Target system for hadron & neutrino beam lines at J-PARC

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(Hadron beam-line SG, Neutrino beam-line SG, Target/Monitor SG)

High-power Targetry for Future Accelerators
September 8, 2003

Contents

• Introduction of J-PARC
• Target and Target system for hadron beam line
• Target system for neutrino beam line
(Y. Hayato will talk about neutrino target tomorrow)
J-PARC:
Japan Proton Accelerator Research Complex

Phase 1: Approved in 2001, will be completed by 2007
Neutrino will be approved for FY2004-8(?)
Site View of the Project

Facility for Neutrino Experiment (2004?~2008?)

Facility for Nuclear/Particle Physics experiment (~2007)

Nuclear Transmutation


3 GeV PS (~2006)

50 GeV PS (~2007)

180 MeV Linac (~2006)
50 GeV PS @J-PARC

- **Beam Energy:**
  - 50 GeV
  - (40 GeV in Phase1-)

- **Beam Intensity:**
  - 3.3x10^{14} ppp, 15 \( \mu \) A
  - (2x10^{14} ppp, 9 \( \mu \) A in Phase1-)
  - (18x10^{14} ppp, 80 \( \mu \) A in future)

- **Beam Power:**
  - 0.75 MW
  - (0.36 MW at Phase1-)
  - (4 MW in future)
Acceleration/extraction cycle

- Injection: 0.17 s
- Acceleration: 1.96 s
- Fast extraction to neutrino beam line: 0.70 s
- Deceleration: 1.90 s
- Slow extraction to hadron beam line: 3.53 s
- Nothing: 0.70 s

Energy vs. Time (Sec.)
Hadron beam line

• Slow extraction beam line
• Physics with high intensity secondary K beam
  • Strangeness Nuclear physics
  • Rare K decay
Target and secondary beam lines

Production target: T1

Rotating Nickel disks
- thickness: ~54 mm
- radius: ~24 cm
- cooled by water
- developed by Y. Yamanoi et. al.

Proton beam
Design of T1

1.3x10^{21} protons/year on Target (4000 hours/year)

• Radiation shielding
• Max. yield of secondary beam
• Temperature rise
• Point source for secondary beam

\[\Rightarrow \text{30\% interaction}\]

\[\Rightarrow \text{Ni target}\]

<table>
<thead>
<tr>
<th></th>
<th>length of 30% interaction (cm)</th>
<th>max. heat density (J/cm^3)</th>
<th>density (g/cm^3)</th>
<th>specific heat (J/g/K)</th>
<th>temperature rise by a pulse (K)</th>
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</thead>
<tbody>
<tr>
<td>Pt</td>
<td>3.15</td>
<td>25000</td>
<td>21.5</td>
<td>0.14</td>
<td>8590</td>
</tr>
<tr>
<td>Ni</td>
<td>5.31</td>
<td>5280</td>
<td>8.9</td>
<td>0.44</td>
<td>1340</td>
</tr>
<tr>
<td>Al</td>
<td>14.06</td>
<td>1940</td>
<td>2.7</td>
<td>0.87</td>
<td>820</td>
</tr>
</tbody>
</table>
Water cooling of T1

- Rotating Ni disks
  - Diameter: 48 cm, Thickness: 54 mm (9 mm-t x 6 disks)
  - 1 rotation per 0.7s (slow extraction period): 85 RPM
- Partially cooled by water

ANSYS:
- After 0.7s exposure
- 1200 W/m²K assumed

Highest ~94°C
Lowest ~40°C

85 RPM

Cooling water

Highest ~196°C
Lowest ~136°C

beam

$\phi 48\text{cm} \times 54\text{mm}^t$

$\phi 24\text{cm} \times 54\text{mm}^t$
Gas cooling of T1

**Natural convection**
- 10 W/m²K assumed
- Highest ~ 602°C: too high
- Lowest ~ 409°C

**Forced convection**
- 100 W/m²K assumed
- Highest ~ 148°C: still high
- Lowest ~ 40°C
R&D for T1

Items

• Optimization of diameter, thickness, # of disks (gaps)
• Rotation speed, Method of rotation
• Durability
• Container & shielding
• Cooling system
• Beam window & vacuum sealing
• Maintenance method

⇒

• Prototypes
• Mockup

Nickel disks (φ24cm x 6mm x 9, 24kg)
Water velocity at T1(1)

Relative velocity between disk and water
- affects on heat transfer coefficient
- measured by PIV (Particle Image Velocimetry)

One Ni and two acrylic disks

YAG Laser

CCD Camera
Water velocity at T1(2)

- Results:
  - Typ. velocity ~ 1 m/s @85RPM
  - Gap between disks should be > 2mm
  - RPM should be < 150RPM

⇒ Fluid simulation
  - Reproduce relative velocity
  - Estimate heat transfer coefficient
  - Parameter survey on
    - Number of disks (gaps)
    - Gap length
    - Rotation speed
    - Depth in water
    - etc
Container of T1

Target support
Moving system
Alignment pins
Ni target disk
φ48cm × 5.4cm-t
Water pipe
Bearing
Cooling water
Alignment pins
Beam
Target off
Cooling system of T1

Service space

Under test with Mockup

Heat exchanger

Filter

Pump

Out: 37°C

Radioactivity of water after 30 days operation: \(~24 \text{ kBq/cm}^3\)

- Thinned into 15 Bq/cm\(^3\) and thrown away
- (Thinned into 1.2 kBq/cm\(^3\) and moved by tank track)

In: 32°C

2.4 m\(^3\)/h

Water tank: 0.08 m\(^3\)
Mockup around T1

East counter hall at KEK
Beam window for T1

Double wall (SS and Al)
- cooled by He flow
- gap: ~1cm
- remote maintenance

Primary beam line: ~10^{-3} Torr

T1 upstream windows
- diameter: 10cm

T1 target
- Double wall (SS and Al)
- cooled by He flow
- gap: ~1cm
- remote maintenance

Vacuum chamber
- ~10^{-3} Torr

Beam axis
T1 downstream window

• Diameter: ~30cm
• Vacuum side: Aluminum
• Air(T1) side: SS
• 0.1mm-t at center
• 5mm-t at edge (water cooled)

• Temperature rise of SS window at center
  +170ºC (forced convection by He flow (~1m/s) : 100W/m²K)
  +810ºC (natural convection : 10W/m²K)
Shield around T1

Concrete shield block

Service space: 2m(W) × 1m(H)

Iron shield

Concrete shield

Beam

Water pump

T1 container

~18m

~10m

The whole system will be tested by the T1 mockup.
Target Area

Large Vacuum Chamber (~3kW)

Iron block (1.4kW)

D1(7.2kW) Q1(<1kW)

T1 target (12kW)

Beam

2m

Cu collimator (55kW)

Cu collimator (76kW)

2.9m

K1.8

K1.1

KL

Dump
Residual dose around T1

Dose by MARS
One day cooling after 30-days operation
Half year cooling after 1-year operation

Container
2.2 Sv/h
850 mSv/h

T1
650 Sv/h
230 Sv/h

Vacuum flange
30 Sv/h
11 Sv/h

Collimator
380 mSv/h
100 mSv/h

Base plate
560 mSv/h
210 mSv/h

K1.8D1
530 mSv/h
270 mSv/h

K1.8Q1
62 mSv/h
33 mSv/h

Vacuum chamber
SUS 3.2 Sv/h
1.2 Sv/h

Ti 1.1 Sv/h
97 mSv/h

Cooling pipe
0.15 mSv/h

Concrete
0.1 μSv/h

Iron
22 μSv/h

Iron
3.8 mSv/h

Service space 0.1 μSv/h

Q1B
110 mSv/h
49 mSv/h

Collimator
710 mSv/h
420 mSv/h

Trench
Remote maintenance for T1

Maintenance work should be done at service space:

1. Disconnect cables and cooling tubes.
2. Detach vacuum flanges.
3. Replace shields with cask.
4. Detach shaft, disks and upper plate, and move them to stock space.
5. Install new parts with cask.
6. Replace cask with shields.
7. Connect cables and tubes.

Requires remote maintenance tools.

Front view

Side view
Remote vacuum sealing

Design specification
- Inner Diameter: ≥30cm
- Metal sealing
- Small leak: ~$1 \times 10^{-10}$ Pa•m$^3$/s
- Remote operation
  - Operation time: 1~5 min.
  - Small force required

Candidate
- Mechanical holding (V-block)
- Pillow seal
- Radial seal (under development)

Prototype of “Radial seal” developed by Y.Yamanoi(KEK), M.Tsuchiya(IHI Ltd) and Usui Kokusai Sangyou Kaisya Ltd.
Remote lifting Tools

Specification
• Up to 40t
• Short height
• Remote connection
• Video camera viewing
• Two or four points lifting
• Interlock for one-side lifting

Lifting tools from CERN and PSI
Neutrino beam line

νμ beam of ~1GeV

• νμ → νx disappearance
• νμ → νe appearance
Neutrino target

Graphite rod

- **diameter:** 30mm, **Length:** 900mm (80% interaction)
- **beam size:** $\sigma_r \sim 6$mm
- **fixed inside 1st horn**
- **20kw heat load:** cooled by water

⇒ Hayato’s talk tomorrow
Neutrino target station

Machine room
Helium container
Iron shield

Service pit
Stock room for activated parts

22m
11m
33m

40t crane

Ground level

Concrete blocks

Iron shield
Beam window
Baffle
Target & 1st horn
2nd horn
3rd horn

Beam window
Decay volume
Radiation shield and dose

Radiation dose in 0.75MW operation (by MARS)

Outer surface of concrete: <5mSv/h

Floor: <12.5 μSv/h
Helium container

- Reduce radioactivity in gas and corrosion by NOx
- 3m(W)×6m(H)×15m(L), 20cm thick Aluminum
- Filled by 1 kg/cm² Helium gas (130m³)
- Heat load ~170 kW: water cooled
- Under conceptual design
Residual does:
one (seven) day cooling after one year operation (by MARS)

Floor of service pit
\[ \sim 0.007(0.004) \ \mu \text{Sv/h} \]

Upper iron shield
Outer : 22(16) \ \mu \text{Sv/h}
Inner : 0.56(0.42) \text{ Sv/h}

Helium container (Aluminum)
\[ \sim 0.65(0.17) \text{ Sv/h} \]
Stock room for activated parts

- Stock broken and activated targets/horns etc (5~20 years?)
- Use cask and move under ground level

Top view of Target station

Wall: 20cm concrete

Ground level

Concrete

Iron

Stock room
Control of air

Service pit (230m³)
Machine room (140m³)
Keep out in operation time
• Operation time: circulation
• Maintenance: ventilation

Building (8300m³):
• Ventilation through stack

Helium container:
Keep out forever
• Circulation of Helium

Stock room for radioactive parts
Keep out forever
• Operation time: circulation
• Maintenance: ventilation
Cooling and radioactivity

After 3 weeks of 0.75MW operation,

• Target (heat load: 20kW):
  0.001m³ & 300kBq/cm³  
  ⇒ thinned into 20m³ of 15 Bq/cm³ and thrown away

• Horns (heat load: ~30kW):
  0.6m³ & 5kBq/cm³  
  ⇒ 200m³ of 15 Bq/cm³

• Iron shields & Helium container (heat load: ~210kW):
  ~0.1m³, ~30kBq/cm³  
  ⇒ ~200m³ of 15 Bq/cm³
Summary

Target system for 0.75MW-50GeV beam at J-PARC

• under design and R&D stage
  and will be completed by 2007~2008
• Ni disks for hadron beam line
• Carbon rod for neutrino beam line
• Key points on target system
  • Radiation level and residual dose
  • Remote maintenance
  • Cooling
  • Cost, man power, schedule, etc.