Muon Production Target at J-PARC/MUSE

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GFA & SwissFEL Accelerator Seminar @ PSI
Contents

1. Introduction of J-PARC/MUSE & Muon Target
2. Present Status of Muon Target 15min.
3. TOHOKU Earthquake in my case 5 min.
4. Rotating Target 15 min.
5. Measurement of radiation damage to thermal conductivity of isotropic graphite (PIE tests) 15 min.
J-PARC/MUSE & MUON

Japan Proton Accelerator Research Complex

Muon Science Establishment

Muon is a decay product of Pion!

\[ \pi^+ \rightarrow \mu^+ + \nu_\mu \]
\[ \pi^- \rightarrow \mu^- + \bar{\nu}_\mu \]
Topics Explored by Muon

Magnetism and Superconductor

Positive Muon

Determination of internal magnetic field distribution

Non-destructive Measurement

Negative Muon

Ultra Slow Muon Generation

Batteries Material and Hydrogen

Positive Muon

H behavior

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

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

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

Ultra Slow \( \mu^+ \) >\( 10^5-6 \)/s \( \leftarrow \) surface muon (4\( \times \)10^8/s)

- 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 $1.8 \times 10^{10}$/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 $1.5 \times 10^7$/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.

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利用した。今回の成果は、ミュオンを制御して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ドライバ系などを、J-PARC/MUSEグループ（責任者：三宅康博セクションリーダー（KEK物理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/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347号

<table>
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<th>施設名</th>
<th>1パルスあたりのミュオン数</th>
<th>パルス数</th>
<th>年月</th>
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<tbody>
<tr>
<td>J-PARC/MLF</td>
<td>2,500,000</td>
<td>212kW</td>
<td>2012年11月</td>
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<tr>
<td>J-PARC/MLF</td>
<td>72,000</td>
<td>120kW</td>
<td>2010年3月</td>
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<tr>
<td>RAL（英国）</td>
<td>30,000</td>
<td>160kW</td>
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KEKが世界最高強度
パルスミュオン強度

科学 新聞
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

**Isotopic 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,

1 %/year shrinkage of graphite on the beam spot

Neutron irradiation effect to thermal conductivity  
Beam Operation

(Sep. 2008)
First muon beam generation (Day 1)
(Dec. 2009) 327kW proton beam tests
  5min. × 5sets, 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.

Muon target has been successfully operated without replacement.

<table>
<thead>
<tr>
<th>Year</th>
<th>2008</th>
<th>2009</th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
</tr>
</thead>
</table>

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

300kW temperature distribution

IN

Max. 350degC

OUT

Temperature measured by T.C.
Accumulated beam power on Muon Target

Diameter of the proton beam on the muon target becomes smaller ($\sigma=2.6\text{mm}$) than the original design ($\sigma=6\text{mm}$). 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.

Distribution of Beam Density (~Mar. 2013)

Beam density (MWh/mm$^2$)

Distance from center (mm)

15-20 10-15 5-10 0-5
Future Plan of Proton beam

- Original power upgrade plan of RCS to MLF
- Revised plan
- 400 MeV injection
- 534 kW-35s
- 420 kW-eq.
- 300 kW-1 hour
- Short time

Legend:
- ▲ for MR
- ● for MLF
- ★ short time
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.

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.

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

\[ \mu^- + A(Z,N) \rightarrow e^- + A(Z,N) \]

- 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).

Electron Spectrometer

Hodoscope

Tracker

H-Line

Pulsed Proton

SiC Target

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

\textbf{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.)

\textbf{Organization of Advanced Sustainability Initiative for Energy System/Material Muroran Institute of Technology}
Concept of SiC target for DeeMe Project
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

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

High purity SiC are progress

The Conceptual Image of The Prototype “DeeMe” Target Upgrade

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

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

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.
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5. Measurement of radiation damage to thermal conductivity of isotropic graphite (PIE tests)
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
Life just after the earthquake
Damage at My Facility
Check of Target position

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 in Hot cell
- Measurement by Laser displacement meter

Preliminary check of position before transportation

M2 line

- To Neutron Source
- From RCS

100μSv/h on Camera position (measured dose)

Pictures were taken through a vacuum flange for pumping station.

Several ten mSv/h on target position (calculation)

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.

- Displacement (Front)
  - Used target
  - Spare target
  - Ideal mock target

- Displacement (Side)
  - Ideal mock target
  - Used target #1, #2
  - Spare target
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.
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Muon Rotating Target

To distribute the radiation damage of graphite
Learning from, Paul Scherrer Institute (PSI)

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


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 5000 hours/year, 15 rpm)

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

Graphite
Out wheel
In wheel
Shaft
### Bearing & Solid lubricants

<table>
<thead>
<tr>
<th>Type</th>
<th>Temp. (degC)</th>
<th>Pressure (Pa)</th>
<th>Radiation</th>
<th>Speed (rpm)</th>
<th>Storage</th>
<th>Lifetime (hour)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MoS₂ Retainer</td>
<td>&lt;300</td>
<td>10⁵ to 10⁻⁵</td>
<td>general</td>
<td>&lt;500</td>
<td>air</td>
<td>3300</td>
</tr>
<tr>
<td>WS₂ Separator</td>
<td>&lt;350</td>
<td>10⁵ to 10⁻⁵</td>
<td>few</td>
<td>&lt;210</td>
<td>air</td>
<td>330000</td>
</tr>
<tr>
<td>AIP-Ag Ret.-AIP</td>
<td>&lt;350</td>
<td>10⁻³ to 10⁻¹⁰</td>
<td>general</td>
<td>&lt;500</td>
<td>vacuum</td>
<td>17000</td>
</tr>
</tbody>
</table>

MoS₂: For evaluation of Mock-up
WS₂: Hopeful candidate
Few utilization under radiation
AIP-Ag: Stable candidate
Storage problem

Comparison and measurement of the lifetime

**Evaluation of Lifetime AIP-Ag**

\[ L = b(1.5 \times 10^{-3} n + 1) \left( \frac{C}{13 \times F} \right) \times 16667 / n \]

n; rotating speed (r.p.m.) 5r.p.m.
F; Radial load 33N
C; Allowable load [N] 8120N
b; Factor by Circumstance; 0.3 (10⁻³Pa, 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)

<table>
<thead>
<tr>
<th></th>
<th>Graphite (°C)</th>
<th>Out wheel (°C)</th>
<th>In wheel (°C)</th>
<th>Shaft (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Simulation BL</td>
<td>610</td>
<td>300</td>
<td>135</td>
<td><strong>120</strong></td>
</tr>
<tr>
<td>Simulation MU</td>
<td>750</td>
<td>310</td>
<td>160</td>
<td>140</td>
</tr>
<tr>
<td>Experiment MU</td>
<td>750</td>
<td>340</td>
<td>165</td>
<td><strong>135</strong></td>
</tr>
</tbody>
</table>

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
Rotation in 5~500rpm can be performed.
Motor torque can be monitored.
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
Damaged bearings by heating and rotating test

Durability tests of bearings

MoS2-bearing

retainer  shield

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).
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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)

Neutron irradiation effect to thermal conductivity
Measurement for thermal conductivity of graphite

Thermal diffusivity are measured instead of Th. conductivity.

\[ \lambda = D \rho c \]  
(\(\lambda\); Th. Conductivity(W/m/K), \(D\); Th. diffusivity(m²/s), \(\rho\); Density (kg/m³), \(c\); Th. Capacity (J/kg/K))

Conventional Method  
(Laser-flash technique)

- Cutting of specimen
- Measurement

- Temp. @ Heated spot
- Temp. @ Mating surface
- Delay of transmission
- 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

- 2-dimensional thermo-meter
- Modified Thermal Imaging Scope  
  (Bethel. Co. LTD.)

- Periodic heating
- Diode Laser
- Non-destructively
- Target can be used again.
- Decreasing nucl. wastes
- High spatial resolution

- Temp. variation @ Heated spot
- Temp. variation @ distant position from heated spot
- Delay of transmission; \(\theta\)

Comparison of Amplitude

Theoretical Background of this technique

Thermal transport equation

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

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


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

Periodic heating on Point Pexp(\(i\omega t\))

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

Amplitude includes given heat by laser, \(P\)

Temp. variation @ Heated spot

Temp. variation @ distant position from heated spot

Delay of transmission; \(\theta\)

\(\Delta T\); about 5 K

Comparison of Amplitude

Gradient
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

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

The variation of thermal conductivity irradiated by neutrons

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


Data for IG110
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.

<table>
<thead>
<tr>
<th>Rad. Dose (dpa)</th>
<th>Th. Cond. Prediction</th>
<th>Th. Cond. Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>Center of target</td>
<td>0.25 (200 degC)</td>
<td>5 W/m/K</td>
</tr>
<tr>
<td>Edge of target</td>
<td>0.002 (80 degC)</td>
<td>15 W/m/K</td>
</tr>
</tbody>
</table>

Elliptical shape

Thermal conductivity

20mm x 16mm Map pitch 2mm

Horizontal pitch 1mm

Vertical Pitch 1mm

0.25 dpa 200 degC

0.002 dpa 80 degC

Un-irradiated 170 W/m/K
Results
(Mapping)

2-dimensional map of thermal conductivity

Horizontal - distance from center (mm)
Vertical - distance from center (mm)

-35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35

Total Beam Loss on Target

- Beam Loss (a.u.)

- Total (Horizontal)
- Total (Vertical)

Ellipse shape

20mm x 16mm
Map pitch 2mm

54-56
50-54
46-50
42-46
38-42
34-38
30-34
26-30
22-26
18-22
14-18
10-14
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 $\theta$
- 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

\[ T(r, t) = \frac{P}{4\pi Dr_c} \exp(-kr + i(w t - kr)) \]

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

\[ T(r, t) = \frac{P}{4\pi Drc} \exp(-kr + i(wt - kr)) \quad | \quad k = \sqrt{\frac{\omega}{2D}} = \sqrt{\frac{\pi f}{D}} = \lambda^{-1} \]

\[ \lambda; \text{ Thermal diffusion length} \]

Spatial resolution is determined by thermal diffusion length.

Center of Target #1, \( D=1\times10^{-5} \text{ m}^2/\text{s} \), \( f=1 \text{ Hz} \), then, \( \lambda=1.7 \text{ mm} \)

Center of Target #2, \( \lambda=3.6 \text{ mm} \)

From observation of results,
Spatial resolution is less than \( r=2 \text{ mm} \)
Future Plans

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

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

<table>
<thead>
<tr>
<th></th>
<th>$f; Laser$</th>
<th>Sam. Rate IR camera</th>
<th>Th. Dif. Length</th>
<th>Thermal diffusivity</th>
<th>Costs of Thermo-meter</th>
</tr>
</thead>
<tbody>
<tr>
<td>This measurement</td>
<td>1Hz</td>
<td>30Hz</td>
<td>3.6mm</td>
<td>Relative</td>
<td>1.7MJY</td>
</tr>
<tr>
<td>Next measurement</td>
<td>100Hz</td>
<td>10kHz</td>
<td>0.4mm</td>
<td>5 W/m/K</td>
<td>10MJY</td>
</tr>
</tbody>
</table>
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
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.
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.