Moderator Performance at SNS Next Generation Inner Reflector Plug (IRP3)

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Outline

• Background of the study
• High-fidelity modeling method (DAGMC)
• IRP3 design change
• Moderator performance on IRP3
• Summary
SNS Target system

- Inner Reflector Plug (IRP), an essential component in delivering neutrons to the beamlines.
- IRP houses four moderators, Be reflector and stainless steel shielding.
- Cooled by heavy water
SNS IRPs

- Current IRP (IRP2) was installed in 2018 and has a designed lifetime of ~28 GWhr
- It bears very similar design to the old one (IRP1), which was cooled by light water and had been used for ~40 GWhr (~32 GWhr designed lifetime)
- The design of the next generation IRP, IRP3, has been completed. The design change aims to reduce manufacturing difficulty, lower the cost and improve the operation stability and the lifetime of IRP (~38 GWhr)
- Each design change was verified with tolerable moderator performance gain or loss over the time
- It is important to validate the complete design of IRP3 to gauge accurate moderator performance
High-fidelity Modeling at SNS

• Conventional modeling uses code provided surface/body definitions to manually construct geometry model
  – Time consuming
  – Simple geometry

• High-fidelity modeling
  – Converts a CAD model automatically into an input file for the Monte Carlo simulation: *SuperMC & MCAD*
    - Geometry is again limited by the MC codes, specially not able to deal with spline surfaces
    - Logic not perfect in writing cell descriptions
  – Directly run a CAD model in a Monte Carlo simulation: *DAGMC*
    - Versatile in handling geometry
    - Computation speed is ~2-3 slower
DAGMC (Direct Accelerated Geometry Monte Carlo)

- Developed by Prof. P. Wilson’s team, Univ. of Wisconsin-Madison
- Supports MCNP6 (sponsored by SNS), FLUKA, & OpenMC
- Demonstration implementation for Shift, Tripoli & GEANT4
- Acceleration techniques
  - Imprint/merge
  - Surface faceting
  - Oriented bounding box & bounding box tree
- It relies on Cubit/Trellis for the model processing

* P.P.H. Wilson et al. / Fusion Engineering and Design 85 (2010) 1759–1765
High-fidelity Modeling at SNS

- A native CAD model is usually not suited for DAGMC-MCNP6 run
  - Loose definition of geometry in CAD vs. water-tight requirement in MC
    - Gaps
    - Overlaps
  - Small details not necessarily needed
  - Fluid space not defined

- CAD model has to be fixed and checked before DAGMC-MCNP6 run
SNS IRP3

Proton beam window

208 volumes, 8588 surfaces, 20155 curves, and 33780272 triangles

~6 GB memory for each computing core
IRP3 Design Improvement

IRP3

IRP1/2

Split plates
IRP3 Design Improvement

- One third height of Be was replaced with D$_2$O
  - ~0.5 M$\$ reduction
  - < 1% performance drop
- Removal of split plates
  - reduce manufacturing difficulty
- Simplified coolant channels
IRP3 Design Improvement

IRP3

Be around the target was replaced with Al at no cost of moderator performance
IRP3 Design Improvement – top moderators

IRP3

No significant change of top moderators

- Removal of extra pool of premoderating light water

IRP1/2
IRP3 Design Improvement – top decoupled H moderator

- An addition of **2 mm** D2O under the decoupled hydrogen moderator
- and **2.3 mm** of aluminum to support it
IRP3 Design Improvement – top coupled H moderator

- Due to removal of split plates, the neutron chamber is now connected to the target chamber
- Vacuum vessel wall thickness dropped from 4.1 mm to 1.7 mm
IRP3 Design Improvement – bottom moderators

- The poison depths of the water moderator changed
- Change to the bottom coupled hydrogen moderator is the same to the top one
IRP3 Design Improvement – bot. decoupled water moderator

- Removal of 2 mm Al spacer
- Gd poison plate thickness increased from 1.0 mm to 1.3 mm
- Poison depth kept the same 2.5 cm at BL17 side
- Poison depth increased from 1.5 cm to 1.67 cm at BL8 side
Moderator Performance on IRP3

- Replaced IRP1/2 in the as-built model with the as-designed IRP3
- Time-of-flight adjusted point detectors
- Masks limit the point detector’s view of 10x12 cm$^2$ emission surfaces
- Tallied at the outer surfaces of the moderator vessels
Moderator Performance on IRP3 – decoupled H mod.

- Time-averaged intensity: 
  - ~2% gain on the time-averaged intensity
- Pulse peak intensity: 
  - ~1% gain on the pulse peak intensity

BL2 side

BLs 1, 2 & 3
BLs 10, 11 & 12
Moderator Performance on IRP3 – decoupled H mod.

- Similar FWHM
- The gain is mainly due to the pre-moderation of 2 mm D₂O underneath the moderator

BL2 side
Moderator Performance on IRP3 – coupled H mod.

**BL5 side**

- time-averaged intensity gains for E< 0.4 eV, up to ~10% at 1 meV
- similar gain on the pulse peak intensity
- epithermal neutrons lose ~4% in the time-averaged intensity
Moderator Performance on IRP3 – coupled H mod.

- ~5% wider pulse width for thermal and cold neutrons
- ~2% narrower pulse width for epithermal neutrons
- The gain on thermal and cold neutrons is due to the thinned vessel wall thickness at neutron emission surface
- The loss on epithermal neutrons is likely due to the removal of the split plate
**Moderator Performance on IRP3 – decoupled water mod.**

- **Time-averaged intensity**
  - ~10-13% gain on the time-averaged intensity
  - ~4% gain on the pulse peak intensity

**BL8 side**

- 1.3G IRP1/2 BL8
- 1.3G IRP3 - BL8
- IRP3 vs IRP1/2

**Peak Intensity of the pulses Comprehensive Comparison**

- 1.3G IRP1/2 BL8
- 1.3G IRP3 - BL8
- IRP3 vs IRP1/2
Moderator Performance on IRP3 – decoupled water mod.

- ~7% wider on pulse width
- ~10-13% gain on time-averaged intensity
- ~4% gain on pulse peak intensity

Combined results of PD increase from 1.5 cm to 1.67 cm and Gd poison plate increase from 1.0 mm to 1.3 mm

- Previous studies
  - 2 mm PD increase
    - ~15-20% gain on time-averaged intensity
    - ~7% gain on pulse peak intensity
  - 0.3 mm thickness increase of Gd poison plate
    - ~3% drop on both time-averaged and pulse peak intensity
Moderator Performance on IRP3 – decoupled water mod.

Time-averaged intensity

BL17 side

• No gain on the time-averaged intensity
• ~4% gain on the pulse peak intensity
Moderator Performance on IRP3 – decoupled water mod.

- Similar pulse width
- No gain on time-averaged intensity
- ~4% gain on pulse peak intensity

Combined results of removal of 2mm Al spacer, Gd poison plate increase from 1.0 mm to 1.3 mm and PD increase from 1.5 cm to 1.67 cm on the other side

- Previous studies
  - Removal of 2mm Al & 2 mm PD increase on the other side
    - ~1% gain on time-averaged intensity
    - ~5% gain on pulse peak intensity
  - 0.3 mm thickness increase of Gd poison plate
    - ~1% drop on both time-averaged and pulse peak intensity
Summary

• IRP3 at SNS was effectively modeled for DAGMC-MCNP6 run

• Such a high-fidelity modeling method was proved to be efficient and accurate.

• Moderator performance at IRP3 was shown to be generally higher than that in previous generation IRPs, which proves that the design improvement of IRP3 though intended for the manufacturing and operation purpose does not impact moderator performance

• Up to ~10% performance increase on water and coupled hydrogen moderator

• In addition, the lifetime of IRP3 is expected to increase by ~30%

• It is worthwhile to adapt to the DAGMC method for complicated structures and systems in future studies
SNS target monolith
Moderator Performance on IRP3 – decoupled H mod.

BL11 side

- similar on the time-averaged intensity
- ~1% loss on the pulse peak intensity