STATUS AND FUTURE PROSPECT OF MUON TARGET AT J-PARC MLF

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Muon Science:
Many presentations in this workshop
PRESENT STATUS OF MUON TARGET AT J-PARC MLF
Japan Proton Accelerator Research Complex

Neutrino Experimental Facility (v)

295 km to Kamioka

MLF 2nd Target Station

Materials & Life Science Facility (MLF, muon)

A round: 1,568m

30 GeV Main Ring Synchrotron (MR)
Design beam power:
Fast Extraction to v: 750kW → 1.3MW
Slow Extraction to HEF: > 100 kW

COMET: search for μ-ε conversion

Material Irradiation Facility for ADS R&D

3GeV Rapid Cycling Synchrotron (RCS)
25Hz, 1MW

Hadron Experimental Facility (HEF)
MATERIALS AND LIFE SCIENCE EXPERIMENTAL FACILITY (MLF)

3GeV-RCS

Neutron Target

Muon Target (Graphite) 5% beam loss

1MW in future 500kW at present

Production of the most intense pulsed muon beam all over the world
Muon Target at FL1.6m is highly activated.
- 2-m Iron-shield is required for maintenance
- Access of worker from maintenance area (FL 4m- 6m)
- Beam operation with Ceiling shield.
- Activated air is circulated and limited in beam line.
REPLACEMENT OF MUON TARGET

- Transportation of target by Transfer cask
- Replacement of target at Hot cell
- Measures against contamination, Clean booth with negative pressure, Air-line mask and Anorak suit

- Residual radiation dose:
  5 Sv/h @surface
- Tritium production on target
  0.5 TBq /year @1 MW
Muon Fixed Target from 2008 till 2014

Isotropic Graphite IG-430U (Toyo Tanso)
Diameter; 70mm
Thickness; 20mm

P-Beam diameter; 14 mm (2sigma)
Design: 4kW heat @ 1MW proton beam
In actual: 1.3 kW @ 333 kW p-beam

Stainless steel pipe (Water)
Copper frame
Hot Iso-static Press method

Titanium layer as stress absorber
Silver brazing method

6-years stable operation W/O replacement
Lifetime: Irradiation damage of graphite
1 year at 1 MW operation

• Rotating target method is applied to distribute the irradiation damage of graphite to a wider area.
• Cooling by thermal radiation
• Lifetime of graphite: 30 years
• Lifetime is determined by solid lubricant of bearings

Solid lubricant:
- Silver coating with MoS2 at PSI, < 1 year
- Tungsten Disulfide at J-PARC MLF
Aiming lifetime; 10 years

P-Beam diameter; 14 mm (2s)
4kW heat @ 1MW proton beam
Thickness of graphite 20 mm
HISTORY OF BEAM OPERATION

Rotating Target without replacement
- Operational time: 17000 hours (Nov. 2014 ~ July. 2019)
  6000 MWh
- Rotation: ~16 M revolutions
  (4.5 M revolutions /year @ 15r.p.m.)
- Stable 500-kW operation in 1 year

Oct. 2014
1 MW proton beam operation

By Rotating target
By Fixed target

Trouble on rotation system
ALMOST 1-MW OPERATION TEST

The 1-MW operation for 11 hours was successfully completed on 3rd July, 2019.

The results showed in good agreement with predictions through the simulations.
Trouble on Rotation System in 2018

- Rotating target has been successfully operated for 5 years.
- When rotation feedthrough from air to vacuum was replaced in regular maintenance of 2018, the flexible coupling was broken.
- During operation, it was intact.
- We found the mistake of the machining process.
- We could replace the broken one.
- But the problem is that two couplings are used in the rotating target. The lower one could not be replaced easily.

Decision

- Replacement of target with extension of shutdown for entire MLF
- Continuation of operation by current target
For Beam operation, and Replacement of Target

- It has been confirmed that the rotating target is not broken with current 500-kW proton beam even without rotation through FEM simulation. Furthermore Monitoring system was upgraded.
- The main issue is emission of tritium from hot graphite.
- The exhaust of vacuum pump is temporarily stored in a buffer tank system and is vented after measurement of concentration of RI.

- Proton beam operation started again with upgrade of the monitoring and the buffer tank system.
- It was not broken.
- The target will be replaced with a new and appropriate one next week.
FUTURE PROSPECT OF MUON TARGET AT J-PARC MLF
MLF 2\textsuperscript{nd} TARGET STATION (TS2)
PROPOSAL OF FUTURE PROJECT WAS SUBMITTED

Current MLF facility: tandem target

MLF 2\textsuperscript{nd} target station: common target

1.5MW 25Hz
Double pulse

0.75MW 25Hz
Single pulse

0.75MW 12.5Hz
Single pulse

Time structure of a possible plan
--Science by higher peak intensity

Extreme Condition
(High pressure, High external field)
Muon Micro Beam : small sample

Bio Science (soft matter)
Muon Micro Beam : small protein crystal

Real Space, Real time (nonuniform system)
Muon Micro Beam, Stroboscopic measurement
Imaging, In situ, Operand, Element analysis
Industrial applications,
DEMANDS FOR NEW TARGET MATERIALS

For MLF TS1:
- Graphite is the most popular and excellent target material.
- Demands for Graphite-substitute material
  - Higher oxidation resistance: SiC-coated graphite
  - Higher density: NITE SiC/SiC

For MLF TS2:
- Common target with Neutron target
- Tungsten is desired for higher efficiency of Muon production.
- TFGR W-TiC tungsten: solution to recrystallize and irradiation embrittlement
- Tungsten by Additive manufacturing

### Density

<table>
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<tr>
<th>Material</th>
<th>Density (g/cc)</th>
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<tbody>
<tr>
<td>W</td>
<td>19.3</td>
</tr>
<tr>
<td>Hg</td>
<td>13.5</td>
</tr>
<tr>
<td>Pb</td>
<td>11.4</td>
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<tr>
<td>PbBi</td>
<td>10.6</td>
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<tr>
<td>Fe</td>
<td>7.87</td>
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</tbody>
</table>

Higher density leads higher efficiency of muon transport, because of lower spatial volume of mu/pion on target.
RESEARCH FOR SiC-COATED GRAPHITE UNDER RADIATE COLLAB.

- Higher oxidation resistance
- Proton Irradiation at BLIP, Brookhaven National Laboratory
- Post Irradiation Effect at Pacific Northwest National Laboratory
- Thermal shock experiment, HRT43 at CERN

SEM microscope analysis of cold specimens
SiC coating deposited by CVD is intact.

PIE testing at Pacific Northwest National Laboratory

SiC coated IG-110 were finally broken to pieces. Other graphite survived.

Visual check of irradiated specimens
Crack was observed only on IG-110U substrate specimens, that was not designed for SiC coating.
RESEARCH FOR NITE SIC/SIC

- Higher efficiency of muon transport due to higher density
- Solution of brittleness by pseudo ductility of SiC composite material
- Proton-irradiation tests at RCNP, Osaka
- Measurement of Tritium emission
- Thermal shock experiment, HRT35 at CERN

Proton irradiation test at RCNP

Two tube furnace and 3H traps, HT & HTO

Monolithic SiC

SiC/SiC composite

CERN HiRadMat HRT35
440 GeV, 1.2E11 protons/pulse, Gaussian, σ=0.3 mm.

Completely different emission from CVD-SiC

Preliminary

Stripe-like damage was observed.
Results of SEM analysis by J. Maestre et al.
Disturbance of crack propagation was observed.
TUNGSTEN AS TARGET MATERIAL

- Tungsten is expected as the target material.
- For use of tungsten as muon production target, the boundary between cooling material and vacuum in beamline disturb transportation of muon. Thermal radiation cooling is desired. It should be used at high temperature. (MLF TS2, COMET, mu2e,)

✓ Tungsten is brittle because grain boundary is weak.
✓ Britteness is improved by heavy plastic working.


G. Pintsuk et al.

H. Bolt et al., (2002)

MTC-KEK collaboration, JSPS KAKENHI 19H01913.

- The use of W as target material is limited by “recrystallization embrittlement” and “irradiation embrittlement”.
Toughened Fine-Grained Recrystallized W-TiC, (TFGR W-TiC) is developed by Prof. Kurishita at Tohoku University. Now the activities are transferred to KEK and Metal Technology Co. LTD collaboration.

- Equiaxed, fine grains with TiC precipitates
- GB reinforced by TiC enrichment
- No recrystallization embrittlement
- High sink density: Resistance to irradiation is anticipated.
- DBTT (nil-ductility tem.) < RT
- Thermal shock experiment, HRT48 at CERN
RESEARCH FOR TUNGSTEN BY ADDITIVE MANUFACTURING

• Removal of impurity by pre-heating in vacuum
• Improvement of mechanical property by columnar structure
• New target concept by near-net-shape

Results will come soon!!

Additive Manufacturing by EB
Additive Manufacturing by laser in vacuum
SUMMARY
SUMMARY

Present status
- Muon production by Fixed target from 2008 till 2014
- High residual radiation dose and contamination
- Installation of Rotating target in 2014 to extend lifetime
- The successful 1-MW operation for 11 hours on 3rd July, 2019
- Trouble on rotation system
- Replacement of Rotating target next week

Future prospect
- Future facility: MLF 2nd target station
- Developments of SiC coated graphite, NITE SiC/SiC, TFGR tungsten, Additive manufacturing of tungsten
- Proton irradiation tests & PIE tests

Thanks for your attention