

Developments of High-density Atomized U_3Si_2 Fuel in KAERI



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01 Introduction to KIMQI Project

01-1 Background of the KIMQI Project

» Status of Research Reactor Fuel Conversion

- Most HEU fuels are converted with **commercial U_3Si_2 fuel** (max. U-density 4.8 gU/cm³).
- Some high-power RRs still use HEU fuels → Need to be converted to LEU fuel
 1. Development of **advanced LEU fuel using U-Mo** (dispersion and monolithic)
 2. Development of **high U-density LEU fuel using the U_3Si_2 powder** (dispersion)
- Atomized powder is known to be advantageous for increasing U-density.

Fuel Compound	Density (g/cm ³)	U-density (g-U/cm ³)	Relative U-density	Typical Enrichment	Typical Fuel Form
U	19.1	19.1	1.00	N/A	N/A
U-7Mo	18.4	17.1	0.90	LEU	Dispersion/Plate(KJRR)
U-10Mo	18.2	16.4	0.86	LEU	Monolithic Foil/Plate
U_3Si	15.6	15.0	0.79	LEU	Dispersion/Pin(HANARO)
U_3Si_2	12.2	11.3	0.59	LEU	Dispersion/Plate
U_3O_8	8.4	7.1	0.37	HEU	Dispersion/Plate
UAl_x^2	N/A	4.5	0.24	HEU	Dispersion/Plate

01-2 Objectives of the KIMQI Project

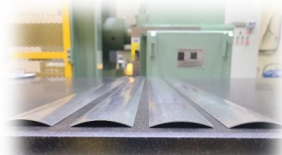
» Qualification of atomized U_3Si_2 fuel

Qualification of HD U_3Si_2 Fuel

KIMQI-FUTURE



KIMQI-GTA



KIMQI-FUTURE

- Fabrication of atomized high-density U_3Si_2 fuel plates (flat-type, dispersion)
- BR2 Irradiation and NDE & DE PIE

KIMQI-GTA

- Fabrication of atomized high-density U_3Si_2 fuel assembly (curved-type, dispersion)
- BR2 Irradiation and NDE & DE PIE

Qualification of HD U_3Si_2 Fuel

- Qualification of atomized U_3Si_2 powder/fuel
- Qualification of KAERI as a vendor for MTR fuel assemblies to enable bidding on future contracts

01-3

Key Milestone of the KIMQI Project

KIMQI-FUTURE
Fabrication



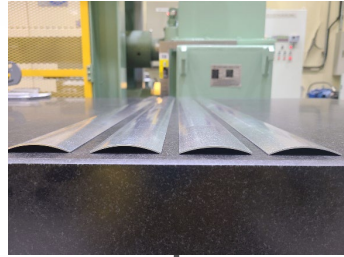
2021

KIMQI-FUTURE
Irradiation & PIE



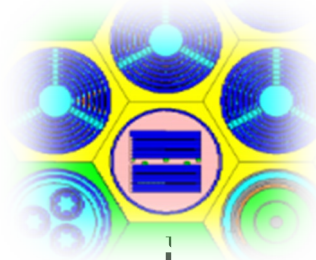
2021-2023

KIMQI-GTA
Fabrication



2022-2023

KIMQI-GTA
Irradiation & PIE



2023-2025

HD Atomized Silicide Qualification Report



2025

KAERI Qualified as
MTR Fuel Assembly Vendor



2026

02

Fabrication of High-density Atomized U_3Si_2 Fuel

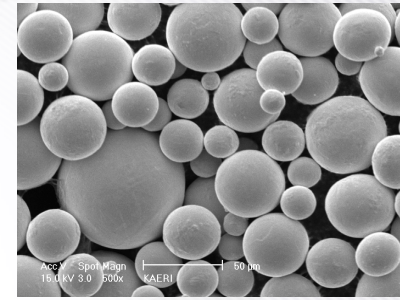
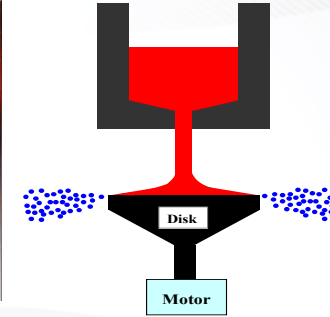
02-1 Fuel Fabrication Facility in KAERI



Fabrication Facility for RR Fuel



Atomized powder fabrication



HANARO fuel fabrication

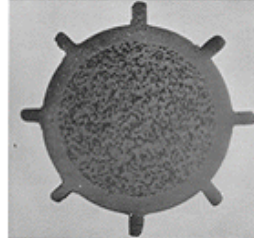
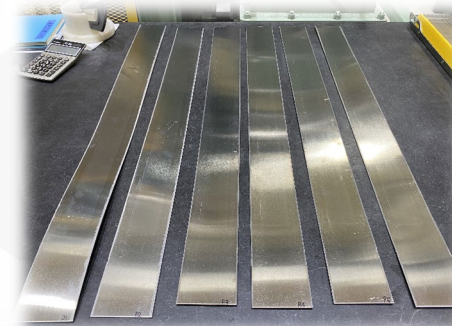
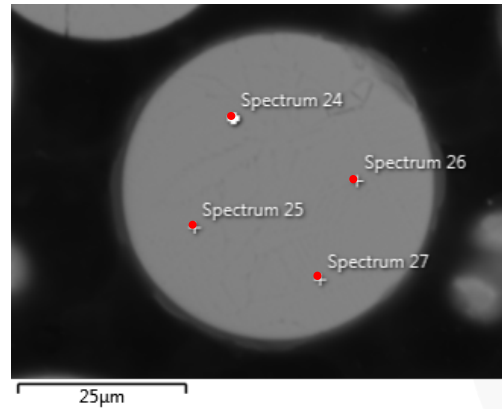
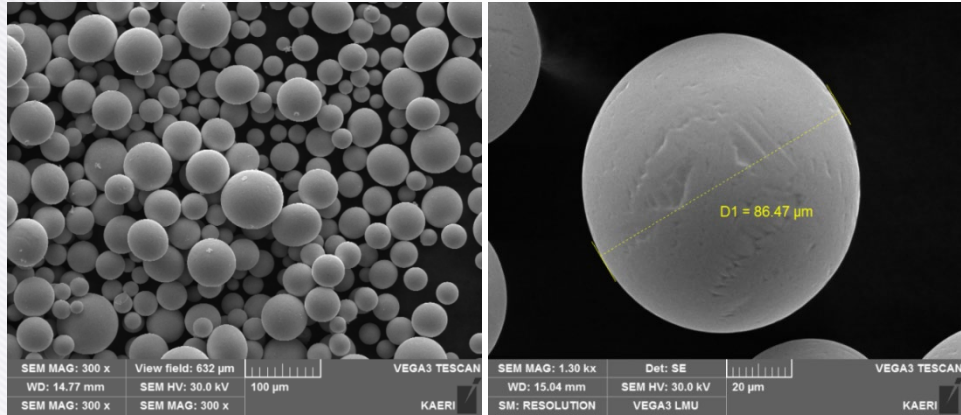


Plate fuel fabrication

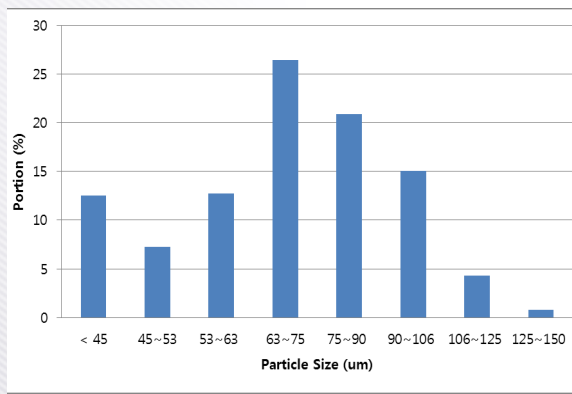


02-2 Fabrication of Atomized U_3Si_2 Powders

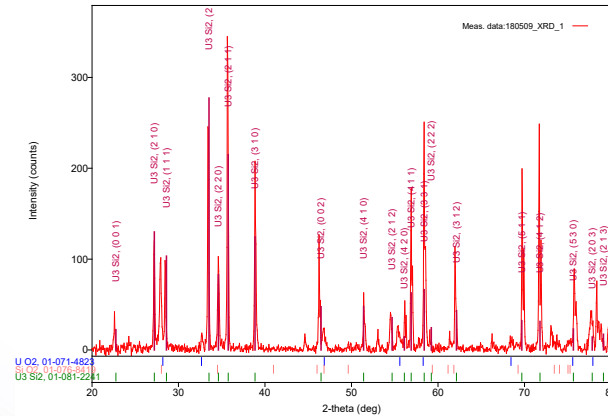
» Atomized U_3Si_2 powders were successfully fabricated.



Spectrum	U (at.%)	Si (at.%)	U/Si ratio
24	60.8	39.2	1.55
25	60.4	39.6	1.53
26	60.1	39.9	1.51
27	61.0	39.0	1.56



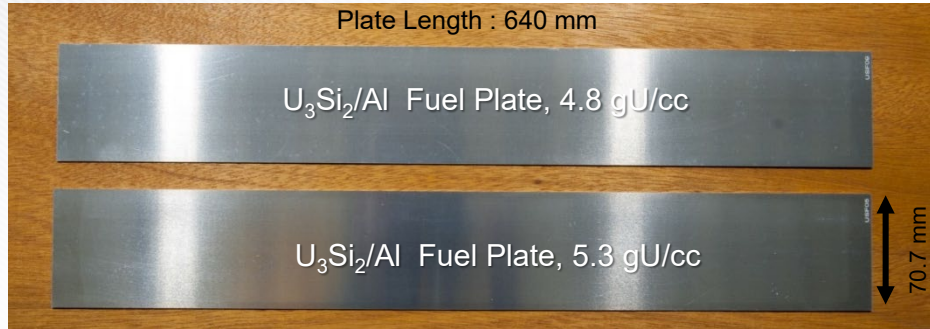
[Particle Size Distribution]



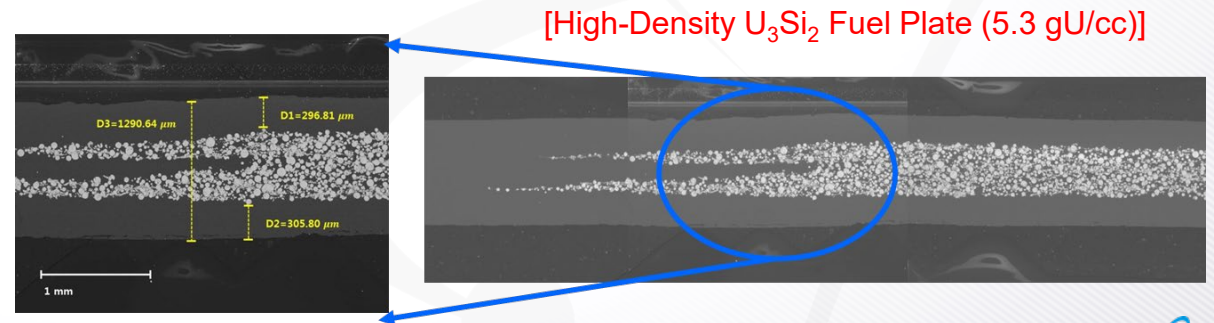
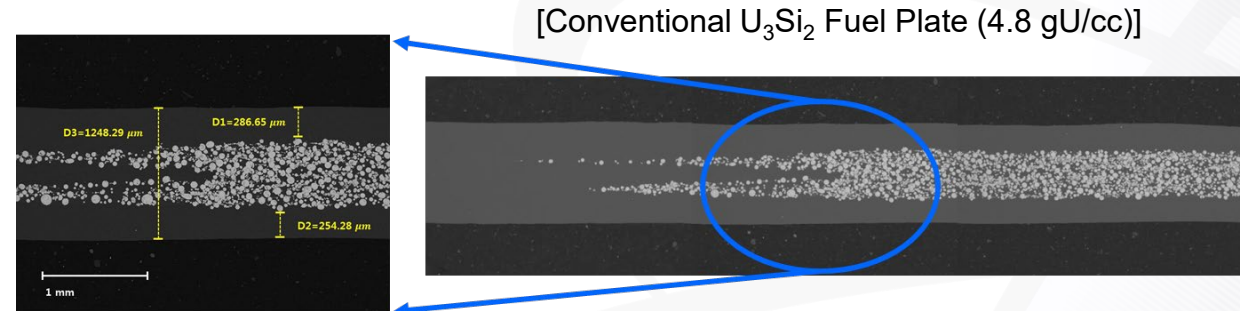
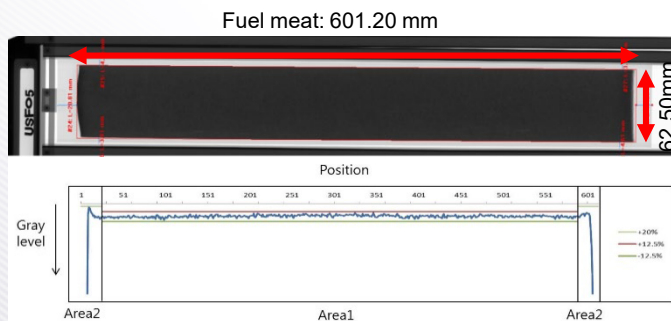
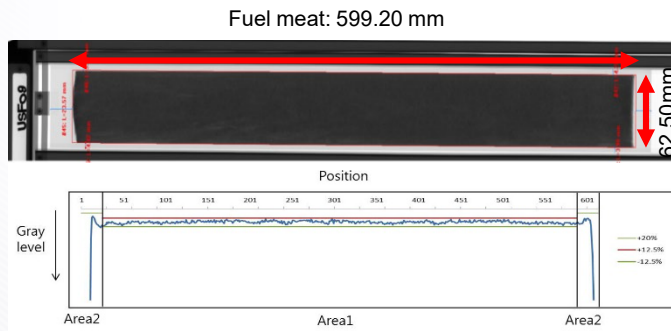
[XRD analysis]

- Successful mass production of atomized U_3Si_2 powders
 - Temperature during atomization: up to 1,950 °C
 - Mean particle size: 60~80 μm
 - Composition: Si 7.4~7.8 wt. %
 - Satisfying the impurity requirements for BR2 fuels

02-3 Prototype of Atomized U_3Si_2 Fuel Plates

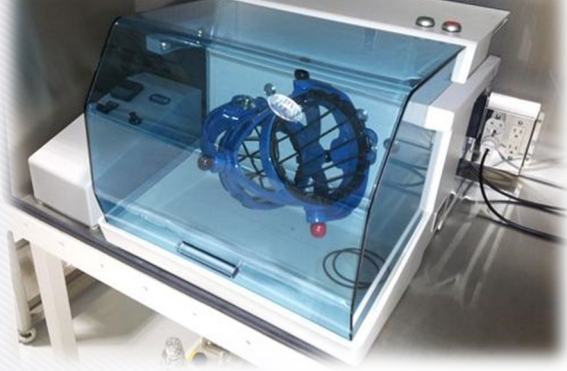


- KJRR-size U_3Si_2/Al fuel plates were successfully fabricated. (4.8 gU/cc and 5.3 gU/cc)
 - Improved Roughness
 - Satisfying all inspection criteria (based on the KJRR specifications)

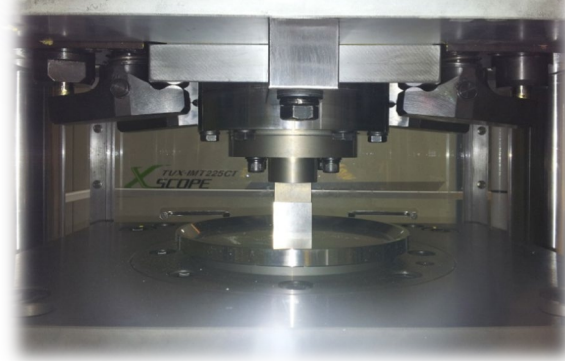


02-4 Fabrication of KIMQI-FUTURE Plates

Powder Mixing



Compaction



Assembling



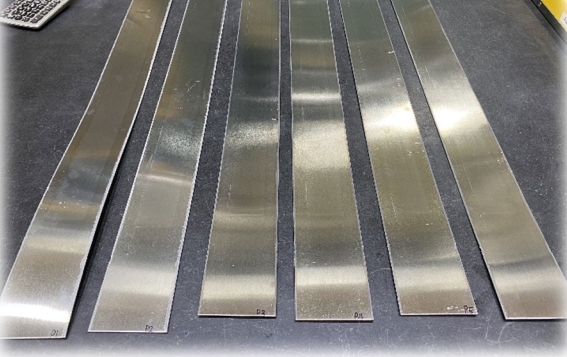
Welding



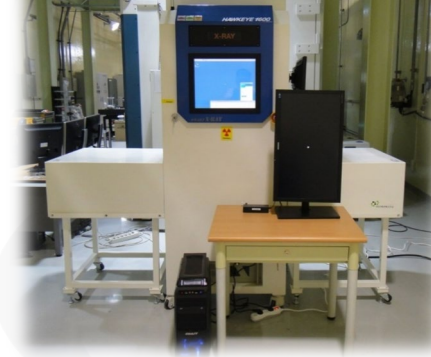
Hot & Cold Rolling



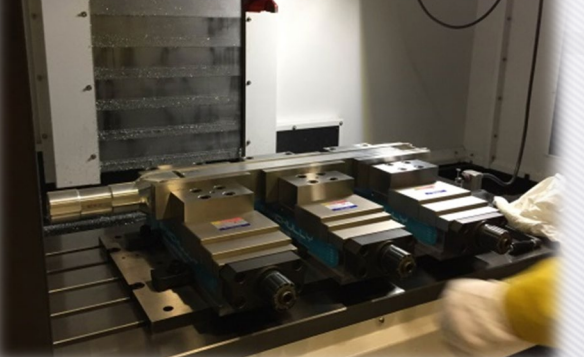
Before final machining



Inspections



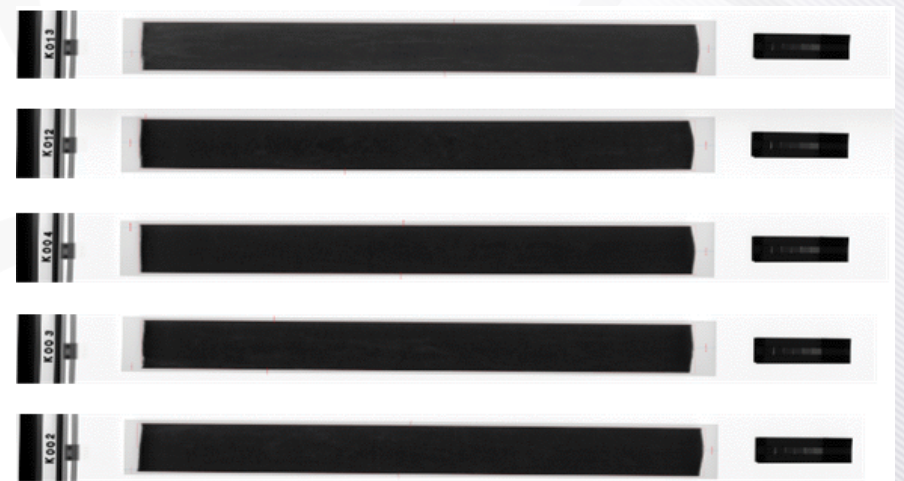
Final machining



02-4 Fabrication of KIMQI-FUTURE Plates

» Successfully fabricated 5 KIMQI-FUTURE plates (with 1 archive plate)

- High-density 5.3 gU/cm^3 atomized U_3Si_2 flat fuel plates
- A nominal size of 970 mm x 61 mm with a nominal thickness of 1.27 mm
- Satisfied all criteria based on the BR2 specifications



KIMQI-FUTURE Fuel Plates

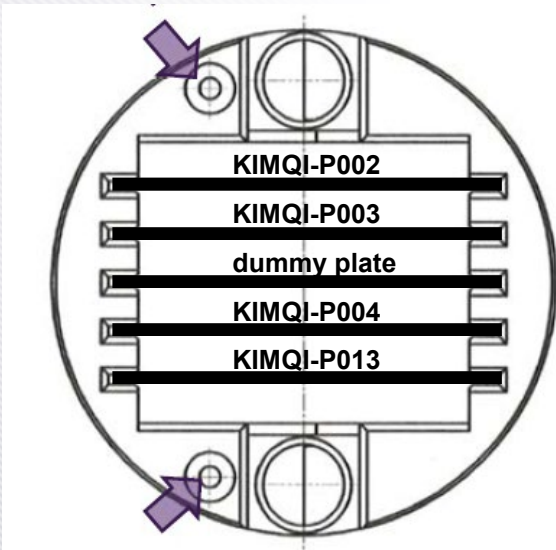
03

Irradiation of High-density Atomized U_3Si_2 Fuel

03-1 Descriptions of the KIMQI-FUTURE Plates

Summary of the KIMQI-FUTURE key plate parameters

Plate ID	Plate Dimension	Fuel Type & U-density	U-235 Mass (g)	Plate Thickness (mm)	Fuel Meat Thickness (mm)	Cladding Type	Porosity(%)
KIMQI-P002	970x61x1.27 mm	U ₃ Si ₂ -Al dispersion (atomized), 5.3 gU/cm ³	18.3±0.2	1.27	0.51	Al-6061	8.09
KIMQI-P003							6.76
KIMQI-P004							7.43
KIMQI-P013							8.47



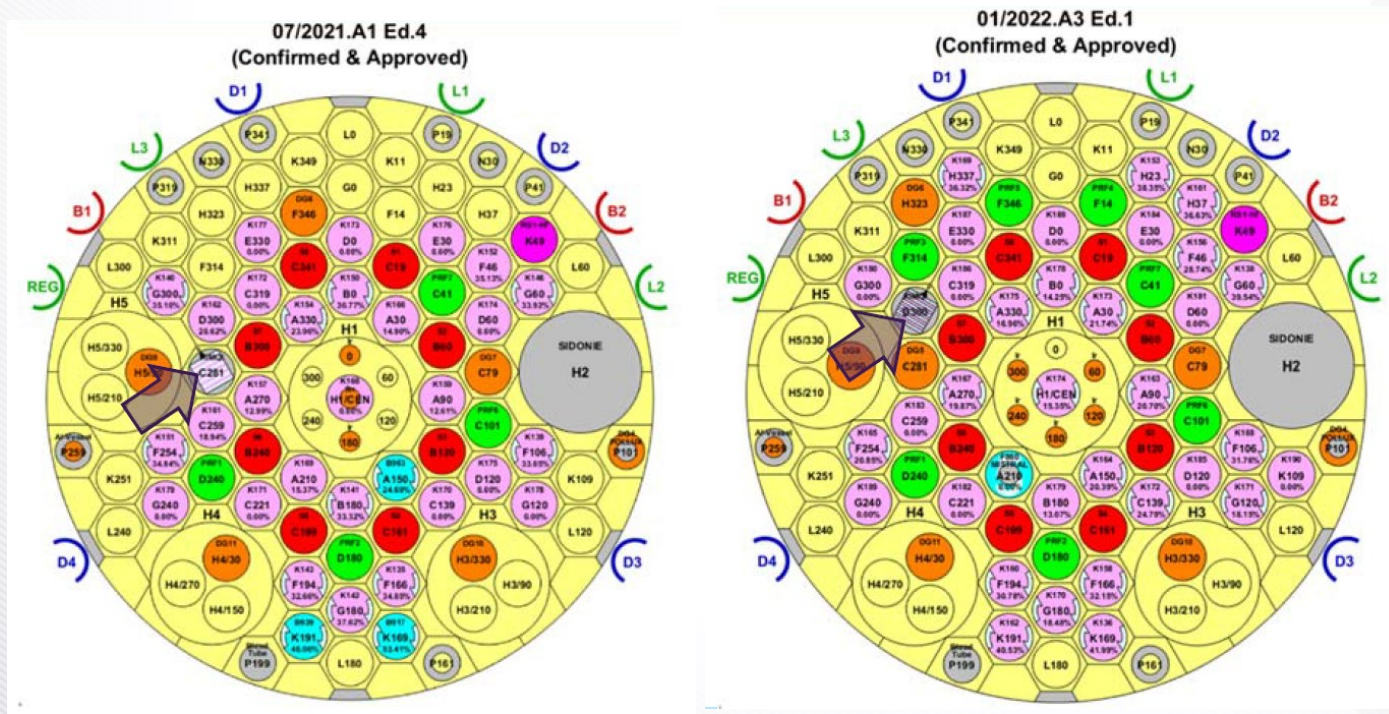
- 4 identical K-F plates are loaded into the FUTURE-5 basket during all cycles.

03-2 KIMQI-FUTURE Irradiation Conditions

» Irradiations were completed in 2nd irradiation cycle

● Target irradiation conditions:

- Target peak heat flux (edge): 470 W/cm² at 1st BOC
- Target peak Burnup: ≥ 70% U-235

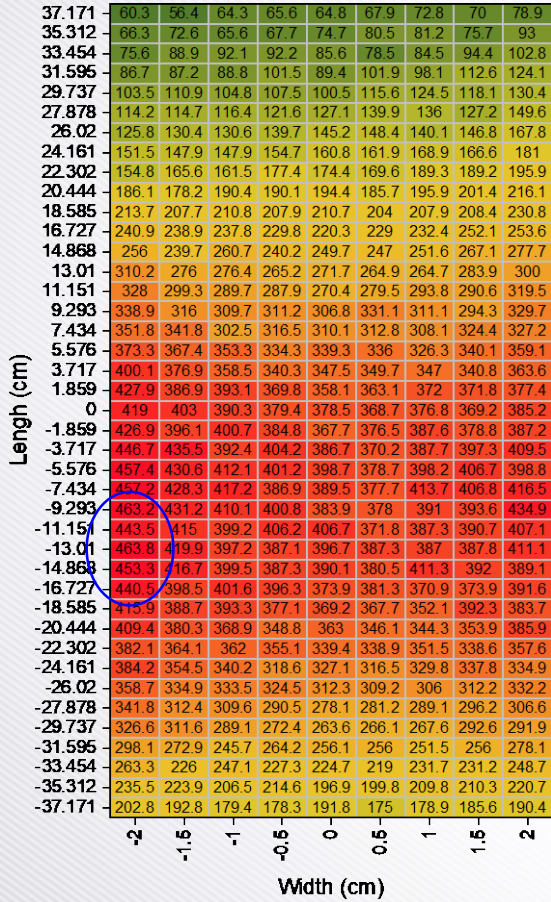


Basket Slot	Cycle A - 07/2021 33 days in position C281	Cycle B - 01/2022 31 days in position D300
Position and 0° direction		
	C281	D300
Duration (days)	33	31
Average power (MW)	51.53	53.12
Peak 235U Burnup EOC (%)	51.6 – 54.3	70.8 – 72.6

03-3

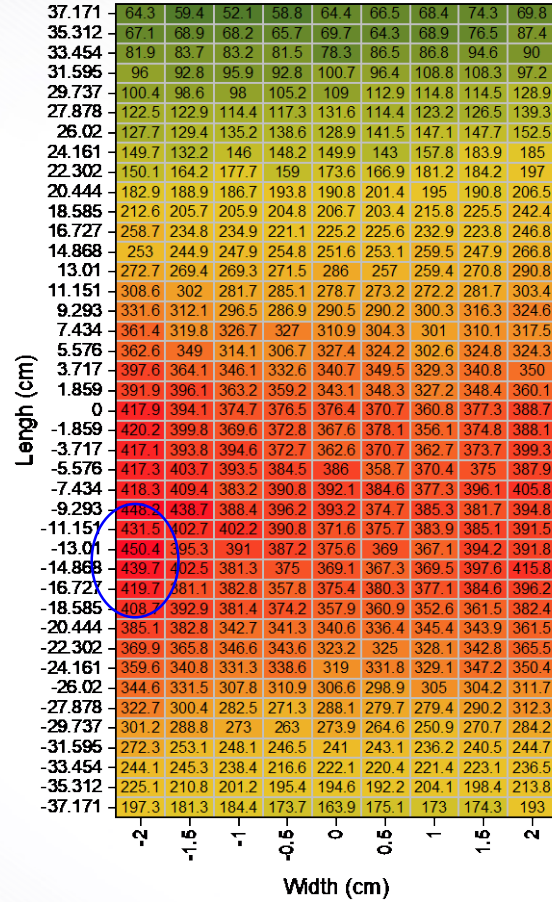
Heat Flux Distributions at Beginning of 1st Cycle

KIMQI-P002



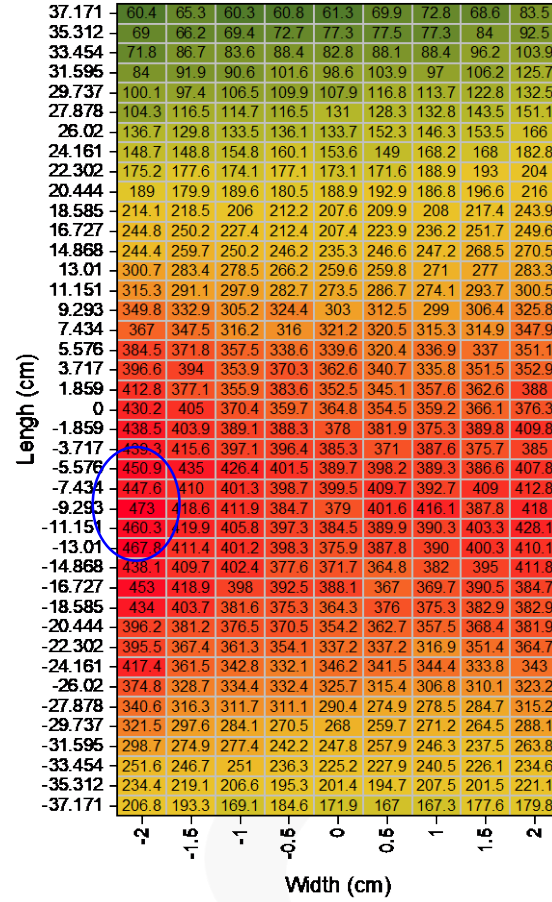
Max: 463.8 W/cm²
Avg: 280 W/cm²

KIMQI-P003



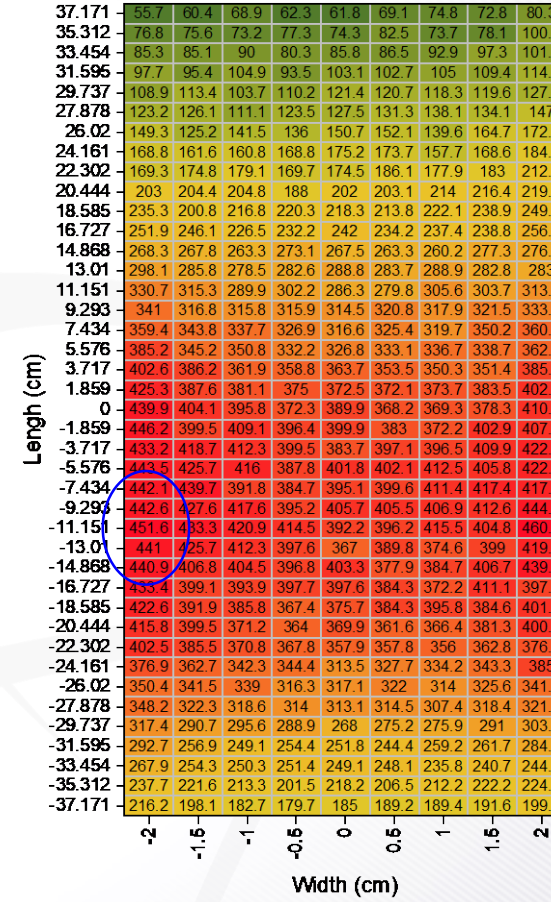
Max: 450.4 W/cm²
Avg: 272 W/cm²

KIMQI-P004



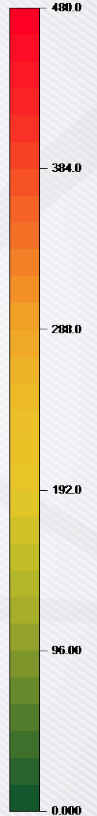
Max: 473.0 W/cm²
Avg: 281 W/cm²

KIMQI-P013



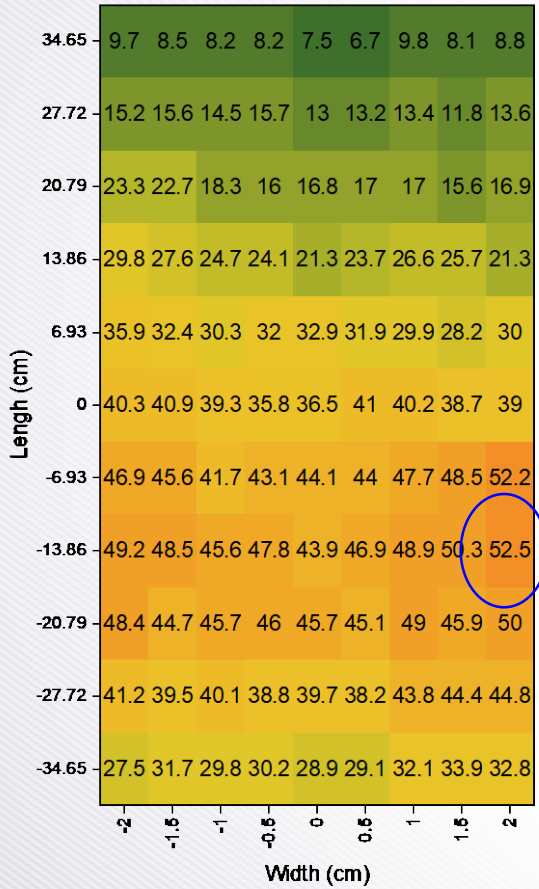
Max: 451.6 W/cm²
Avg: 288 W/cm²

Heat Flux
(W/cm²)



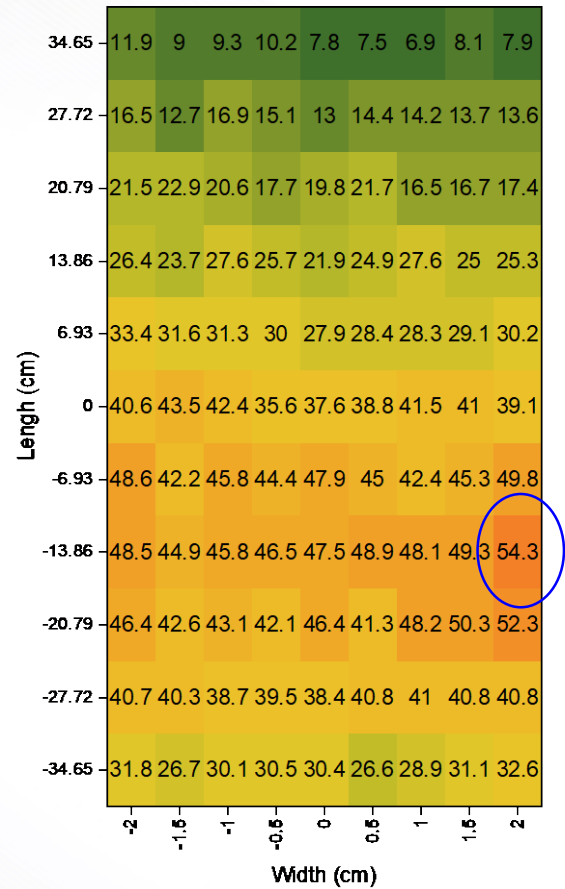
03-4 Burnup Distributions after 1st Cycle

KIMQI-P002



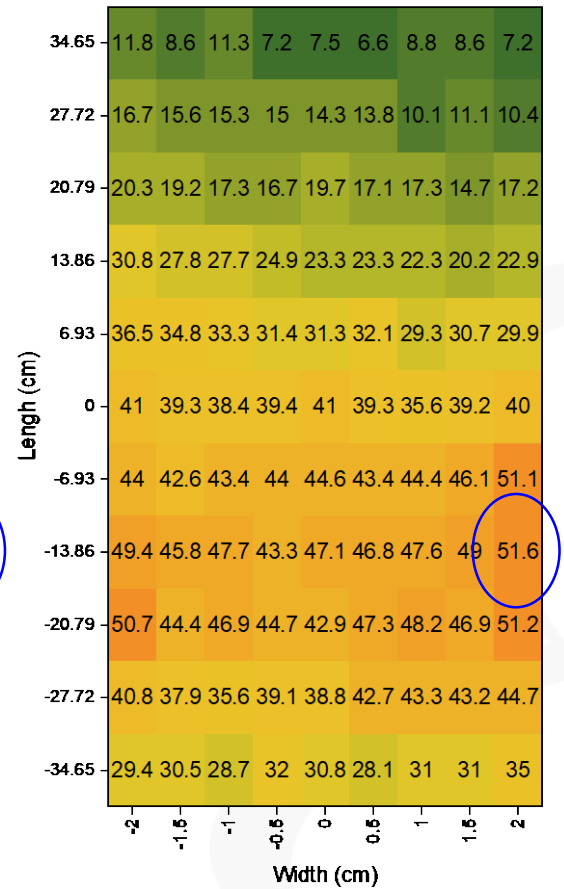
Max: 52.5 %
Avg: 31.7 %

KIMQI-P003



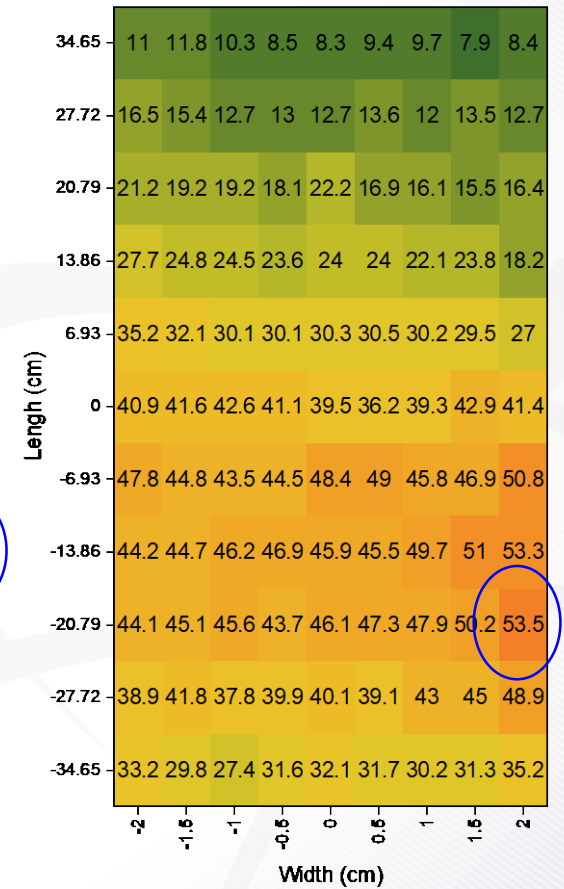
Max: 54.3 %
Avg: 31.6 %

KIMQI-P004

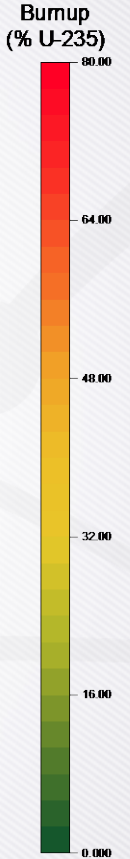


Max: 51.6 %
Avg: 31.6 %

KIMQI-P013



Max: 53.5 %
Avg: 31.9 %



03-5 Visual Inspection after 1st Cycle

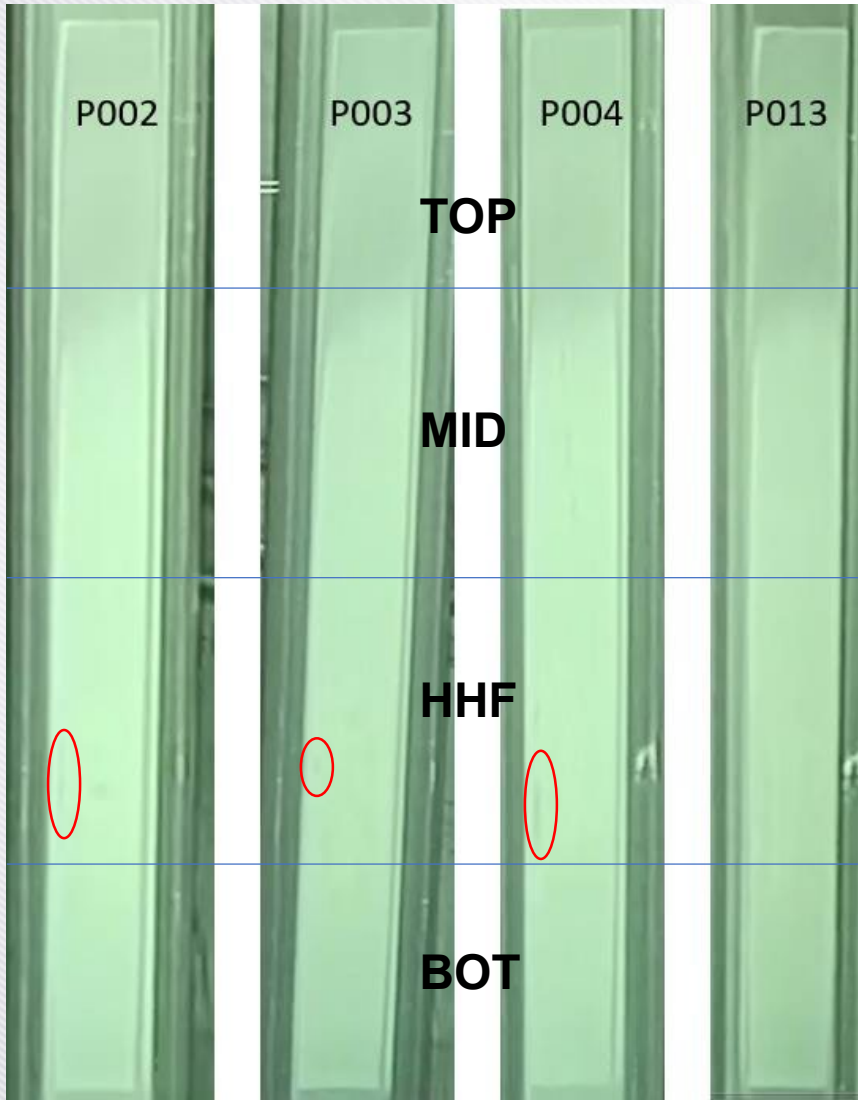
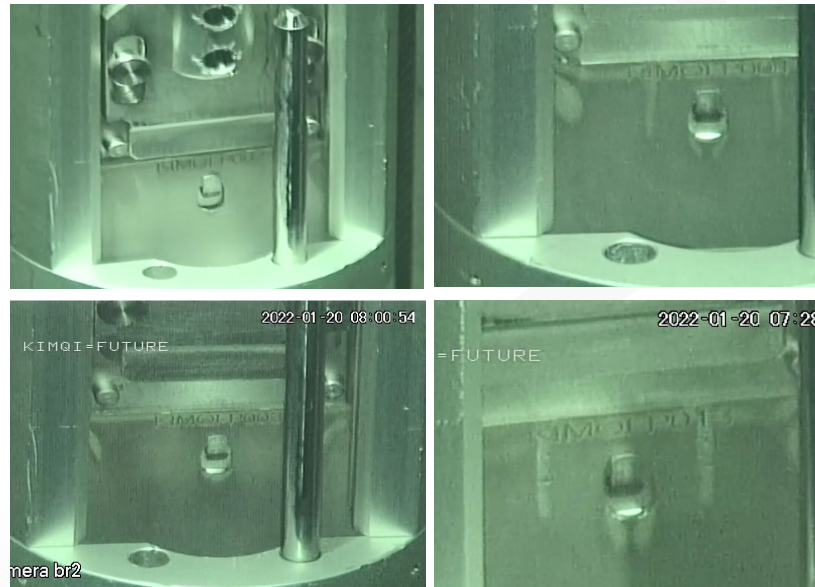


Plate ID	ID verified	TOP	MIDDLE	HHF	BOTTOM	SLIDE IN	Leak detection
KIMQI-P002	Yes	Clean	Clean	Minor Shading	Clean	Easy	No fission products detected
KIMQI-P003	Yes	Clean	Clean	Minor Shading	Clean	Easy	
KIMQI-P004	Yes	Clean	Clean	Minor Shading	Clean	Easy	
KIMQI-P013	Yes	Clean	Clean	Clean	Clean	Easy	



- All IDs verified
- Generally clean surface
- Some minor shading observed in the lower 2/3 section (corresponding to high heat flux region)
- All plates slide easily in and out of the basket indicating no remarkable dimensional changes

03-6 Burnup Distributions after 2nd Cycle

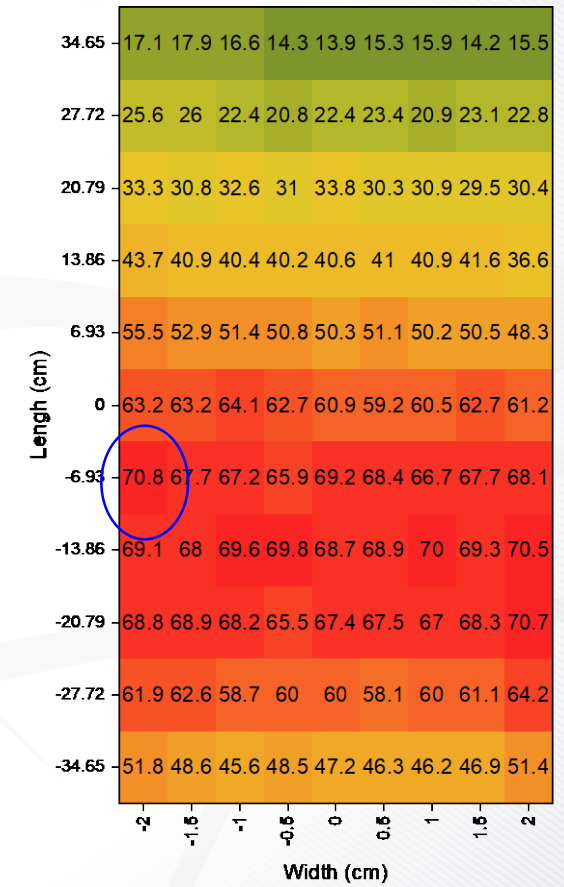
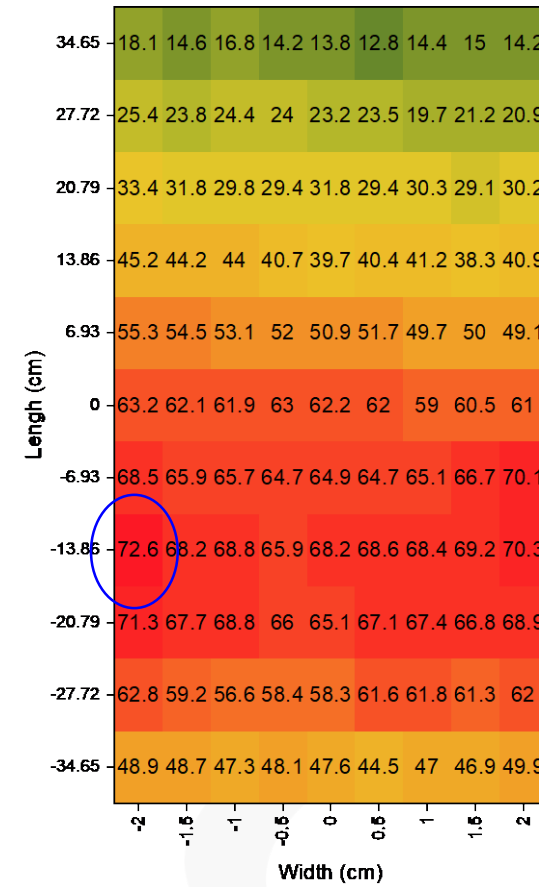
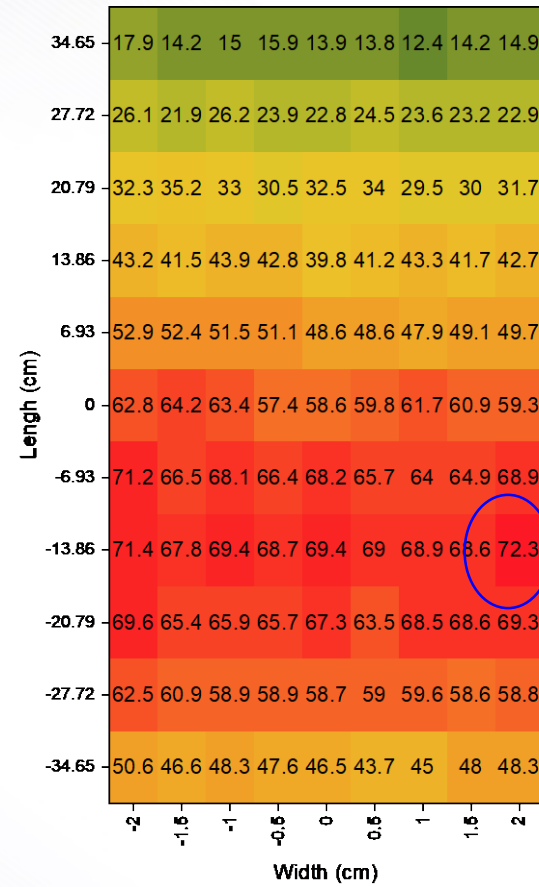
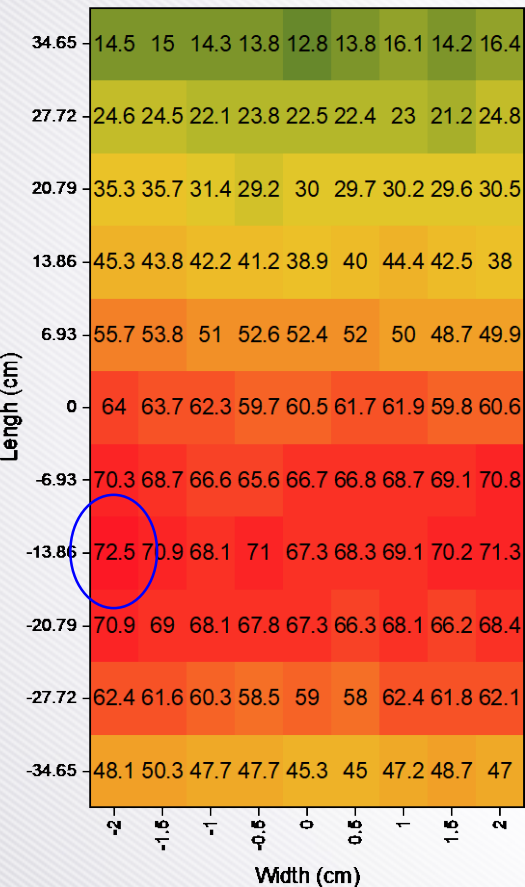
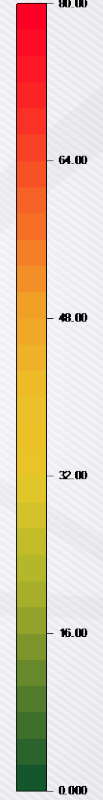
KIMQI-P002

KIMQI-P003

KIMQI-P004

KIMQI-P013

Bumup
(% U-235)



Max: 72.5 %
Avg: 48.9 %

Max: 72.3 %
Avg: 48.6 %

Max: **72.6 %**
Avg: 48.6 %

Max: 70.8 %
Avg: 48.9 %

03-7 Visual Inspection after 2nd Irradiation Cycle

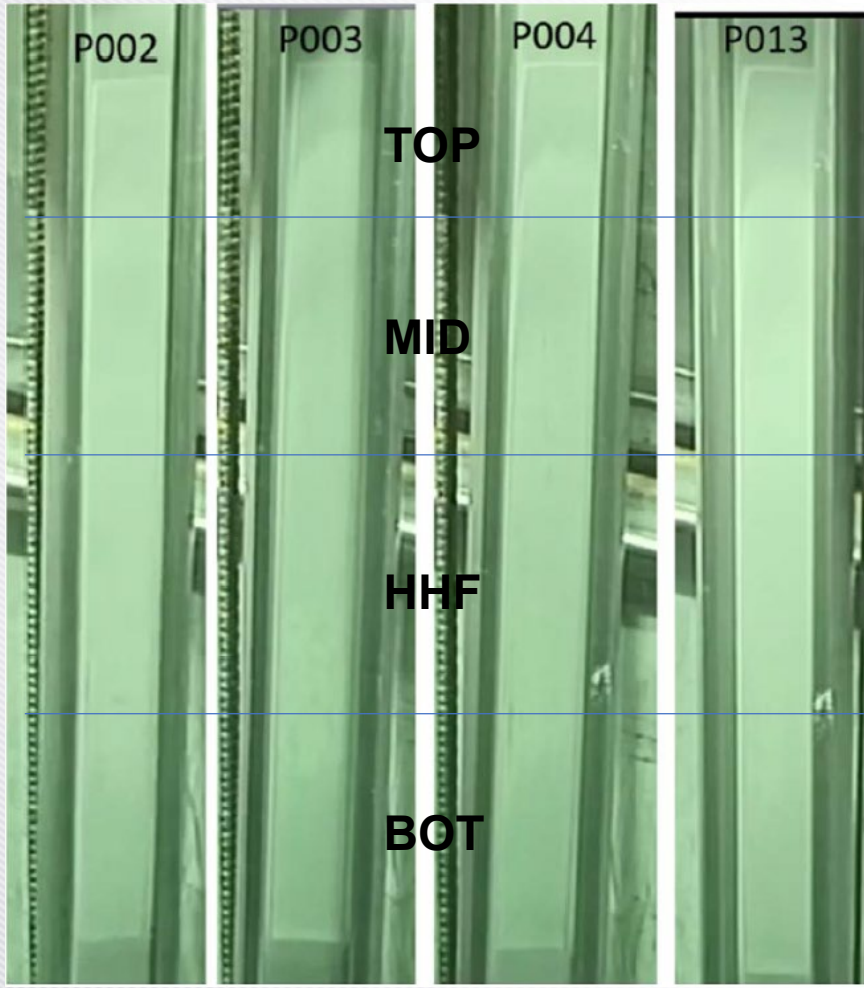
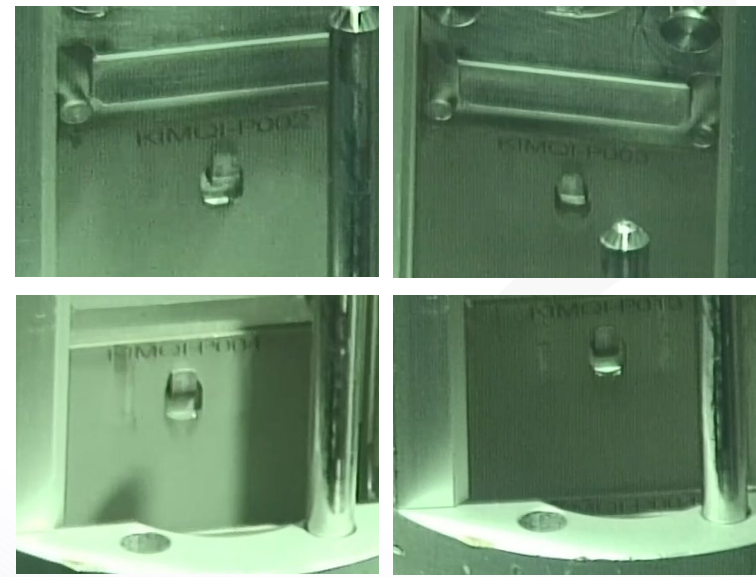


Plate ID	ID verified	TOP	MIDDLE	HHF	BOTTOM	SLIDE IN	Leak detection
KIMQI-P002	Yes	Clean	Clean	Minor Shading	Clean	Easy	
KIMQI-P003	Yes	Clean	Clean	Minor Shading	Clean	Easy	No fission products detected
KIMQI-P004	Yes	Clean	Clean	Minor Shading	Clean	Easy	
KIMQI-P013	Yes	Clean	Clean	Minor Shading	Clean	Easy	



- All IDs verified
- Generally clean surface
- Some minor shading observed in the lower 2/3 section (corresponding to high heat flux region)
- All plates slide easily in and out of the basket indicating no remarkable dimensional changes

04

Summary and Future Works

04 Summary and Future Works

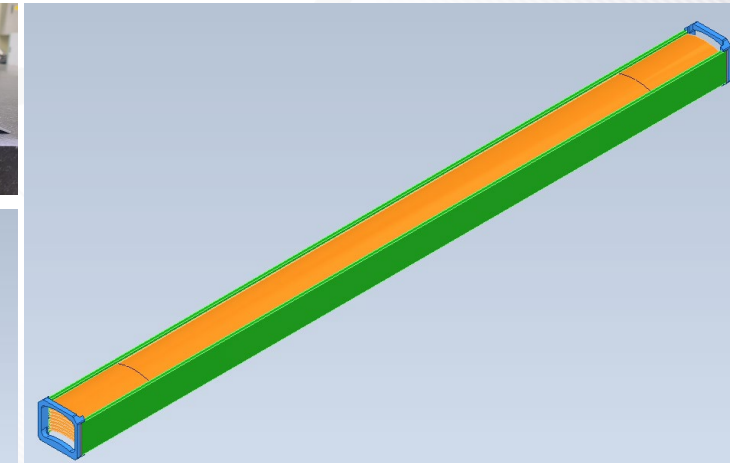
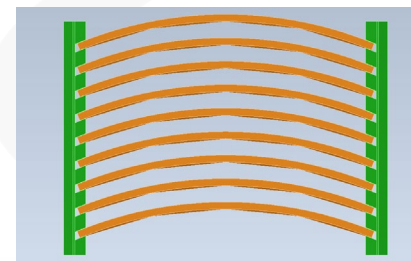
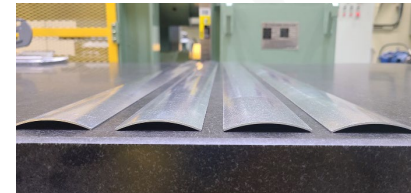
» KIMQI-FUTURE Irradiation were completed successfully.

- All KIMQI-FUTURE plates were irradiated without any remarkable problems and achieved target heat flux and burnup.
- Non-destructive and destructive PIE will be completed in 2023.

» KIMQI-GTA Irradiation will be started in 2023.

- High-density U_3Si_2 curved fuel assembly will be fabricated and irradiated in 2023 with a similar irradiation condition of KIMQI-FUTURE.

Plate ID	Peak Heat Flux BOC1 (W/cm ²)	Peak Burnup EOC2 (% U-235)	Visual Inspection Results
KIMQI-P002	464	72.5	Only minor shading, No remarkable dimensional changes, No FPs release
KIMQI-P003	450	72.3	
KIMQI-P004	473	72.6	
KIMQI-P013	460	70.8	





THANK YOU



Korea Atomic Energy
Research Institute