The JPARC Neutrino Target

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Contents

• Introduction
  ■ T2K experiment, JPARC accelerator, $\nu$ beam line

• Neutrino Target
  ■ Conceptual design
  ■ Choice of the cooling method
  ■ Prototyping
  ■ Cooling test

• Summary
Main Physics goals: **Discovery of** $\nu_\mu \rightarrow \nu_e$ **Oscillation**

- Pure $\nu_\mu$ beam (~1GeV)
- $\nu_\mu$ Energy spectrum measurement
J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA (aka JAERI)
J-PARC status

- Buildings for LINAC and 3GeVPS finished.
- North-east part of tunnel for 50GeV PS finished.
- South-west part of tunnel will finish in FY2006.
- First beam on 50GeV PS in FY2008
J-PARK $\nu$ beam

- **Conventional $\nu_\mu$ beam**
  
  Focus $\pi^+(\pi^-)$ with the magnetic field
  
  Proton beam
  
  $\pi^\pm$ meson produced @ target
  
  $\nu_\mu$ ($\bar{\nu}_\mu$) is produced from $\pi^+(\pi^-)$ decay.
  
  Charged particles stop at the dump

- **Narrow band beam:** Off-axis beam
  
  First Application (ref.: BNL-E889 Proposal)
  
  Super-K.

  Neutrino oscillation @ $\Delta m^2=3\times10^{-3}\text{eV}^2$
**J-PARC neutrino beam line**

Proton Energy: 50GeV  
(40/30GeV @ T=0)

# of Protons / pulse: $3.3 \times 10^{14}$

Beam Power: 750kW  
→ 4MW @ Phase II

- Bunch structure:
  - 8 (15) bunches/spill
  - Spill width: ~5µs
  - Cycle: ~3.64 (3.94) sec
  - Bunch spacing: ~600(300) ns
  - Bunch length: 58ns (Full width)

**Diagram highlights:**
- Primary Proton beam line
- Extraction point
- Target
- Target station
- Decay volume
- beam dump
- muon monitor
- Near neutrino detector
- Workshop
Target Station

- Accommodate
  - Baffle: Graphite, 32mmø hole \( \times 1.7m \) long to protect 1st horn
  - Target
  - 3 Horns

- Area filled with Helium gas
  - reduce Tritium, NOx production

- Highly radio-activated
  - \( \sim 1Sv/h \)
  - Need remote-controlled maintenance system

- Need cooling (Helium vessel, radiation shield,..)
Target: Conceptual design

- Core: Isotopic-Graphite: IG-43 (Toyo Tanso Co. Ltd)
  - Energy deposit... Total: 58kJ/spill, Max: 186J/g
    \[ \Delta T \approx 200K \]
    \[ \sigma_{eq} = 7.42 \ [\text{MPa}] \] \[ \leftrightarrow \] Tensile strength = 37.2 [MPa]

- Co-axial 2 layer cooling pipe: Graphite / Ti-6Al-4V, Helium cooling

Distribution of the energy deposit in the target (w/ 1 spill)
Expected radiation damage of the target:
- The approximation formula used by NuMI target group: 0.25 dpa/year
- MARS simulation: 0.15~0.20 dpa/year

Dimension change: shrinkage by ~5mm in length in 5 years at maximum. ~75µm in radius

Degradation of thermal conductivity: decreased by 97% @ 200 °C, 70~80% @ 400 °C

Magnitude of the damage strongly depends on the irradiation temperature.

It is better to keep the temperature of target around 400 ~ 800 °C
# Target cooling: Water or Helium?

<table>
<thead>
<tr>
<th>Advantage</th>
<th>Water Cooling</th>
<th>Helium Gas cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>☺ Very Efficient</td>
<td>☺ We can control $T_{\text{target}}$ to minimize the irradiation effect. ($T_{\text{target}} = 400 \sim 800 , ^\circ\text{C}$)</td>
<td></td>
</tr>
<tr>
<td>☺ High Heat transfer ratio</td>
<td>☺ Reduce radioactive waste water</td>
<td></td>
</tr>
<tr>
<td>☺ Already tested.</td>
<td>☺ No target container is needed</td>
<td></td>
</tr>
<tr>
<td>☺ Simple circulation system</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Disadvantage</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>☹ large Irradiation effect</td>
<td>☹ Very High flow rate</td>
</tr>
<tr>
<td>$\leftarrow T_{\text{target}} \leq 300 , ^\circ\text{C}$ to avoid the water boiling:</td>
<td>$\sim 2000 , \text{l/min} , [0.5\text{MPa}]$</td>
</tr>
<tr>
<td>$T_{\text{target}} , @ , \text{surface} , &lt; , 100 , ^\circ\text{C}$</td>
<td>$\sim 12000 , \text{l/min} , [0.1\text{MPa}]$</td>
</tr>
<tr>
<td>☹ Target container is needed.</td>
<td>☹ Circulation system is complicated.</td>
</tr>
<tr>
<td>☹ $\Delta P_{\text{water}} = \sim 2\text{MPa}$ due to the temperature rise by a beam hit.</td>
<td>☹ Special treatment for the high temperature gas (200, ^\circ\text{C}) is necessary.</td>
</tr>
<tr>
<td>☹ Huge radioactive waste water</td>
<td></td>
</tr>
</tbody>
</table>

*Oct. 10, 2005*
FEM simulation of He cooling

- Assumptions: **0.19MPa**
  - He Initial temperature: **25 °C**
  - He flow rate: **6000 [l/min] → 194 [m/sec]**
  - Heat convection rate: **820 [W/m²/K]**

- Target Temperature
  - Max: ~ 500 °C
  - Min: ~ 300 °C
  - Avg.: ~ 380 °C

- Helium Temperature
  - Max: ~ 160 °C
  - Avg.: ~ 40 °C
  - (∆T = 135 °C)
FEM simulation of He cooling

- Assumptions: **0.19MPa**
  (Possible pressure drop at the downstream of target is taken into account.)
- He Initial temperature: **25 °C**
- He flow rate: **6000 [l/min] → 194 [m/sec]**
- Heat convection rate: **820 [W/m²/K]**
Prototype design of Target system

Optimization of the upstream part and graphite cap is in progress.

Inner Pipe: $t=2.0\text{mm}$ Graphite

Outer Pipe $t=0.3\text{mm}$ Ti-6Al-4V

+ $t=0.5\text{mm}$ Ceramic coating (Thermal Spraying)
Target / Cooling pipe design

Graphite Inner pipe

Outer pipe
Ti-6Al-4V

Inner pipe
IG-43

target
IG-43

spacer

Cooling path
- Sectional area
  \[ = 5.1 \times 10^{-4} \text{ [m}^2\text{]} \]
- Pressure drop
  \[ = \sim 0.8\text{MPa} \]

cf. Inner radius of 1\textsuperscript{st} horn
\[ = 54\text{mm} \phi \]
Mechanical Prototype of Graphite Parts

The manufacturability is confirmed!

IG-43 Toyo Tanso Co. Ltd
Machining by Toyo Tanso Co. Ltd.

Target Core
Inner Cooling Pipe
2mm thickness

Cap
Assembled with the acrylic-plastic outer-pipe
Prototypes of Ti-Alloy parts

- Check the manufacturability
  - Made Ti-6Al-4V pipe with 0.3mm thickness by TIG welding
    - Pass the Helium leak test and pressure proof test
  - Test of the brazing between Ti-6Al-4V and Graphite
    - Pretreatment for Ti-alloy (Ni-plating) is effective.
    - We have narrowed down the blazing material

<table>
<thead>
<tr>
<th>Brazing material</th>
<th>Strength [MPa]</th>
<th>note</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tensile</td>
<td>Shearing</td>
</tr>
<tr>
<td>BAg-8 + Ti (2%)</td>
<td>8.6</td>
<td>13.3</td>
</tr>
<tr>
<td>BPd-4</td>
<td>11.3</td>
<td>15.6</td>
</tr>
</tbody>
</table>
Helium circulation system

- Helium system is placed at the machine room of the TS.
  - Helium compressor
  - 1st Heat exchanger (Water Jacket)
    - The outflow of heat from the exhaust helium (~200°C) to the TS should be minimized to keep the alignment precision.
    - The helium pipe will be surrounded by the water jacket.
      → It works as a heat exchanger.
  - 2nd Heat exchanger

\[
\begin{align*}
\text{Compressor} & \quad \rightarrow \quad 0.11\text{MPa} \quad \sim 100^\circ\text{C} \\
& \quad \downarrow \\
0.11\text{MPa} & \quad \sim 25^\circ\text{C} \\
& \quad \downarrow \\
2^\text{nd} \text{Heat exchanger} & \quad \rightarrow \quad 0.23\text{MPa} \quad 25^\circ\text{C} \\
& \quad \downarrow \\
0.16\text{MPa} & \quad \sim 200^\circ\text{C} \\
& \quad \downarrow \\
1^\text{st} \text{Heat exchanger} & \quad \rightarrow \quad 0.11\text{MPa} \quad \sim 100^\circ\text{C} \\
& \quad \downarrow \\
0.23\text{MPa} & \quad 25^\circ\text{C} \\
& \quad \downarrow \\
\text{Cooling water} & \quad \rightarrow \quad \text{Target}
\end{align*}
\]
He cooling test (1/20 scale)

- Measure the cooling power using the heater which simulates the heating at the target.

- The flow rate of Available Helium-compressor is 1/20 of actual system
  - Small size heater and cooling pipe is used so that the helium flow is turbulence as well as actual target cooling.
  - Heating power is also 1/20.

- Heat exchanger for this test is not commercially available → We made the double-tube for the heat exchange using Swagelok® joints.

Test of 1st Heat Ex.
# He cooling test parameter

<table>
<thead>
<tr>
<th>Parameter</th>
<th>1/20 test</th>
<th>Actual equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inner/Outer radius of flow path</td>
<td>8mmφ / 10.5mmφ</td>
<td>30mmφ / 39.4mmφ</td>
</tr>
<tr>
<td>Heating power</td>
<td>~1KW / 600mm</td>
<td>~20kW / 900mm</td>
</tr>
<tr>
<td>Helium flow rate</td>
<td>1[g/s] / 370[l/min]</td>
<td>24[g/s] / 9000[l/min]</td>
</tr>
<tr>
<td>Helium flow speed</td>
<td>170[m/s]</td>
<td>290[m/s]</td>
</tr>
<tr>
<td>Reynolds number</td>
<td>~3500</td>
<td>~22000</td>
</tr>
<tr>
<td>Heat transfer coeff.</td>
<td>670 W/m²/K</td>
<td>~790 W/m²/K</td>
</tr>
<tr>
<td>Helium ΔT</td>
<td>200K</td>
<td>200K</td>
</tr>
<tr>
<td>Heater Temp.</td>
<td>~300°C</td>
<td>~570°C</td>
</tr>
</tbody>
</table>
Test setup

Heater (8mm φ): 1kW

Cooling pipe (Inner diameter = 10.5mm φ)

Helium flow

Ceramic spacer (1mm φ)
Heat Exchanger

Expectation:
Helium: 200°C → 25°C @ 1g/s
Water: 15°C → 17°C @ 10 l/min

This heat exchanger has the purpose of the test of the water-jacket for the helium cooling pipe (1st heat exchanger) in the actual system.
He flow @ test setup

- Helium mass flow rate of \(~1.2\text{[g/s]}\) is achieved. (\(\leftarrow 1\text{g/s}\) is expected)
- Measured pressure drop indicates the flow is turbulence.

![Graph showing pressure drop vs. helium flow rate]
<table>
<thead>
<tr>
<th></th>
<th>measured</th>
<th>expected</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating power</td>
<td>~1.1KW</td>
<td></td>
</tr>
<tr>
<td>Helium flow rate</td>
<td>1.2[g/s] / 220[l/min] @ 0.19MPa</td>
<td></td>
</tr>
<tr>
<td>Helium flow speed</td>
<td>100[m/s] @ intake (0.19MPa)</td>
<td>200[m/s] @ exhaust (~0.16MPa)</td>
</tr>
<tr>
<td>Heat transfer coefficient</td>
<td>640 W/m²/K @ middle of target</td>
<td>795 W/m²/K (average)</td>
</tr>
<tr>
<td>Helium ΔT</td>
<td>182K</td>
<td>178K</td>
</tr>
<tr>
<td>Heater surface Temp. @ center</td>
<td>180°C</td>
<td>~167°C</td>
</tr>
</tbody>
</table>

- The heat exchanger works well.
  - Helium: 185°C → 14°C @ 1.2g/s
  - Water: 13.7°C → 16.3°C @ 8.6 l/min
Summary

- **T2K ν experiment** … Neutrino Oscillation search. **2009~**
- **J-PARC ... Japan Proton Accelerator Research Complex**
  - Linac + 3GeV PS + 50 GeV PS → MLF, Hadron beam, ν beam
  - Construction is in progress.
  - Neutrino beam line ... 1st application of Off-axis Narrow band beam.

- **Neutrino Target**
  - Graphite Bar + Co-axial 2-layer cooling pipe (graphite, Ti-Alloy)
  - **Helium Gas Cooling**
    - Several difficulties are found in the water cooling.
    - The cooling capability is checked by the FEM and the 1/20-scale test.
  - 1st Prototype of the target and cooling pipe is designed.
    - Mechanical prototypes of the graphite parts are made.
    - Welding of Ti-Alloy and the brazing between graphite and Ti-Alloy are tested.