Evaluation of Thermal-Hydraulic Performance for HANARO Irradiation Test of High Density LEU Target

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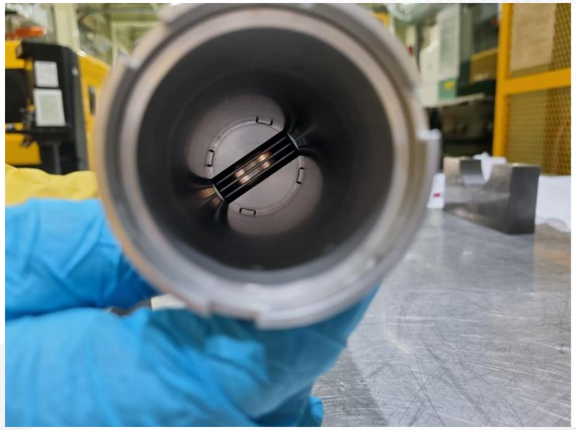
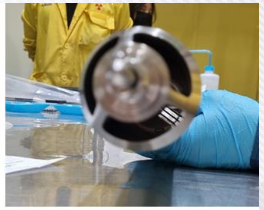
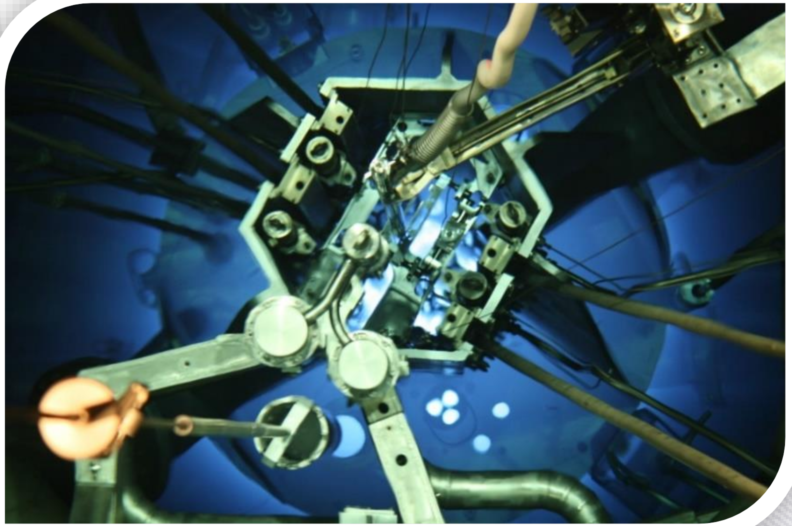






Backgrounds – (1)

◆ **Test objectives : Verification of in-core performance of high density LEU target manufactured by centrifugal atomization technology**

- Conversion from HEU(High Enriched Uranium) to LEU(Low-)

- Increase of fission ^{99}Mo production efficiency
- Reduction of radioactive waste amount

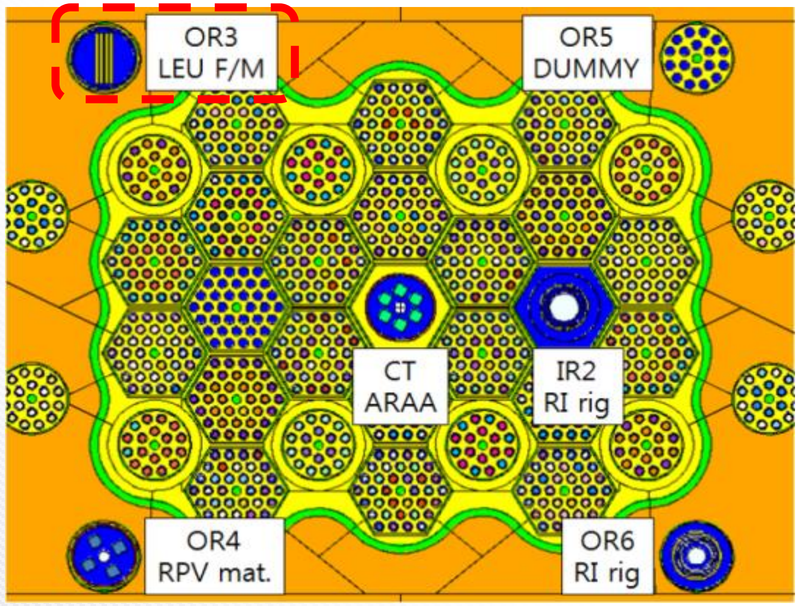
◆ **Outlines**

- Materials : 2 plates of **3.2 gU/cc** and 2 plates of **4.0 gU/cc**
- Test requirement : Target burnup > U-235 depletion of 10%
- Test facility : HANARO (OR4 irradiation hole)

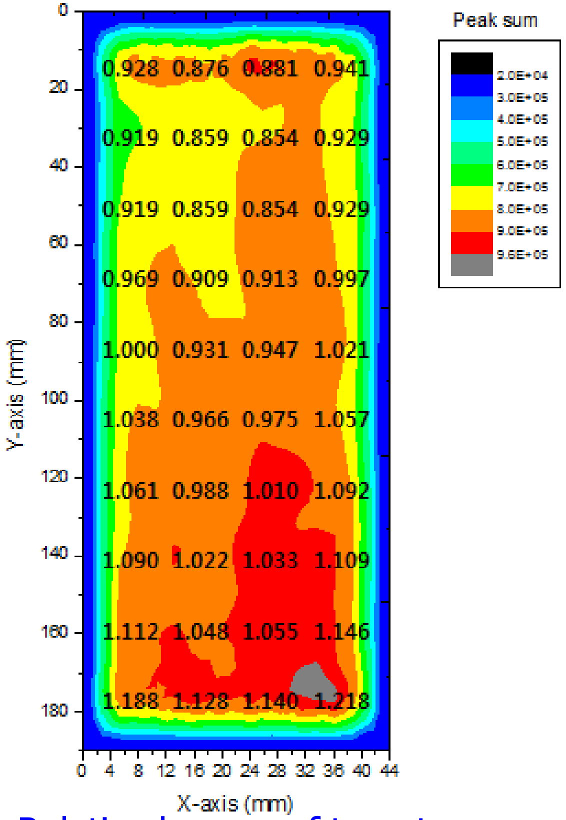
Backgrounds – (3)

◆ Test history

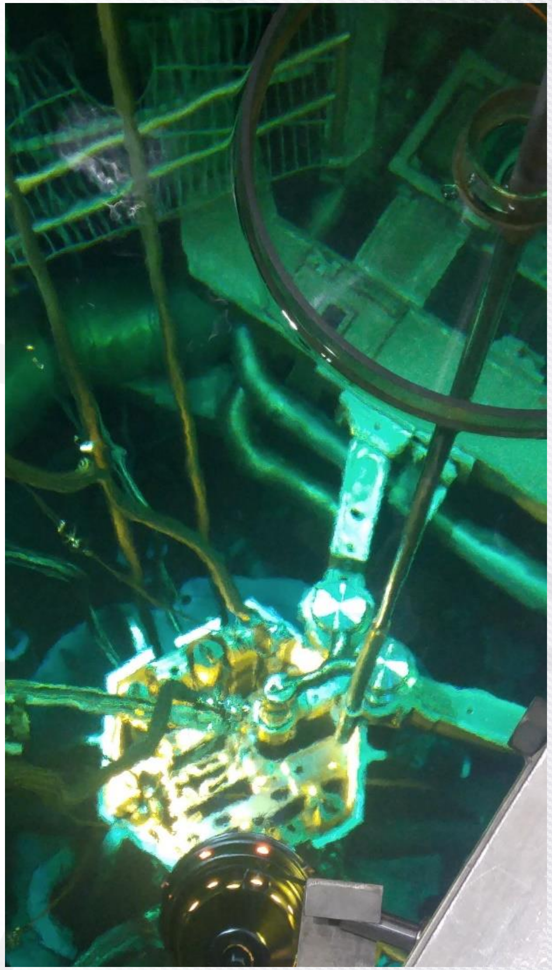
- Irradiation of 6 plates of **2.6 gU/cc** at HANARO OR3 in 2018
  - ✓ To be applied at KJRR
- Burnup : U-235 depletion up to 10.57%
- Effect of uranium loading amount??



MCNP model for KJRR target irradiation (OR3)



Relative burnup of target
(color : gamma scanning, number : burnup calculation)

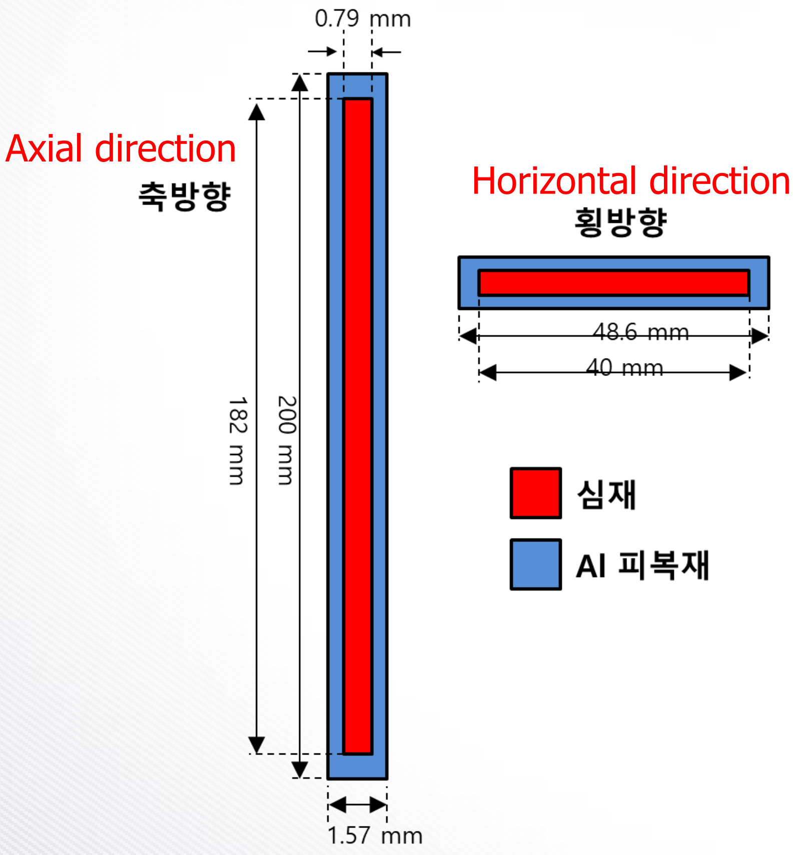


Test rig loading

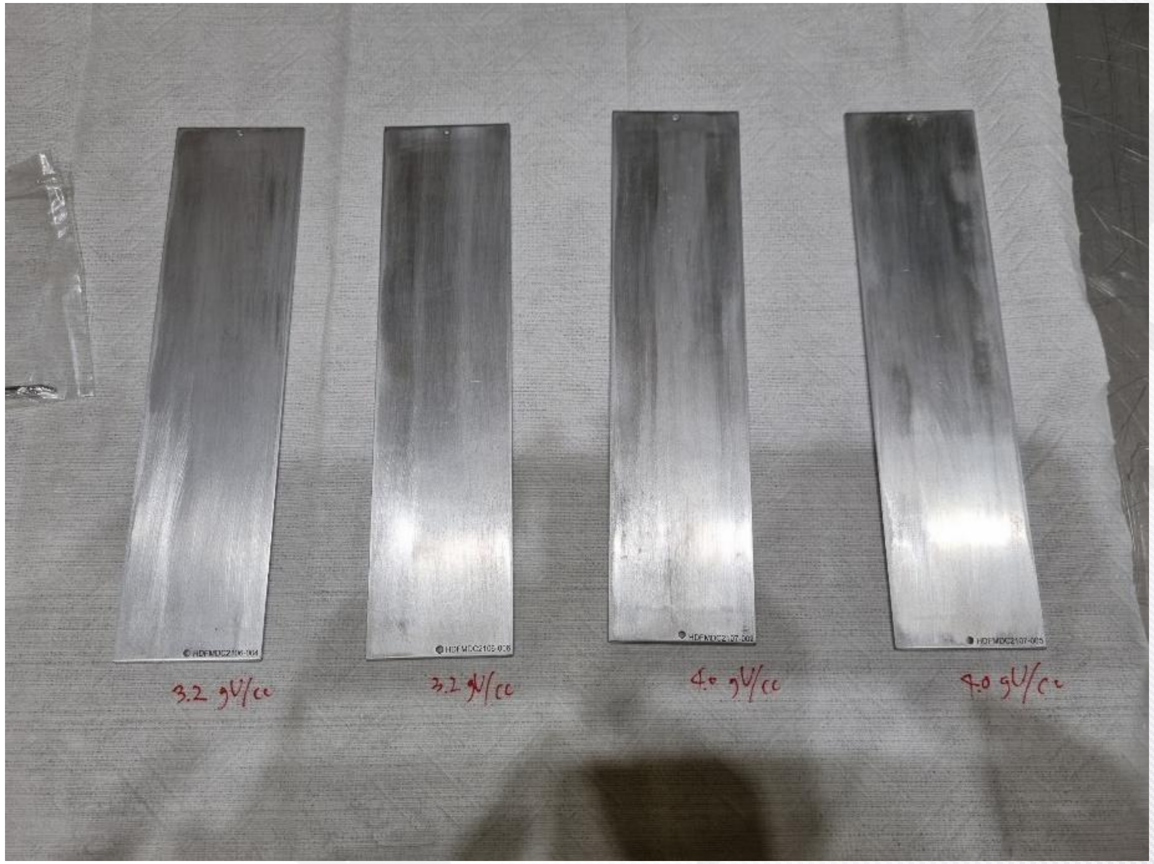
Target and Test Rig – (1)

◆ LEU targets : 4 plates

- Manufactured by centrifugal atomization technology



Design of target

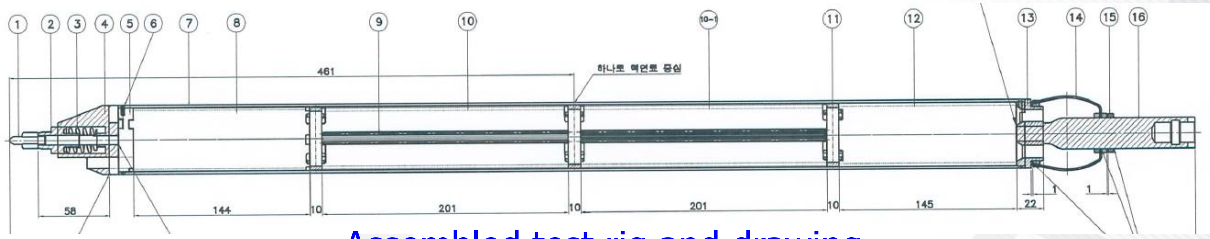


Manufactured target

Target and Test Rig – (2)

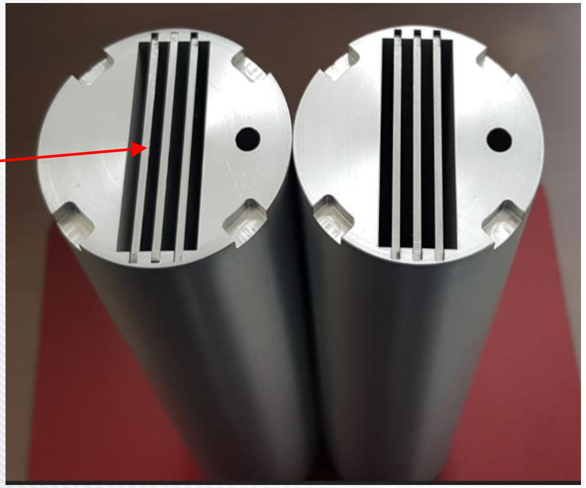
◆ Test rig (ID: 20F-02K)

- Target installation in housing cluster
- Both side cooling by coolant
- Total 6 plates : 4 targets, 2 dummies
- Same design with KJRR target test



Assembled test rig and drawing

LEU target



Upper and lower housing cluster

Upper housing cluster (assembled)

Lower housing cluster (assembled)

Out-of-reactor hydraulic test – (1)

◆ To measure hydraulic characteristics

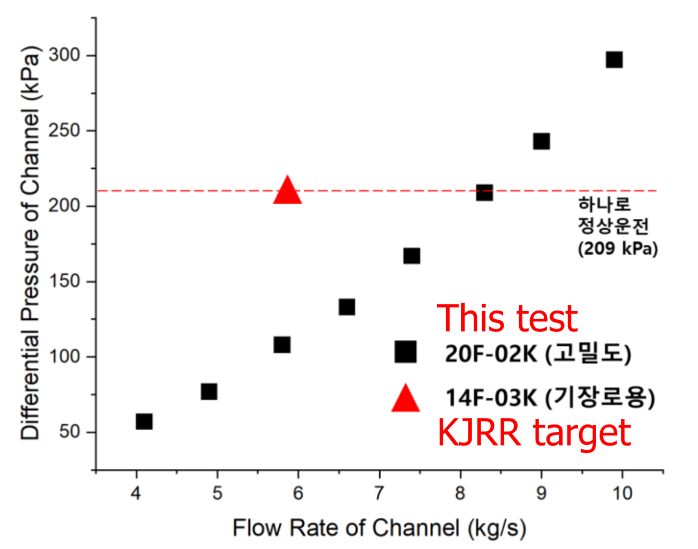
- Test facility : Single channel test loop in KAERI
  - ✓ Simulating single channel of HANARO (test hole)
- Test items
  - ✓ Measurement of flow rate and differential pressure
    - – Flow rate of channel
    - – Evaluation of cooling flow rate for test targets by measurement of differential pressure of bypass flow
  - ✓ Measurement of vibration
    - – by LDV(Laser Doppler Vibrometer)
    - – Measurement of displacement by flow-induced vibration
    - – Evaluation of frequency
  - ✓ Endurance test : Omission (<u>Relative short test duration</u>!!!!)

Rig hydraulic test

Out-of-reactor hydraulic test – (2)

◆ Measurement of channel flow rate

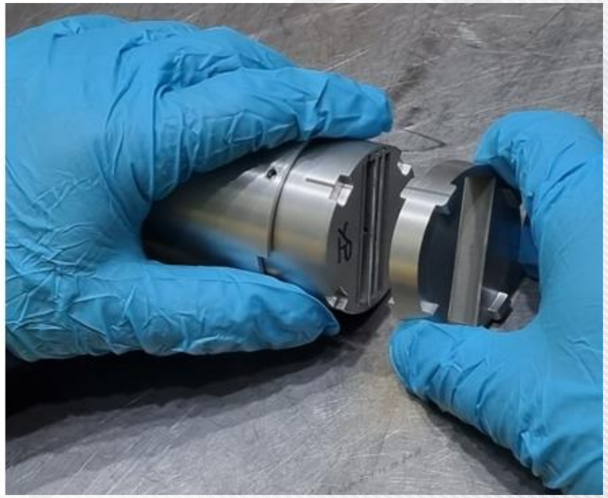
- Observation of difference with KJRR target test
  - ✓ Why? Target and test rig are same design!!!
- Main reason : Misassembling housing cluster and housing cap
  - ✓ Blockage of coolant channel by housing cap
  - ✓ Confirmed by verification test : Assembling is very important to maintain cooling capability!!!



Measurement of channel flow rate

Test name	Rig	Channel flow rate (kg/s)
HANARO fuel (dummy)	Cylindrical assembly	12.7
14F-03K	KJRR target test rig	6.15
20F-02K	High density target test rig	8.3

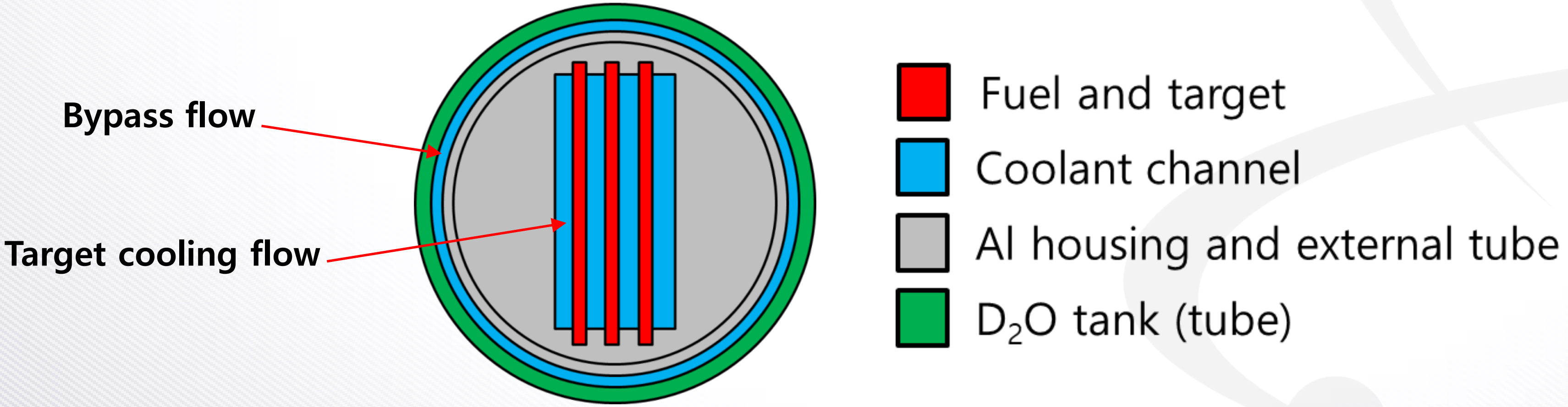
Comparison of channel flow rate


Assembling between housing cluster and housing cap

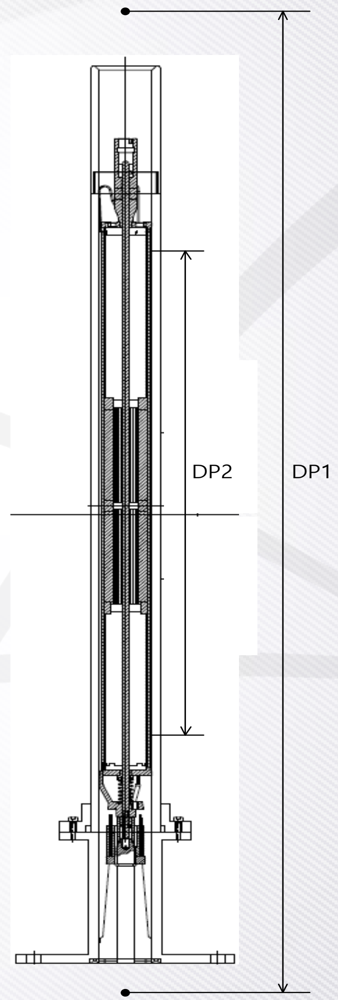
Out-of-reactor hydraulic test – (3)

◆ Evaluation of target cooling flow rate

- Measurement of bypass flow differential pressure (DP2)
  - ✓ Consideration of design value, coolant information
- Target cooling flow rate = channel flow rate (DP1) – bypass flow rate (DP2)
  - ✓ Conservative assumption : Bypass flow of 120% (low cooling rate)
  - ✓ Test system uncertainty : 5%
- Target cooling flow rate : 4.18 kg/s



Coolant flow path of test rig (horizontal cross section)



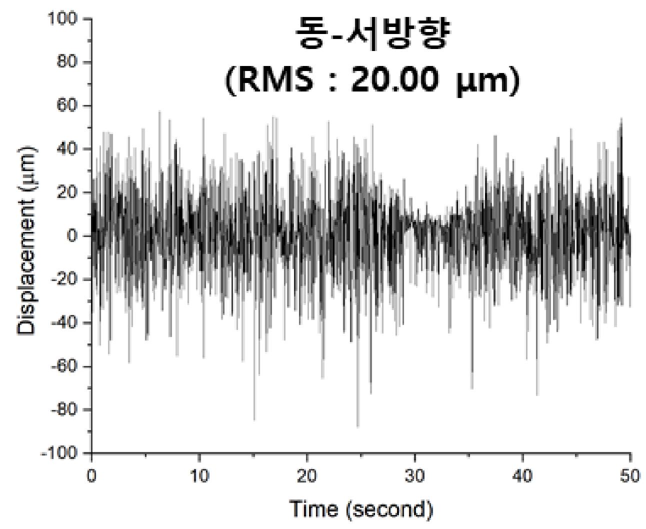
Measurement point of differential pressure

Out-of-reactor hydraulic test – (4)

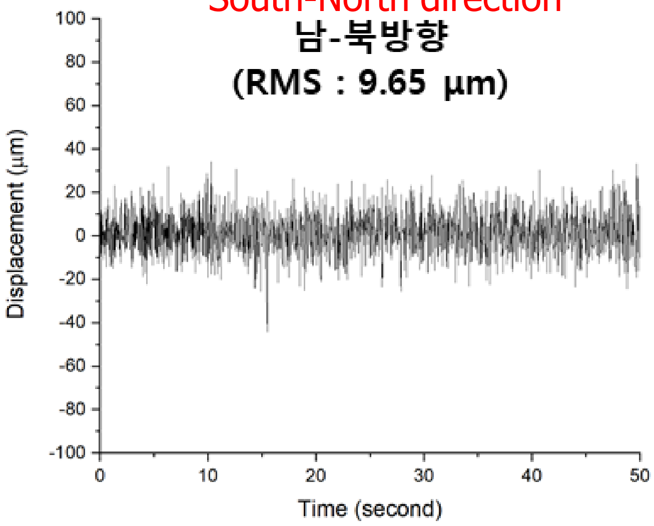
◆ Measurement of vibration

- Measured by LDV(Laser Doppler Vibrometer)
  - ✓ Measuring point : grapple head of test rig
- Similar with KJRR target test rig
  - ✓ RMS displacement : ~ 20 μm (criteria : < 300 μm)
  - ✓ No resonance frequency

East-West direction



South-North direction



Vibration displacement of test rig

Measuring equipment

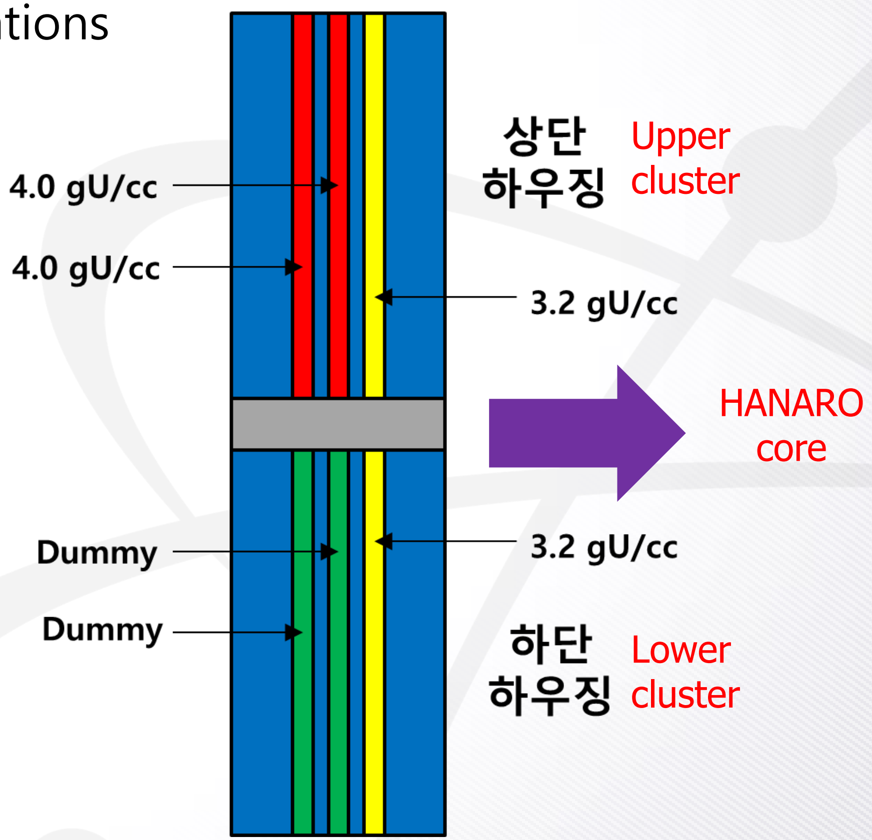
Thermal-Hydraulic Evaluations – (1)

◆ Heat flux of target

- Conservative evaluation (Assumption)
  - ✓ The Highest heat flux result among the various evaluations
    - – HANARO operation cycle 99-1, 97-3 model
  - ✓ Misload of target and direction
    - – All 4.0 gU/cc targets installation in upper cluster
  - ✓ No target depletion

Unit : W/cm^2		Beginning of cycle (268.9 mm)		Middle of cycle (423.0 mm)		End of cycle (545.1 mm)	
		Avg.	Max.	Avg.	Max.	Avg.	Max.
Lower	plate03	175.2	204.7	197.4	212.9	192.1	217.6
Upper	plate04	124.1	171.1	148.3	218.1	172.3	228.5
	plate05	117.3	168.6	140.9	215.1	164.8	229.1
	plate06	125.7	172.6	151.7	224.5	178.4	237.8

Heat flux of targets



Location of target installation

Thermal-Hydraulic Evaluations – (2)

◆ TH performance and safety analysis

- Code : TH_Calc Win 1.0a
  - ✓ TH analysis and thermal margin evaluation for the core using plate type fuel
  - ✓ Validation : Similar performance with TMAP (KJRR licensing code)

◆ Safety evaluation criteria

- Target plate : the highest heat flux target in upper and lower cluster
- Criteria
  - ✓ **Normal operation,**
    - **ONB temperature margin > 3℃**
  - ✓ **Accident condition, (control rod absorber withdrawal/locked rotor of pump)**
    - **Target temperature (meat) < 400℃**
    - **MCHFR > 1.5**

Thermal-Hydraulic Evaluations – (3)

◆ Uncertainty

- Consideration of manufacturing value of target and test rig

Item	Uncertainty	F_q	F_b	F_f
U-235 homogeneity (local)	0.200	1.200		1.200
U-235 loading per plate	0.020	1.020	1.010	1.020
core calculation	0.150	1.150	1.075	1.150
cannel spacing	0.040		1.071	1.015
Random error combined		1.251	1.104	1.251
Power measurement	0.050	1.050	1.050	1.050
Heat transfer coefficient	0.200			1.200
Systematic error combined		1.050	1.050	1.260
Total		**1.313**	**1.159**	**1.577**

Thermal-Hydraulic Evaluations – (4)

◆ Safety analysis under normal operation

- Violation of criterion under normal operation at 30 MW : ONB temperature margin
  - ✓ Under 27 MW, the criterion will be met.

30 MW, ☹	Lower target (3.2 gU/cc)		Upper target (4.0 gU/cc)	
Mode	B.E.	C.E.	B.E.	C.E.
Average heat flux (W/cm^2)	197.4		178.4	
Power peaking factor	1.133		1.333	
Housing exit coolant temperature (℃)	39.29	40.15	44.52	46.08
Target surface temperature (℃)	70.06	92.97	104.87	152.24
Cladding temperature (℃)	78.14	104.55	122.12	176.89
Target meat temperature (℃)	99.75	135.49	214.95	309.52
ONB temperature margin (℃)	79.32	55.13	42.73	-5.91
CHFR	9.29	6.48	4.01	2.80

27 MW, ☺	Lower target (3.2 gU/cc)		Upper target (4.0 gU/cc)	
Mode	B.E.	C.E.	B.E.	C.E.
Average heat flux (W/cm^2)	177.66		160.56	
Power peaking factor	1.133		1.333	
Housing exit coolant temperature (℃)	38.96	39.74	43.72	45.12
Target surface temperature (℃)	66.77	87.50	98.15	140.87
Cladding temperature (℃)	74.06	97.93	113.68	163.06
Target meat temperature (℃)	93.54	125.82	197.22	282.42
ONB temperature margin (℃)	82.60	60.61	49.45	5.46
CHFR	10.42	7.27	4.47	3.13

Thermal-Hydraulic Evaluations – (5)

◆ Safety analysis under accident condition : OK!! (satisfaction)

	Lower target (3.2 gU/cc)		Upper target (4.0 gU/cc)	
Mode	RIA	LOFA	RIA	LOFA
Average heat flux (W/cm^2)	177.66		160.56	
Power peaking factor	1.133		1.333	
Housing exit coolant temperature (℃)	40.90	42.69	47.80	51.90
Target surface temperature (℃)	102.93	116.98	172.48	200.59
Cladding temperature (℃)	116.59	127.42	201.54	222.78
Target meat temperature (℃)	153.13	155.30	357.90	342.14
ONB temperature margin (℃)	45.17	30.42	-26.15	-56.83
CHFR	5.53	6.68	2.36	2.74

Conclusions and Current Status

◆ Conclusions

- ✓ The results of the hydraulic test showed a difference from the test results with KJRR target test despite same design. This was found to be due to misassembled housing cluster cover during the out-of-reactor hydraulic test. Therefore, there should be no mistake in the process of assembling the rig for the target test. It should be confirmed during the assembling between the rig and target.
- ✓ As the result of the safety analysis, it was confirmed that the ONB temperature margin at the full power (30 MW_{th}) operation exceeded the allowable criterion. It was satisfied at 27 MW_{th}, so HANARO should be operated with less than 27 MW_{th} for high density LEU target testing.
- ✓ When accident condition was assumed, all acceptable criteria were met from the safety evaluation.

◆ Current status

- ✓ The test of high density LEU targets is running without any problem!!

  (HANARO 101 operation cycle, Reactor power : 25 MW)