Performance and operational feedback of T2K graphite target

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Outline

- Overview of the graphite target in J-PARC NU beam line
- Status of He cooling
- Electric potential
- Check after the earthquake in 2011
- Current status of T2K target
T2K target design

- Material: Isotropic graphite (IG-430 by Toyo. Tanso. Co. ltd.)
  - Tensile strength = 37.2MPa
  - Geometry: \( L = \sim 900\text{mm} \) (~2 \( \lambda_{\text{int}} \)), \( \phi = 26\text{mm} \) (main part)
    (cf. proton beam size: \( \sigma_x = \sigma_y = 4.2\text{mm} \))
- Energy deposit: \( 41\text{kJ}/3.3 \times 10^{14} \) proton (30GeV)
  - Thermal shock: \( \Delta T = 200\text{K} \), \( \sigma_{\text{eq}} = 7.2\text{MPa} \)
    → Safety factor = 3.5 (including cyclic fatigue)
- Heat load: 19.6kW for 750kW beam
T2K target design

- He cooling for high temperature op. to reduce rad. damage.
  - Graphite: Max: ~800K, Surface: ~400K (for 750kW)
  - He gas: Flow rate = 560 Nm$^3$/h, $\Delta T = 170K$ (30K→200K)
  - Ti-alloy case. (Ti-6Al-4V): Case also cooled by He.
- Oxidization is determine the lifetime: Goal $O_2 < 100$ ppm
- Installed inside 1st horn inner conductor.
  - Cantilevered support for the remote maintenance.
    Install/Uninstall from 1st horn using the manipulator
  - Pulsed HV (~1kV) applied from horn via capacitive coupling with horn.
T2K target design

Co-axial 2 cooling pipe (Graphite & Ti-Alloy)

Graphite-graphite bonding with thread. Graphite part is fixed to Ti parts with bolts.

Metal seal

Proton beam
He cooling simulation

Mass flow rate = 32 g/s

30 GeV, 0.4735Hz, 750 kW, Radiation damaged graphite (20 [W/m.K])
The information on the target during the beam is very limited.
- Temperature of cooling helium.
- He circ. system: Pressure, by-pass ratio (He leak).

Snapshot of online monitor (200kW beam)
Measured He temperature

- Actual He temperature is **consistent** with expectation for 200kW beam operation.

<table>
<thead>
<tr>
<th></th>
<th>Helium gas</th>
<th>Target Max. Temperature [°C] ***</th>
<th>Ti max. temperature [°C]</th>
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<tbody>
<tr>
<td><strong>Simulation</strong></td>
<td></td>
<td></td>
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<tr>
<td>(200kW)</td>
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<tr>
<td></td>
<td>Flow rate</td>
<td>Pressure [MPa] @ Target out</td>
<td>Temperature raise [K]</td>
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<tr>
<td></td>
<td>[Nm³/h]</td>
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<tr>
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<td>~105</td>
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<tr>
<td>(200kW)</td>
<td>302</td>
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<td>~72</td>
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<tr>
<td>Data</td>
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<td>~0.10</td>
<td>~70</td>
</tr>
<tr>
<td></td>
<td>(Not monitoring)</td>
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</tbody>
</table>

### Graphical Representation

- **Beam Power** (Beam on/off)
- **He flow rate**
- **He pressure**: compressor out
- **He temperature**: target inlet
- **He temperature raise**
- **Short beam stop**

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*** No radiation damage is assumed.
Degradation of the coolant He gas

- Tritium production due to the beam operation
  - $^3$H $180$[Bq/L] for T2K Run-3 ($1.37 \times 10^{20}$ POT)
    - HTO = 174 [Bq/L]
    - HT = 6 [Bq/L]
  - Regulation for the exhaust to outside: 5 [Bq/L] (3 month average)
    - $\times \sim 400$ dilution is necessary.
      - The He system was modified, and the volume other than the target itself can be a vacuum for He gas replacement.
  - The volume of He for target cooling is 4~6 m$^3$ (in atm. pressure) while the capacity of Target station ventilation is $\sim 1300$[m$^3$/h].
    - It is not difficult to dilute enough.
  - Issue: No O$_2$ contamination measurement is installed.
    - We can not find the O2 sensor which work at $>0.2$MPa.
    - We plan to install gas chromatograph in target station & gas sampling system from Target / TS He-vessel, etc
T2K target is installed in the 1st horn: the same voltage as 1st horn.
- Electrical insulation is considered for the support structure and He tubing.
- Ti-alloy case is connected to ground with high register (~8MΩ) in order not to be charged up.
Checked item after the earthquake

Target was shaken together with the 1st horn which is hanged by the horn support frame.

- It is expected that the horn support frame collide with the TS He vessel and/or 2nd horn support module.
- Checked Item before beam
  - He flow: **No significant change after earth quake.**
  - X-ray inspection for spear targets → Next page.
  - Check by the web-camera: **No damage was found.** ↓
- Checked Item with beam
  - “Beam based alignment”
    : Check the muon yield/proton intensity
Inspection of the spares after the earthquake.

- At this moment, we have 2 spare targets.
  - One is same structure as the used one. (Machining precision is improved)
  - Another spare is made with new design by RAL group.
- When earthquake happened, the spares were also fixed as the cantilever. To expect the damage of the installed target, we did the X-ray inspection for the spares.

No clack was observed.
Target and Inner tube are at correct position.
No graphite fragment observed at the bottom.
→ We judged that we will continue to use the installed target.
Beam based alignment of baffle, target.

- Scan the beam position using low intensity (~$4 \times 10^{11}$ p/pulse) and narrow size ($\sigma_{x,y} \approx 2$ mm) beam.
- There is two change for the muon monitor signal
  - Muon yield / proton ... targeting efficiency
  - Muon profile width ... The muon produced by the interaction of protons at the beam dump.
- During the beam scan horns are turned off.
  - It is possible to check the horn alignment by comparing the muon profile w/ horn on.
Beam based alignment using muon monitor

- Target/baffle position may be shifted by ~1mm. It is within the acceptable range.

### Horizontal beam scan

- **Muon yield** / proton
- Preliminary
- Run39
- Run40

### Vertical beam scan

- Preliminary
- Run29
- Run39, Run40

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### Muon profile width

- Preliminary
- Run39
- Run40

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Run29 (Before EQ)
Run39, Run40 (After EQ)
By the way, ....

- Relation between the muon profile center and proton beam position depends on the horn current. (It is reproduced by MC.)
  - Positive correlation in 250kA case $\leftrightarrow$ Negative correlation in 200kA case
- For T2K horn, the muon direction is not depends on the proton beam position if the horn current is a certain value between 200kA and 250kA.
  - The neutrino beam direction become stable, but it is impossible to adjust proton beam position using muon measurement.
Current status of T2K target

- 1st target is exposed to ~$3.4 \times 10^{20}$ POT as of Nov. 2012.
- No abnormal thing was observed.
  - There is no significant radioactivity in the strainer in He circulation system. We exhausted cooling He gas via the filter with 0.1µm and no radio activation was observed at the filter.
  - The neutrino yield normalized by the proton intensity is stable within the uncertainty of proton / neutrino intensity and horn current monitoring.
- Issues:
  - We do not have the system to monitor the Oxygen contamination in He cooling line. So we plan to install the gas chromatography system in TS.

![Graph showing neutrino yield](image)

Neutrino yield (On-axis detector @ 280m) normalized by proton intensity.
Summary

- Design of T2K target is reviewed.
- He cooling is working as expected at this moment.
  - Current issue is the lack of $O_2$ contamination monitoring
- T2K target survive the large earthquake.
  - Alignment is checked using the muon monitor by scanning the proton beam orbit.
- No degradation of the graphite is observed for $3.4 \times 10^{20}$ POT.