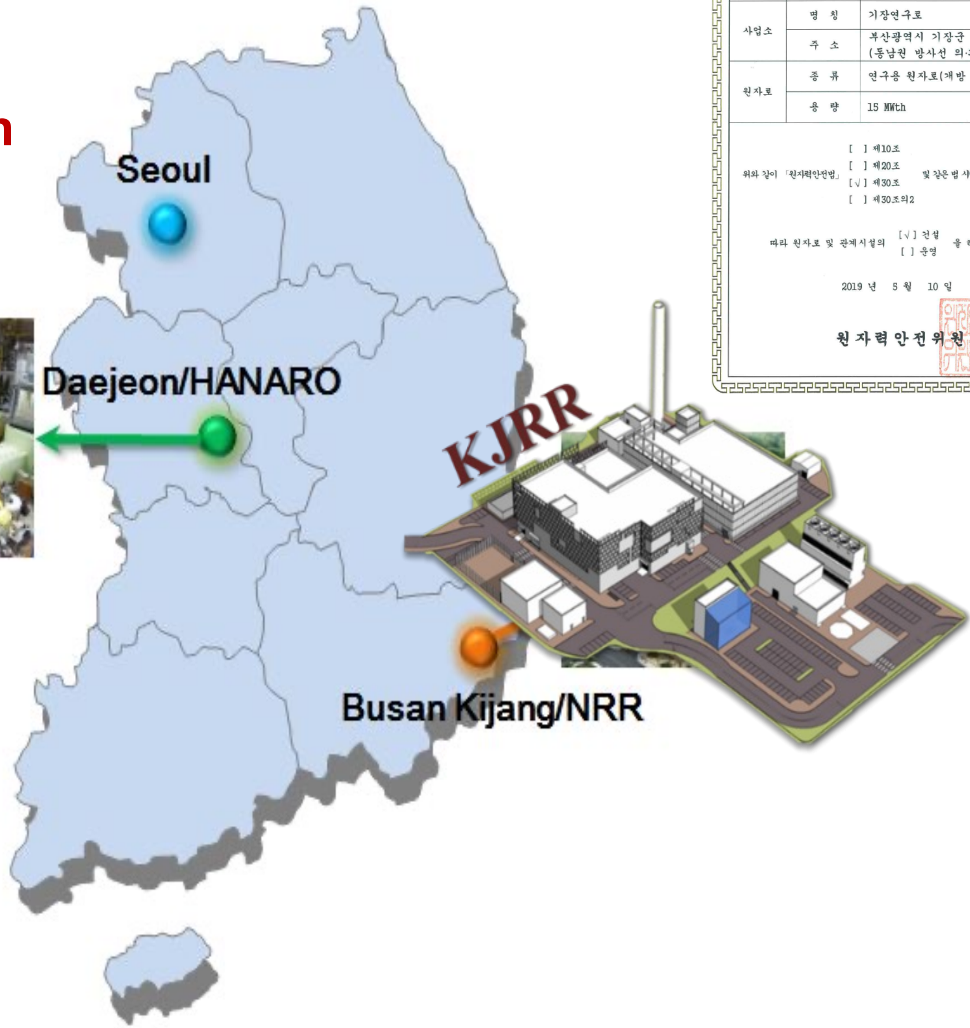


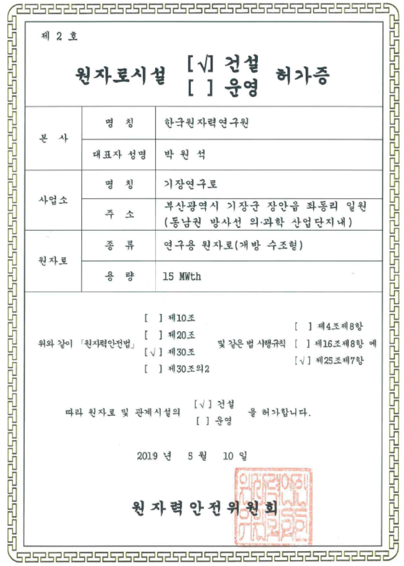
ZrN-coated-U-7Mo/Al, Full-size (q"max= 450 W/cm^2 at 70% BU)

Kijang Research Reactor(KJRR) Project

New Research Reactor Project in Korea

- **Purposes**
  - **- Medical and Industrial RI Production (Mo-99 & RI)**
  - **- Neutron Irradiation Service**





제 2 호

원자로시설 [√] 건설 [ ] 운영 허가증

본 사	명 칭	한국원자력연구원
	대표자 성명	박 원 석
사업소	명 칭	기장연구로
	주 소	부산광역시 기장군 장안읍 좌동리 일원 (동남권 방사선 의·과학 산업단지내)
원자로	종 류	연구용 원자로(개방 수조형)
	용 량	15 MWth

위와 같이 「원자력안전법」 [ ] 제10조 [ ] 제20조 [√] 제30조 [ ] 제30조의2 및 같은 법 시행규칙 [ ] 제4조제8항 [ ] 제16조제8항 [√] 제25조제7항 에 따라 원자로 및 관계시설의 [√] 건설 [ ] 운영 을 허가합니다.

2019 년 5 월 10 일

원 자 력 안 전 위 원 회

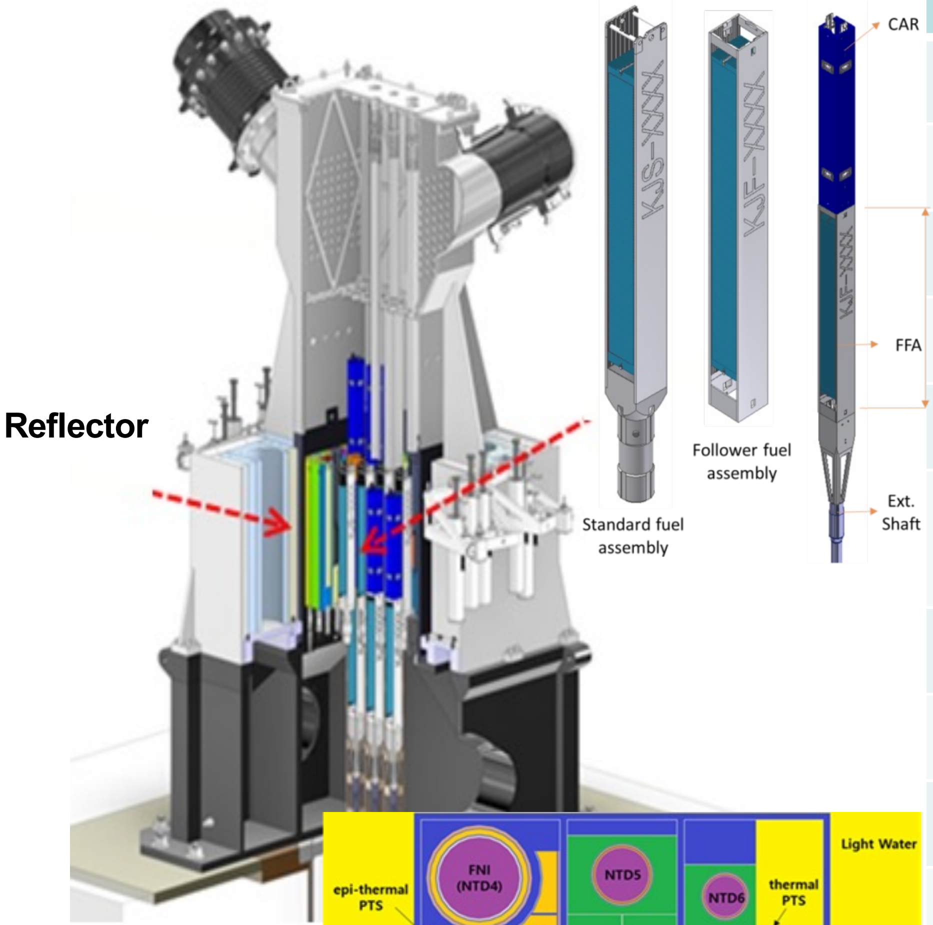
- Launched in 2012

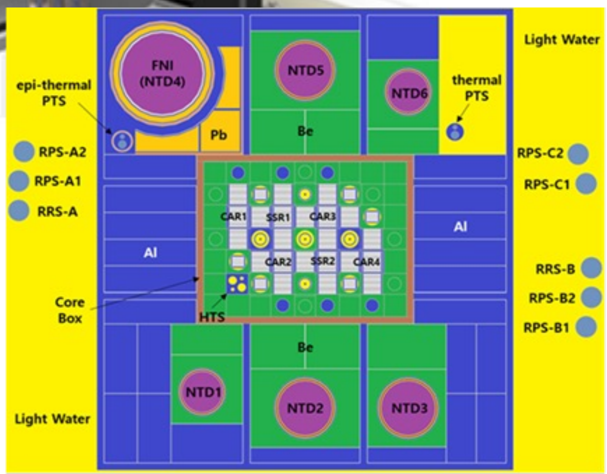
- Location: Kijang, Busan

- <u>Construction Permit : May 10, 2019</u>

- Aiming at 1st Criticality: Dec. 2027

KJRR Specification

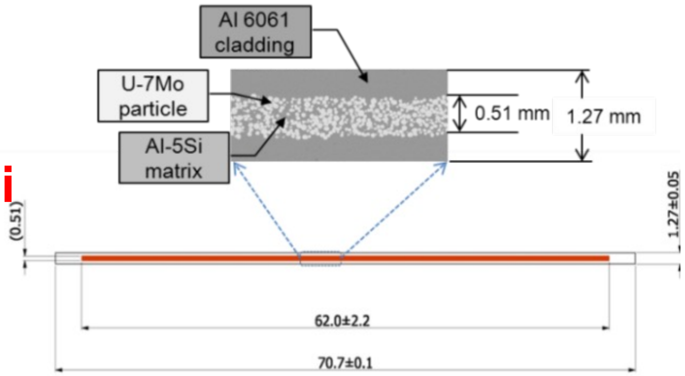


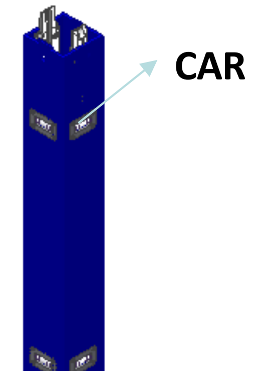


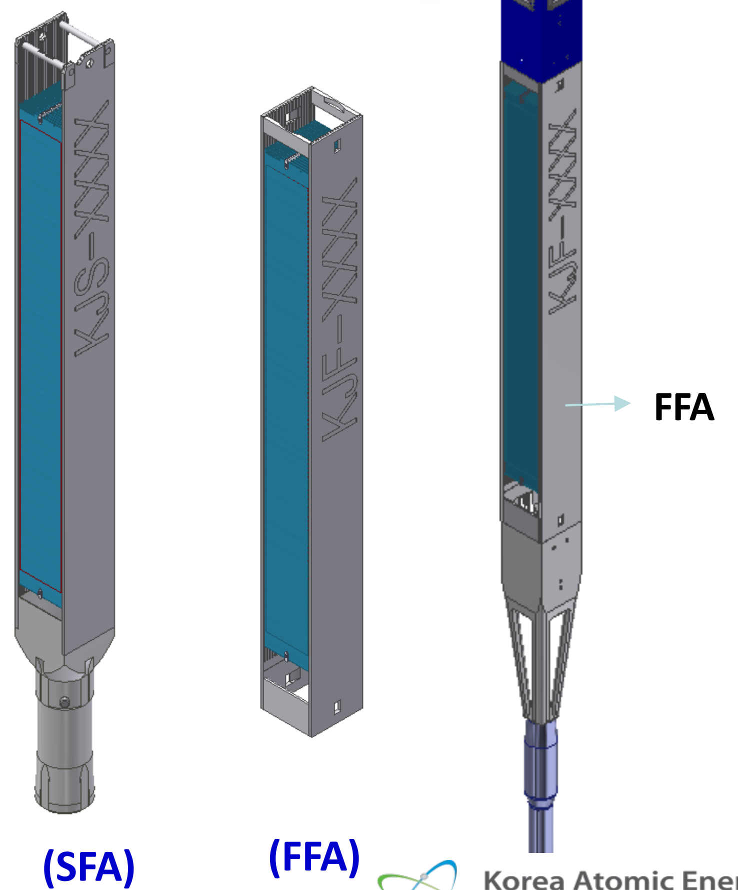
Parameter	Specification
Reactor Type	Open-tank-in-pool
Power	15 MW_{th}
Max. thermal flux	>3.0 x 10^{14} $n/cm^2.s$
Life time(year)	50
Operation day/yr	~300
Fuel Assembly	U-Mo dispersion, plate type Standard FA(16), Follower FA(6)
Coolant	H_2O
Moderator	H_2O
Reflector	Be, Al
Absorber	Hafnium
Coolant Condition	- pH : 5.5~ 6.2 - Inlet temp. : 35 °C - Flow velocity : 6 m/sec in FAs - Flow direction : Downward

U-Mo Fuel for KJRR

- **Fuel (Fuel Meat & Fuel Plate)**
  - ✓ LEU : 19.75±0.2 wt% U^{235}
  - ✓ Meat : **U-7wt%Mo dispersed in Al-5wt%Si**
  - ✓ Cladding : Al-6061
  - ✓ Meat (mm) : 62.0 x 600 x 0.51
  - ✓ Plate (mm) : 70.7 x 640 x 1.27
- **Uranium Density in Fuel Meat**
  - ✓ Inner(17)/outer(4) fuel plate : 8.0/6.5 g-U/cm^3
  - ✓ Initial core : LDU 5.0/4.0/3.5/3.0/2.2 g-U/cm^3
- **U-235 mass**
  - ✓ FA : ~ 607 g
- **FA dimension**
  - ✓ SFA (mm) : 76.2 x 76.2 x 1010
  - ✓ FFA (mm) : 76.2 x 76.2 x 760.5
  - ✓ Material of components : Al-6061 T6
- **Heat flux(nom./max.) : 41.5 / 110 W/cm^2**
- **Burnup (FA average/Local Peak) :**
  ~58 % / ~ 80 at.% U-235 depletion







Korea Atomic Energy Research Institute

Plate Fuel/FM Target Fabrication Facility

➢ **Plate Fuel Fabrication Infrastructure**

- Purpose: Supply U-Mo plate fuel / FM target to KJRR
- Period : 2011 ~ 2013 (3 years)

➢ **Facility Installation**

- Location : Room # 230~232 in RR fuel fabrication building
- Period :
  - · Plate fabrication facility : 2011.01 ~ 2012.12
  - · Inspection facility : 2012.01 ~ 2013.06
  - · Fuel assembly facility : 2013.01 ~2013.12

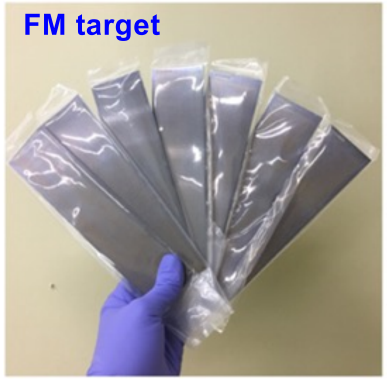
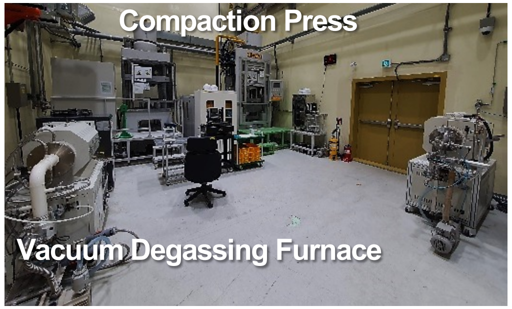
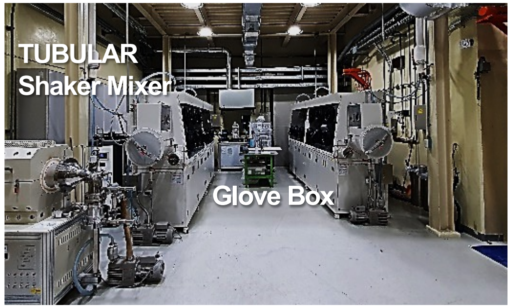


Plate Fuel/Target Fabrication Facility

- **KAERI's fuel fabrication system: Fuel Plate Fabrication, Assembly Fabrication, Inspection**
- **Fabrication Capability: 100 FAs/yr (> 2,000 Plates/year) and 4,000 FM Targets/year**





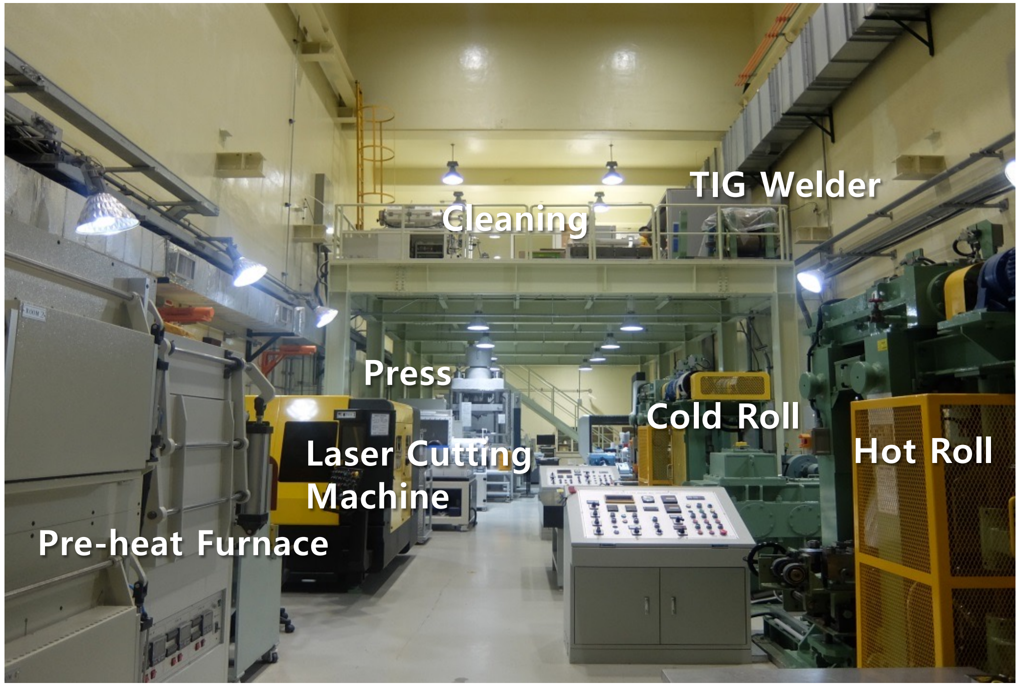
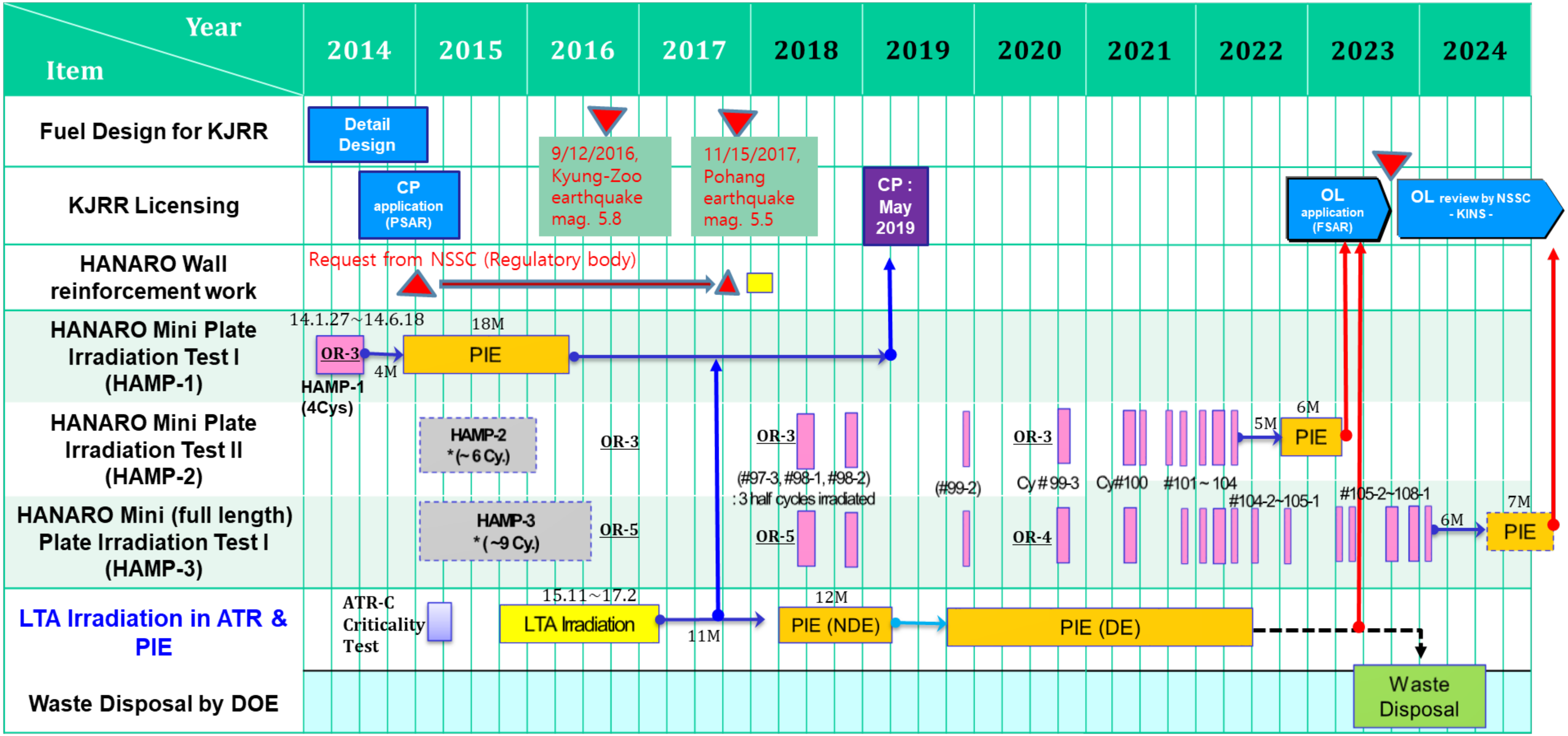


Plate Fuel/FM Target Fabrication Facility in KAER

Use	Process	Equipment
Plate Fab.	Powder heat treatment	• 2 Vacuum degassing furnace (10^{-7} torr)
	Mixing	• TUBULAR shaker mixer (three dimensional movement) • Glove Box
	Compaction	• 300 ton Press (2 set)
	Etching & Cleaning	• Cleaning room with scrubbing system
	Welding	• TIG welder
	Hot rolling	• Pre-heat furnace • Hot roller (dia. 400mm)
	Cold rolling	• Cold roller (dia. 380mm) • Leveler
	Machining	• Laser cutting machine, CNC milling machine
	Etc.	• Shearing machine, Laser ID marking
Assembly Fab.	Swaging	• Swaging machine
	Welding	• Electron Beam (EB) welder
	Machining	• Machining center(MCT)
Inspection	Inspection	• 2 X-rays (CT & location, homogeneity, stray particle) • UT • 3-dimensional measuring system • Gap spacing measuring system • MTS for tensile test of swaged side plates

Schedule of U-Mo Fuel Irradiation Tests

As of August, 2024



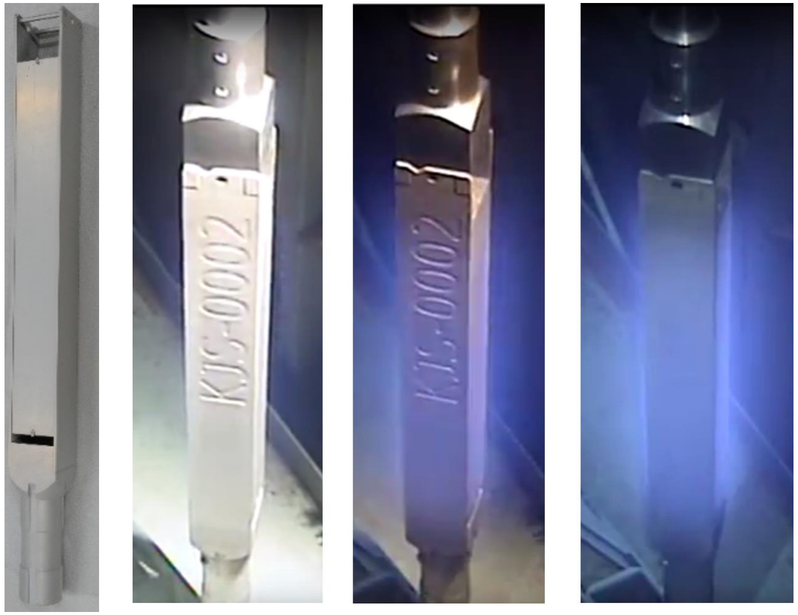
Korea Atomic Energy Research Institute

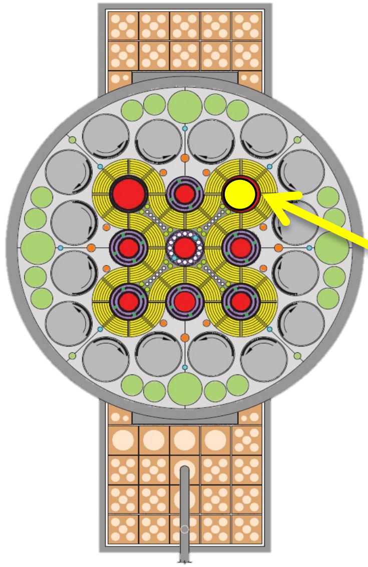
Qualification Test Condition Summary

Parameters	FA irradiation (KJRR-LTA)	HAMP-1 and 2	HAMP-3
U-235 enrichment	19.75 ± 0.2 %		
Number of plates	19 (8.0 g-U/cm³) 2 (6.5 g-U/cm³)	10 (8.0 g-U/cm³) 2 (6.5 g-U/cm³)	4 (8.0 g-U/cm³)
Fuel meat dimension (mm)	0.51±0.03 (T) 62±1.8 (W) 600±5 (L)	0.51±0.03 (T) 25±1.8 (W) 70±5 (L)	0.51±0.03 (T) 25±1.8 (W) 600±5 (L)
Fuel plate dimension (mm)	1.27±0.05 (T) 70.7±0.2 (W) 640±0.5 (L)	1.27±0.05 (T) 35±0.2 (W) 130±0.5 (L)	1.27±0.05 (T) 35±0.2 (W) 640±0.5 (L)
Achieved/Target BU (U^{235} depletion %)	70.8 % (FA Avg.) 83.1 % (Local Peak)	HAMP-1: Avg. 61%/ peak 66% HAMP-2: Avg. 64%/ peak 66 %	80.9 % (Plate Avg.) 90 % (Local Peak)
Average heat flux at BOC (W/cm²)	126	~ 225 (HAMP-1) ~ 184 (HAMP-2)	170
Peak heat flux at BOC (W/cm²)	182	~ 257 (HAMP-1) ~ 205 (HAMP-2)	240

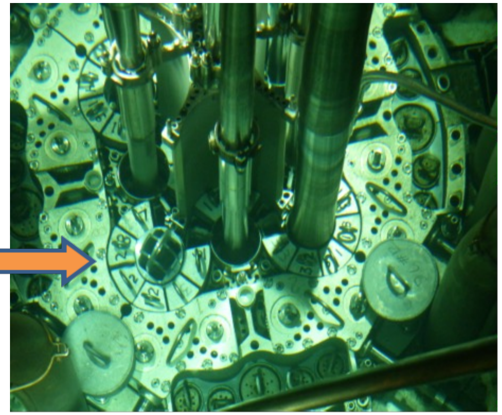
KJRR-LTA Irradiation Test (CRADA with DOE)

KJRR Lead Test Assembly (KJS-0002) :
Before and After irradiation test in the ATR core





Advanced Test Reactor



ATR Core

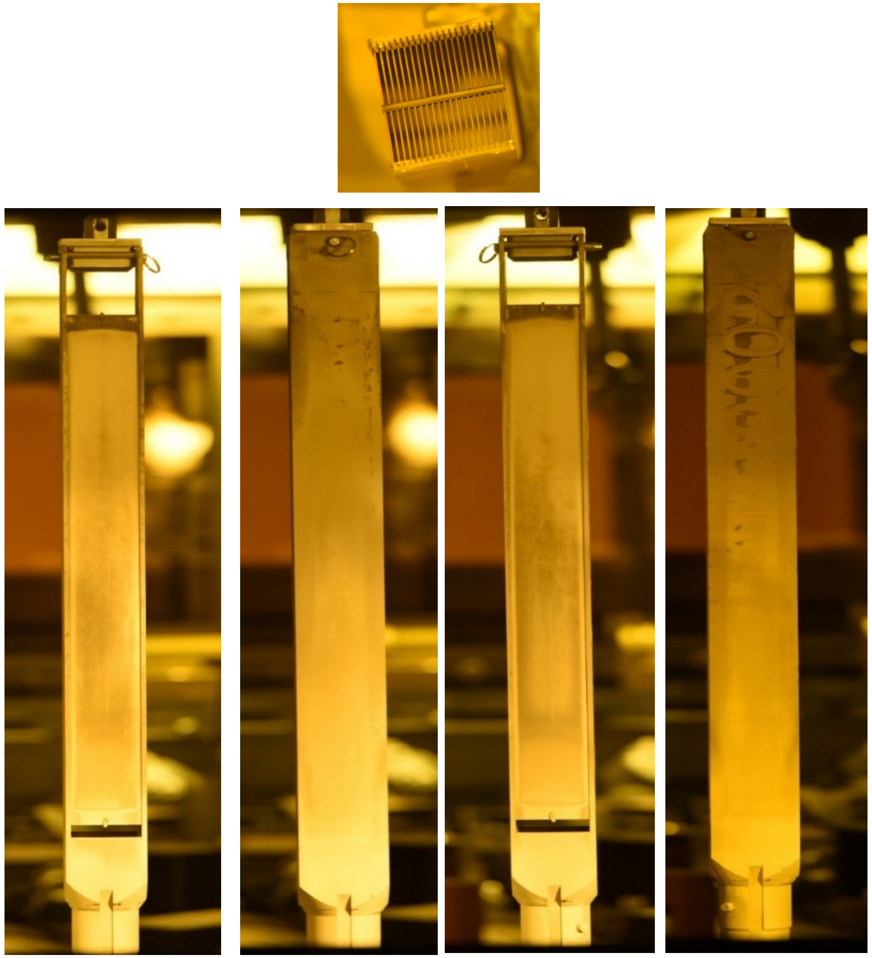
After final cycle (ATR 160B Cycle)

Irradiation Test	2015.10.26 – 2017.02.23
Achieved Burnup (FA Average)	70 at% U-235 Depletion
Achieved Burnup (Local Peak)	83.1 at% U-235 Depletion
Peak Heat Flux (W/cm^2)	182
Effective Full Power Day (EFPD)	216.6
PIE	NDE : 2018.2 ~ 2019.9 DE : 2019.10 ~ 2022.4

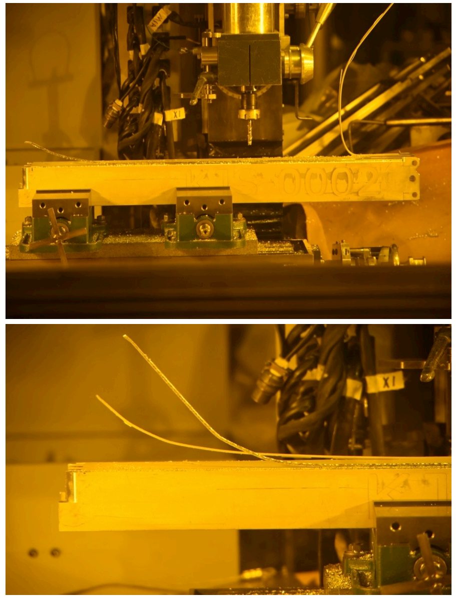
Non-Destructive PIE of KJRR-LTA

* Inner cask (insert) with the fuel assembly removed from the outer cask

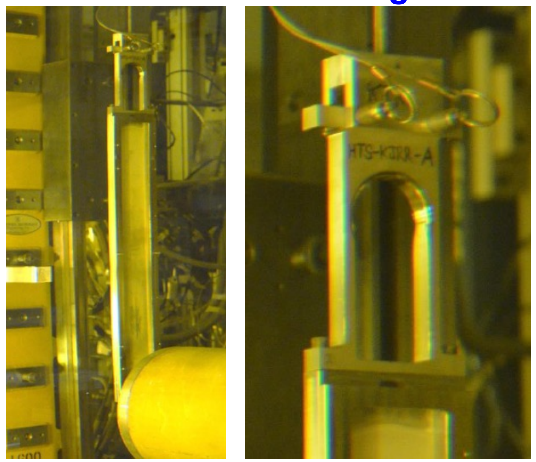
* Fuel Assembly Visual Examinations



* Disassembly



* Gamma Scanning



Plate/Oxide thickness was evaluated by profilometry and ECT measurement using the BONA4INL bench station

Optical Microstructure

KJS00050 (#20 plate) U-7Mo/Al-5Si 8 gU/cc with highest BU (83.1%)

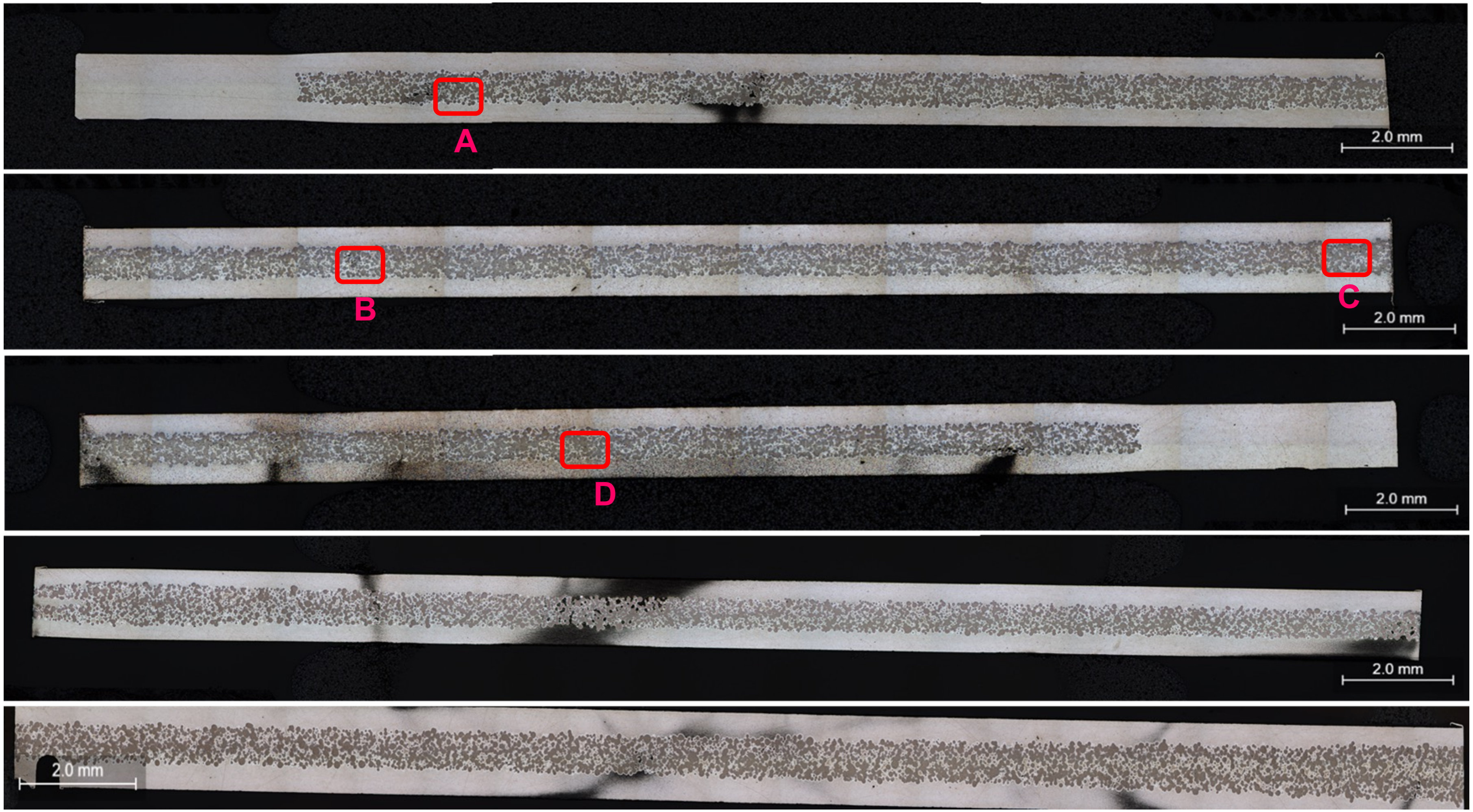
Left
(BU 82.7-80.2%)

Middle
(BU 80.2-80.4%)

Right
(BU 80.4-83.1%)

Top
(BU 72.9-74.7%)

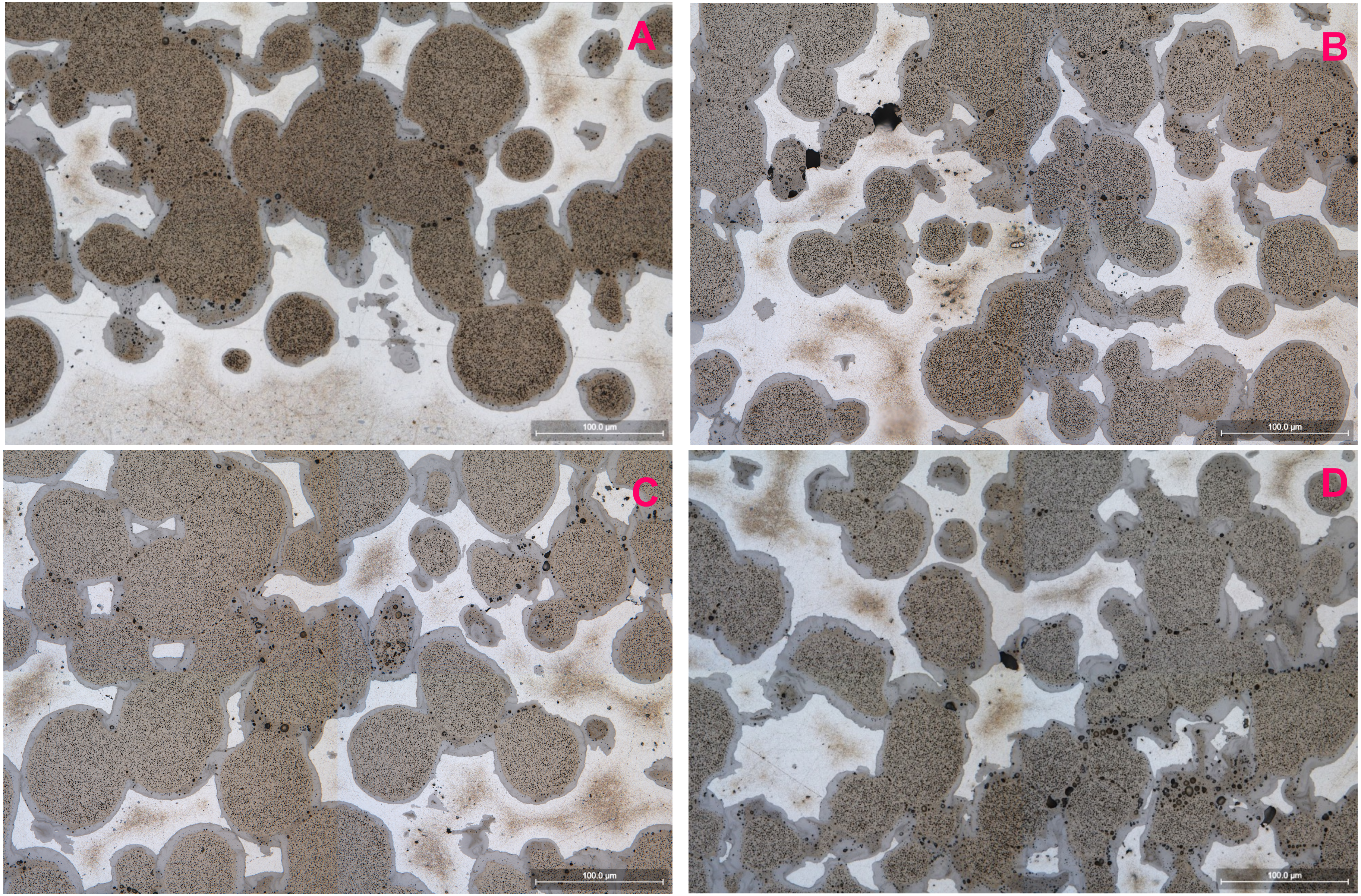
Bottom
(BU 75.7-74.5%)



KJS00050 (#20 plate) U-7Mo/Al-5Si 8 gU/cc with highest BU

BU 82.7%

BU 80.2%



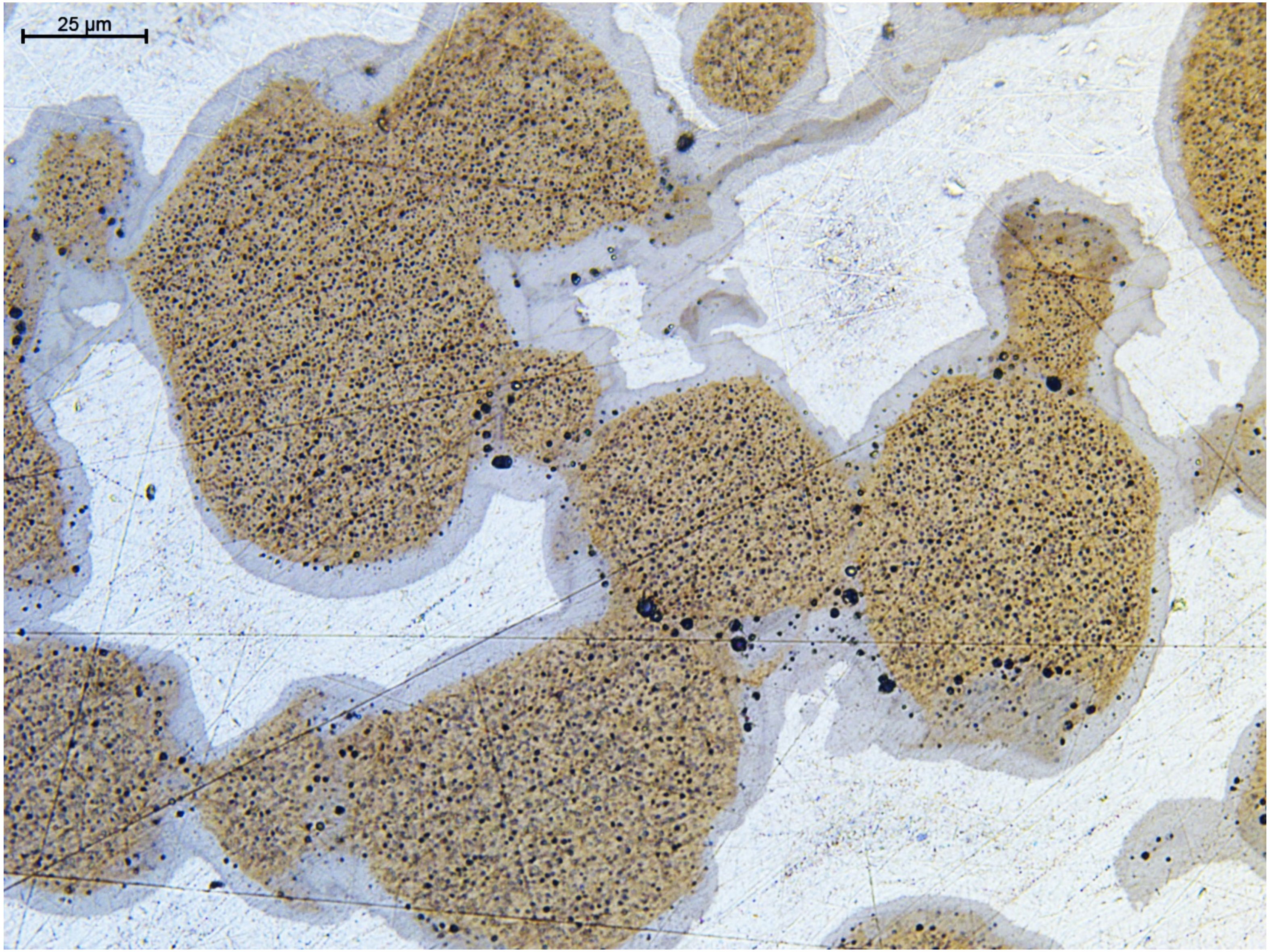
BU 80.4%

BU 83.1%

KJS00050 (#20 plate) U-7Mo/Al-5Si 8 gU/cc with highest BU

- Very homogeneous and fine irr. bubbles(< 5μm)
- Enough to prove sound performance of KJRR fuel even at higher BU (>80 at%U-235)

BU 83.1%

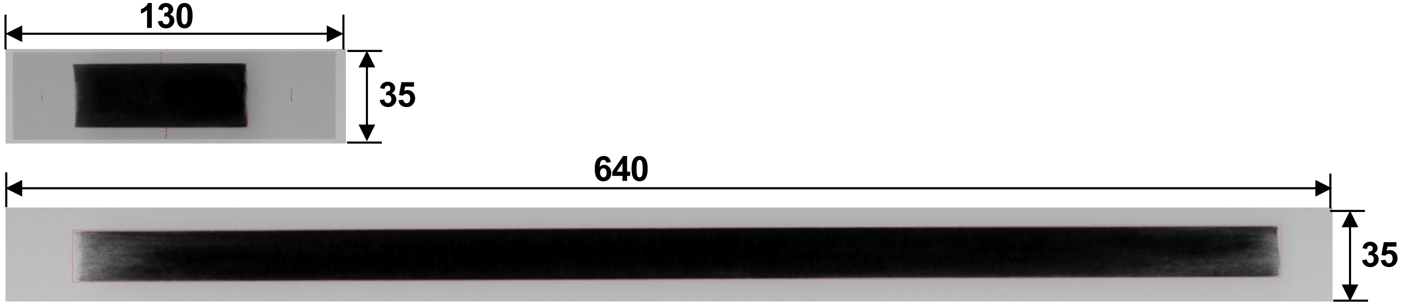


Fuel Qualification : HAMP-1,2 & HAMP-3

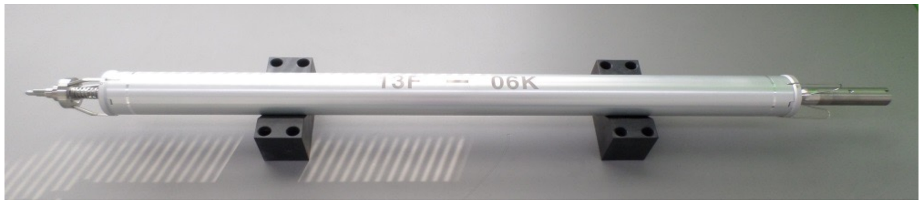
- Size of HAMP-1,2 and -3 plates

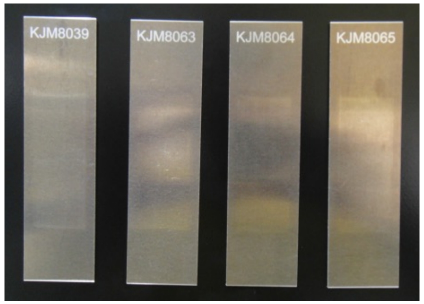
HAMP-1, 2

HAMP-3

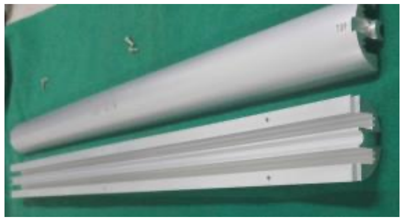


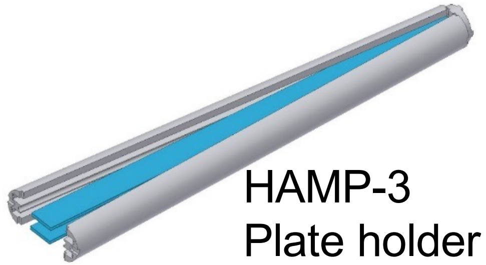
- HAMP-1,2 plates & capsule





- HAMP-3 plates & capsule



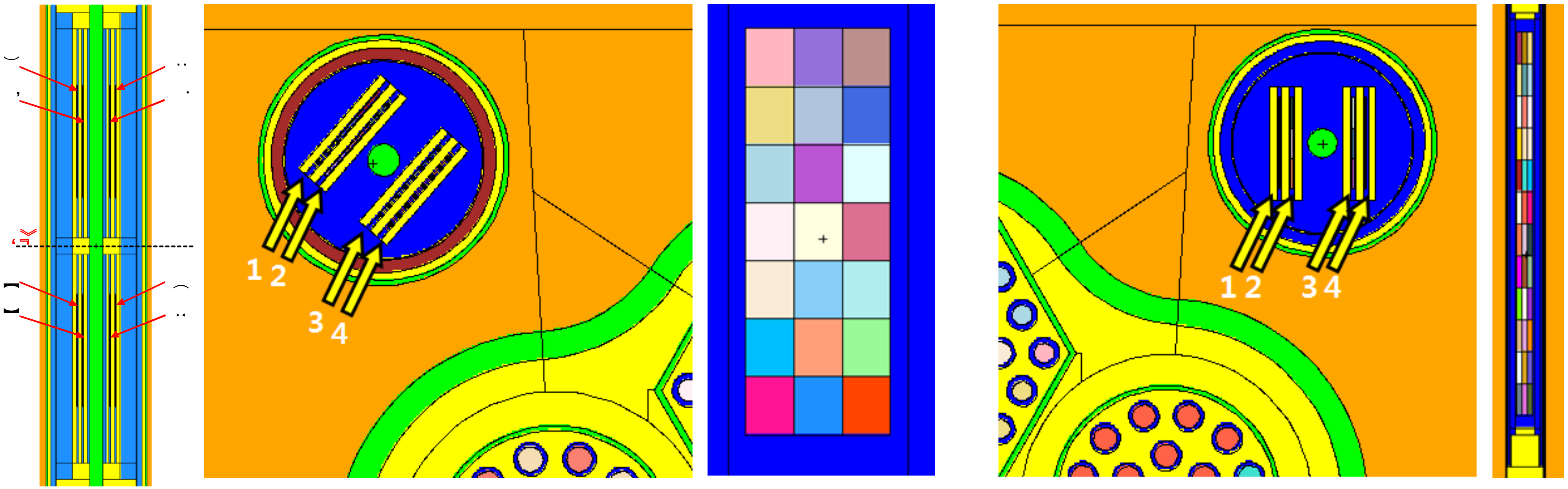


HAMP-3
Plate holder

HAMP-2 & HAMP-3 : As-run analysis (1/2)

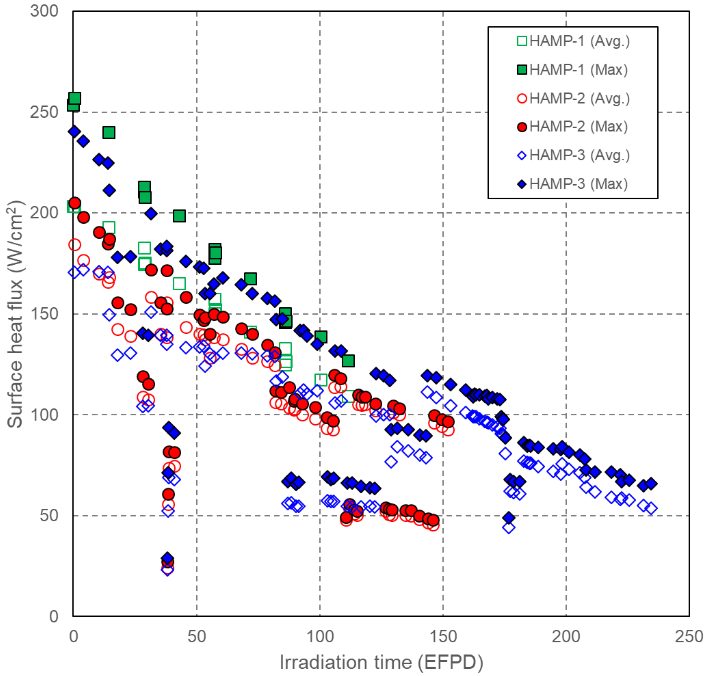
- **HAMP-1,2 (in OR-3)**
  - 8 U-Mo mini-plates (HAMP-1)
  - 4 U-Mo mini-plates and 4 others(coated U-Mo/U_3Si_2)(HAMP-2)

- **HAMP-3 (in OR-5)**
  - 4 U-Mo mini-plates
    (full length & half width)

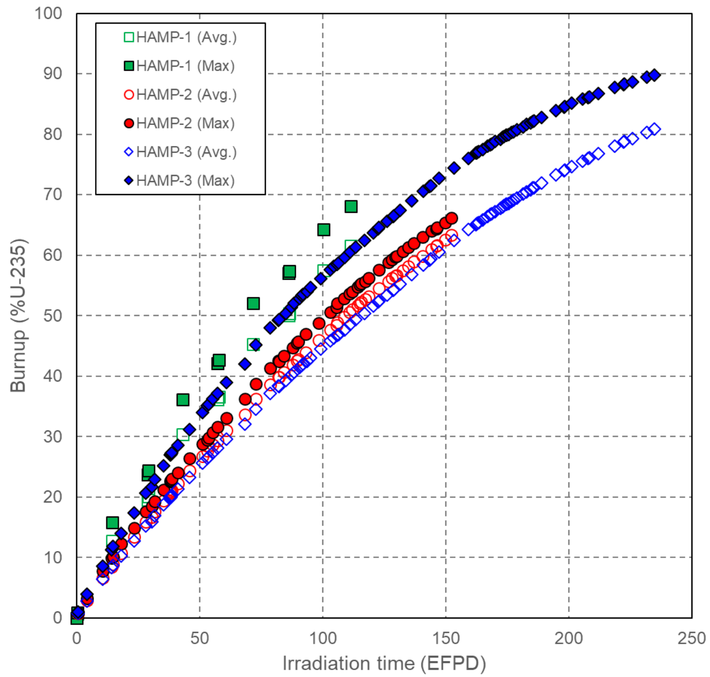


- **HAMP-1 irr. test has been completed during the cycles #92~#95 (111.4 EFPDs) (2014.01.27 ~ 2014.06.18)**
- **HAMP-2 irr. test has been completed during the cycles #97-3 ~ #105-1 (152 EFPDs) (2018.06.10 ~ 2022.04.25)**
- **HAMP-3 irradiation test has been completed up to cycle #97-3 ~ #108-1 (234.7 EFPDs) (2018.06.10 ~ 2024.02.06).**
- **HAMP-1, 2 and 3 irradiation tests were successfully finished without any abnormality. Throughout the cycles, any fission products releases were not detected in the HANARO**

HAMP-1,2 & -3 : As-run analysis (2/2)



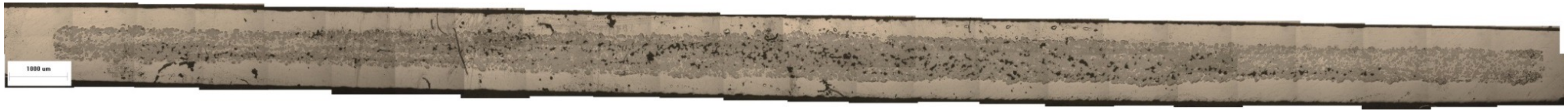
(Peak and Average) Heat flux of the mini-plates of HAMP-1,2 and HAMP-3

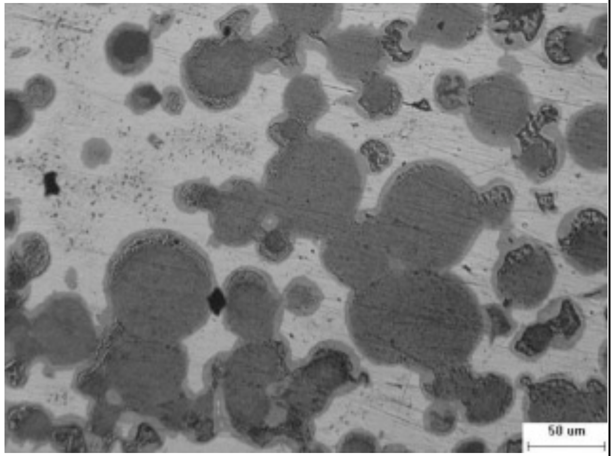
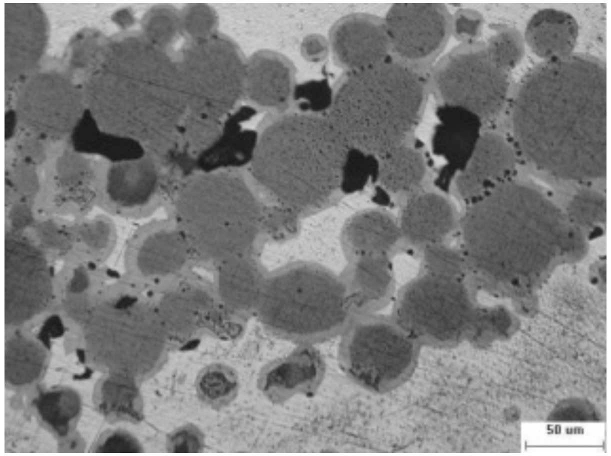
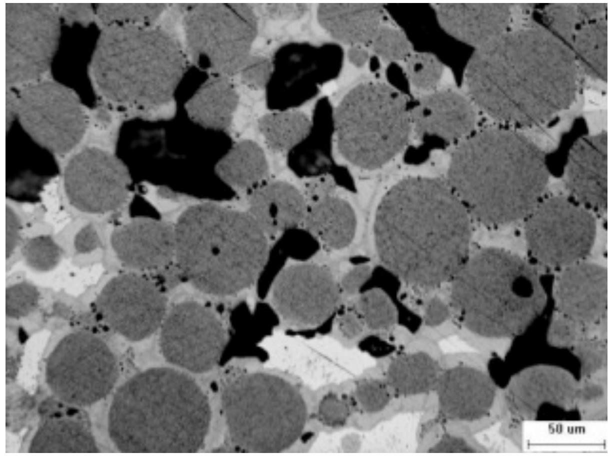


(Peak and Average) Burnup of the mini-plates of HAMP-1,2 and HAMP-3

- **The analysis results of heat flux and burnup of HAMP-2 & HAMP-3 for HANARO cycle #97-2, 98-1, 98-2, 99-2, 99-3, 100, 101, 102, 103, 104-1 and up to cycle # 108-1**
- **Ave. surface heat flux : 225 (HAMP-1) / 184 (HAMP-2) / 170 (HAMP-3) W/cm^2**
- **Local max. surface heat flux : 257 (HAMP-1) / 205 (HAMP-2) / 240 (HAMP-3) W/cm^2**
- **Ave BU : 61 (HAMP-1) / 64 (HAMP-2) / 81 (HAMP-3) at%U^{235}**
- **Local max. BU : 65.9 (HAMP-1) / 66.2 (HAMP-2) / 89.7 (HAMP-3) at%U^{235}**

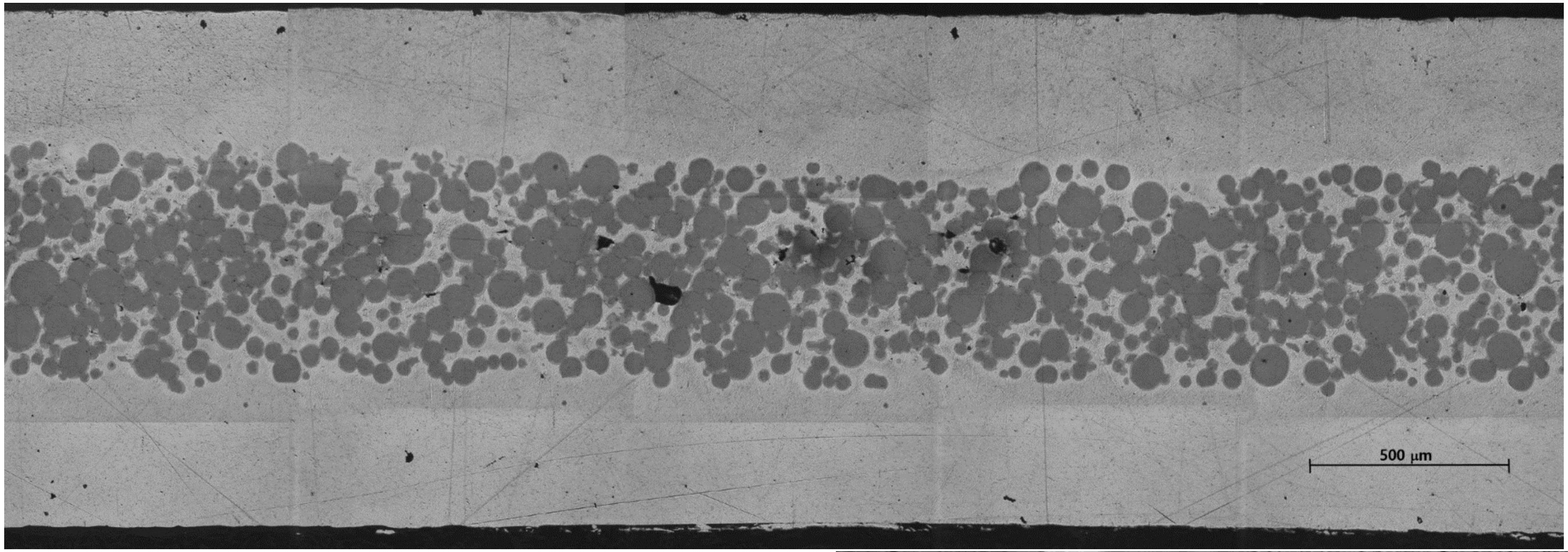
Microstructure (HAMP-1) 8-M-1 (FD 5.1×10^{21} f/cm^3, BU66%)



Zone 1	Zone 2	Zone 3
		

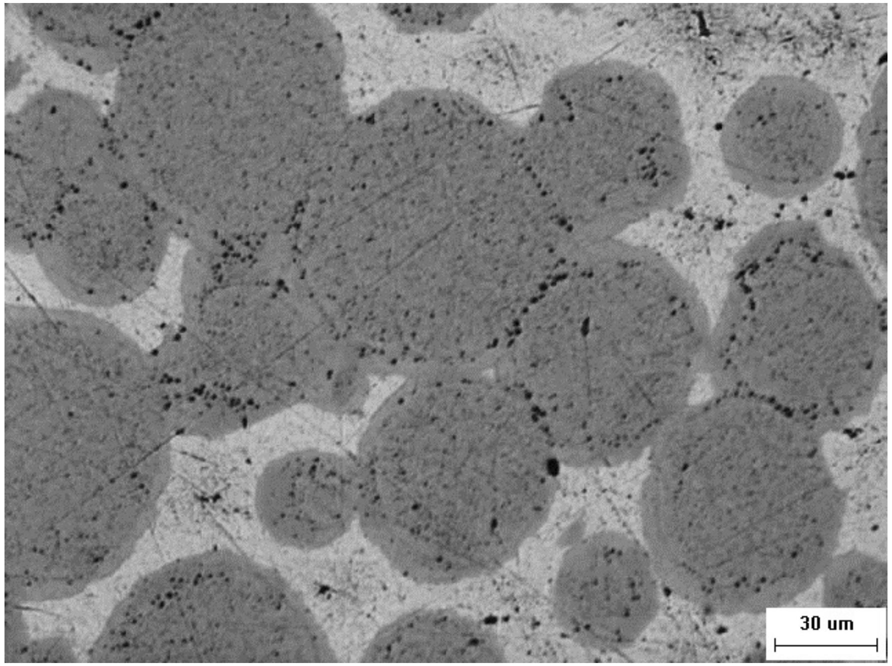
- ❑ there is substantial interaction layer(IL) formation as well as Al matrix reduction, and pores appears to grow and linkup to form larger pores mostly at the periphery of ILs
- ❑ the gross porosity followed by extensive IL formation resulted mainly from local inhomogeneity of U-Mo particle distribution
- ❑ the number as well as size of larger pores appears to increase in the dog-bone area due to apparent higher local fuel loadings

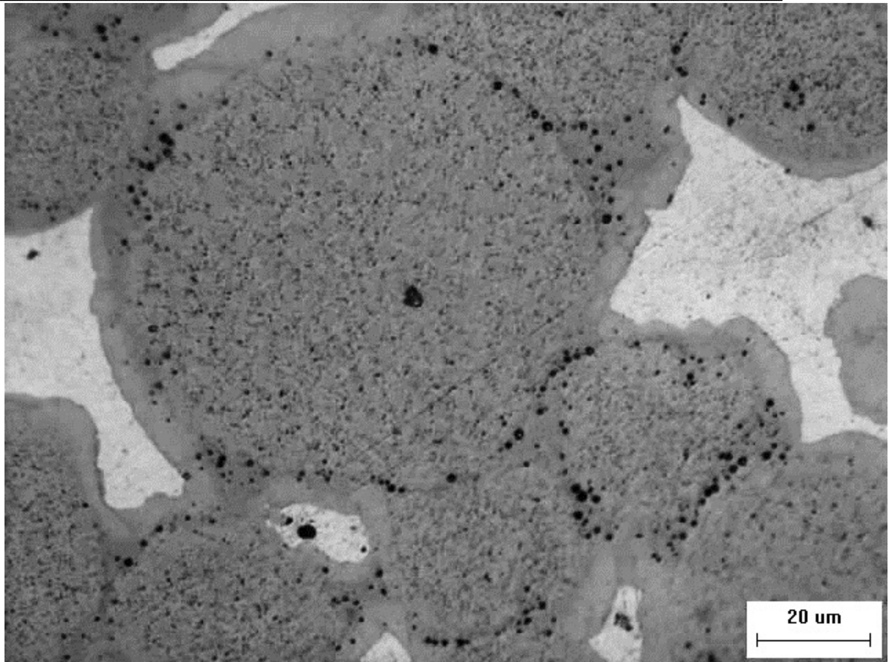
Microstructure(HAMP-2) U-7Mo/Al-5Si 8gU/cc (KJM8065)



FD 4.5x10^{21} f/cm^{3}
BU 61%

IL~5.4 μm

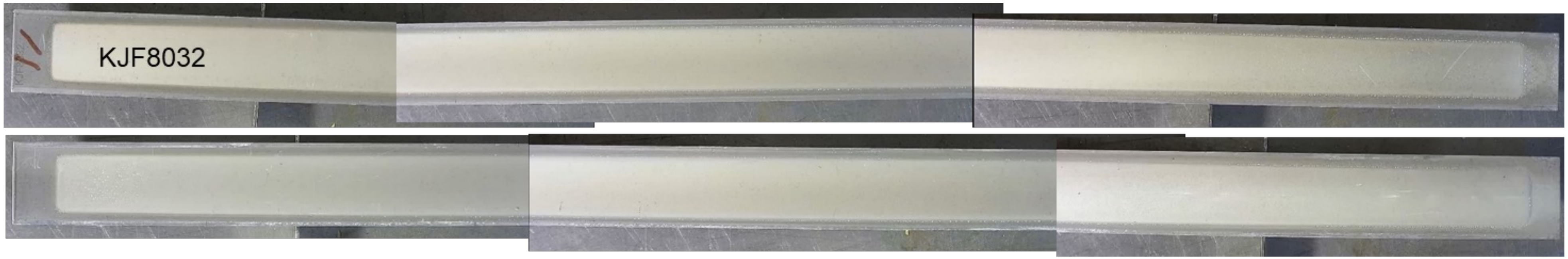




HAMP-3 : Post-Irradiation Examination (PIE)

- Non-destructive examination (NDE) has been performed at IMEF in KAERI.
- No abnormality was found for all plates during visual inspection.

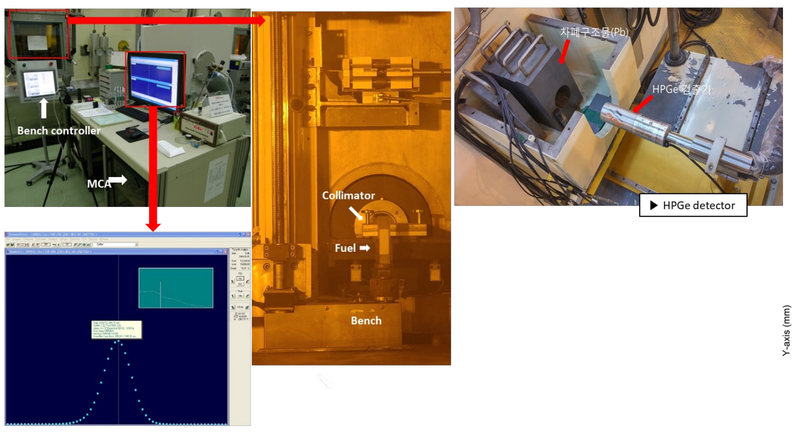
Dismantling irradiation capsule



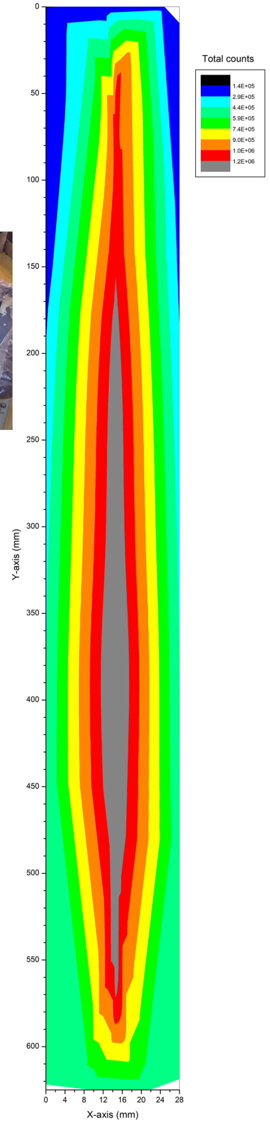
Visual inspection of an irradiate plate

HAMP-3 : PIE and As-run analysis

- ❑ Comparison between As-run analysis and gamma-scanning



Gamma scanning procedure



Gamma scanning results (Total count)

KJF8032

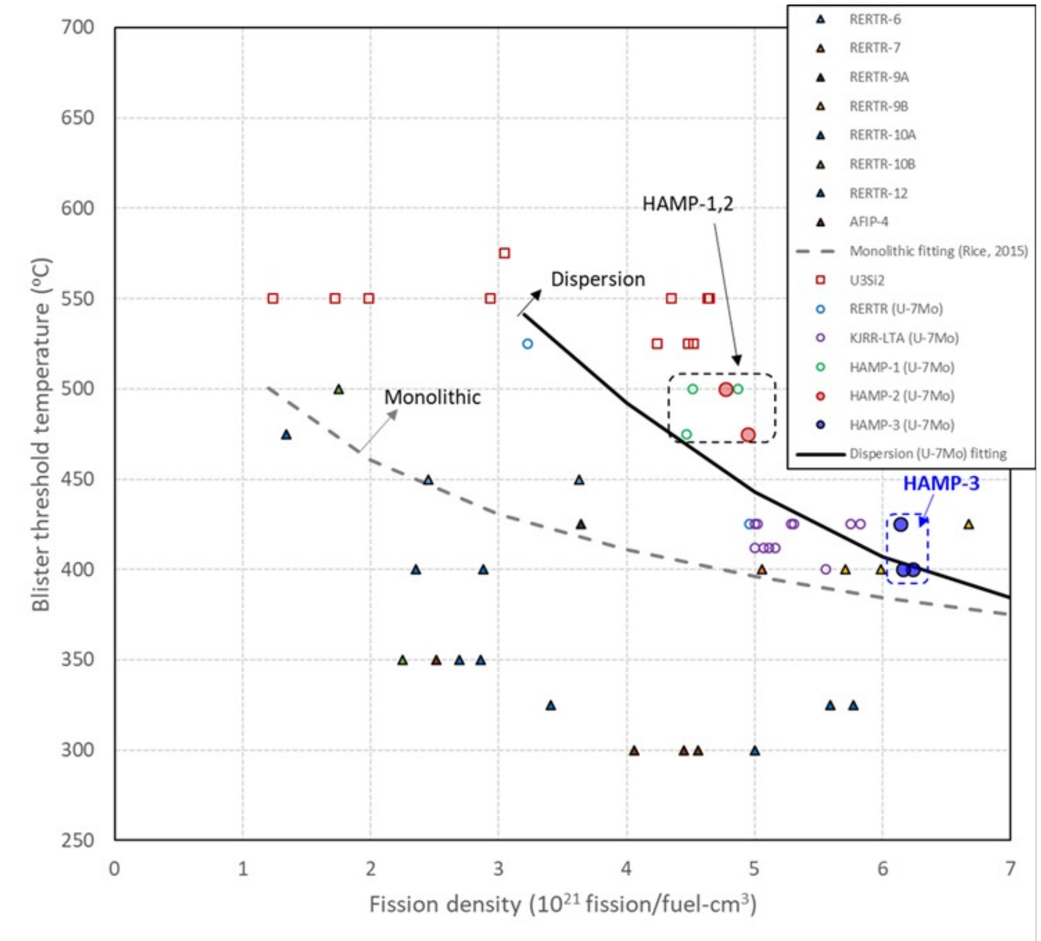
66.0%	63.5%	63.4%	65.9%
71.6%	69.3%	69.4%	71.8%
77.3%	74.9%	75.2%	77.5%
81.6%	80.0%	79.9%	82.2%
84.9%	83.4%	83.5%	85.7%
87.2%	85.8%	86.2%	87.9%
88.4%	87.3%	87.6%	89.2%
88.8%	87.7%	88.1%	89.8%
88.4%	87.1%	87.5%	89.3%
86.7%	85.6%	85.9%	87.7%
83.9%	82.5%	83.0%	85.3%
80.8%	79.2%	79.4%	81.7%

As-run analysis results

Total count distribution of gamma scanning is consistent to burnup distribution calculated by As-run analysis.

➔ No abnormality by fission product or fuel constituent redistribution during irradiation was found.

Blister Test



- **Blister-threshold T (U-Mo dispersion):**
  - ➢ **LTA : 400~425°C**
  - ➢ **HAMP-1 : 475~500°C**
  - ➢ **HAMP-2 : 500°C**
  - ➢ **HAMP-3 : 400~425°C**
- **Blister spot size < ~5 mm**
- **Location of blister spot is associated with highest BU position**

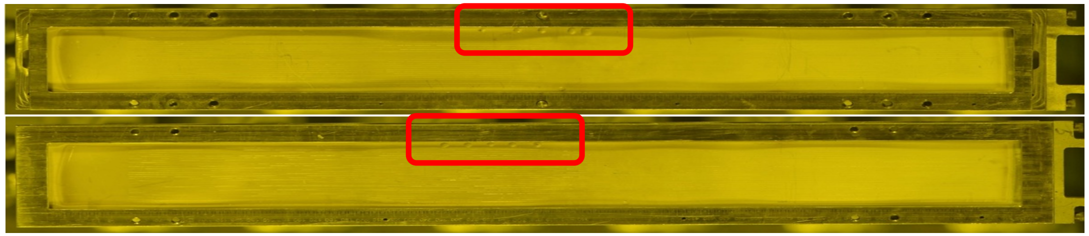
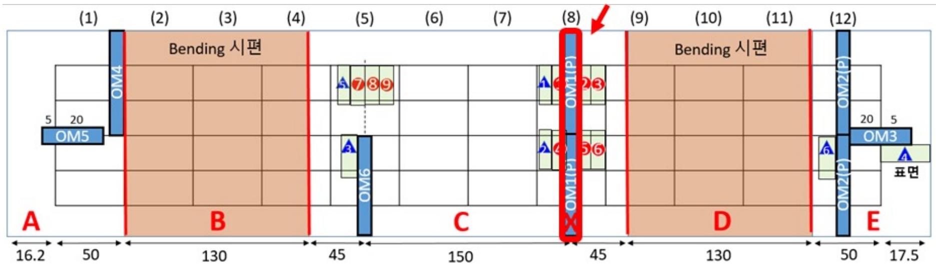


Plate ID : KJS00041

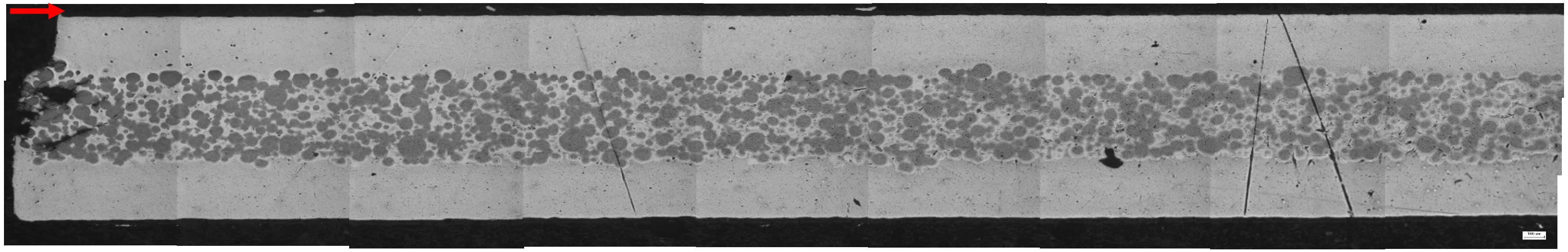
Plate ID	U-Loading (g-U/cc)	Plate Avg. BU (at% U-235)	Fuel Fission Density ($\times 10^{21}$ fissions/cm^3)	Blister-threshold T (°C)
KJL00007	6.5	76.6	5.83	425
KJS00074	8.0	70.3	5.28	425
KJS00046	8.0	61.2	5.03	425
KJS00069	8.0	66.9	5.00	425
KJS00015	8.0	66.9	5.07	412
KJS00022	8.0	67.8	2.01	412
KJS00019	8.0	68.3	5.11	412
KJS00079	8.0	68.9	5.16	412
KJS00072	8.0	70.6	5.31	425
KJS00017	8.0	73.5	5.56	400
KJS00041	8.0	73.8	5.75	425

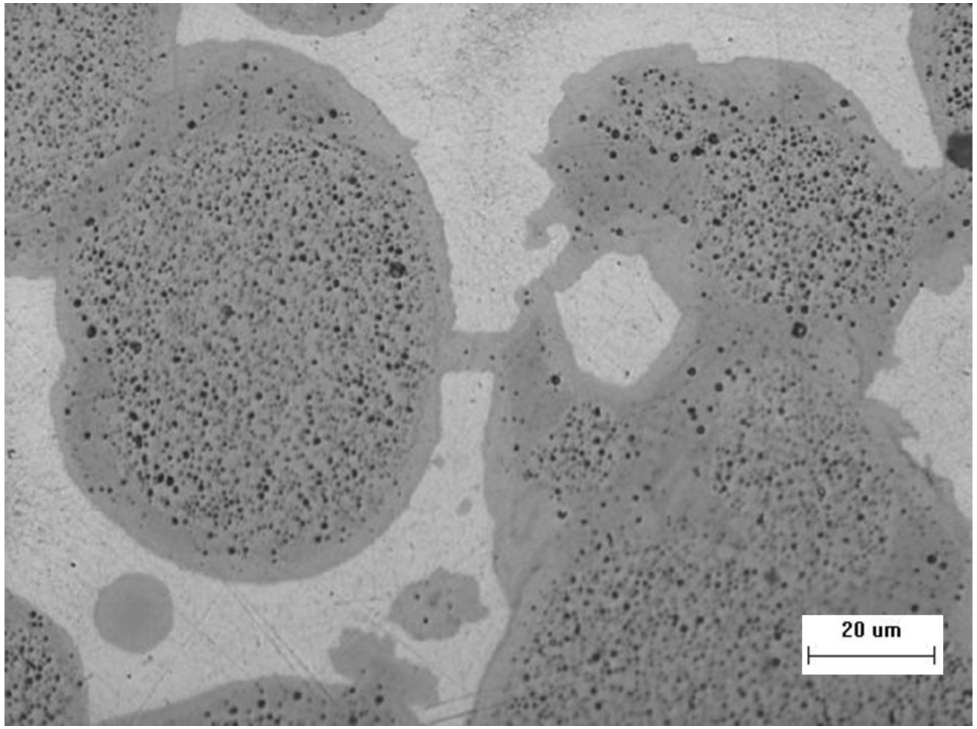
Microstructure(HAMP-3) U-7Mo/Al-5Si 8gU/cc (KJF8032)



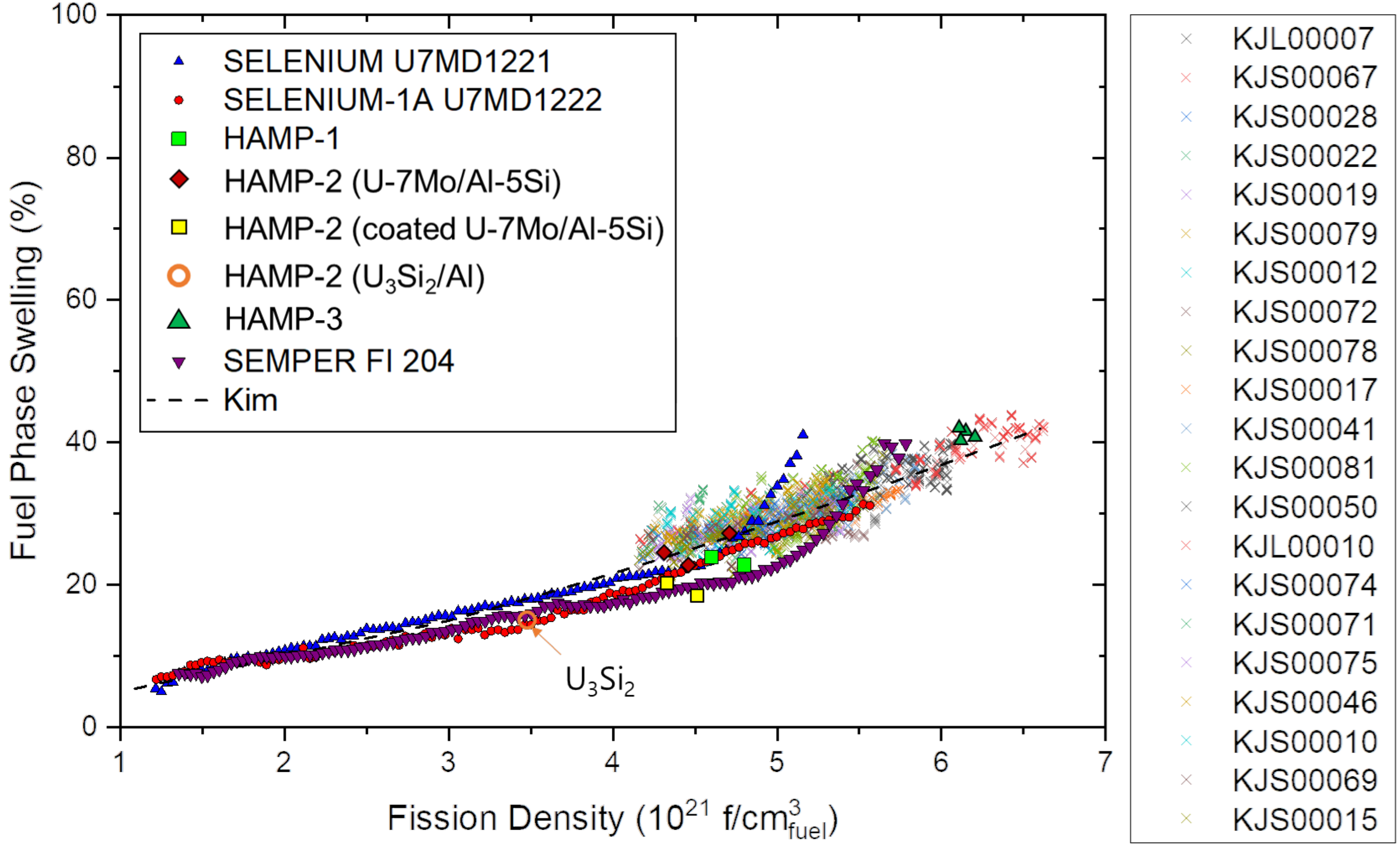
- **OM-1**

Panorama at BU(87.7~89.8%)





Fuel Swelling Comparison



KJRR LTA

Irradiated HAMP-1~3 and KJRR LTA fuels show

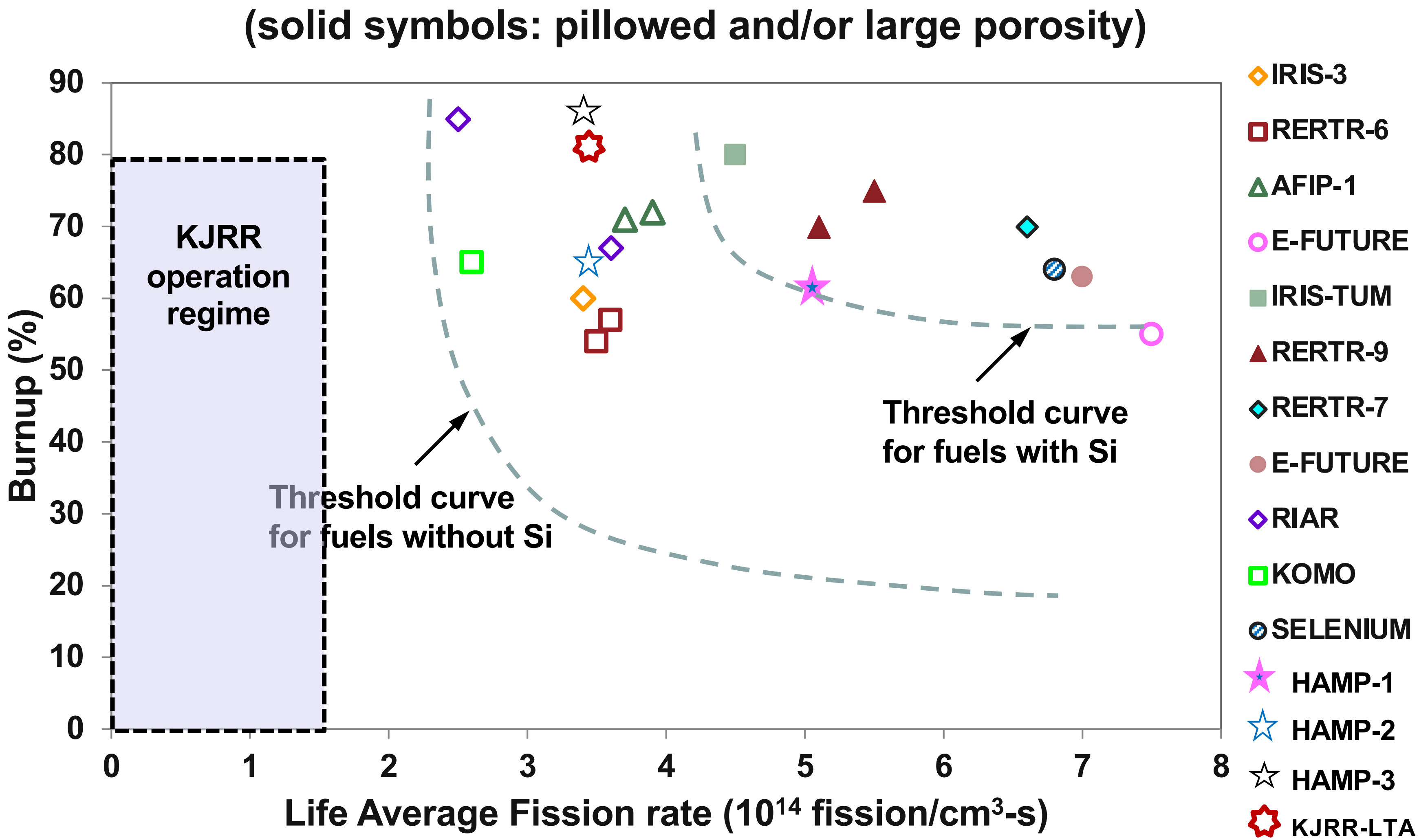
- Very stable irradiation fuel performance
- Predictable fuel behavior

SELENIUM dataset from A. Leenaers, RRFM (2017)

*** Kim model from U-10Mo monolithic dataset [Y.S. Kim, JNM, 419 (2011)291]**

Failure Criteria U-Mo/Al-Si Dispersion Fuel

G. Hofman and YS.KIM June 2015.



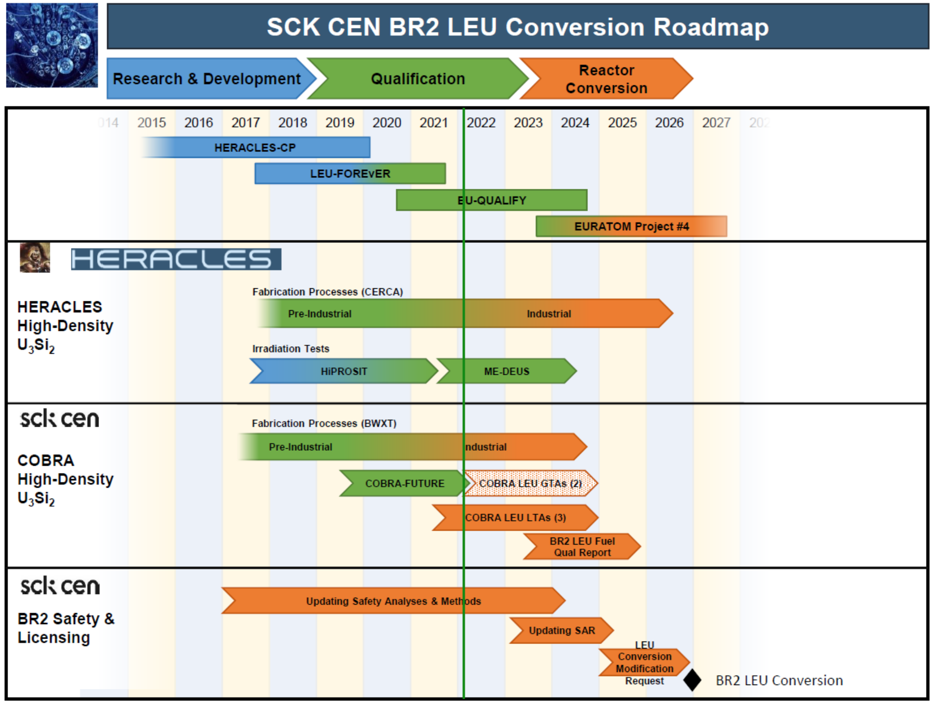
- Performance of U-Mo/Al-Si dispersion fuel will be safe and predictable
  - under the conditions, q''_{max} < 250 W/cm^2 and high BU(~90%)

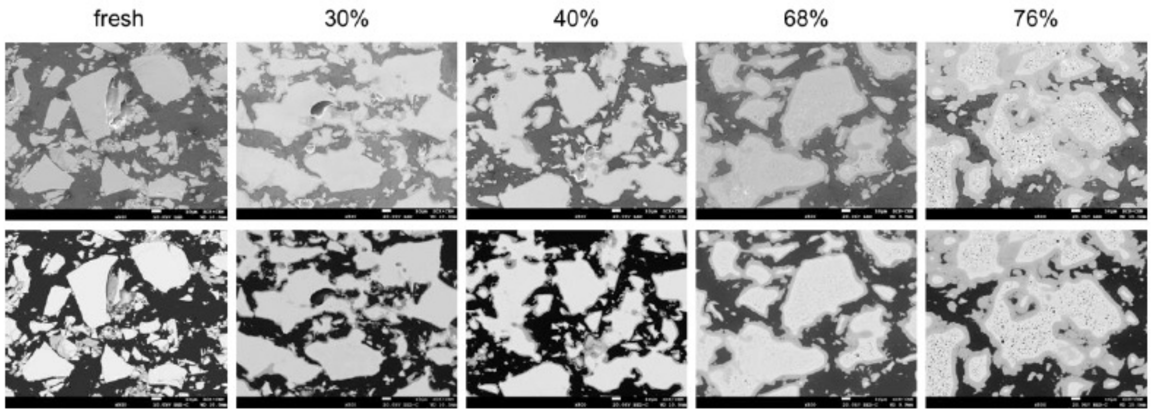
Development of High Density U_3Si_2 Fuel

Sven Van den Berghe, RRFM-2022

U_3Si_2 fuel with 5.3 g-U/cc

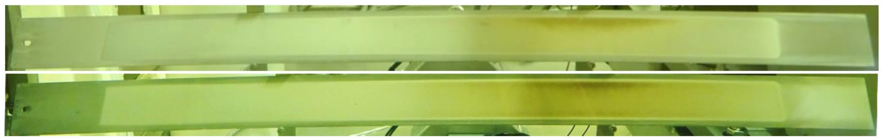
- **Back-up Solution for U-Mo for converting BR-2, HFIR, JHR**
- **Initiated in 2017**
  - CERCA
    - LEU-FOREvER – HiPROSIT irradiation
  - BWXT
    - COBRA-FUTURE irradiation
- **COBRA-LTA test**
  - fabricated by CERCA (3 LTAs)
  - irradiation test in BR-2 (2025 May~Dec.)





COBRA-FUTURE microstructure

LEU-FOREvER – HiPROSIT irradiation (CERCA)



COBRA-FUTURE irradiation (BWXT)

Qualification of High Density Atomized U_3Si_2

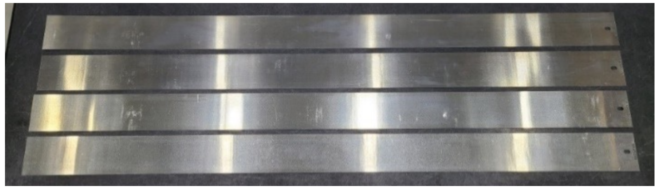
KIMQI (KAERI High Density AtoMized Silicide Fuel Qualification Irradiation) Project

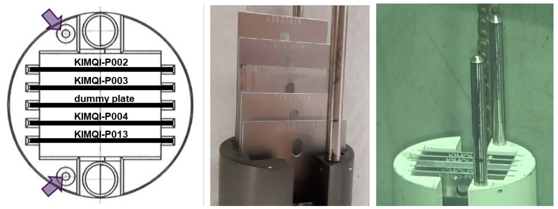
Irradiation Campaign in cooperation with SCK CEN (BR-2)

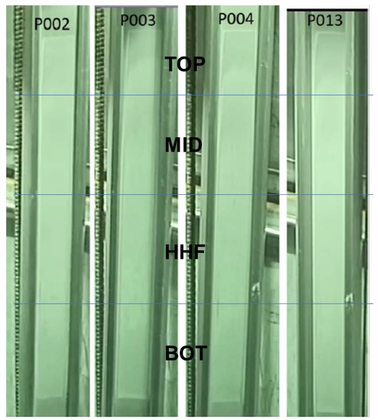
- **Phase 1 (2021~2023): KIMQI-FUTURE for Fuel Performance Confirmation**
  - ✓ Irradiation test and PIE with 4 full-size 5.3 gU/cc U_3Si_2 flat fuel plate
  - ✓ surface heat flux :470 W/cm^2 (max.)
  - ✓ peak burnup : 70% at%U^{235}
- **Phase 2 (2023~2025): KIMQI-GTA Generic Fuel Qualification Program**
  - ✓ Irradiation test and PIE 1 full-size 5.3 gU/cc U_3Si_2 Generic Test Assembly with ~10 curved plates
  - ✓ surface heat flux :470 W/cm^2 (max.)
  - ✓ peak burnup : 70% at%U^{235}

⇒ Qualification for HD U_3Si_2 fuel

KIMQI-FUTURE



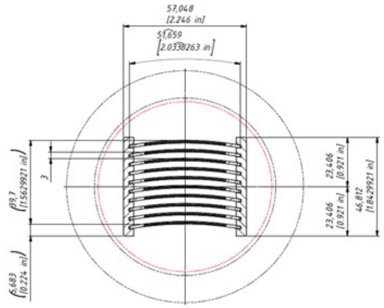


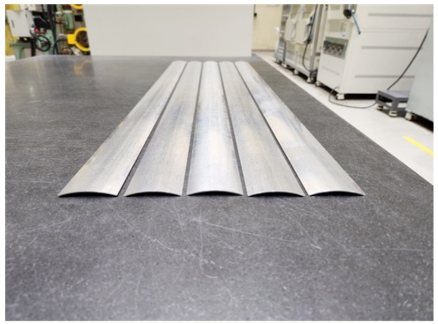


- Irradiation test (2 cycles) of KIMQI-FUTURE was completed successfully (Jan. 2022)

  Peak BU : 70.8~72.6 at%U-235

KIMQI-GTA



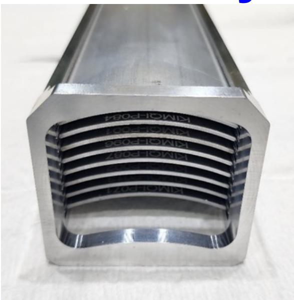


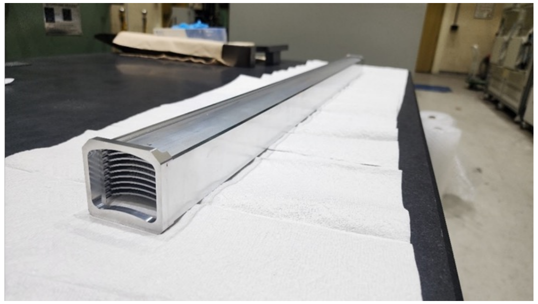
full-size 5.3 gU/cc U_3Si_2 curved fuel plate

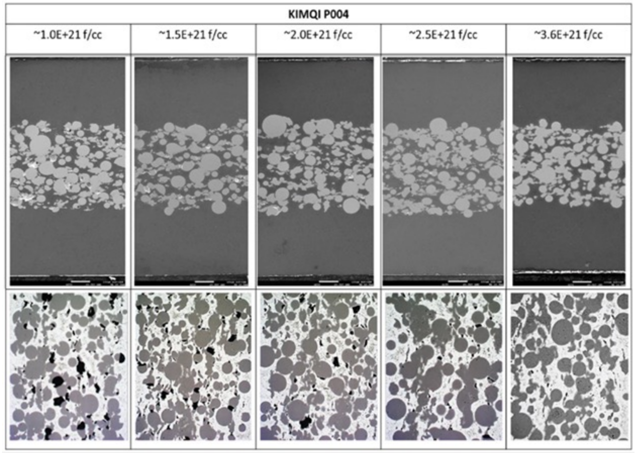
KIMQI-GTA Irradiation Test

Summary of KIMQI-GTA Irradiation Test

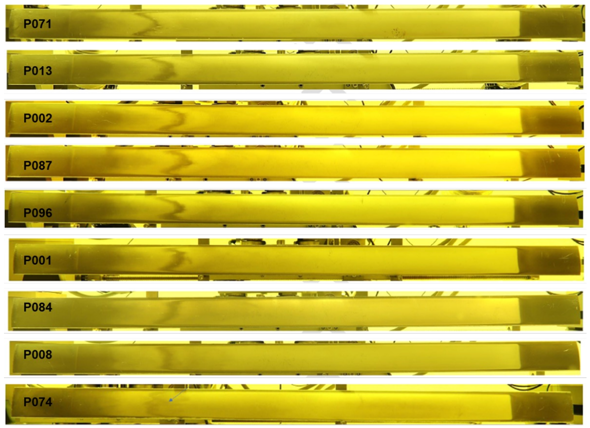
Ref : T.W. Cho, RRFM-2025





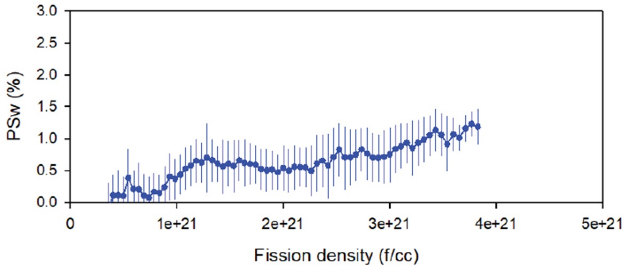


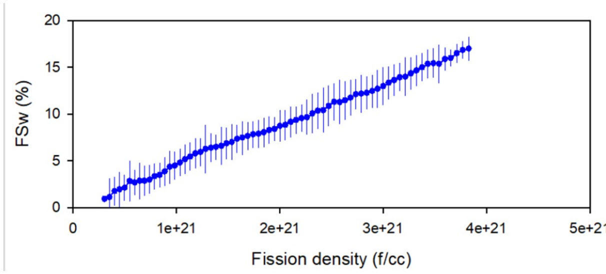
Microstructure evolution of irradiated KIMQI-FUTURE plates as a function of the burnup



Key irradiation results of the KIMQI-GTA

Plate ID	Peak Heat Flux BOC1 (W/cm^2)	Avg. ^{235}U Burnup EOC2 (%)	Peak ^{235}U Burnup EOC2 (%)
KIMQI-P071	485.0	47.3	75.2
KIMQI-P013	463.5	43.8	73.2
KIMQI-P002	436.5	41.6	71.3
KIMQI-P087	433.5	40.3	71.1
KIMQI-P096	427.4	39.9	70.0
KIMQI-P001	437.1	40.0	70.0
KIMQI-P084	443.7	40.8	70.3
KIMQI-P008	475.2	42.5	70.9
KIMQI-P074	496.1	45.2	73.9





- KIMQI-GTA irradiation('23.11~'24.02) was completed successfully, achieving the target heat flux and burnup without any fuel failures.
- Fuel particle swelling exhibited stable and predictable increases with burnup

→ **Support to MURR Project**

Korea Atomic Energy Research Institute

Conclusion

- **PIE analysis of KJRR-LTA (U-7Mo/Al-5Si dispersion fuel) was performed to verify the safe in-pile performance behavior**
  - ➢ **KJRR-LTA was irradiated with no abnormal swelling to BU of 83 at%U-235**
  - ➢ **Non-destructive and destructive PIE results on KJRR-LTA were enough to prove very stable irradiation performance and predictable fuel behavior up to high BU**

- **HAMP series irradiation test were successfully finished without any abnormality, in which HAMP-1, 2 and HAMP-3 have achieved average burnups of 61% / 64% / 81% and local peak burnups of 66% / 66% / 90% U^{235} depletion, respectively.**

- **Performance of U-Mo/Al-Si dispersion fuel will be safe and predictable, if U-Mo fuel is used under the conditions, q"max < 250 W/cm^2 and high BU(~90%).**


Thank You!
KAERI
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Research Institute