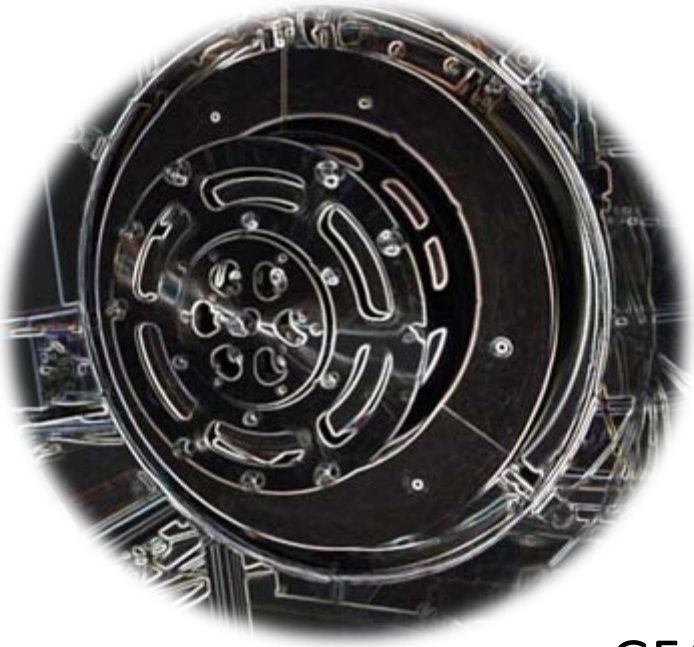
Muon Production Target at J-PARC/MUSE



Shunsuke Makimura

shunsuke.makimura@kek.jp

J-PARC Center, MLF Division,

Muon Section (KEK-IMSS)

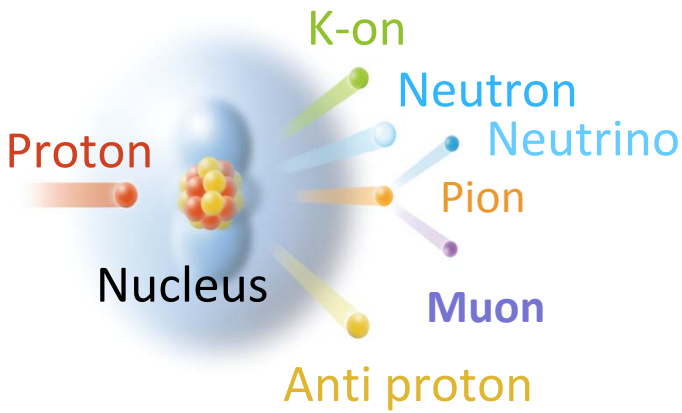
15th April 2013

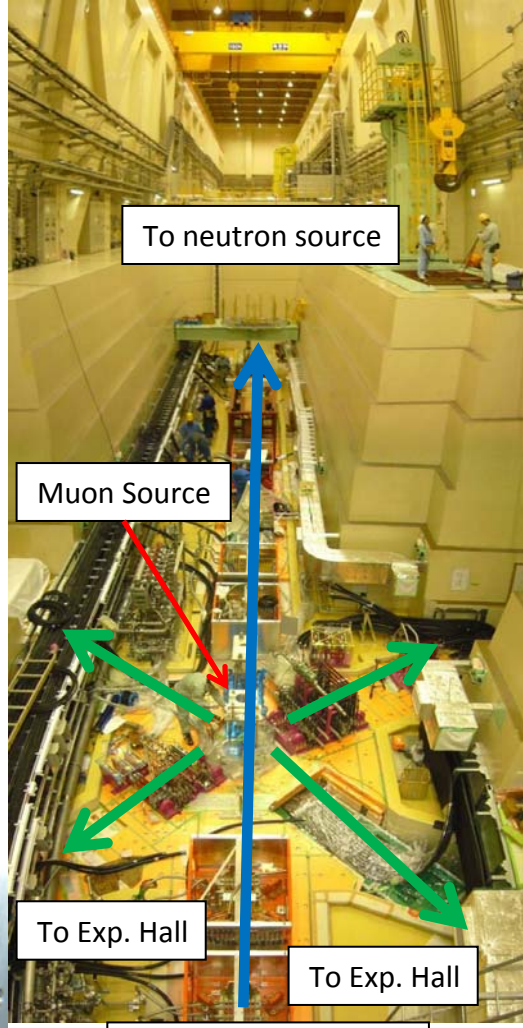
GFA & SwissFEL Accelerator Seminar @ PSI

Contents

J-PARC/MUSE & MUON

Japan Proton Accelerator Research Complex



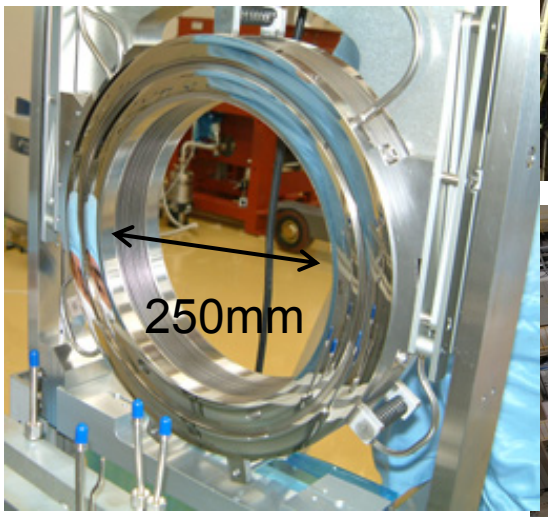


MUon Science Establishment

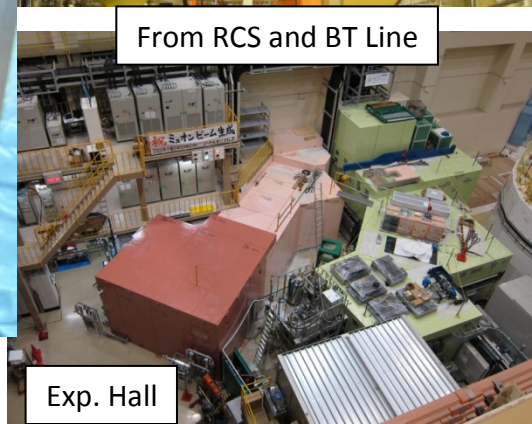
Muon is a decay product of Pion!

$$\pi^+ \rightarrow \mu^+ + \nu_\mu$$

$$\pi^- \rightarrow \mu^- + \bar{\nu}_\mu$$



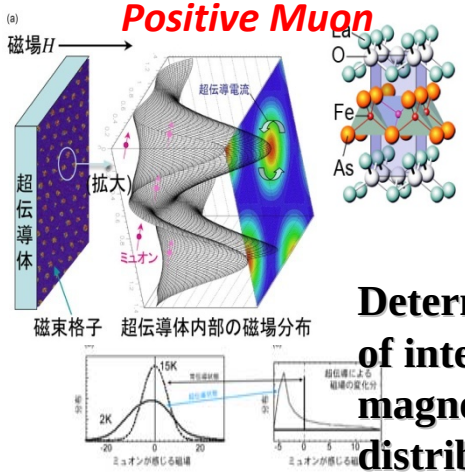
KEK-MSL pillowseal



Topics Explored by Muon

Magnetism and Superconductor

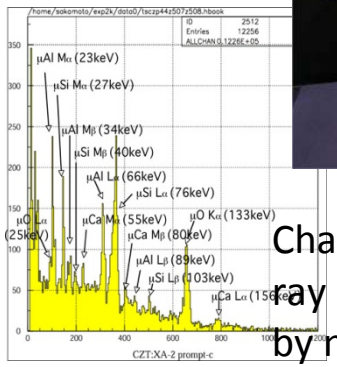
Positive Muon



Determination of internal magnetic field distribution

Non-destructive Measurement

Negative Muon

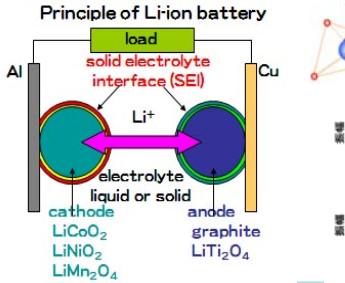


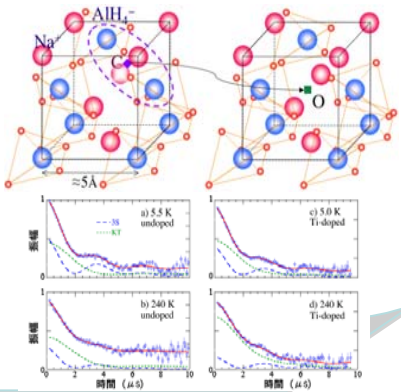
Characteristic X-ray measurement by negative muons

Batteries Material and Hydrogen

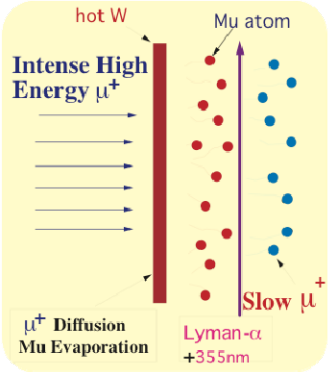
Positvie Muon

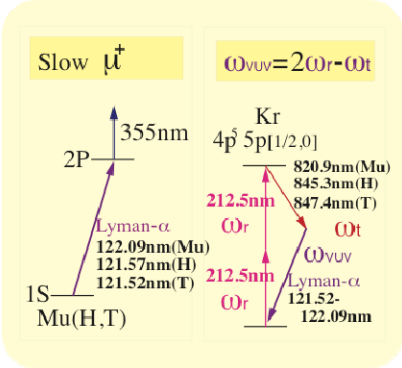
H behavior





Ultra Slow Muon Generation





100 μJ @122 nm

Ultra Slow μ+ >10^{5-6}/s ←surface muon (4×10^8/s)

Surface Muon (4 MeV, Range ~0.1mm) for BULK

Ultra Slow Muon(0.05-30 keV, Range 1 nm to ~100 nm)

- **Study Nano-science(Interfaces or multi-layered film)**
- **Surface Chemistry-Catalysis on nano-particle**

D-Line, since Sep., 2008

[The world-most intense pulsed muon beam achieved at J-PARC MUSE]

At the J-PARC Muon Facility (MUSE), the intensity of the pulsed surface muon beam was recorded to be 1.8 x 10^6/s on November 2009, which was produced by a primary proton beam at a corresponding power of **120 kW** delivered from the Rapid Cycle Synchrotron (RCS). The figure surpassed that obtained at the Muon facility of Rutherford Appleton Laboratory in the UK, pushing MUSE to the world frontier of muon science. It also means that the unprecedentedly high muon flux of 1.5 x 10^7/s (surface muons) will be achieved at MUSE when the RCS proton beam power reaches the designed value of 1 MW within a few years.

2010年(平成22年)3月16日(火曜日)

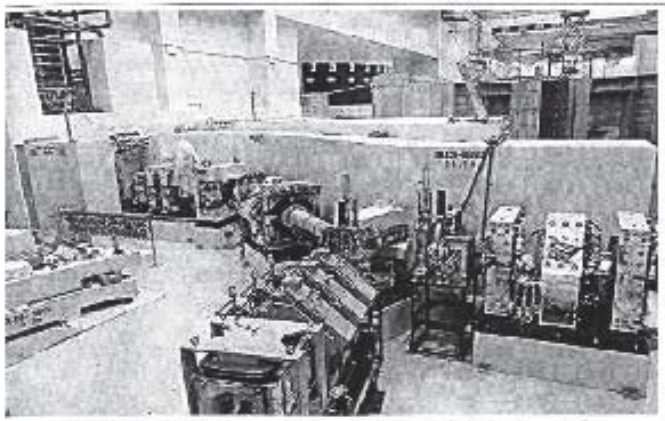
世界最高出力を達成

J-PARC「ミュオン」発生装置

東海村の大強度陽子加速器施設（J-PARC）物質・生命科学実験施設で、物質の微細な構造の測定などに使うミュオンの発生装置が昨年暮れ、世界最高の出力を達成していたことが、施設を運営するJ-PARCセンターの計測で分かった。

ミュオンは、光速近くまで加速した陽子を黒鉛に衝突させると発生する素粒子。磁気に敏感に反応するため、物質に当てることで、その物質内部の磁気がどうなっているかや、物質中に含まれる水素の状態などを、極めて高い精度で測定できる。新しい磁性材料をはじめ、超電導素材、燃料電池の材料開発などに威力を発揮すると期待されている。

ミュオンは断続的に発生するが、1回あたりの計測値は1万2000個に達しており、世界にある発生装置の2倍以上。高い効率での測定ができる。陽子加速器の出力を上げれば、同18万個のミュオンが得られることも確認。世界最高レベルの計測装置として、基礎科学や産業分野まで、幅広い利用が進みそうだ。



世界最高強度のミュオン発生が確認されたJ-PARCの実験施設。左から延びるのがミュオンの通り道だ（J-PARCセンター提供。建設中の撮影）

科学新聞

72年4月2日新・夕 第版6頁

世界最高強度 ミュオン発生

J-PARC 実験で成功

We achieved World strongest pulsed surface muon beam at J-PARC MUSE D1&D2 area even with 120 kW intensity. on November,10th 2009

Press Released on Nov. 26th, 2012

■建設中のミュオンUラインで、世界最高強度のパルスミュオン強度を達成

J-PARC/MLFのミュオン実験施設では、超低速ミュオンビームライン（Uライン）を現在建設中。このUラインにおいて11月7日、同ミュオン実験施設の低速・高速ミュオンビームライン（Dライン）が平成21年12月に達成した、1パルス当たり世界最高強度のパルスミュオンの約20倍のパルスミュオン強度を達成したことを確認した。今回の成果は、ミュオン標的で生成したミュオンを高い効率で捕獲し、実験装置まで輸送する超伝導ソレノイド電磁石や超伝導軸収束系などを、J-PARC/MUSEグループ（責任者：三宅康博セクションリーダー（KEK物質構造科学研究所教授））等が、低温セクションの協力の下、開発したことによるものである。今後、この世界最高強度のパルスミュオンを超低速化して創り出される超低速ミュオン顕微鏡計画を完成させる。「超低速ミュオン顕微鏡」についての詳細記事は、KEKホームページ（http://www.kek.jp/jp/ja/NewsRoom/Highlights/20120920170000/）をご覧ください。

The Science News 科学新聞 2012年（平成24年）12月14日（金曜日） 第3417号

科学新聞

パルスミュオン強度 KEKが世界最高達成

J-PARCに物質・生命科学実験施設（MLF）のミュオン施設（MUSE）で、世界最高となるパルスあたりのミュオン強度2.5万倍（公表）に到いたれた超ミュオンビーム強度212kW）が達成されたこと。これは一昨年、同施設で達成した7万2千キロ（72kW）、12万倍（180000メW）を超えるもの。世界でも初めて扱いた施設である。

この成果は、高エネルギー加速器研究機構（KEK）の物質・生命科学研究所の三宅康博教授らのMUSEグループが開発した「超伝導ソレノイド電磁石」や「超伝導軸収束系」などの開発、「超伝導軸収束系」、および「超伝導軸収束系」という軸収束系の開発などにより、ミュオン生成ターゲットで発生したミュオンの高効率での捕獲、輸送を実現したものである。

ミュオンを利用した研究は、物質・磁性・原子核といった物性物理学、原子核の特性解析、さらに宇宙線や地球の環境分析などに多岐にわたっている。そして、ミュオン強度の向上は、実験時間の短縮化、分解能の向上などにつながる重要なファクターである。今回実現された強度では、従来の約1/10の時間で同等の実験ができ、これまで見えなかった現象を観測することが可能になる。

ミュオンを利用した研究は、

施設名	1パルスあたりのミュオン数		
J-PARC/MLF	2,500,000	212kW	2012年11月
J-PARC/MLF	72,000 180,000	120kW 300kW	2010年3月
RAL（英国）	30,000	160kW	

INTRODUCTION for Muon Target

Muon Target (Graphite)

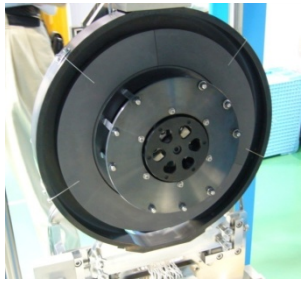
Muon Target System

Radioactive components

Fixed Target

Irradiation Damage of graphite

Proton Beam Operation



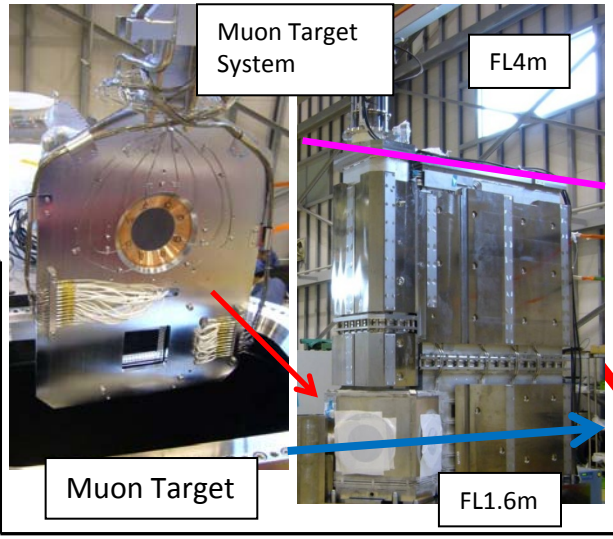
Rotating Target

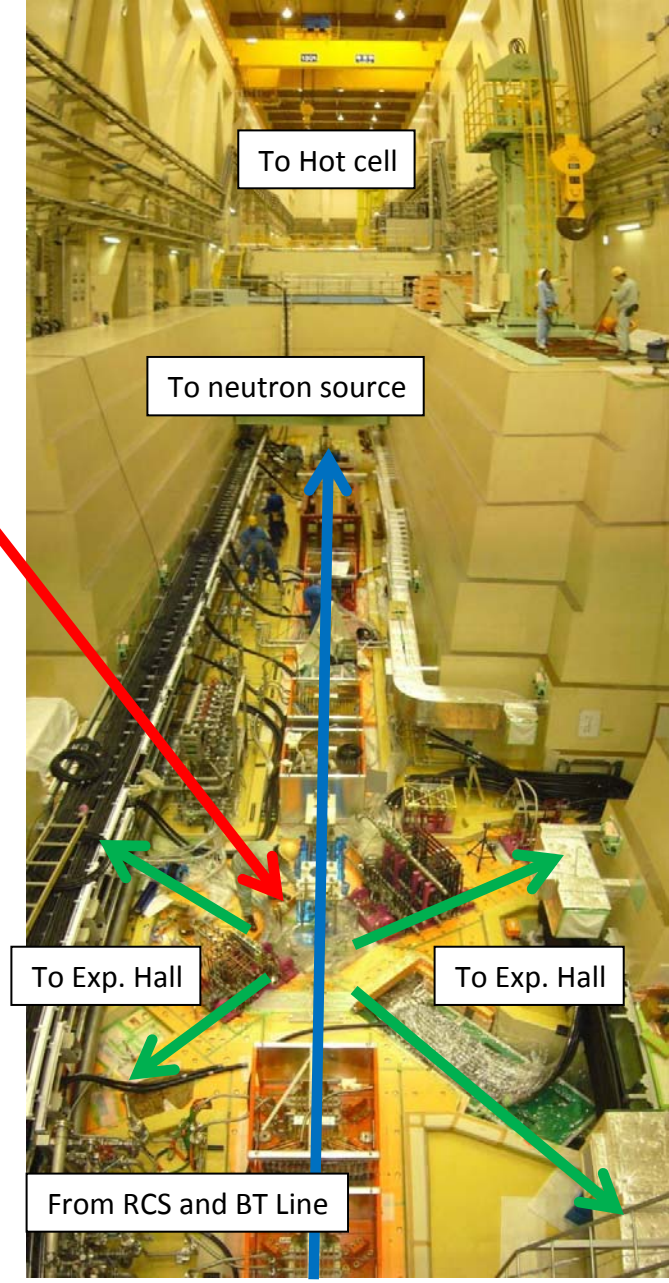
Post Irradiation Effect

Replacements and Checking

Remote controlled task in Hot cell

SiC Rotating Target for DeeMe project

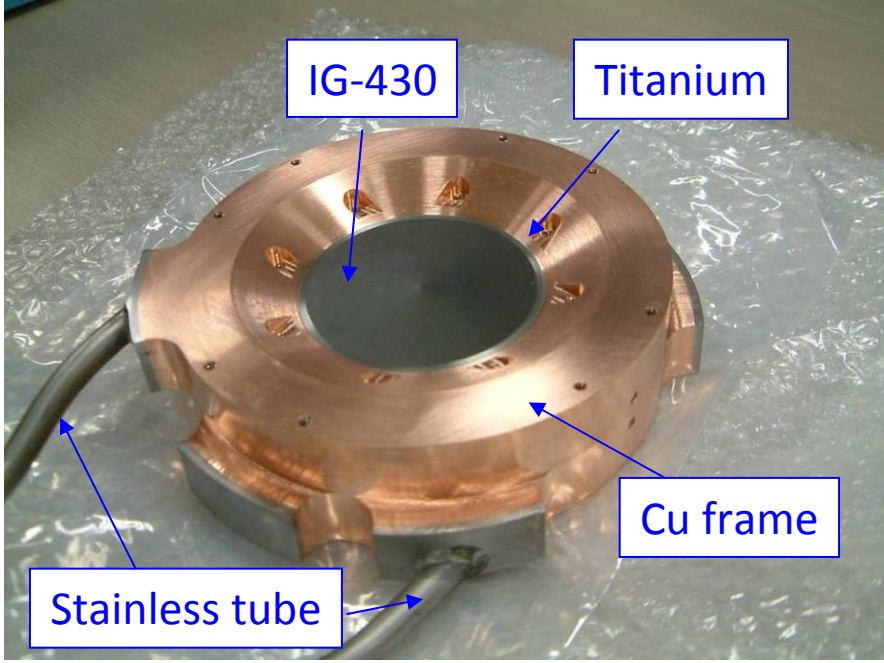




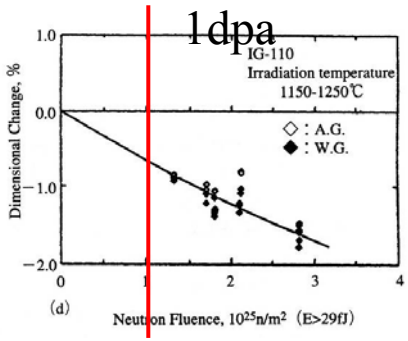
We, Muon Section in MLF, learned a lot of things from PSI, ISIS, and TRIUMF. Especially, Dr. Gerd Heidenreich in PSI. We really appreciate their support.

Current Fixed Muon Target

Isotropic Graphite
Thickness; 20 mm, Diameter 70 mm
Fixed edge-cooling method
4-kW heat @1MW,
beam diameter 24 mm (2σ=12mm)
Titanium layer; Absorber of thermal stress

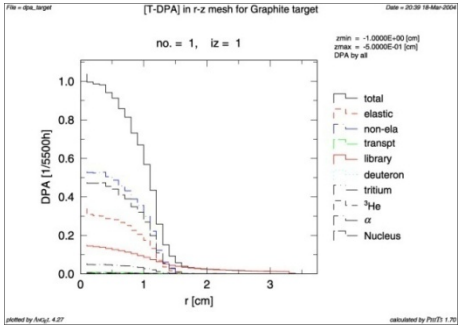


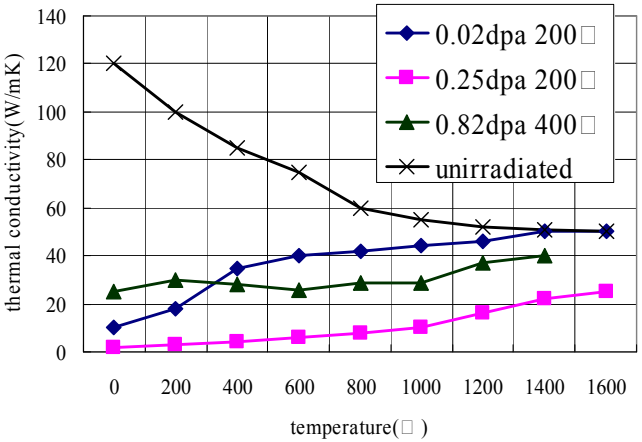
Lifetime; 0.8dpa (@1MW, 1dpa/year)
Radiation damage of graphite by proton beam (dimension and th. conductivity)
Temperature dependence, The highest shrinkage rate; 1%/1dpa,



H. Matsuo, graphite1991 [No.150] 290-302
1 %/year shrinkage of graphite on the beam spot

Beam profile By Kawamura





Neutron irradiation effect to thermal conductivity

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

Beam Operation

(Sep. 2008)

First muon beam generation (Day 1)

(Dec.2009) 327kW proton beam tests

5min.×5set, 1hour×1set

(loss on target□1.2kW)

Continuous 120kW operation was started.

(Nov. 2010) Continuous 200kW operation

(Mar. 2011) TOHOKU Earthquake

(Dec. 2011) Resume of Proton Operation

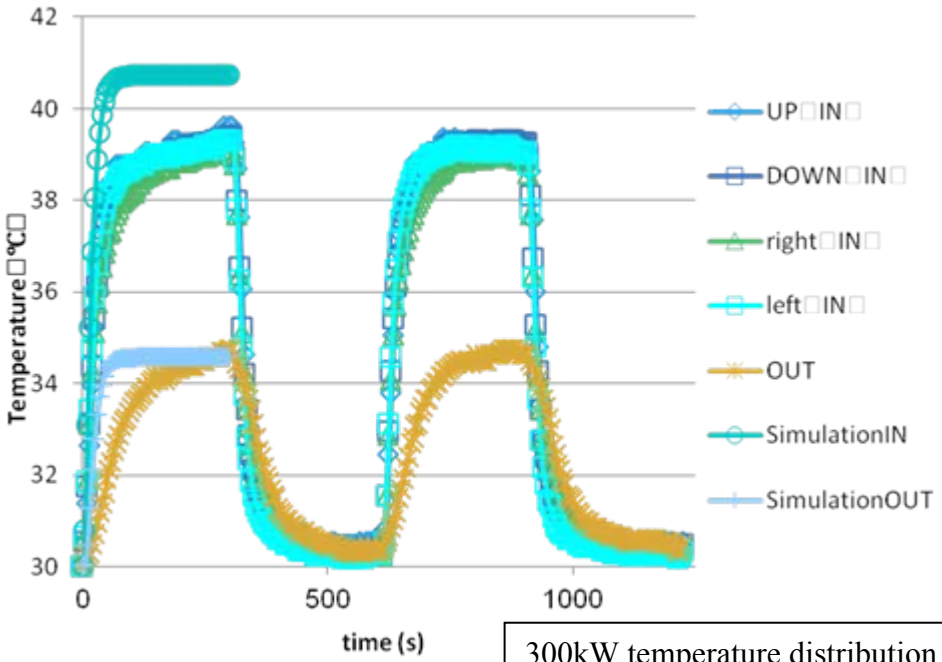
(Mar. 2012)

200kW continuous operation was started.

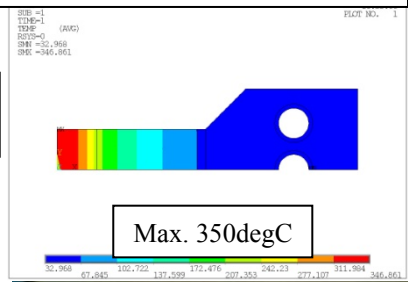
(Nov. 2012)

300kW continuous operation was started.

RUN28, 7th, Dec. 2009 (327kW);
Beam loss;1200W□In Simulation□1300W□

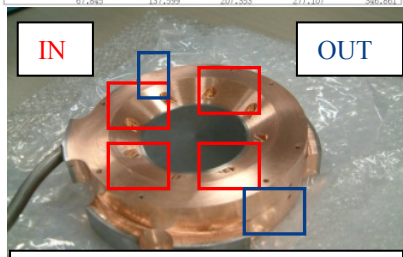


300kW temperature distribution



Muon target has been successfully operated without replacement.

	2008	2009	2010	2011	2012	2013
Proton Beam	Sep.Day1 20kW Op.	120kW Op. Dec. 300kW	200kW Op.	Earthquake	200kW Op.	300kW Op.



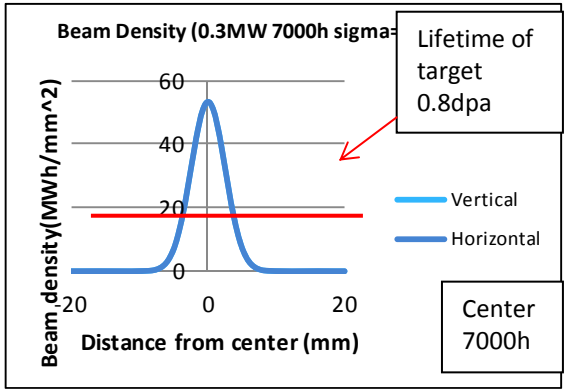
Temperature measured by T.C.

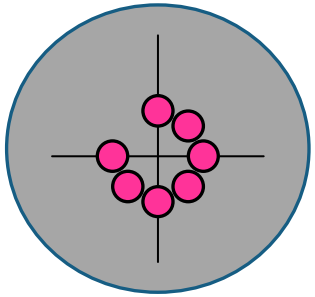
Accumulated beam power on Muon Target

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.

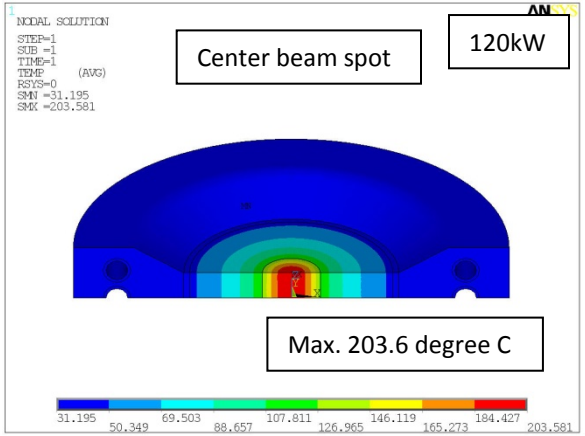
Beam painting for each RUN, every three weeks, was adopted.

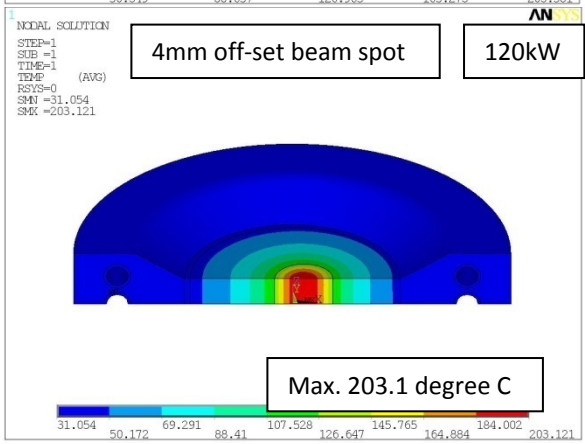
The radiation damage of graphite will reach to lifetime on July of 2013.



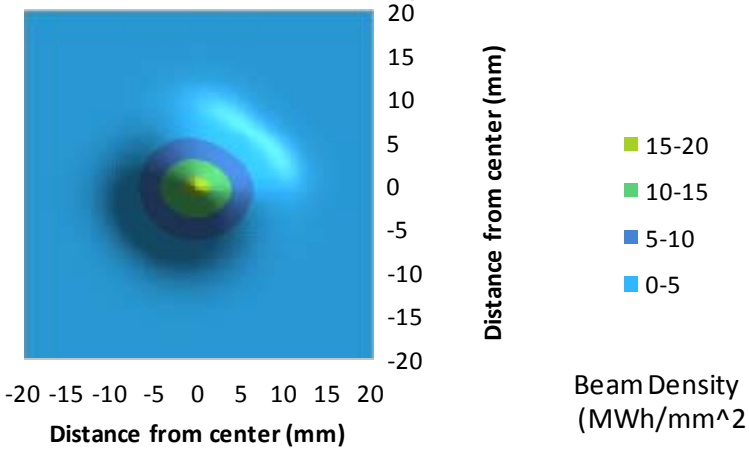


Beam painting by off-set beam

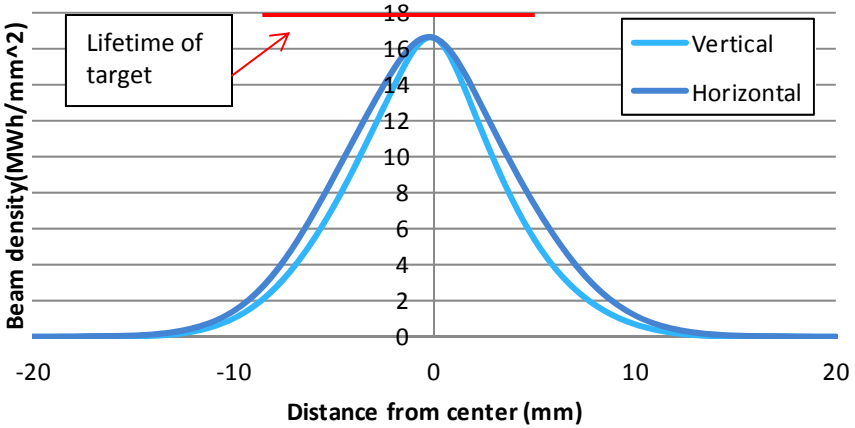




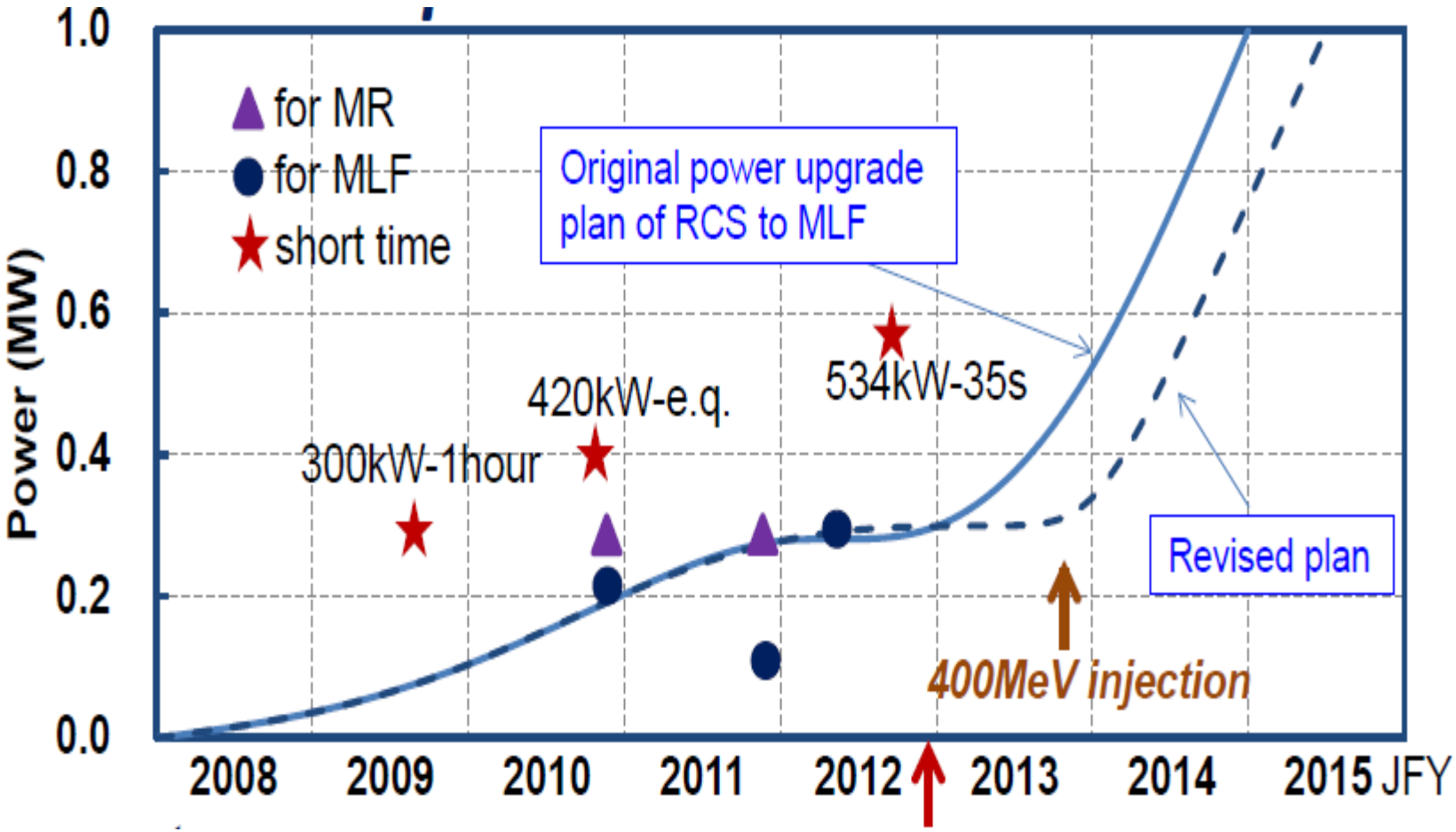
Distribution of Beam Density (~Mar. 2013)



Distribution of Beam density (~Mar.2013)



Future Plan of Proton beam



Remote-Controlled Commissioning in Hot Cell

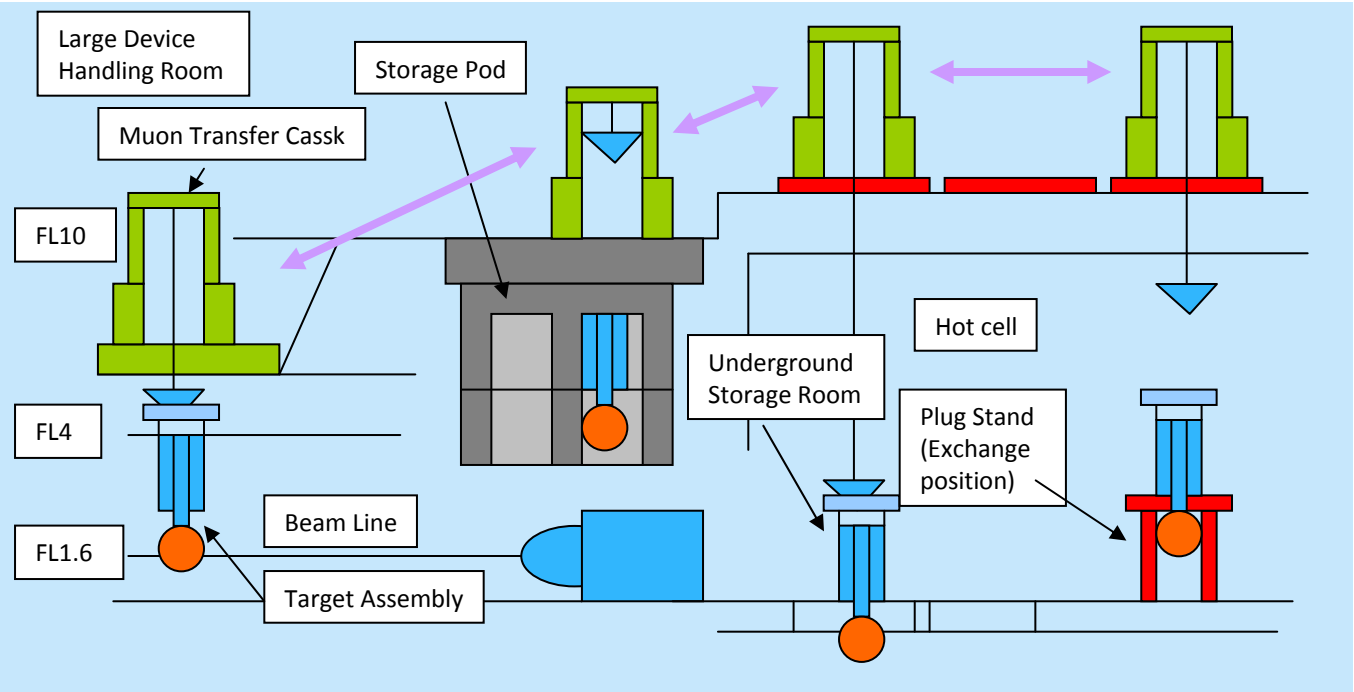
Muon target will become highly radioactive up to 5-10Sv/h. Therefore the replacement of the muon target must be performed through a remote control.

Muon target will be transported by a shielding vessel, Muon Transfer Cask.

The remote controlled commissioning has been performed in Apr.2008, Oct. 2008, Aug.2009, Sep.2011, Sep.2012

Transportation of the attachment

Shielding vessel, Muon Transfer Cask



Replacement of Muon Target

Development of Graphite Rotating Target

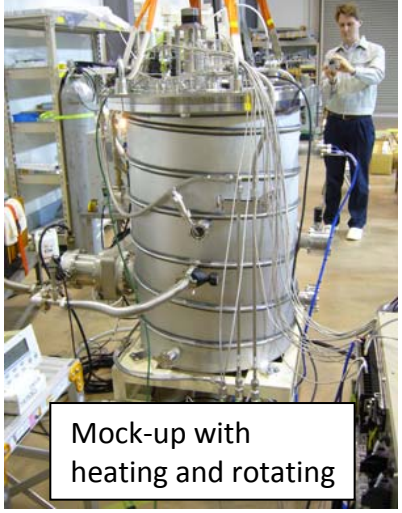
(It will be introduced later.)

Rotating target method to distribute the radiation damage to a wider area,.
The lifetime of the bearings is critical.
Expected lifetime; 10 years

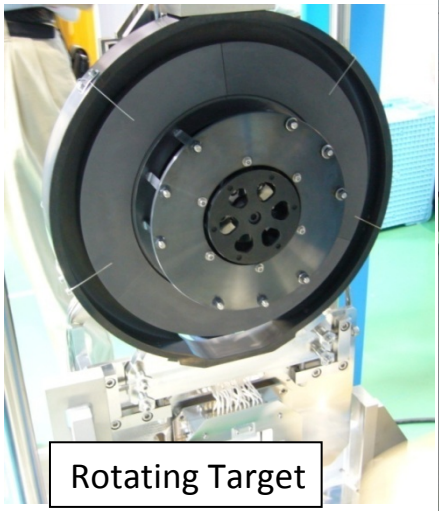
The durability tests of the bearings by the mock-up with heating and rotating

Candidate of solid lubricant for bearing
WS_2, MoS_2, Silver coat

Rotating Target to be installed was fabricated.
Remote-controlled commissioning was successfully completed.

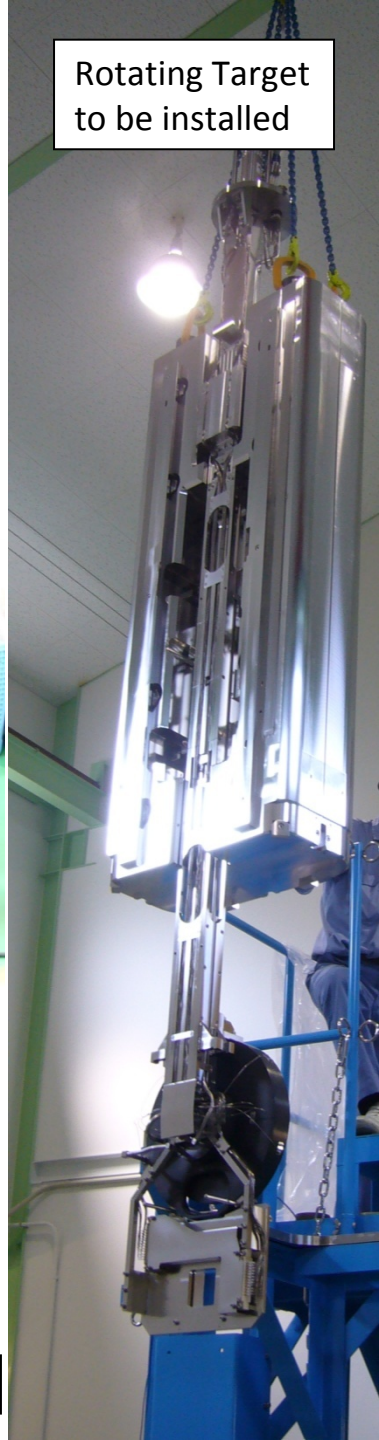


Mock-up with heating and rotating



Rotating Target

Disassemble and Observation



Rotating Target to be installed

Hopefully, Graphite Rotating Target will be installed in summer of 2013.

Development of SiC Rotating Target for DeeMe

DeeMe ~ Muon-electron Conversion Search

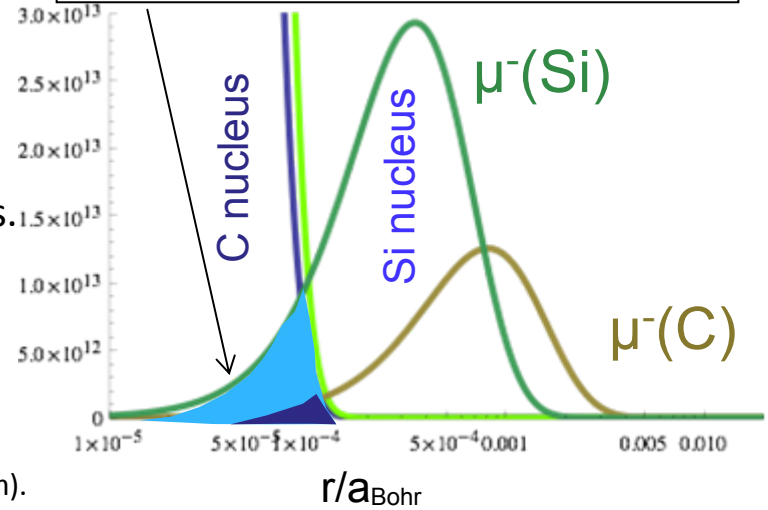
Representative; M. Aoki, Osaka University

$$\mu^- + A(Z,N) \longrightarrow e^- + A(Z,N)$$

- 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).

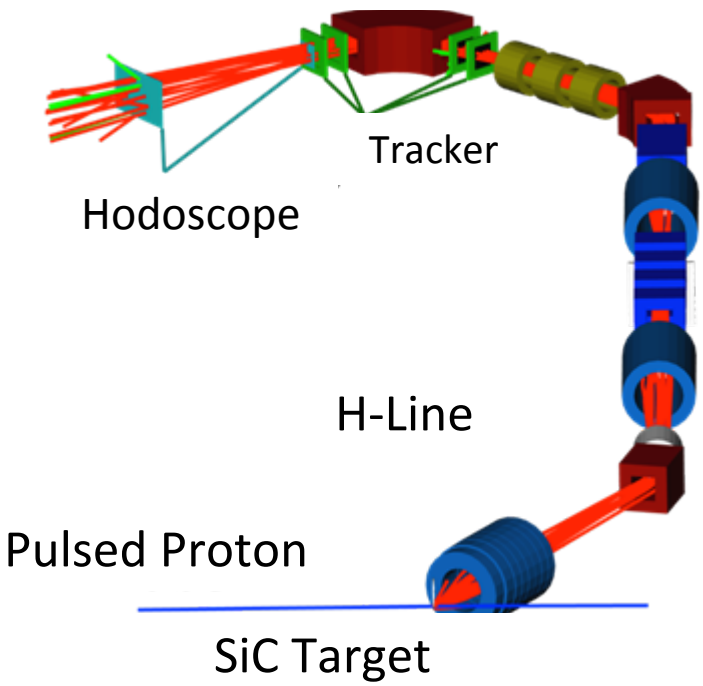
Si → C: 11-times larger overlap

μ^- reaction ε: 8%(C)→67%(Si)



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

Electron Spectrometer



R&D for silicone 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

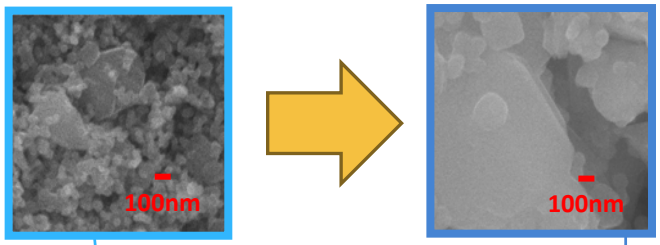
Concept of SiC target for DeeMe Project

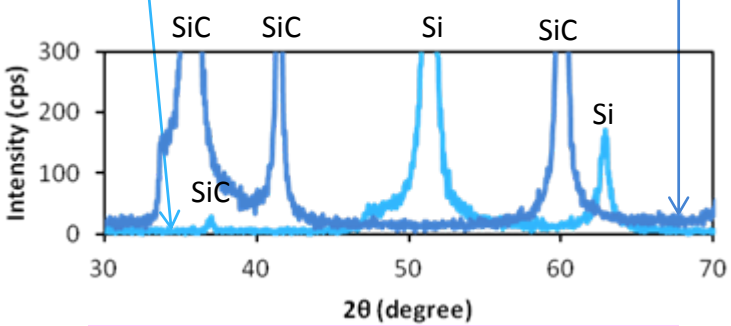
by A. Kohyama, H. Kishimoto and C. Kanda
(OASIS, Muroran Institute of Technology)

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

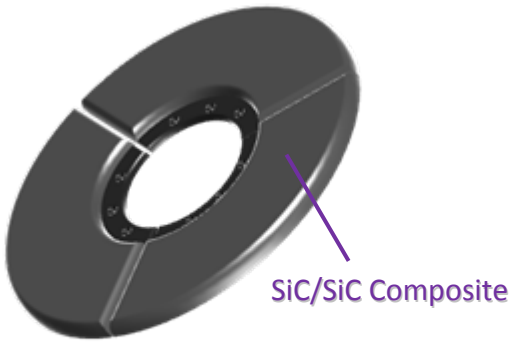




High purity SiC are progress

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

The Conceptual Image of The Prototype "DeeMe" Target Upgrade



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

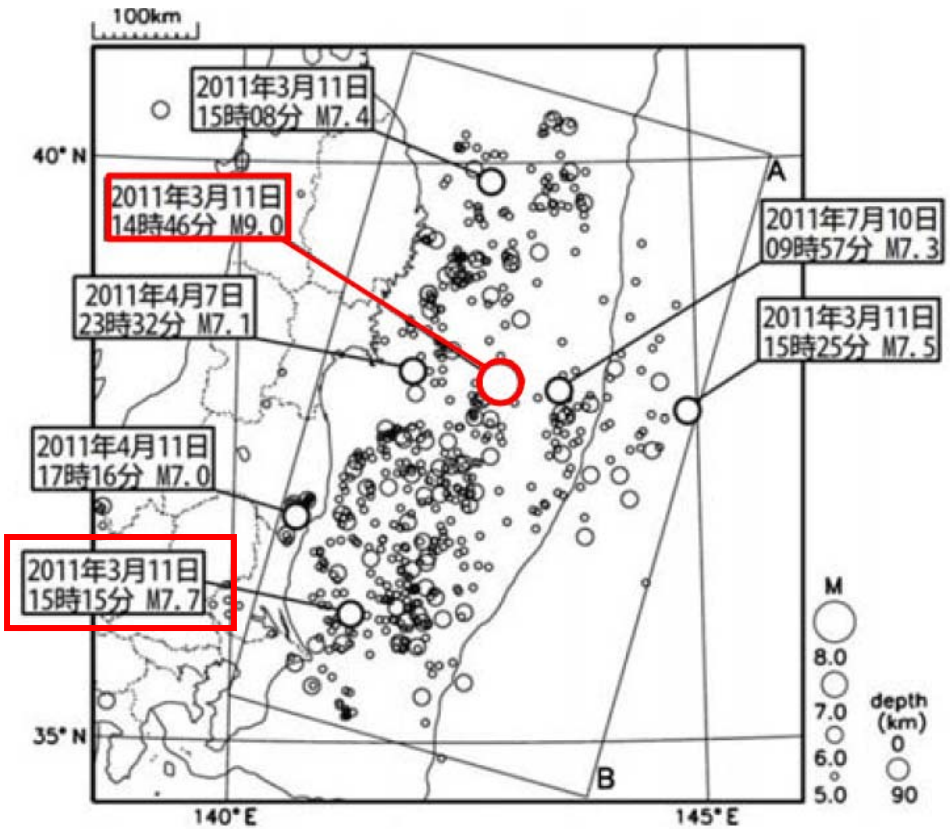
Summary of MUSE & Muon Target

- In J-PARC/MUSE, various Physics Researches are in progress with using the world strongest pulsed muon beam.
- Muon fixed graphite target was installed and has been operated successfully.
- Muon target can be replaced by remote handling.
- Graphite and SiC rotating targets have been fabricated.

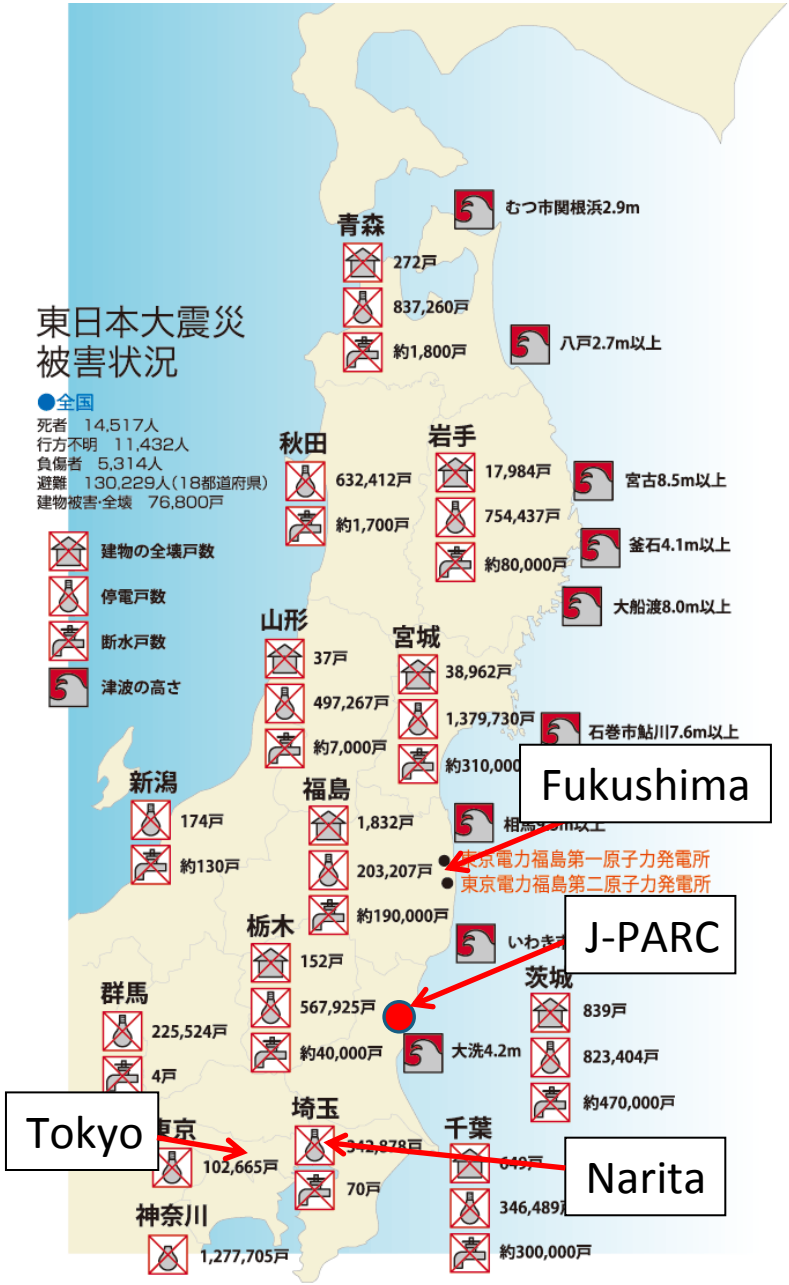
Contents

TOHOKU Earthquake in my case

At 14:46 JST on March 11, 2011, a magnitude 9.0 earthquake - now known as the Great East Japan Earthquake - struck off the pacific coast of Japan.



Report from Cabinet office, government of Japan



Report from Reconstruction Agency

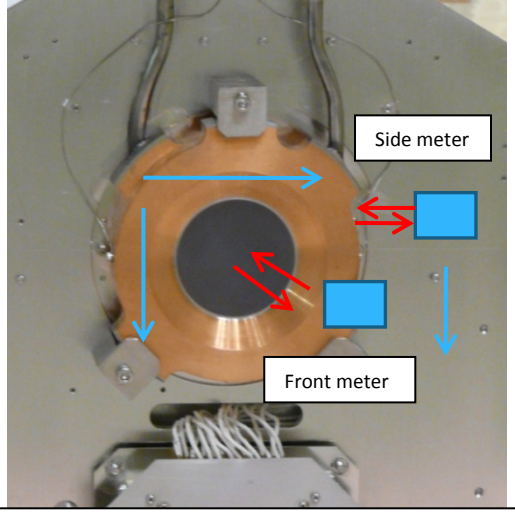
Life just after the earthquake

Damage at My Facility

Check of Target position

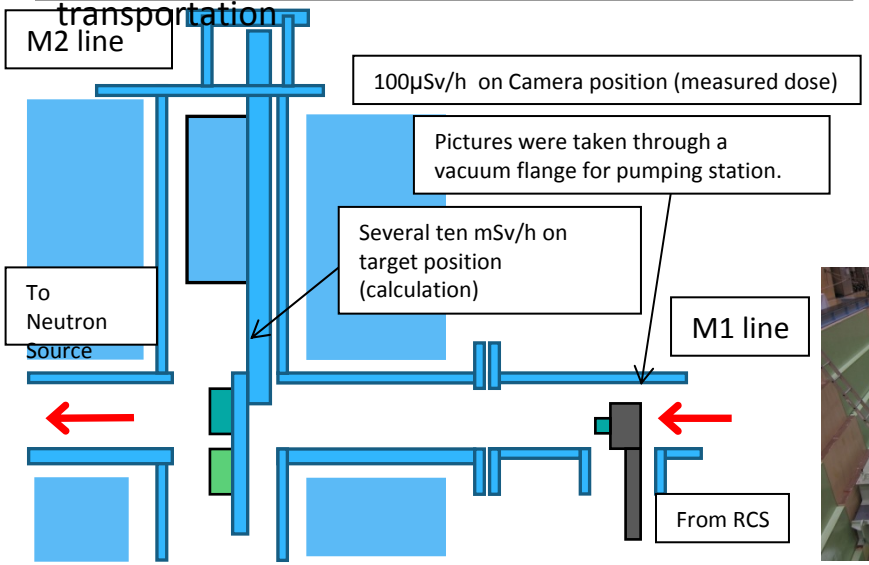
Measurement in Hot cell

After the tremendous earthquake, the status of the target had to be confirmed. Measurement of Target position was performed. (Check of the distortion by the Earthquake)

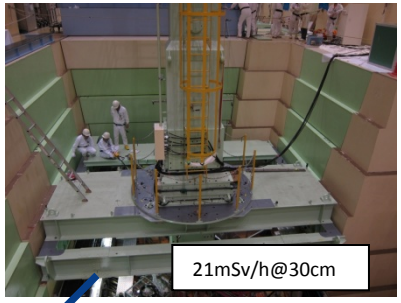


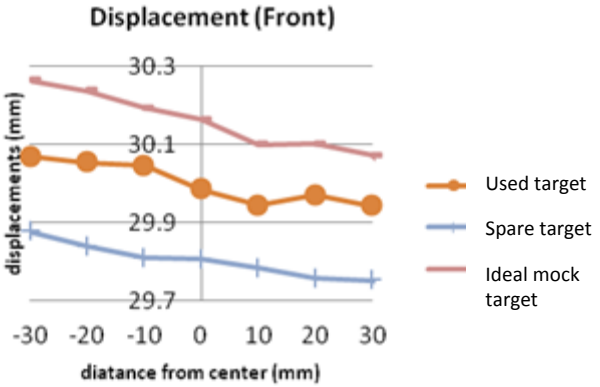
Measurement by Laser displacement meter

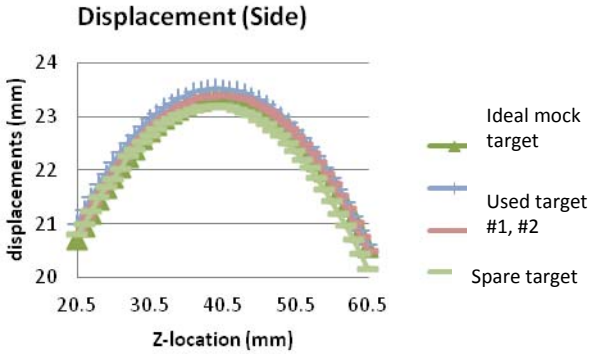
Preliminary check of position before transportation



Muon Target on the center of vacuum duct







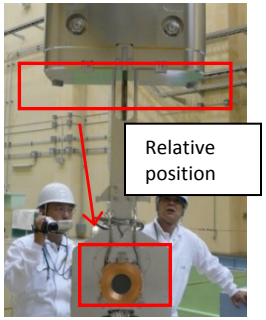
☐Measurement of Target position

Originally the muon target was relatively located within ±0.5mm precision to the pins of the target chamber in the beam line.

Resolution; Below ±0.1mm

Results; ±0.2mm

It was confirmed the target could be used continuously.



Summary of Restoration from EARTHQUAKE

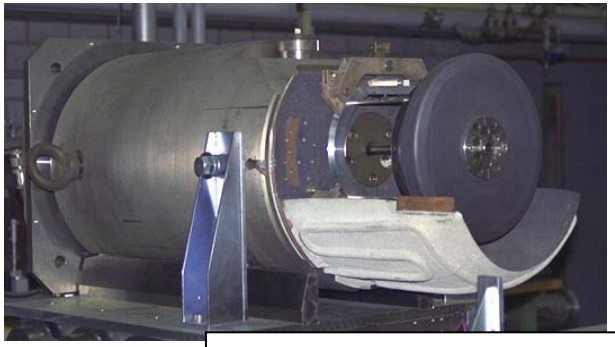
- On March 11, 2011, a magnitude 9.0 earthquake - struck off the pacific coast of Japan.
- The distortion of muon target by the earthquake was measured and confirmed it's enough small.
- By hard working, the accelerators of J-PARC were recovered by December of 2011 and beam is now reaching experiment area.
- We would like to thank all of you who has been encouraging and supporting J-PARC and would like to ask your continuing support of J-PARC.

Contents

Muon Rotating Target

To distribute the radiation damage of graphite

Learning from, Paul Scherrer Institute (PSI)



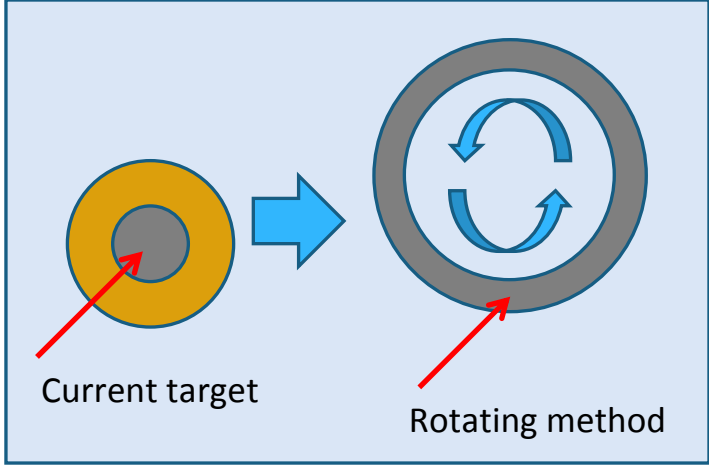
M target

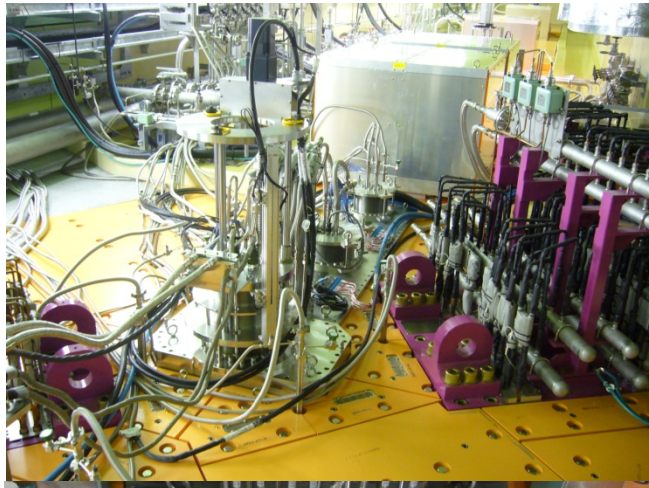
Beam loss is similar to our target. The distance between bearing & target is large. Lifetime; more than 10 years

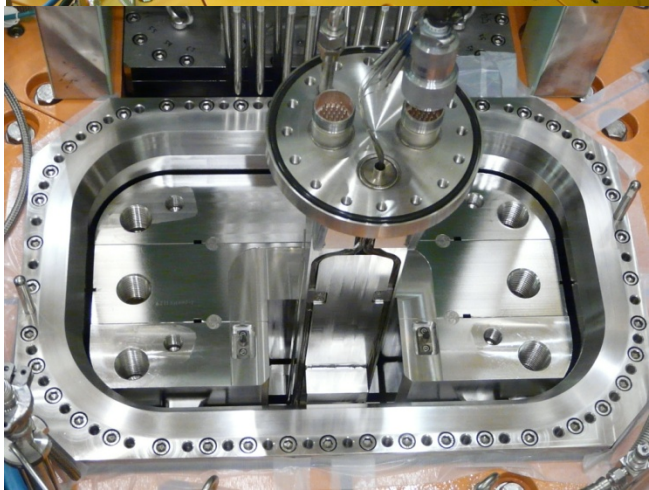
E target

Lifetime; 1 year

G. Heidenreich, Carbon and Beryllium Targets at PSI, Proc.20thICFA Advanced Beam Dynamics Workshop on High Intensity and High Brightness Hadron Beams, ICFA-HB2002, Batavia Illinois 2002, Proc. AIP 642, 122 (2002).







Rotating Target @MUSE

Isotropic Graphite (IG-430)

Thickness; 20 mm, O. D.;330mm, I. D.; 230mm

(Limitation; the rectangular aperture size of radioactive chamber in the beam line.)

Temperature; 610 degC,

Lifetime of the bearing; Critical

Muon Rotating Target @J-PARC

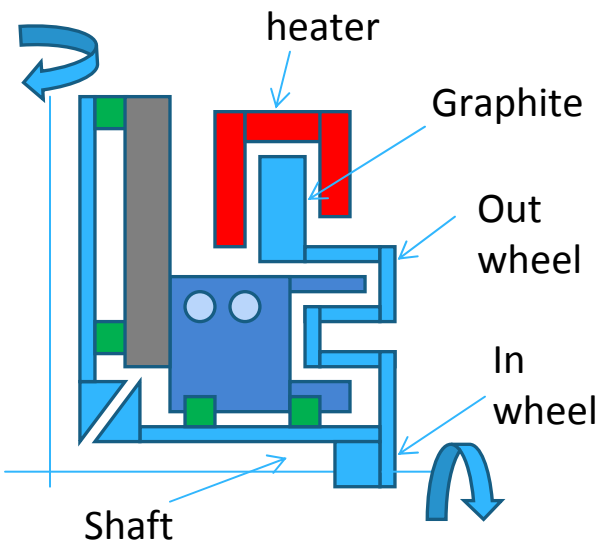
Linear Motion; Target, Monitor, OUT
Rotating body is supported by 2 bearings.
Horizontal shaft, Vertical shaft, Bevel gears

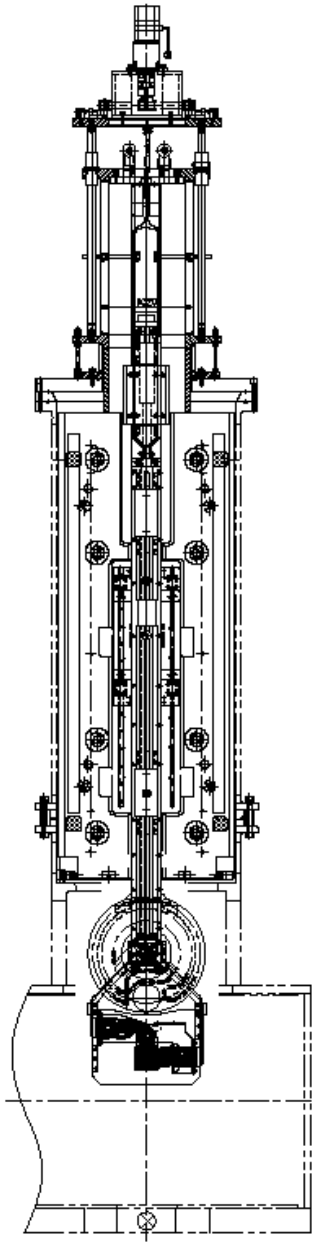
Bearings

Vacuum (10^{-5}Pa)
High temperature (200 °C)
High radiation (10 MGy/year)

Aiming lifetime;
10 years (0.5 year by fixed target)
45 million revolutions
(assuming 5000hours/year, 15rpm)

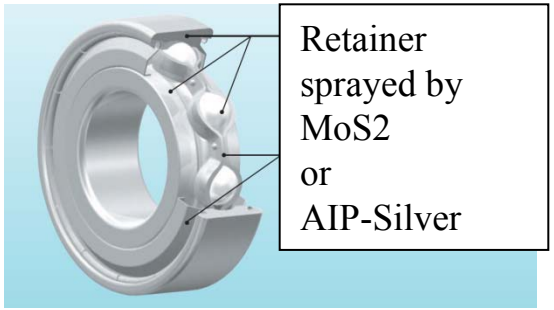
EXCEV Bearing (JTEKT Co., LTD)
- Rings, ball; SUS440C
- Outer diameter; 40mm
- Inner diameter; 17 mm
- Thickness; 12 mm

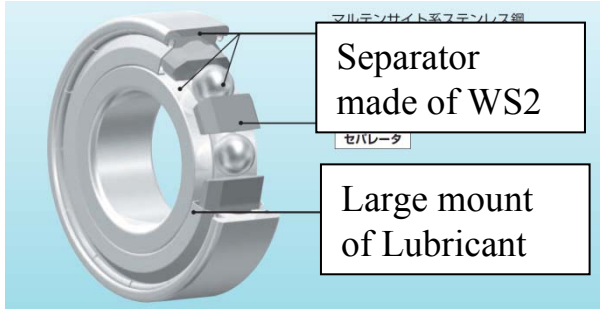




Bearing & Solid lubricants

	Type	Temp. (degC)	Pressure (Pa)	Radiation	Speed (rpm)	Storage	Lifetime (hour)
MoS_2	Retainer	<300	10^5 to 10^{-5}	general	<500	air	3300
WS_2	Separator	<350	10^5 to 10^{-5}	few	<210	air	330000
AIP-Ag	Ret.-AIP	<350	10^{-3} to 10^{-10}	general	<500	vacuum	17000





Captured from
JTEKT(KOYO) Catalog

MoS_2; For evaluation of Mock-up

WS_2; Hopeful candidate

Few utilization under radiation

AIP-Ag; Stable candidate

Storage problem

Comparison and measurement of the lifetime

Evaluation of Lifetime AIP-Ag

$$L = b(1.5\times10^{-3}n+1)\left(\frac{C}{13\times F}\right)\times16667/n$$

n; rotating speed (r.p.m.) 5r.p.m.

F; Radial load 33N

C; Allowable load [N] 8120N

b; Factor by Circumstance; 0.3 (10^{-3}Pa, 300degC)

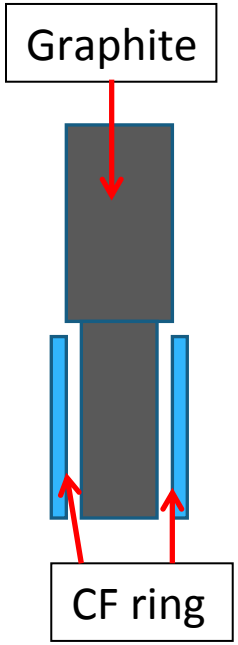
Assuming 5000hours/year

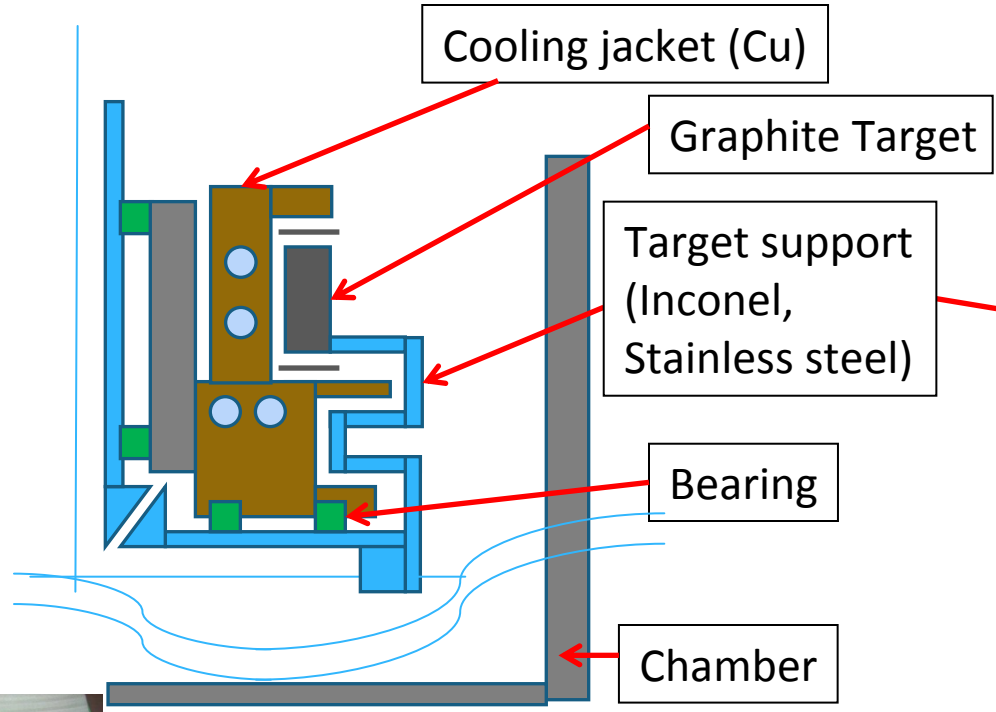
L=17400 (h) =**3.5 (year)**

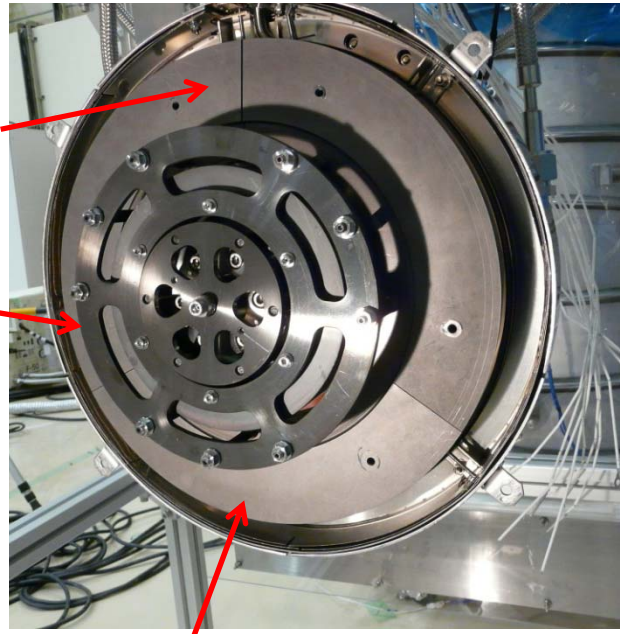
Main Components & Analysis

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

Bearings, Cooling jacket, and Chamber

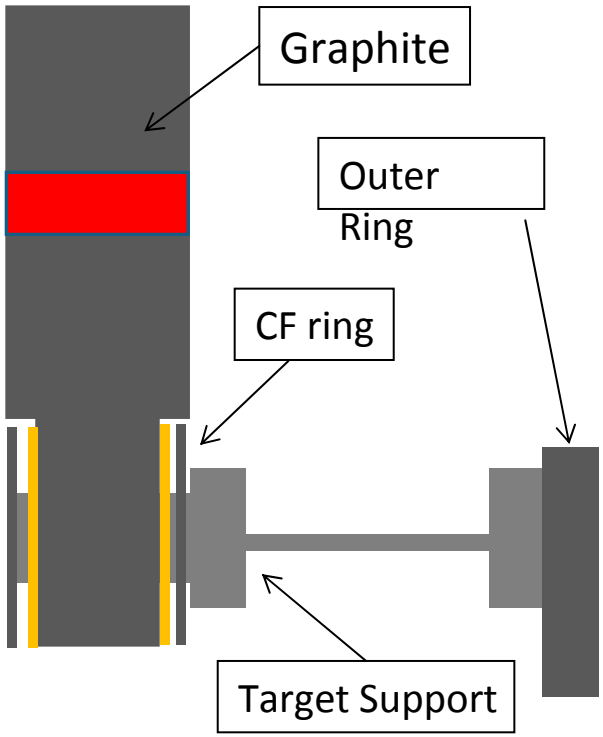






To extend the lifetime of bearings, the temp. of bearing should be as low as possible.
Maze structure of target support

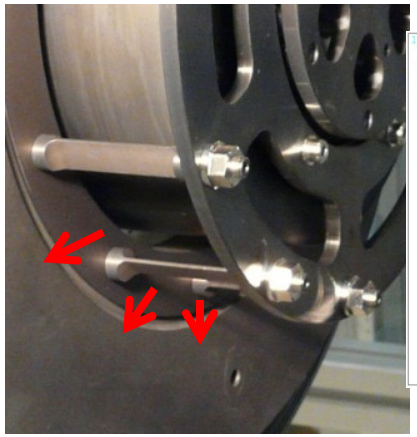
Thermal Stress

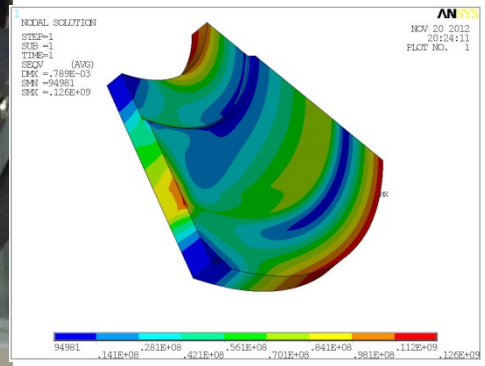


Temperature-Difference

- **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.





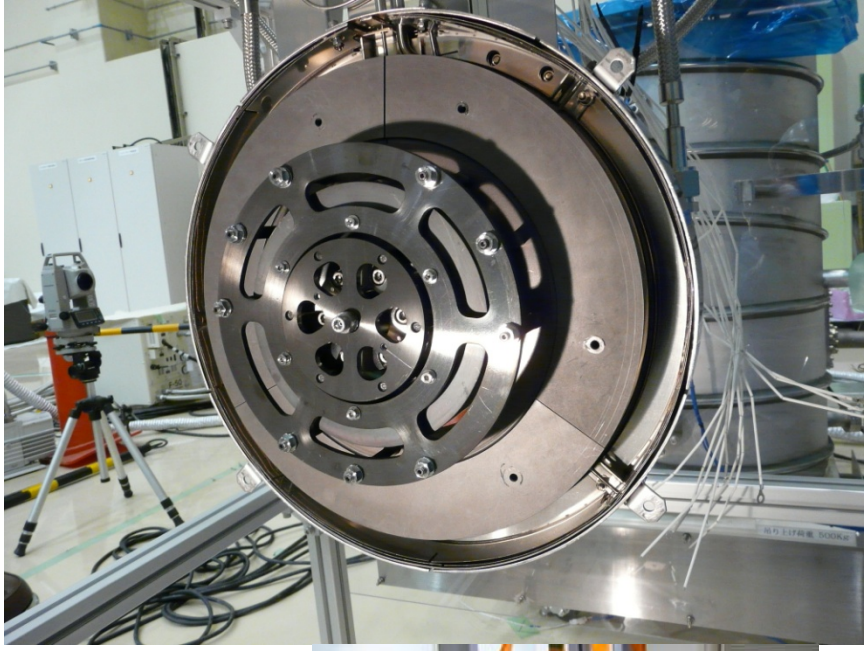
3-Dimensional, Thermal radiation & Transient Analysis
Approximate Temperature-distribution for whole modeling by Finite Difference Method on Microsoft Office Excel

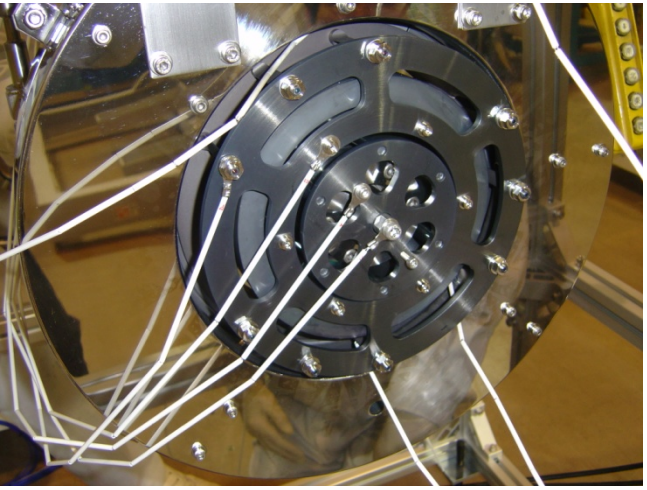
Thermal stress for respective components by Finite Element Method, ANSYS, etc.

Fabrication of Mock-up

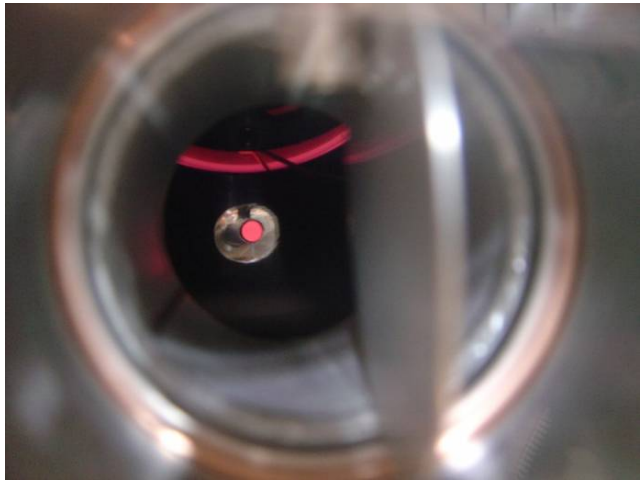
Heating test
  Horizontal shaft; 140 °C
  (Numerical simulation for beam line;120 °C)
Rotating test; 200rpm ~500rpm
  (Actual rotating speed; 15 ~ 20 r.p.m.)

Purpose
Durability tests of Bearings
Improvement for structure of the target
Development of Measuring system





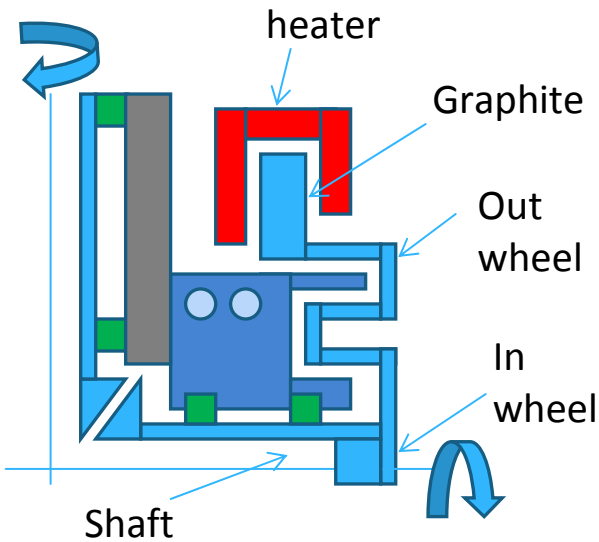
Entire heating



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

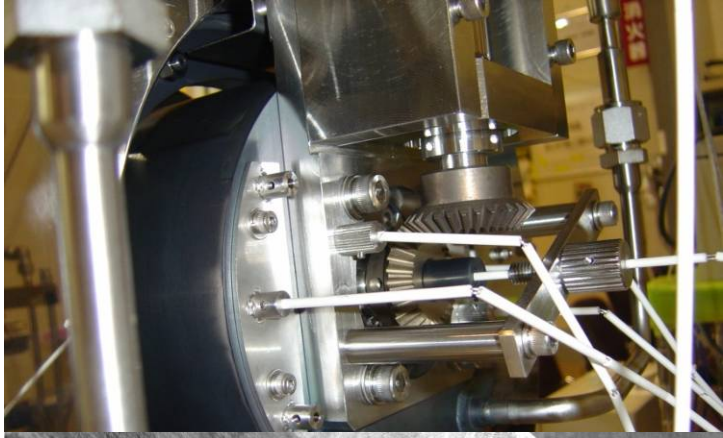
Anelva 954-7606, **Magnetic clutch**
Maximum torque; 5.3N□m
Allowable rotating speed; 500r.p.m.
Cobalt Magnet, SS304, 440C stainless steel

Bevel gear

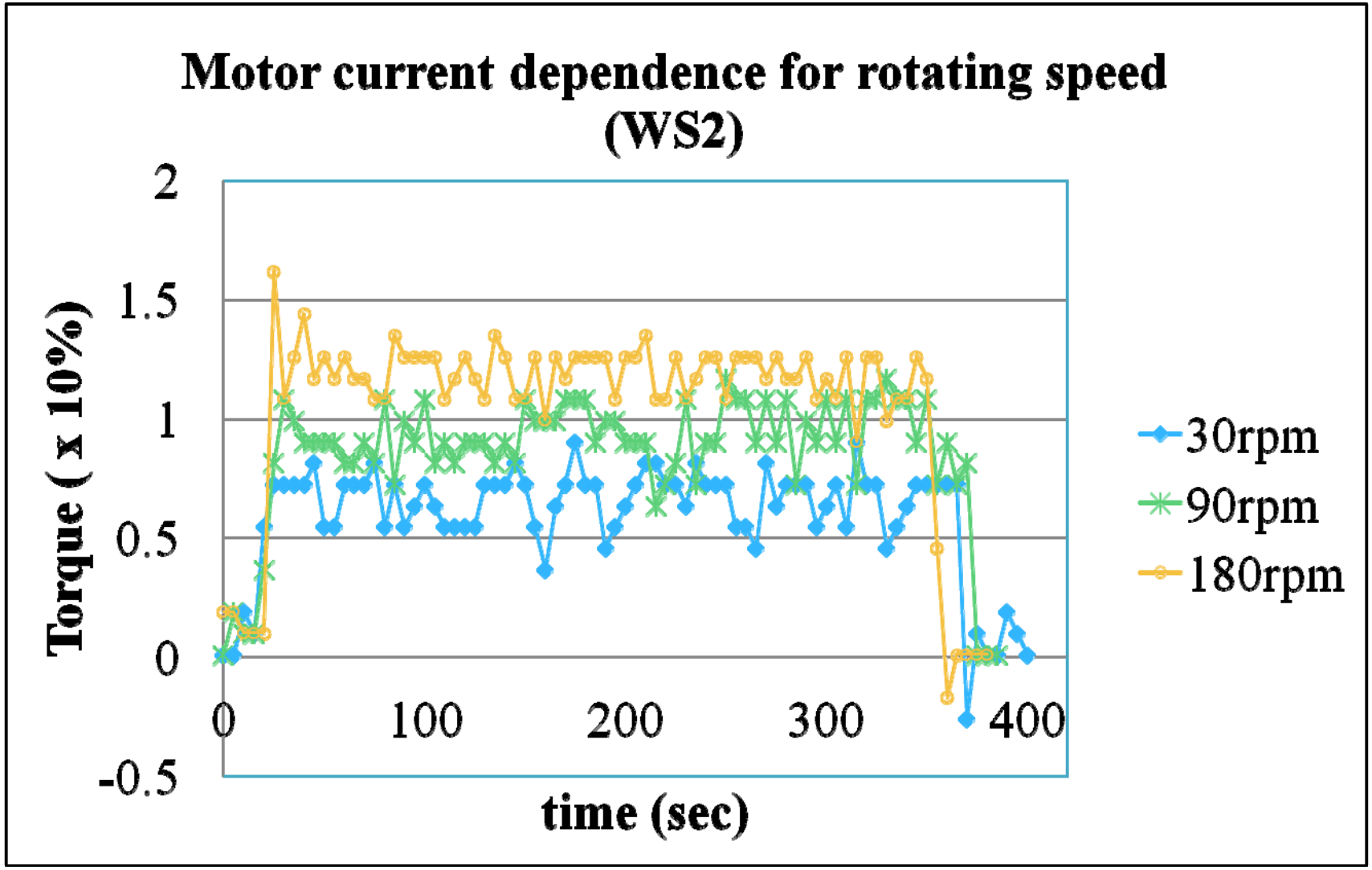
SS440C stainless steel, without lubricant
Load; almost 0 (N) for normal operation
Comparison through SEM;
After and before a long interval test

Radiation-resistant AC servo motor

Wako-giken CO., LTD.
Resolver Encoder
Power output; 60W
Torque; 0.76Nm



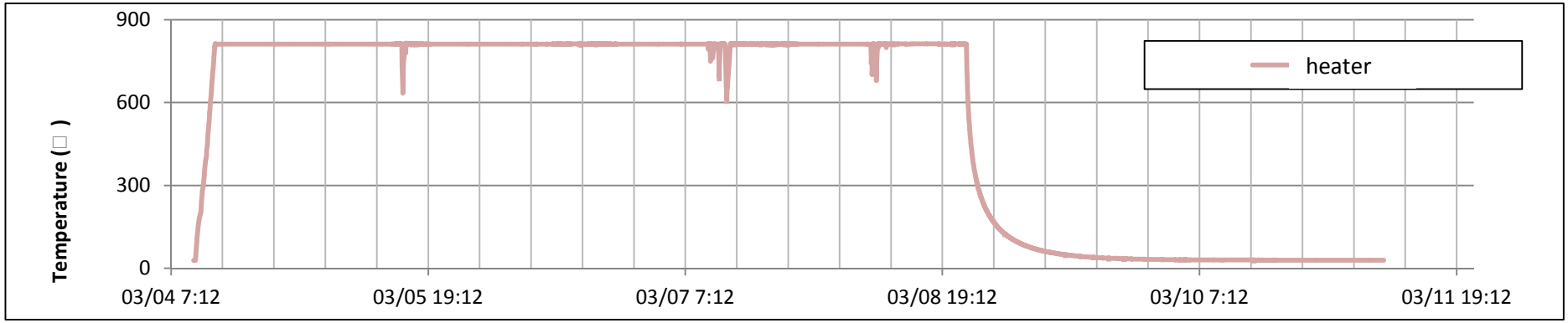
Present Status of Rotating Tests by Mock-up

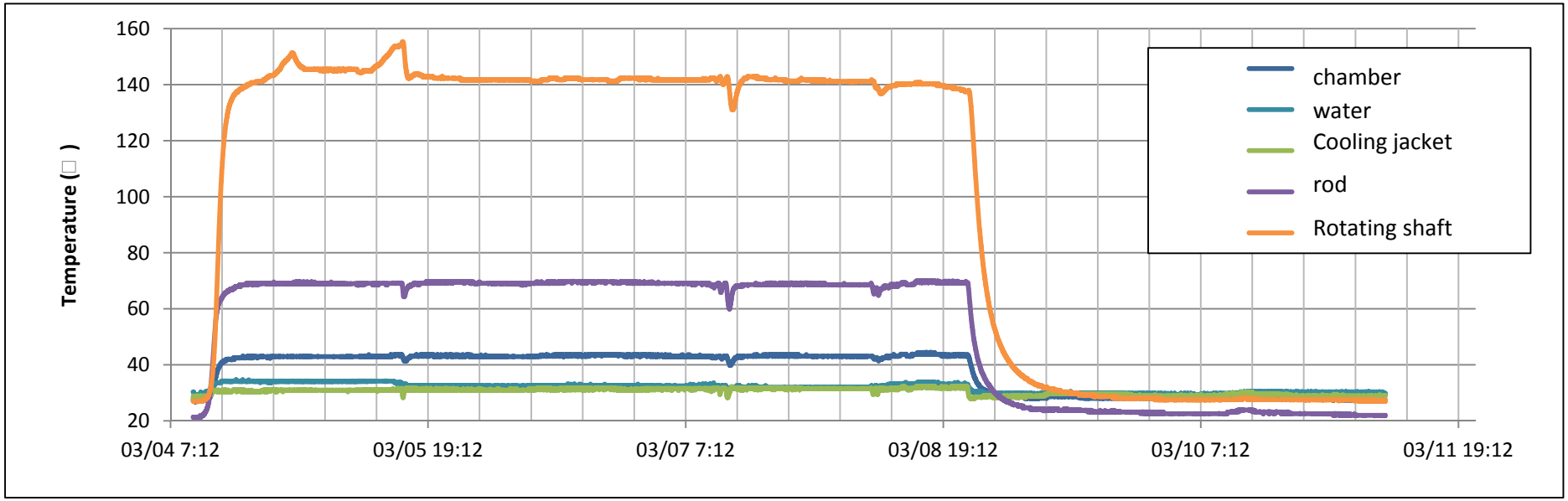


Rotation in 5~500rpm can be performed.

Motor torque can be monitored.

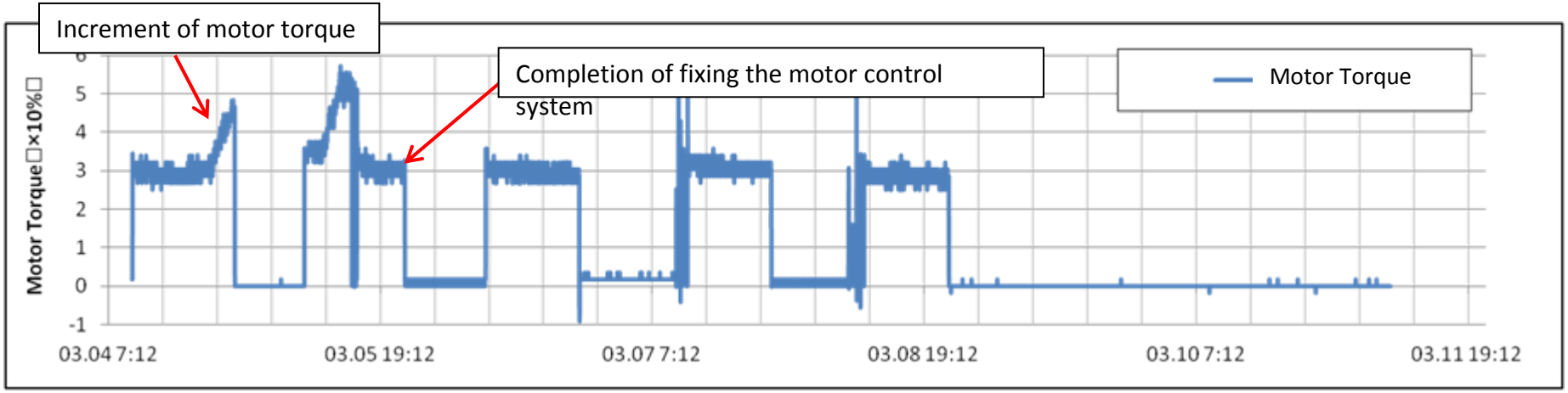
First Continuous Durability Test (5 days)





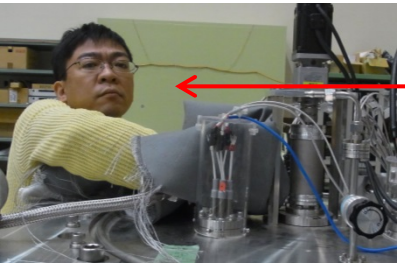
From 4th to 8th March of 2013, we started the continuous durability tests.
Target temperature was measured by an infrared thermometer without logging.
750□□760□; Stable heating.
Continuous operation; sometimes the motor alignment interfered with the heating.

Motor Torque Logging through the Durability Test

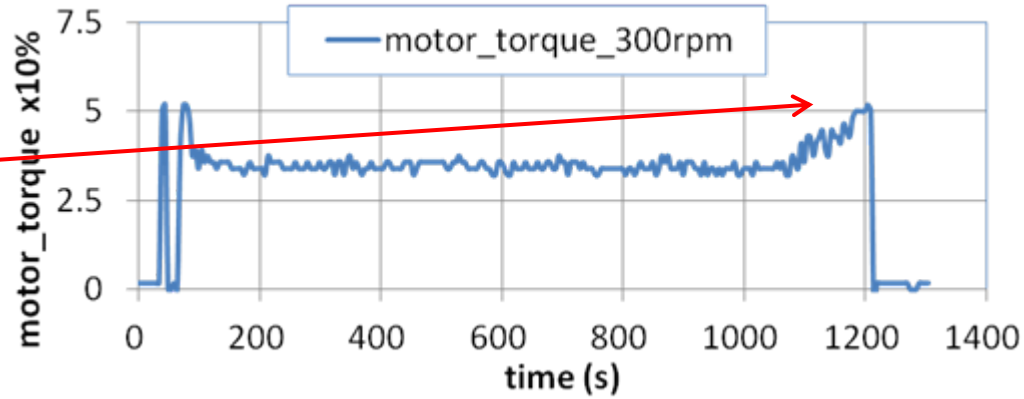


The motor torque increased on the first day.
But the interlock system for monitoring the motor torque was found out to be immature.
The motor was stopped in the midnight.
After the improvement of the interlock system, the motor torque never increased again.

Additional interlock test for motor torque

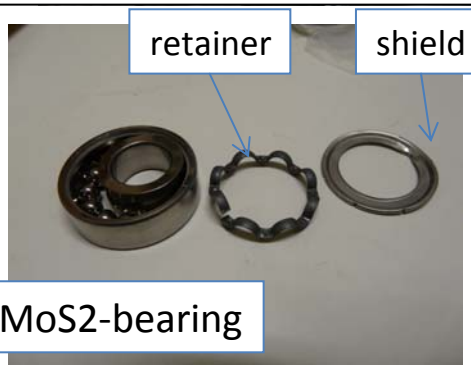


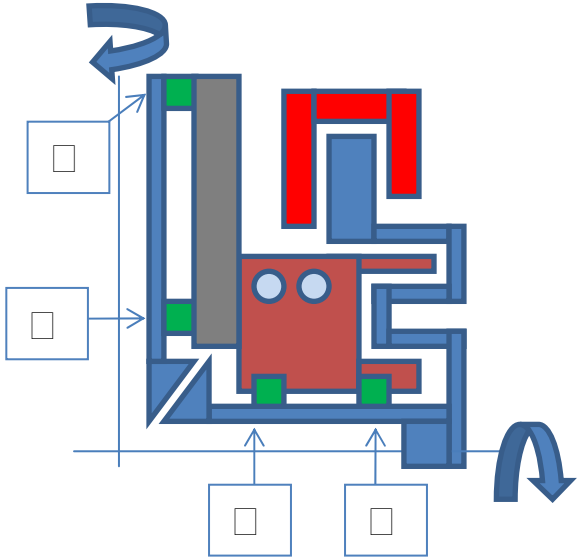
Sensitive Clutch Machine, Makimura

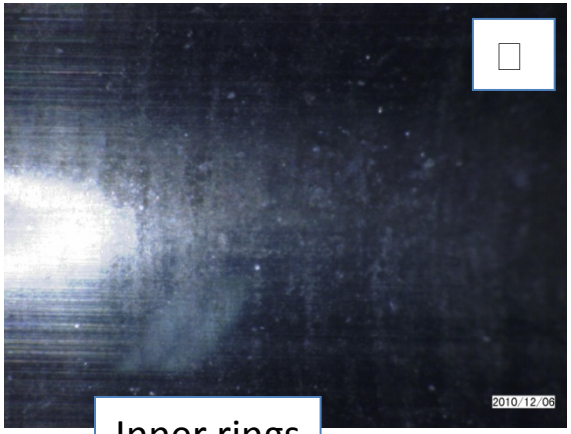


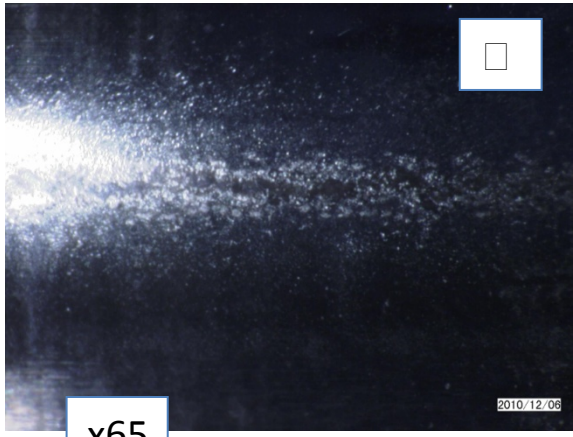
Damaged bearings by heating and rotating test

Durability tests of bearings



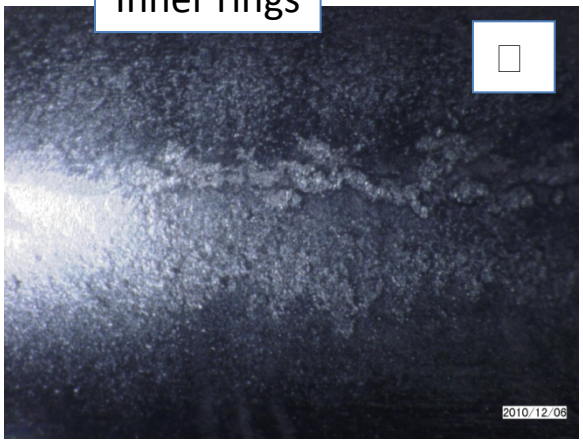


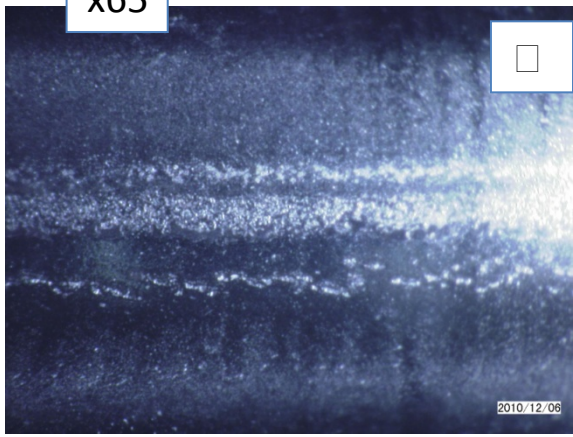




Inner rings

x65





□No damage
□More damaged than predicted
Thermal expansion of the vertical rod, Axial load
□, □ 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).

Contents

Motivation for PIE tests in our case

Lifetime; dimensional change of graphite by proton irradiation

,which depends on the irradiated temp.

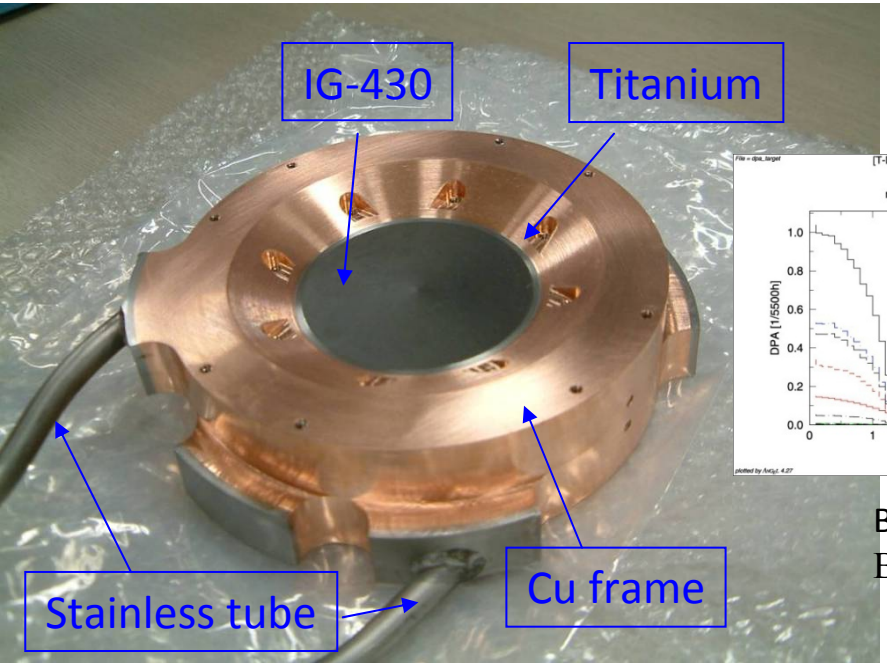
Then, How much is it?

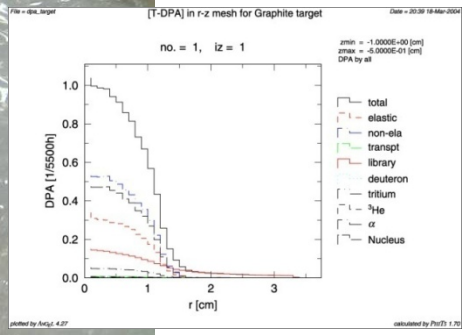
We must guess the thermal conductivity.
The utilized data is obtained at same condition?
We hope to know actual radiation damage.
(Even if the measurement is performed in R.T.)

Domestic conditions in Muon Gr.

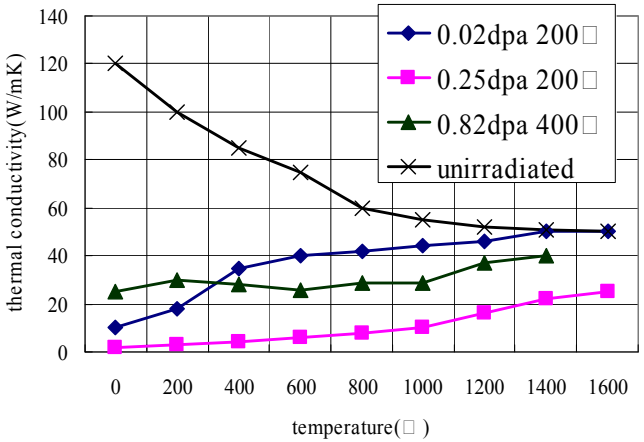
We are Muon Experimental Group, not Muon Target Group.
The Man-power for Muon Target is incredibly small.

- ◆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

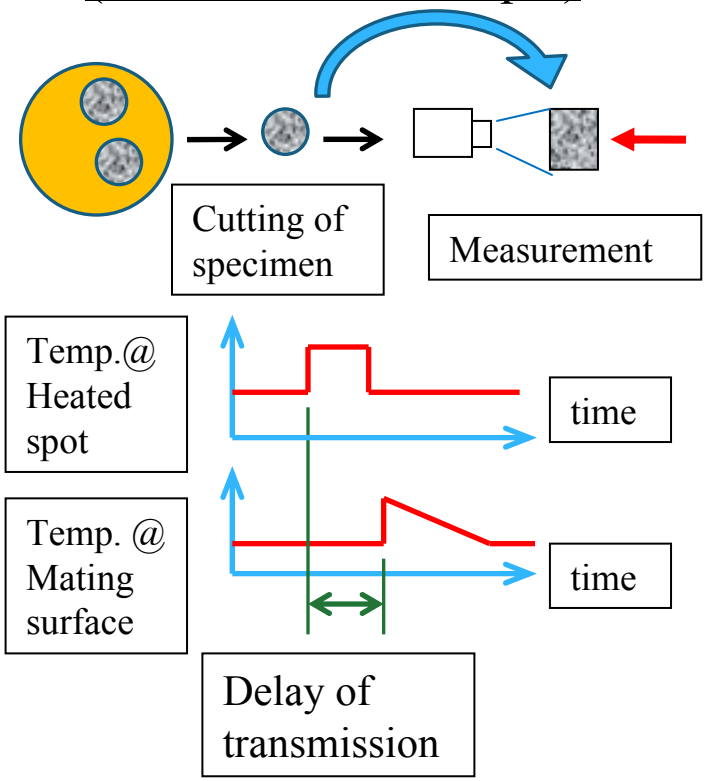
T. Maruyama et al., Journal of Nuclear Materials 195 (1992) 44-50.

Measurement for thermal conductivity of graphite

Thermal diffusivity are measured instead of Th. conductivity.

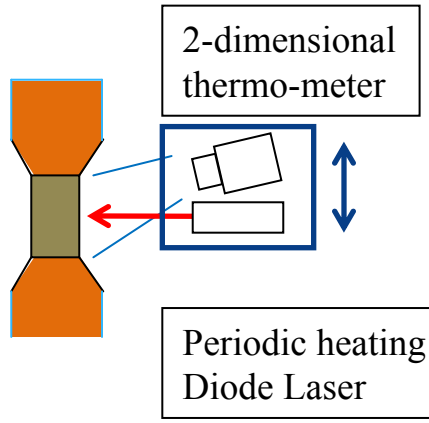
$\lambda = D\rho c$ (λ; Th. Conductivity(W/m/K), D; Th. diffusivity(m^2/s), ρ; Density (kg/m^3), c; Th. Capacity (J/kg/K))

Conventional Method (Laser-flash technique)



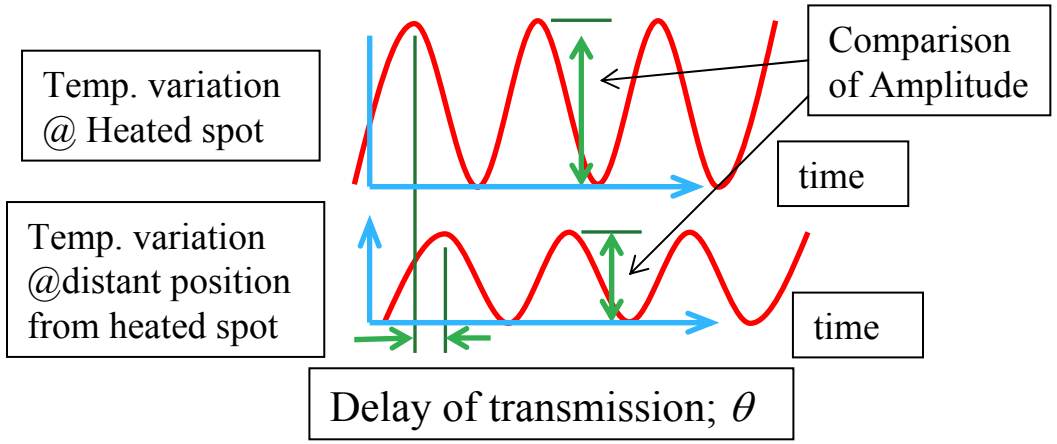
- The target must be destroyed.
- We must consider transportation and the scattered radioactive powders.
- The spatial resolution is limited by sample size.

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

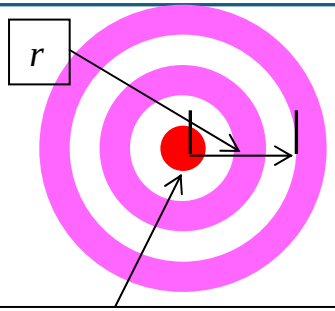
Thermal transport equation

D; Th. diffusivity(m^2/s), ρ; Density (kg/m^3), c; Th. Capacity (J/kg/K))

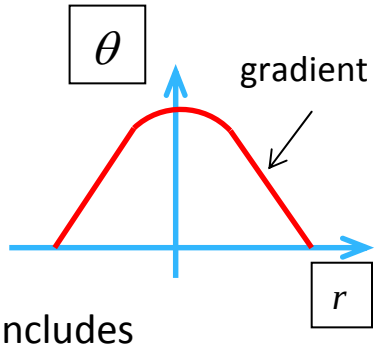
$$T(r,t) = \underbrace{\frac{P}{4\pi Drc}}_{\text{Amplitude}} \exp(-kr + i(wt \underbrace{- kr}_{\theta}))$$

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

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

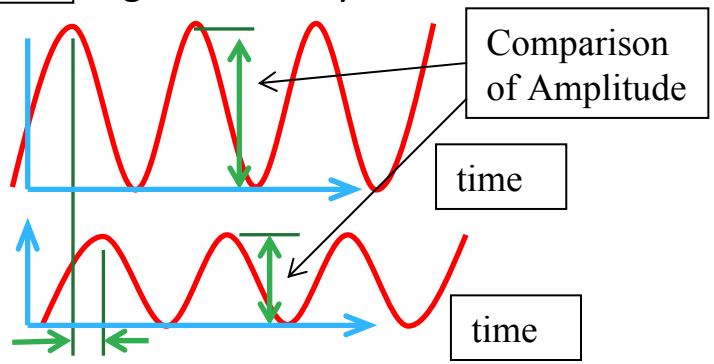


$$\frac{\theta}{r} = -\sqrt{\frac{\pi f}{D}}$$



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

Amplitude includes given heat by laser, *P*



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

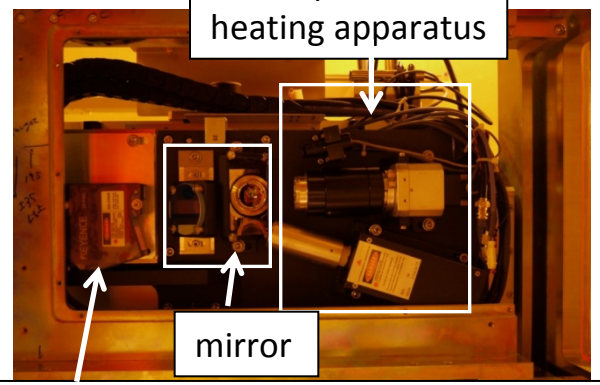
Relative measurements based on an exact Th. Cond., obtained by other technique (Laser flash method).

Un-irradiated Th. Cond. 170W/m/K

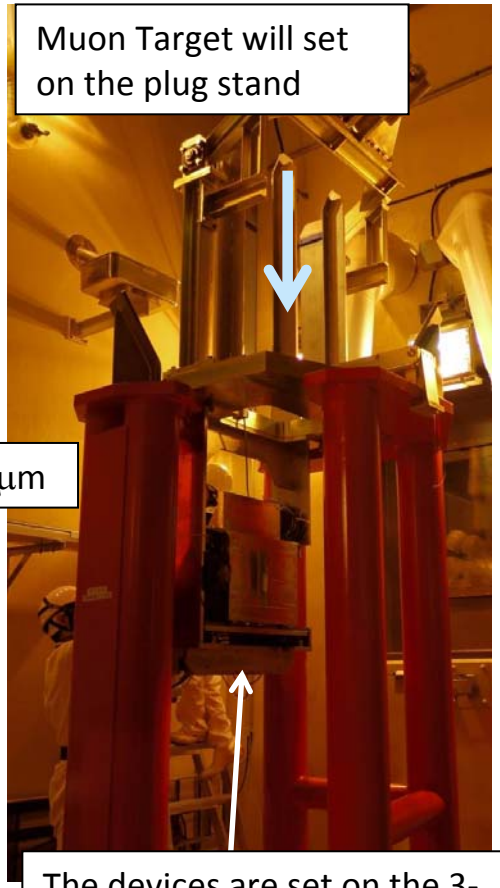
Measuring Apparatus of thermal conductivity

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

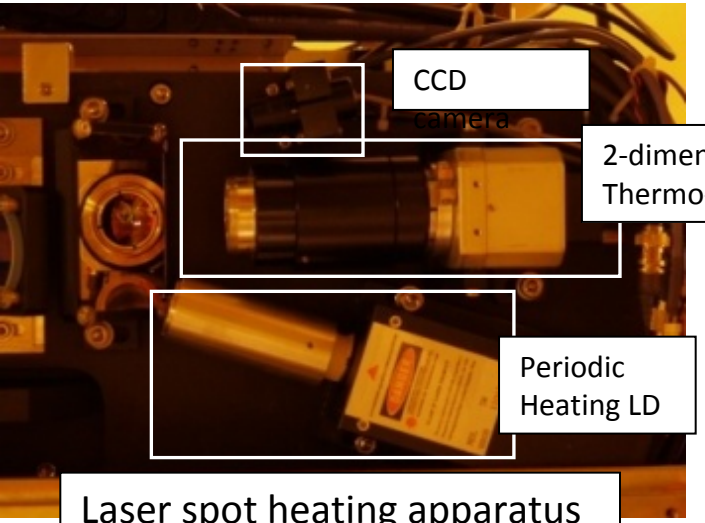
Integrated measuring apparatus is set on a three-dimensional movable stage, which is set on plug stand.
Relative position is confirmed by laser displacement meter.



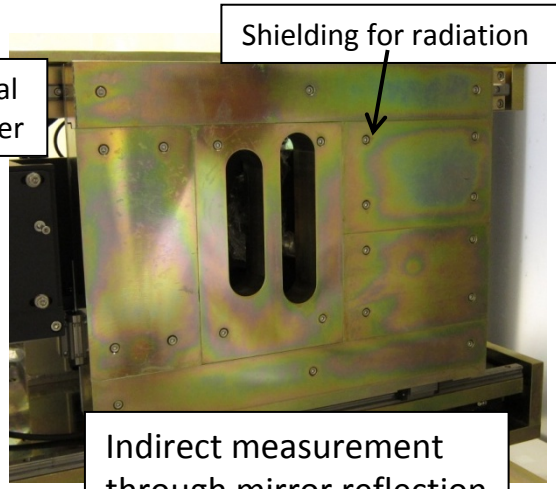
Laser displacement meter; resolution 1μm



The devices are set on the 3-dimensional motion stage. Position resolution; 10μm

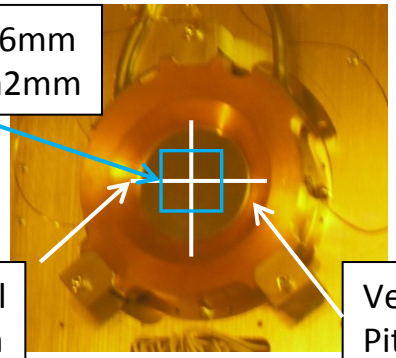


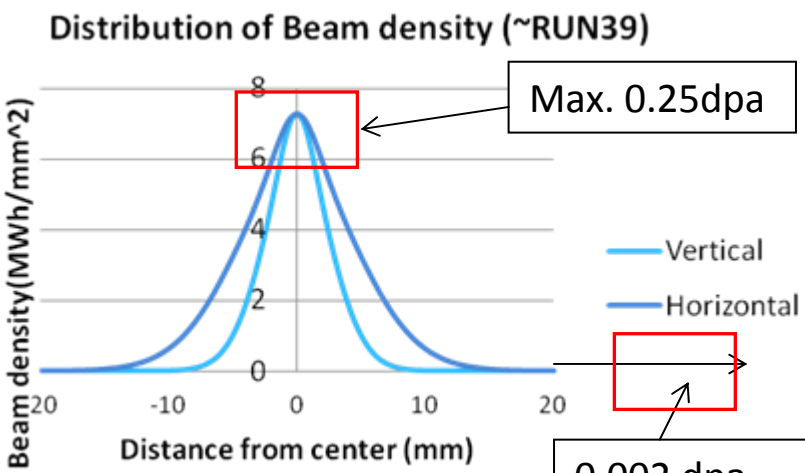
Laser spot heating apparatus



Indirect measurement through mirror reflection

Beam Profile and Anticipated Th. Conductivity

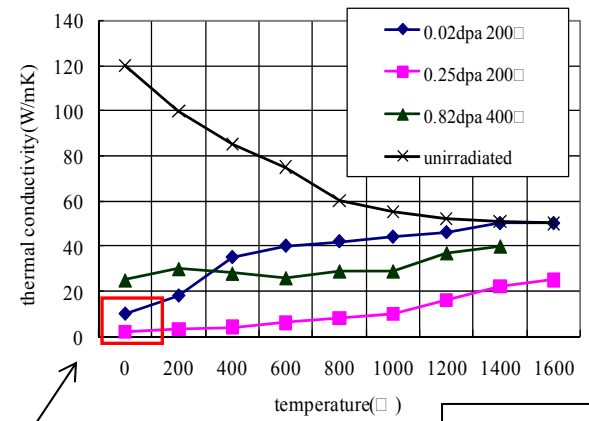




0.002 dpa

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.

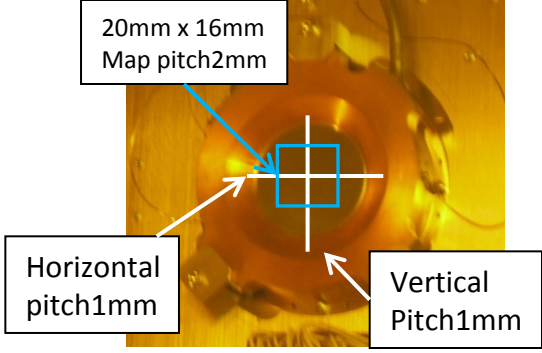
If decrement of conductivity is proportional to radiation dose, the distribution for the thermal conductivity corresponds to the beam profile.

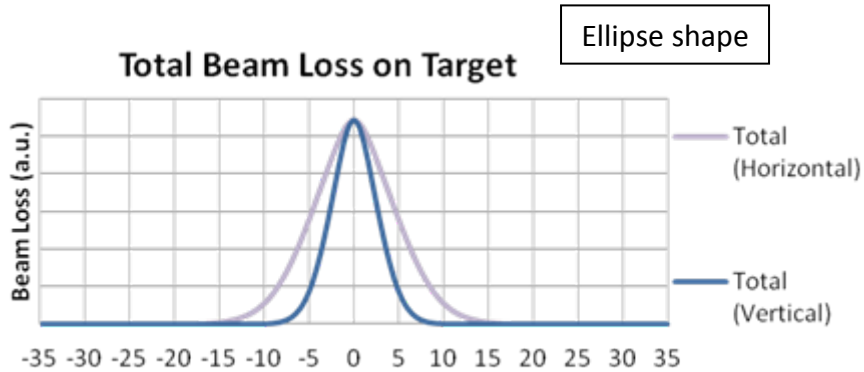
From Simulation
Th. Conductivity can be anticipated,
0.25dpa on center 200degC; 5W/m/K
0.002dpa on edge 80degC; 10W/m/K

Measurement in Hot cell

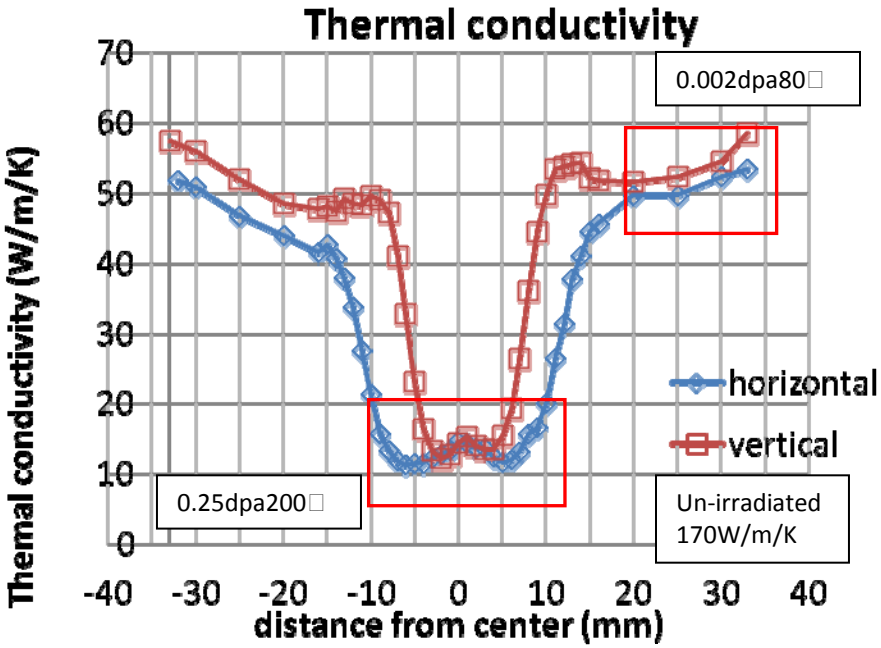
Results

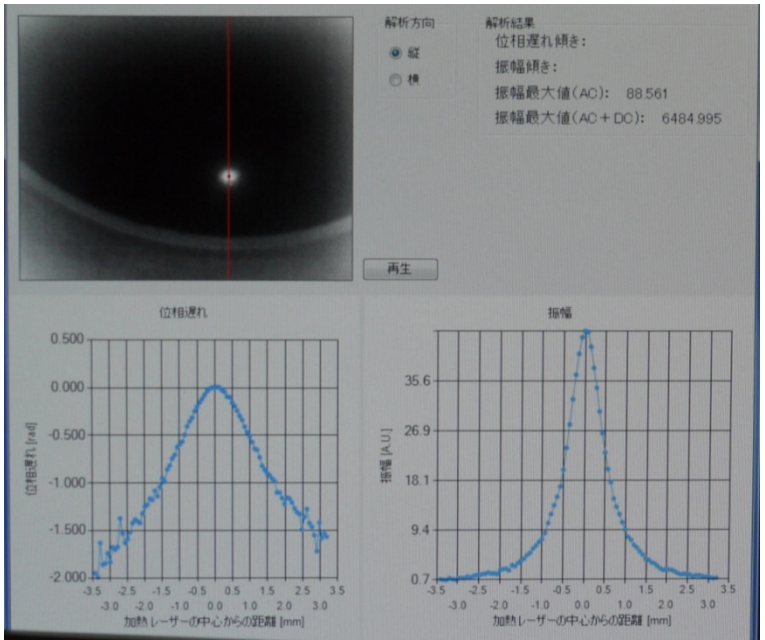
We could observe an annealing effect on the center of beam spot because of high temperature.
The beam profile for horizontal/vertical could be observed.
Thermal conductivity was higher than the prediction.





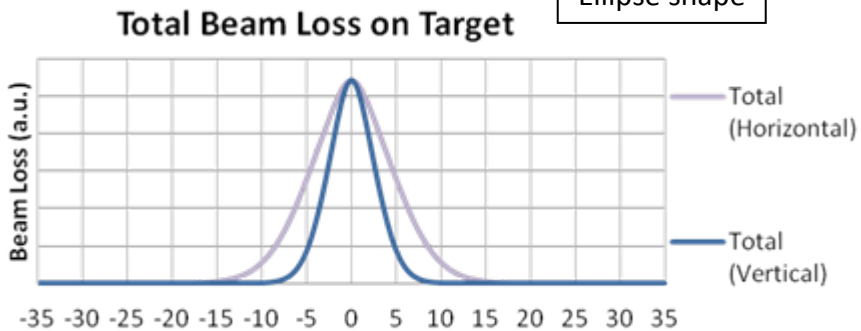
	Rad. Dose (dpa)	Th.Cond. Prediction	Th.Cond. Results
Center of target	0.25 (200 degC)	5 W/m/K	15 W/m/K
Edge of target	0.002 (80 degC)	15W/m/K	50 W/m/K

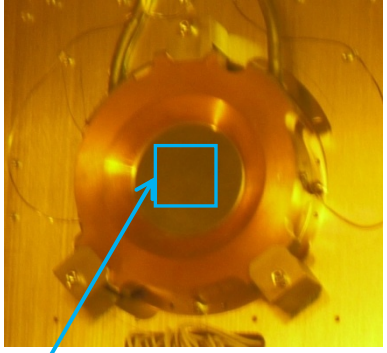




Results (Mapping)

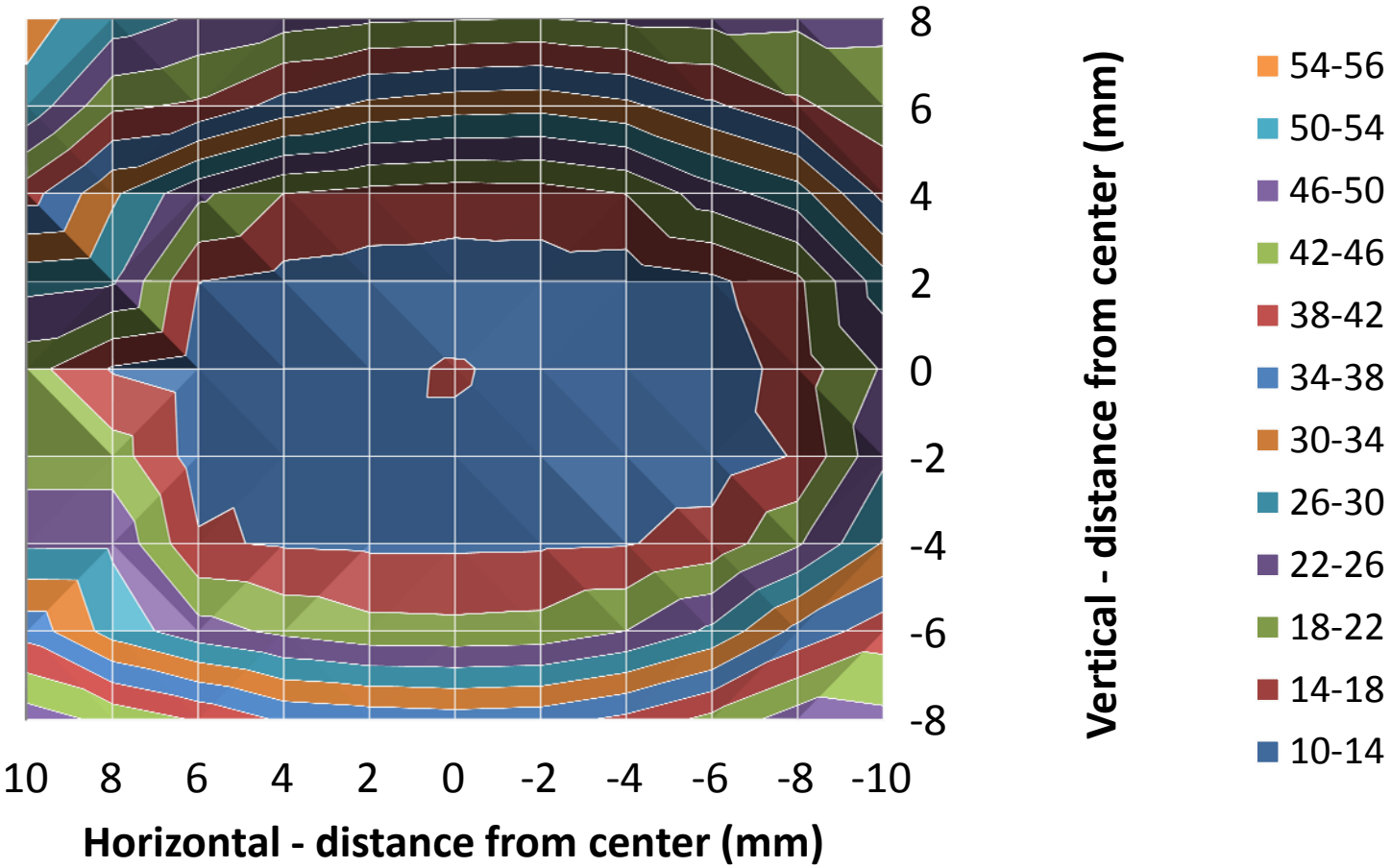
Ellipse shape





20mm x 16mm
Map pitch2mm

2-dimensional map of thermal conductivity



Summary & Future Plans

Advantages of this new technique

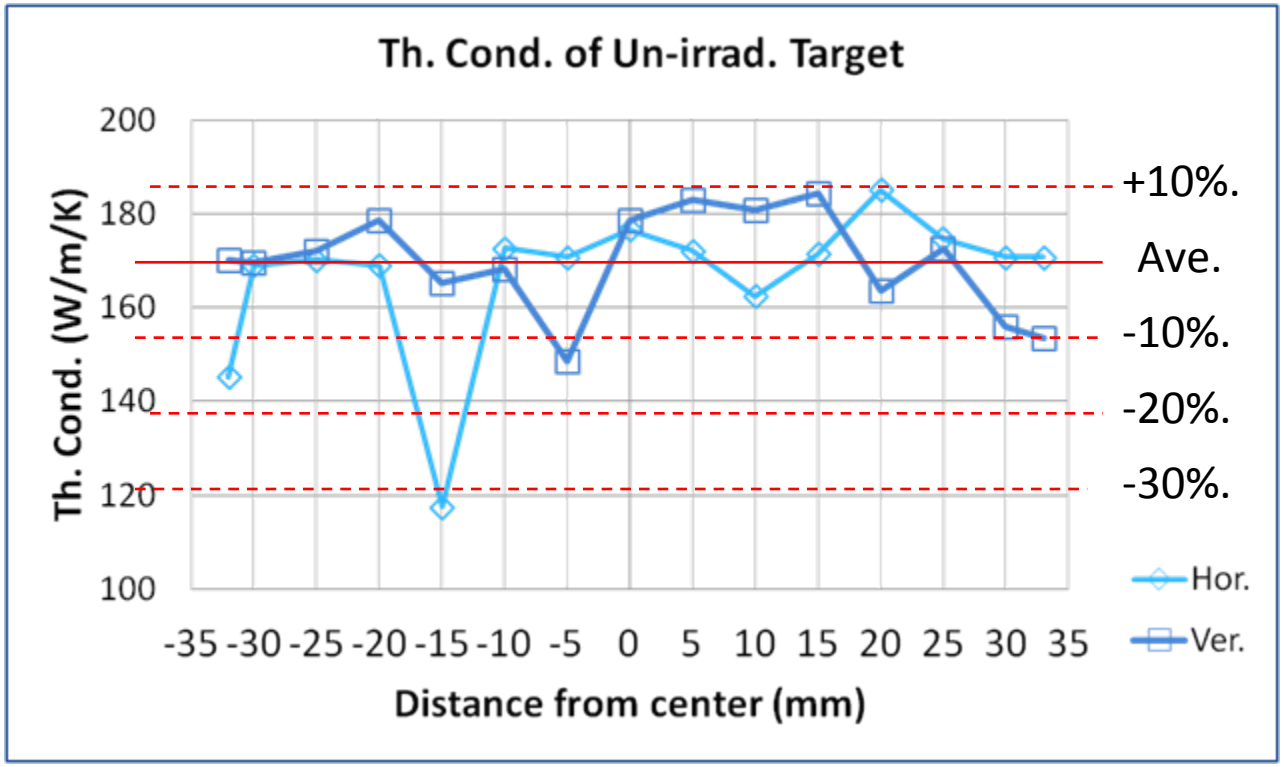
- Non-destructively
- Target can be used again.
- Decreasing nuclear wastes
- High spatial resolution

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.

Thank you for your attention.

Quantitative Performance



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

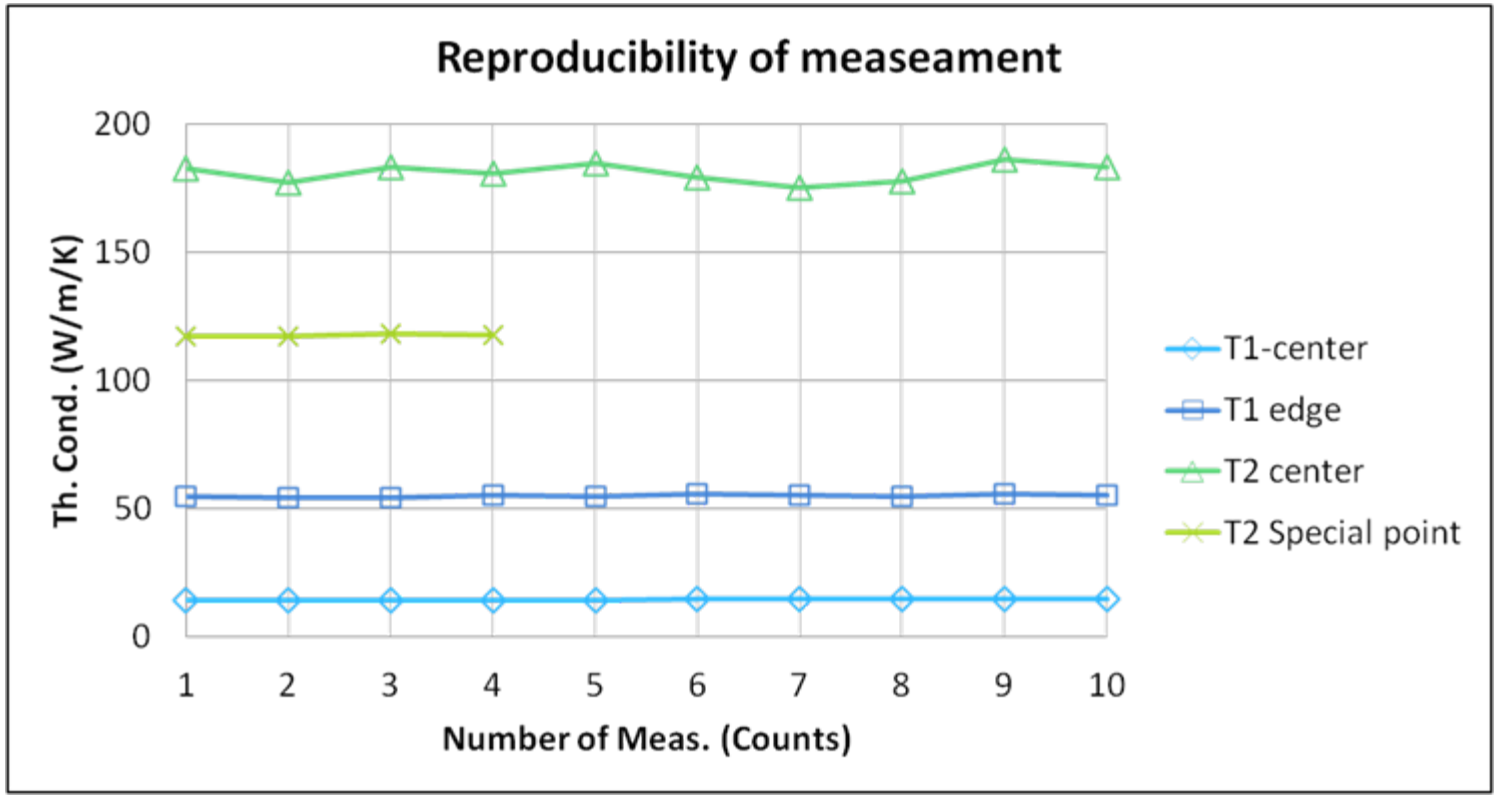
Amplitude includes given heat by laser, *P*

Absorption rate of laser

Surface condition

Etc.

Reproducibility of Measurement



Used target #1

Center~ error; less than 2% Edge~ less than 2%

Un-irradiated Target #2

Center~ less than 5% Specially different position; less than 1%

Reproducibility is less than 5%

Spatial Resolution

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

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

λ ; Thermal diffusion length

Spatial resolution is determined by thermal diffusion length.

Center of Target #1, D=1x10^{-5} m^2/s, f=1 Hz, then, λ=1.7mm
Center of Target #2, λ=3.6 mm

From observation of results,
Spatial resolution is less than r=2mm

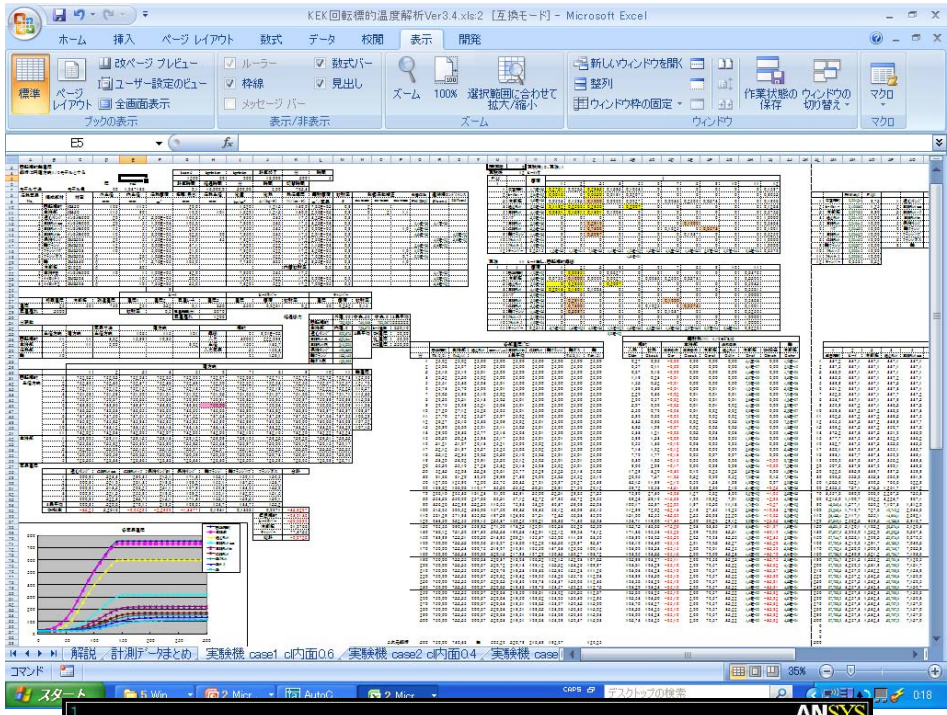
Future Plans

To improve quantitative performance, D must be evaluated by not amplitude but delay of wave-propagation θ.

Cost and Performance with
higher speed 2-dimensional thermo-meter

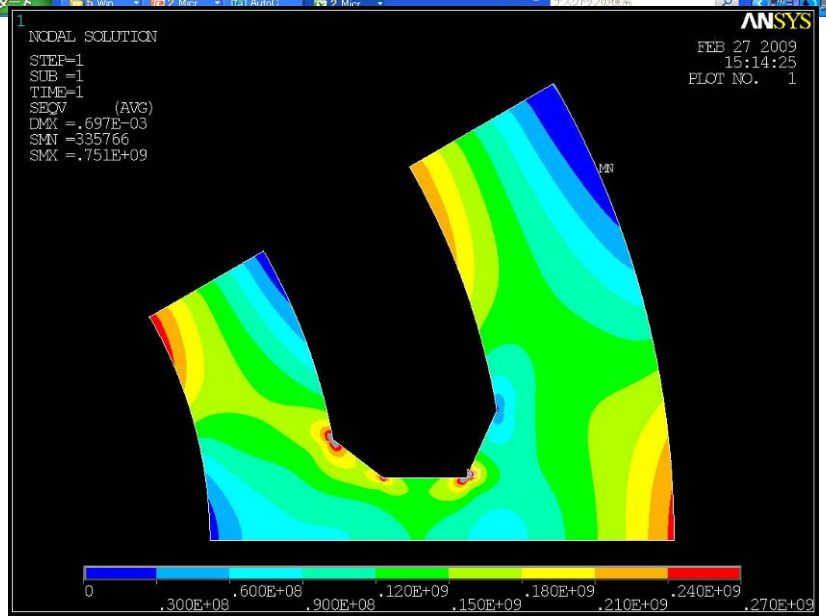
	f; Laser	Sam. Rate IR cameta	Th. Dif. Length	Thermal diffusivity	Costs of Thermo-meter
This measurement	1Hz	30Hz	3.6mm	Relative	1.7MJY
Next measurement	100Hz	10kHz	0.4mm	5 W/m/K	10MJY

Simulation for temperature distribution, Thermal stress



Temperature distribution

- ➢Numerical simulation by Excel VBA
- ➢Total model
- ➢Thermal radiation and conduction, (Emissivity, View factor, Reflection)
- ➢Rotating speed



Thermal stress

- ➢Analysis by FEM
- ➢Partial model
- ➢Results from temperature distribution by VBA are introduced to the analysis.

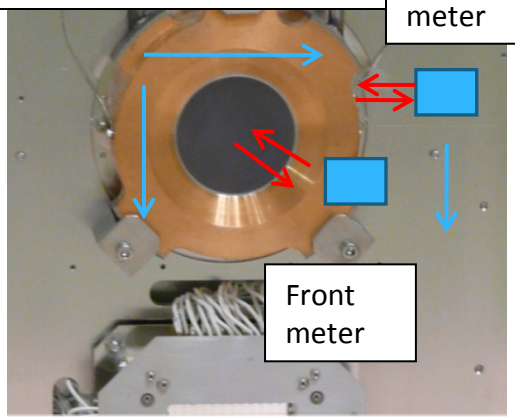
Commissioning in Summer, 2011

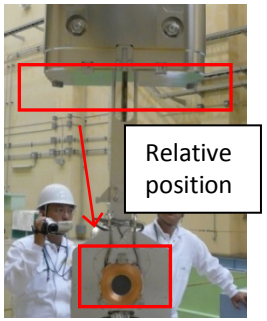
Measurement of Used Target position
(Check of distortion by Earthquake, performed with PIE)
Originally the muon target was relatively located within
±0.5mm precision to the pins of the target chamber in the beam line.

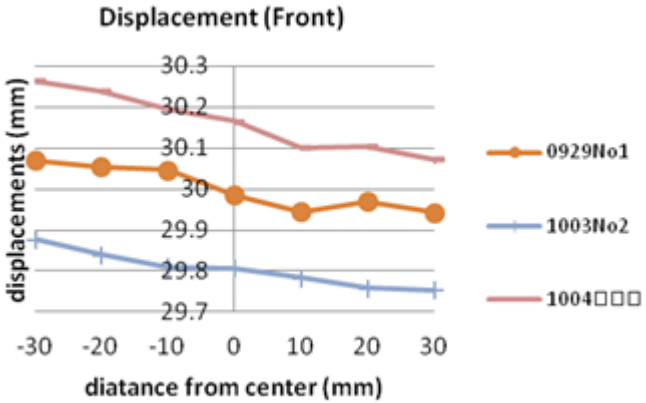
Position of the used target were compared with a spare target and an ideal mock target.

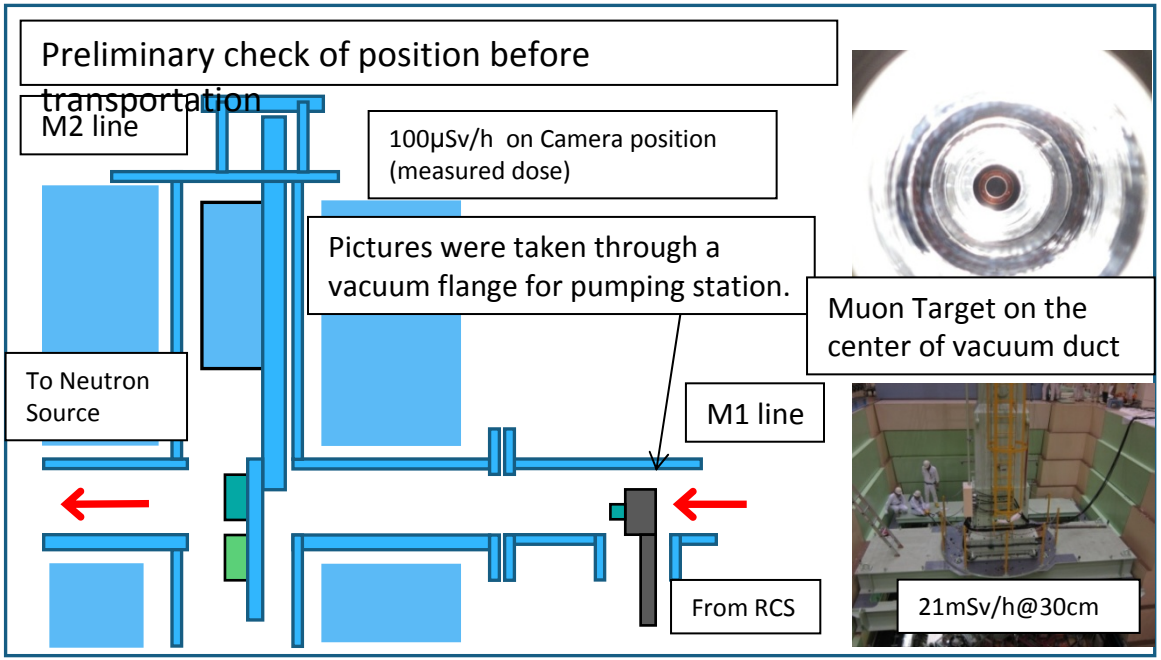
Relative position reproducibility ; <±0.1mm

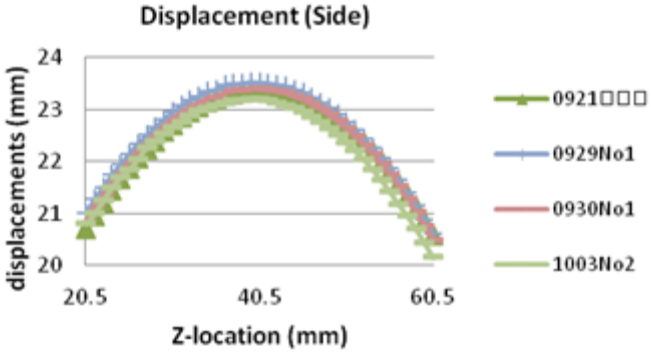
Measurement by laser displacement meter in Hot cell









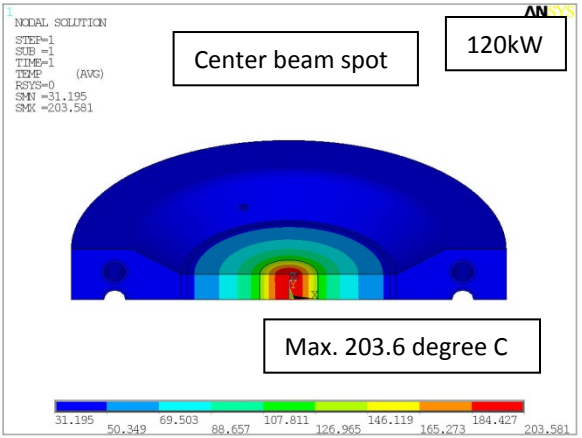


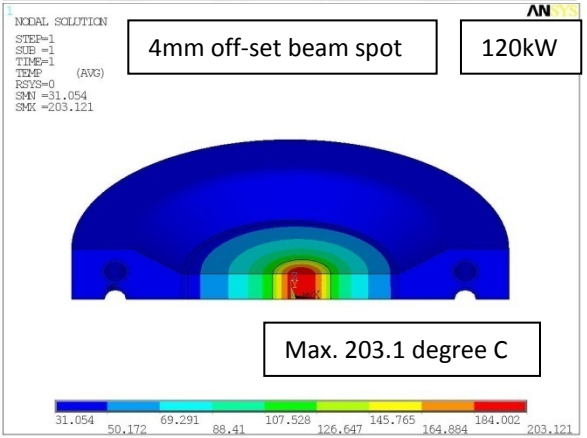
Used Target were located within 0.2mm precision against the ideal mock target.

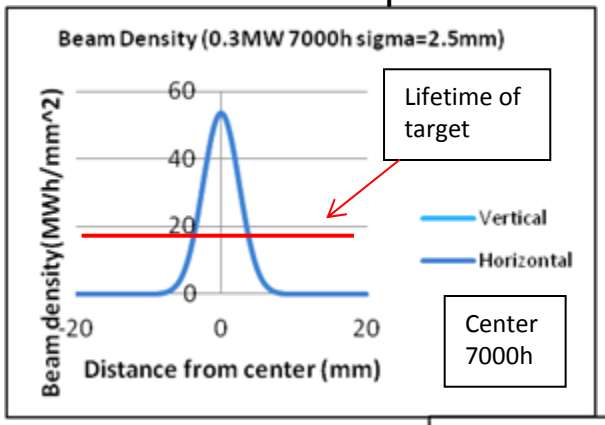
Alignment of beam profile on the muon target

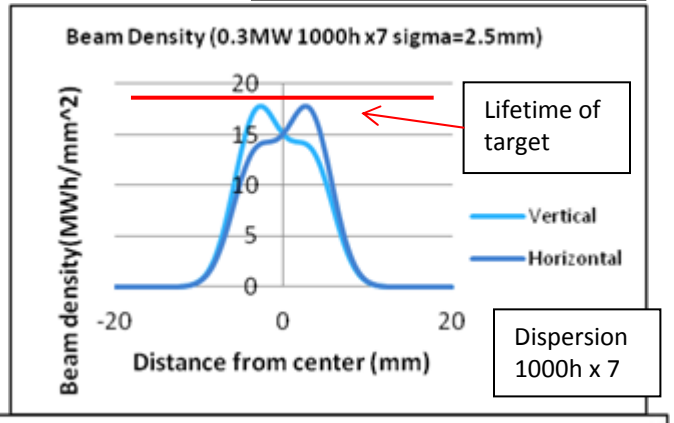
At present, we observed higher radiation than the prediction.
When the diameter of the proton beam on the muon target becomes smaller (sigma=2.6mm) than the original design (sigma=6mm), the beam loss between the muon target and the neutron source becomes smaller. On the other hands, the lifetime of the muon target will be shortened by the smaller diameter of the proton beam.
The off-set and painting of the proton beam position achieve both a low beam loss and a dispersion of the radiation damage.
Now we start to evaluate the effect of the dispersion method.

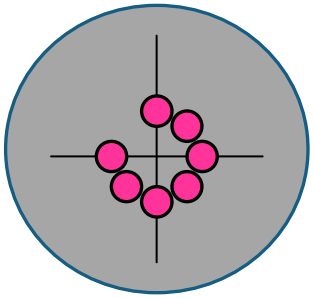
More evaluation is required.



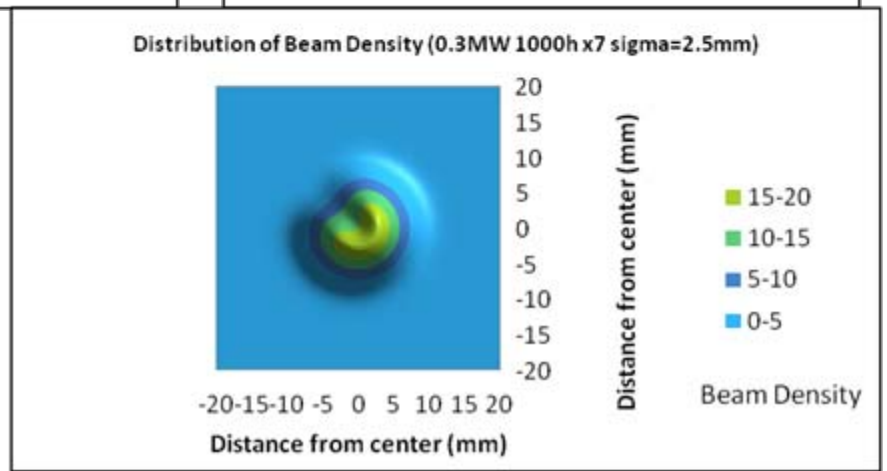






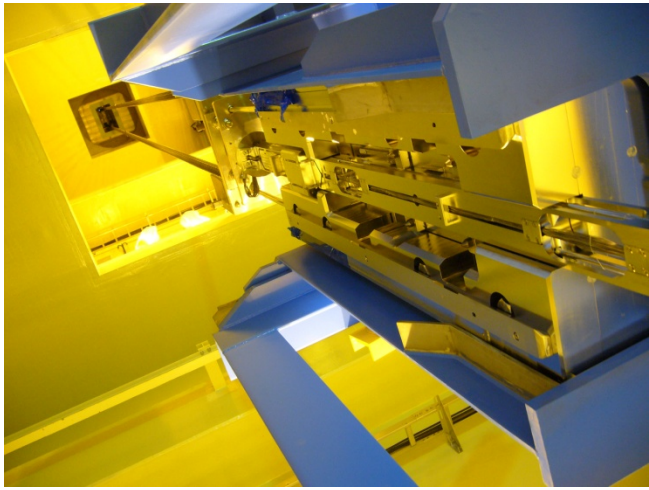


Beam painting by off-set beam



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.