2020/01/27
FRONTIER Task 3 Workshop @ ORNL

Corrosion experiment DURING electron irradiation performed by KURRI-LINAC

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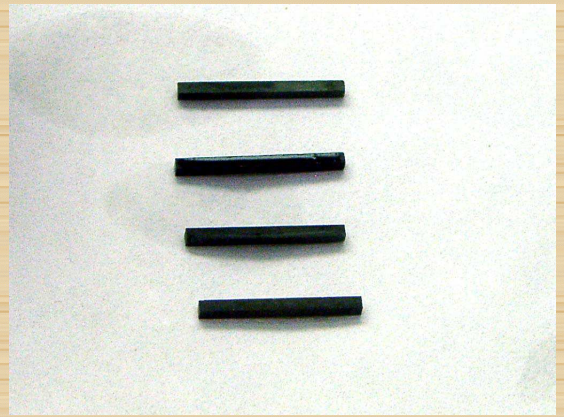
Corrosion DURING irradiation

In 2003, ceramics specimens irradiated by japanese experimental fast-reactor JOYO using CMIR-5 rig were extracted from their capsules. Two capsules were filled with white infiltrate that showed strong acid. It was considered Na was infiltrated to the capsules. All ceramic materials (α-Al_2O_3, AlN, β-Si_3N_4 and β-SiC) were stable in liquid Na without irradiation, but these specimens showed severe damage. β-Si_3N_4 and β-SiC showed good shape but showed large swelling (up to 10%), and furthermore, α-Al_2O_3 and AlN were disrupted into small pieces.

α-Al_2O_3 and AlN



β-Si_3N_4 and β-SiC

T62 capsule

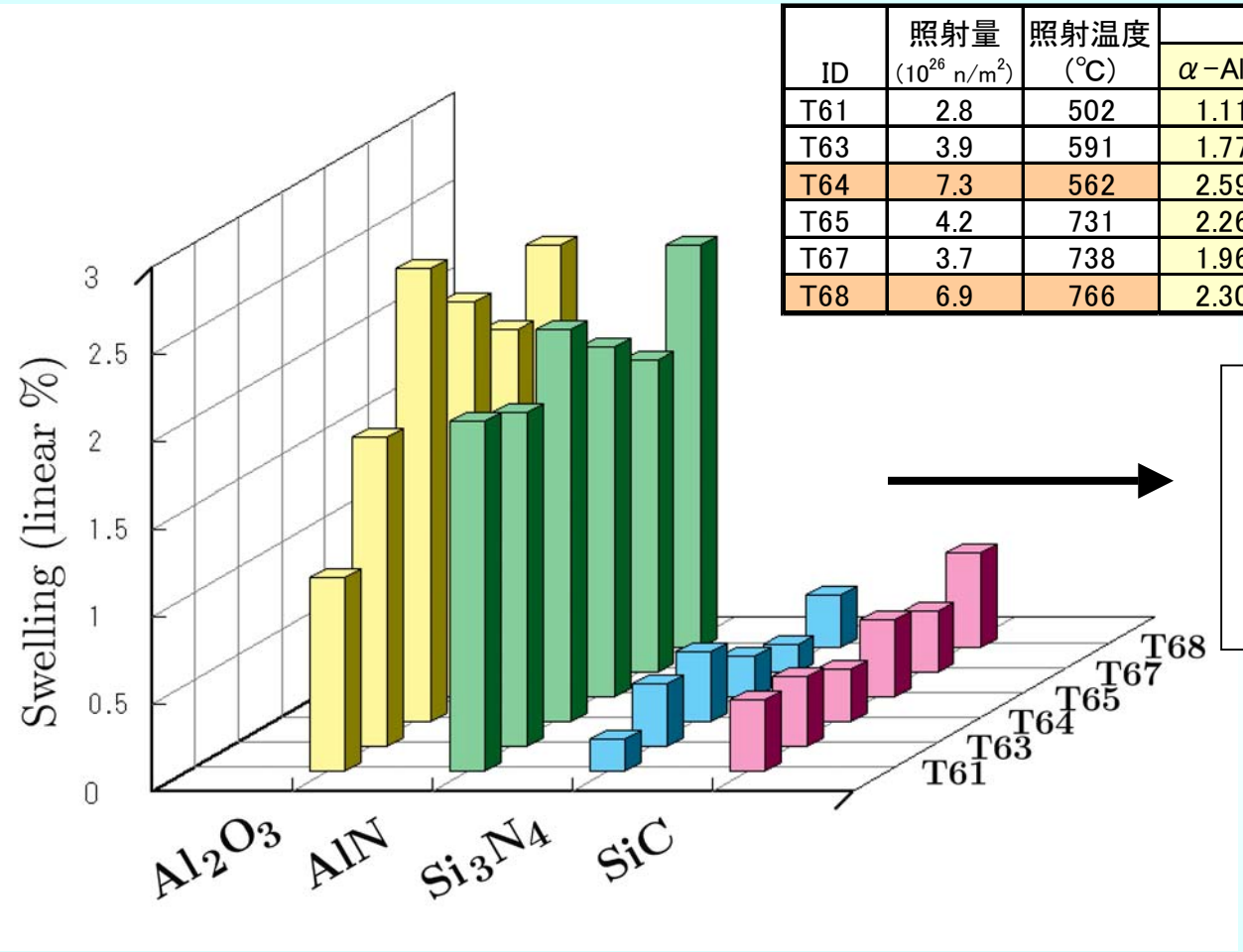
5.3×10^{26} n/m^2 (fast) at 502℃

T66 capsule

8.0×10^{26} n/m^2 (fast) at 677℃

4種類の材料間でのスエリングの比較

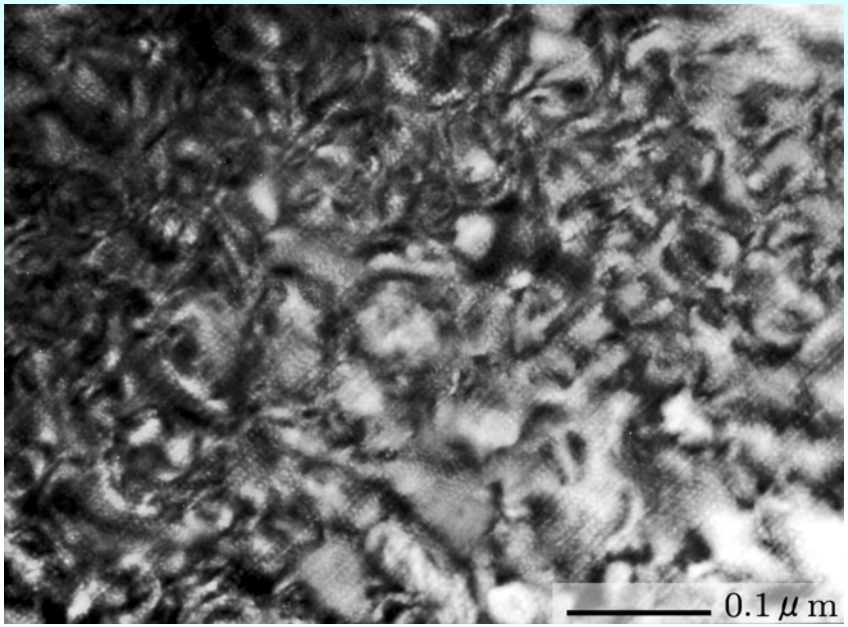
ID	照射量 (10^{26} n/m^2)	照射温度 (℃)	スエリング(%)			
			α −Al_2O_3	AlN	β −Si_3N_4	β −SiC
T61	2.8	502	1.110	2.000	0.193	0.417
T63	3.9	591	1.770	1.920	0.355	0.399
T64	7.3	562	2.590	2.240	0.397	0.304
T65	4.2	731	2.260	2.000	0.229	0.445
T67	3.7	738	1.960	1.780	0.161	0.351
T68	6.9	766	2.300	2.300	0.303	0.535



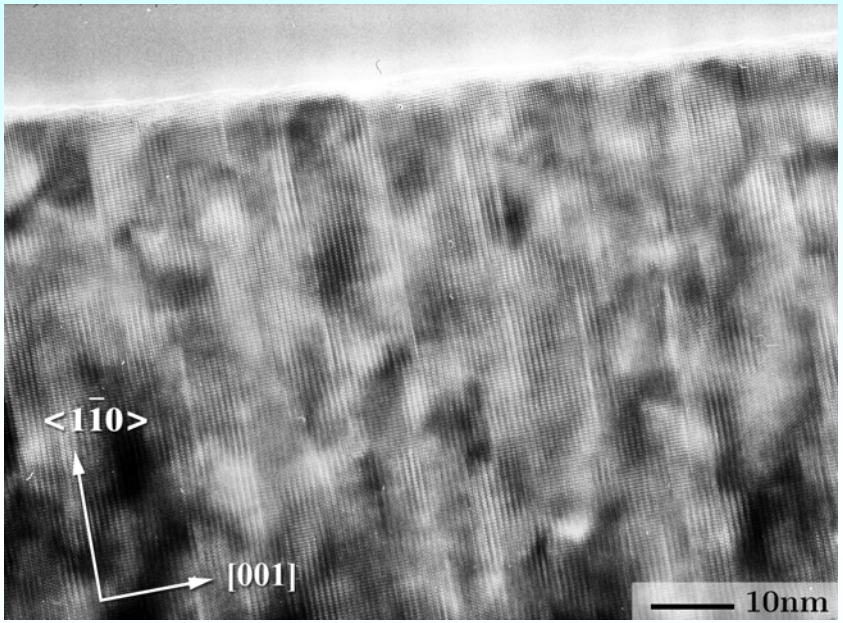
α -Al_2O_3, AlN と β -Si_3N_4, β -SiC との間で明らかな差がある

CMIR-4 及びCMIR-5 T6x 棒状試料の照射後スエリング測定結果（4種の材料間の比較）

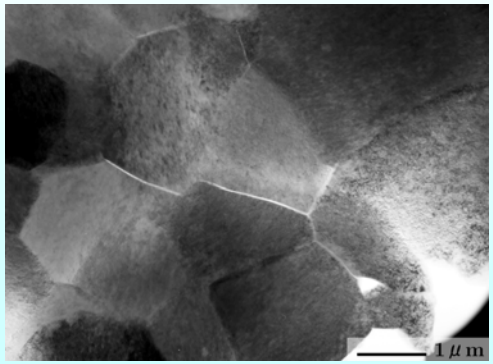
転位ループ導入面(1)

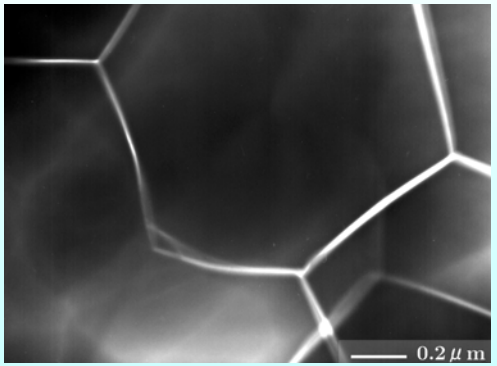


α-Al_2O_3に導入された転位ループ
と粒界クラック



β-SiCに導入された転位ループ
（観察面は{100}面）と粒界クラック



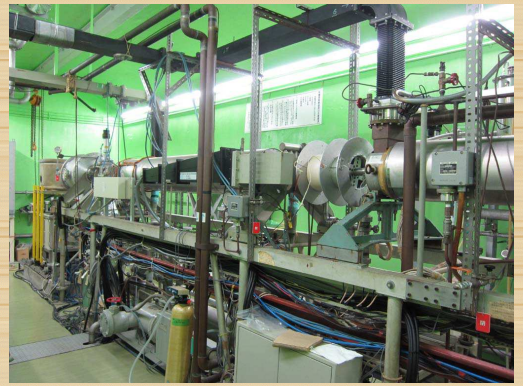


30MeV Electron Irradiation

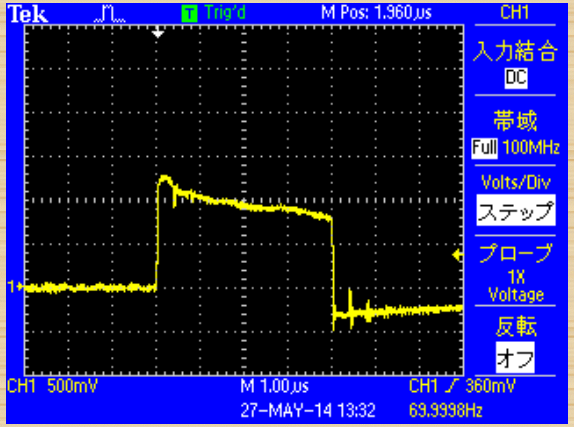
30MeV Electron Accelerator

KURRI-LINAC

Kyoto University
Research Reactor Institute, Kumatori



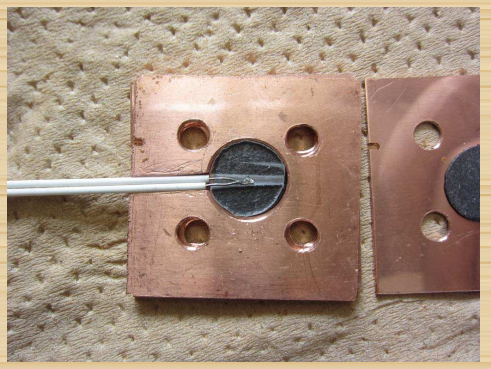
Accelerate Energy: 28-32MeV
The beam current: ～230 μ A
Peak current of pulse: ～600mA
Pulse width: 4 μ s
Pulse frequency: ～100Hz
Energy Flux: ～7kW in several cm^2
　　> the divertor in ITER, 10MW/m^2

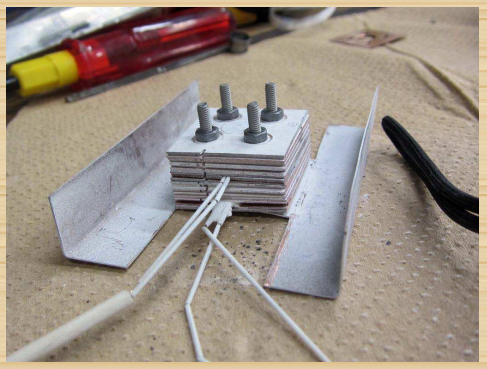


The Range of 30MeV Electron → ～5cm (in ceramics)

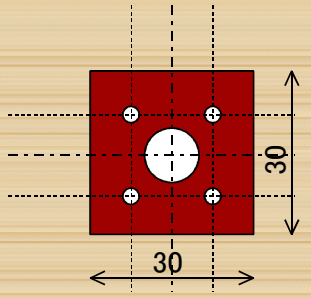
Energy of PKA (max): 125keV → Energy of PKA (average): 225eV
Number of Displacement Atoms per PKA: 3-4 atoms → Mainly Point Defects

Medium Temperature Irradiation





t = 0.7mm
Cu Specimen Holder



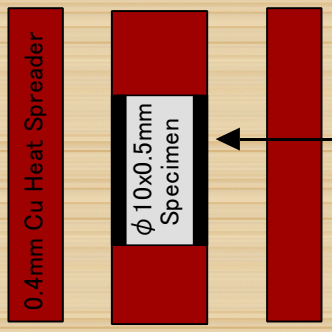
30MeV Electron Beam

□15mm Al Square tube
Cooling Water

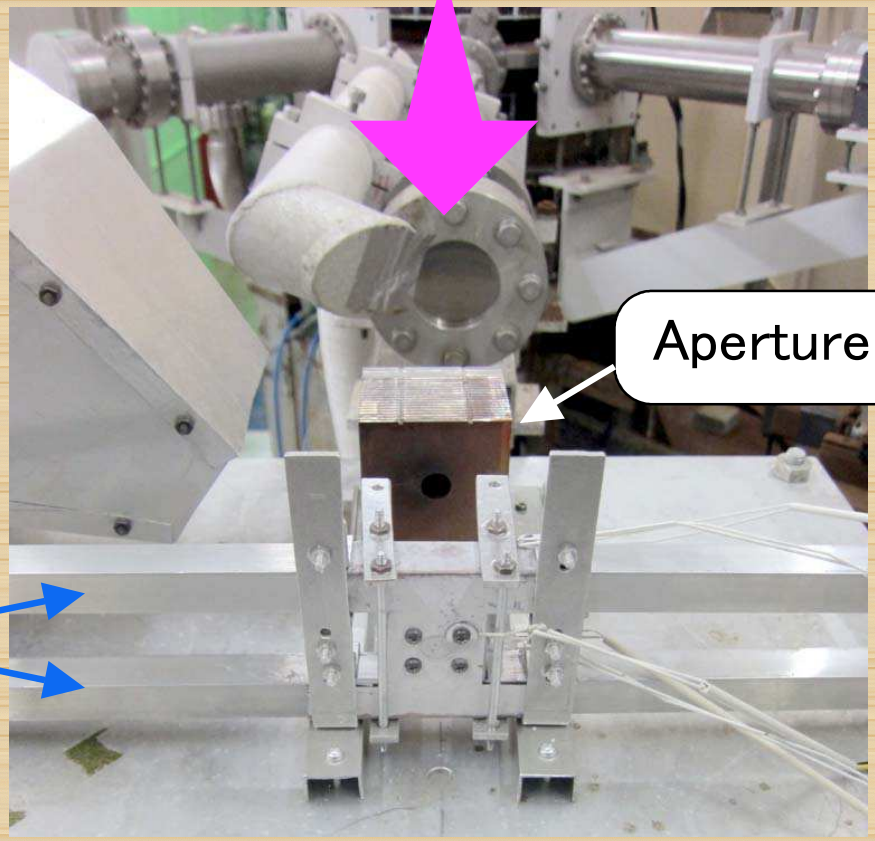
Ti screw and nut

Vertical orientated Graphite seat
(90 W/m･K)

□15mm Al Square tube
Cooling Water

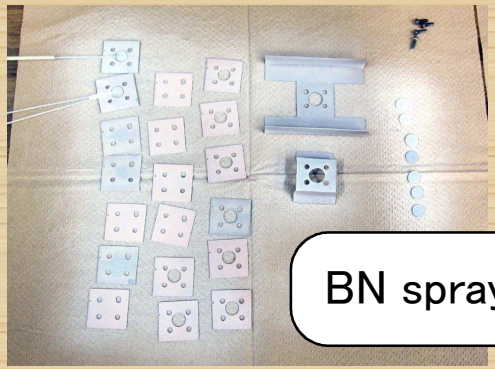


Beam



Aperture

Al water pipe

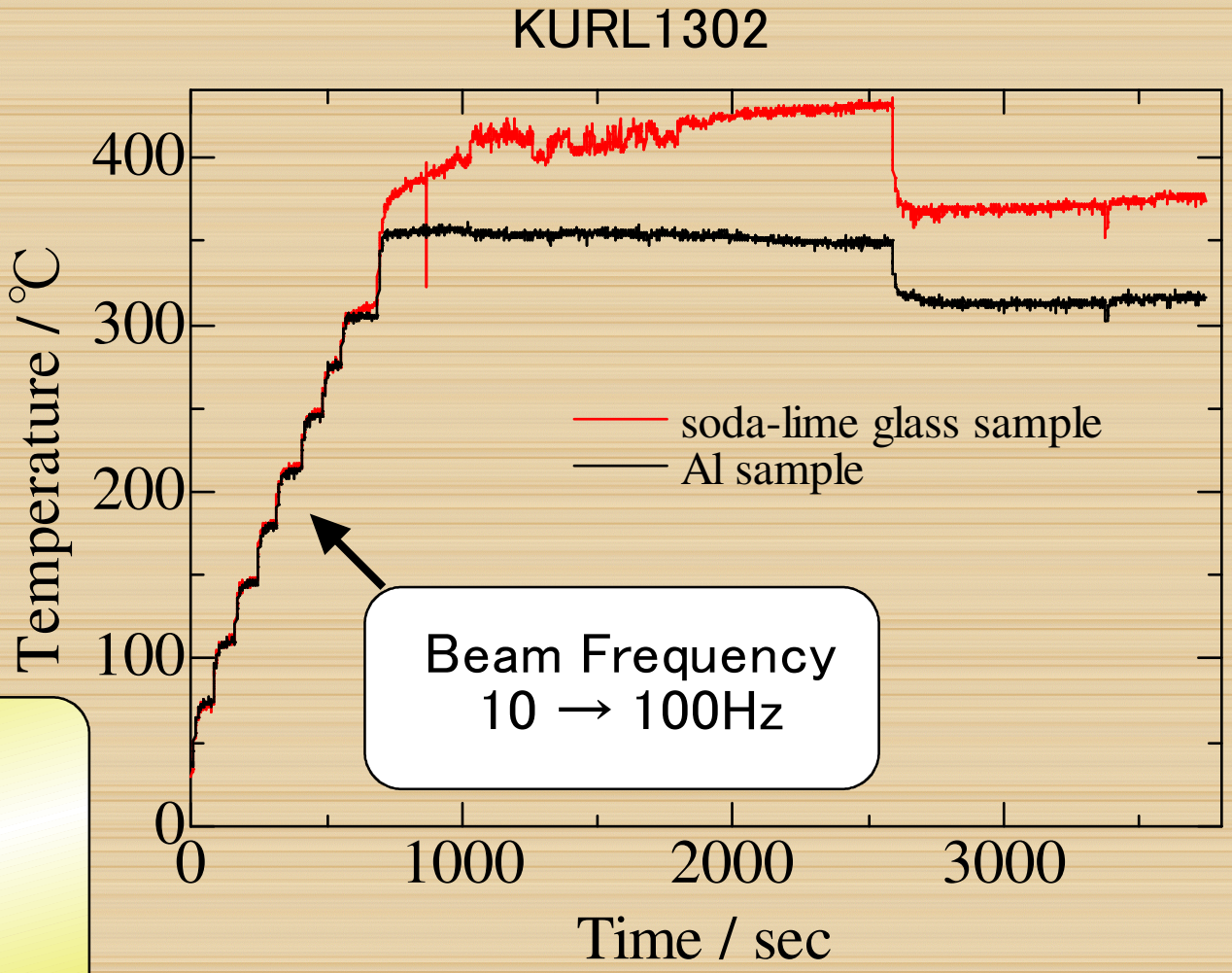


BN spray coating

Indirect Water cooling system
Cu Heat sink and Al water pipe

KURL1301: 300 ℃ / 5.84 kW
32MeV, 4 μ s x 570mA x 80Hz

KURL1302: 380 ℃ / 5.63 kW
32MeV, 4 μ s x 550mA x 80Hz



Get over the high heat flux
(> 10 MW/m)

Achieved a reliable irradiation
at around 400℃

Radio Activity

High Energy Electrons → Brems. X-rays →
Photonuclear Reaction （γ, n）→ Radio-Activation

MT ID KURL1302 (Typical conditions):
32MeV, peak 4 μs 560mA, 80Hz
→ surface neutron flux 5.7×10^{9} n/cm^2 s
2013/3/11 → 3/14 (72h non-stop)
2.8×10^{20} e → 0.01 dpa
Surface dose rate: 2013/3/17 : 14.2 mSv/h
2014/4/14 : 318 μSv/h

Specimens:
Sapphire, α-Al_2O_3 (Toray A-999), AlN (Tokuyama SH-50, wo Y_2O_3), β-SiC (Bridgestone Pure beta, p-type), β-SiC（Tokai Carbon n-type translucent and non-translucent）, α-SiC（Nippon Steel 4H n-type single crystal）

Cu-64: $T_{1/2}$ 12.7h, Co-60: $T_{1/2}$ 5.27y

Low energy (<10MeV) Irradiation

The Range of 30MeV Electron → ～5cm (in ceramics)

30MeV, Target: Oxigen atom E_d = 30eV,
Energy of PKA (max): 125keV → Energy of PKA (average): 225eV
Number of Displacement Atoms per PKA: 3.8 atoms

→ Mainly Point Defects

Typical 4days irradiation gives
about 3×10^20e in 2cm^2,
→ Displacement: O: 0.01dpa

The Range of 8MeV Electron → ～5.4mm (in SS)
～2.2mm (in tungsten)

8MeV, Target: Fe atom E_d = 40eV,
Energy of PKA (max): 2.7keV → Energy of PKA (average): 149eV
Number of Displacement Atoms per PKA: 1.9 atoms

8MeV, Target: W atom E_d = 60eV,
Energy of PKA (max): 0.84keV → Energy of PKA (average): 118eV
Number of Displacement Atoms per PKA: 1.0 atoms

→ Still Induce Point Defects

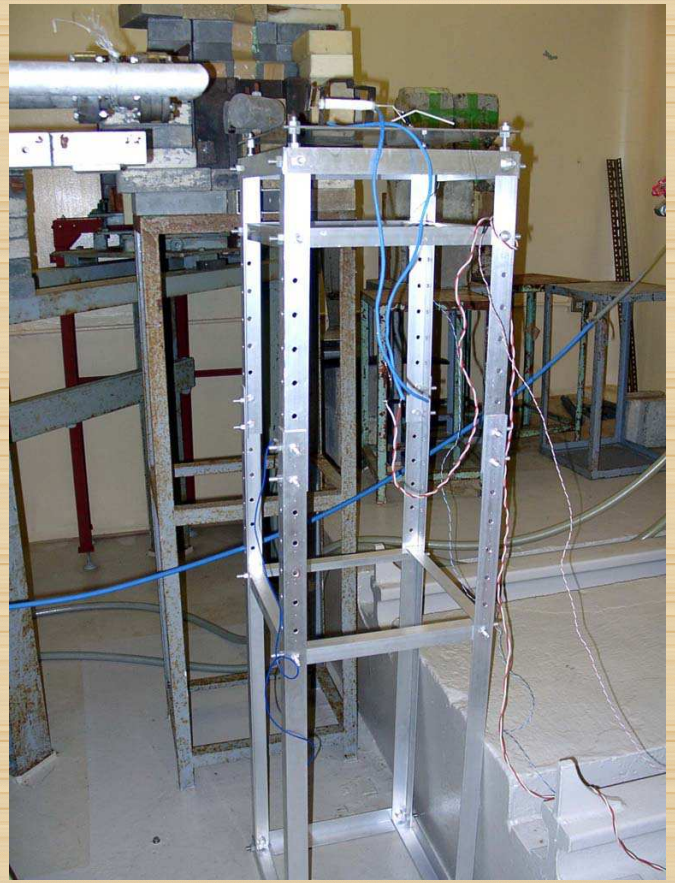
Typical 4days irradiation gives
about 3×10^20e in 2cm^2,
→ Displacement:
Fe: 0.012dpa
W: 0.011dpa

High Temperature Irradiation

Temperature Control:
Beam Frequency
+ Kanthal heater

KURL0602

KURL0702



KURL0602: 1095℃
Quartz Glass tube and alumina cement, kanthal heater
30MeV, 3 μ s x 500mA x 30Hz (1.35kW)

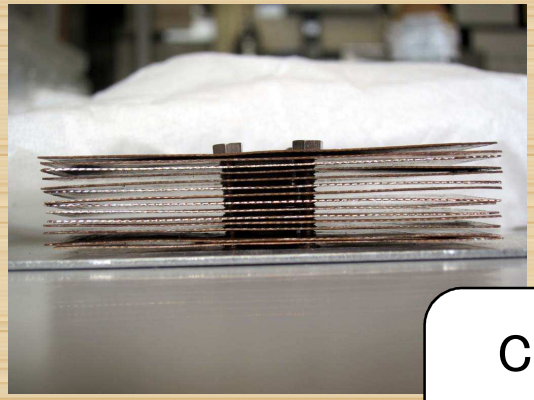
KURL0702: 700℃
Alumina tube and alumina cement, kanthal heater
30MeV, 3 μ s x 530mA x 12Hz (0.57kW)

Low Temperature Irradiation

KURL0604

Liquid Nitrogen Supply

KURL0604: −165℃ / 1.35kW
Liquid Nitrogen cooled system
30MeV, 3 μs x 500mA x 30Hz



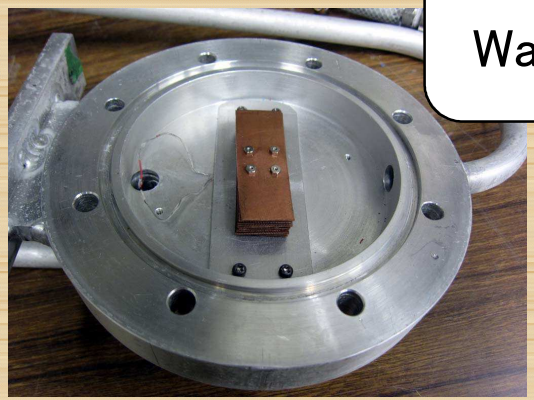
KURL1201
KURL1401

Cu Heat sink
put in
Water chamber

Cu heat sink in Water chamber

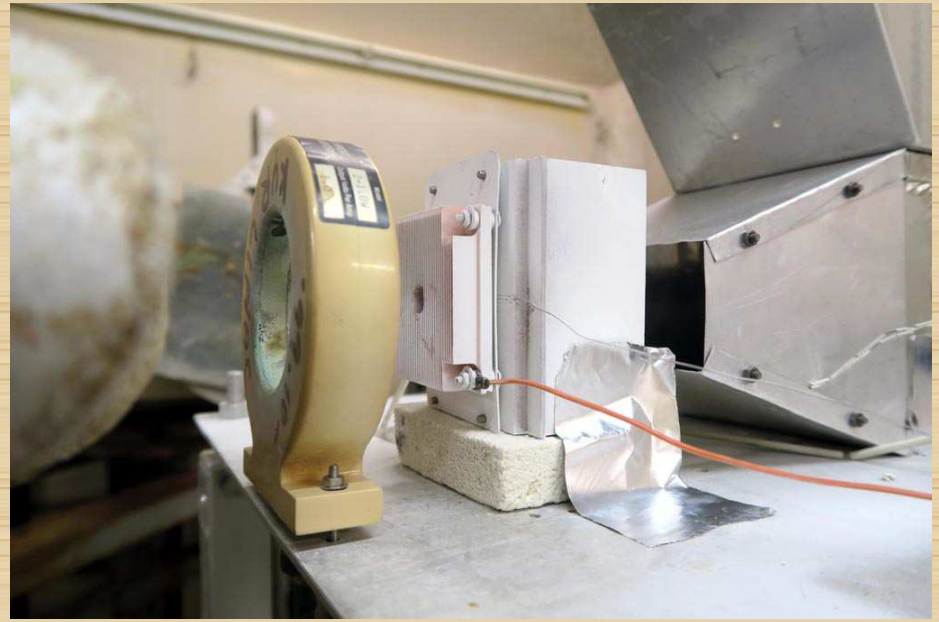
KURL1201: 80℃ / 6.0kW
32MeV, 4 μs x 590mA x 80Hz

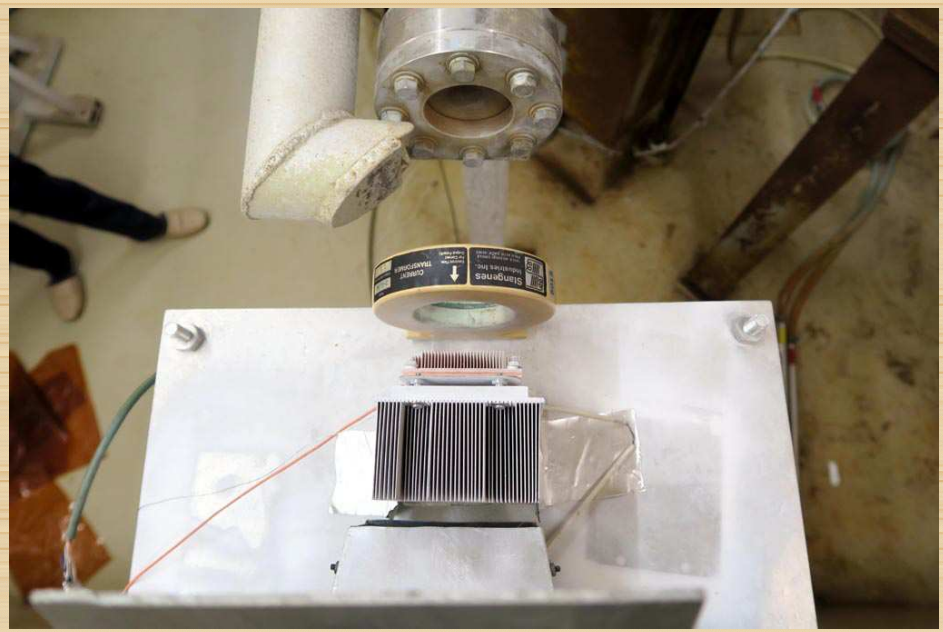
KURL1401: 90℃ / 4.7kW
28MeV, 4 μs x 600mA x 70Hz

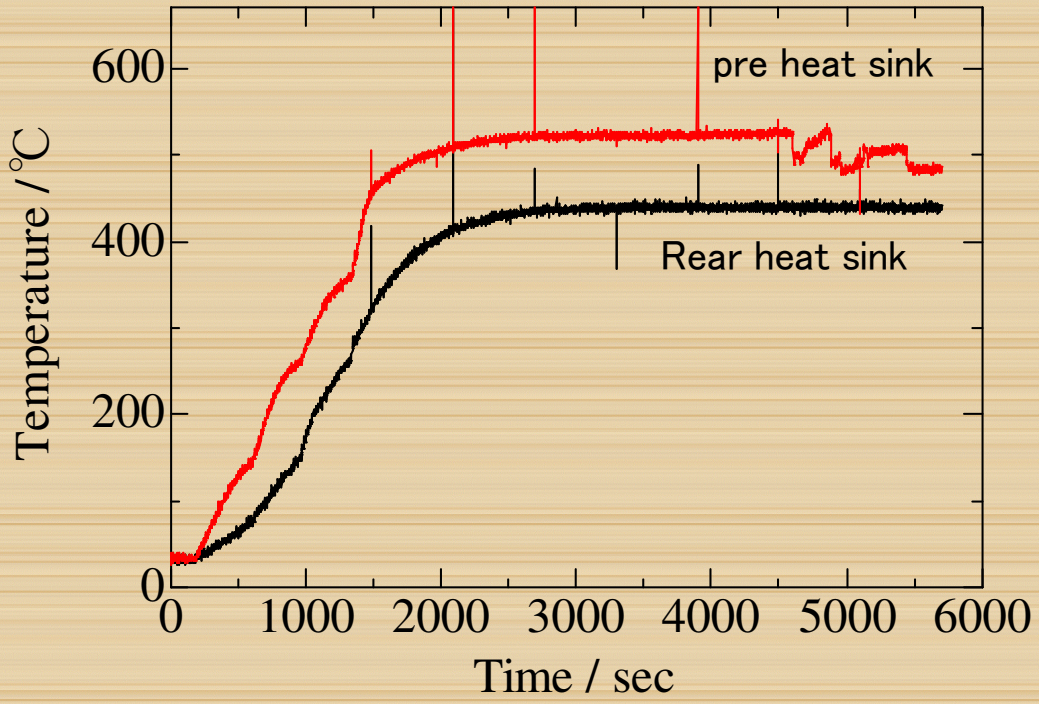


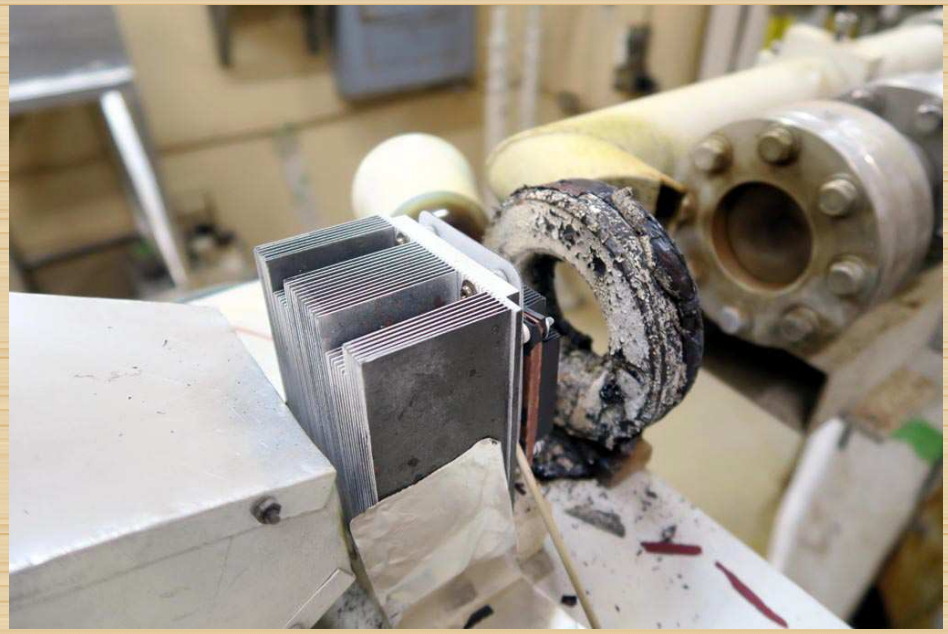
Very Stable and Established Irradiation System

KURL1801 First attempt for Liquid-metal corrosion test



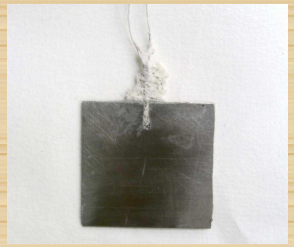






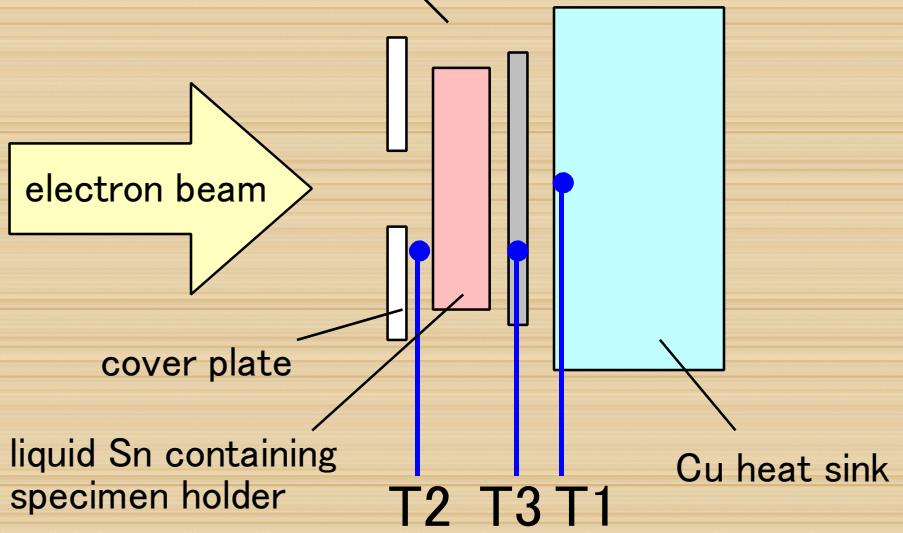
CT monitor and pre heat sink was burn!

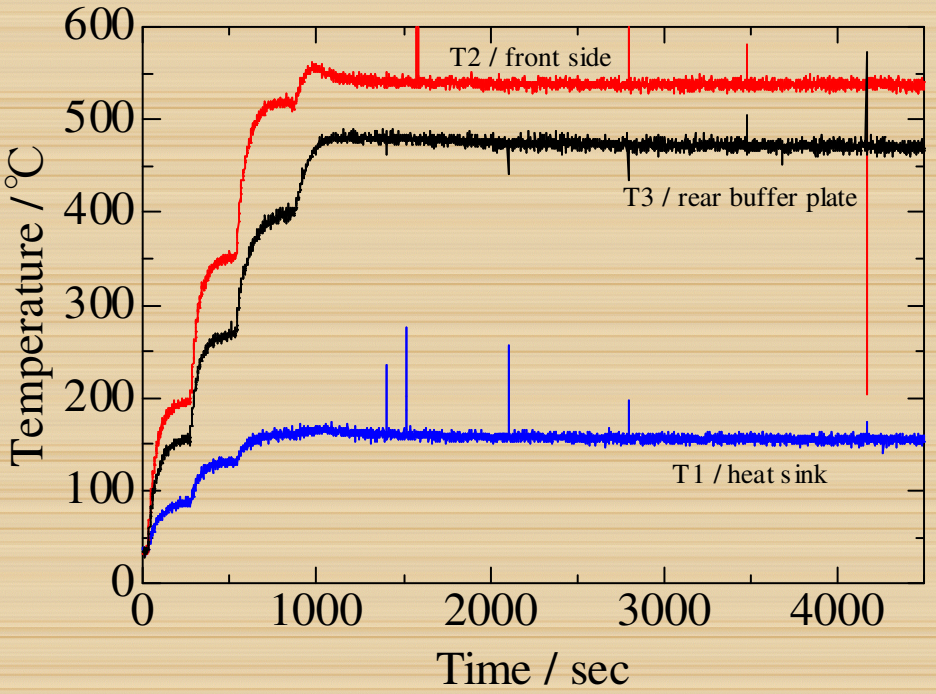
KURL1801 Second attempt for Liquid-metal corrosion test



stainless buffer plate
with thermo couple

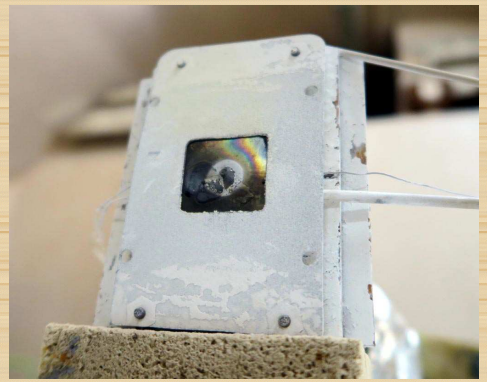
Rear heat sink was too effective and the temperature was not elevated.



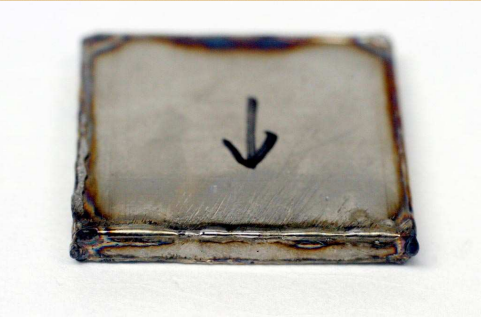


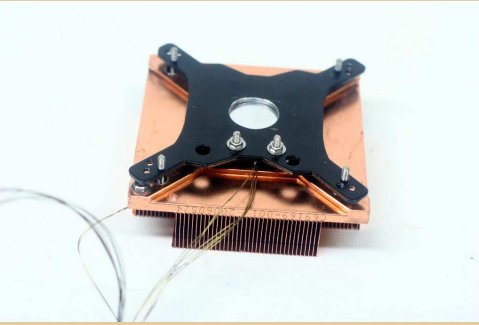
Beam time: 2.4×10^5 sec (66.7h)

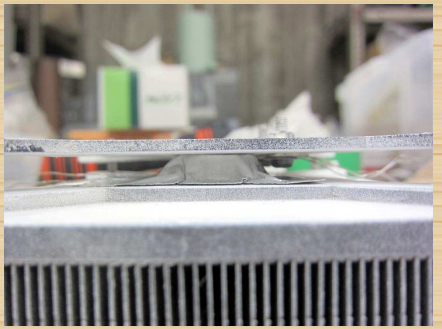
Dose: 1.1×10^{20} e, 4.4 mdpa (for Fe E_d=40keV)

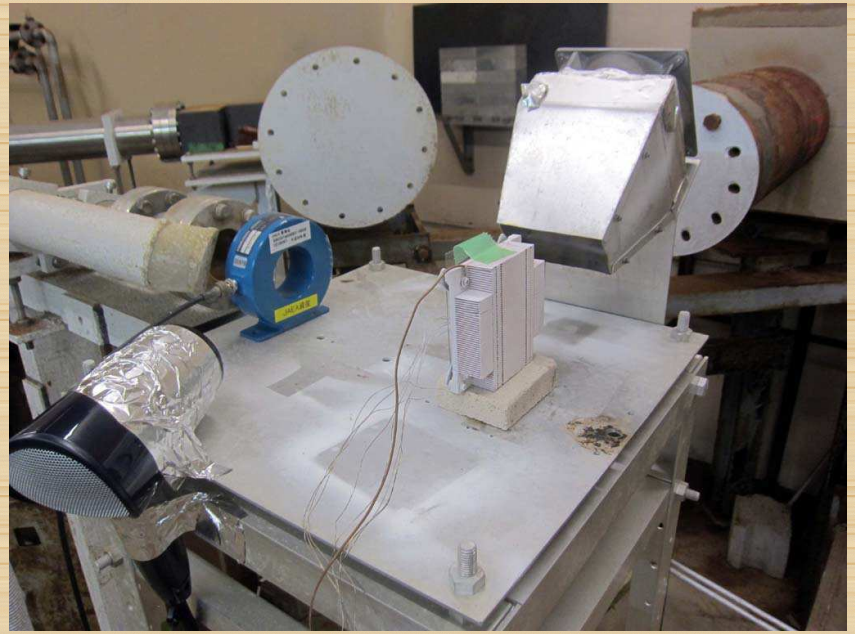


KURL1901 Third attempt for Liquid-metal corrosion test



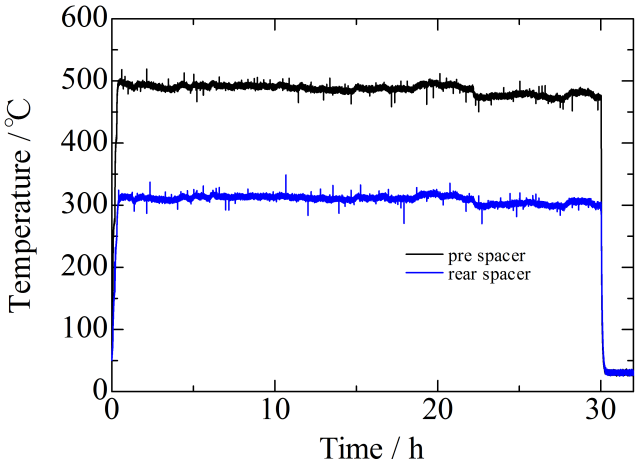


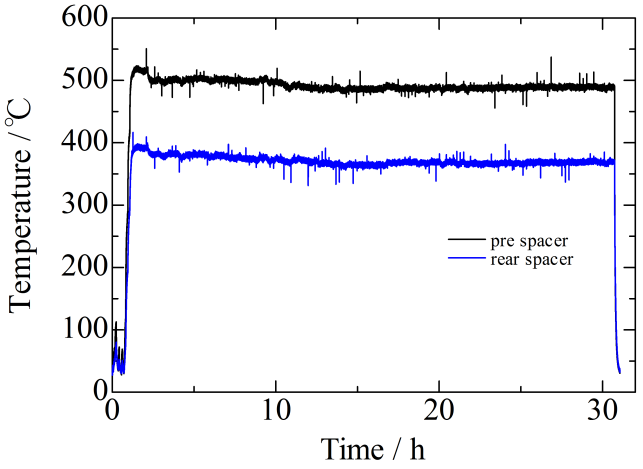




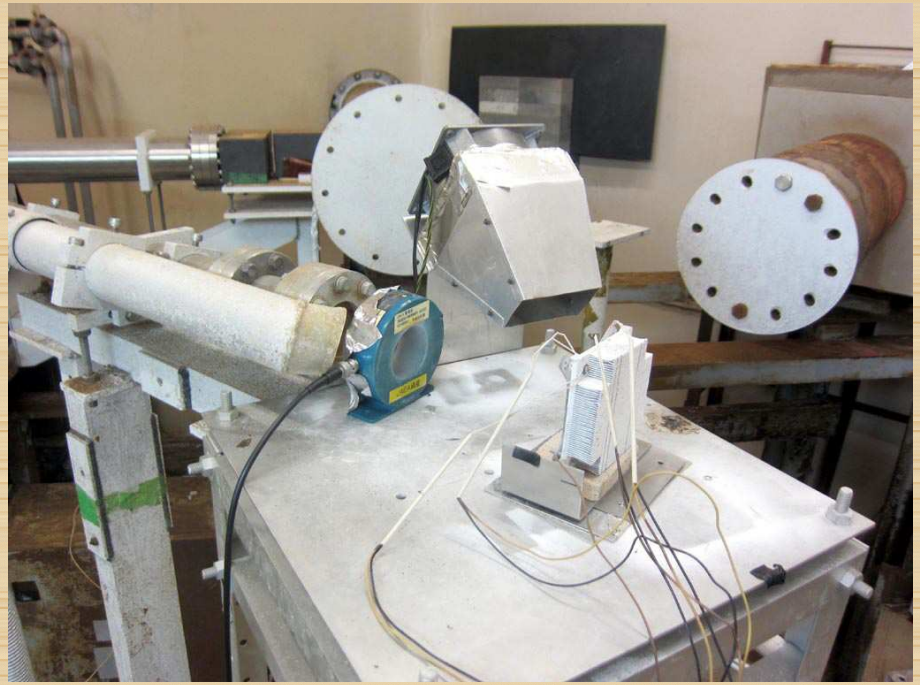
1st specimen (NTK04L, pre oxidation 1000℃ 10h)
Beam time: 1.1×10^5 sec (32.5h)
Dose: 5.8×10^{19} e, 2.3 mdpa (for Fe E_d=40keV)

2nd specimen (ODS sp-10 pre oxidation 1000℃ 10h)
Beam time: 1.1×10^5 sec (32.5h)
Dose: 6.5×10^{19} e, 2.6 mdpa (for Fe E_d=40keV)





KURL1902 4th attempt for Liquid-metal corrosion test



1st specimen (FeCrAl-ODS / Pb-Li)
Beam time: 1.1×10^5 sec (32.5h)
Dose: 6.6×10^{19} e, 2.6 mdpa (for Fe E_d=40keV)

2nd specimen (JLF-1-SS430/Pb-Li)
Beam time: 1.1×10^5 sec (32.5h)
Dose: 6.8×10^{19} e, 2.7 mdpa (for Fe E_d=40keV)

1st specimen
Temperature monitor was failed because of trouble on AD8495 thermo-couple amplifier.
Another attempt showed:
pre-spacer 630℃, rear-spacer 430℃