Oak Ridge National Laboratory

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

W. Lu, F. X. Gallmeier, & K. R. Gawne

Oak Ridge National Laboratory, Oak Ridge, TN 37831 USA

23rd International Collaboration on Advanced Neutron Sources (ICANS XXIII)
Chattanooga, TN USA   Oct. 13-18, 2019

ORNL is managed by UT-Battelle, LLC for the US Department of Energy

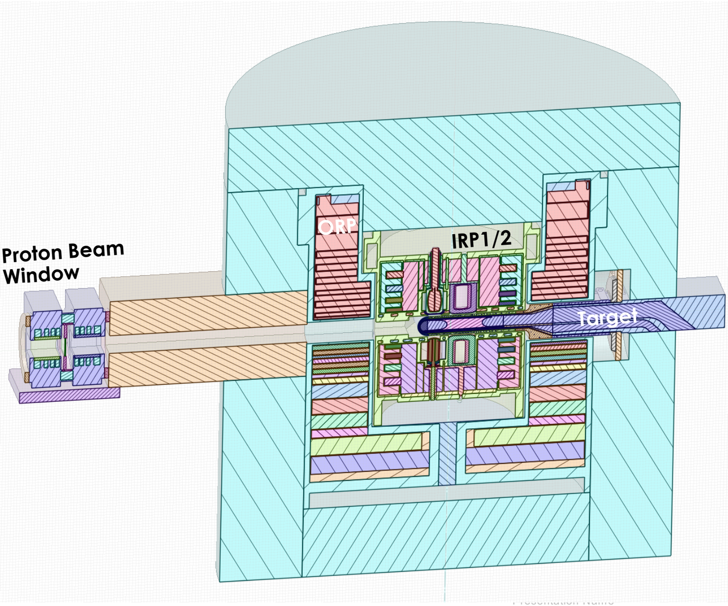
U.S. DEPARTMENT OF ENERGY

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

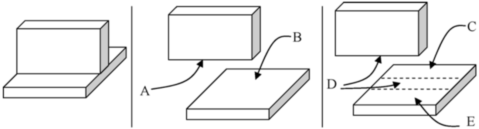
- Current IRP (IRP2) was installed in 2018 and has a designed lifetime of ~28 GWhr
- It bears very similar design to the old one (IRP1), which was cooled by light water and had been used for ~40 GWhr (~32 GWhr designed lifetime)
- The design of the next generation IRP, IRP3, has been completed. The design 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

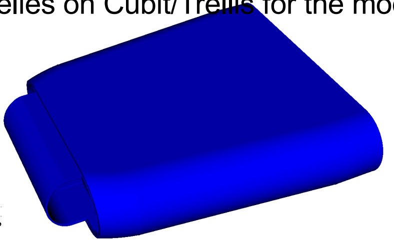
- Conventional modeling uses code provided surface/body definitions to manually construct geometry model
  - Time consuming
  - Simple geometry
- High-fidelity modeling
  - Converts a CAD model automatically into an input file for the Monte Carlo simulation: ***SuperMC & MCAD***
    - Geometry is again 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)

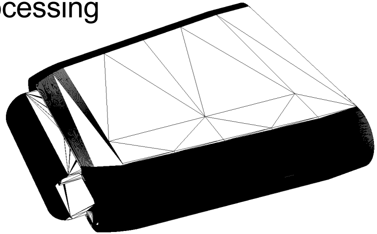
- Developed by Prof. P. Wilson's team, Univ. of Wisconsin-Madison
  http://svalinn.github.io/DAGMC/index.html
- Supports MCNP6 (sponsored by SNS), FLUKA, & OpenMC
- Demonstration implementation for Shift, Tripoli & GEANT4
- Acceleration techniques
  - Imprint/merge
  - Surface faceting
  - Oriented bounding 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*

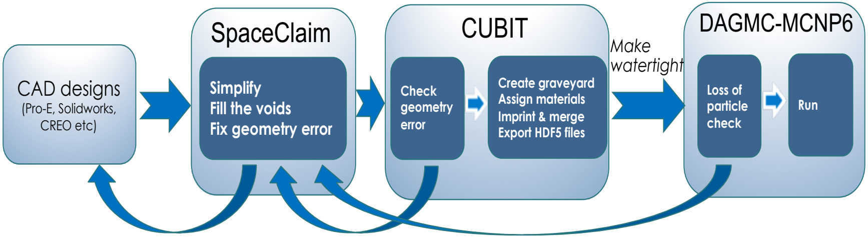


faceting



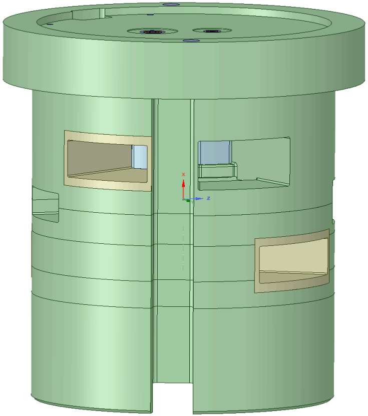
High-fidelity Modeling at SNS

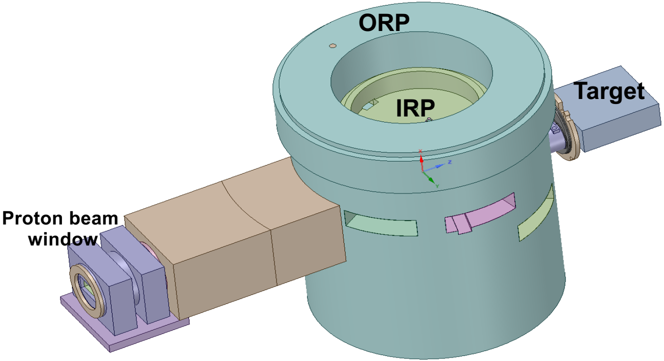
- A native CAD model is usually not suited for DAGMC-MCNP6 run
  - Loose definition of geometry in CAD vs. water-tight requirement in MC
    - Gaps
    - Overlaps
  - Small details not necessarily needed
  - Fluid space not defined
- CAD model has to be fixed and checked before DAGMC-MCNP6 run



Flow-chart of CAD model preparation for a DAGMC-MCNP6 run

SNS IRP3

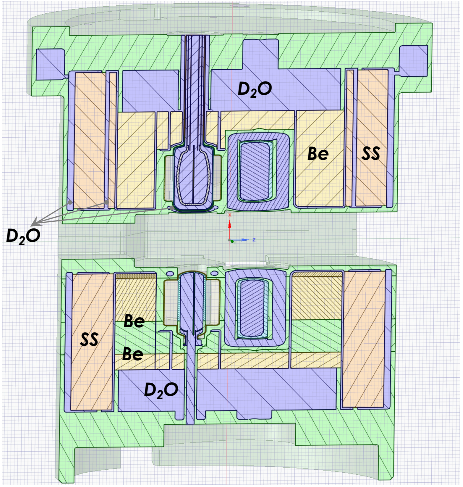




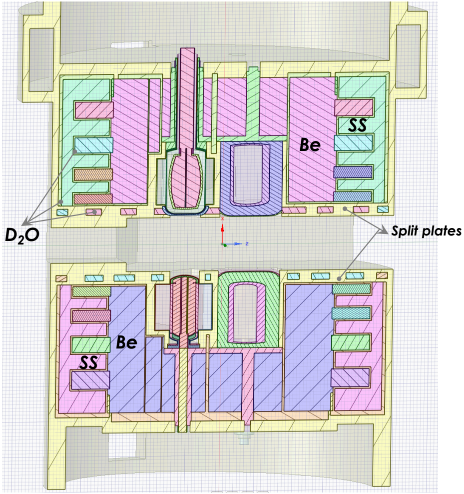
208 volumes, 8588 surfaces, 20155 curves, and 33780272 triangles

~6 GB memory for each computing core

IRP3 Design Improvement

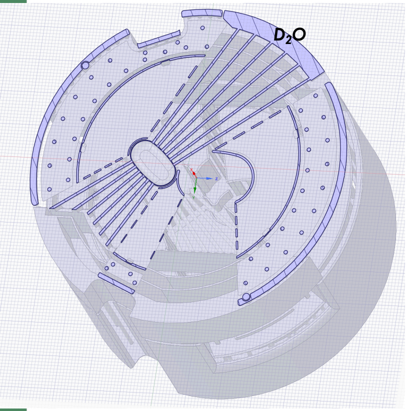


IRP3

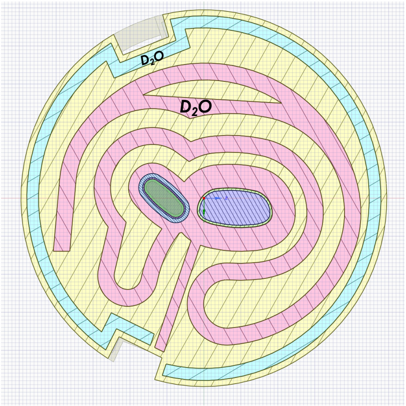


IRP1/2

IRP3 Design Improvement



IRP3

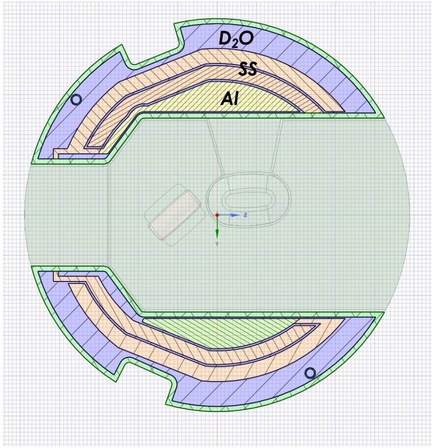


IRP1/2

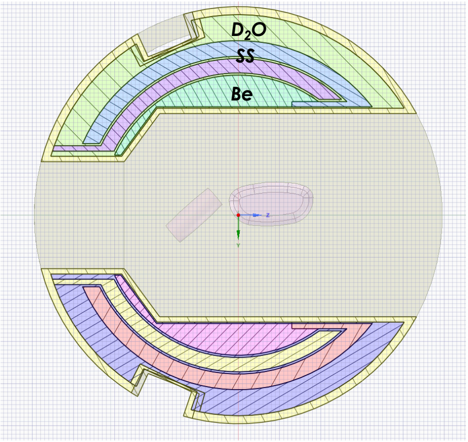
- One third height of Be was replaced with D_2O
  - ~0.5 M $ reduction
  - < 1% performance drop
- Removal of split plates
  - reduce manufacturing difficulty
- Simplified coolant channels

OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

IRP3 Design Improvement



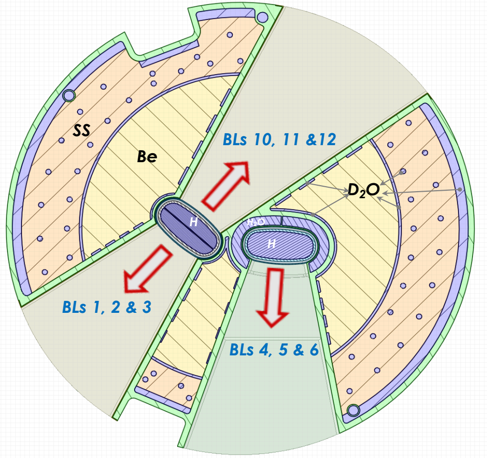
IRP3



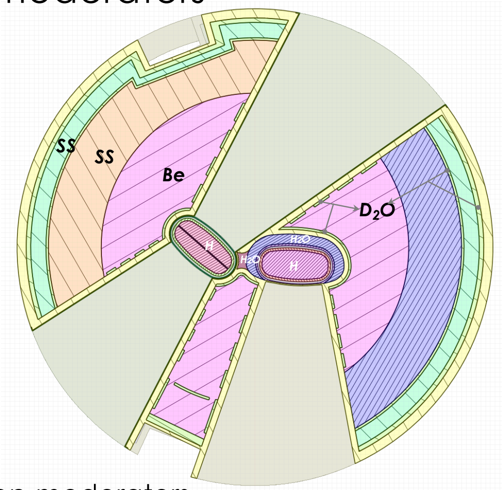
IRP1/2

Be around the target was replaced with Al at no cost of moderator performance

IRP3 Design Improvement – top moderators



IRP3



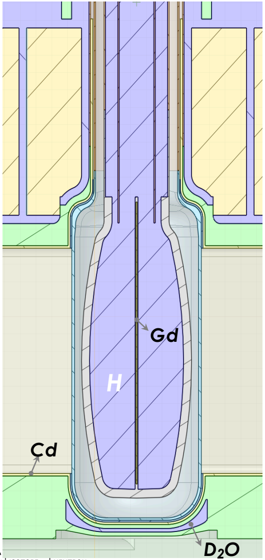
IRP1/2

No significant change of top moderators

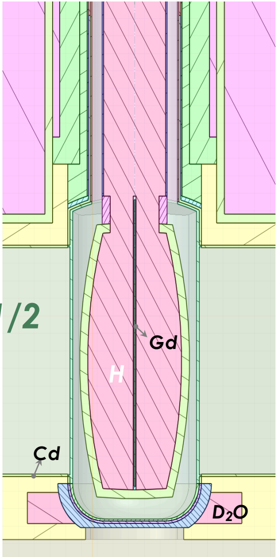
– Removal of extra pool of premoderating light water

IRP3 Design Improvement – top decoupled H moderator

IRP3



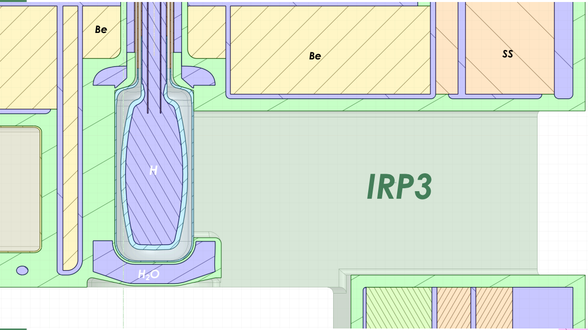
IRP1/2



- An addition of **2 mm** D2O under the decoupled hydrogen moderator
- and **2.3 mm** of aluminum to support it

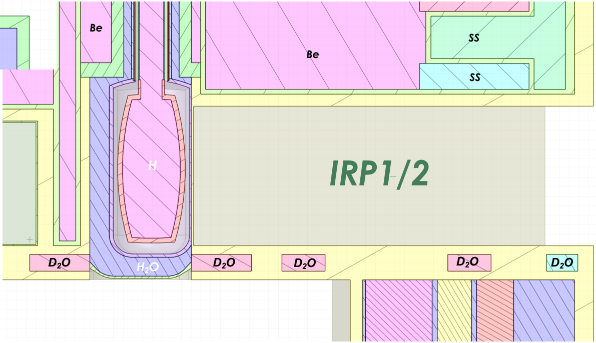
OAK RIDGE National Laboratory | ISOTOPE REACTOR | NEUTRON SOURCE

IRP3 Design Improvement – top coupled H moderator

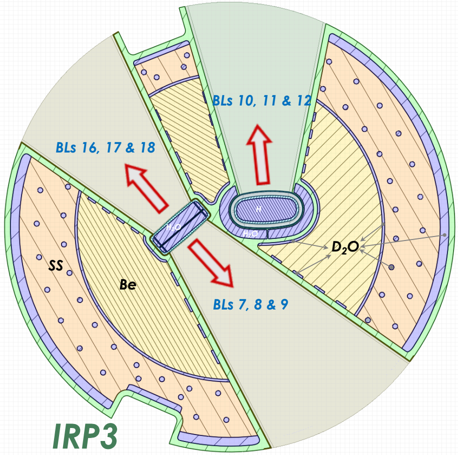


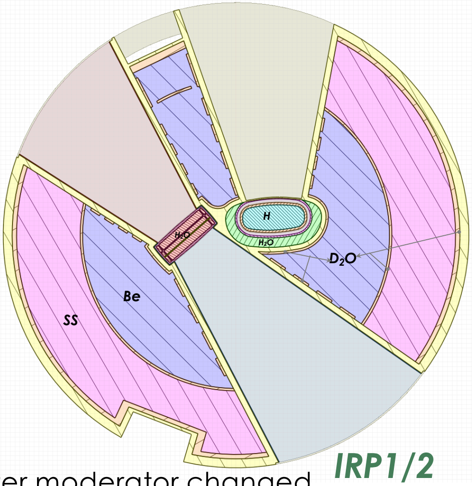
- Vacuum vessel wall thickness dropped from 4.1 mm to 1.7 mm

- Due to removal of split plates, the neutron chamber is now connected to the target chamber



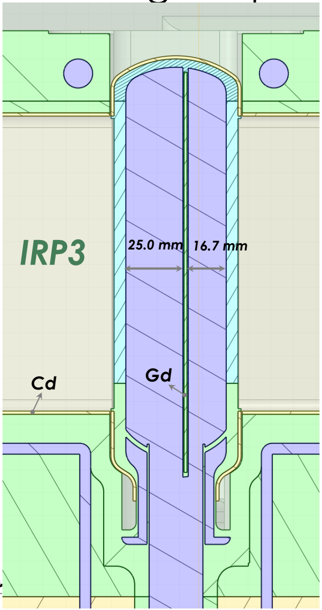
IRP3 Design Improvement – bottom moderators



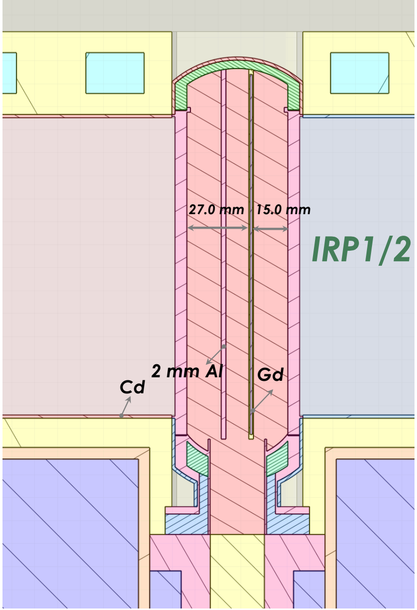


- The poison depths of the water moderator changed
- Change to the bottom coupled hydrogen moderator is the same to the top one

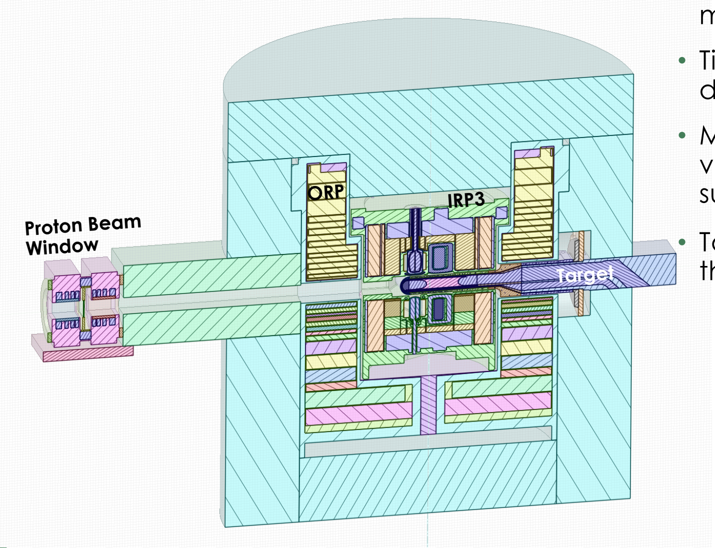
IRP3 Design Improvement – bot. decoupled water moderator



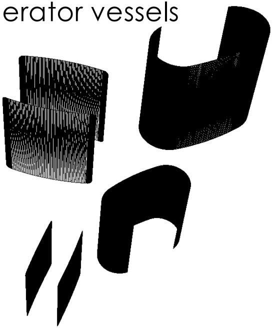
- Removal of 2 mm Al spacer
- Gd poison plate thickness increased from 1.0 mm to 1.3 mm
- Poison depth kept the same 2.5 cm at BL17 side
- Poison depth increased from 1.5 cm to 1.67 cm at BL8 side



Moderator Performance on IRP3

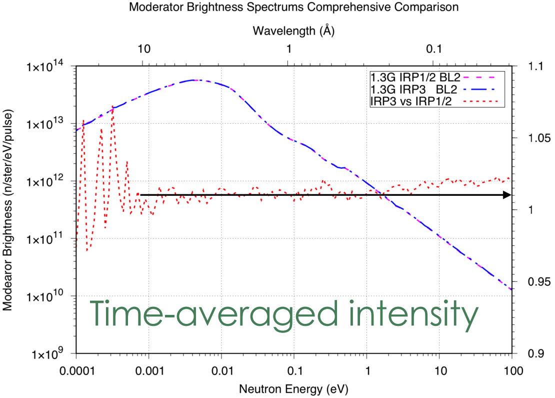


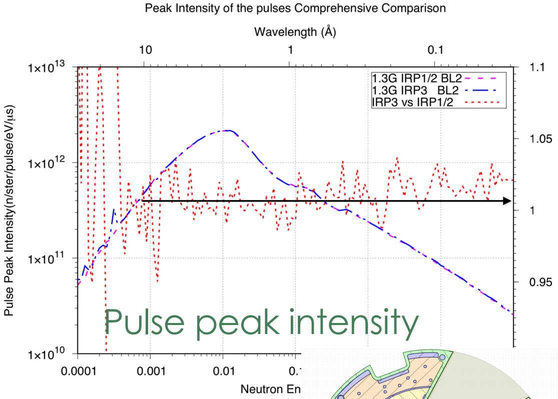
- Replaced IRP1/2 in the as-built model with the as-designed IRP3
- Time-of-flight adjusted point detectors
- Masks limit the point detector's view of 10x12 cm^2 emission surfaces
- Tallied at the outer surfaces of the moderator vessels

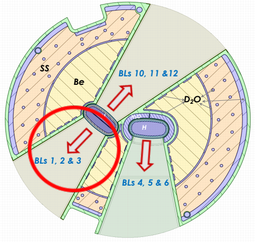


Oak Ridge National Laboratory | High Flux Isotope Reactor | Spallation Neutron Source

Moderator Performance on IRP3 – decoupled H mod.



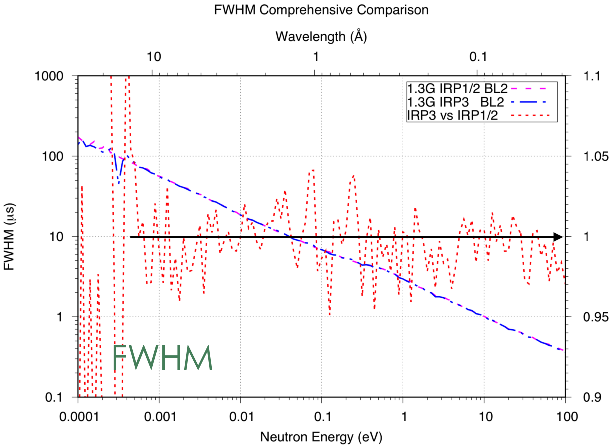




BL2 side

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

Moderator Performance on IRP3 – decoupled H mod.



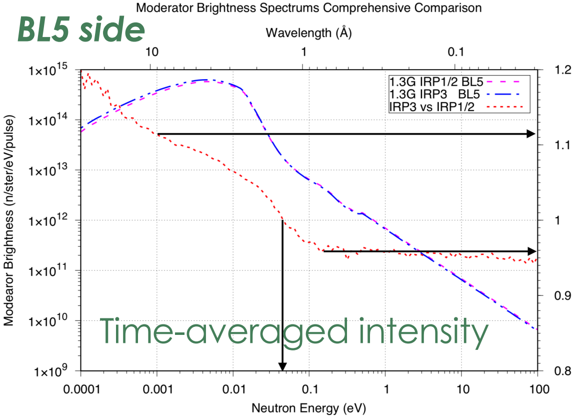
BL2 side

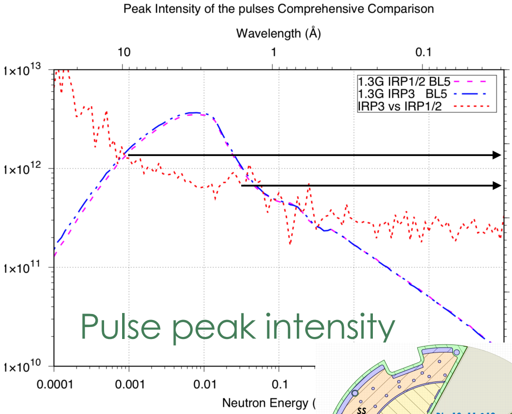
- Similar FWHM
- The gain is mainly due to the pre-moderation of 2 mm D_2O underneath the moderator

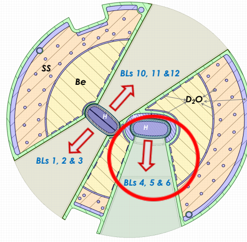
OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

Moderator Performance on IRP3 – coupled H mod.

BL5 side

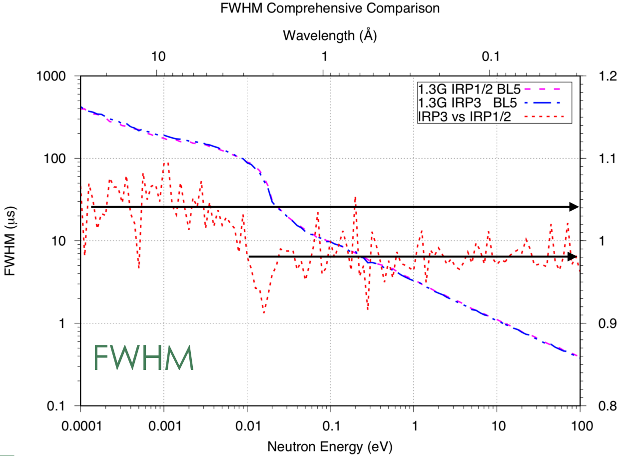






- time-averaged intensity gains for E< 0.4 eV, up to ~10% at 1 meV
- similar gain on the pulse peak intensity
- epithermal neutrons lose ~4% in the time-averaged intensity

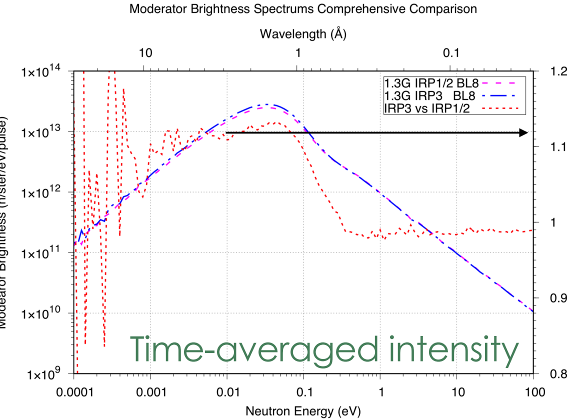
Moderator Performance on IRP3 – coupled H mod.

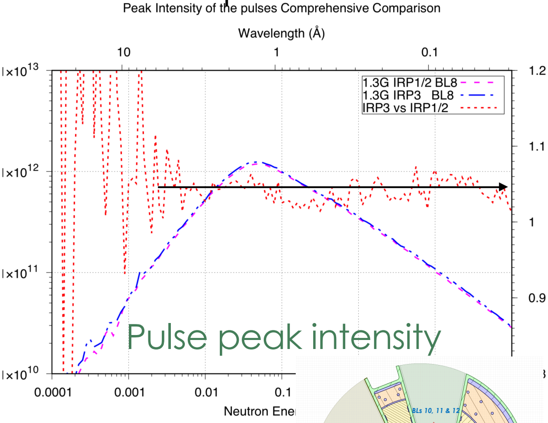


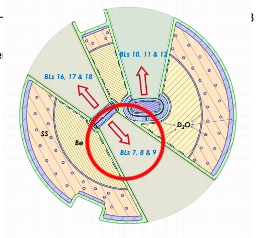
BL5 side

- ~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.



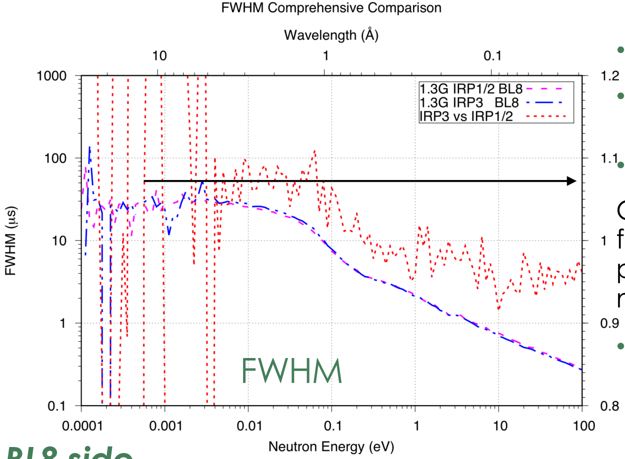




BL8 side

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

Moderator Performance on IRP3 – decoupled water mod.



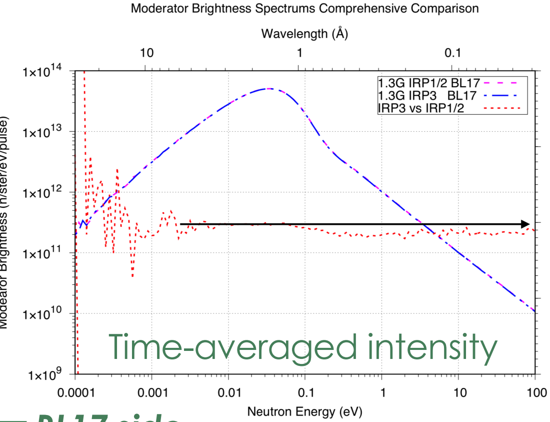
BL8 side

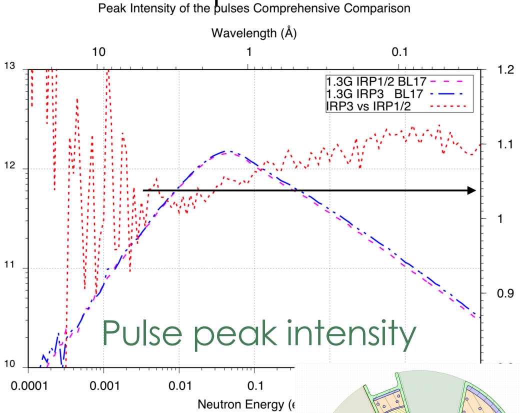
- ~7% wider on pulse width
- ~10-13% gain on time-averaged intensity
- ~4% gain on pulse peak intensity

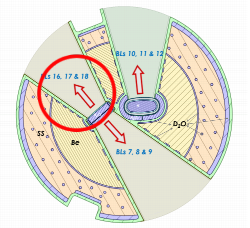
Combined results of PD increase from 1.5 cm to 1.67 cm and Gd poison plate increase from 1.0 mm to 1.3 mm

- 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.





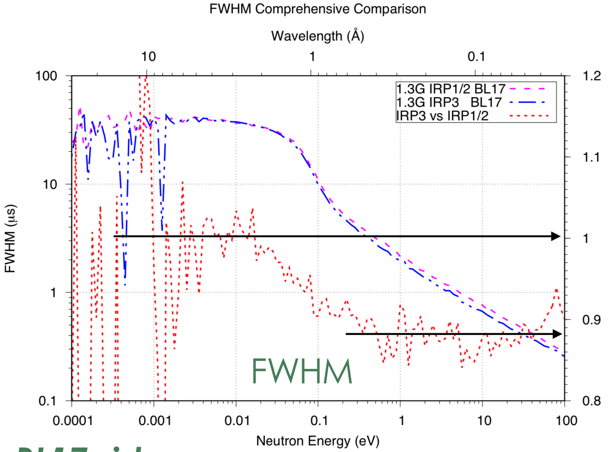


BL17 side

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

OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

Moderator Performance on IRP3 – decoupled water mod.



BL17 side

- 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

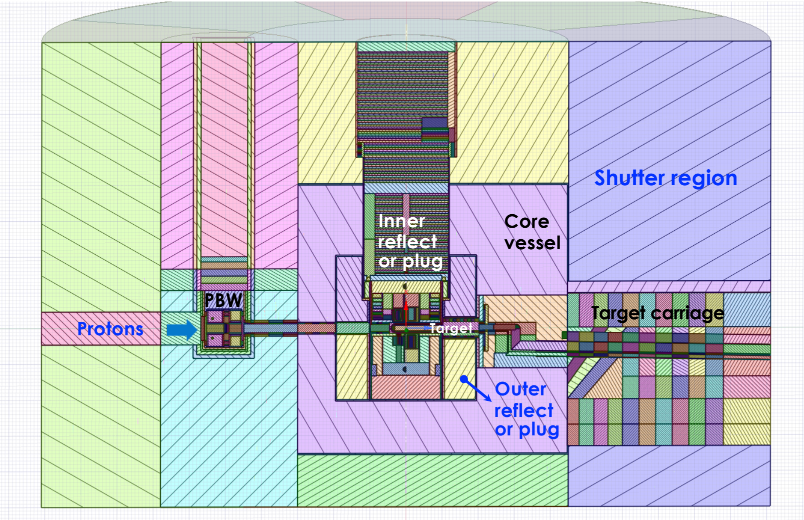
- Previous studies
  - Removal of 2mm Al & 2 mm PD increase on the other side
    - ~1% gain on time-averaged intensity
    - ~5% gain on pulse peak intensity
  - 0.3 mm thickness increase of Gd poison plate
    - ~1% drop on both time-averaged and pulse peak intensity

Summary

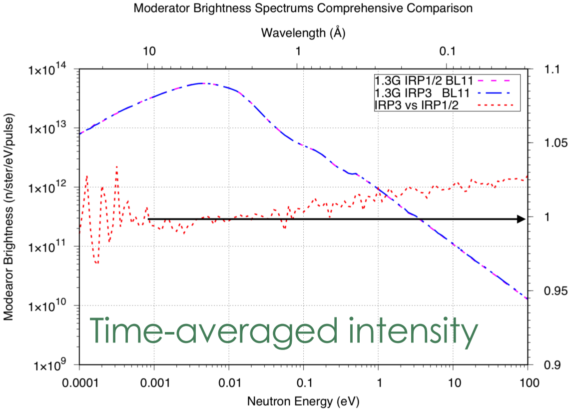
- IRP3 at SNS was effectively modeled for DAGMC-MCNP6 run
- Such a high-fidelity modeling method was proved to be efficient and accurate.
- Moderator performance at IRP3 was shown to be generally higher than that in previous generation IRPs, which proves that the design improvement of IRP3 though intended 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

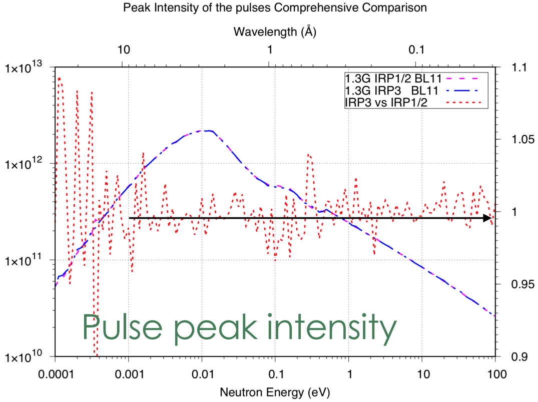
OAK RIDGE National Laboratory | HIGH FLUX ISOTOPE REACTOR | SPALLATION NEUTRON SOURCE

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