Fluence Monitor Design for Irradiation Test at CT and IP hole of HANARO

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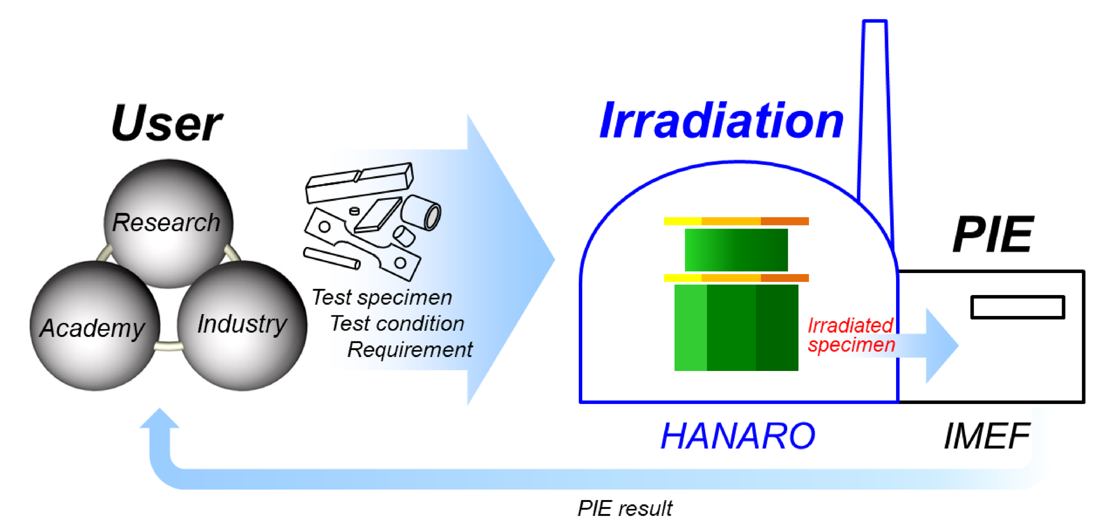
Introduction

"Irradiation Test"

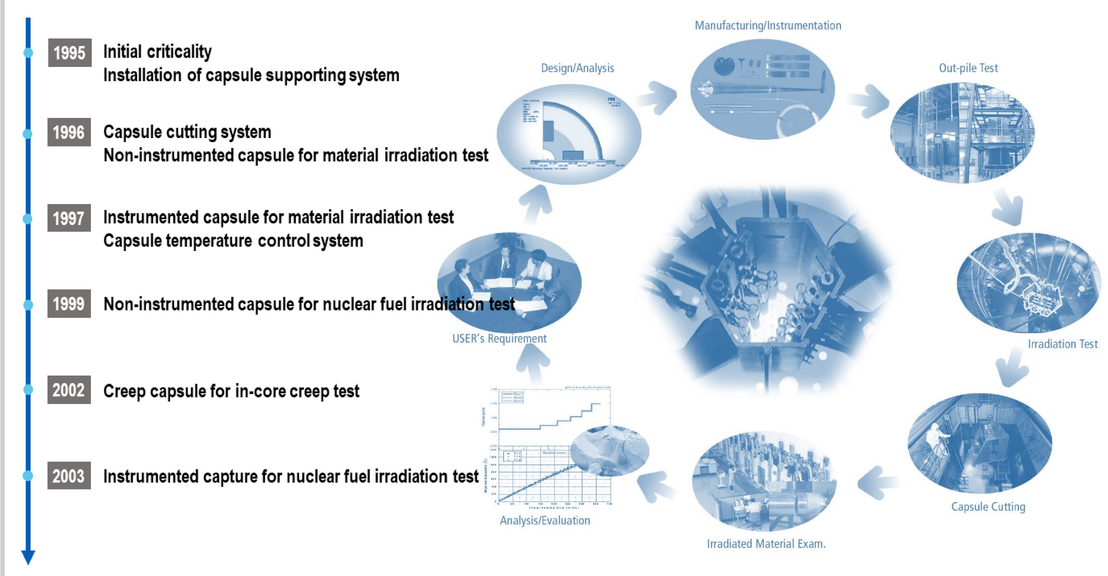


- "Irradiation Test" : An important process for evaluating the durability and safety of materials
- Procedure : Sample selection & fabrication → Determination of irradiation condition → Fabrication of irradiation device (e.g., capsule) → Irradiation → Measurement of conditions (dose/temperature/etc.) → Material analysis

Role of HANARO Members

- Playing a significant role in the development or verification of new materials and system in the field of nuclear energy industries.

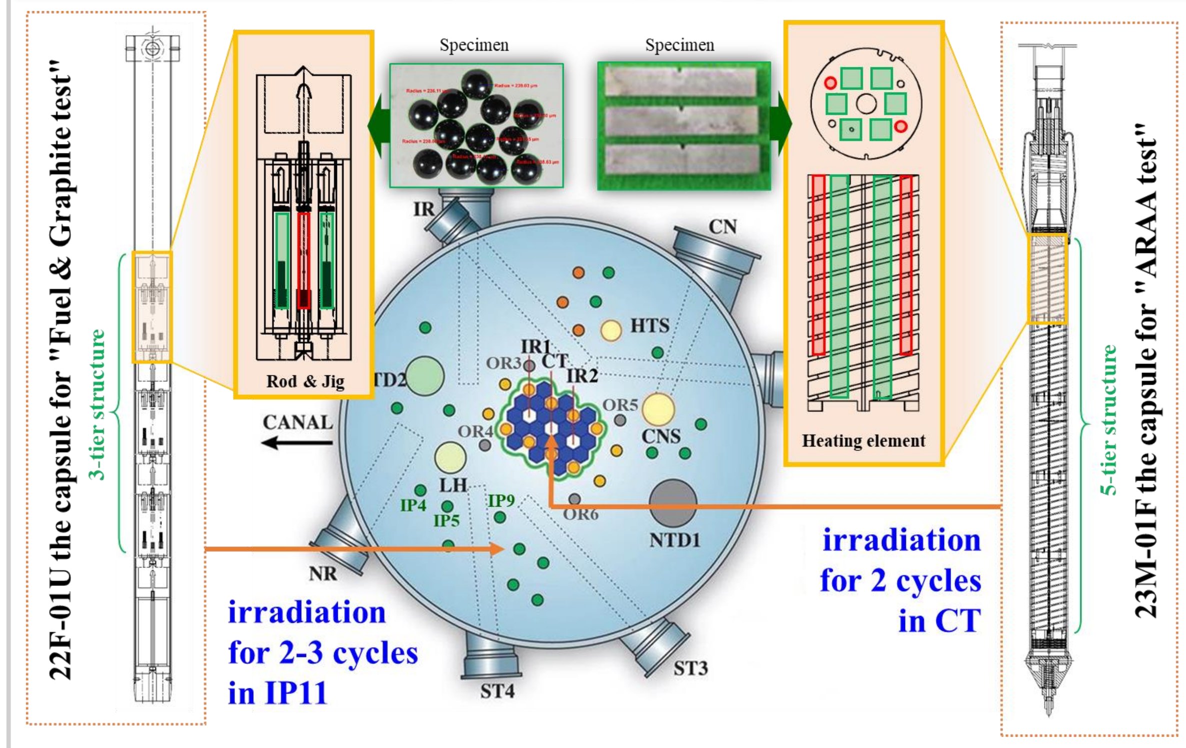
Irradiation Test at HANARO



- "HANARO reached its first criticality in 1995, and various test equipments were developed for domestic user's requirements.
- The neutron dose on the samples from irradiation test at HANARO has been evaluated using both FM measurements and MCNP code calculation.
- Discrepancy of 10-20% has been shown between the measurement and calculation.

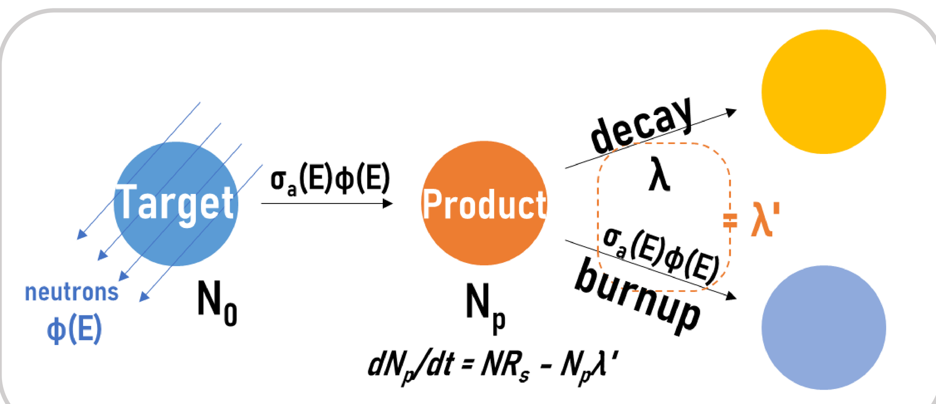
HANARO : High-flux Advanced Neutron Application ReactOr
FM : Fluence Monitor
MCNP : Monte Carlo N-Particle

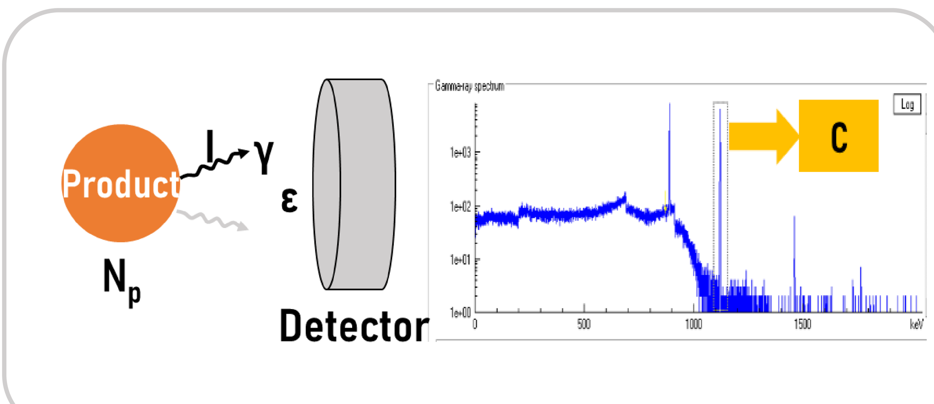
Irradiation Tests in progress (2024 currently)

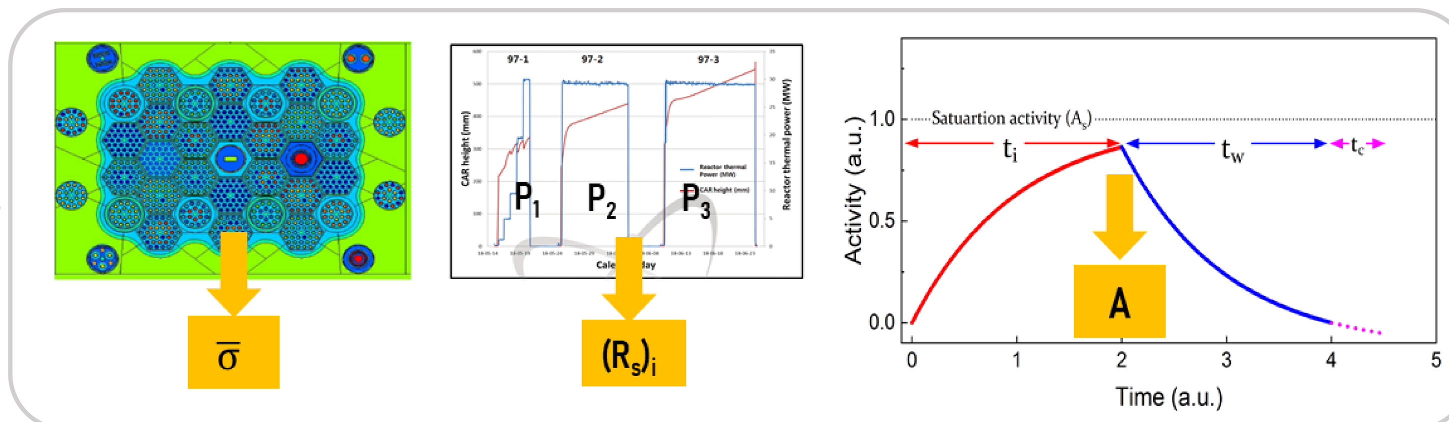


- In 2024, new irradiation tests for nuclear fusion reactor materials and, validation of the quantitative analysis of elements for non-proliferation are scheduled at HANARO.
- FMs such as Ni, Fe, Nb and Co wire for thermal and fast neutron measurements was addressed for these tests.

Dose Evaluation Methodology using FM for long-term irradiation







Variation in neutron flux due to reactor operation | Product loss due to reactions | Depletion of target atoms ← Considerations in long-term irradiation test

Details are described in ASTM E261

Evaluation & Fabrication (23M-01F "ARAA capsule" case)

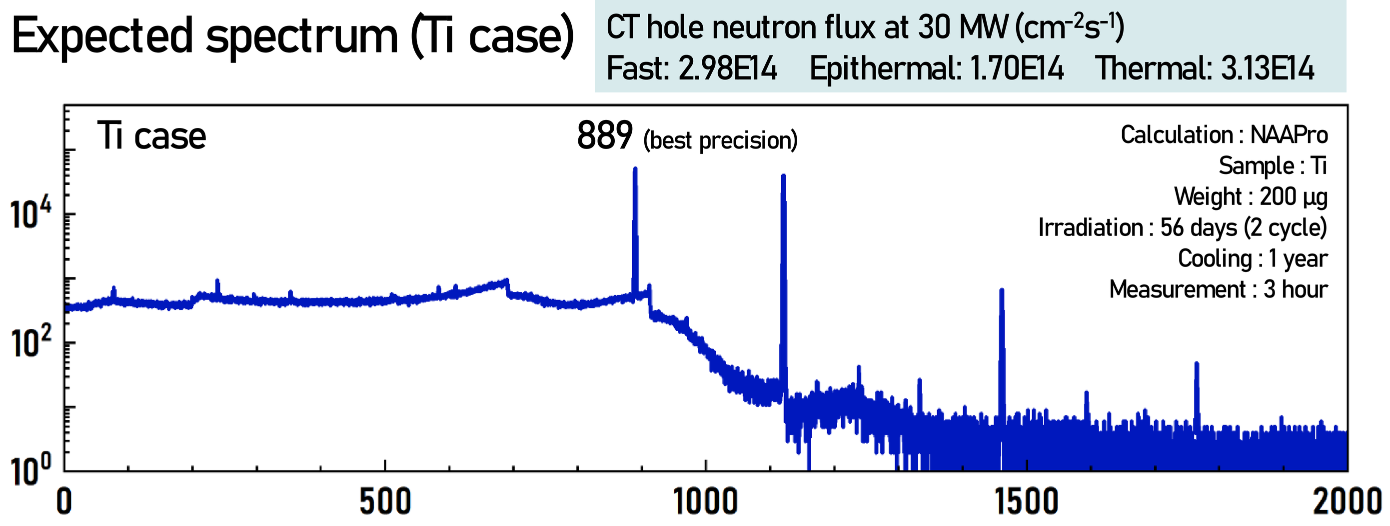
- Selected FMs for fast neutron dose measurement

Element	Reaction	Energy response range (MeV)			σ uncertainty (%)	Gamma energy (keV)
		Low	Median	High		
Nb	$^{93}Nb(n,n')^{93m}Nb$	0.951	2.57	5.79	3.01	31
	$^{93}Nb(n,g)^{94}Nb$	-	-	-	-	703
	$^{94}Nb(n,g)^{95}Nb$	-	-	-	-	766
Ti	$^{47}Ti(n,p)^{47}Sc$	1.70	3.63	7.67	3.77	159
	$^{46}Ti(n,p)^{46}Sc$	3.70	5.72	9.43	2.48	889, 1121
	$^{48}Ti(n,p)^{48}Sc$	5.92	8.06	12.3	2.56	
	$^{47}Ti(n,\alpha)^{44}Ca$	2.80	5.10	9.12	-	
Ni	$^{58}Ni(n,p)^{58}Co$	1.98	3.94	7.51	2.44	811, 864, 1675
	$^{58}Ni(n,\alpha)^{55}Fe$	2.74	5.16	8.72	-	126
	$^{60}Ni(n,p)^{60}Co$	4.72	6.82	10.8	10.3	1173, 1332
Fe	$^{54}Fe(n,p)^{54}Mn$	2.27	4.09	7.54	2.12	835
	$^{56}Fe(n,p)^{56}Mn$	5.45	7.27	11.3	2.26	
	$^{56}Fe(n,\alpha)^{53}Cr$	5.19	7.53	11.3	-	
Cu	$^{63}Cu(n,\alpha)^{60}Co$	4.53	6.99	11.0	2.36	1173, 1332

■ Gamma-detectable isotope ■ Short (for long-term test) half-life isotope ■ Stable isotope

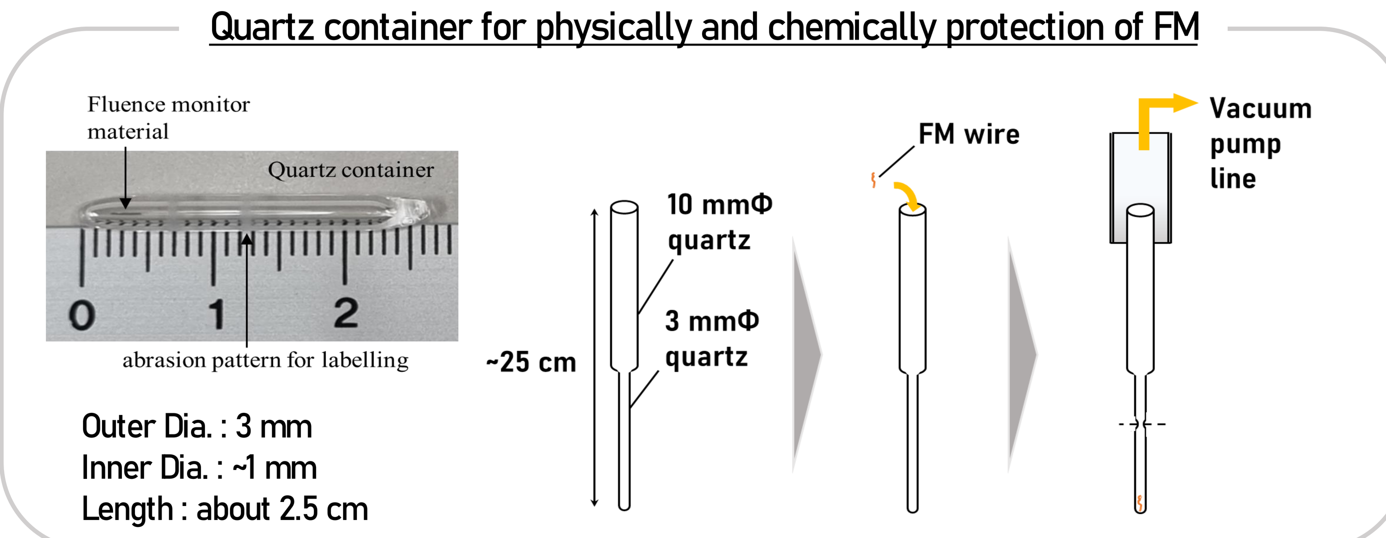
- FM activities
  - Condition : 56 days (EFPD) irradiation at CT hole, 1 year cooling
  - Specific activity of all FMs was ranged between 0.002 and 0.5 Ci/g.
- Expected spectrum (Ti case)

CT hole neutron flux at 30 MW ($cm^{-2}s^{-1}$)
Fast: 2.98E14 Epithermal: 1.70E14 Thermal: 3.13E14



- Fabrication of FM
  - All FMs were fabricated to weigth ~200 μg, due to impractically small size of FM below 200 μg.
  - Two kinds of containers were used.

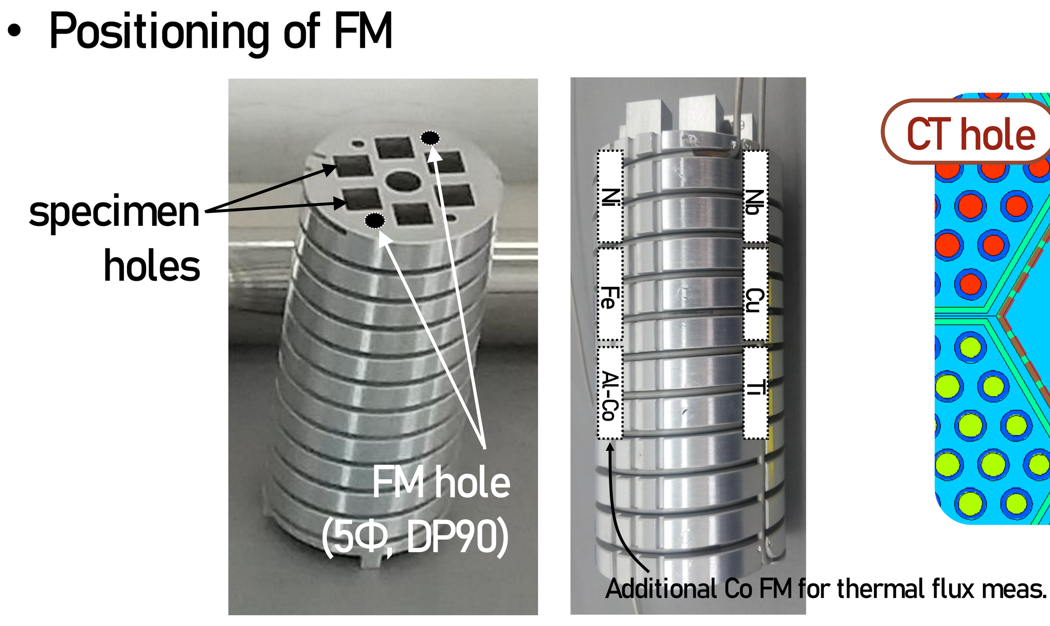
Quartz container for physically and chemically protection of FM

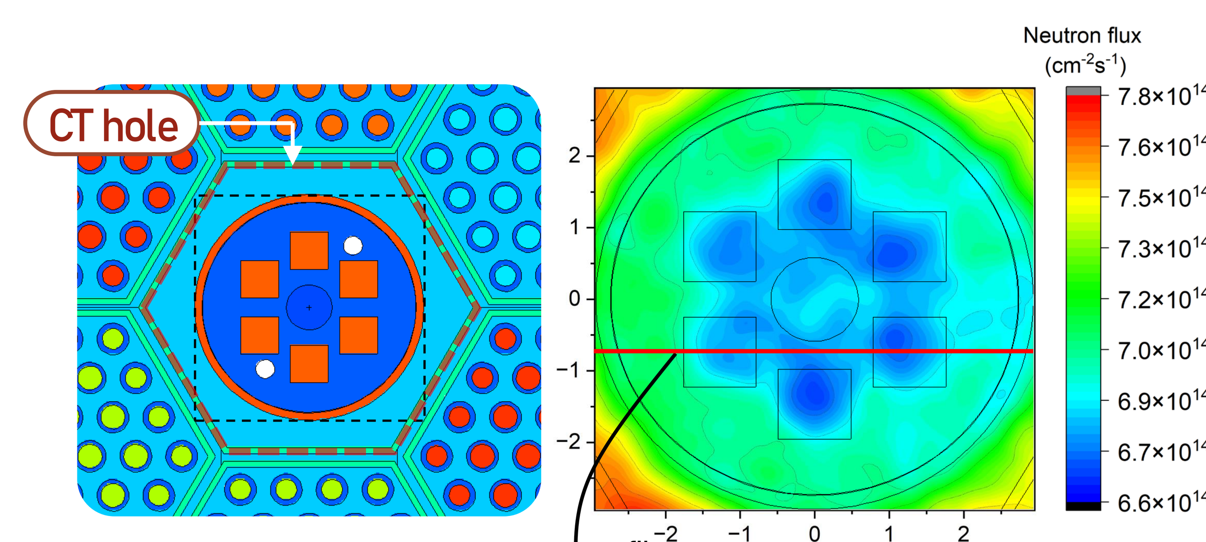


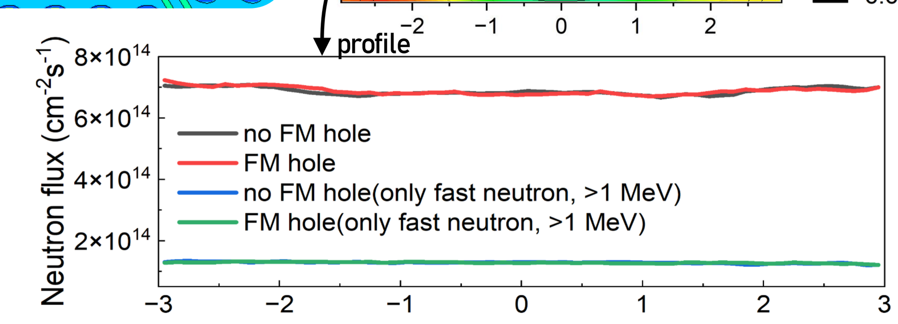
Traditional metal (Al) containers were also used

- Quartz container was sealed under a vacuum condition (about 0.001 Torr) to minimize unwanted activation.
- Each specimen is distinguished by a pattern engraved on the surface of the container through slight abrasion.

- Positioning of FM







- Making a holes (5 mm dia. and 90 mm depth) on the top of each heating materials (which is containing samples), FM containers are inserted in the holes
- This method has been previously confirmed to ensure no heat transfer issues with the specimen.
- Presence of FM holes does not create distortion significantly in the neutron field.

Conclusion

- We have fabricated FMs for irradiation test capsules newly loaded into the HANARO reactor in 2024
- Through ongoing experiments using various metals, we plan to enhance the accuracy of characterization of HANARO irradiation holes and performance evaluation of irradiation test in the future.

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