

# 하나로 이용 중성자 영상 및 관련 연구 현황

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2022. 10. 19

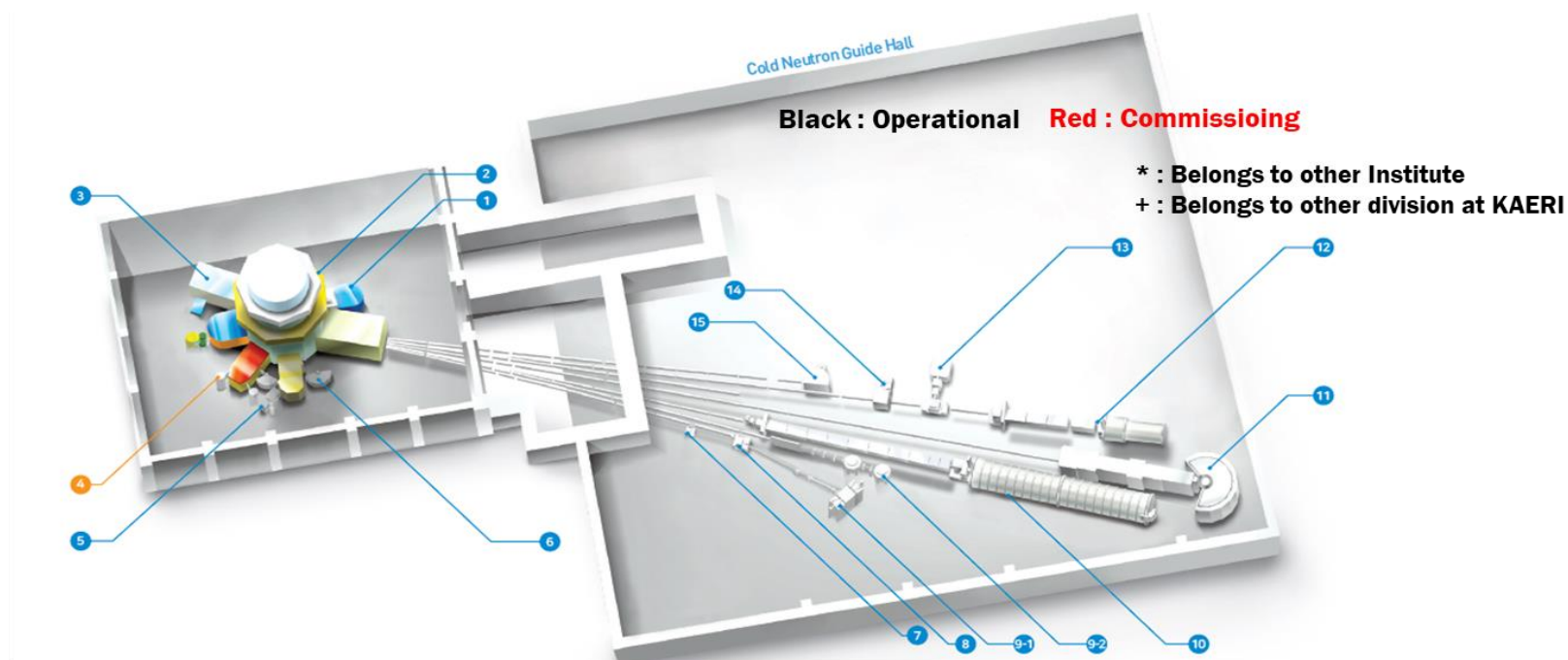
김종열 [중성자과학부]

# Contents

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1. 하나로 중성자 영상 장치(**NRF, ENF**)
2. 중성자 영상 시스템
3. 하나로 중성자 영상 실험 결과
4. 요약

# 하나로 중성자 장치



**01 Residual Stress Instrument**

**02 Ex-core Neutron irradiation Facility**

**03 Neutron Radiography Facility**

**\*04 Bio-diffractometer with neutron image plate Camera(KRIBB)**

**05 Four Circle neutron Diffractometer**

**06 High Resolution Powder Diffractometer**

**07 Guide Test Station**

**08 Vertical type REFlectometer**

**+09 Cold Neutron Activation Station**

**10 40m Small Angle Neutron Scattering instrument**

**11 Disk-Chopper Time-of-Flight spectrometer**

**12 18m Small Angle Neutron Scattering instrument**

**\*13 KIST Ultra-Small Angle Neutron Scattering instrument**

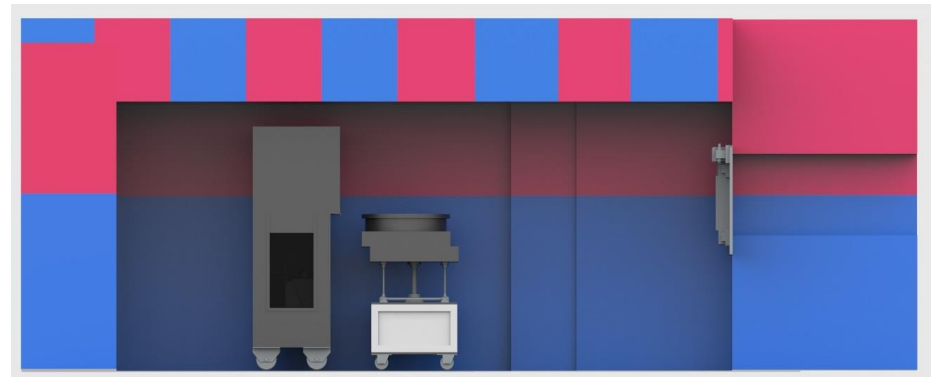
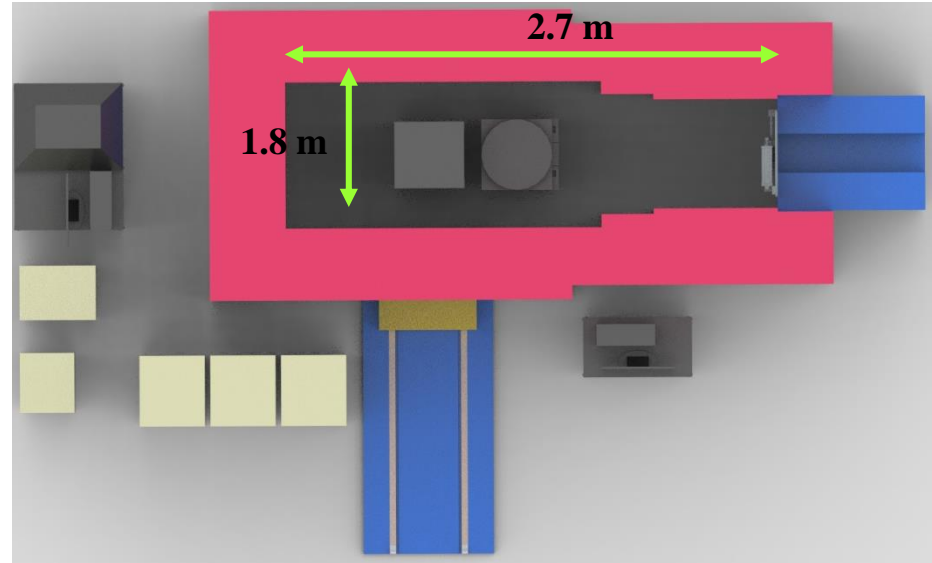
**14 Bio-REFlectometer**

**15 Cold neutron Triple-Axis Spectrometer**

# 하나로 중성자 영상 장치 (NRF)



- 물질마다 서로 다른 중성자 투과 특성을 활용하여 비파괴 검사를 수행하는 장치로 **1997**년 설치됨.
- 초기에는 필름법으로 비파괴 검사(항공기 부품 등)를 수행함.



# 하나로 중성자 영상 장치 (NRF)

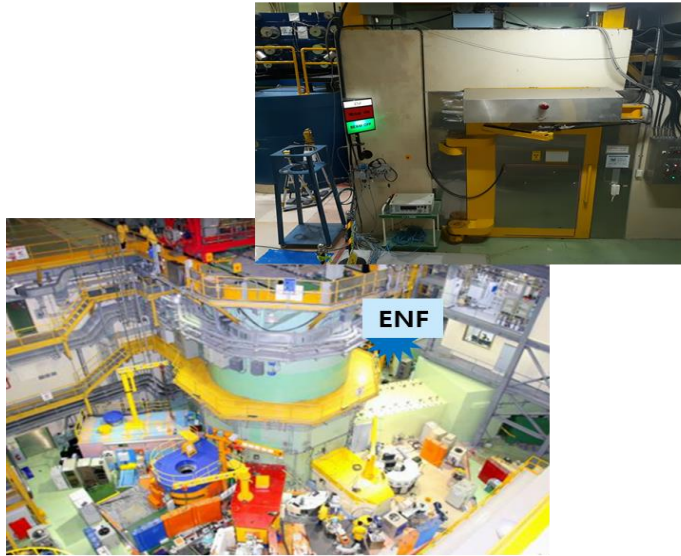


## Applications

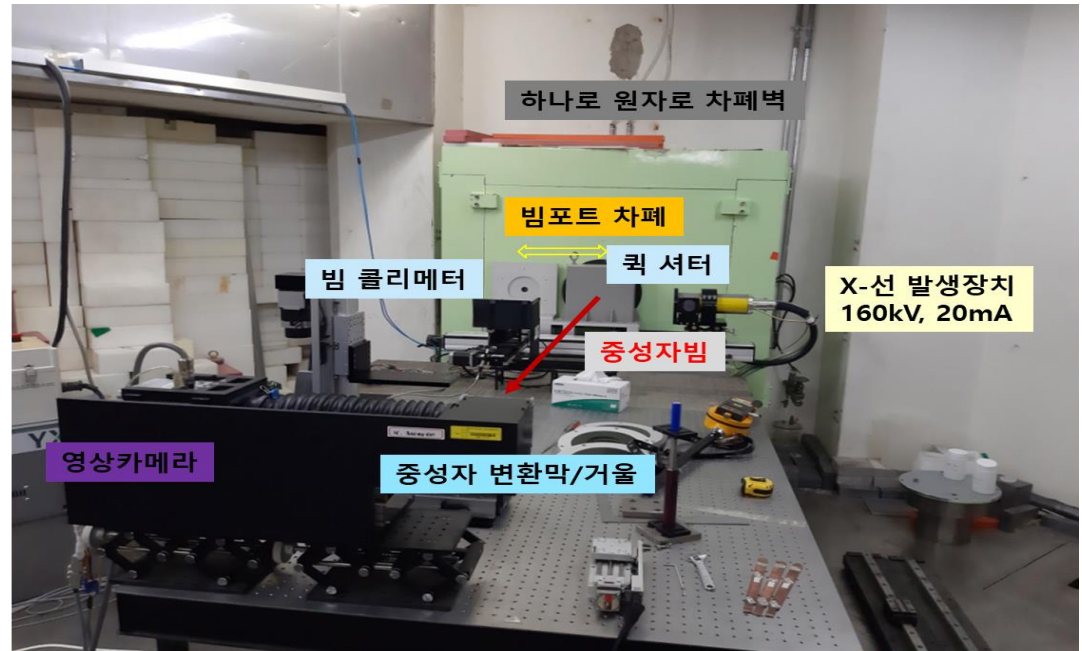
- ✓ Ordinary Non-Destructive Test
- ✓ PEM Fuel Cell Research with Hyundai-Motor
- ✓ Li-Ion Battery
- ✓ Visualization of Two-phase Flow in Heat Exchanger

	Property	Remark
Thermal neutron flux (Max)	$2.0 \times 10^7 \text{ n/cm}^2 \cdot \text{s}$	
L/D ratio	267	
Beam Size	350 x 450 mm <sup>2</sup>	
Inner space	2.7m(length)x2.0m(height)x1.8m(width)	
Imaging detector	Lens-coupled CCD camera (High Resolution: Andor, Princeton, Vers-Array, High Speed: Red Lake)	Image size: 5cm x 5cm ~ 10cm x 10cm Image resolution: 50μm ~ 150μm
	Film Method	

# 하나로 중성자 영상 장치 (ENF)



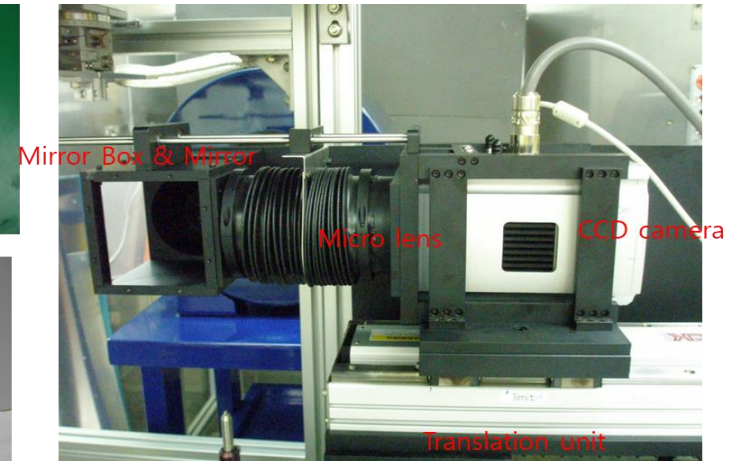
하나로 원자로



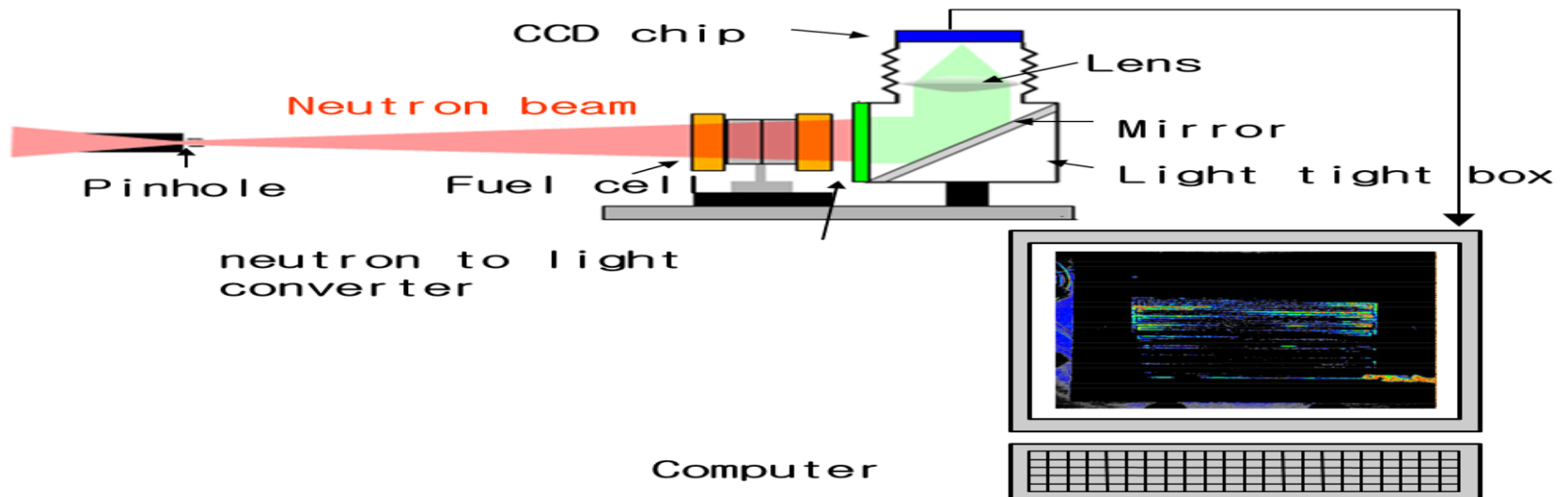
	Property	Remark
Filter	Si(D20cm, L40cm), Bi(D10cm, L15cm)	
Thermal neutron flux (Max)	$1.49 \times 10^8 \text{ n/cm}^2 \cdot \text{s}$	
Inner space	5.5m(length)x3.5m(height)x4m(width)	
Imaging detector	Lens-coupled CCD camera (Andor DW936N-BV)	Image size: 5cm x 5cm ~ 10cm x 10cm Image resolution: 50 $\mu$ m ~ 150 $\mu$ m
	Fiber optic-coupled CCD camera (Princeton)	Image size: 3cm x 3cm (Max.) Image resolution: 30 $\mu$ m ~ 50 $\mu$ m



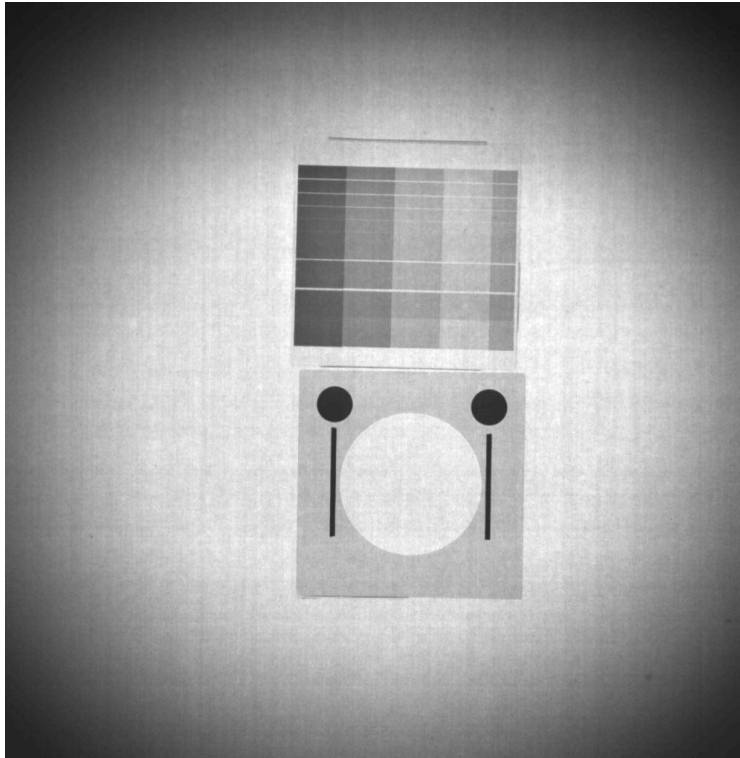
# 중성자 영상 시스템



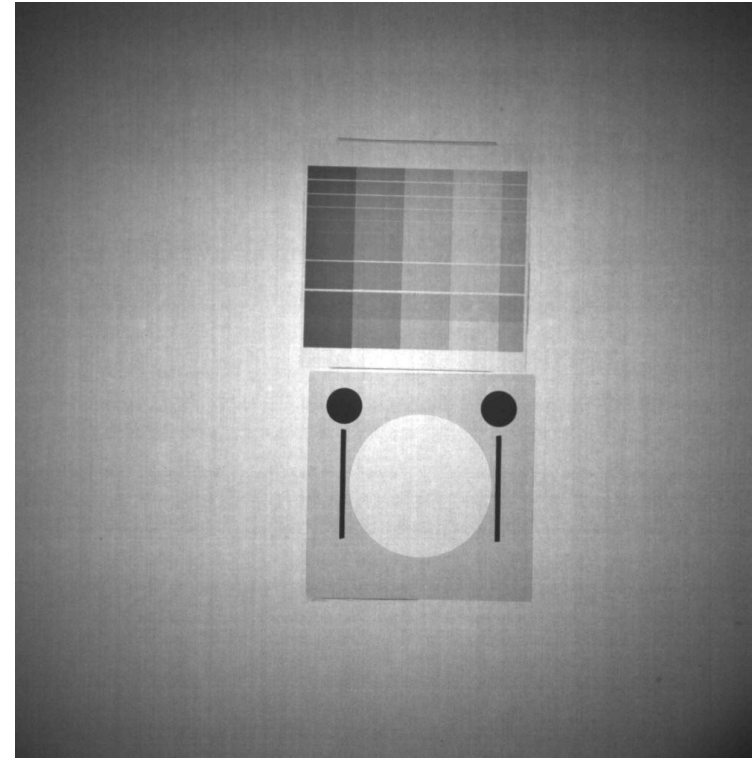
CCD Pixel size : 13.5  $\mu\text{m}$



# 중성자 영상 시스템 (Beam aperture, L/D)



**Beam aperture: 2cm**  
측정 시간: **30s**

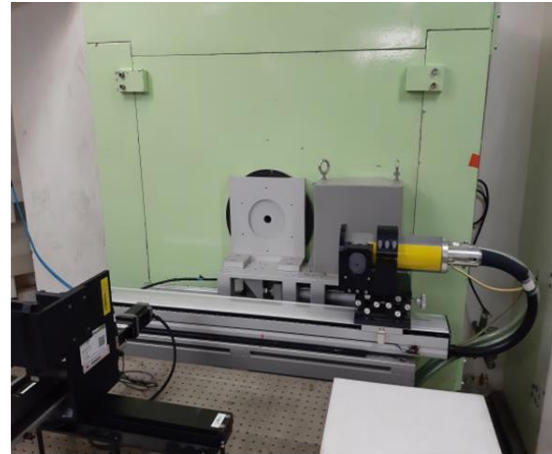
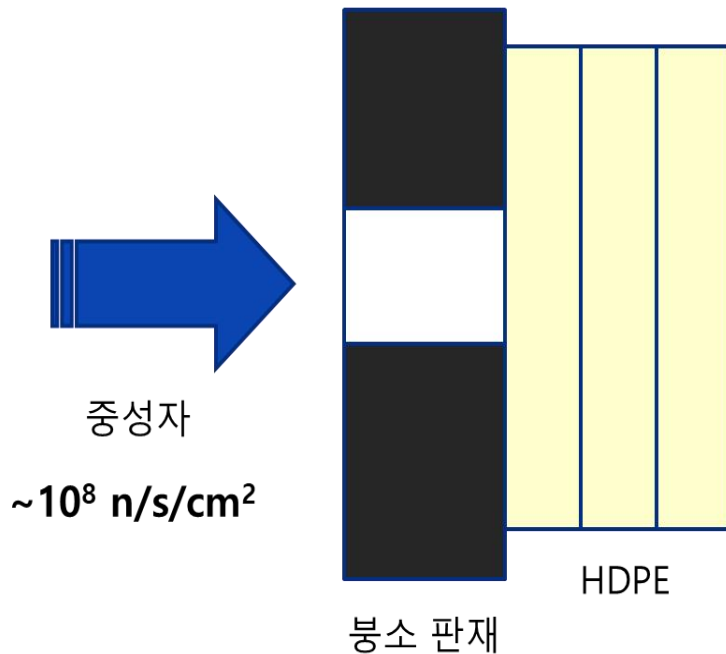


**Beam aperture: 5cm**  
측정 시간: **5s**

측정 조건: 하나로 출력 **21Mw**, 시료까지의 거리(**D**)=**313cm**

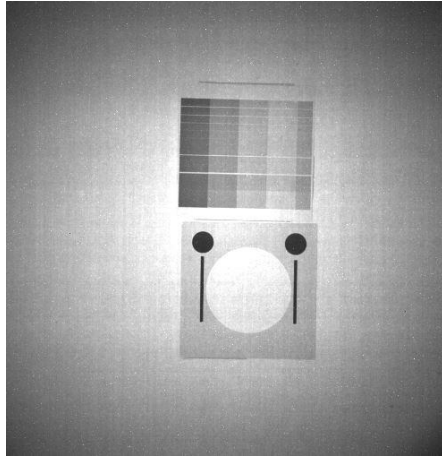


# 중성자 영상 시스템 (감쇄 중성자 영상)

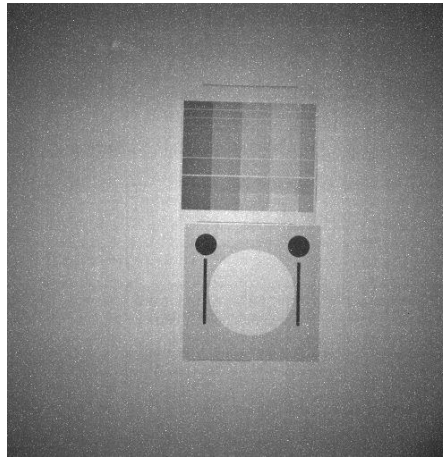


HDPE 두께 (cm)	투과율
0.1	0.97
0.2	0.94
0.3	0.91
0.4	0.88
0.5	0.85
0.6	0.82
0.7	0.79
0.8	0.77
0.9	0.74
1	0.72
1.5	0.61
2	0.52
2.5	0.44
3	0.37

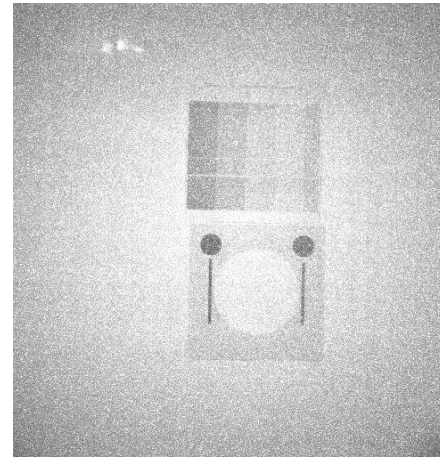
# 중성자 영상 시스템 (감쇄 중성자 영상)



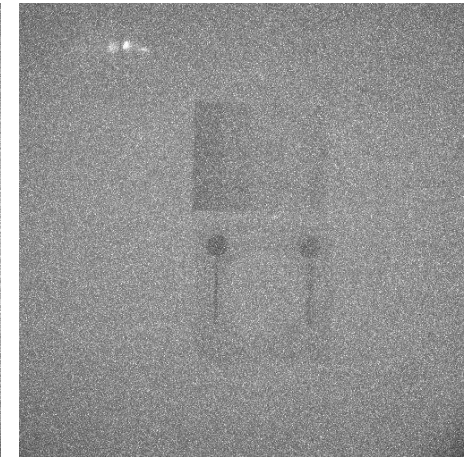
**Beam aperture: 5cm**  
**HDPE: 5mm**  
측정 시간: 90s



**Beam aperture: 5cm**  
**HDPE: 10mm**  
측정 시간: 600s



**Beam aperture: 5cm**  
**HDPE: 15mm**  
측정 시간: 3600s



**Beam aperture: 5cm**  
**HDPE: 20mm**  
측정 시간: 3600s

측정 조건: 하나로 출력 **21Mw**, 시료까지의 거리(**D**)=**313cm**

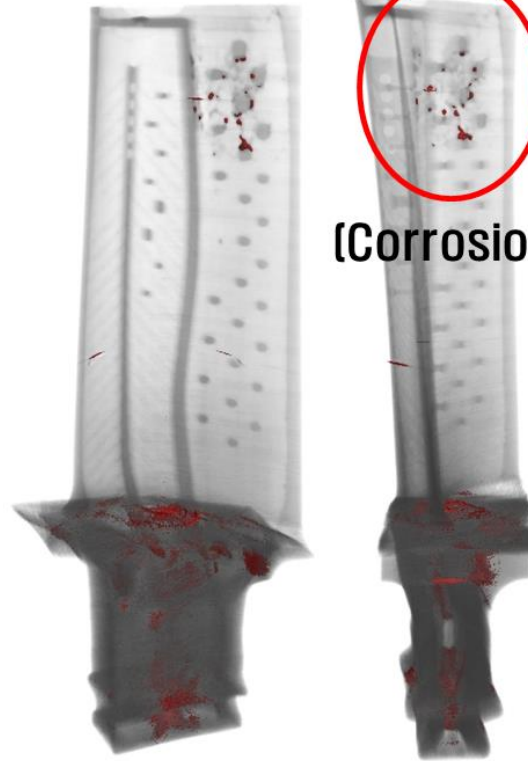
# 하나로 중성자 영상 실험 결과

We conduct **NDT irregularly** to check or find the problem with **Korean Air force**.

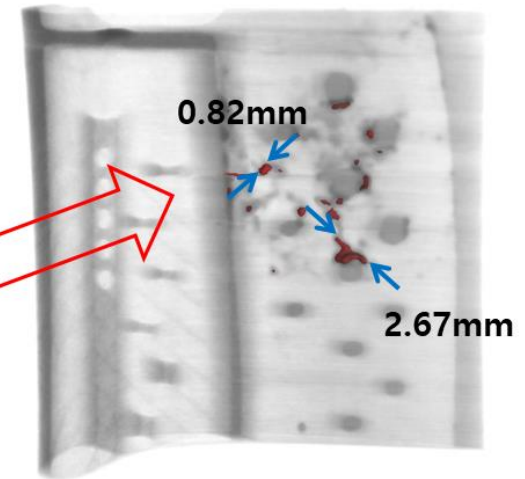
New



Used

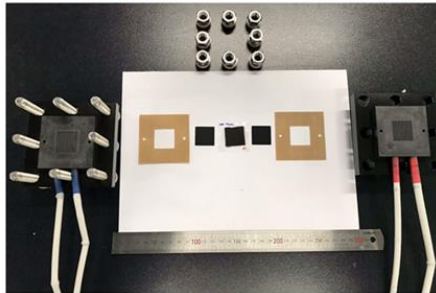


[Corrosion]

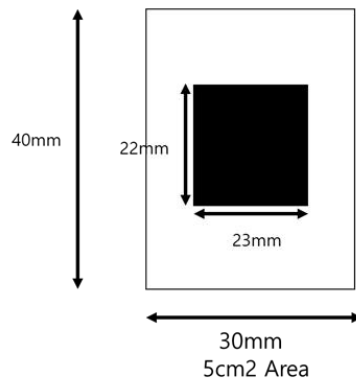
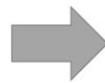


# 하나로 중성자 영상 실험 결과

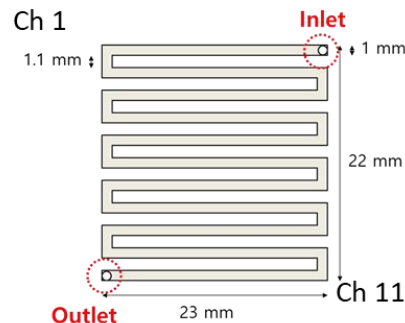
## 연료전지 셀



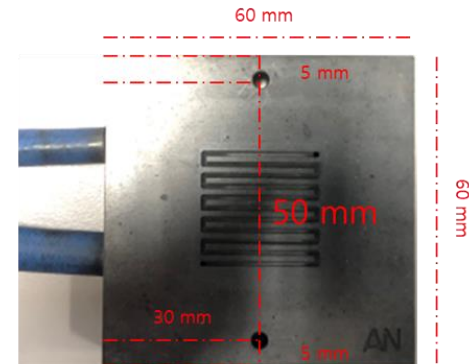
Assembly



MEA: N211, Pt/C 40wt%, 0.4mg/cm<sup>2</sup> (양극 모두),  
Active area: 5cm<sup>2</sup>



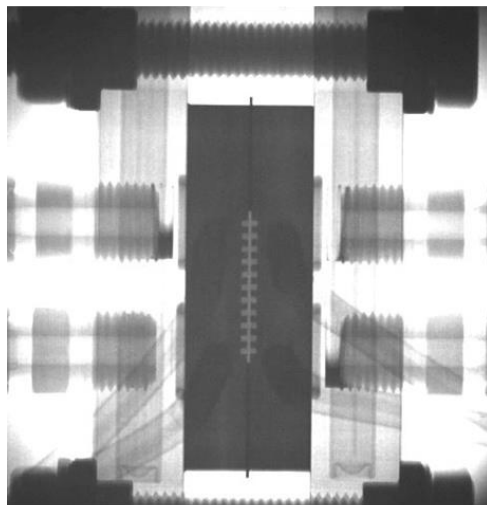
유로 (ch 11개)



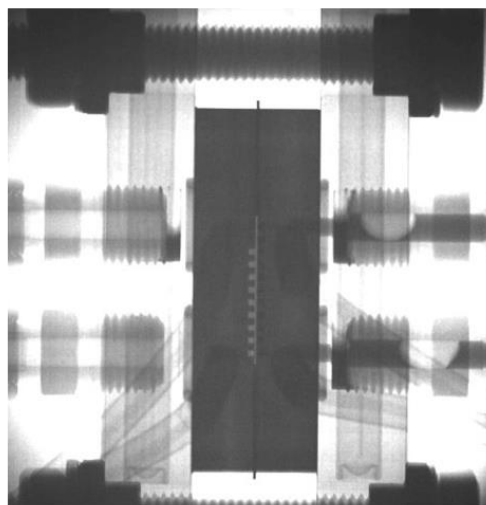
분리판 (bipolar plate)



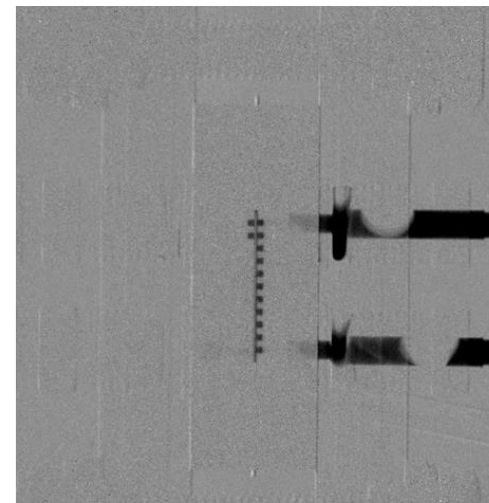
# 하나로 중성자 영상 실험 결과



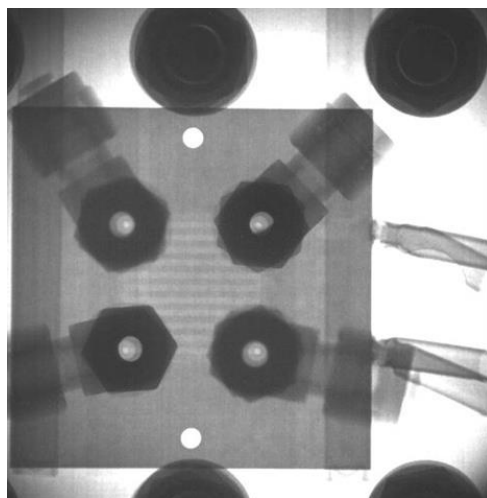
Dry



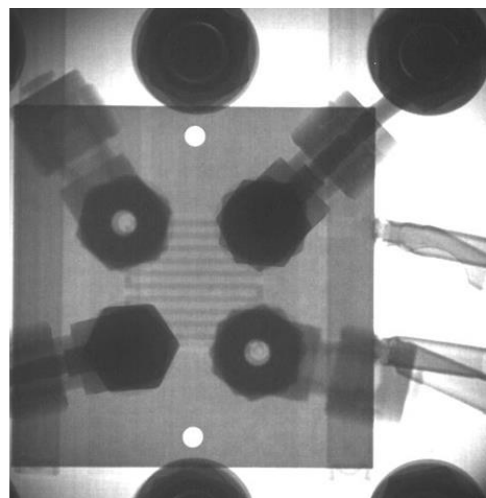
Wet



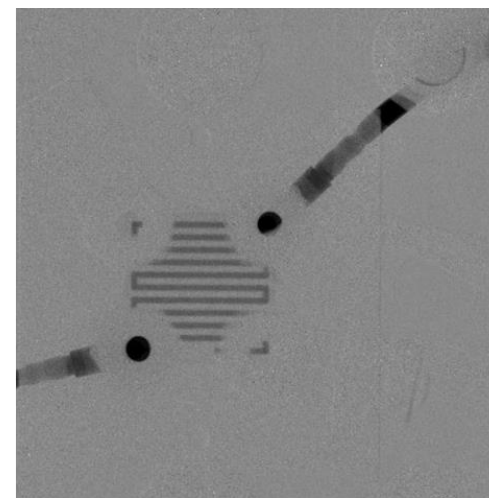
Wet / Dry



Dry



Wet

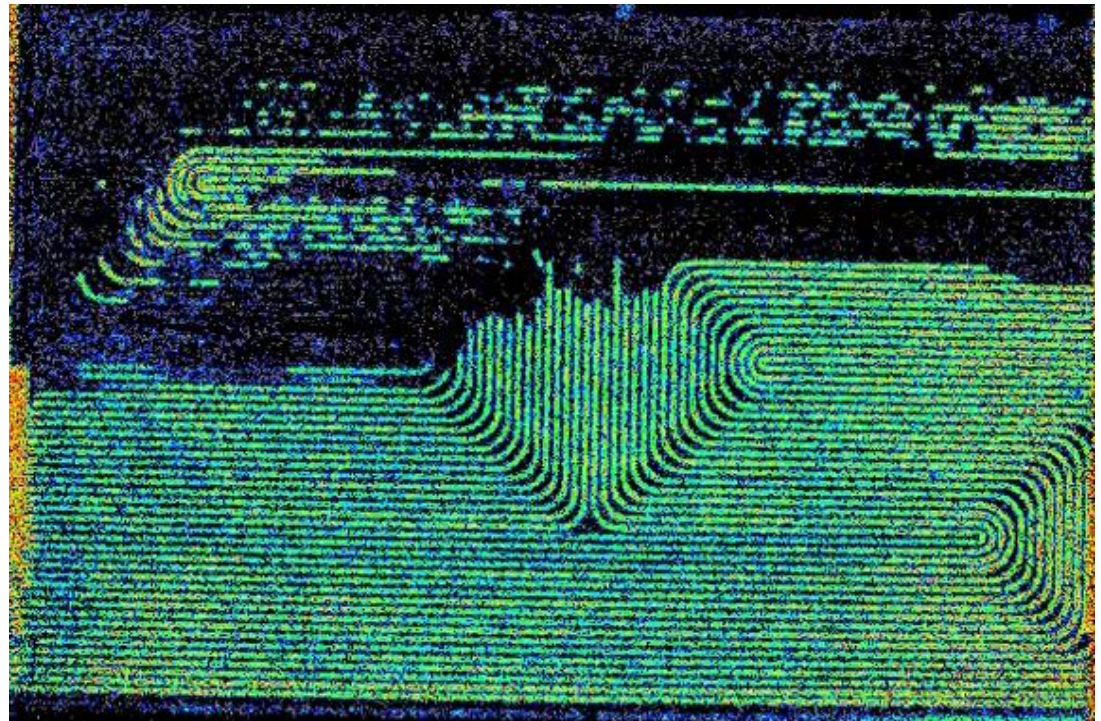
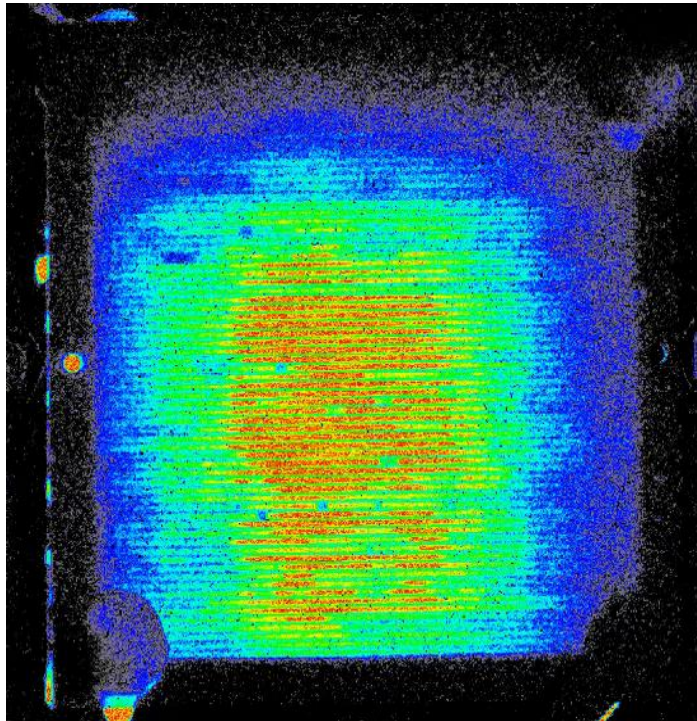


Wet / Dry



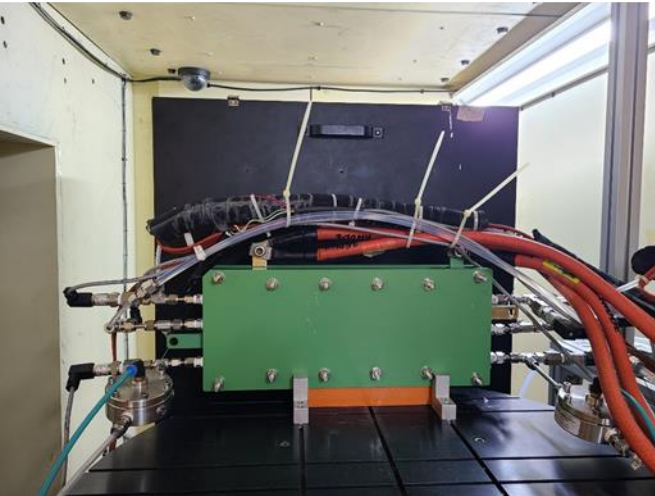
# 하나로 중성자 영상 실험 결과

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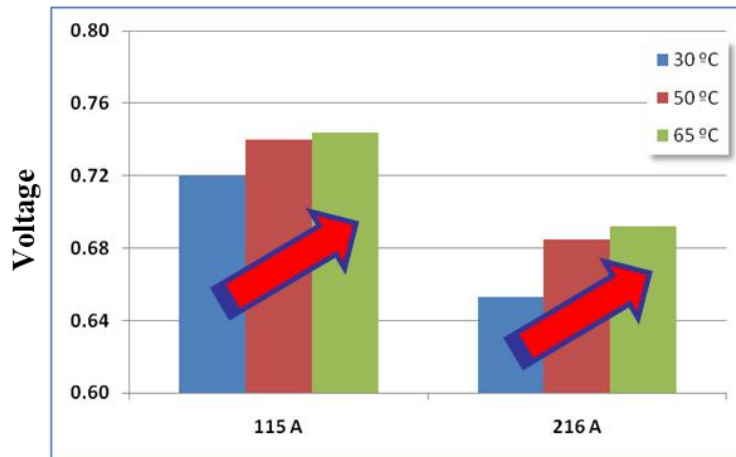
# 하나로 중성자 영상 실험 결과



Fuel cell test station: 500W 출력  
수소 유량: 5 lpm (liter/min)

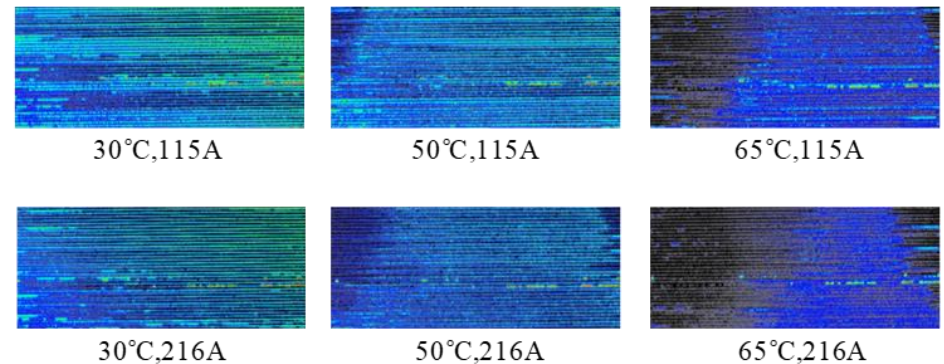
# 하나로 중성자 영상 실험 결과

<Performance with temperature and current>

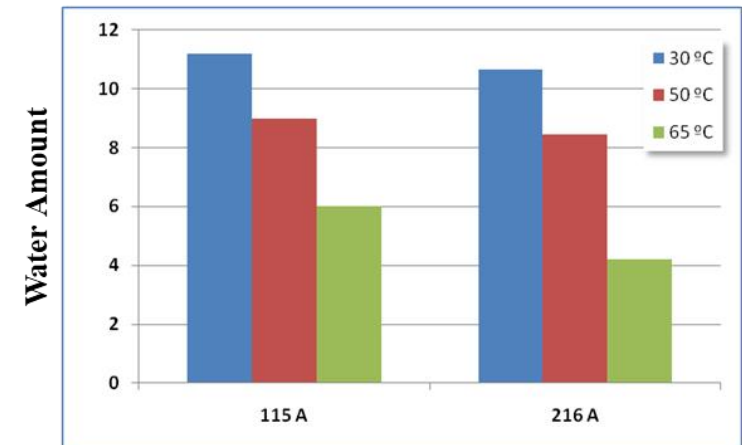


- Power increases from 62kW to 66kW as temperature increases from 30° C to 65° C in the fuel cell car.
- Water amount in the cell decreases as cell temperature and current increases.

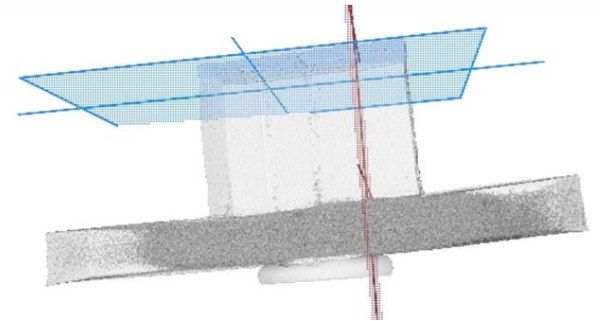
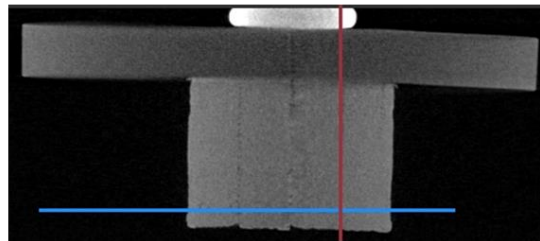
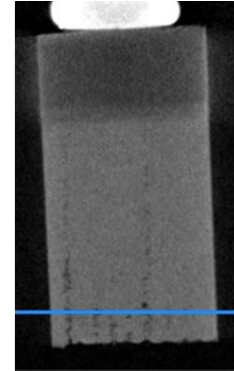
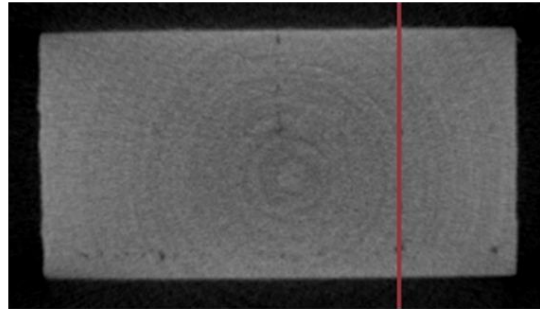
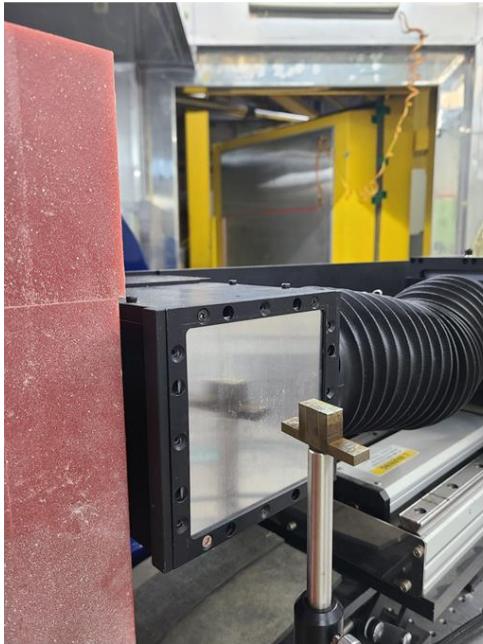
<Neutron image with temperature and current>



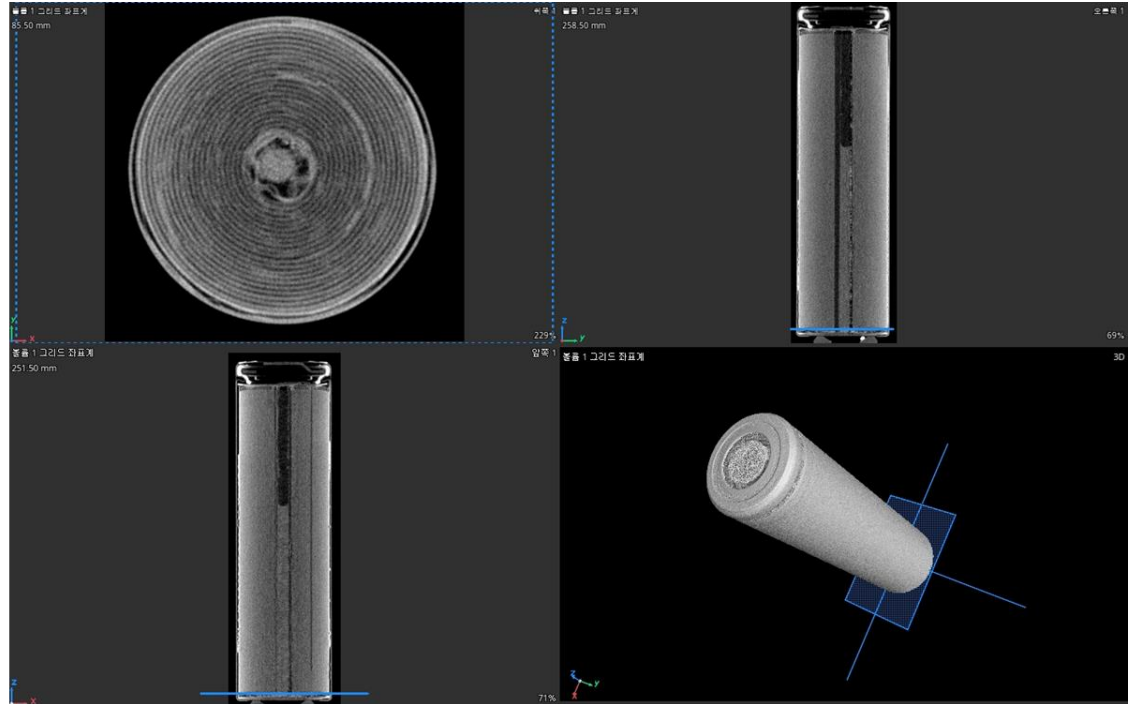
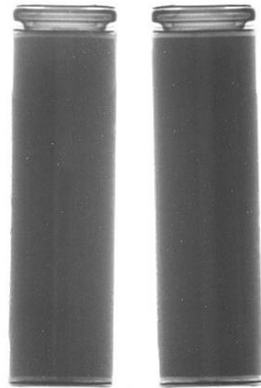
<Water amount with temperature and current>



# 하나로 중성자 영상 실험 결과

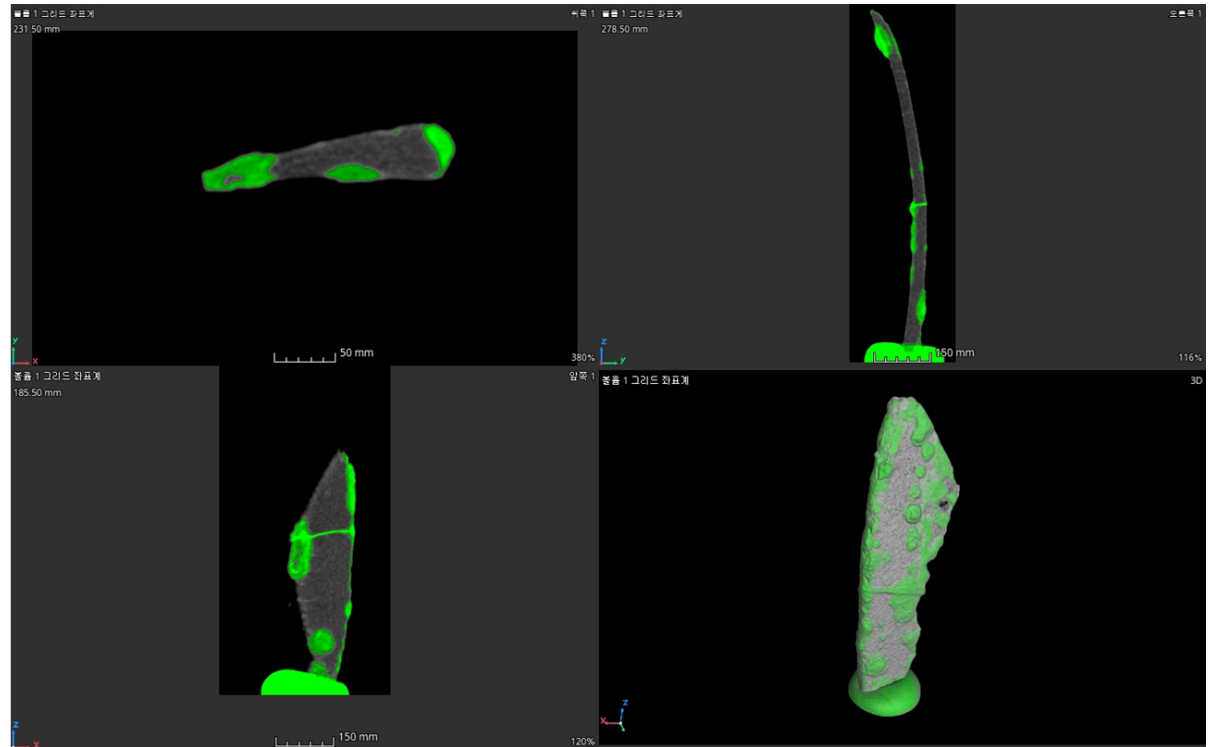
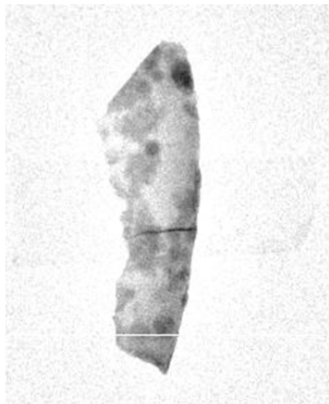


# 하나로 중성자 영상 실험 결과

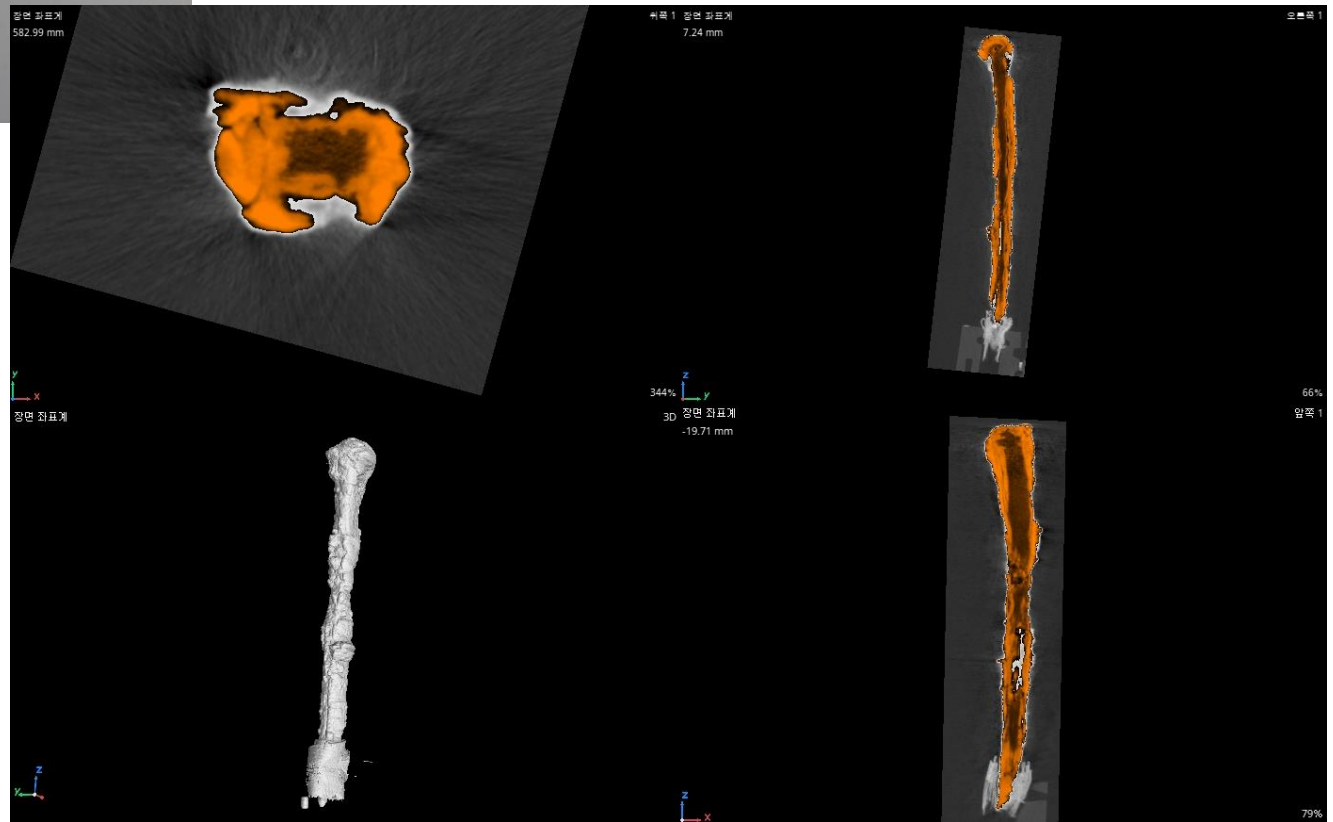




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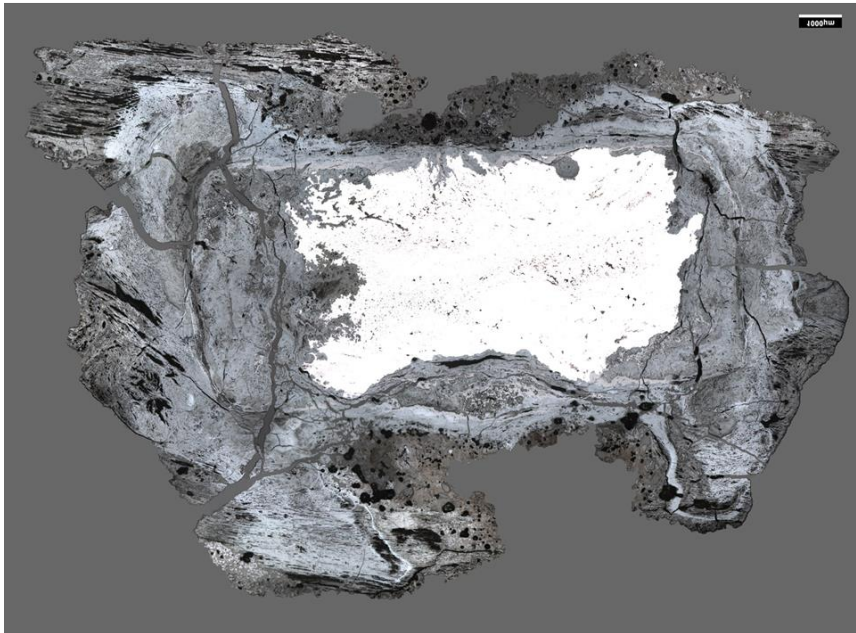


# 하나로 중성자 영상 실험 결과



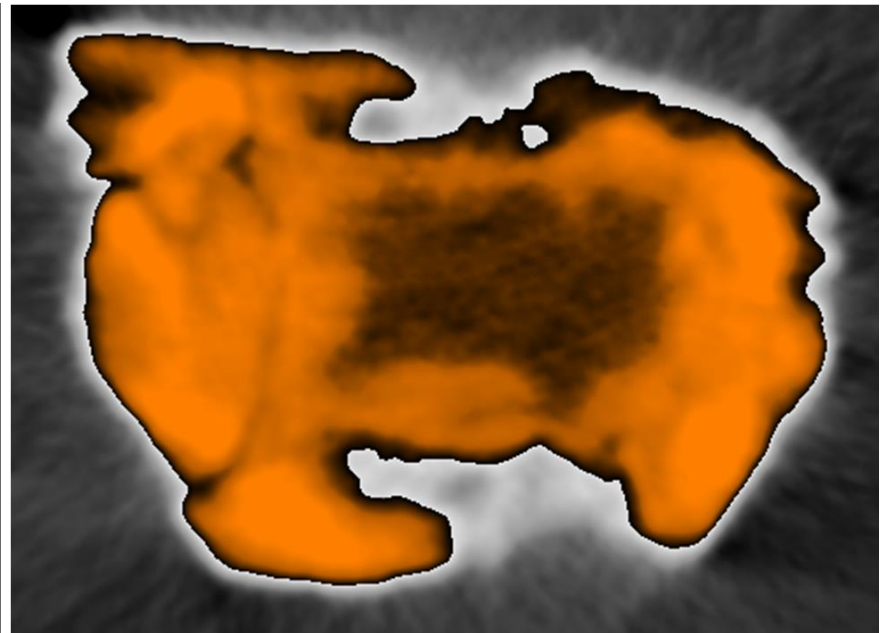
# 하나로 중성자 영상 실험 결과

금속현미경 사진



우측 부식물 두께: 약 3.74mm  
좌측 부식물 두께: 약 5.59mm

중성자 토모그래피



우측 부식물 두께: 약 3.64mm  
좌측 부식물 두께: 약 6.04mm

## 요약

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- 연구용 원자로 하나로에서는 2개의 장치를 활용하여 영상 실험이 가능함.
- 중성자 영상 시스템에서 beam aperture 크기, 섬광체 두께 등이 영상의 해상도와 측정 시간에 영향을 미침.
- 하나로 중성자 영상 장치를 활용하여 항공기 부품 비파괴 검사, 연료 전지 내부 가시화, 3D 금속 프린팅 내부 검사, 금속 유물 내부 검사 등을 수행하고 있음.

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**THANK YOU!!!**