Low temperature irradiation tests on stabilizer materials using reactor neutrons at KUR

Makoto YOSHIDA
(KEK)

RESMM12
FNAL
Feb. 13-15, 2012

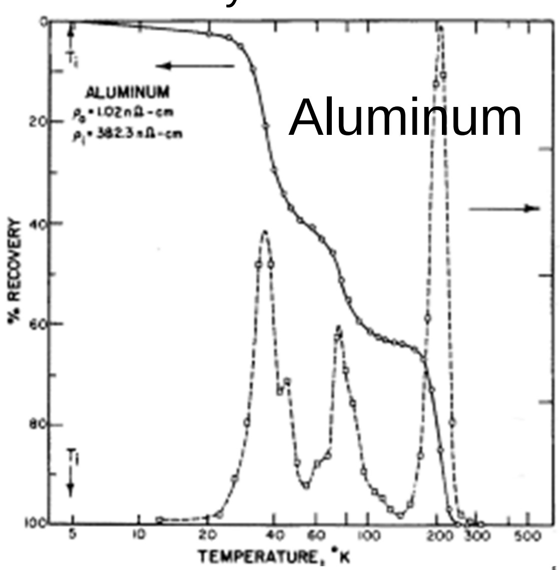
Irradiation effects on Al, Cu in literature

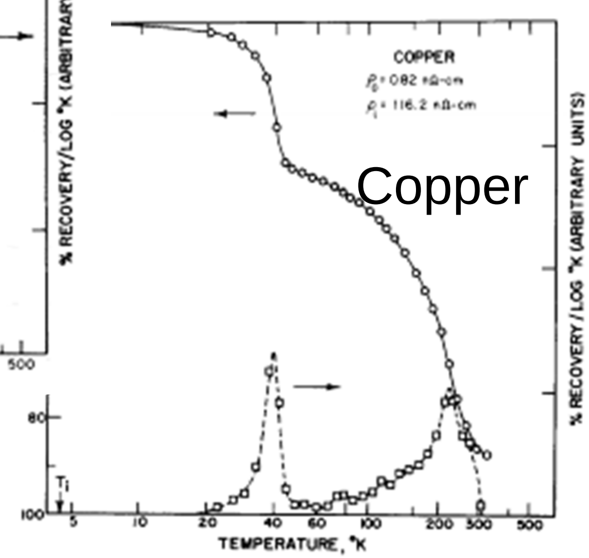
Table 3
Irradiation induced resistivity, ρ_i, defect concentration, C_i, and ratio of induced to residual resistivity, ρ_i/ρ_0.

Element	Induced resistivity, ρ_i (nΩ · cm)	Induced concentration a) (10^{-4} a.f.)	ρ_i/ρ_0
Aluminum	382.3	5.6	275
Nickel	363.9	5.6	31
Copper	116.2	4.8	142
Silver	87.9	3.6	54
Gold	102.7	4.0	40
Platinum	264.6	3.6	48
Iron	1137.2	9.1	21
Molybdenum	593.3	6.0	142
Cobalt	794.6	8.0	9

- pure Al (RRR=2286)
  - Fast neutron 2×10^{22} n/m^2 Induces ρ_i=3.8nΩ.m [1]
    - ρ_i=0.02nΩ.m for 10^{20} n/m^2
  - Perfect recovery by anneal at RT
- pure Cu (RRR=2280)
  - ρ_i=1.2nΩ.m [1]
  - 10% damage remains after annealing at RT

Recovery after irradiation 2×10^{22} n/m^2 (E>0.1MeV)





How about cold-worked Al-stabilizer
→ tests at KUR

[1] J.A. Horak and T.H. Blewitt, J. Nucl. Materials, Vol. 49 (1973) p161

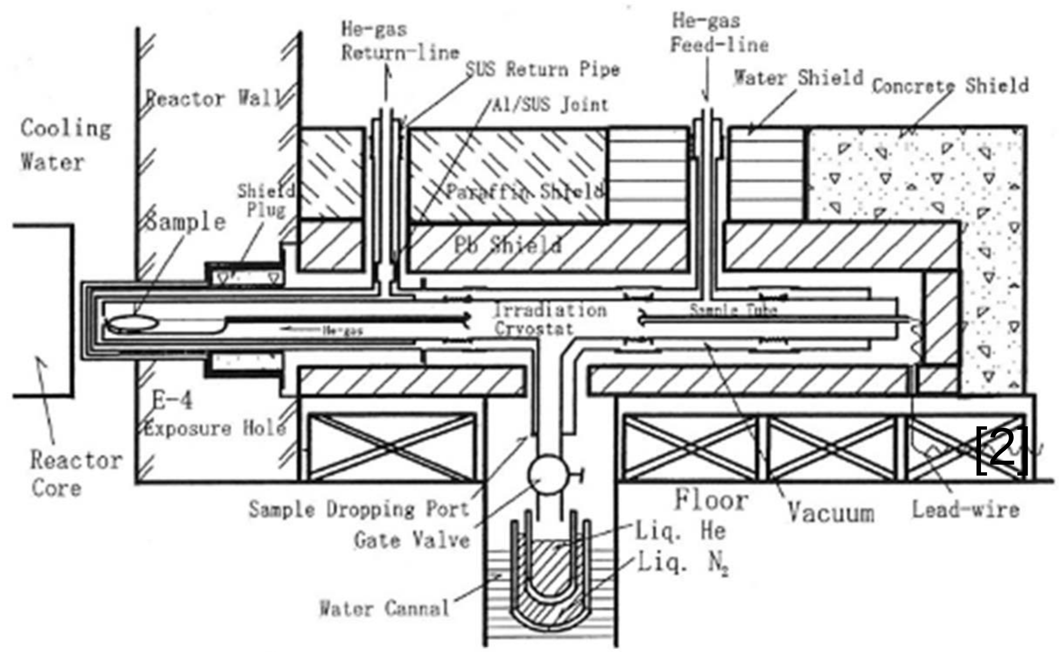
Low Temperature Irradiation Facility

- Kyoto Univ. Research Reactor Institute
- 5MW max. thermal power

- Cryostat close to reactor core
- Sample cool down by He gas loop
  - 10K – 20K

- Fast neutron flux
  - Measured by Ni activation in 2010
  - 1.4×10^{15} n/m^2/s (>0.1MeV) @1MW

[2] M. Okada et al., NIM A463 (2001) pp213-219



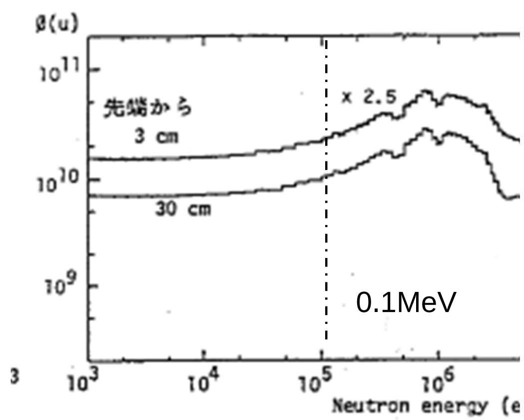


Fig. 15 Neutron energy spectrum in LTL of KUR for ordinary core (above 1000 eV)

KUR-TR287 (

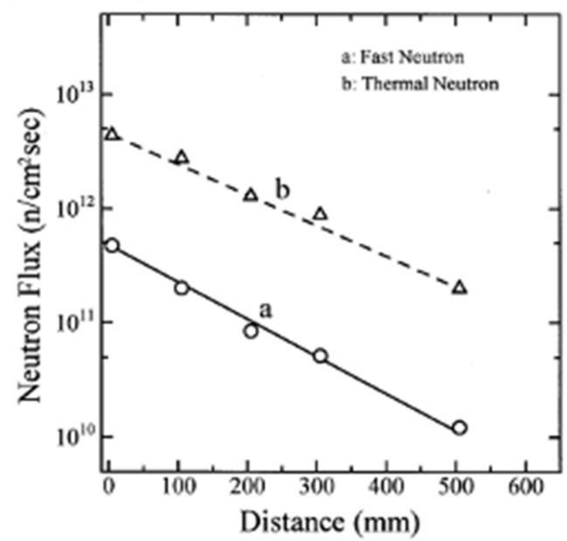
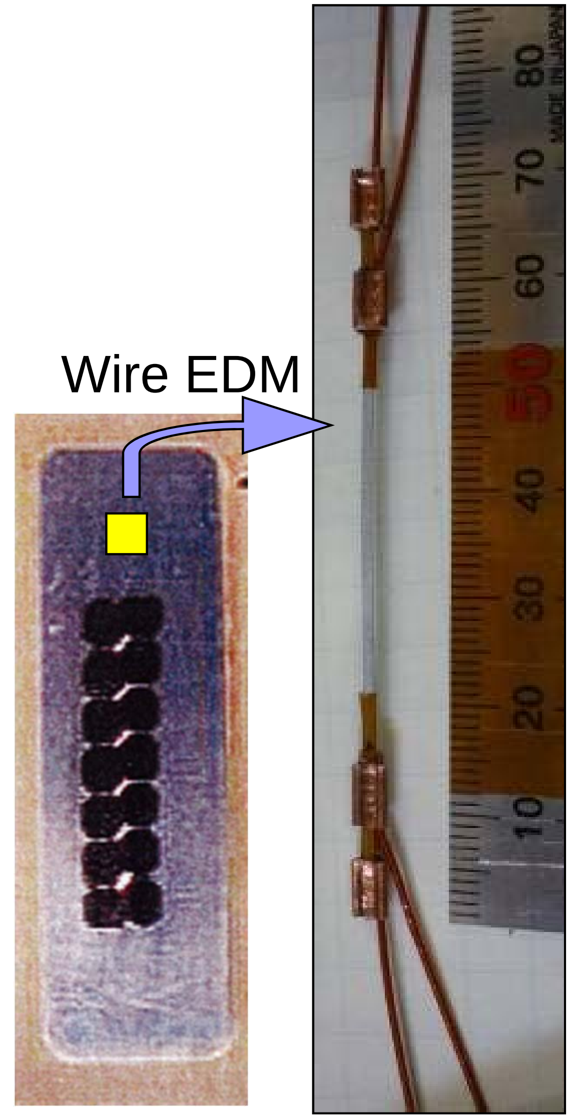


Fig. 7. Neutron flux distribution as a function of distance from top of sample chamber, (a) fast-neutron and (b) thermal neutron.

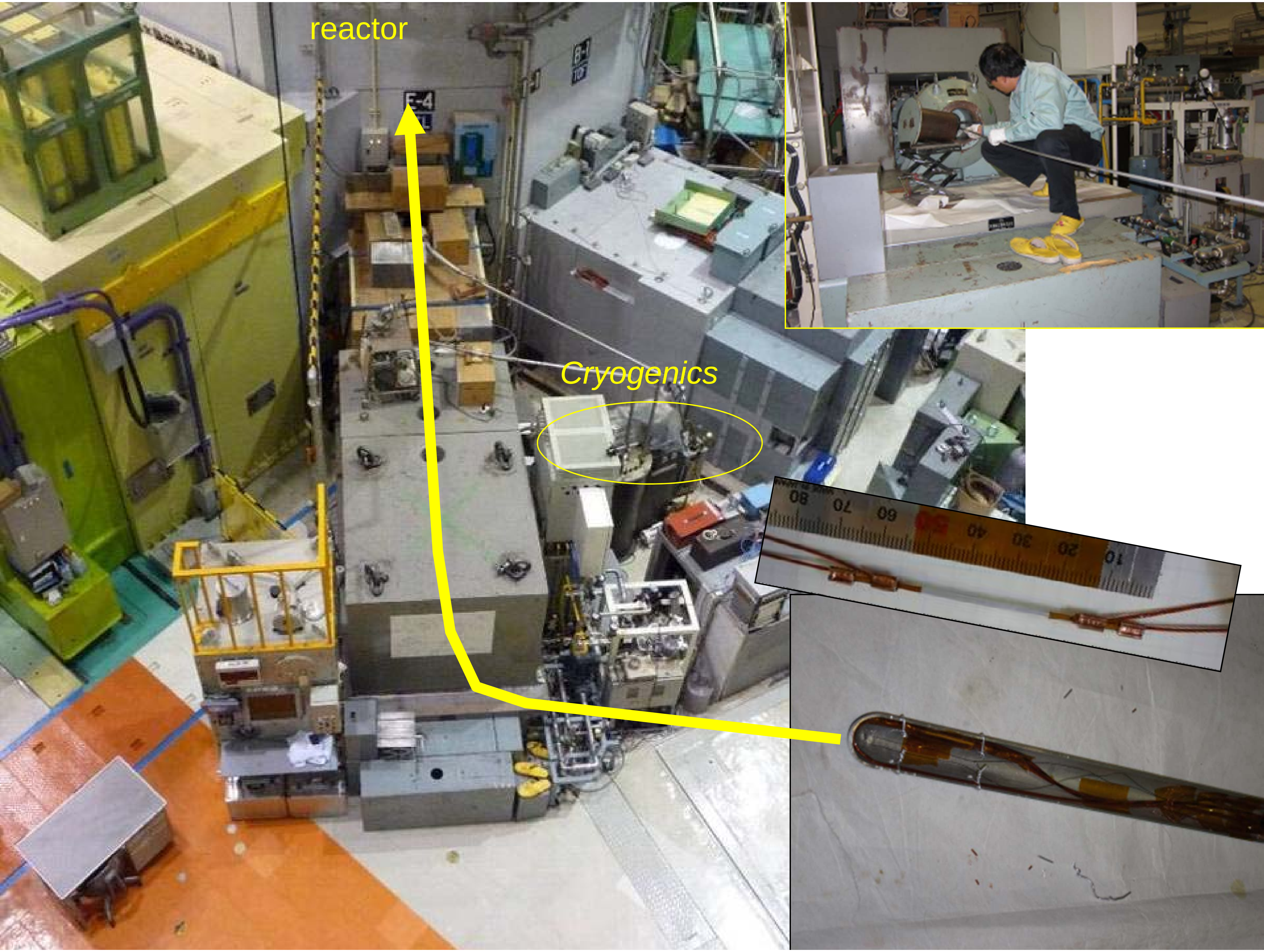
Irradiation sample

- Aluminum stabilizer sample from the superconductor by wire electrical discharge machining in KEK
  - Keep defects by cold-work
- Size: 1mmx1mmx70mm
- Voltage taps with 45mm spacing
- 4 wire resistance measurement by nano-voltmeter
- CERNOX CX-1050-SD close to sample temperature (also irradiated)



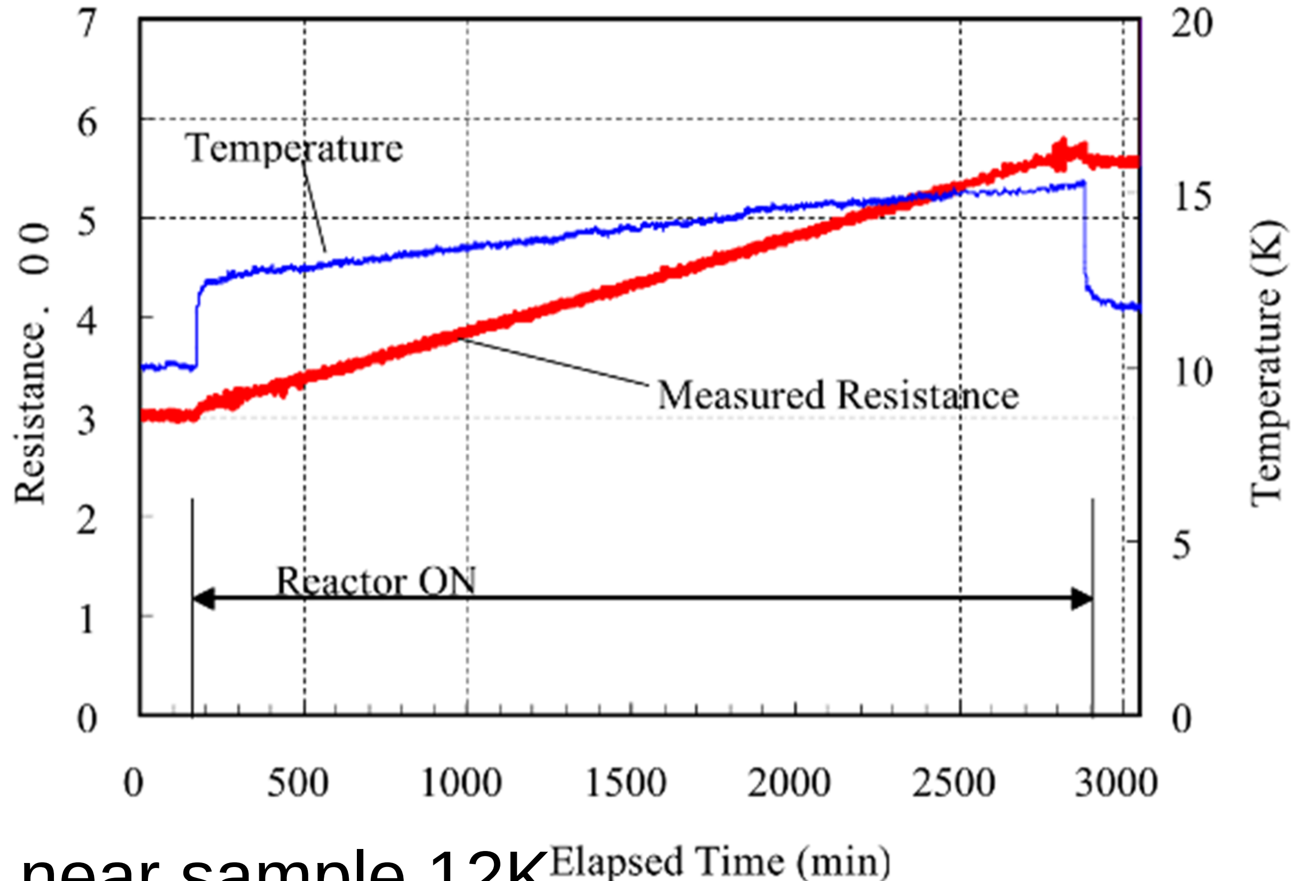
Irradiation sample

- 5N aluminum + Cu, Mg with 10 % cold work
- RRR=450
  - 1.35mΩ @RT, 3μΩ @10K


reactor
Cryogenics

Al-Cu-Mg

1mmx1mmx45mm(Vsens)

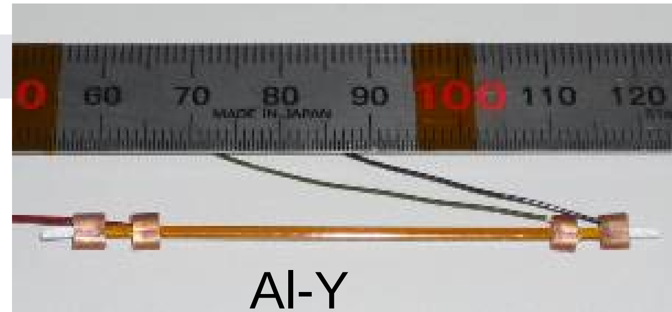


- He gas temperature near sample 12K
- Resistance changes linearly from low dose (No thershold)
  - 3.1μΩ → 5.7μΩ
  - induced ρ_i = 0.056 nΩ.m for 2.3x10^{20} n/m^2 (>0.1MeV)
  - As expected (cf. [1]), more due to epithermal neutron?
- In COMET, expected ρ_i < 0.2 nΩ.m for 6x10^{20} n/m^2

Temperature drift 12K→15K due to CERNOX sensor degradation?

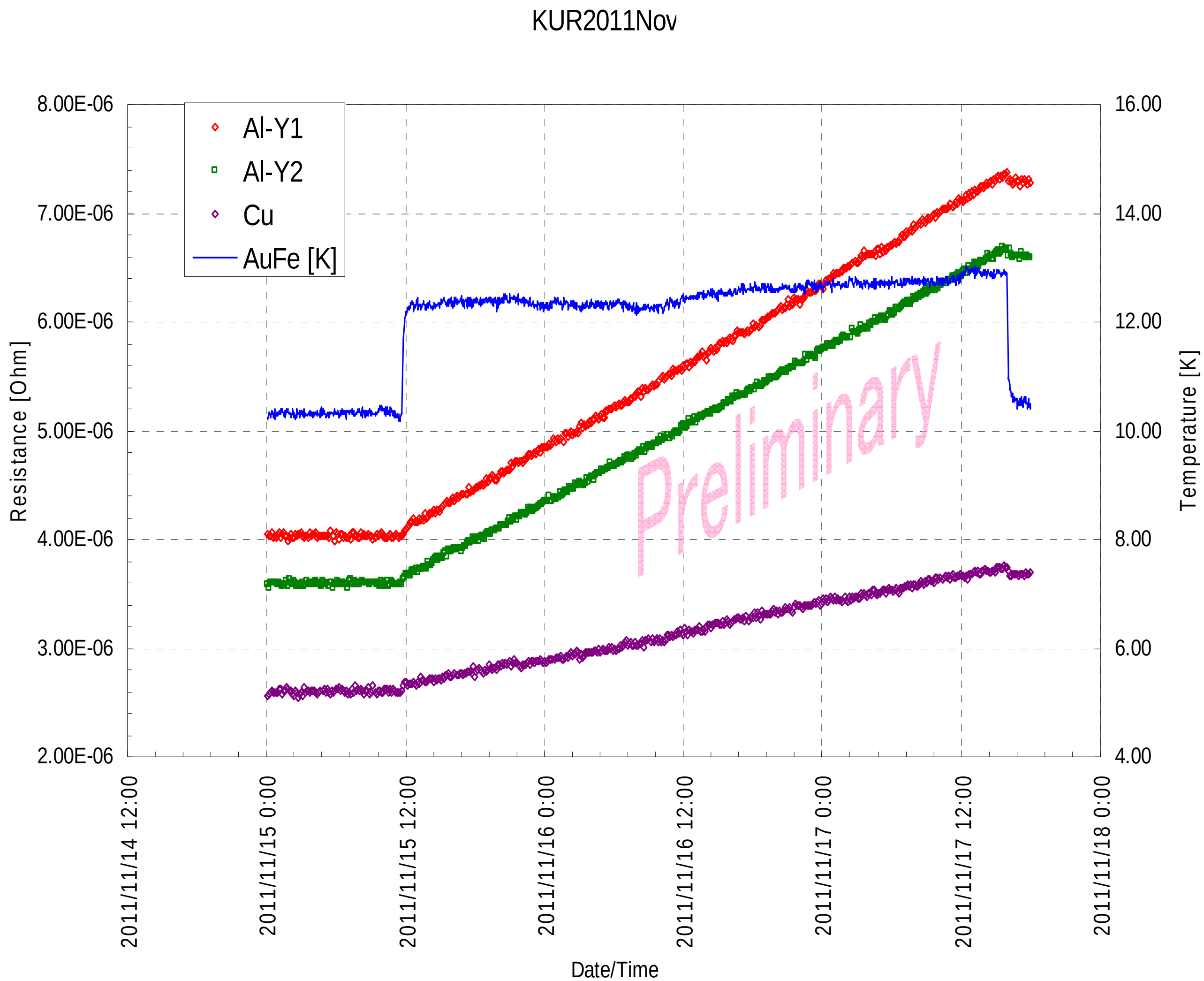
Al-Y, OFHC

OFHC
ϕ1mmx35mm(Vs)
RRR=311

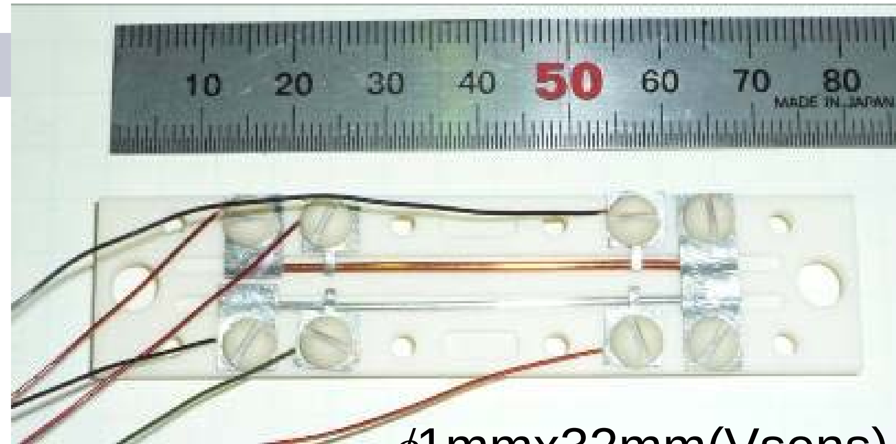


Al-Y
1mmx1mmx45mm(Vs)
RRR=334,361

- Neutron fluence
  - 2.6×10^{20} n/m^2 in 1MWx52hrs
- Al-Y1
  - 4.0μΩ→7.3μΩ
  - ρi = 0.07 Ωm
- Al-Y2
  - 3.6μΩ→6.6μΩ
  - ρi = 0.07 Ωm
- OFHC
  - 2.6μΩ→3.7μΩ
  - ρi = 0.03 Ωm

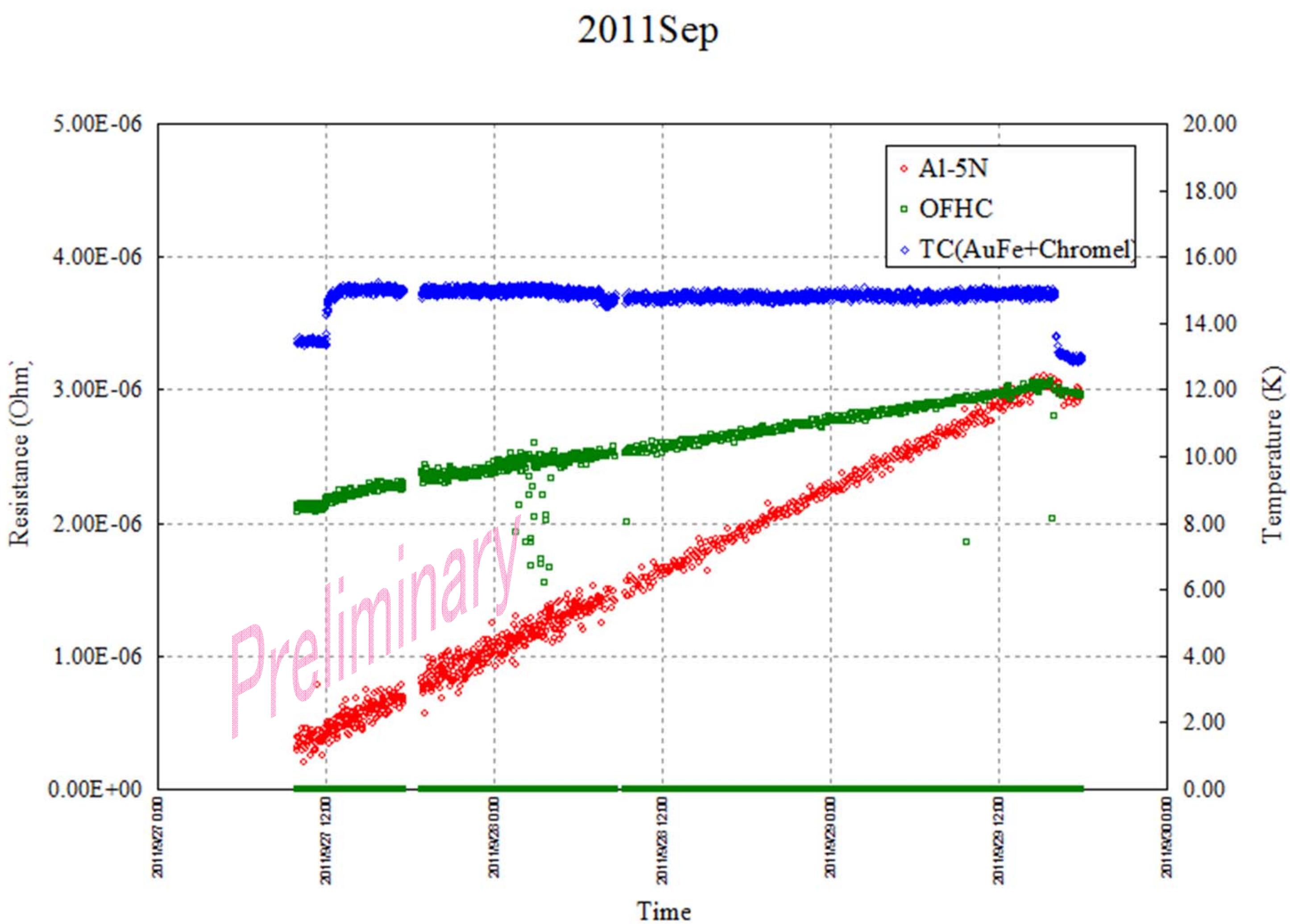


OFHC, 5N Al

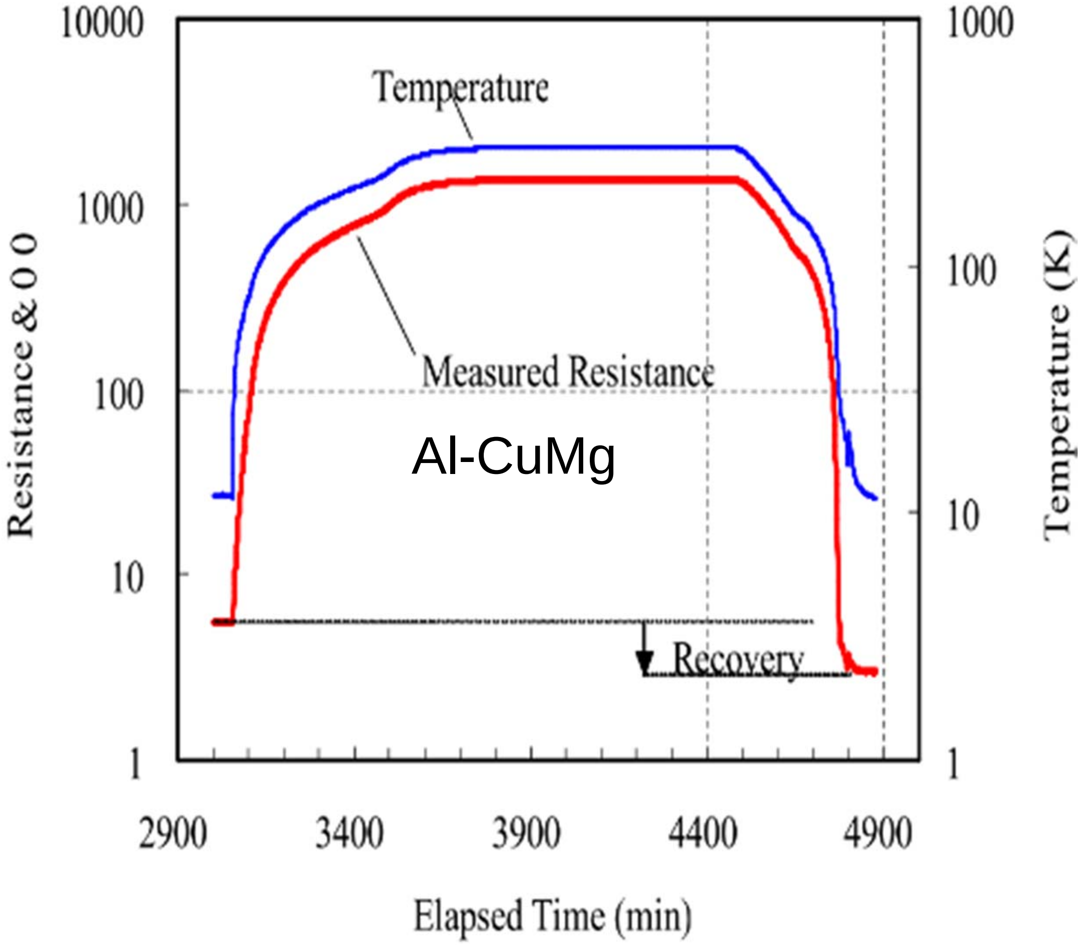


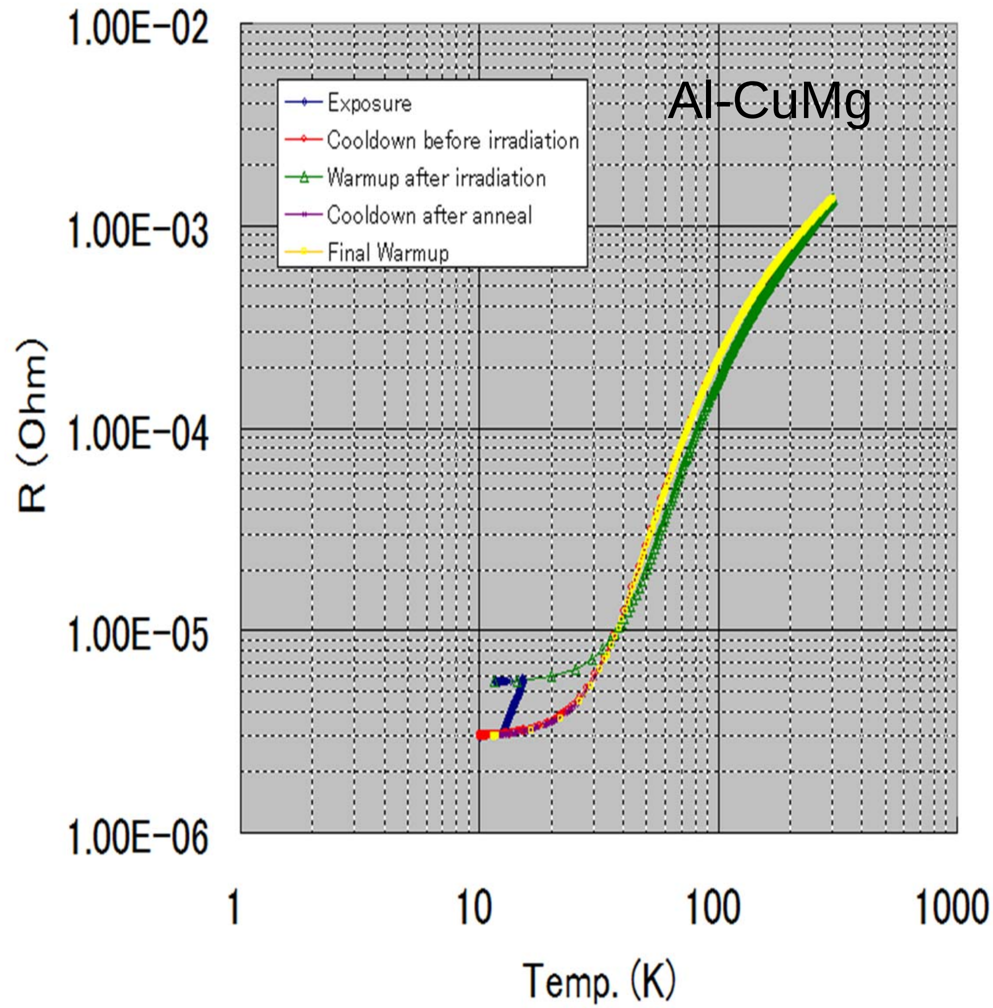
ϕ1mmx32mm(Vsens)
5N-Al: RRR~3000

OFHC: RRR~300



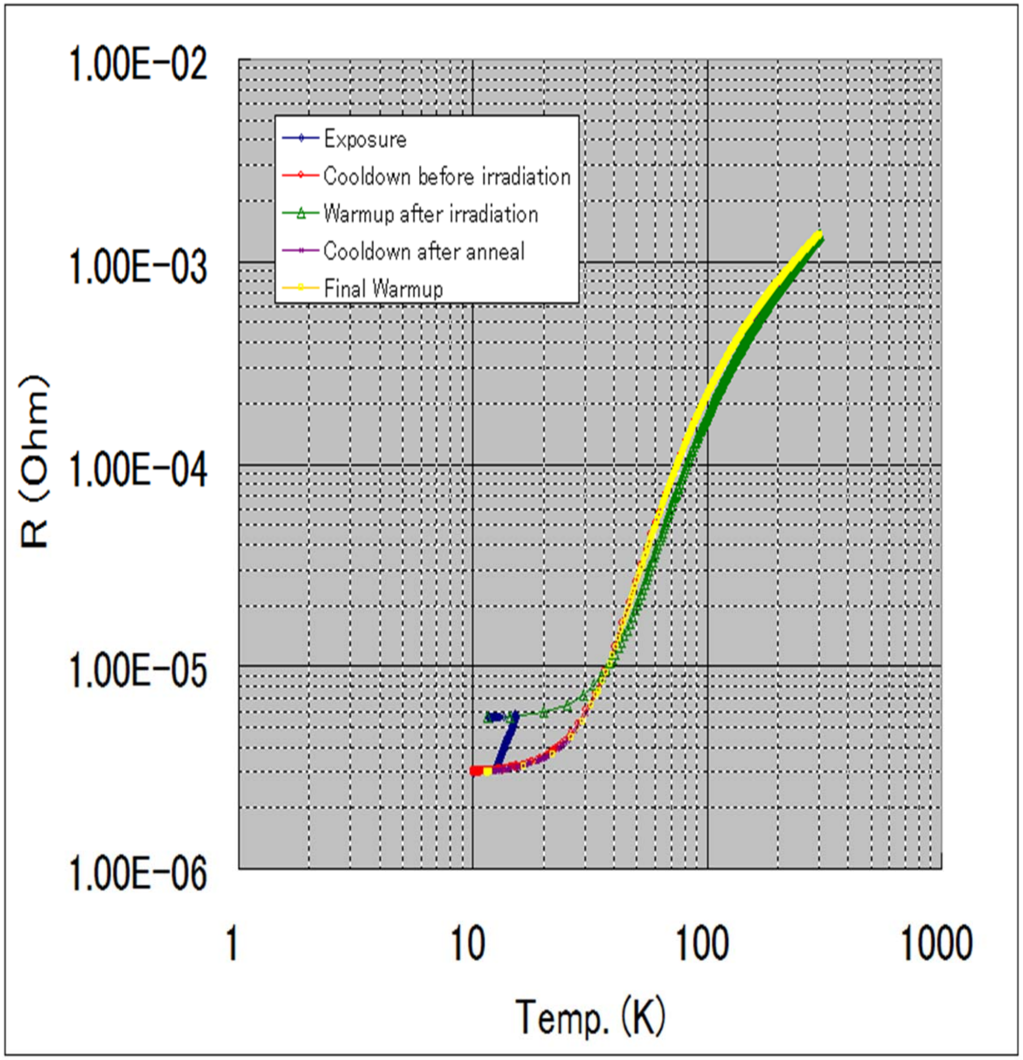
Annealing at Room Temperature

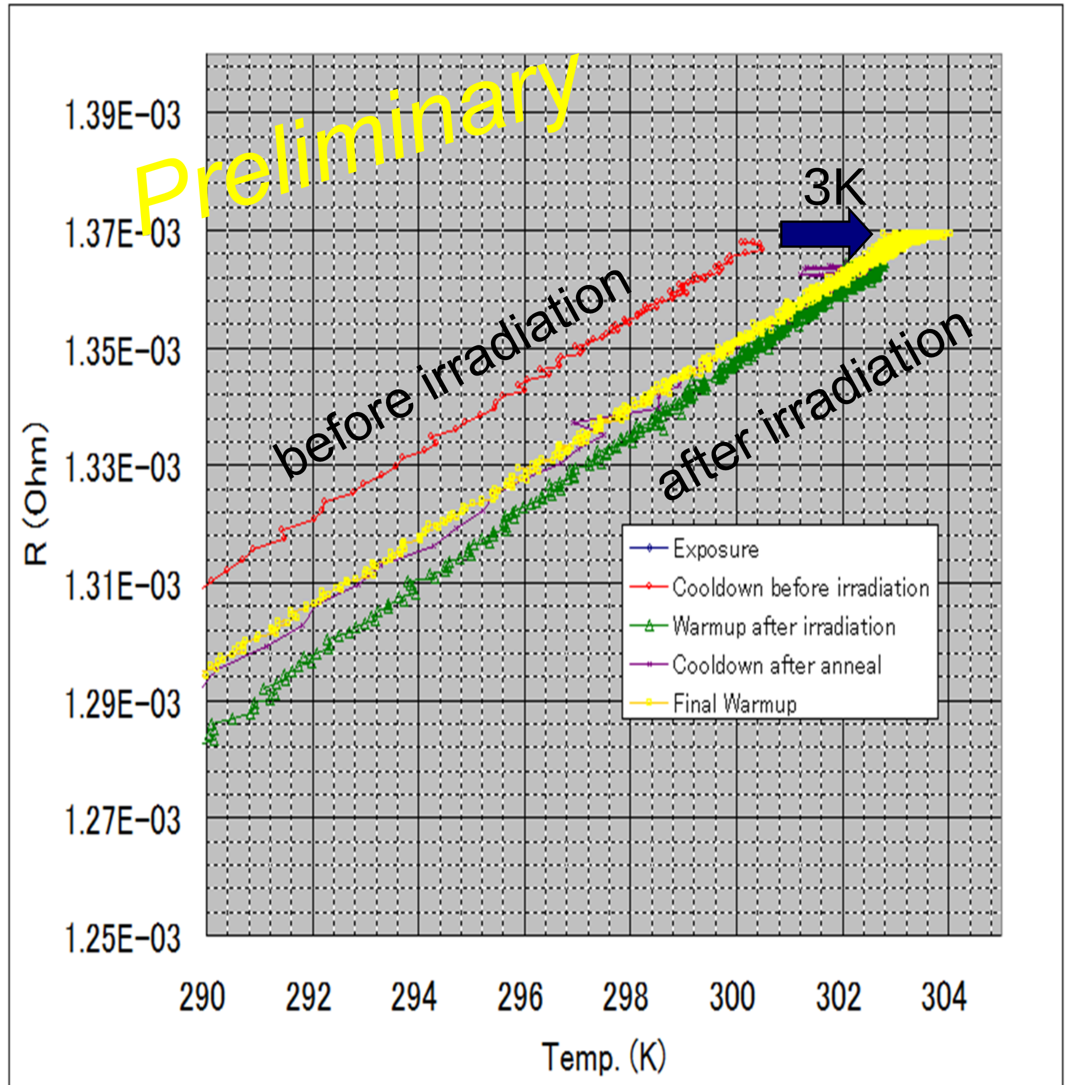




- Al-CuMg recovered perfectly!

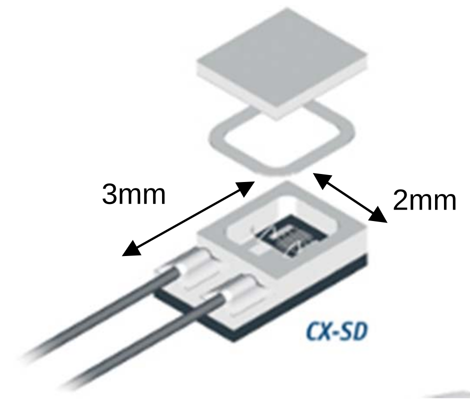
CERNOX degradation?



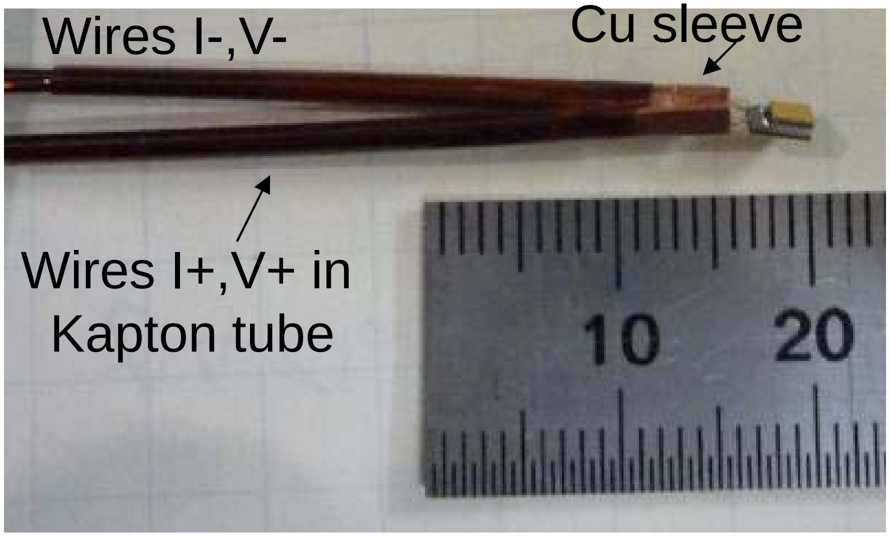


- dR/dT=-0.26Ω/K@300K
- dT=3K → dR=0.78Ω

CERNOX sensor



- Lakeshore CERNOX sensor
  - sputtered zirconium oxy-nitride thin films



SS. Courts and P.R. Swinehart, Advances in Cryogenic Engineering, Vol. 45

- Tested at 10^{19} n/m^2 for LHC
  - Drift ~ 2mK@1.8K

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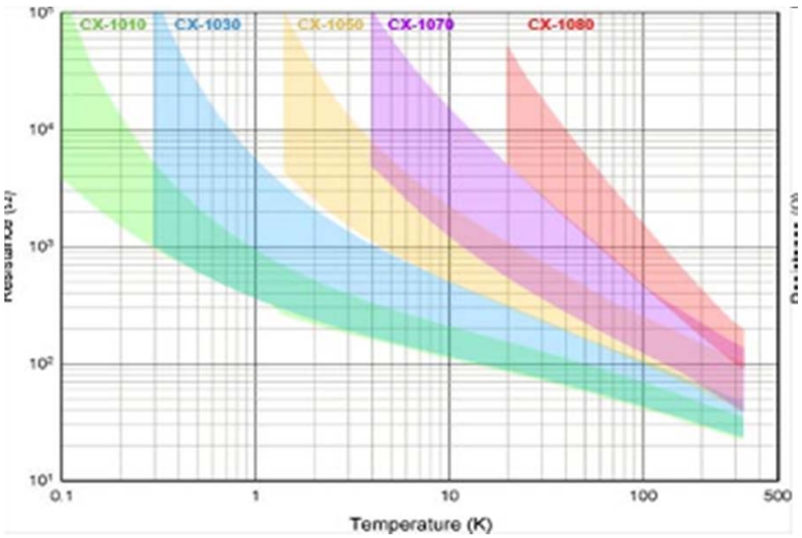
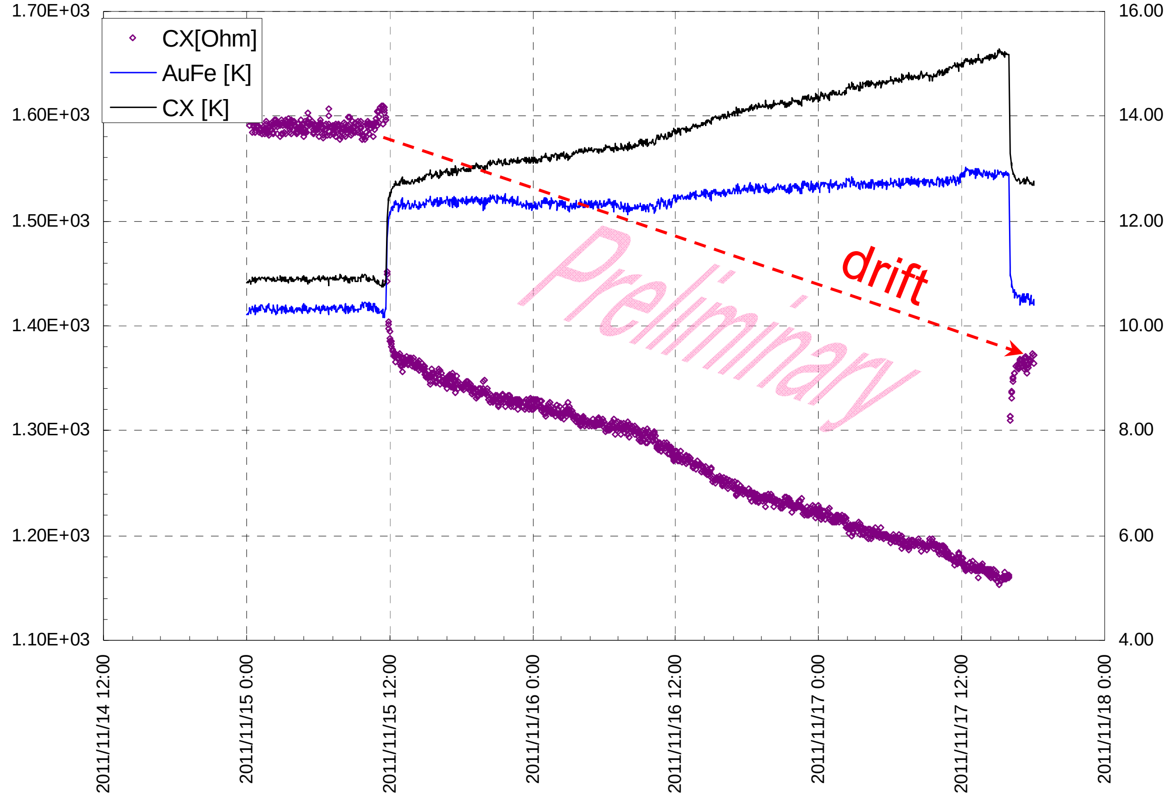


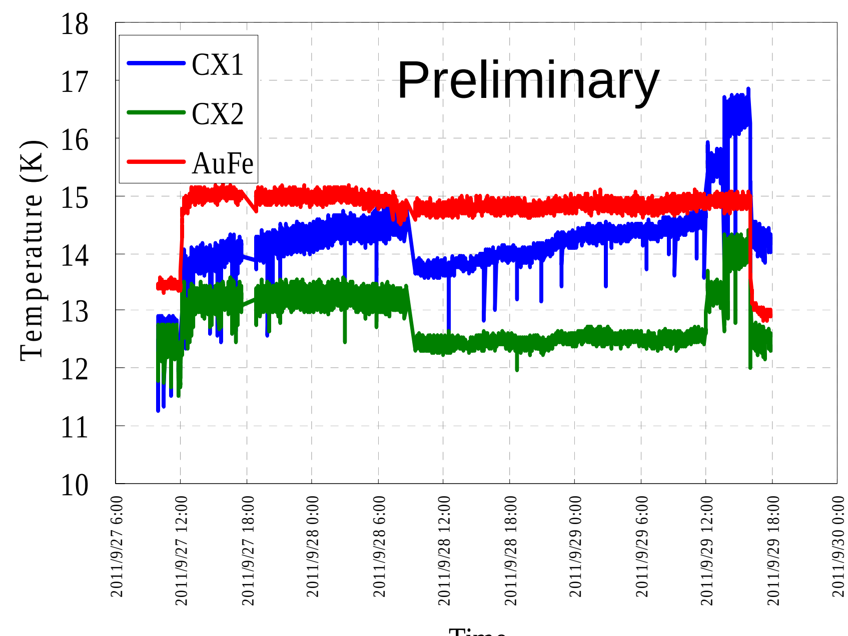
http://www.lakeshore.com/temp/sen/crtd.html

Drift of CERNOX sensor readout

2011Nov



2011Sep



CERNOX drift 1.6kΩ→1.4kΩ for 2.6×10^{20} n/m^2

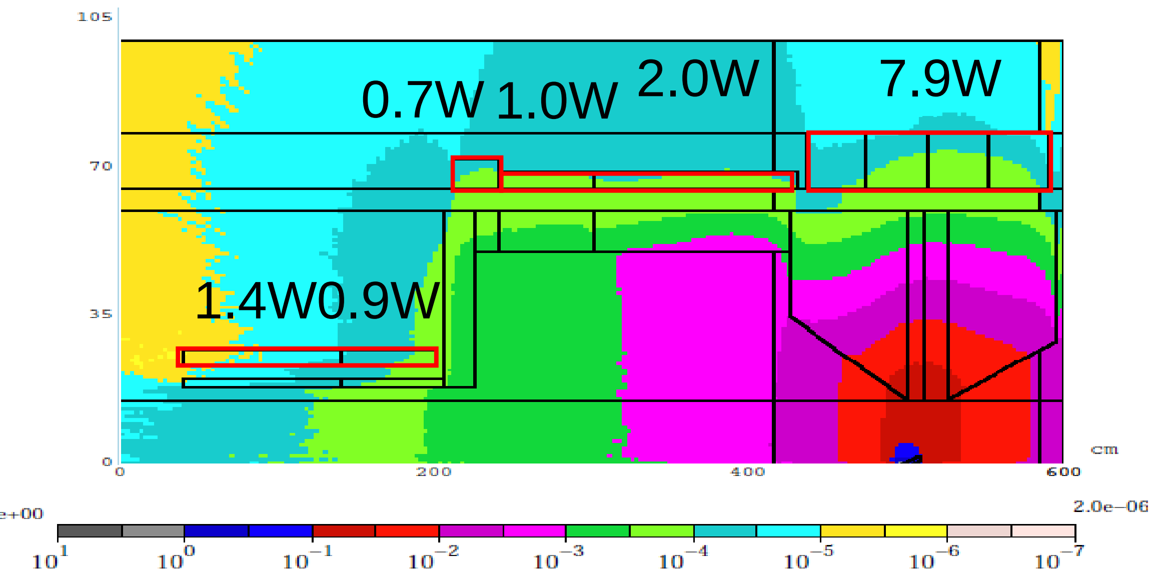
Irradiation effect? Self heating?

Summary

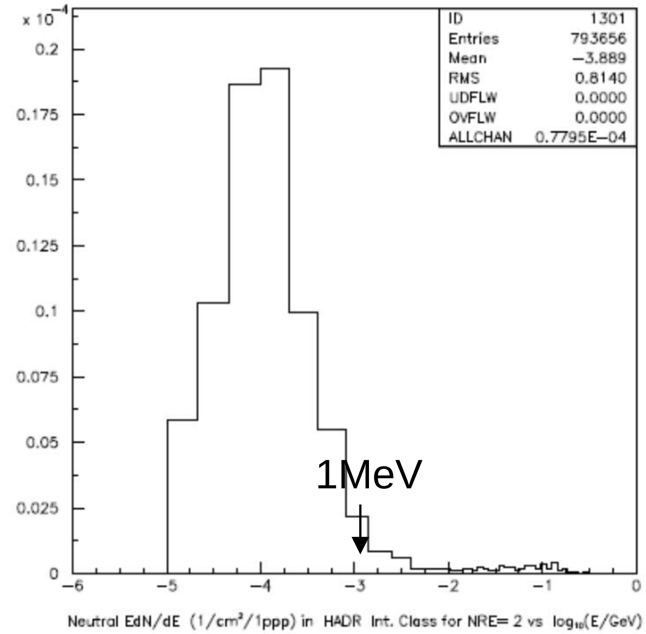
- Stabilizer materials were tested by KUR neutrons
  - Al-CuMg, Al-Y, OFHC
  - Recovery of Al-CuMg has been observed
  - Cycle irradiation effect on Cu will be investigated
- Induced resistance is slightly larger than expected
  - epithermal neutron irradiation? ← Dr. Iwamoto
  - gamma ray?
- CERNOX seems to degrade at 10^{20} n/m2 in temperature range of 10K-20K
  - Need to check recovery by thermal cycle to RT

Backup

Radiation on CS



Neutron flux (n/cm2/proton)



- Maximum heat deposit
  - 10 mW/kg
- Maximum dose
  - 0.07 MGy/10^{21}p
- Neutron flux
  - 1×10^{21} n/m^2/10^{21}p
  - fast neutrons 6×10^{20} n/m^2/10^{21}p (>0.1MeV)

Neutrons penetrates thick 45cm tungsten shield surrounding the target

Neutron fluence for experimental life-time (~10^{21} p) approaches a level of ITER magnets (ITER requirement: 10^{22} n/m^2)

Problematic components

- Stabilizer
  - Aluminum alloy
  - Copper
- Thermal conductor
  - Pure aluminum
  - Copper
  - Aluminum alloy
- Thermo sensor
  - No experience at 10^{21} n/m^2

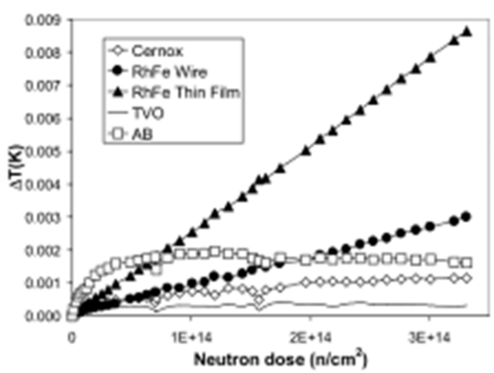


Figure 3 Error on temperature measurement on some sensors during irradiation (Tbath=1.8 K)

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- Fast-neutron irradiation induces defects in metal.
- Defects could be accumulated at Low temperature,
- and causes degradation of electrical/thermal conductivity
- Problems in
  - Quench protection, Stability
  - Cooling

Neutron Flux at KUR-LTL

Makoto Yoshida (KEK)

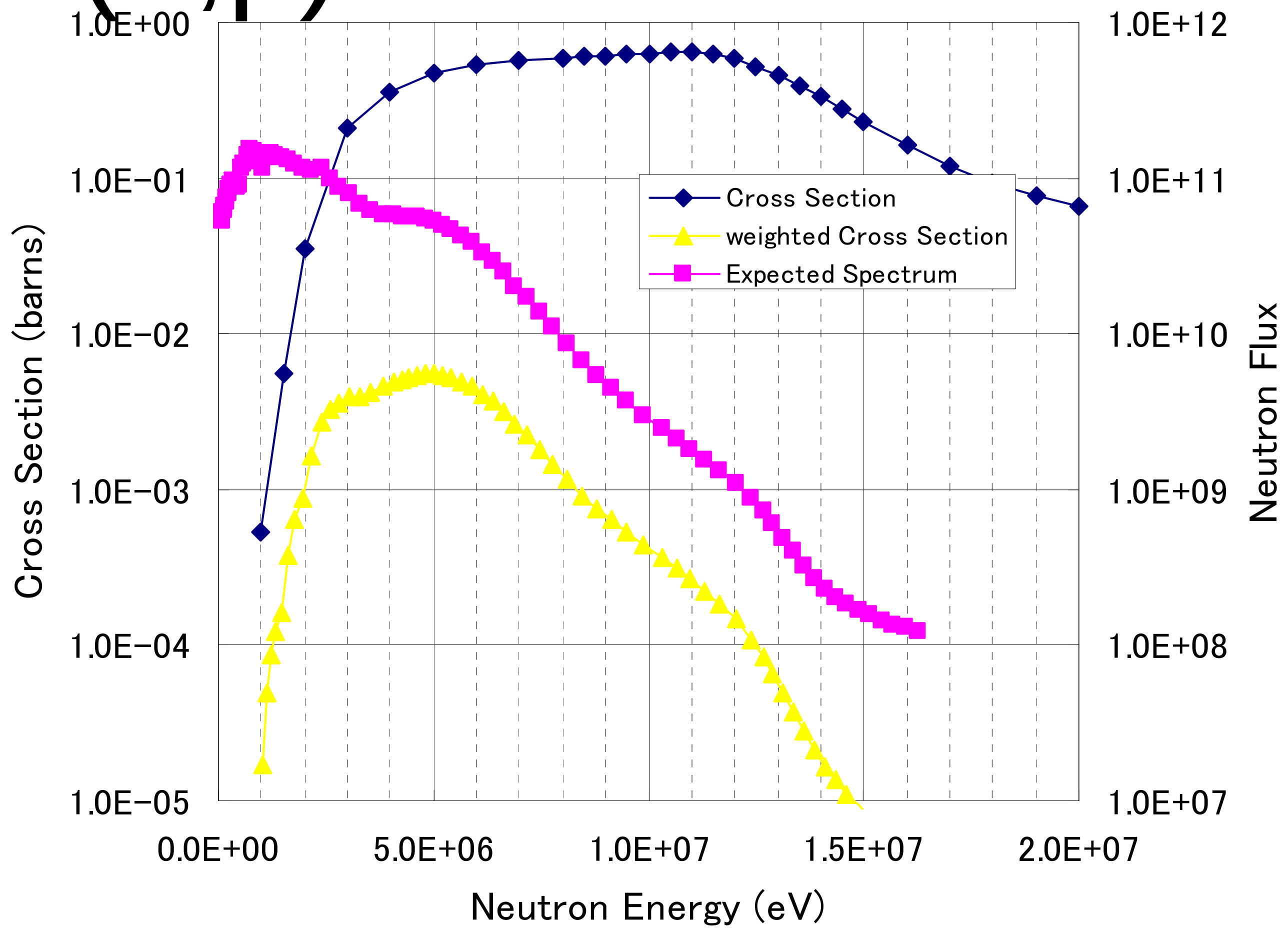
2011/5/25

Ni activation measurement

- Ni foil (10 mg) was irradiated near aluminum sample in LTL sample chamber in Nov. 2010
  - 1 MW x 45 hours
- After 131 day cooling down, gamma ray from Co58 was measured
- Ni58(n,p)Co58 reaction rate during neutron exposure was calculated to be 1.55E-14 $atm^{-1}sec^{-1}$
- Neutron spectrum in LTL sample chamber with old reactor core setup was measured in 1987 [1]

[1] "Measurement of Neutron Spectrum at Irradiation Facilities of Kyoto University Reactor, KUR," K. Kobayashi et al., KURRI Technical Report 287 (1987)

Ni58(n,p)Co58 cross section



- Average cross section in reactor neutron spectrum
  0.194 barns (>1MeV)
- Average down to 0.1 MeV, although the reaction Ni58(n,p)Co58 is sensitive to energy range above a few MeV ...
  0.108 barns (>0.1MeV)

Neutron fluence

- Fast neutron fluence > 1 MeV
  - 45 [hours] x 1.55E-14 [$atm^{-1}sec^{-1}$] / 0.194 [barns]
    = 45[hours]x7.990x10^{14}[$n/m^2/s$]
    =1.3x10^{20} [n/m^2]

- Fast neutron fluence > 0.1 MeV
  - 45 [hours] x 1.55E-14 [$atm^{-1}sec^{-1}$] / 0.108 [barns]
    = 45[hours]x1.435x10^{15}[$n/m^2/s$]
    = 2.3x10^{20} [n/m^2]

*assuming reactor neutron spectrum measured in [1]