Current Status of Pulsed Spallation Neutron Source of J-PARC

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J-PARC = Japan Proton Accelerator Research Complex
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3. Summary
Neutron beam lines (23)  
Hadron Experiment Facility  
Neutrino Exp. Facility (294km to Super KAMIOKANDE)  
Transmutation Facility (Phase II)  
Materials & Life Science Facility (MLF)  
3 GeV Synchrotron (25Hz, 1MW)  
30 GeV Synchrotron (0.75MW)  
Linac (400MeV)  
JRR-3M 800 m to MLF  
• JFY2009 Beams  
• JFY2008 Beams  
• CY2007 Beams  
• JFY2009 Beams
1-MW spallation neutron source of J-PARC

Proton beam window

Proton beam
3 GeV, 25 Hz, 1 MW

5 m

Moderator
Liquid H₂
(20K, 1.5 MPa)
100% para H₂

Cryogenic system

Off-gas process system

Mercury target system

Moderator

Liquid H₂

(20K, 1.5 MPa)

100% para H₂

Neutron beam lines (23)
Distinctive feature of moderator system

Poisoned Moderator (PM)
- Ag-In-Cd (AIC) decoupler to achieve high decoupling energy @ 1 eV
- Optimized decoupler configuration to lower pulse tail
- Cd poison to increase initial intensity

Decoupled Moderator (DM)

Coupled Moderator (CM)
- Large & Cylindrical
- Wide angle beam extraction

High Intensity

High Resolution

F. Maekawa et al., NIM A 620 159 (2010)
Codes and nuclear data used at design stage

- **Particle transport simulation**
  - Code: PHITS, MCNPX
  - Data Library: LA150 / (ENDFB)
    - Scattering kernel (ENDFB-VI)
    - JENDL 3.3
      - JENDL-based KERMA
      - DPA Cross section
    - JENDL-FF
      - Experimental based nuclide yield
        (Target: He-4, N-14, O-16)

- **Time evolution of Induced radioactivity**
  - Code: DCHAIN-SP
  - Data: ENSDF
    - EAF 3.1
    - FENDL/D
  - γ-ray energy
  - Neutron Reaction
    - FENDL/A-2
    - JENDL-Act-96
    - JENDL-3.3
World’s highest performance - intensity

**Time-averaged Neutron flux** (by Au-foil activation)
measured value at the exit of guide tube of BL01 (coupled moderator)
is equivalent to \( \phi = 3 \times 10^9 \, [\text{n/cm}^2\cdot\text{s}] \) @1 MW

Peak neutron intensity is 4.5 times higher than SNS.
more gain than the ratio of repetition rate of 2.4 = (60Hz/25Hz).

Moderator concept with 100% para-hydrogen has been adopted in world’s neutron source projects; China Spallation Neutron Source, European Spallation Source, 2nd target station of SNS at ORNL.
Radiation damage estimation at design stage

- Estimation method
  - Particle flux calculation with PHITS
  - DPA estimation with a DPA cross section
  - Mercury target container: SS316L, 10 dpa
  - Proton beam window: A5083
  - Moderator vessel, A6061-T6, 20 dpa
  - Decoupler, Ag-In-Cd/A083

Calculated DPA map on vertical cross sectional view of spallation neutron source of J-PARC for 5000-hour operation at 1-MW

- Proton beam profile Gaussian
- Foot print 17x8 cm²

Progress in 3-GeV Proton Beam Transport

• Efforts to reduce peak density by non-linear optics with two octupole magnets
• Satisfactory reduction of peak power density reduction by the beam flattening.

✓ 12 J/cc/pulse at 1 MW; ca. 30-40% reduction from gaussian profile without beam flattening. (17 J/cc/pulse w/ gaussian)
✓ promising for suppressing pitting damage on the target vessel

By S. Meigo
2. Efforts in target development towards 1-MW operation

- For the mercury target of J-PARC, pitting damage by pressure wave is decisive factor to limit the lifetime rather than radiation embrittlement.
- Mitigating pitting damage is first priority to achieve stable operation at 1–MW.
- Post irradiation examination (PIE) of the neutron source components, target vessel (SUS316L), proton beam window (A5083), moderator and reflector vessels (A6061-T6), is under discussion.
Operational history of mercury target of J-PARC

- 1-MW equivalent proton beam pulse on mercury target in Jan. 2015 for the first time
- Beam power for user program was ramped up to 500 kW in April, 2015.
- There was twice failures in water-shroud of target in 2015.
- From 2016 to 2017, steady operation at 150 – 200 kW was conducted.

* as of June 28, 2017
# Operational history of mercury target in J-PARC

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** Target vessels are numbered in fabrication order.
Strategy of design & fabrication improvements

Lesson from failures: Defect in joining and welding are initiation of crack propagation

- Eliminating initial defect is important.
  - Reduction of joint lines by monolithic structure for target #8
  - Improvement of inspection method, combination of RT, UT, and PT.

1st-7th (previous)
- Failed at 500kW operation
- Hg vessel
- Water shroud
- Bolts
- Many welds incl. diffusion bonding with constraints between vessels

8th (next)
- Improved structure
- Monolithic structure of water shroud & Hg vessel
- Much fewer welds with constraints

Future
- Final goal for high power operation
- Constraint-free
- Helium layer
- Few welds without constraints

- Fabrication of target #8 has been just completed.
- Target replacement will be performed from Oct. 2.
Cavitation damage mitigation techniques

Target
1st

**Surface hardening**
Reduce cavitation damage
Nitriding & Carburizing, Kolsterising

3rd

**Gas Micro-bubbles injection**
Reduce pressure wave and cavitation damage
Inject helium gas microbubbles (R<50 µm) into flowing mercury (VF:10^{-2} in flow ratio)

4th

**Double-walled structure**
Reduce cavitation damage by high-speed mercury flow and narrow gap

5th
8th

Pressure wave mitigation with gas micro-bubbles

Propagating pressure waves loses energies by shrinkage and change of motion of surrounding bubbles before arriving at target vessel wall.

M. Futakawa et al.

Damage observed on double-walled target

- For target #5, damage about 25 µm was observed on the beam window after 670 MWh (av. 406 kW) in 2015. The data for longer operation period is important.
- Cause of this damage is under investigation.
  - Simulation to study correlation with negative pressure period (presented at IWSMT#13, 2016 by T. Naoe)
  - Experimental studies using a mercury loop with a pressure pulse system

Silicone rubber replica (Struers, RepliSet F1)
Replica enclosed in glass cell and measured depth profile by laser scanning microscope

Outer mercury vessel
Center of band-like damage

-20
-15
-10
-5
0
5
10
15
20
Horizontal distance, µm
-30
-25
-20
-15
-10
-5
0
5
10
Roughness, µm

Boundary of damage
Center
200 µm
50 µm
Further developments for pressure wave mitigation

**Current double-walled type**
- Double walled structure
- Bubble generator

**Double flow type**
- Fast mercury flow plus micro-bubbles effects

**Advanced double flow**
- Blocking pressure wave propagation with gas curtain

- Damage test by generating cavitation by Magnetic IMpact Testing Machine
- Water experiments with double flow channel models
- Mercury flow experiments, gas curtain generation

**Test section**
- Specimen
- Narrow channel
- Impulsive force
- High speed video camera
Post irradiation examination of used components

• No dedicated hot cell available for PIE at MLF.
• In Tokai site of JAEA, Reactor Fuel Examination Facility (RFEF) is available for microscopic and mechanical strength measurements.
• We are discussing to make PIE tests with the RFEF staff.
• One issue is RFEF is operated under different regulation from that applied to MLF.
• We will start preparation to get license to transport the irradiated specimen to RFEF.
Summary

• Pitting damage mitigation in mercury target is a critical issue to achieve 1-MW operation at J-PARC.

• In the next target operation with improved structure, we will increase operational power up to 500 kW in 2018, and observe pitting damage at target front.
  • Note: At J-PARC, beam power per one pulse is 2.4 times higher than that of SNS at ORNL. Operation at 600 kW is untraversed zone in the world.

• Further development of pitting damage mitigation technique is needed.

• PIE of specimens cut out from irradiated neutron source components is under consideration.