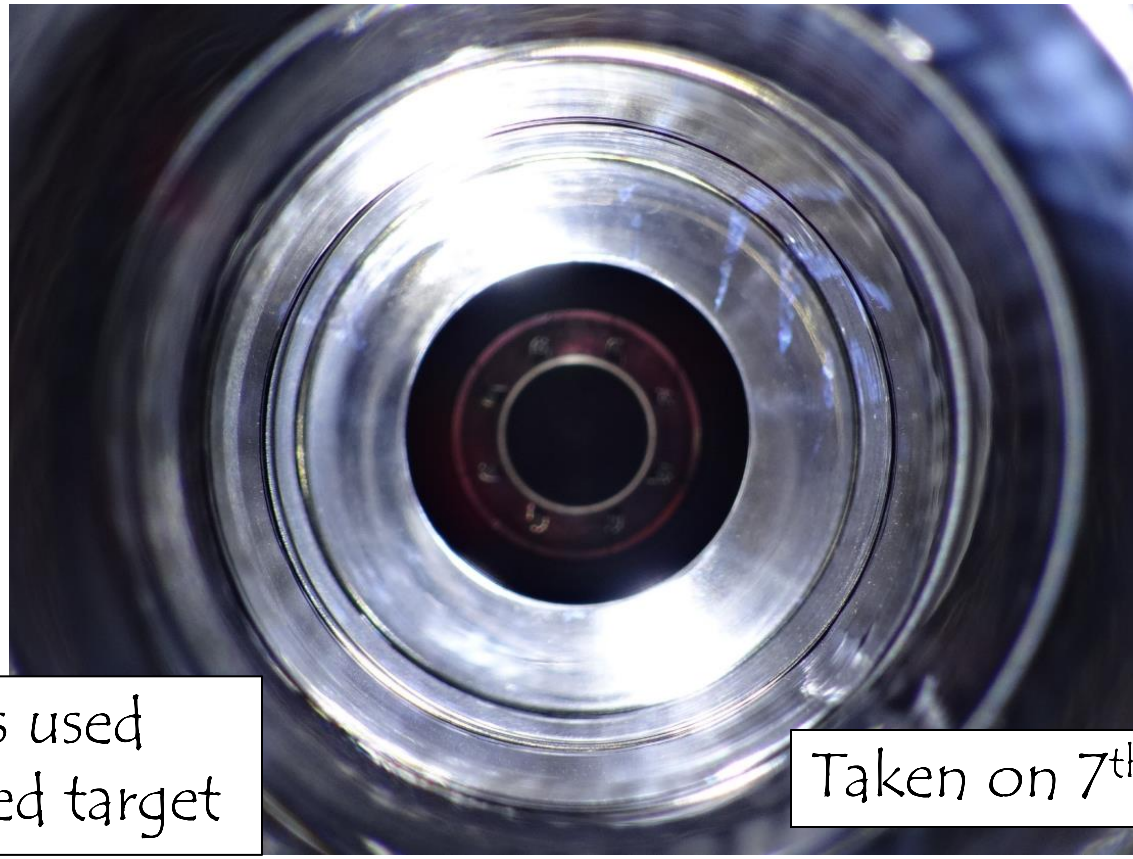
20th October 2014
IWSMT-12@Bregenz

Muon Fixed Target at J-PARC/MUSE

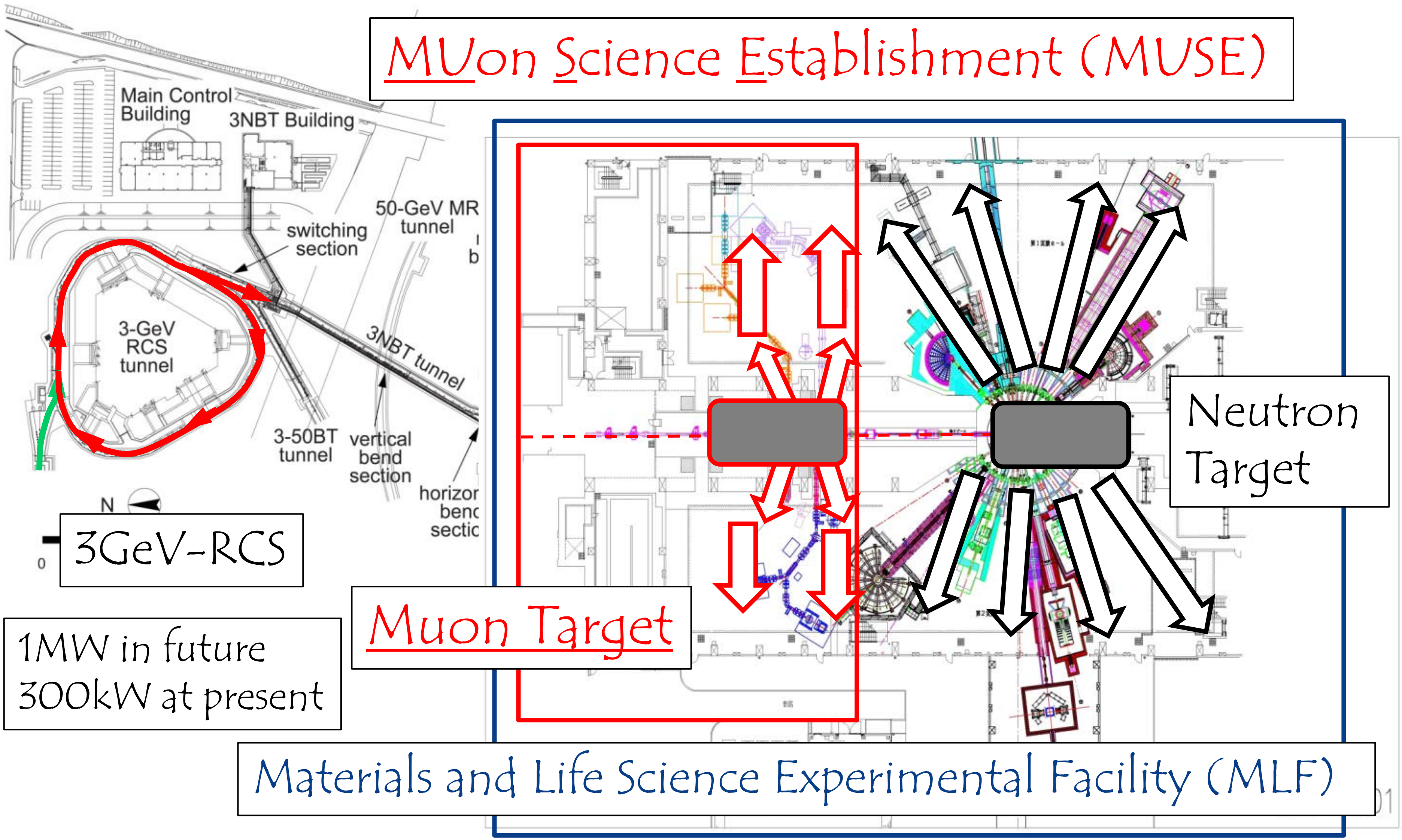


Five-years used
Muon fixed target

Taken on 7th July, 2014

J-PARC Center, MLF Division, Muon Section (KEK)
Shunsuke Makimura (shunsuke.makimura@kek.jp)

J-PARC/MLF/MUSE & MUON TARGET



The most intense pulsed muon beam all over the world

Lifetime evaluation of Muon Fixed Target

P-Beam operation without replacement for five years

Originally-Evaluated Lifetime; 4000 hours (0.8 years) @1MW proton
Actual operation; 100kW~200kW~300kW, Beam parameters,,,

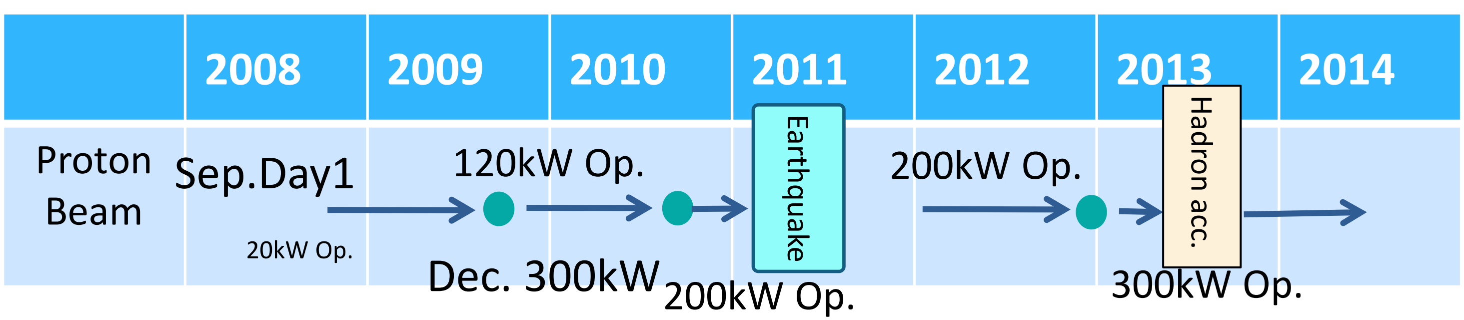
How long is actual lifetime?

- Stress by dimensional change due to P-irradiation
  - ✓ Irradiation effects to graphite, Beam conditions
- Residual stress during manufacturing
- Thermal stress by proton beam loss

History of operation

Overlapping of these stress is necessary for lifetime evaluation.

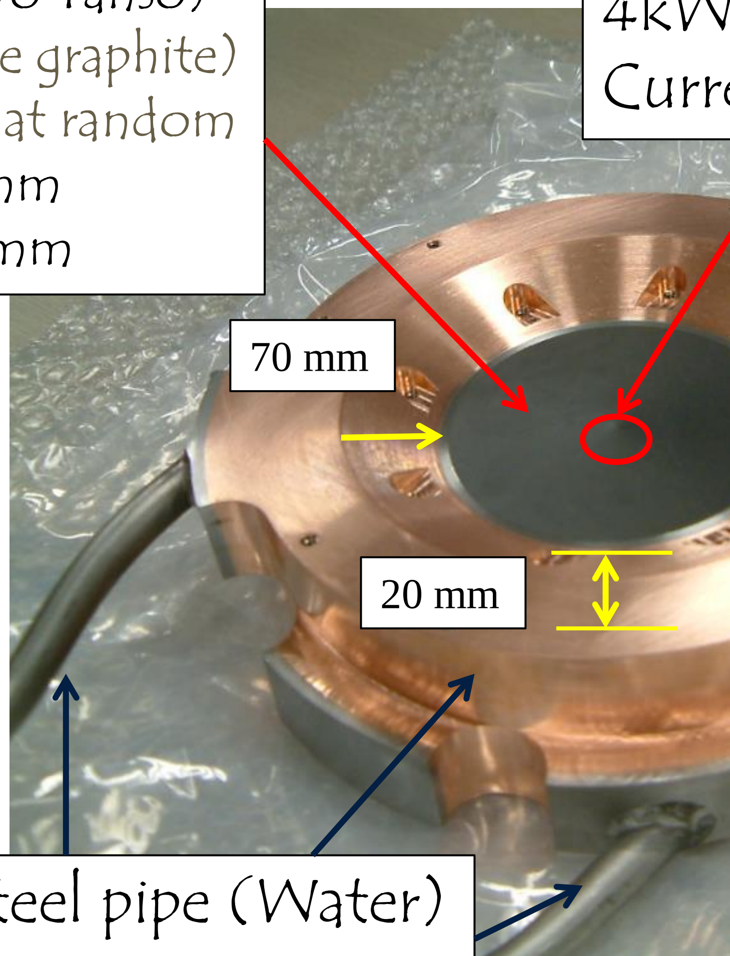
Creep by irradiation is not considered in these simulations.



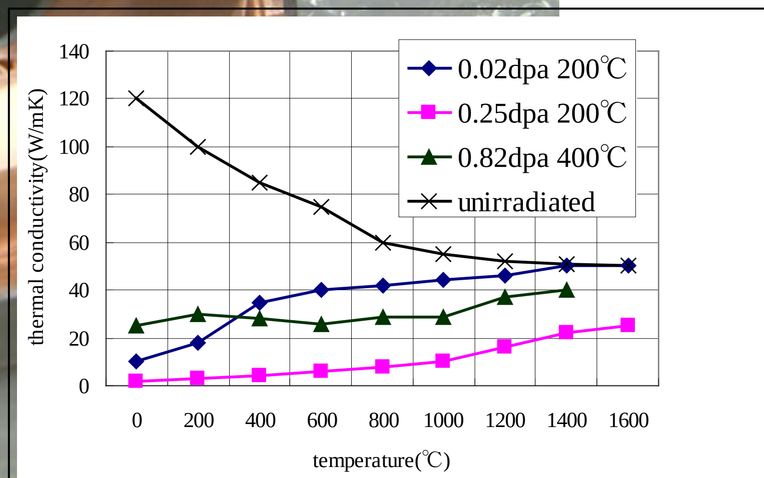
Current Muon Target (Fixed Target)

Isotropic Graphite
IG-430U (Toyo Tanso)
(polycrystalline graphite)
Small grain at random
Diameter; 70mm
Thickness; 20mm

P-Beam diameter; 16 mm (2σ)
4kW heat @ 1MW proton beam
Current beam power; 300 kW



Stainless steel pipe (Water)
Copper frame



Neutron irradiation effect to thermal conductivity
(T. Maruyama et al., Journal of Nuclear Materials 195 (1992) 44-50.)

Dimensional change by proton irradiation

- HOPG (Highly Oriented Pyrolytic Graphite)

c-axis; expansion, a-axis; shrinkage (expansion > shrinkage)
(B. T. Kelly et al., Phil. Trans. A, 260 (1966) 37-49.)

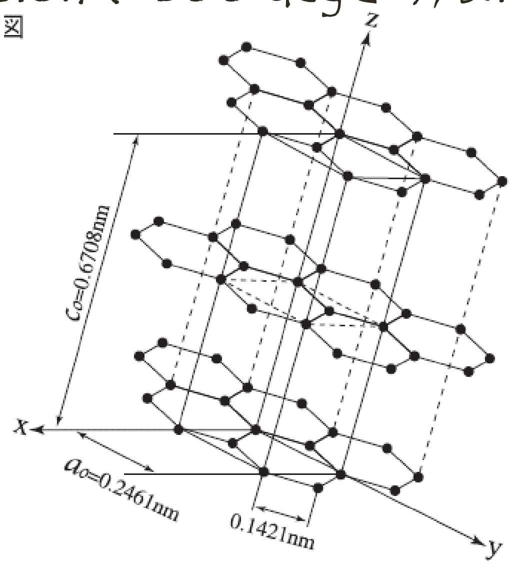
No effect was observed under 2300 K without irradiation.

- Isotropic Graphite

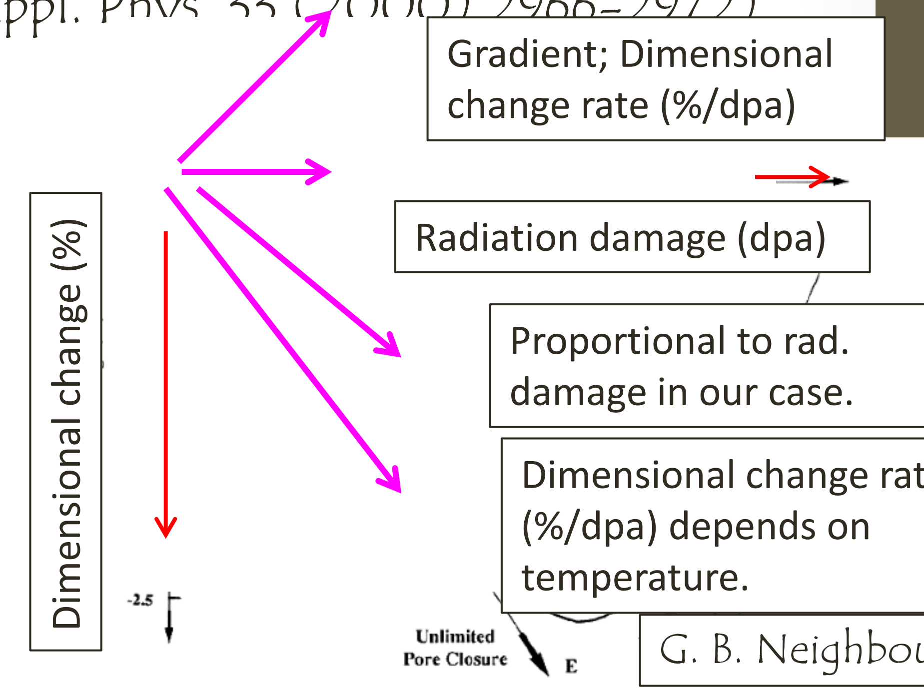
Pore closure, Pore growth, Crystal growth
(G. B. Neighbour, J. Phys. D: Appl. Phys. 33 (2000) 2966-2972)

temp. dependence
Expansion (< 300 degC <), Shrinkage

図



http://www.toyotanso.co.jp/Products/Pruduct_j.pdf



Gradient; Dimensional change rate (%/dpa)

Radiation damage (dpa)

Proportional to rad. damage in our case.

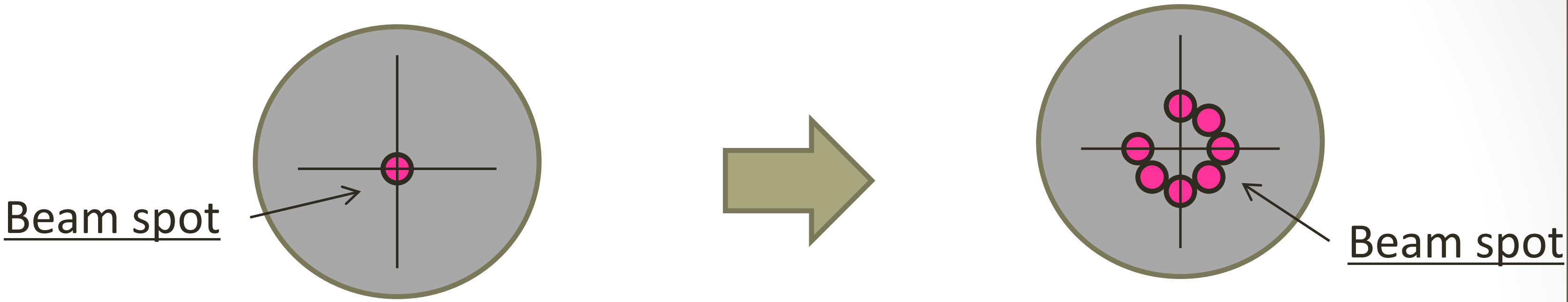
Dimensional change rate (%/dpa) depends on temperature.

G. B. Neighbour

Radiation damage (dpa) – Dimensional change(%)

History of Proton Beam Operation

Since 2012, Beam painting for each RUN, every three weeks



Beam spot on center

Beam position moving method

View from upstream of beam line

- ～RUN36 & RUN40　2 [years] 360 [MWh] @~120kW
  Beam Profile; Center, σh=4.5 [mm], σv=2.5 [mm]
- RUN37 & RUN38　2 [months] 190 [MWh] @200kW
  Beam Profile; Center, σh=4.5 [mm], σv=2.5 [mm]

Ellipse shape

- RUN41 ～ RUN44　5 [months] 480 [MWh] @200kW
  Beam Profile; EXILE (U,D,R, L) 4 mm offset, σh=σv=3.5 [mm]
- RUN45 ～ RUN51 (3/12)　6 [months] 995 [MWh] @300kW
  Beam Profile; EXILE (UR, UL, DR, DL) 4 mm offset, σh=σv=3.5 [mm]

posi. moving since 2012

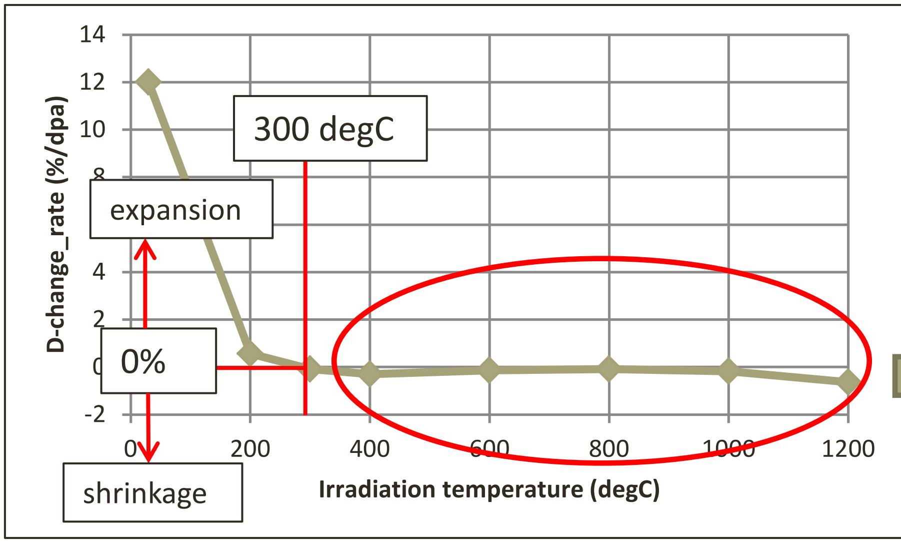
Temperature dependence of dimensional change rate by neutron irradiation

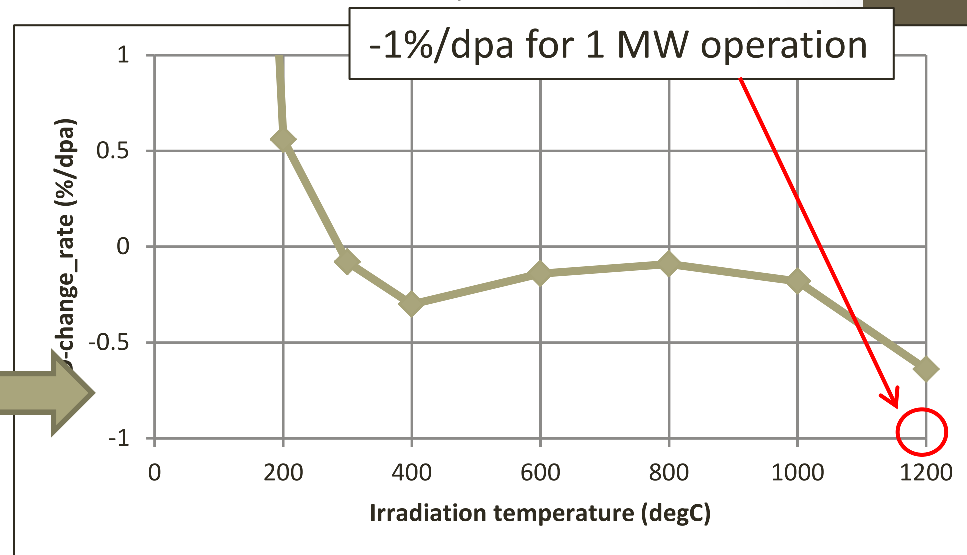
N irradiation data for IG-110
+; expansion, -; shrinkage

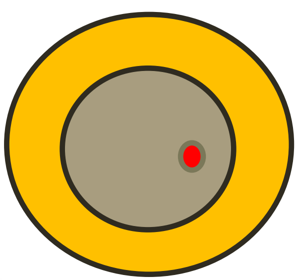
20 degC - 400 degC

T. Maruyama et al., Journal of Nuclear Materials 195(1992)44-50.

600 degC -1200 degC ; H. Matsuo, graphite 1991[150]290-302)



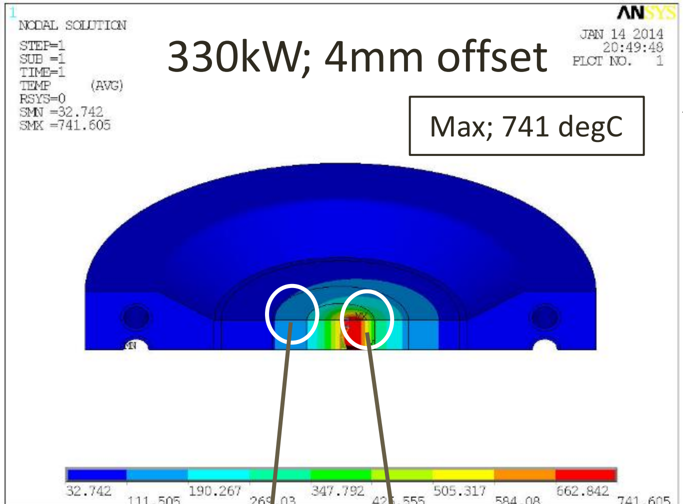




Position moving method

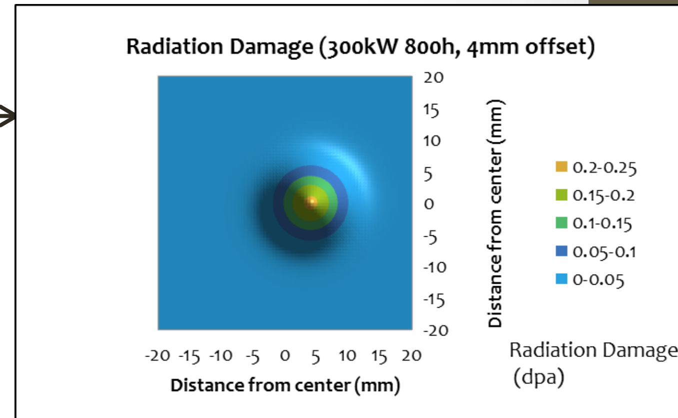
- Dimensional change rate depends on irradiation temperature distribution.
- Temperature distribution depends on beam profile, beam position, and intensity (Beam history).
- Dimensional change rate depends on the beam history.

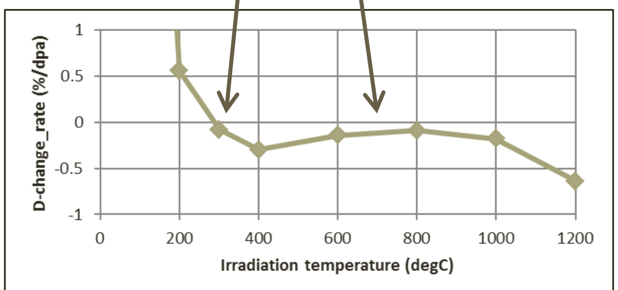
Example (300kW 4 mm offset)



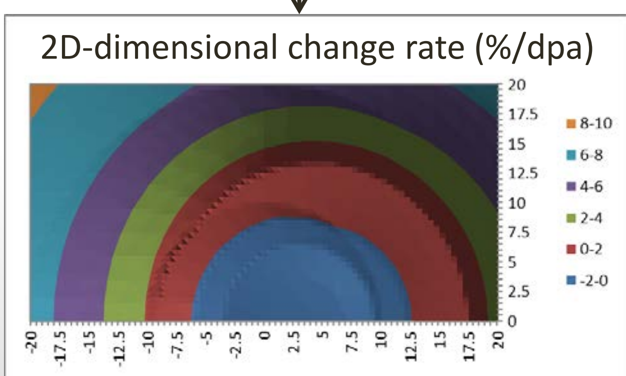
- Beam profile
- Beam position
- Beam power

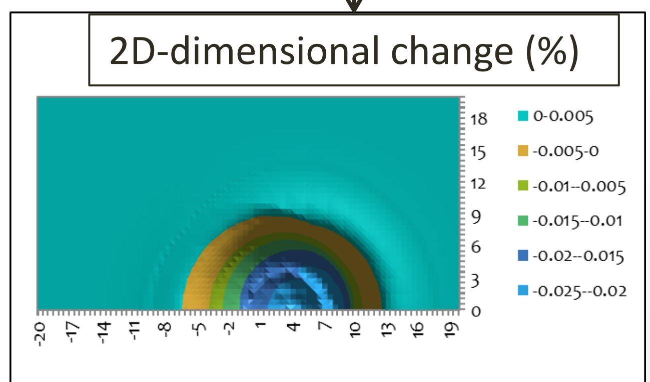
Irradiation time





2D-dimensional change rate (%/dpa) is multiplied to radiation damage (dpa)

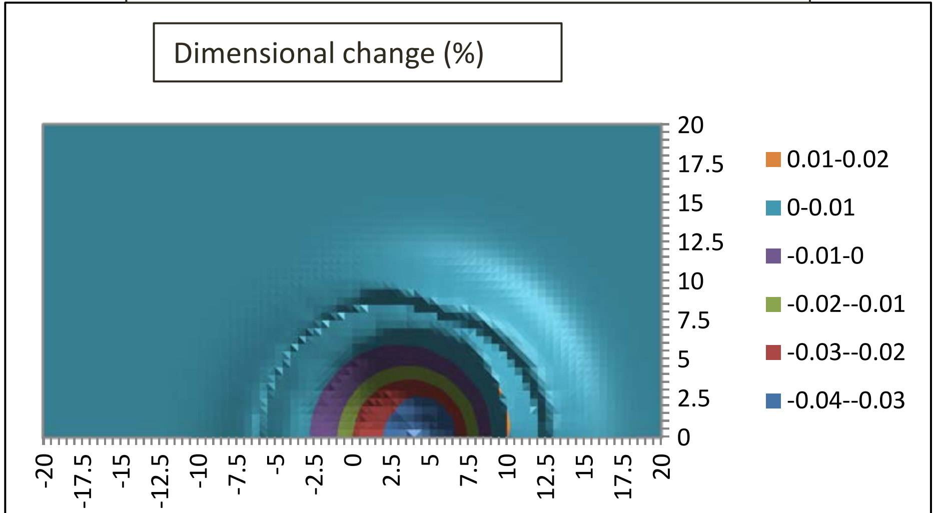




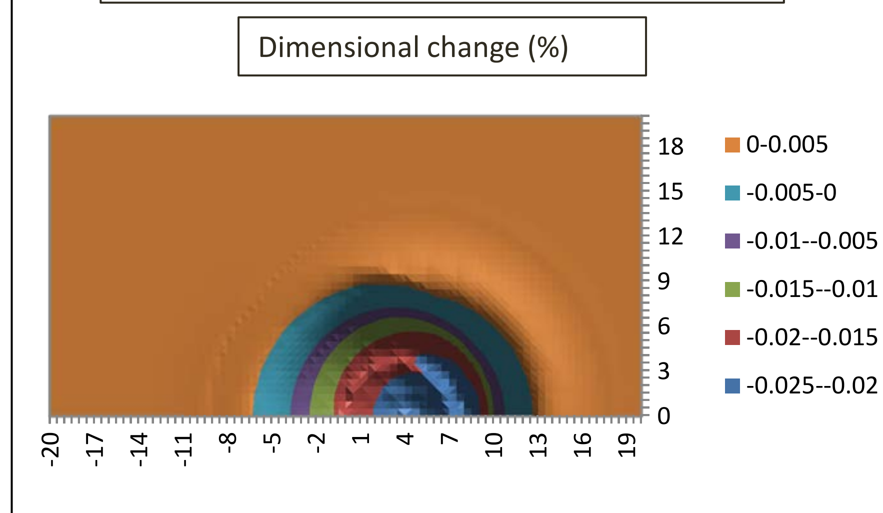
Displacements can be used for stress analyses.

Comparison of 200kW with 300kW irradiation

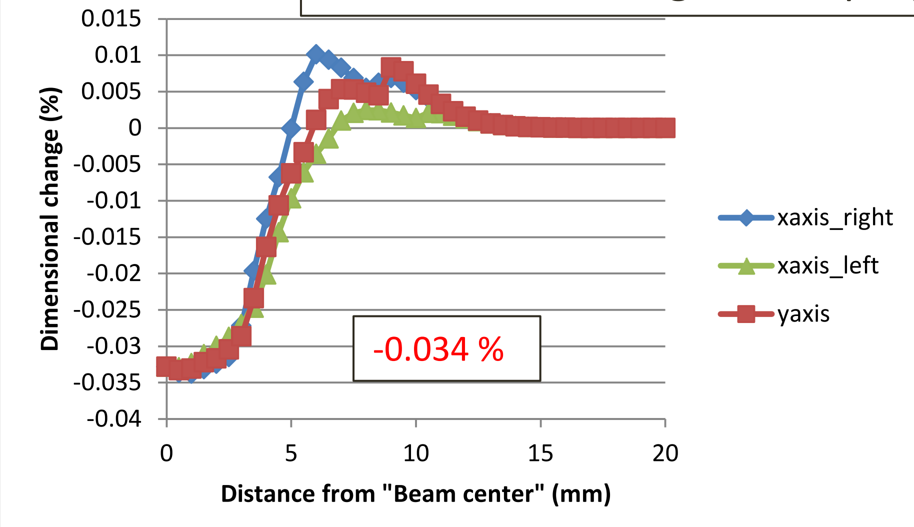
200kW, 700h, 140MWh
4mm offset, σh=σv=3.5 [mm]

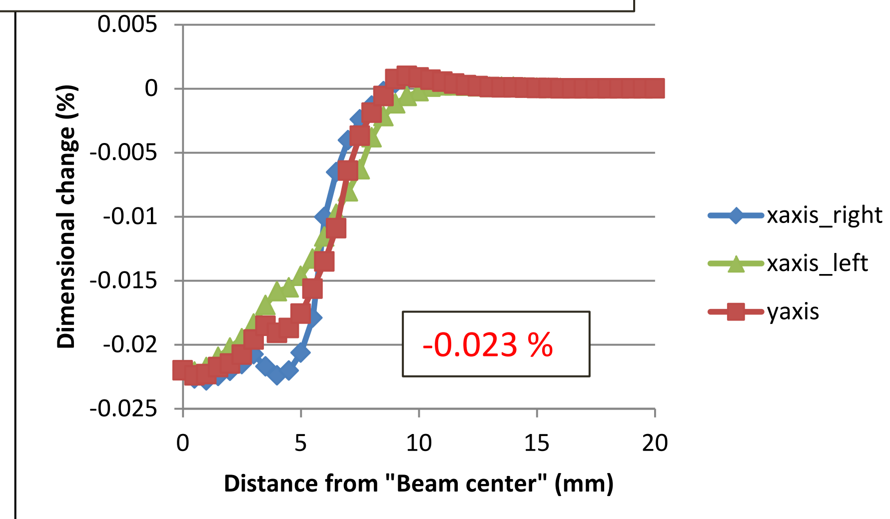


300kW, 700h, 210MWh
4mm offset, σh=σv=3.5 [mm]

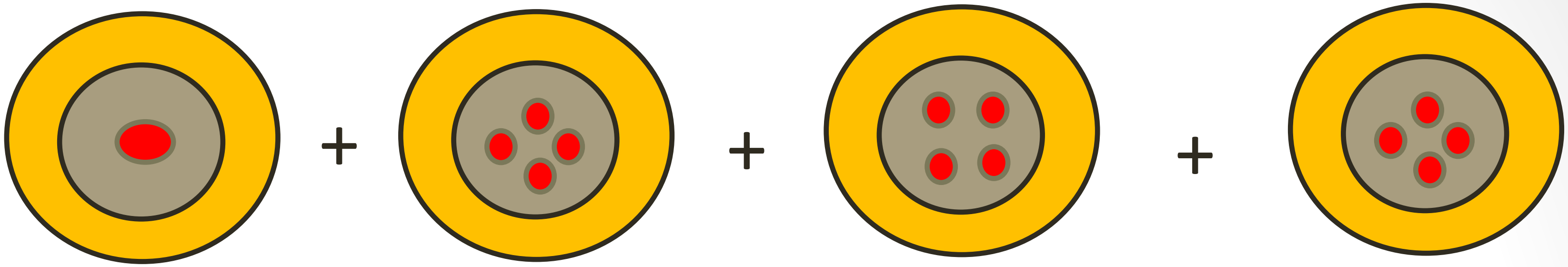


Dimensional change is not proportional to radiation damage.





Accumulated dimensional change



100kW, 200kW, center
Ellipse shape

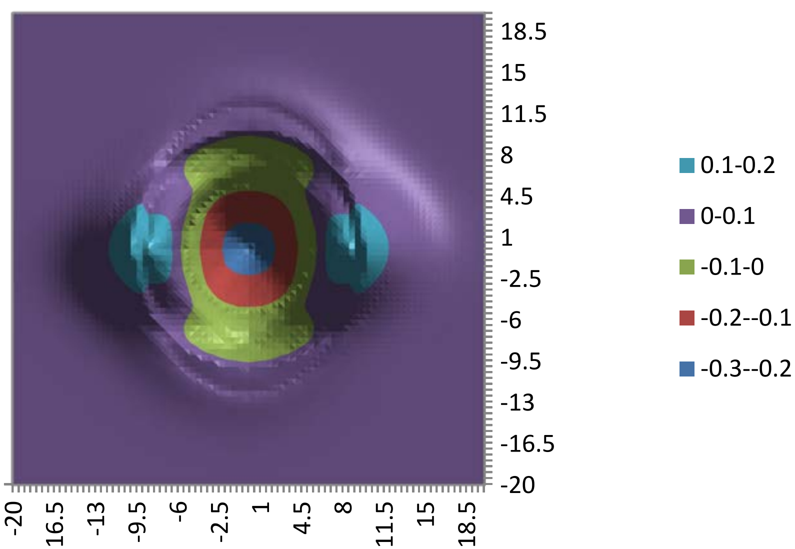
200kW, U, D, R, L
700 hours, respectively

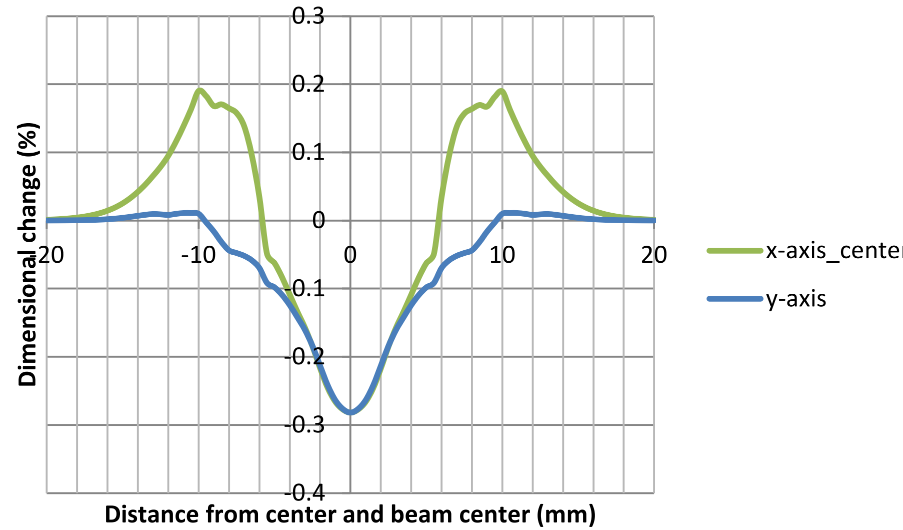
300kW, UR, UL, DR, DL
700 hours, respectively

300kW, U, D, R, L
700 hours, respectively

~RUN 50

~2014 shutdown





Stress by dimensional change

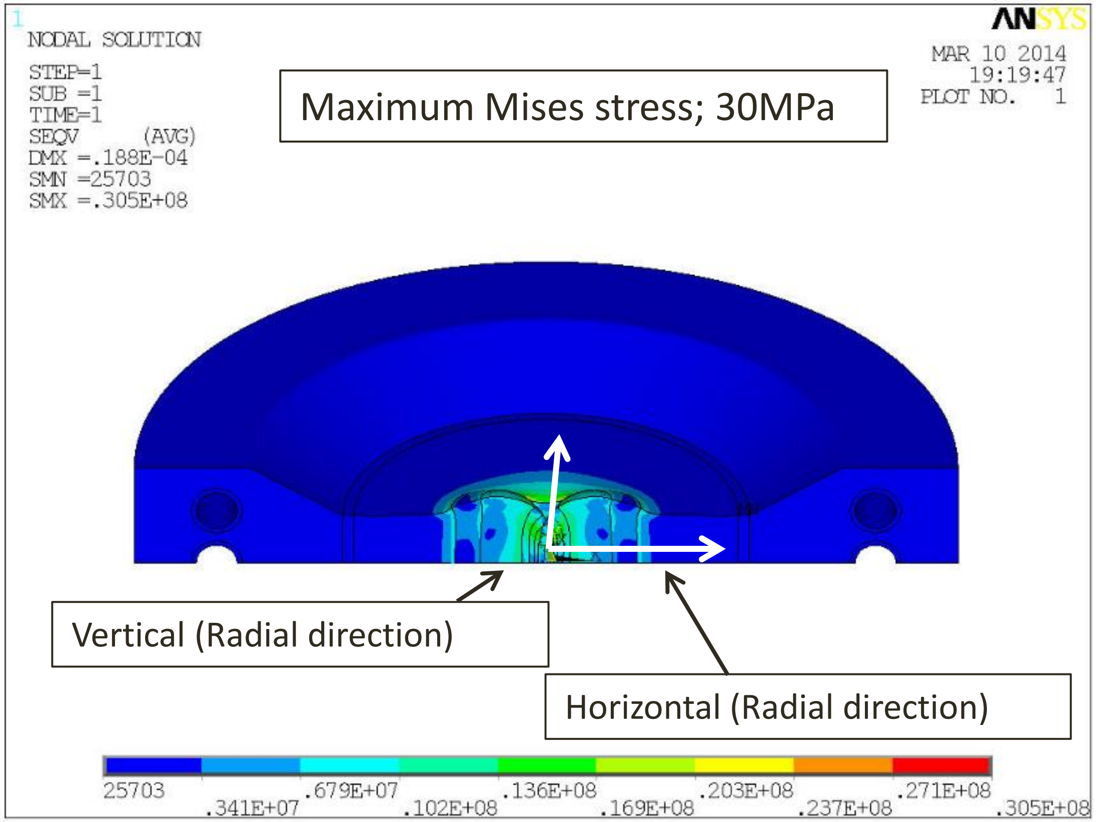
For Strict discussion, knowledge of Material mechanics is required.

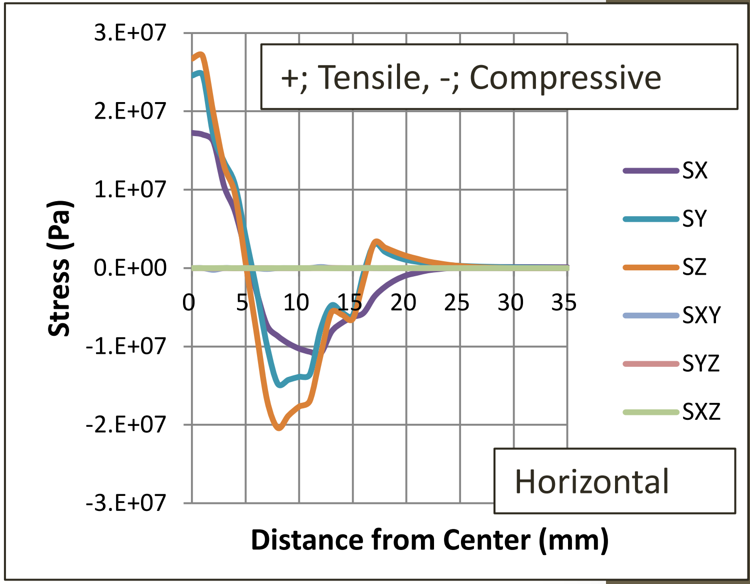
Results

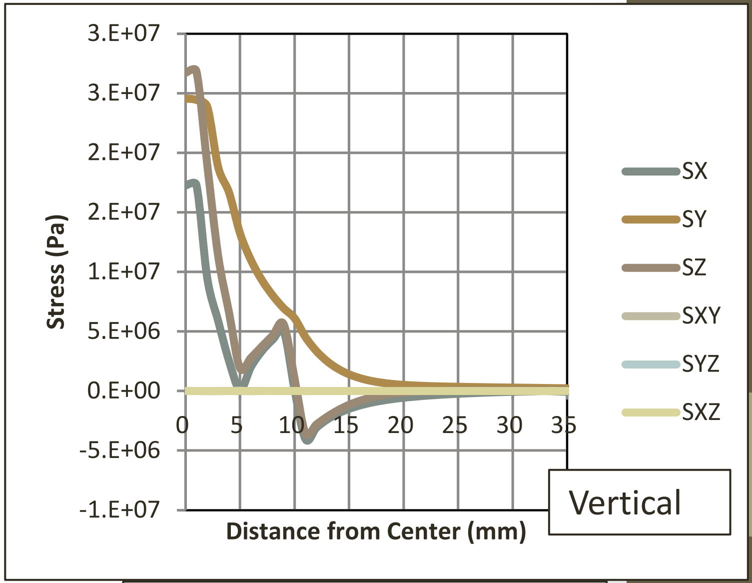
- ☐ Tensile stress on center,
- ☐ Small compressive stress besides the beam spot
- ☐ Ellipse shape

Strength of Isotropic graphite

Tensile; 40MPa, Comp.; 90MPa, Shear; 45MPa





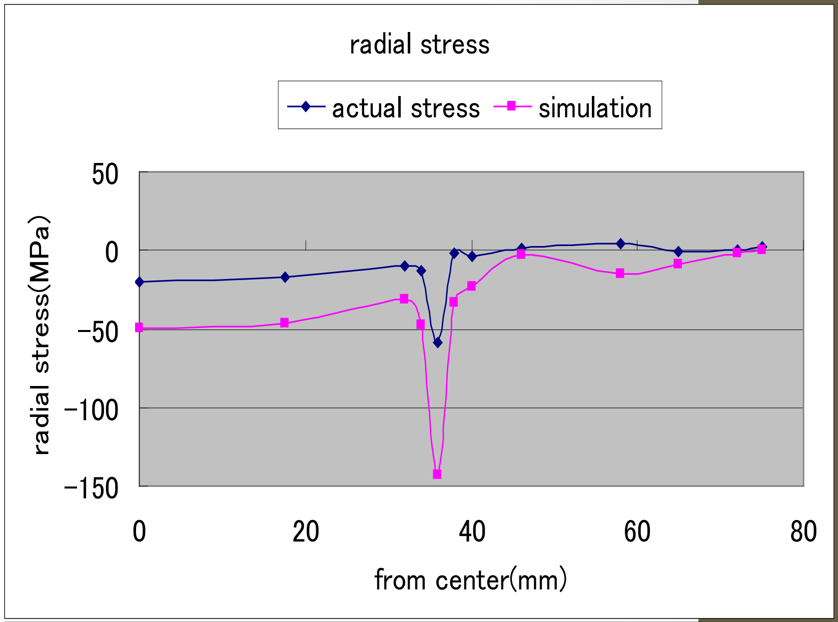


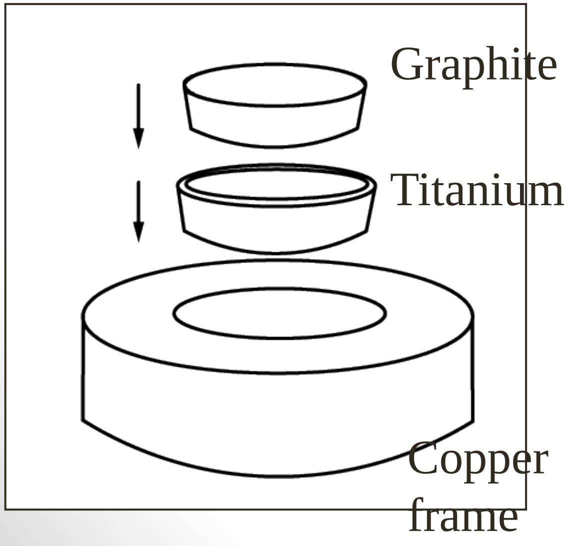
Smaller than the strength

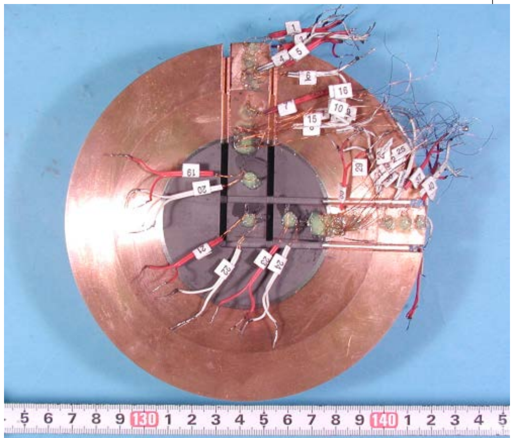
Residual stress during manufacturing

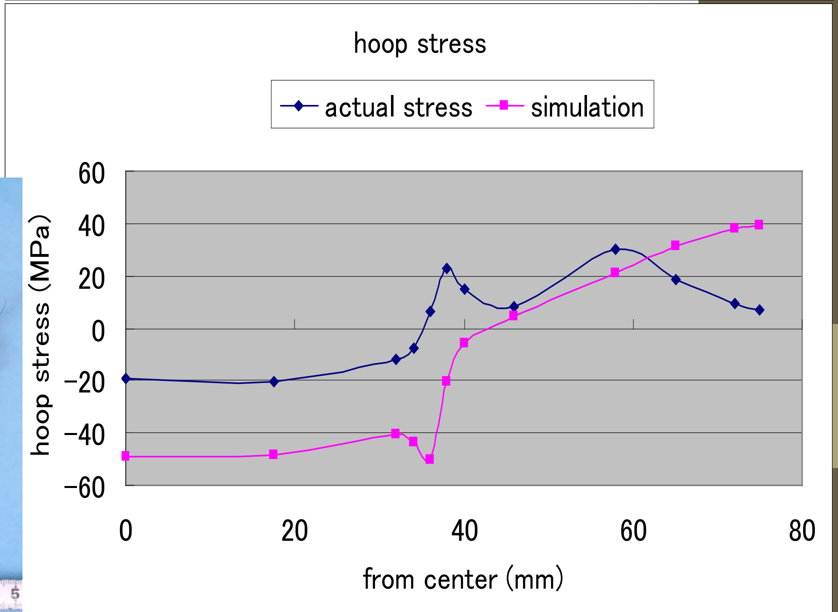
Residual stress as a shrink fit
Plastic-Elastic Analysis by FEM
Simulation; 50MPa
Experiment; 20MPa
Results of experiment reflect the trend of simulation.

Initial residual stress; 40% of Simulation









Stress distribution under actual operation

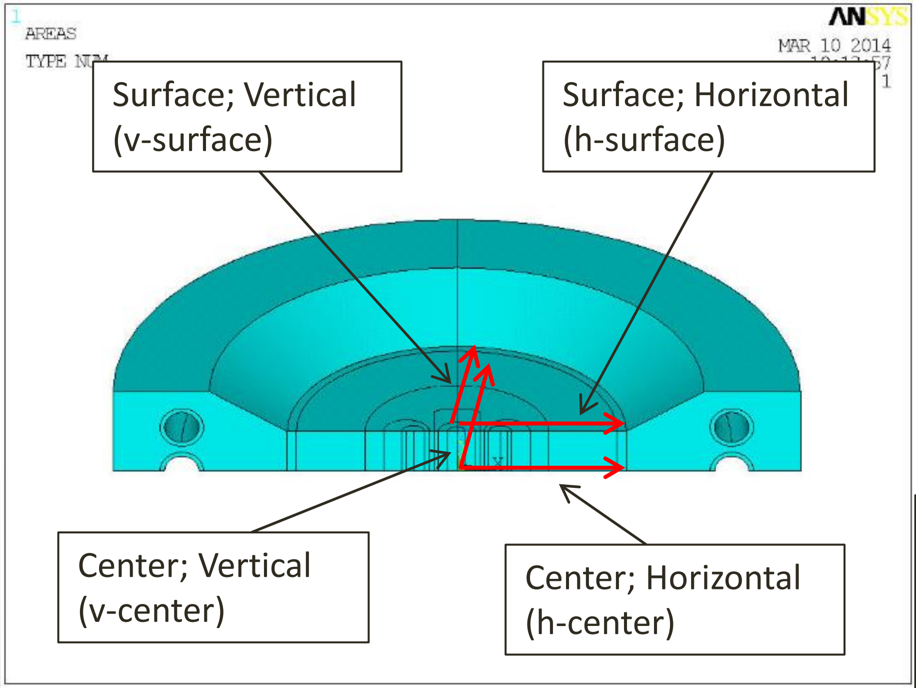
Initial residual stress

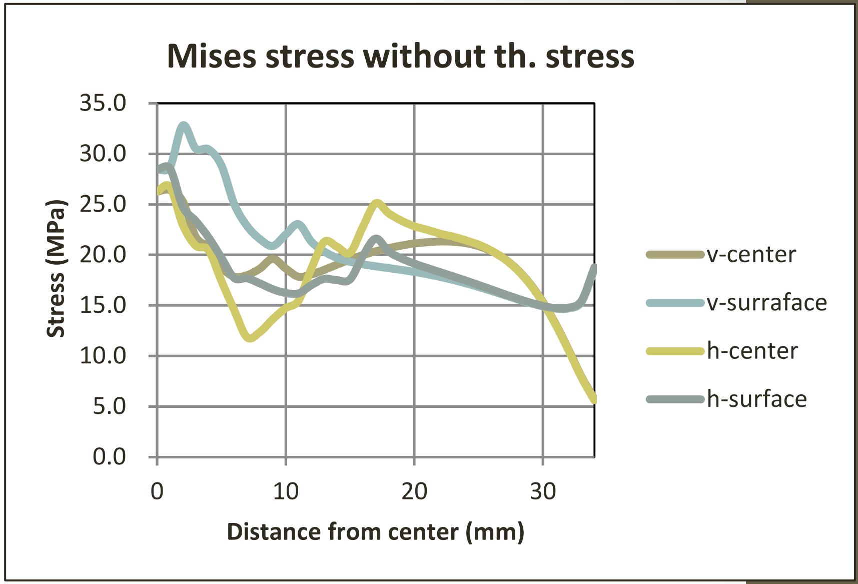
+

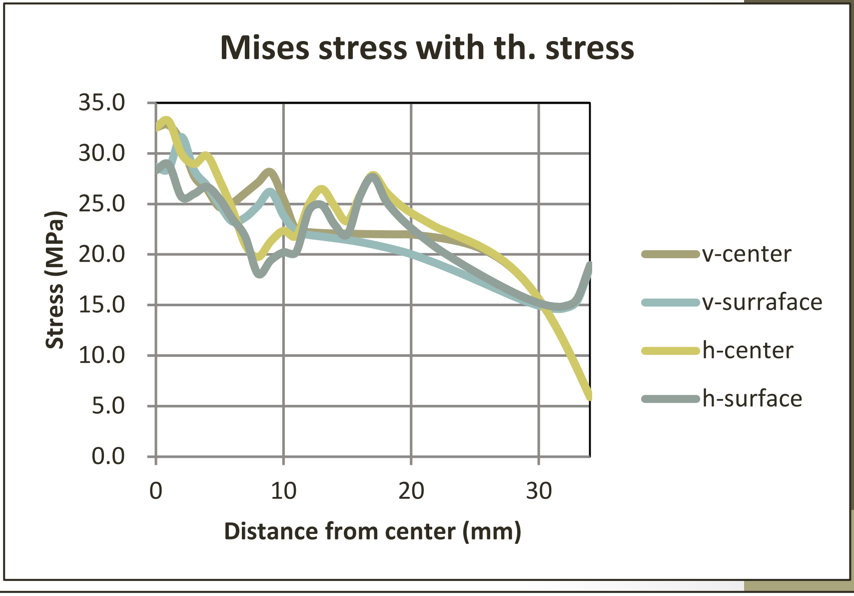
Stress by dimensional change due to irradiation

+

With or without thermal stress by beam loss





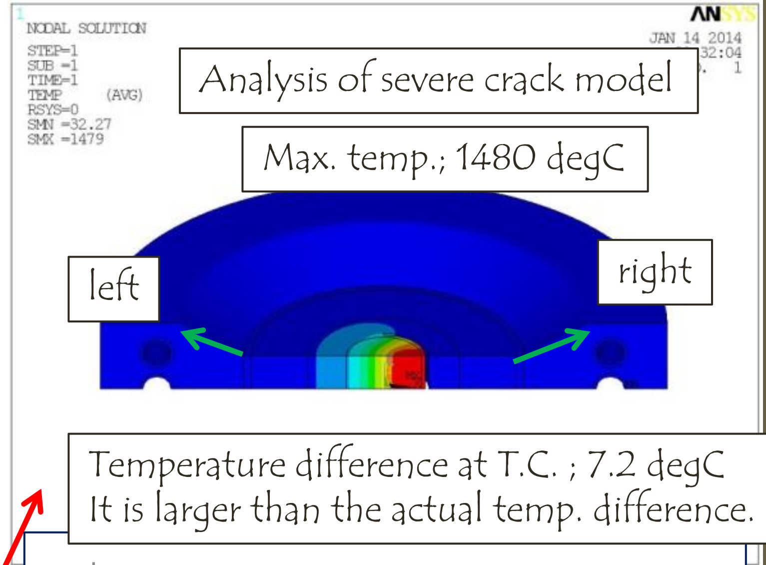


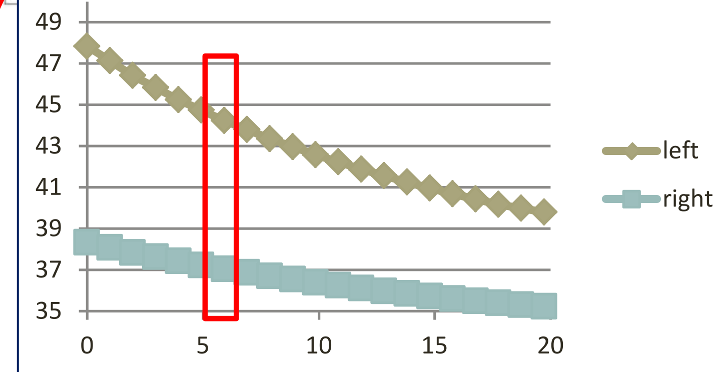
Stress is smaller than strength with and without thermal stress.
Entirely, compressive stress. (Large strength)

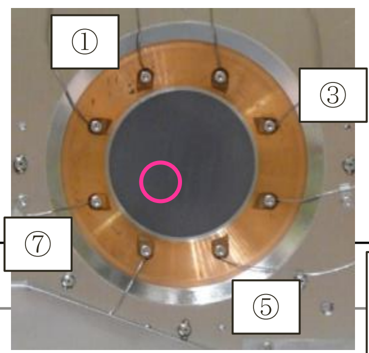
Detection of cracks

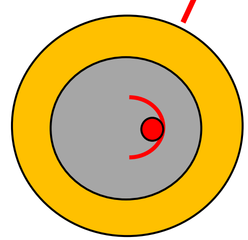
Actually, the sensitive monitoring has been achieved. The offset of the beam position can be monitored by the unbalance of the diagonal temperature .

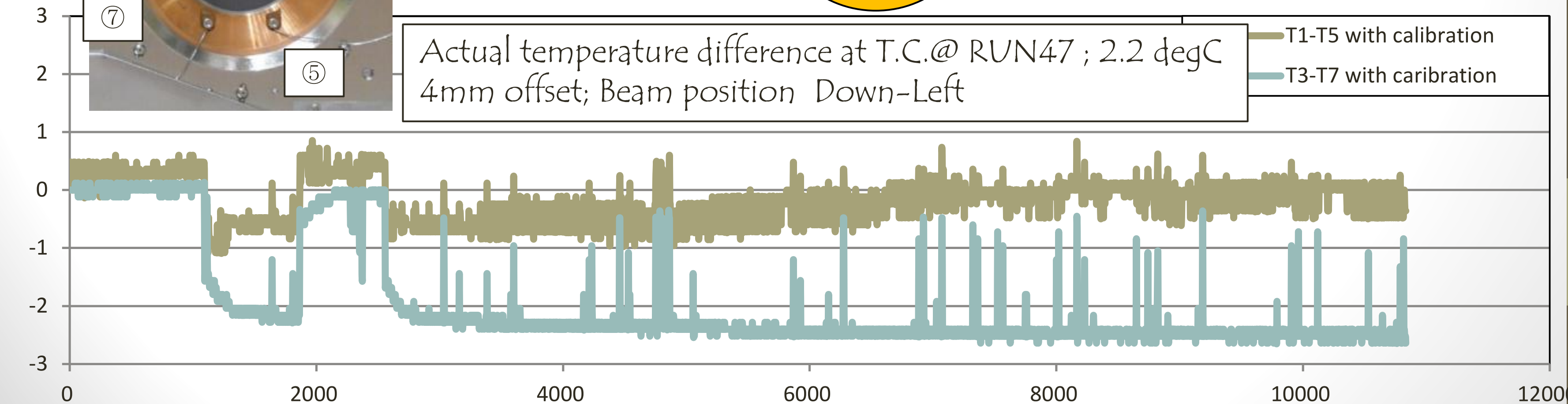
Cracks can be observed, through observation of diagonal thermo-couples,



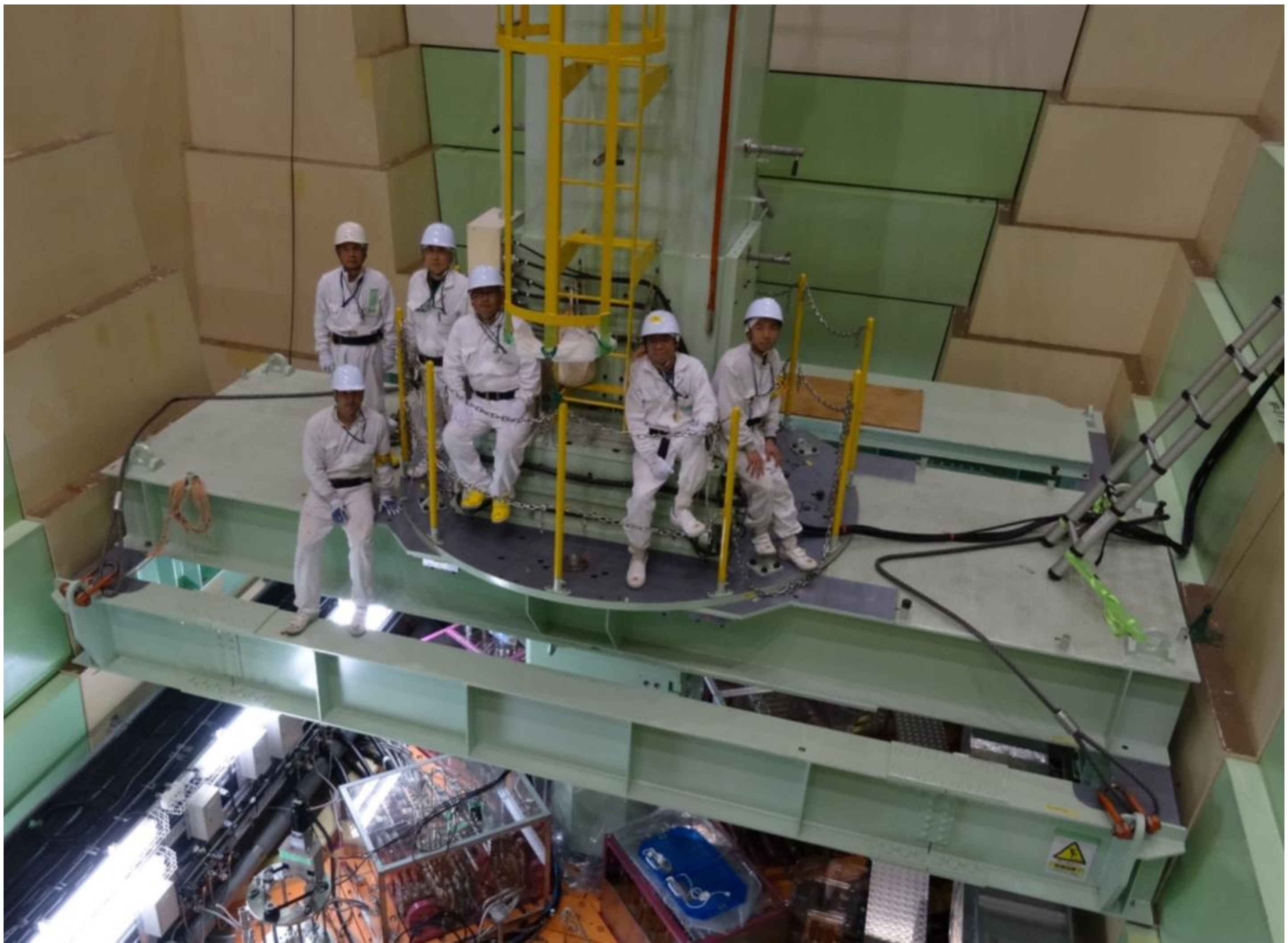






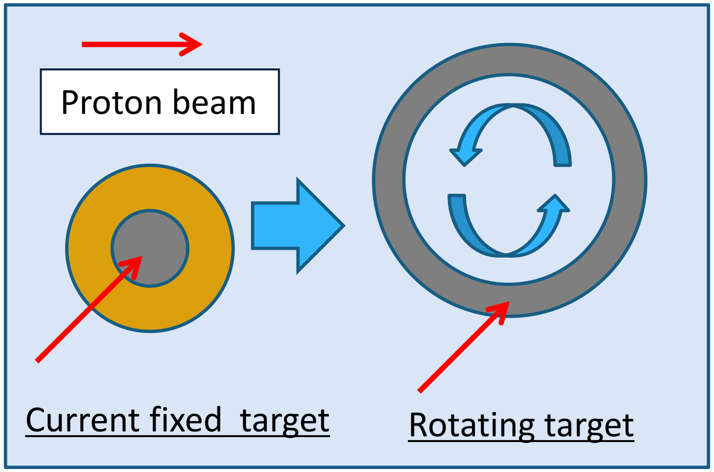


Replacement of used Fixed Target with new Rotating Target



Rotating Target

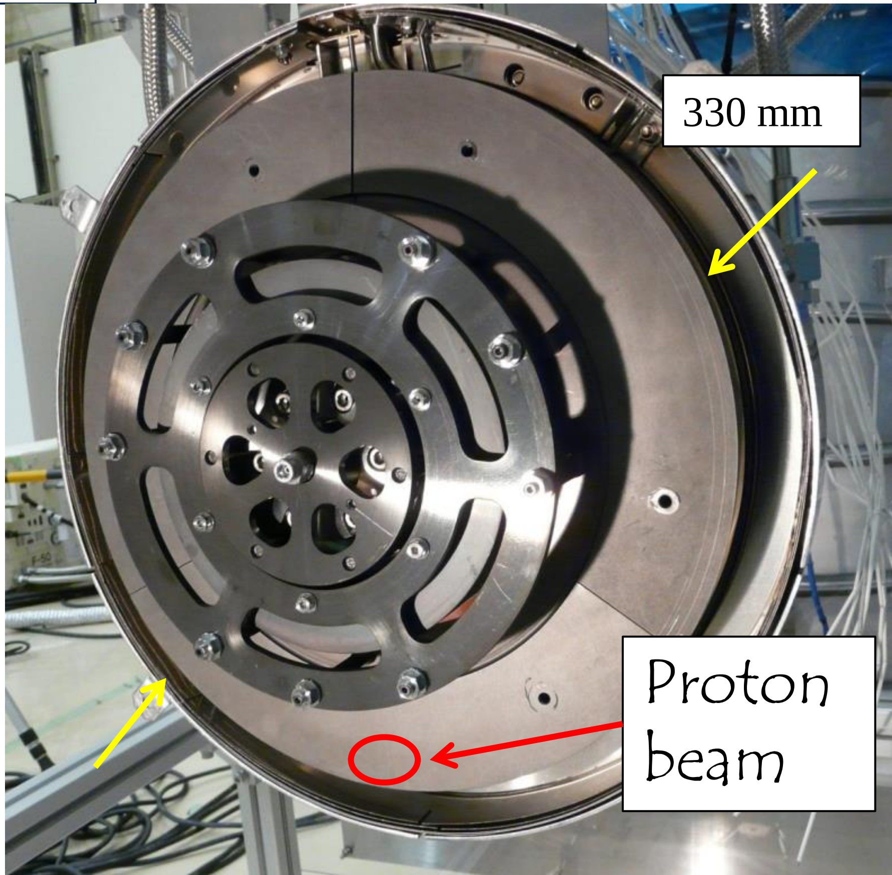
Learning from Paul Scherrer Institute, Rotating target method is applied to distribute the irradiation damage of graphite to a wider area.



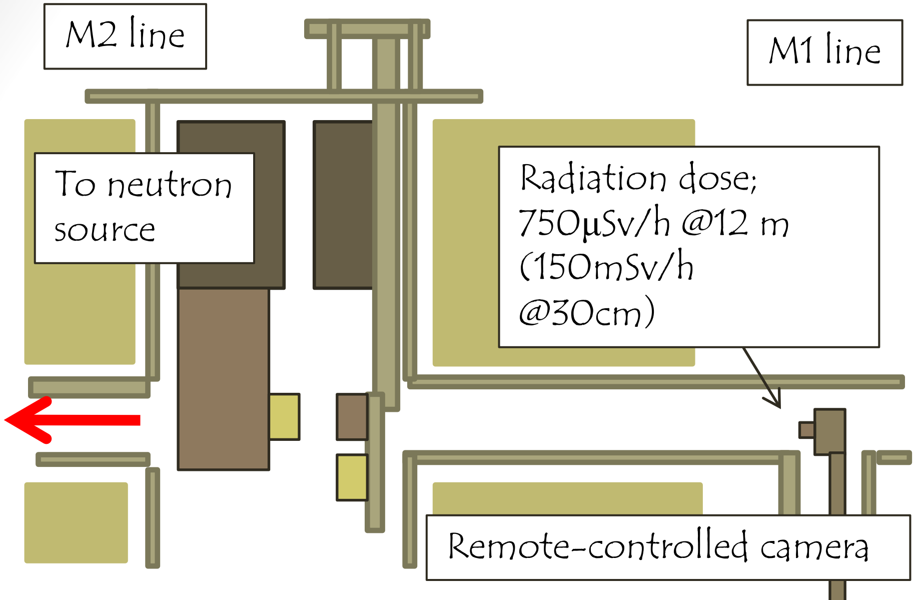
The lifetime of graphite becomes long enough.
The lifetime of bearings is critical.
Solid lubricant;

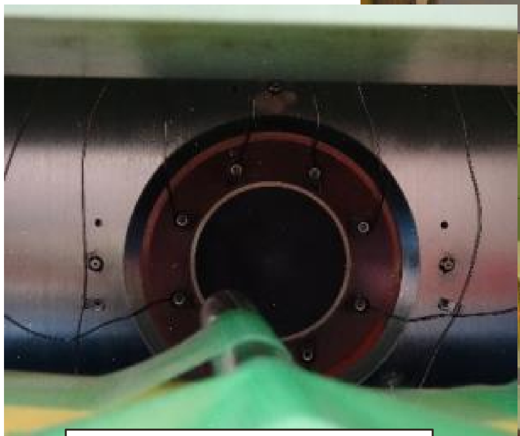
- Silver coating with MoS2 at PSI
- Disulfide tungsten at MUSE

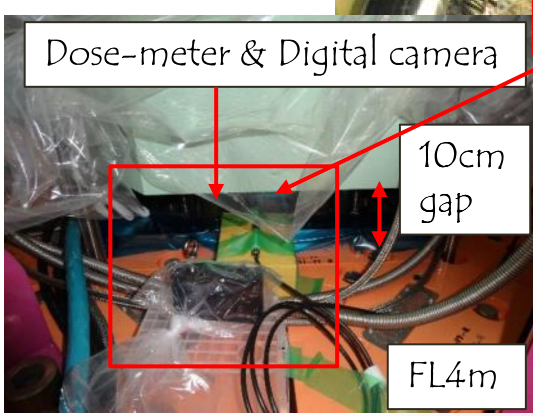
Expected lifetime; 10 years



Replacement of the used Fixed target

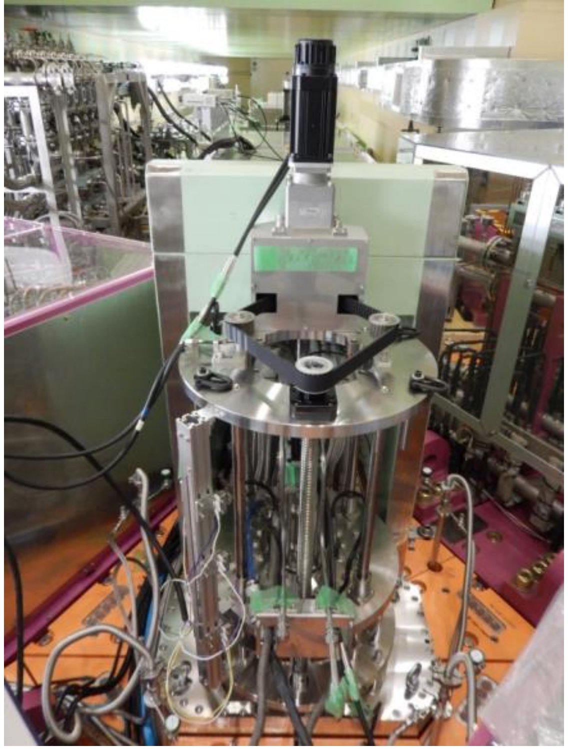






Installation of Rotating Target

Rotating Target was successfully installed on 16th September of 2014.



- □ Vacuum pressure 10^{-5} Pa
- □ Control system

Confirmed

Summary of Muon fixed target

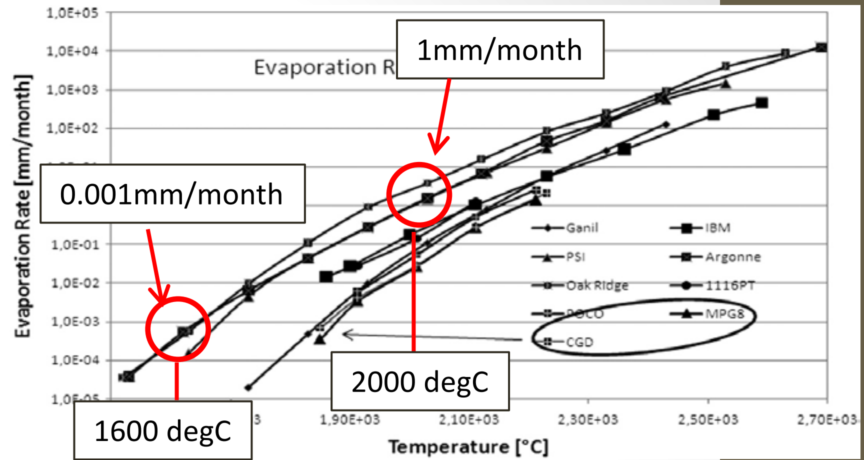
- Proton beam has been successfully operated by fixed target without replacement for five years.
- The lifetime of the muon fixed target is evaluated with consideration of radiation effect and history of proton beam operation.
- The five-years used fixed target was successfully replaced with the new rotating target this September.

Isotropic Graphite

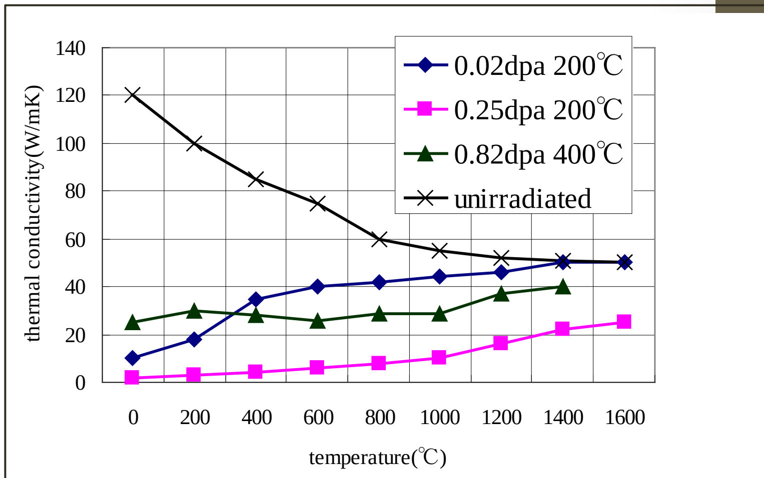
- Isotropic graphite
  (polycrystalline graphite)
  Small grain at random

⇔Highly Ordered Pyrolytic Graphite (HOPG)

- For accelerator, nuclear reactor
  - Low density
  - High resistance to heat
  - Low Young's modulus
  - High strength
  - Low residual radiation



Evaporation rate of graphite
(M.S. Avilov et al., Nuclear Instruments and Methods, A618 (2010) 1)



Neutron irradiation effect to thermal conductivity
(T. Maruyama et al., Journal of Nuclear Materials 195 (1992) 44-50.)

Irradiation effect to thermal conductivity

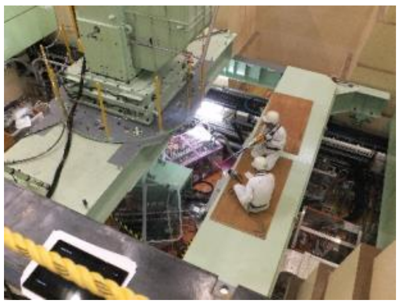
Removal of used Fixed Target

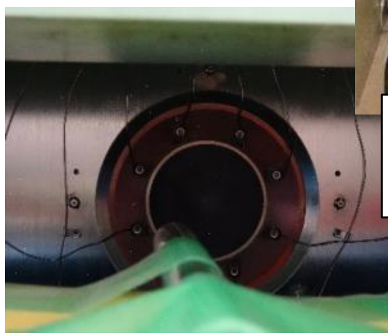
Successfully, used fixed target was removed from beam line and was inserted into tentative storage vessel.

30th July, 2014

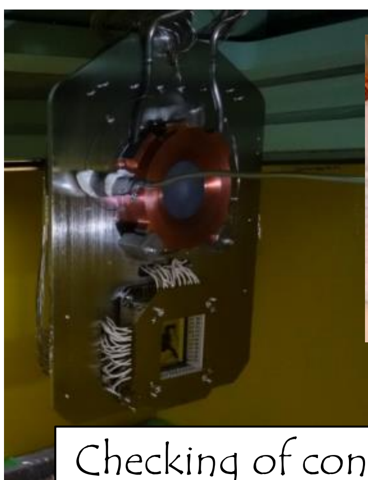
Transfer cask can be controlled from FL-10m.

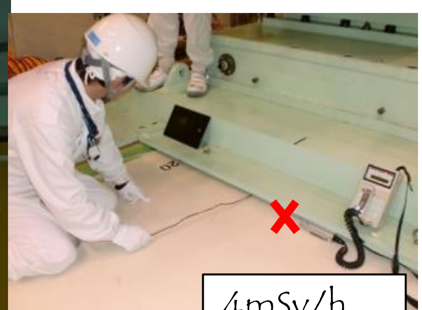
Radiation dose on the surface of transfer cask including used target





400 mSv/h @20cm





4mSv/h

Checking of contamination
Small contamination was observed.

Use fixed target at tentative storage vessel

80 μSv/h

Spatial radiation dose; 6 μSv/h (Height 1m)

Unit for evaluation of irradiation damage

- Accelerator operation; View Point of Accelerator
  [MWh/cm2, protons/cm2]
- Proton beam irradiation; V.P. of Muon Target
  [protons/cm2 ⟺ dpa]
- Neutron irradiation; V.P. of material irradiation
  [neutrons/cm2 ⟺ dpa]

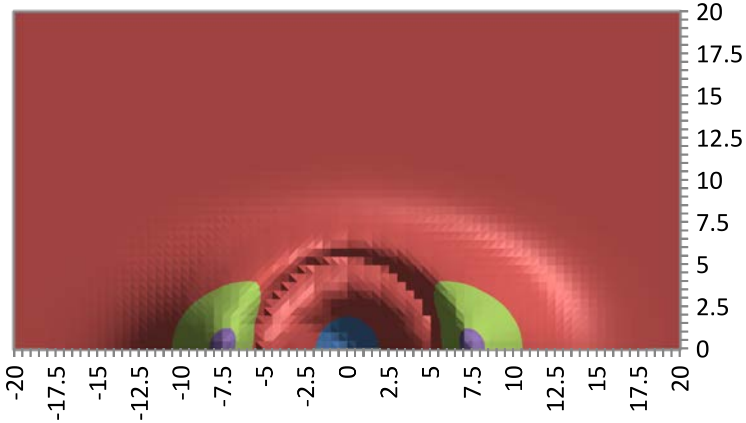
Neutron irradiation is associated with proton irradiation by Monte Carlo code.

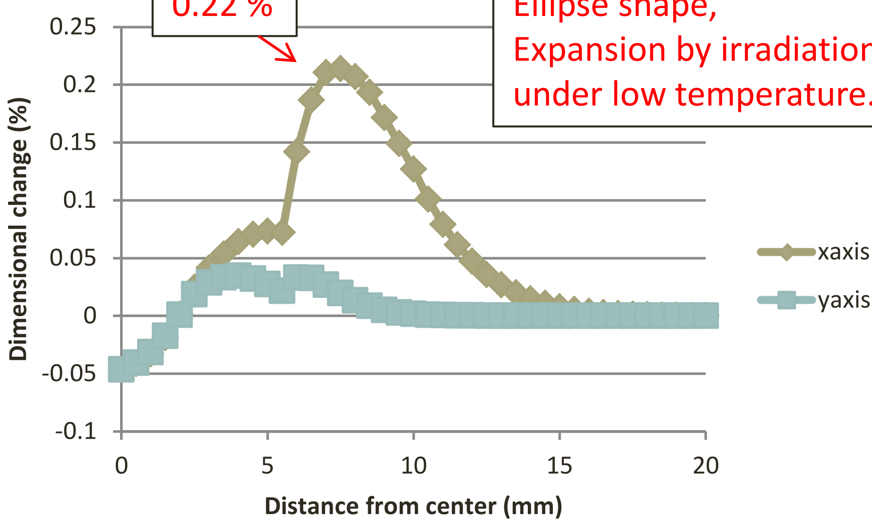
Charge of proton ; 1.6×10^{-19} [C], 1 [A]=1 [C/s]
1 [MWh]=1/3 [mAh (3GeV)]=1.2 [As (3GeV)]=1.2 [C]=7.5×10^{18} [protons]
1 [proton/cm^2 @3GeV]=9×10^{-23} [dpa], 1.1 $\times10^{22}$ [p/cm^2]=1 [dpa]
through PHITS evaluation by Kawamura

Effect by neutron irradiation; 1 [MeV]=1.6×10^{-13} [J] = 160 [fJ]
7.7×10^{20} [n/cm^2]=1 [dpa], 1×10^{25} [n/m^2]=1.3 [dpa]
(T. Maruyama et al., Journal of Nuclear Materials 195(1992)44-50.)

Comparison of 120kW with 200kW irradiation

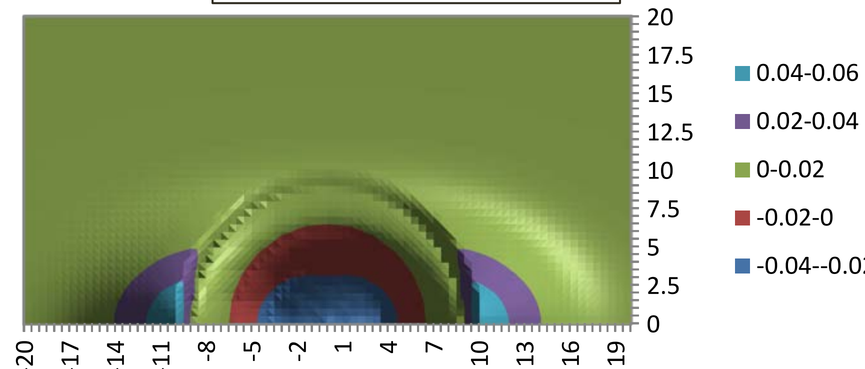
～RUN36 & RUN40 @~120kW, 360MWh
Center, σh=4.5 [mm], σv=2.5 [mm]

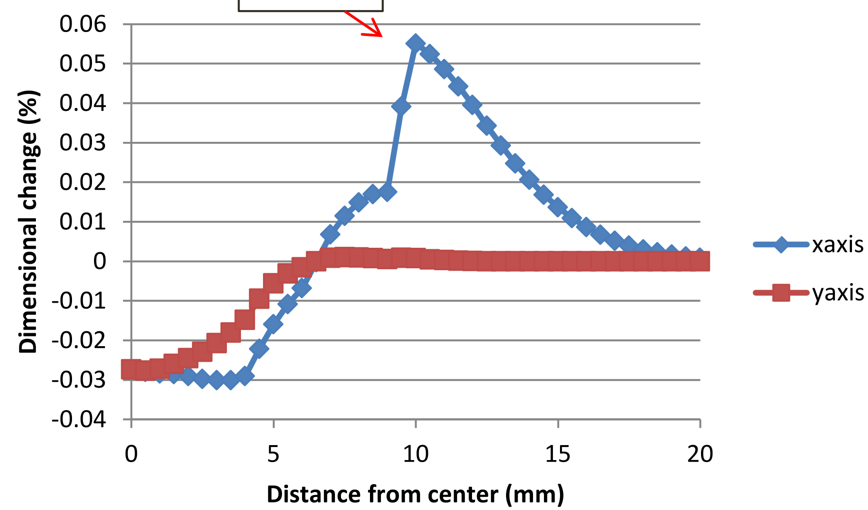




Ellipse shape,
Expansion by irradiation
under low temperature.

RUN37 & RUN38 @200kW, 190MWh
Center, σh=4.5 [mm], σv=2.5 [mm]



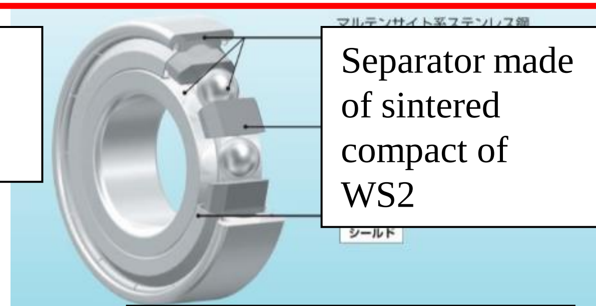


Radiation damage; 360MWh vs 190 MWh, Dimensional change; 0.22 % vs 0.05 %

Bearing & Solid lubricants

For our target, the bearing is used under 100 MGy/year, 400 Kelvins, 10^{-5} Pa

	Type	Temp. (Kelvins)	Pressure (Pa)	Radiation	Speed (rpm)	Storage	Lifetime @15rpm (hour)
MoS_2	coating	<570	10^5 to 10^{-5}	general	<500	air	1100
Ag	coating	<600	10^{-3} to 10^{-10}	general	<500	vacuum	5800
WS_2	Separator	<600	10^5 to 10^{-5}	few	<210	air	110000



Captured from JTEKT(KOYO) Catalog

Evaluation by the formula of the JTEKT Catalog

Disulfide Tungsten is used for MUSE target.

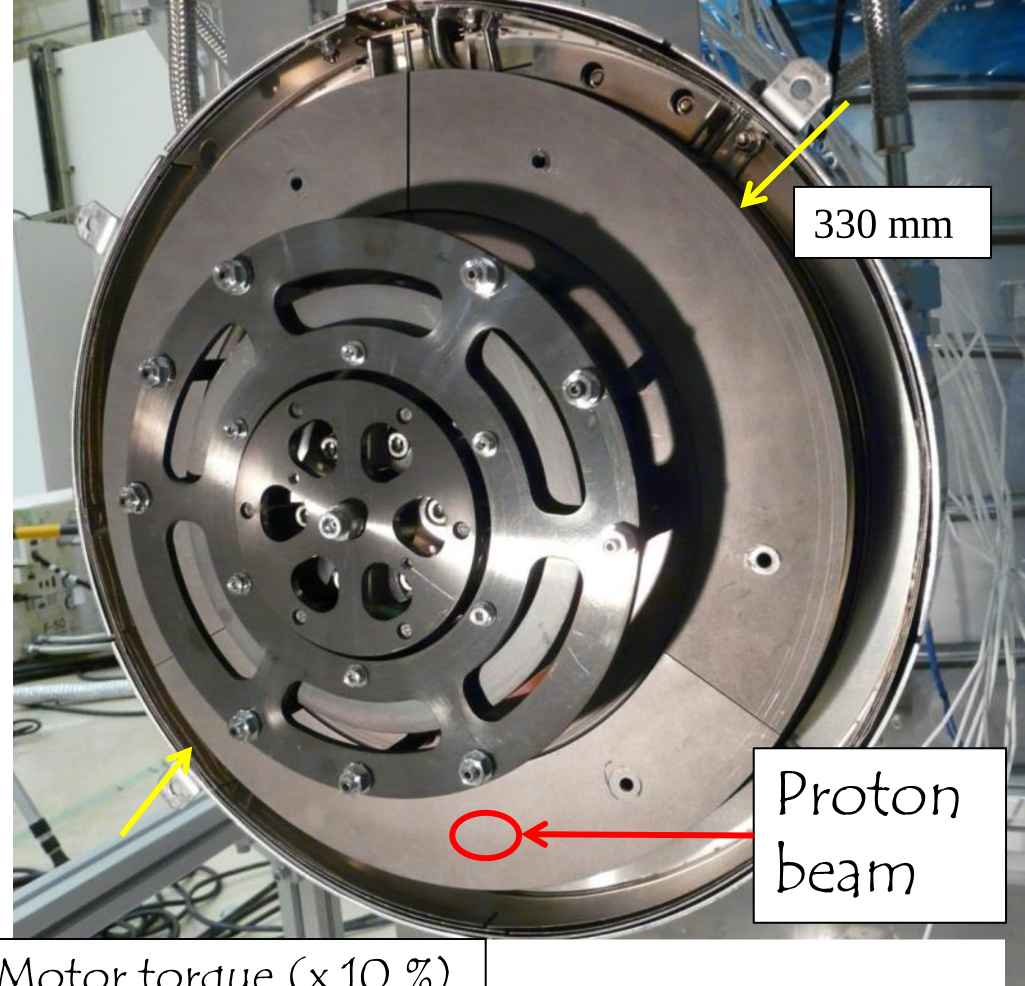
Anticipated Lifetime is 20 years!!

Radiation resistance of WS2 should be confirmed.

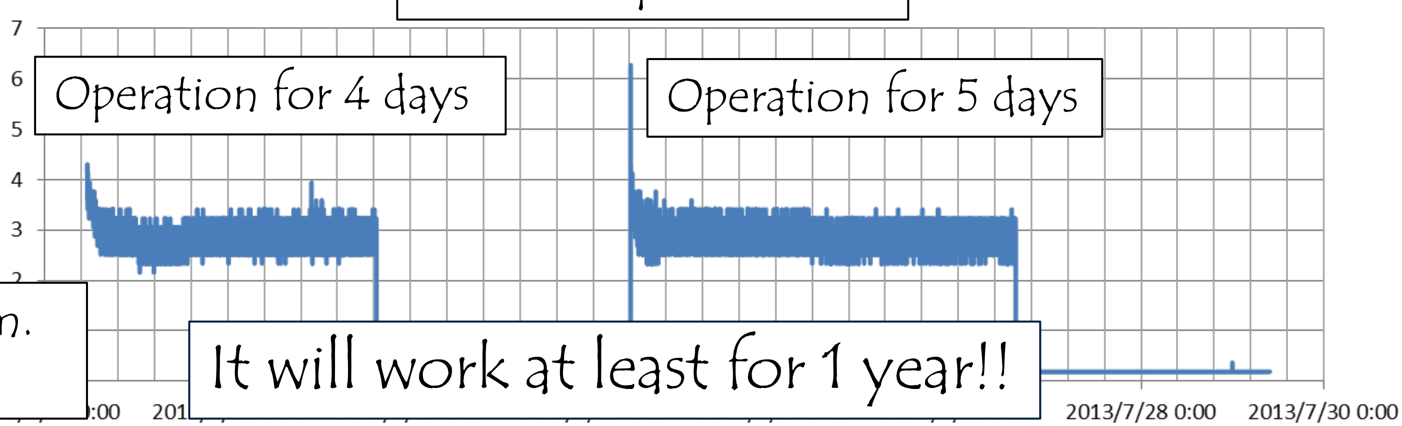
Mock-up of Rotating Target

Durability tests of
Target & bearings
Heating & Rotating tests

Heating test



Motor torque (x 10 %)



9 days with 300 r.p.m.
(4800h @15 r.p.m.)

It will work at least for 1 year!!

Comparison among the muon facilities in the world

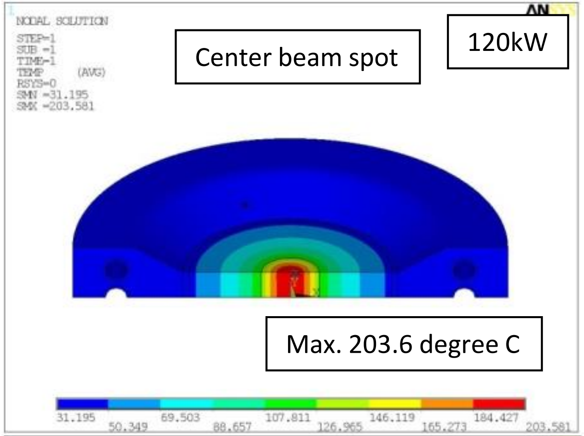
Country	Japan	U.K.	Switzerland	Canada
Facility	J-PARC MUSE	RAL ISIS	PSI	TRIUMF
Proton Energy [GeV]	3.0	0.8	0.59	0.5
Proton Intensity [MW]	1.0(*Goal*)	0.16	1.3	0.1
Surface Muons [/s]	3×10^7(D)	6×10^5	3×10^7	2×10^6
μSR data [Mevt/hour]	1800(*Goal*)	100	40	40
Negative Muons [/s]	1×10^7	7×10^4	2×10^7	1×10^6
Low Energy Muon [/s] Ultra Slow Muons [/s]	6×10^5(*Goal*)	----	8×10^3	----
DC / Pulse	Pulse (25Hz)	Pulse (50Hz)	DC	DC
Experiment areas	2+(2+4)	5	6	4
Operation	from 2008	from 1986	from 1974	from 1975

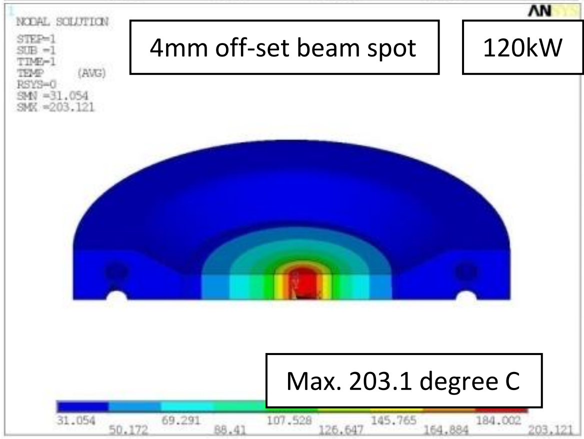
Accumulated beam power on Muon Target

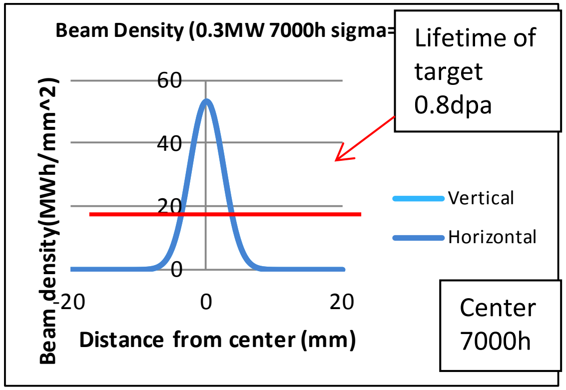
Diameter of the proton beam on the muon target becomes smaller (σ=2.6mm) than the original design (σ=6mm).
Even by 300kW operation, the radiation damage of graphite would reach to the lifetime.

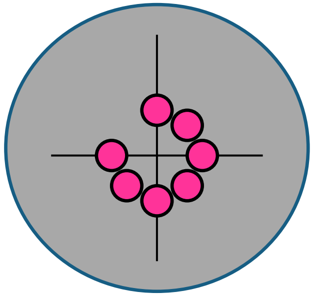
Beam painting for each RUN, every three weeks, was adopted.

The radiation damage of graphite will reach to lifetime on July of 2013.



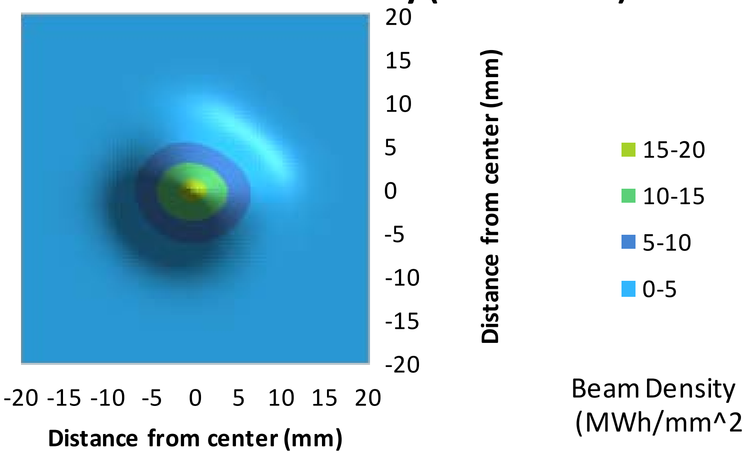




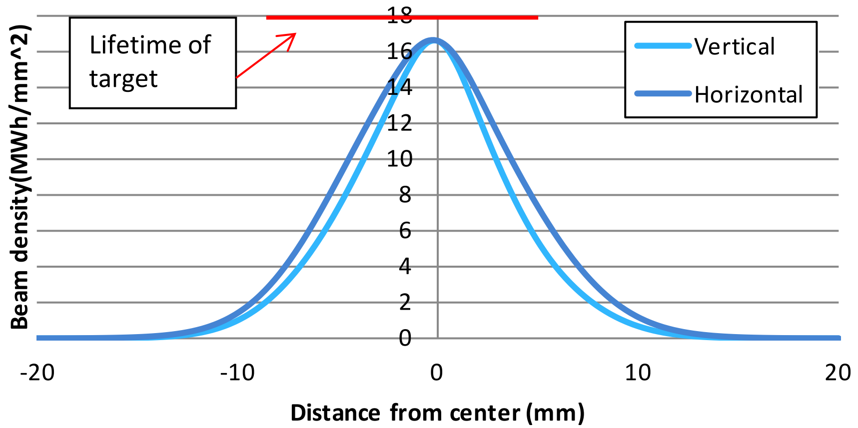


Beam painting by off-set beam

Distribution of Beam Density (~Mar. 2013)



Distribution of Beam density (~Mar.2013)



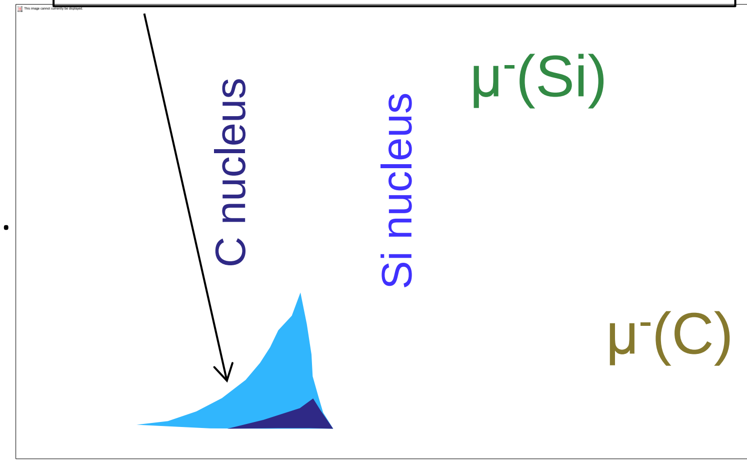
Development of SiC Rotating Target for DeeMe

DeeMe ~ Muon-electron Conversion Search
Representative; M. Aoki, Osaka University

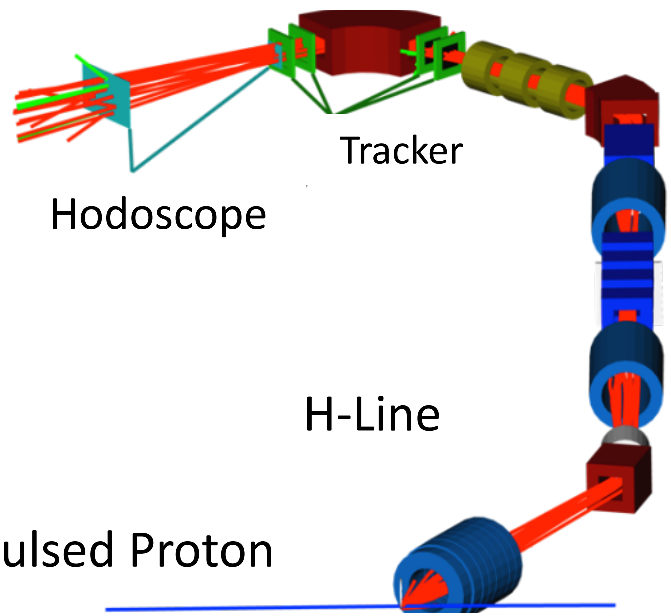
$$\boxed{\mu^- + A(Z,N) \rightarrow e^- + A(Z,N)}$$

- Forbidden in the Standard Model(SM) of particle physics.
- No signals found yet.
- Discovery of the signal
  → a proof of the physics beyond SM.
  - Complementary to high-energy frontier experiments: LHC, ILC.
  - Can explain the neutrino oscillation phenomena (Seesaw Mechanism).

Si → C: 11-times larger overlap
μ^- reaction ε: 8%(C)→67%(Si)



Eff. of Muon Reaction: 6 times larger than C.



R&D for silicon carbide

Candidates of Target Materials
✓CVD, Atm. Pressure Sintered, Reaction Sintered SiC
✓Nano-Infiltration and Transient Eutectic phase process SiC/SiC

SiC/SiC Plate

NITE SiC/SiC
✓High thermal conductivity (controllable)
✓Large and Complex Shapes
✓Excellent Mechanical Properties (Strength or Pseudo-ductility)
✓Excellent Radiation Resistance anticipated

Collaboration with A. Kohyama, H. Kishimoto and Y. Kohno (OASIS Gr.)
Organization of Advanced Sustainability Initiative for Energy System/Material
Muroran Institute of Technology

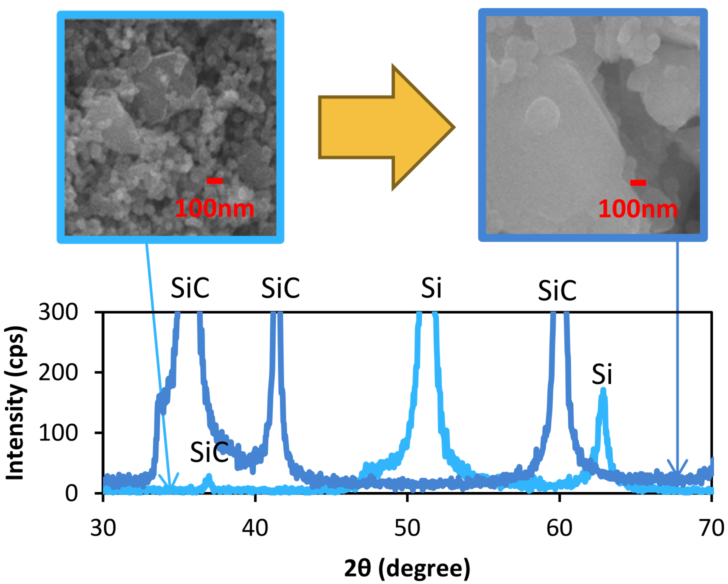
Concept of SiC target for DeeMe Project

by A. Kohyama, H. Kishimoto and C. Kanda
(OASIS, Muroran Institute of Technology)

The prototype “DeeMe” target by monolithic SiC is under serious concern from its brittleness.

The replacement by innovative SiC/SiC may change the target into “Reliable/Stable/High Performance ” .

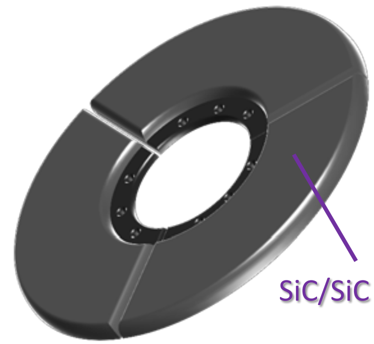
Advanced of NIC



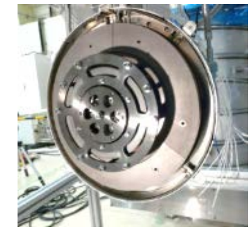
High purity SiC are progress

Issues remained: Porosity (< 1 %) / Si (< 100ppm)

The Conceptual Image of The Prototype “DeeMe” Target Upgrade



SiC/SiC Composite



NIC-SiC Prototype (Monolithic SiC)

APPROACH

Now :

R & D of “NIC “ Process is on-going

The Next Step :

SiC/SiC Plate Processing by “NIC “
- “NITE” Process as the back-up

The Prototype will be made during 2013
The performance verification will also be done

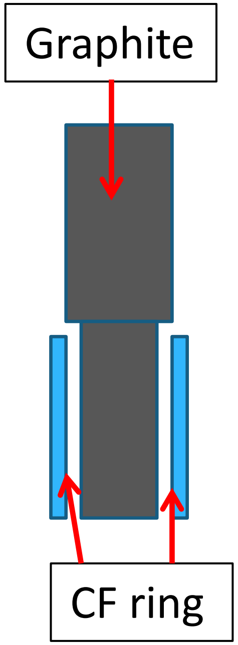
NIC （Nano-Infiltration and In-situ Carbonization） process:
low cost/reasonable performance under development

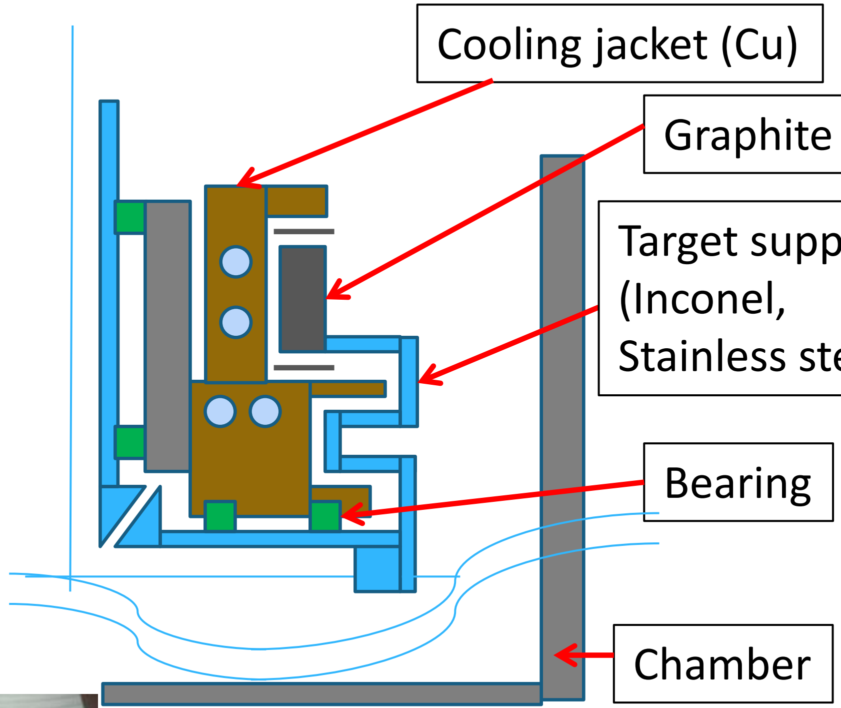
NITE （Nano-powder Infiltration and Transient Eutectic） :
high cost/high performance process established

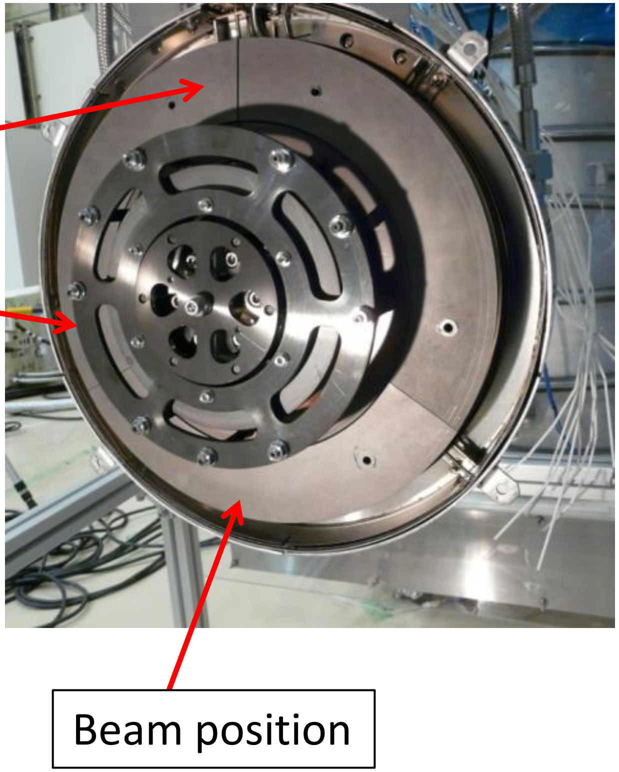
Main Components & Analysis

Rotating Wheel;
Graphite Target divided to three units, Centrifugal force (CF) rings, Target support

Bearings, Cooling jacket, and Chamber

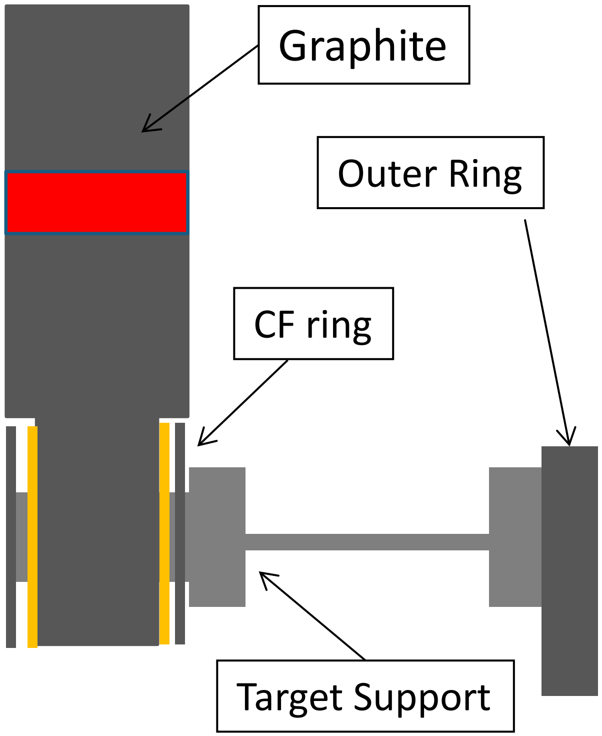






To extend the lifetime of bearings, the temp. of bearing should be as low as possible.
Maze structure of target support

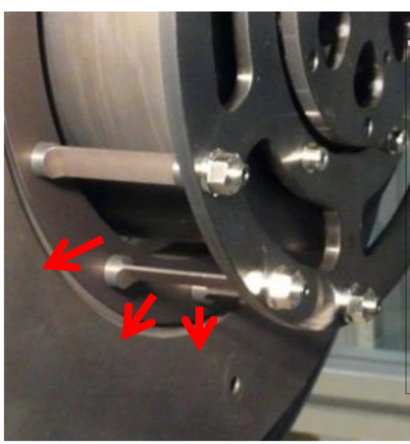
Thermal Stress



Temperature-Difference

- ☐ **Graphite**
- ☐ **Target Support**

Thermal reflector
between Centrifugal Force Ring and Graphite
It will decrease the thermal stress for both components instead of increment of graphite temperature.



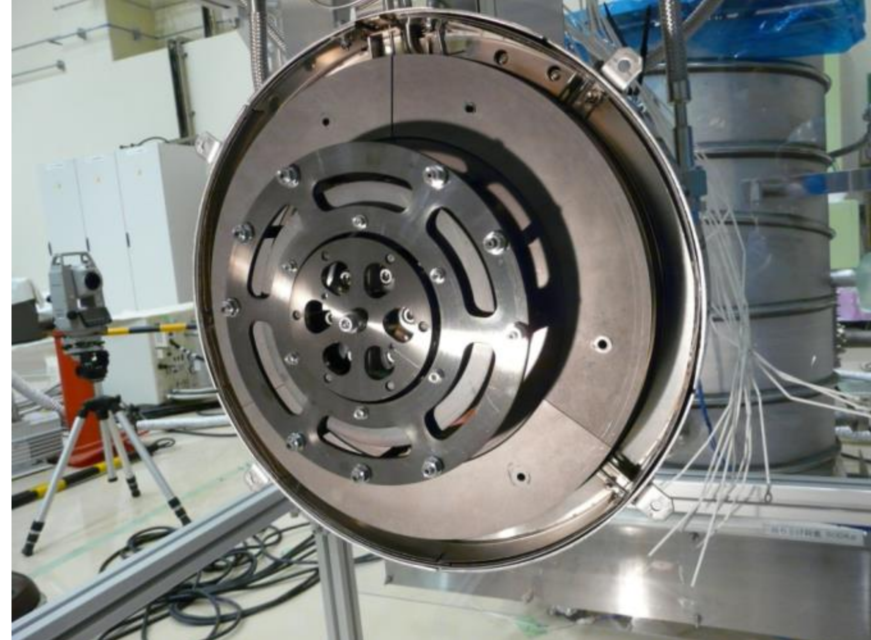
3-Dimensional, Thermal radiation & Transient Analysis
Approximate Temperature-distribution for whole modeling by Finite Difference Method on Microsoft Office Excel

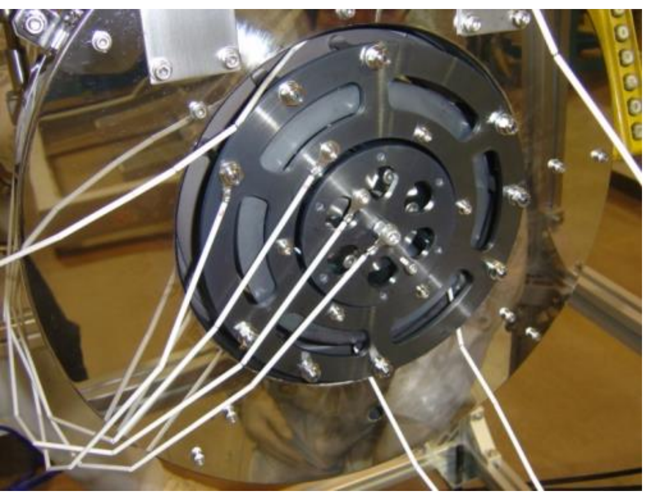
Thermal stress for respective components by Finite Element Method, ANSYS, etc.

Fabrication of Mock-up

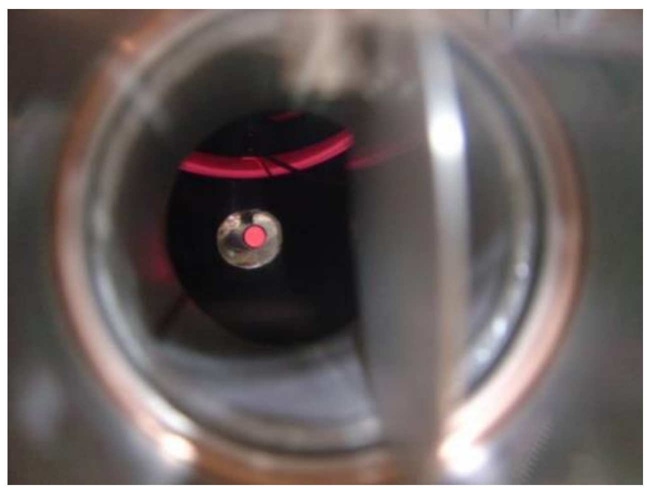
Heating test
  Horizontal shaft; 140 °C
  (Numerical simulation for beam line;120 °C)
Rotating test; 200rpm ~500rpm
  (Actual rotating speed; 15 ~ 20 r.p.m.)

<u>Purpose</u>
Durability tests of Bearings
Improvement for structure of the target
Development of Measuring system

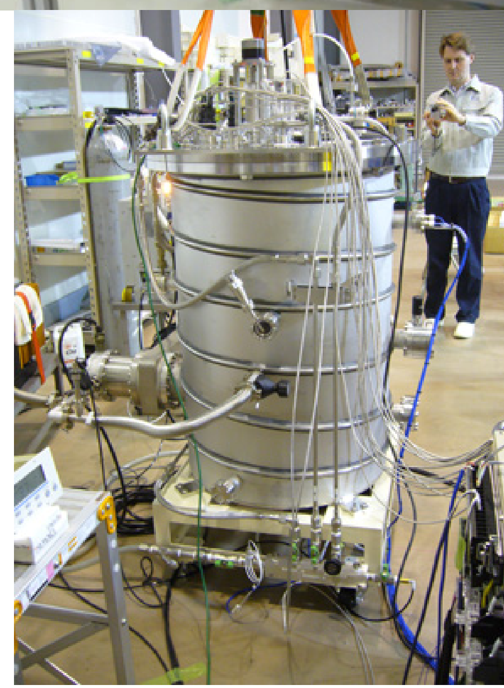




Entire heating

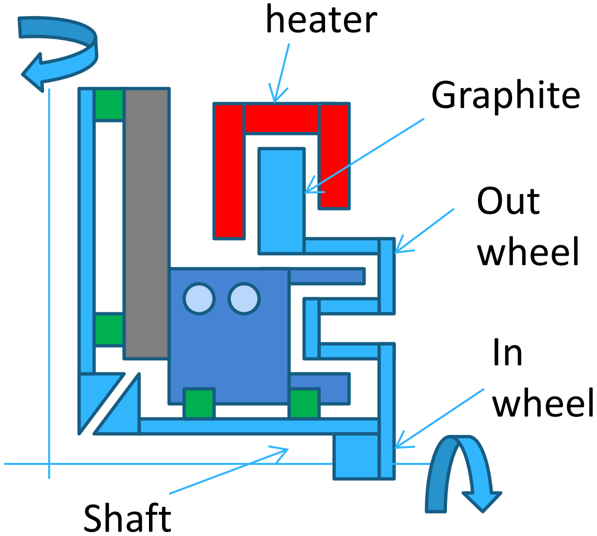


Thermal Radiation Thermometer



Vacuum chamber

Present Status of Heating Tests by Mock-up



In proton beam line, temperature of shaft; 120 °C
In Mock-up, Aiming 140 °C

In proton beam line
Thermal radiation from graphite is reflected by chamber.
In Mock-up
Graphite is covered with heater.
5-layered reflectors, Low emissivity

Graphite in Mock-up must be hotter than beam line.
Graphite; 610 °C (Beam line), 750 °C (Mock-up)

	Graphite (°C)	Out wheel (°C)	In wheel (°C)	Shaft (°C)
Simulation BL	610	300	135	120
Simulation MU	750	310	160	140
Experiment MU	750	340	165	135

Temperature of shaft in mock up reached to temperature in beam line !!

Rotary Motion Feed-through, Bevel gear, Motor

Rotary Motion Feed-through

Anelva 954-7606, **Magnetic clutch**

Maximum torque; 5.3N・m

Allowable rotating speed;   500r.p.m.

Cobalt Magnet, SS304, 440C stainless steel

Bevel gear

SS440C stainless steel, without lubricant

Load; almost 0 (N) for normal operation

Comparison through SEM;

After and before a long interval test

Radiation-resistant AC servo motor

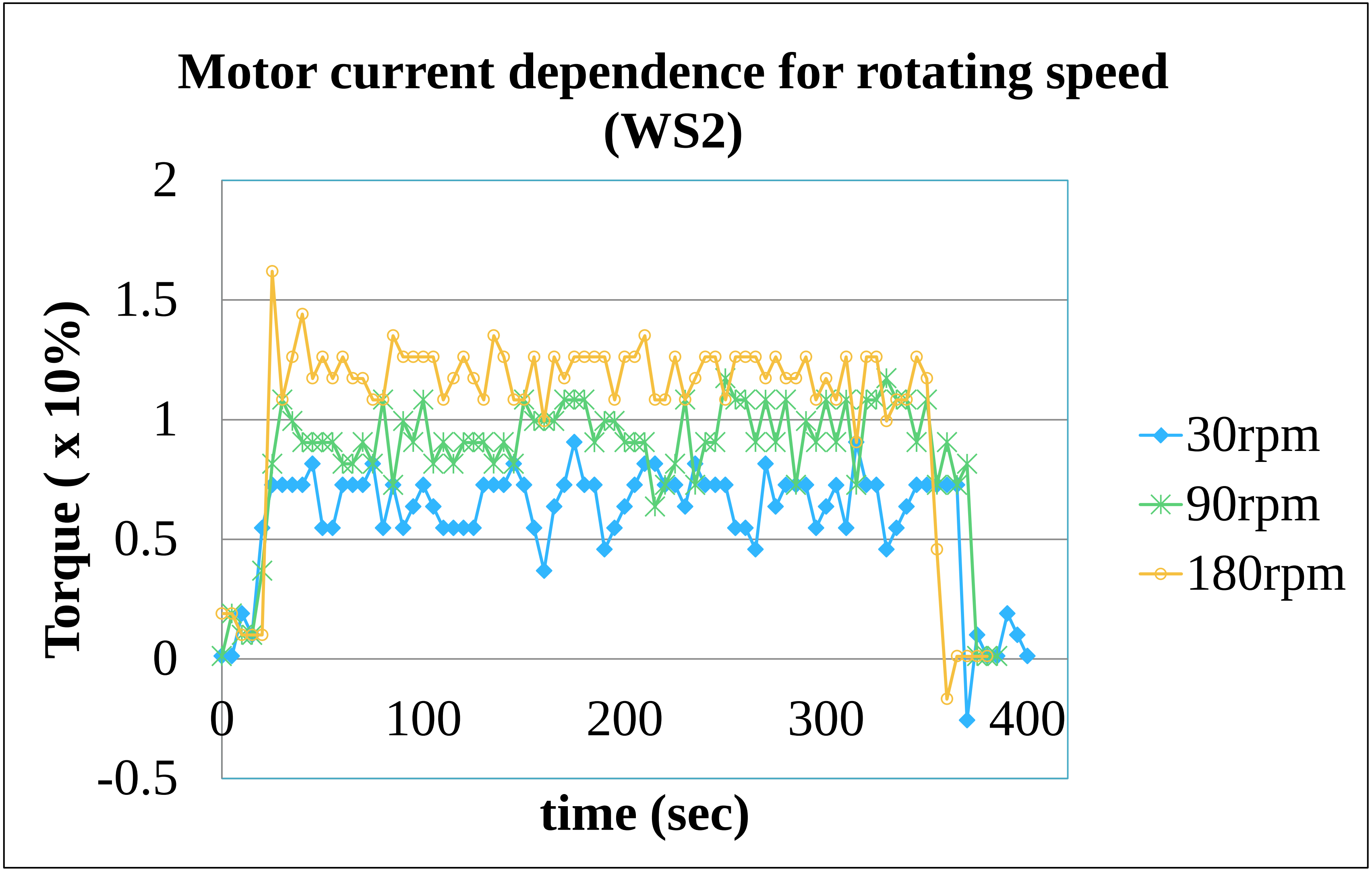
Wako-giken CO., LTD.

Resolver Encoder

Power output; 60W

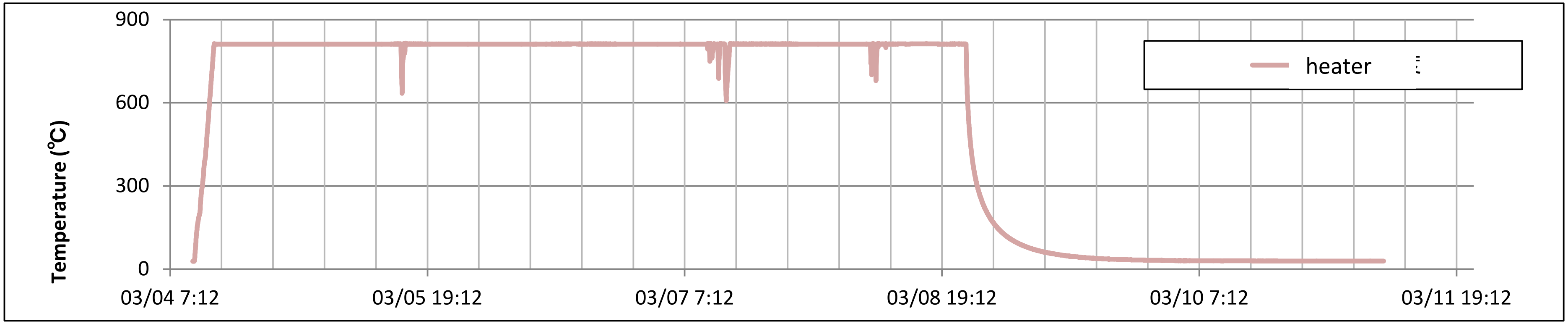
Torque; 0.76Nm

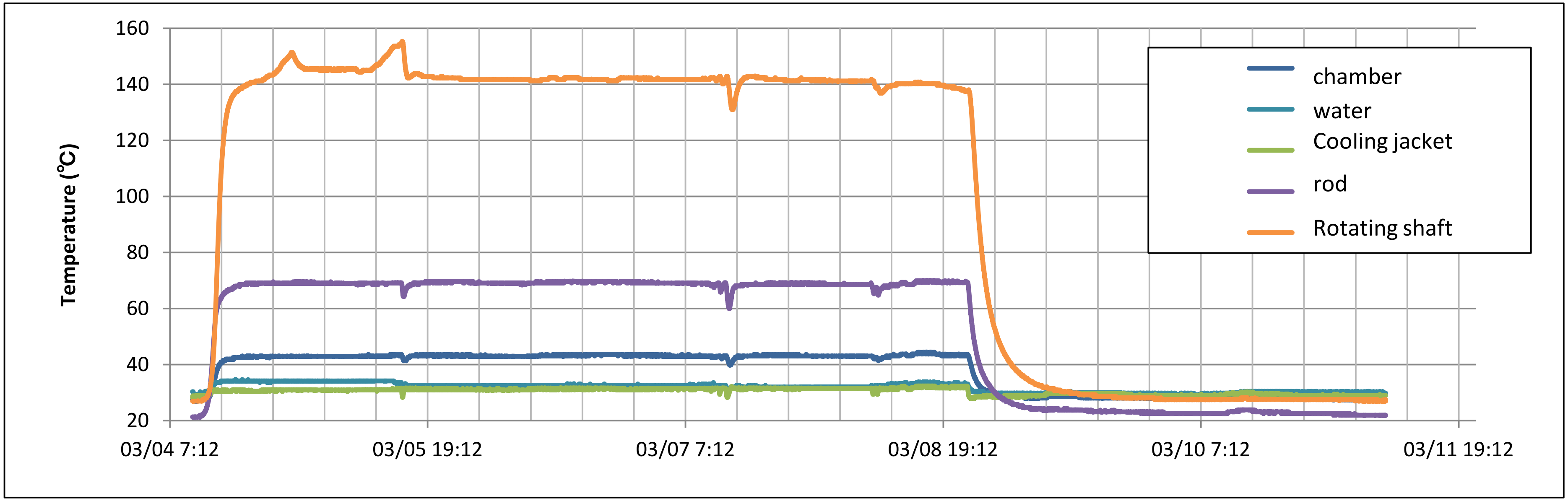
Present Status of Rotating Tests by Mock-up



Rotation in 5~500rpm can be performed.
Motor torque can be monitored.

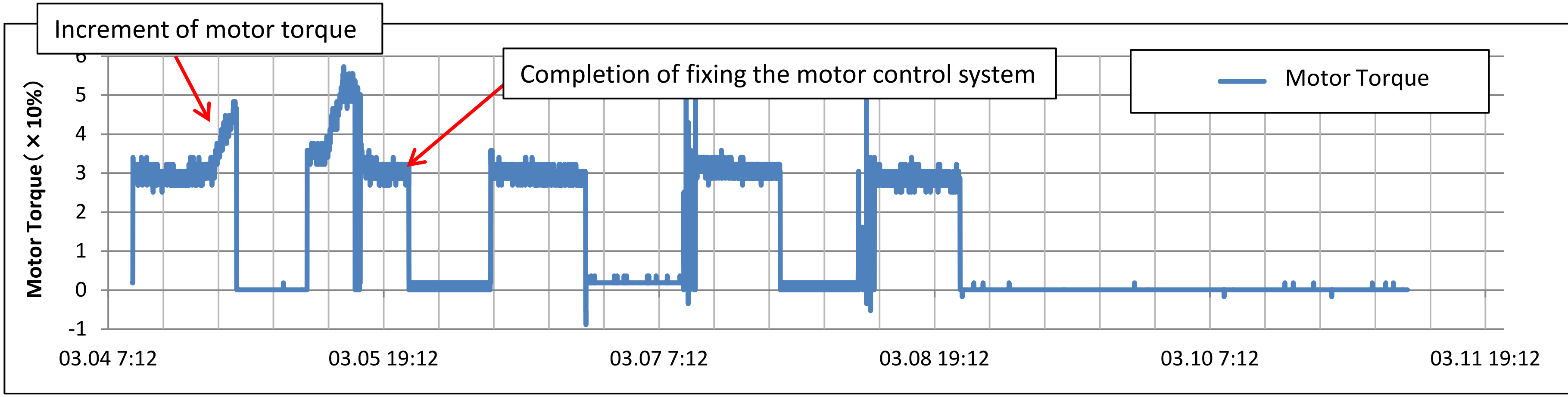
First Continuous Durability Test (5 days)





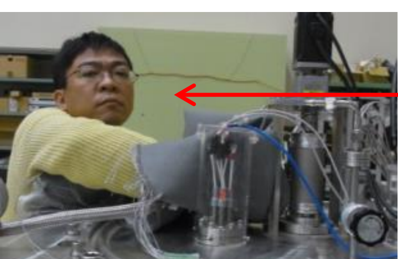
From 4th to 8th March of 2013, we started the continuous durability tests.
Target temperature was measured by an infrared thermometer without logging.
750℃～760℃; Stable heating.
Continuous operation; sometimes the motor alignment interfered with the heating.

Motor Torque Logging through the Durability Test

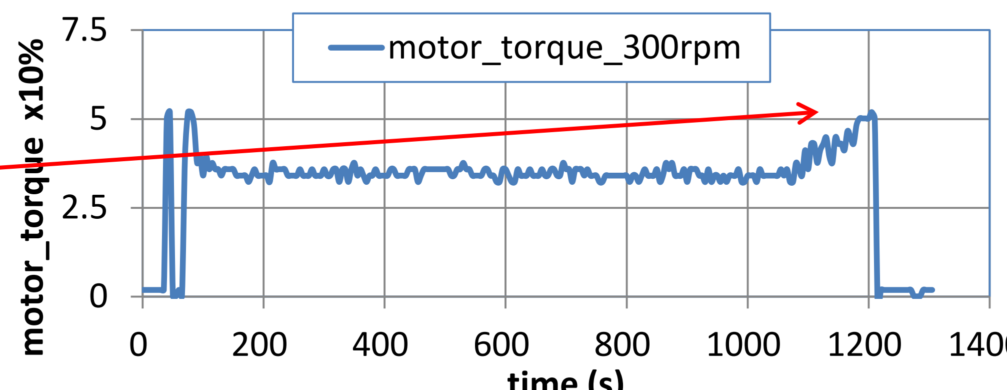


The motor torque increased on the first day.
But the interlock system for monitoring the motor torque was found out to be immature.
The motor was stopped in the midnight.
After the improvement of the interlock system, the motor torque never increased again.

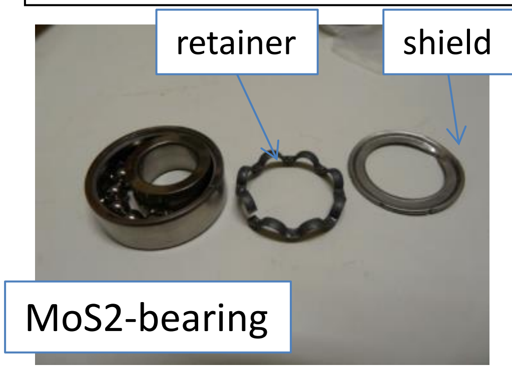
Additional interlock test for motor torque

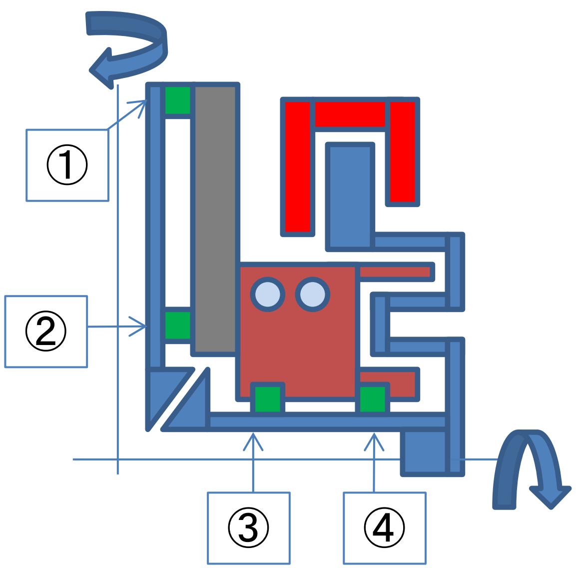


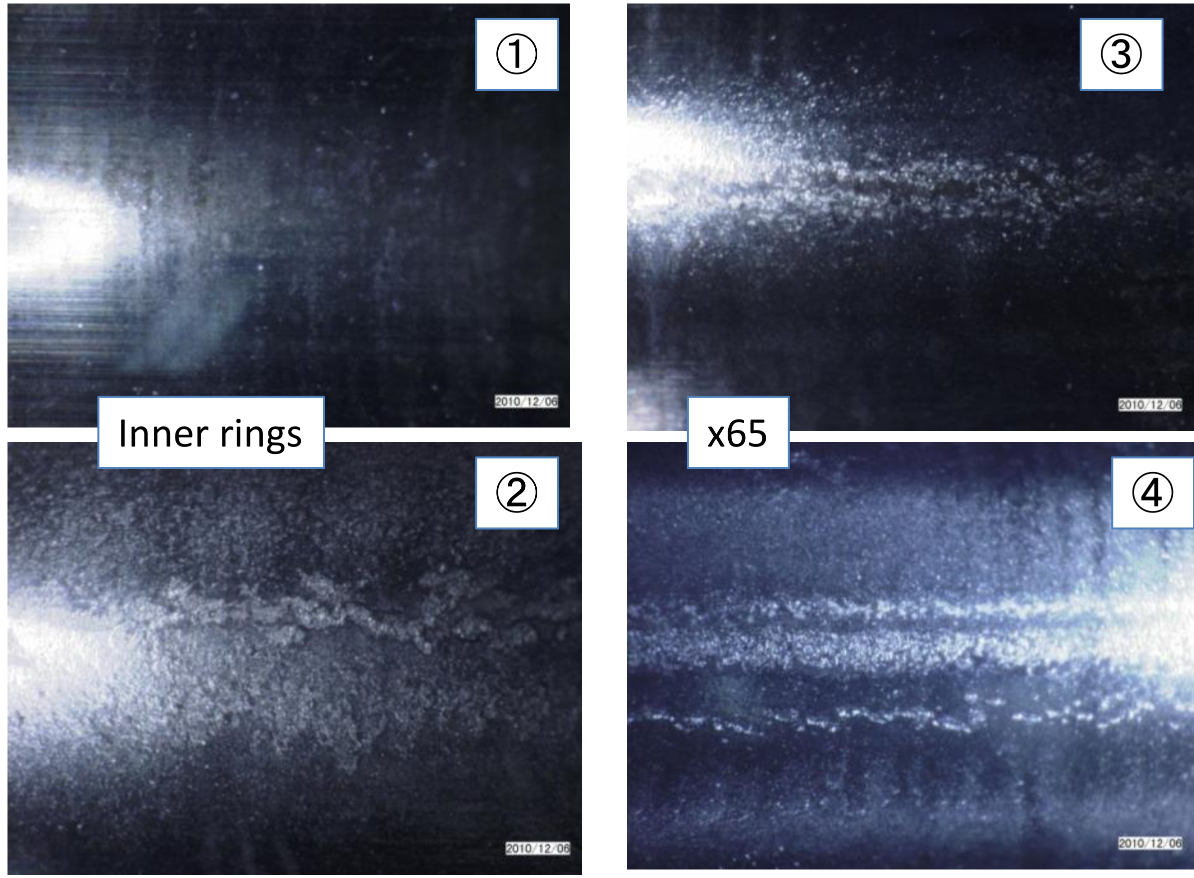
Sensitive Clutch
Machine, Makimura



Damaged bearings by heating and rotating test







①No damage
②More damaged than predicted
Thermal expansion of the vertical rod, Axial load
③, ④ Observation of electrical spark
→Ball is exchanged to Ceramic.

Summary of Rotating Target

To extend the lifetime of the muon target with a fixed edge-cooling method, the rotating target method is adopted.

The mock-up was fabricated and the heating and rotating tests have been continuously performed.

The continuous durability tests has been performed to determine the solid lubricant and to find the items to be improved.

The commissioning test for the remote-controlled replacements of the rotating target was completed.

The rotating target will be installed in the beam line (Shutdown of 2013).

Motivation for PIE tests in our case

Lifetime; dimensional change of graphite by proton irradiation

,which depends on the irradiated temp.

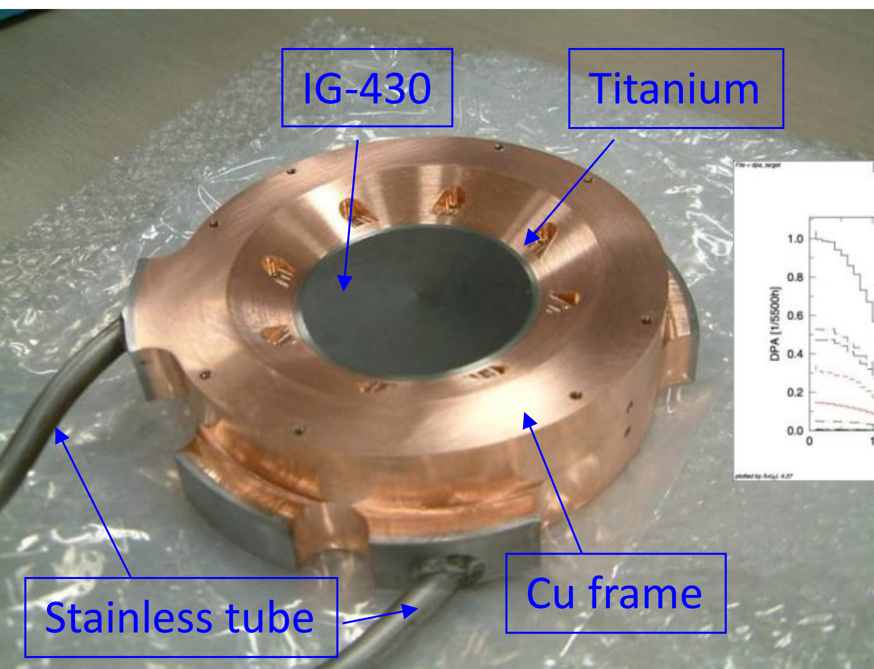
Then, How much is it?

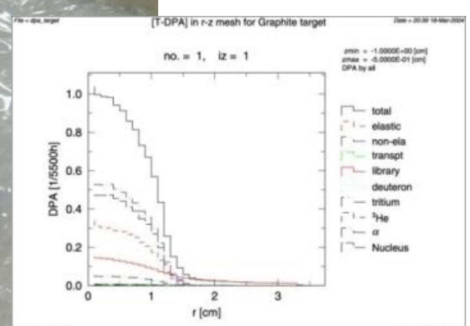
We must guess the thermal conductivity.
The utilized data is obtained at same condition?
We hope to know actual radiation damage.
(Even if the measurement is performed in R.T.)

Domestic conditions in Muon Gr.

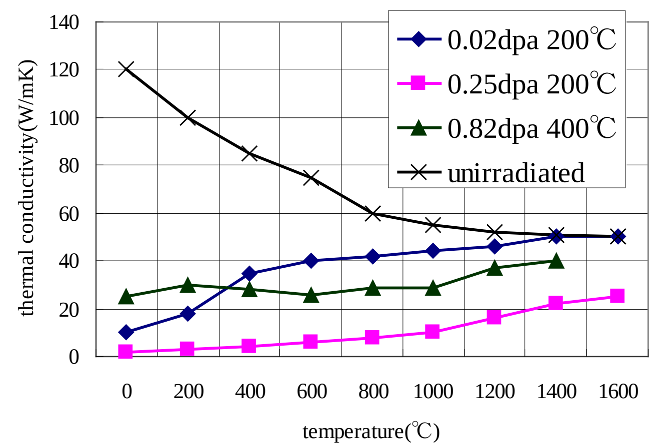
We are Muon Experimental Group, not Muon Target Group.
The Man-power for Muon Target is incredibly small.

- ◆No active disposal, Non-destructively
- ◆Low costs, Low man-power
- ◆But High performance
  (My Pride as Engineer)





Beam profile
By Kawamura



Neutron irradiation effect to thermal conductivity

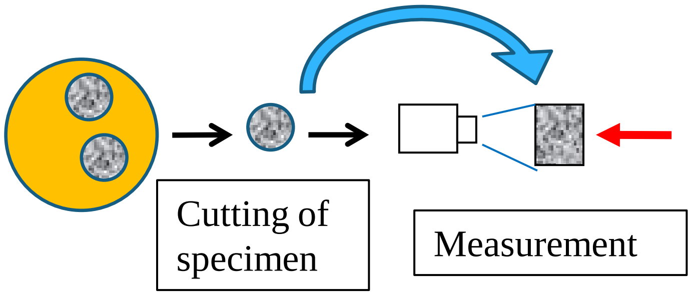
T. Maruyama et al., Journal of Nuclear Materials 195 (1992) 44-50.

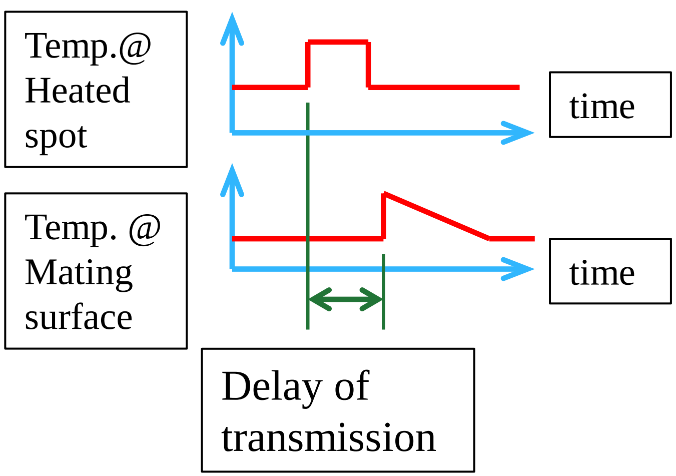
Measurement for thermal conductivity of graphite

Thermal diffusivity are measured instead of Th. conductivity.

$\lambda = D\rho c$ (λ; Th. Conductivity(W/m/K), D; Th. diffusivity(m^2/s), ρ; Density (kg/m^3), c; Th. Capacity (J/kg/K))

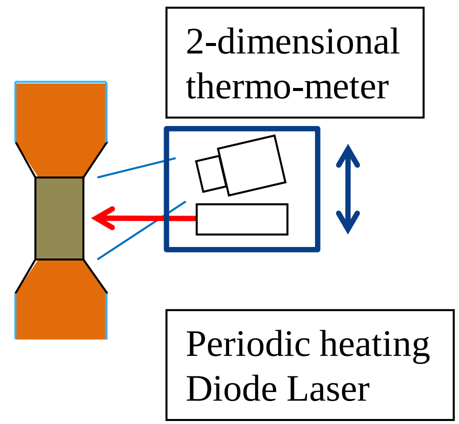
Conventional Method (Laser-flash technique)





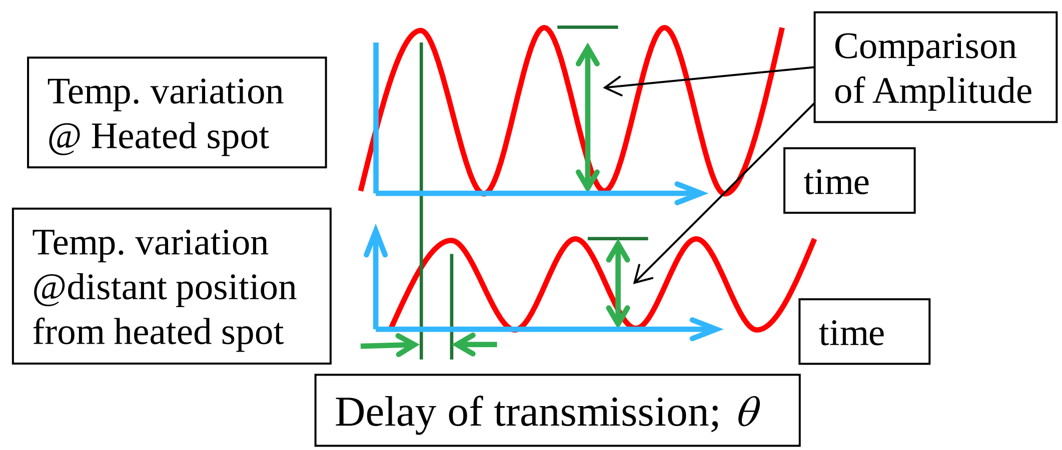
- ☐The target must be destroyed.
- ☐We must consider transportation and the scattered radioactive powders.
- ☐The spatial resolution is limited by sample size.

New method for this experiment Laser Spot Heating technique



- ➢Non-destructively
- ➢Target can be used again.
- ➢Decreasing nucl. wastes
- ➢High spatial resolution

Modified Thermal Imaging Scope (Bethel. Co. LTD.)



(H. Kato et al., Meas. Sci. Technol. 12 (2001) 2074-2080)

Theoretical Background of this technique

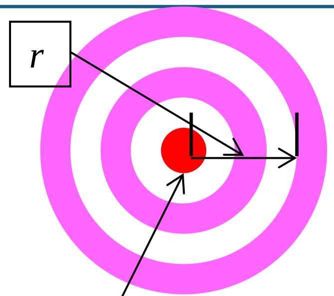
Thermal transport equation

D; Th. diffusivity(m²/s), ρ; Density (kg/m³), c; Th. Capacity (J/kg/K))

$$T(r,t) = \underbrace{\frac{P}{4\pi Drc}}_{\text{Amplitude}} \exp(-kr + i(wt - \underbrace{kr}_{\theta}))$$

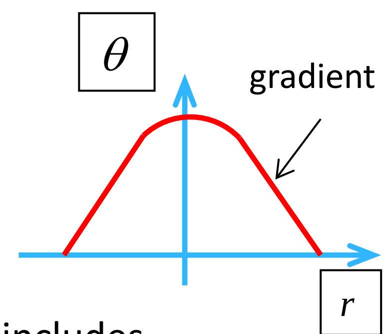
$$\boxed{k = \sqrt{\frac{\omega}{2D}} = \sqrt{\frac{\pi f}{D}} = \lambda^{-1}}$$

Carslaw H S and Jaeger J C 1959 Conduction of Heat in Solids (Oxford: Clarendon)p 263

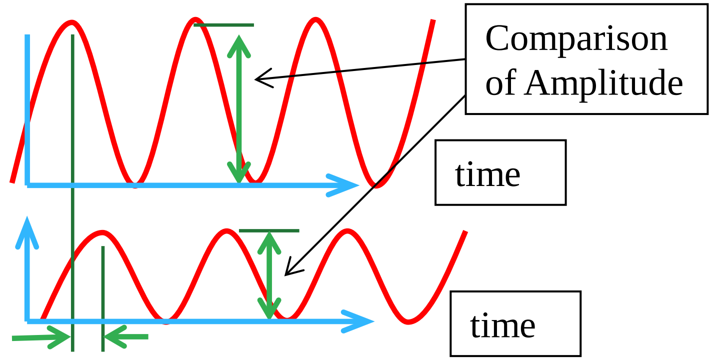


Periodic heating on Point $P\exp(i\omega t)$

$$\frac{\theta}{r} = -\sqrt{\frac{\pi f}{D}}$$



Amplitude includes given heat by laser, *P*



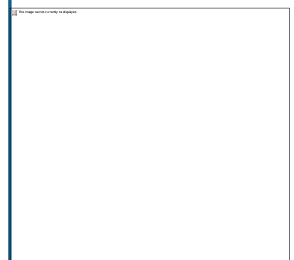
Temp. variation @ Heated spot

Temp. variation @distant position from heated spot

Delay of transmission; θ

ΔT; about 5 K

Feasibility of Apparatus



Thermo-meter

Distribution of Th. Cond. must be measured.

2-dimensional infrared thermo-meter

Expensive!!

Evaluation by Delay

High quantitative performance

Evaluation by Amplitude

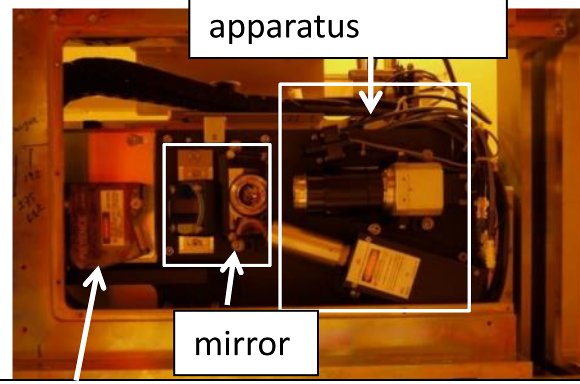
Low quantitative per., but low costs

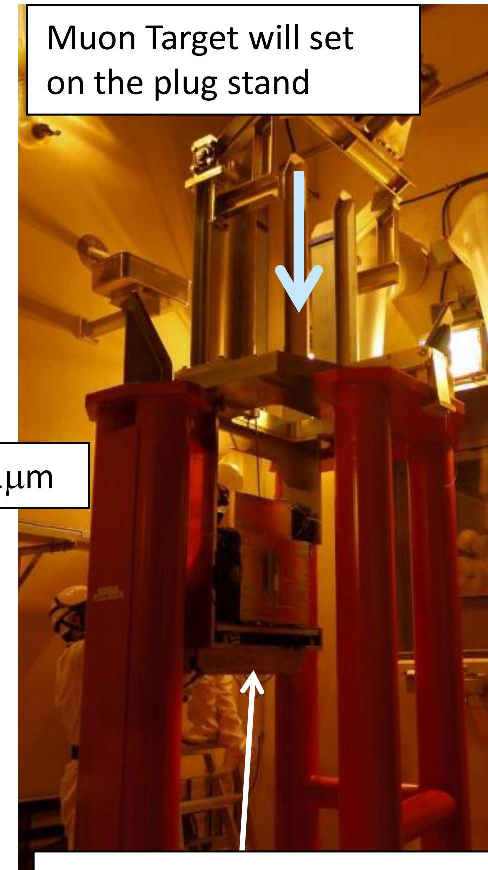
Relative measurements based on an exact Th. Cond., obtained by other technique (Laser flash method). Un-irradiated Th. Cond. 170W/m/K

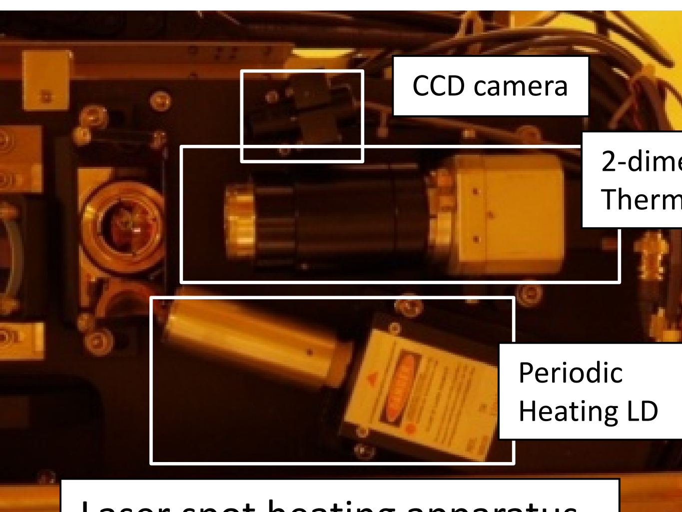
Measuring Apparatus of thermal conductivity

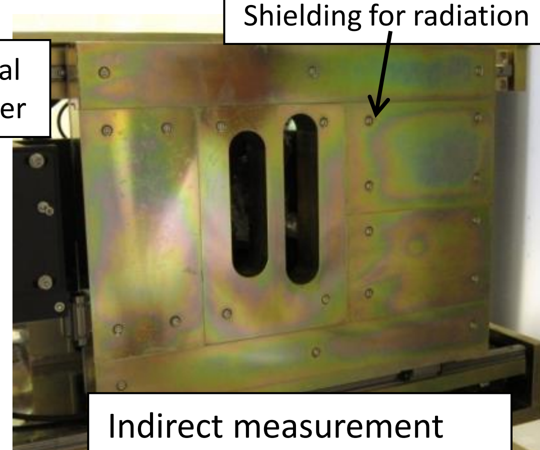
Vicinity of Muon Target; 5Sv/h, 5Gy/h for organic material (by Kawamura)
Assumption; Lifetime of measuring device, 100Gy, this means 20 hours
50mm iron shielding decreases the dose to 20 %. Extended Lifetime; 100 hours
Measurements with mirror reflection

Integrated measuring apparatus is set on a three-dimensional movable stage, which is set on plug stand.
Relative position is confirmed by laser displacement meter.

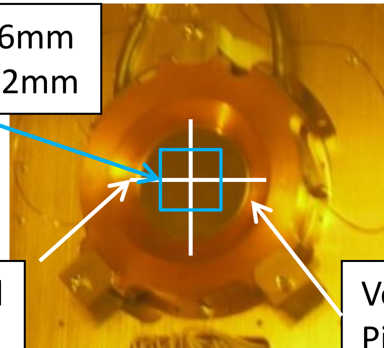








Beam Profile and Anticipated Th. Conductivity

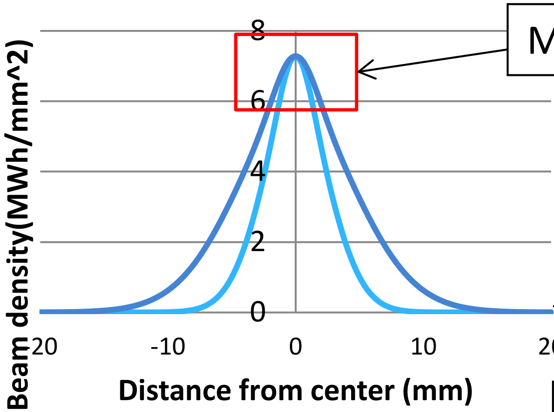


20mm x 16mm
Map pitch2mm

Horizontal
pitch1mm

Vertical
Pitch1mm

Distribution of Beam density (~RUN39)

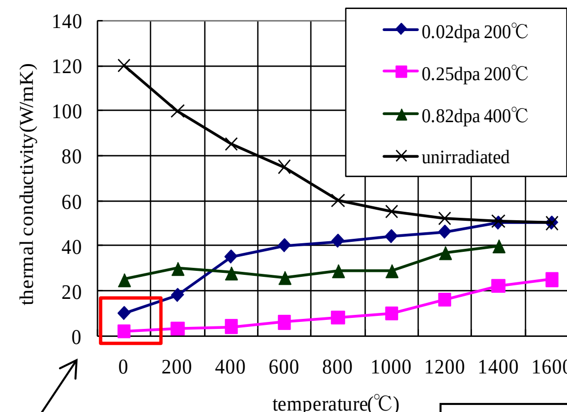


Max. 0.25dpa

0.002 dpa

The variation of thermal conductivity irradiated by neutrons

Annealing effect



Data for IG110

T.Maruyama et al., Journal of Nuclear Materials 195 (1992) 44-50.

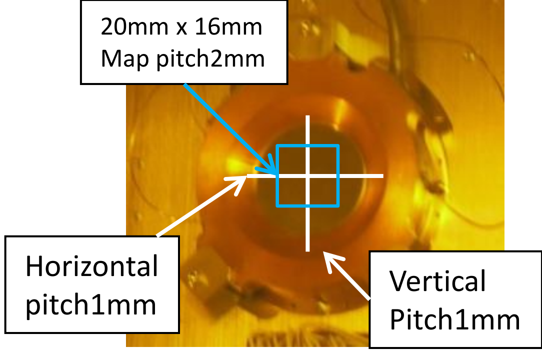
If decrement of conductivity is proportional to radiation dose, the distribution for the thermal conductivity corresponds to the beam profile.

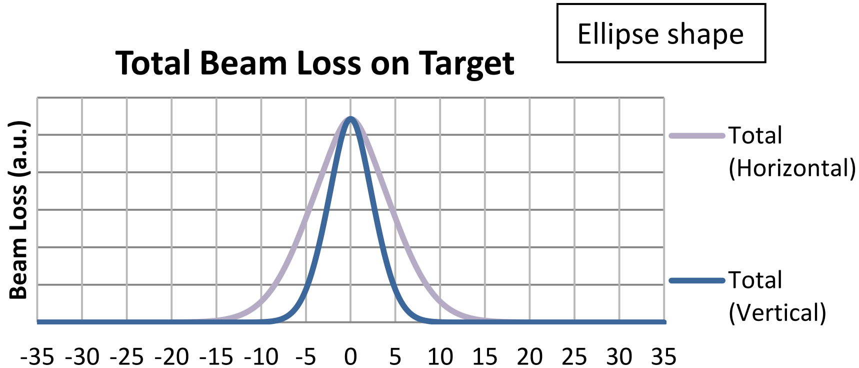
From Simulation
Th. Conductivity can be anticipated,
0.25dpa on center 200degC; 5W/m/K
0.002dpa on edge 80degC; 10W/m/K

Measurement in Hot cell

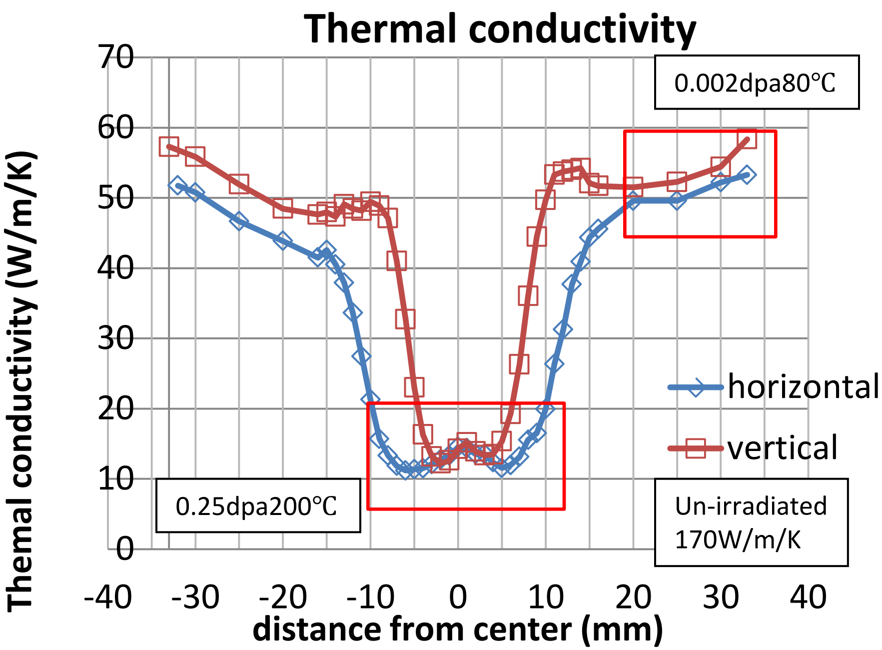
Results

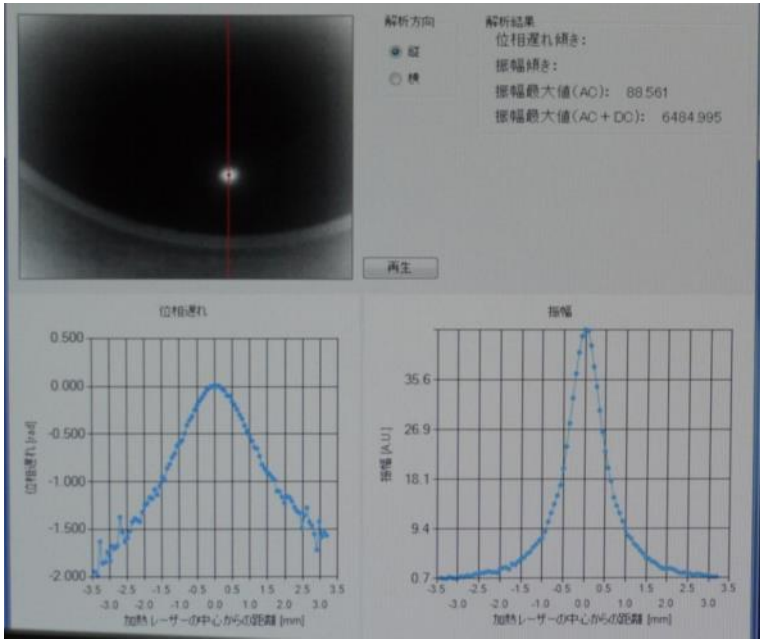
We could observe an annealing effect on the center of beam spot because of high temperature.
The beam profile for horizontal/vertical could be observed.
Thermal conductivity was higher than the prediction.



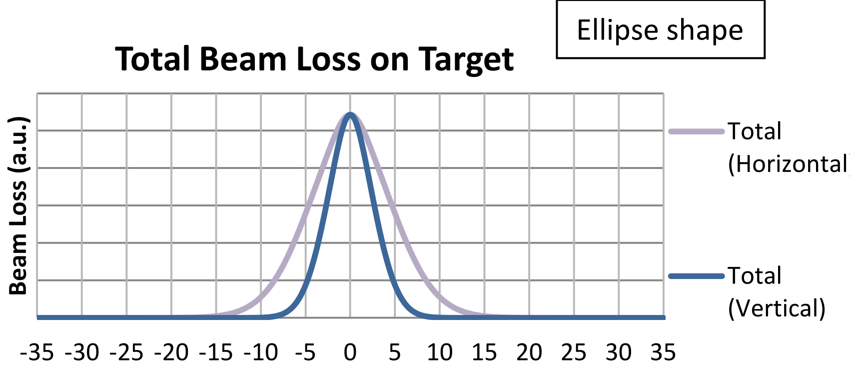


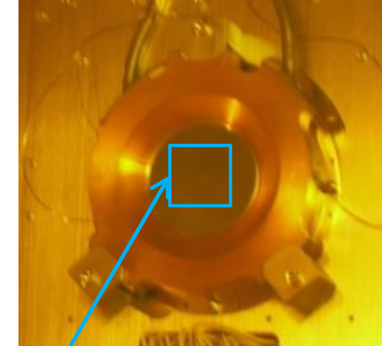
	Rad. Dose (dpa)	Th.Cond. Prediction	Th.Cond. Results
Center of target	0.25 (200 degC)	5 W/m/K	15 W/m/K
Edge of target	0.002 (80 degC)	15W/m/K	50 W/m/K



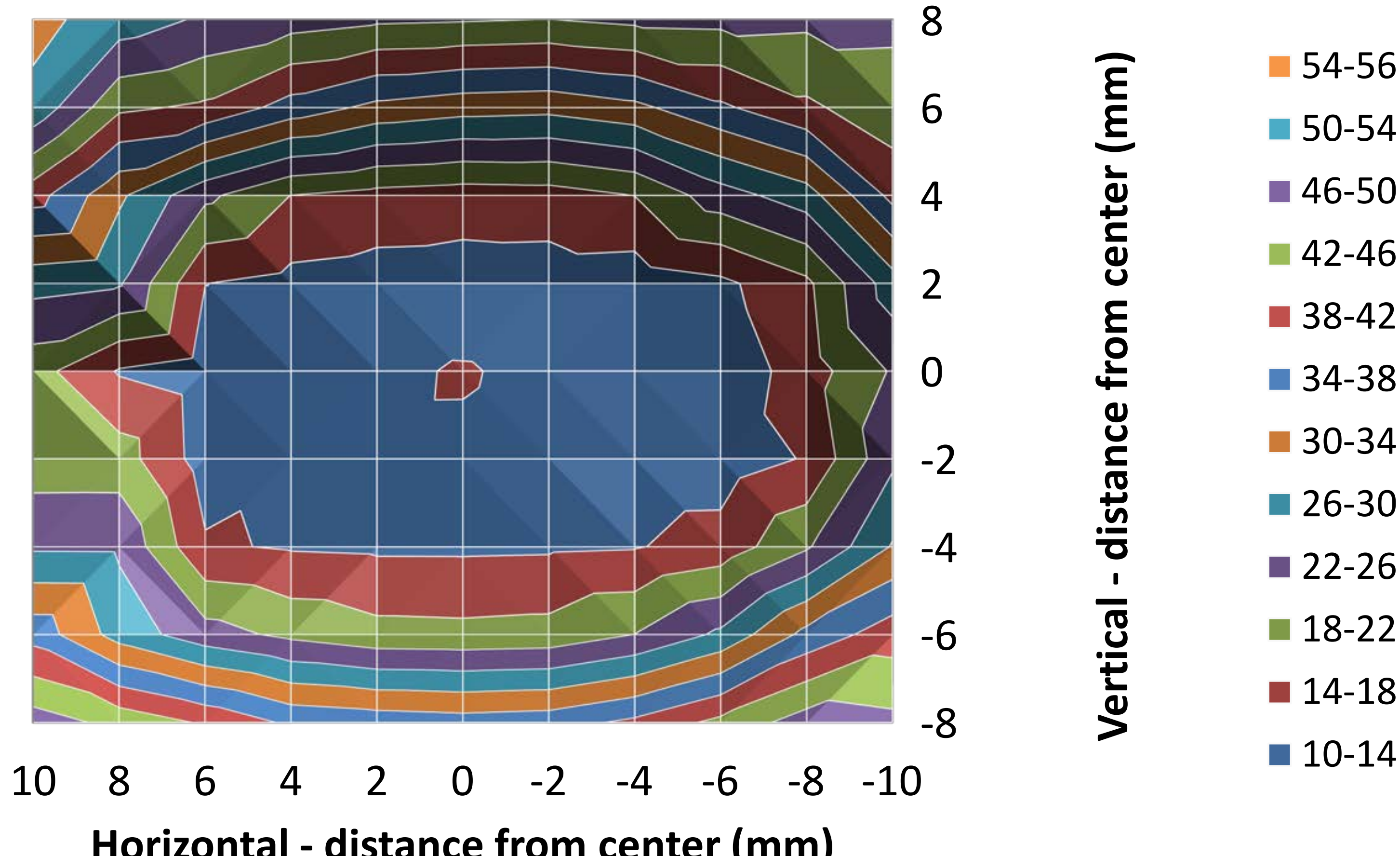


Results (Mapping)





2-dimensional map of thermal conductivity



Summary & Future Plans

Advantages of this new technique

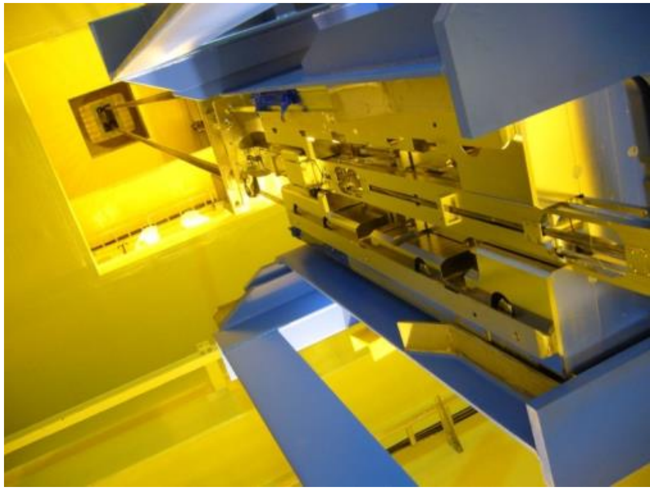
- Non-destructively
- Target can be used again.
- Decreasing nuclear wastes
- High spatial resolution

Summary &Future Plans

- Improvement of quantitative performance by meas. of θ
  ~High speed infrared thermo-meter
- We began to measure proton-irradiation damage to thermal conductivity of graphite by brand-new laser spot heating technique.
- Measurement can be performed, non-destructively, without contact, and with high resolution. Target can be used again.
- Distribution of thermal conductivity (relatively) can be measured successfully.

Storage and Disposal of Used Target

After installation of rotating target, the used target requires storage and disposal. They are stored in temporary storage pods and an underground storage room.
The preliminary design of the disposal vessel has been completed.
The detailed design of the disposal can not be completed, because a facility for disposal is not determined.



Remote controlled commissioning for storage has been completed.

Remote controlled commissioning for cutting has been completed.

The facility for disposal must be determined now.

Isotropic Graphite

- Isotropic graphite
  (polycrystalline graphite)

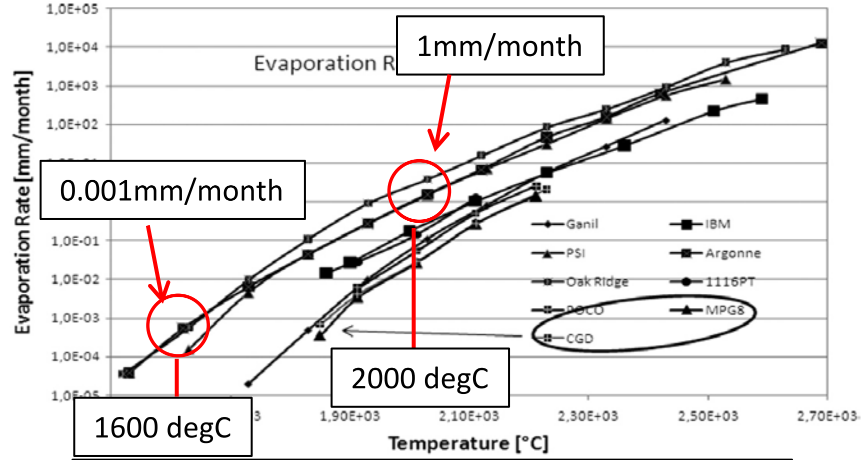
⇔Highly Ordered Pyrolytic Graphite (HOPG)

- For accelerator, nuclear reactor

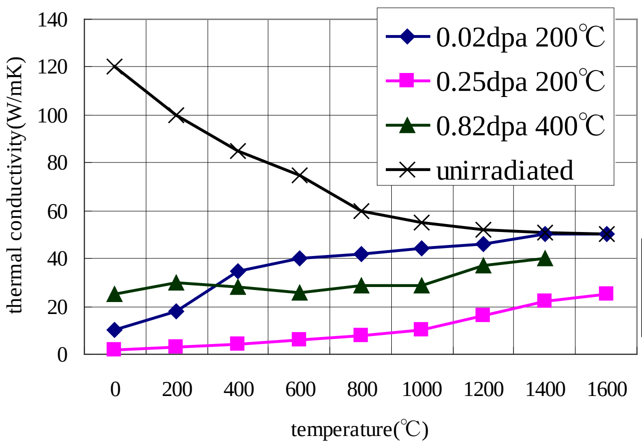
Low density, High resistance to heat, Low Young's modulus, High strength, Low residual radiation

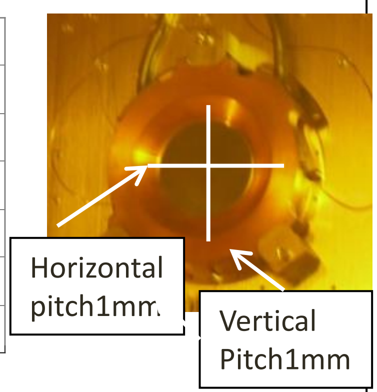
IG-430U (Toyo Tanso); Muon Target

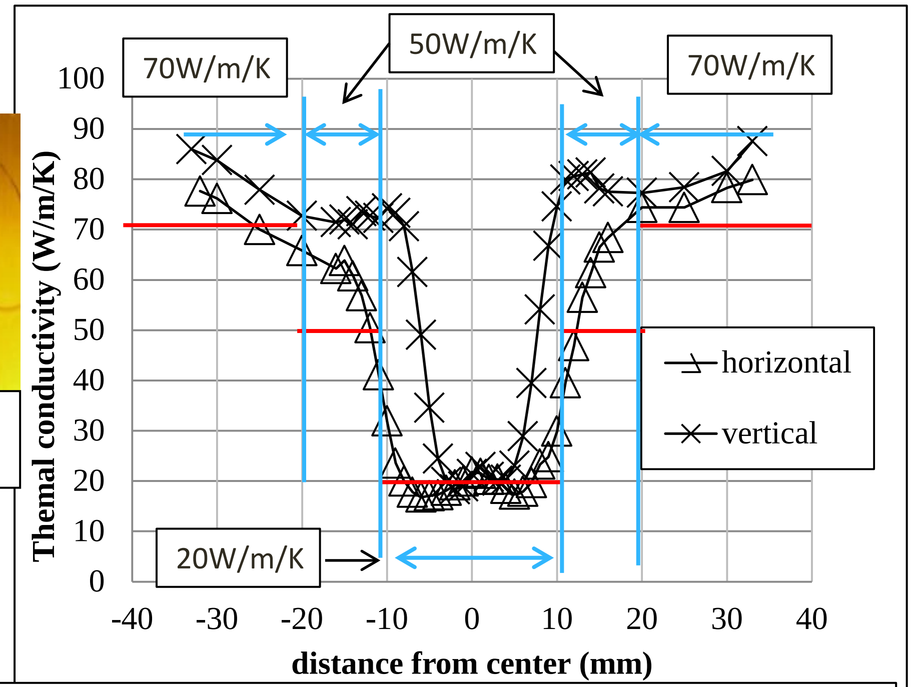
(IG-110; irradiation data obtained systematically)



Evaporation rate of graphite
(M.S. Avilov et al., Nuclear Instruments and Methods, A618 (2010) 1)







Neutron irradiation effect to thermal conductivity
(T. Maruyama et al., Journal of Nuclear Materials 195 (1992) 44-50.)

Irradiation effect to thermal conductivity

Record obtained at our facility was used for following evaluation