Oak Ridge National Laboratory

Beamline diagnostics for tracking neutron beam performance at the Spallation Neutron Source

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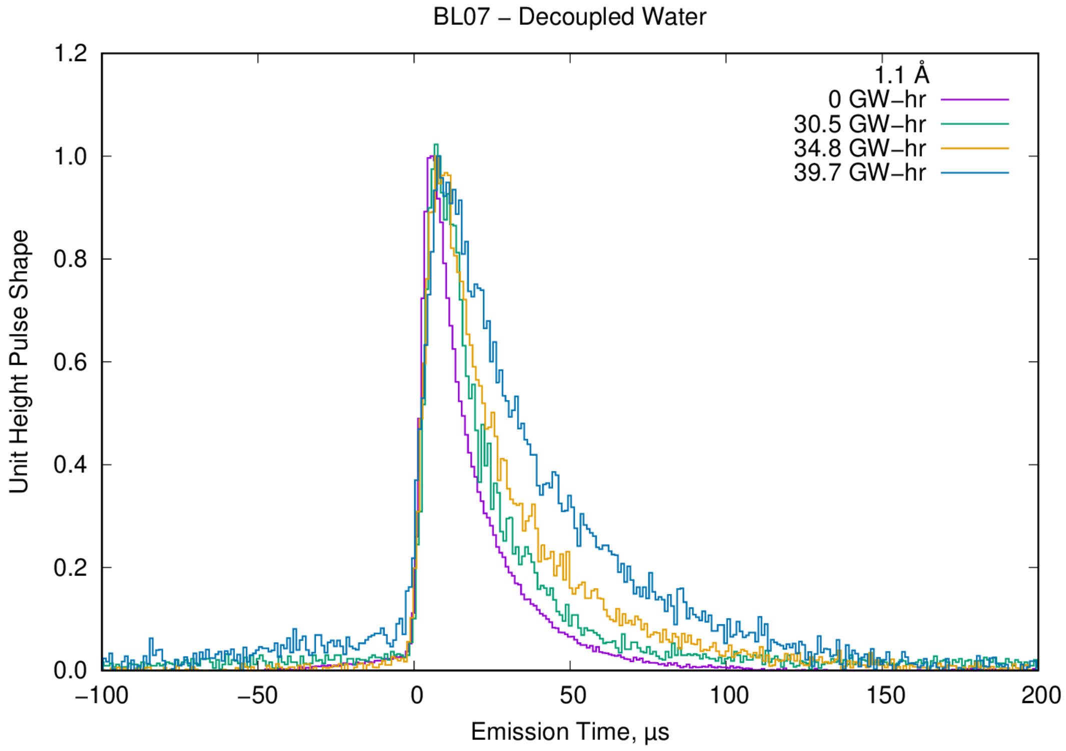
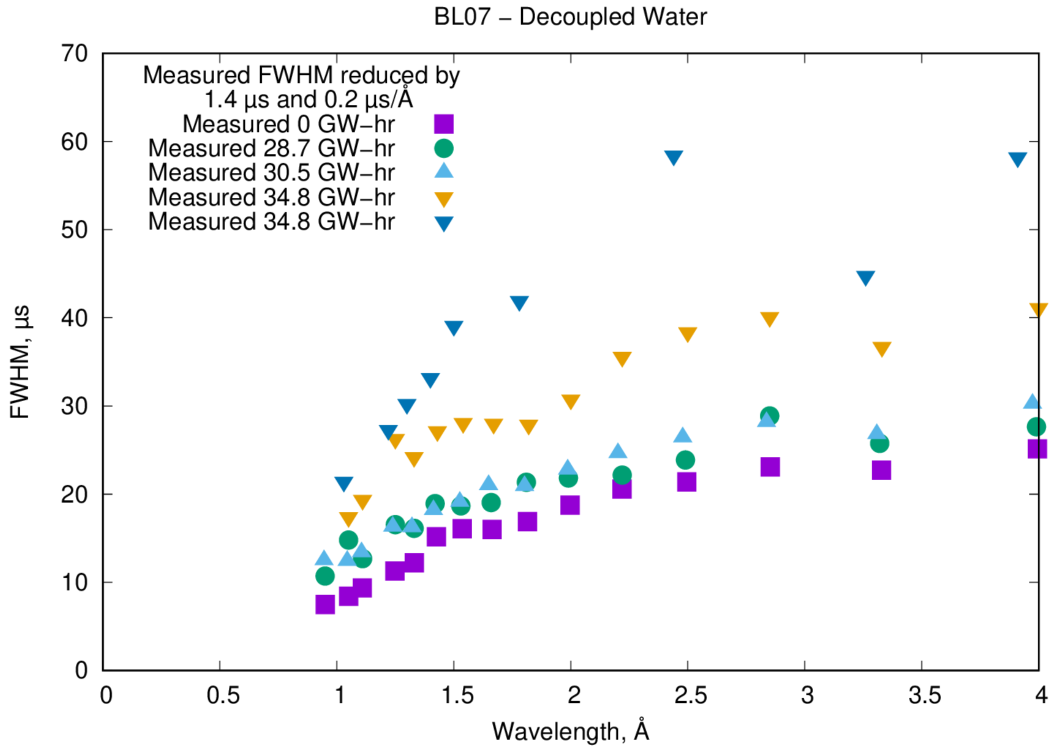
Outline

- So you've got a neutron beam – now what?
  - Characterization of EACH beamline as early as possible is essential; verifying shielding, KPI, and performance – AND as the starting point of a long term monitoring process...
- How can we characterize a neutron beam
  - Energy (wavelength / velocity) spectral distribution
  - Energy-dependent time distribution
  - Transverse extent (i.e., beam footprint)
  - "other stuff" – background / contamination, etc.
- All sounds like commissioning – but we have exactly the same set of questions all along...

Example: VULCAN pulse shape changes over IRP life

- VULCAN instrument (an engineering diffractometer on the decoupled poisoned water moderator) sees enormous changes in the beam over the life of the Inner Reflector Plug (IRP2 replaced with IRP3 in Dec)
- IRP2 was designed for around 30 GW-hr of beam operation against poison and decoupler burnup – it ended up staying in service through 40 GW-hr of operation
- Dedicated pulse shape measurements indicate change at nominal end of life, rapidly worsening, despite subtle changes in routine instrument calibration





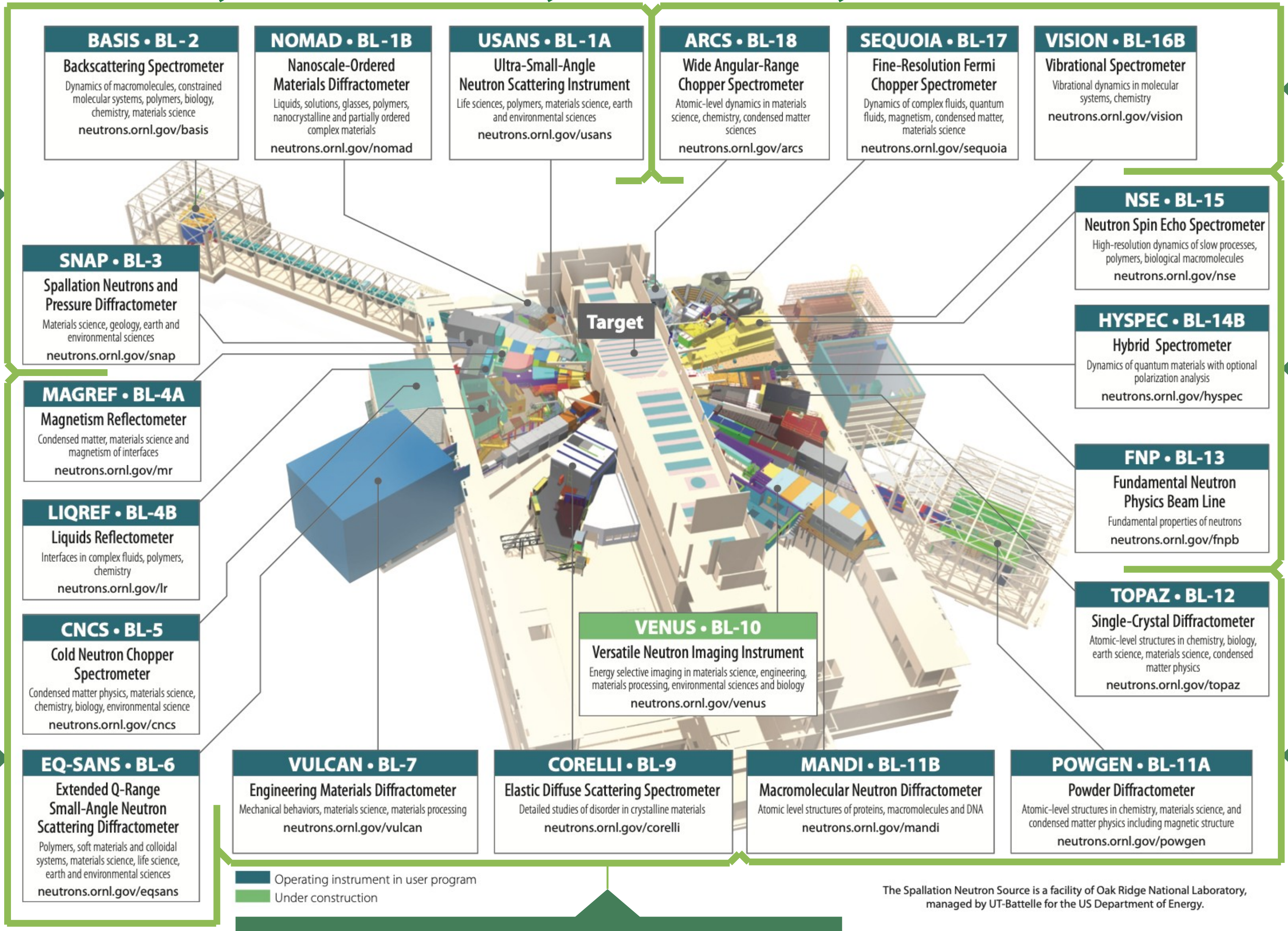
Fast, Comprehensive Before / After Comparisons

- Measured count-rate at variety of incident energies for direct geometry spectrometers (ARCS, SEQUOIA, HYSPEC, CNCS)
- Measured neutron spectral distributions for white-beam instruments (BASIS, SNAP, EQ-SANS, VULCAN, VENUS, VISION)
- Used both *in situ* beam monitors and a dedicated beam monitor in the sample position
- Not a complete comparison – didn't look at pulse shape / resolution, just at raw intensity numbers
- Before and after (IRP replacement) comparison prompts immediate followup with instrument teams and justification for further examination
- Some instrument monitor problems were even identified during the "before" comparisons, permitting significant improvement in instrument operations

Instruments Measured: BASIS, SNAP, CNCS, EQ-SANS, VULCAN, POWGEN, HYSPEC, VISION, SEQUIOA & ARCS

Decoupled Hydrogen Moderator

Top Coupled Hydrogen Moderator



Decoupled Water Moderator (thick side)

Bottom Coupled Hydrogen Moderator

Decoupled Hydrogen Moderator

Decoupled Water Moderator (thin side)

Summary of design changes from IRP-2 to IRP-3

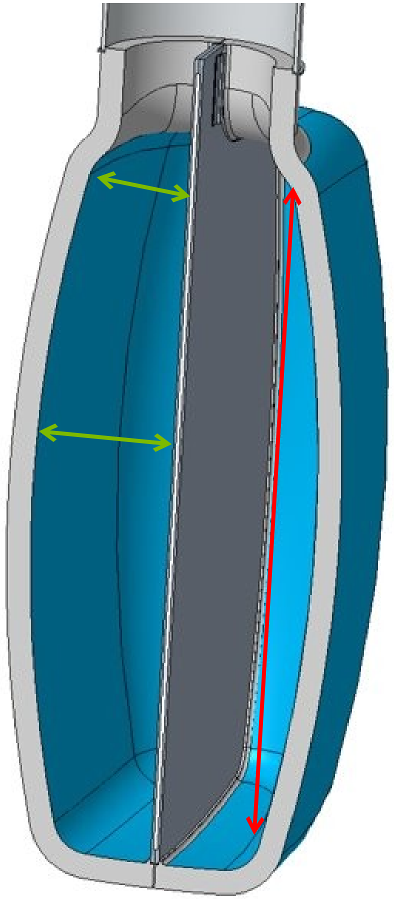
- “Basically” the same – not identical, with “minor changes”
- The poison thickness (gadolinium) in the decoupled water moderator was increased from 1 mm to 1.3 mm to match the lifetime of the decoupled hydrogen moderator and increase the IRP 3 lifetime to 38 GW-hr, with a +3% / +8% performance impact (thick/thin side)
- Aluminum flow baffle removed from decoupled water moderator vessel (thin side, now 17 not 15 mm thick) with 10% expected performance increase (pulse-integrated)
- Coupled hydrogen moderator has improved wrapping of pre-moderator medium and reduced aluminum thickness at emission face enhancing cold neutron flux by ~8%.
- Increased penetration of stinger feeding decoupled hydrogen moderator as a first measure countering the power non-linearity.
- All these changes described apply to a comparison at beginning-of-life for both IRPs, but that’s not what we have – we have IRP 2 EOL to IRP 3 BOL, which adds PPU
  - 1.0 GeV to 1.3 GeV
  - Hydrogen catalyst

Nominal Moderator Geometry (at room temperature)

* Inlet pipe not shown

0.813 inch (20.7 mm) space nominally

1.139 inch (28.9 mm) space nominally

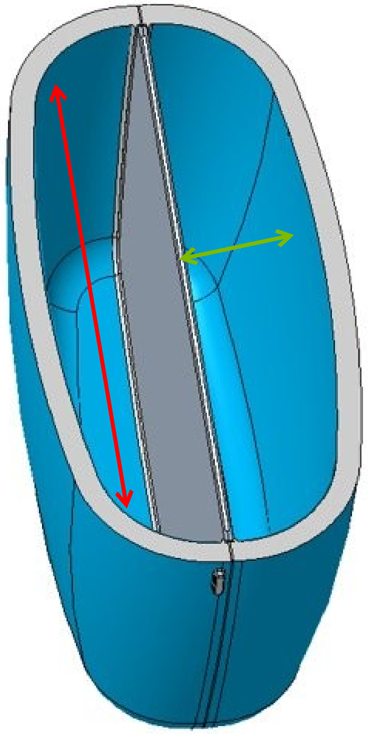


11 inch (280 mm) spherical radius internal surface of moderator

The hydrogen thickness of the moderator varies across the face due to the shape of the moderator

Inside portion 5.3 inch (135 mm) tall at center

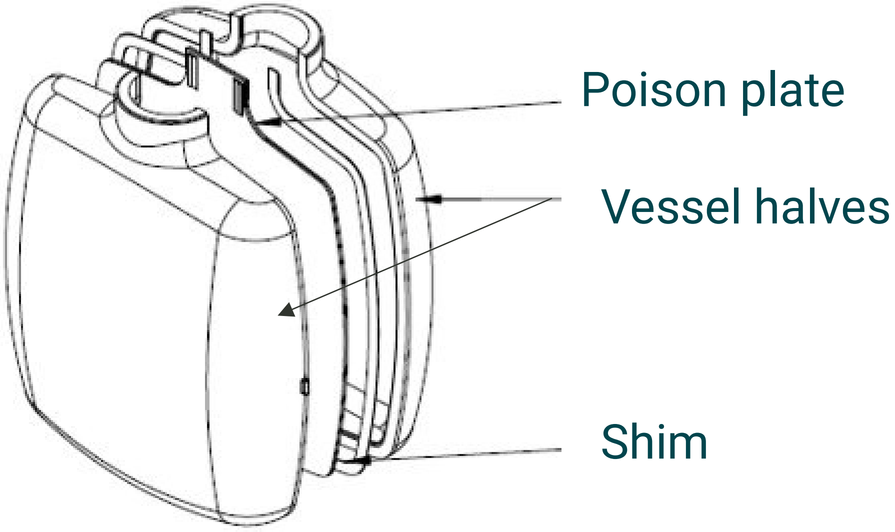
Inside portion 3.8 inch (97 mm) wide



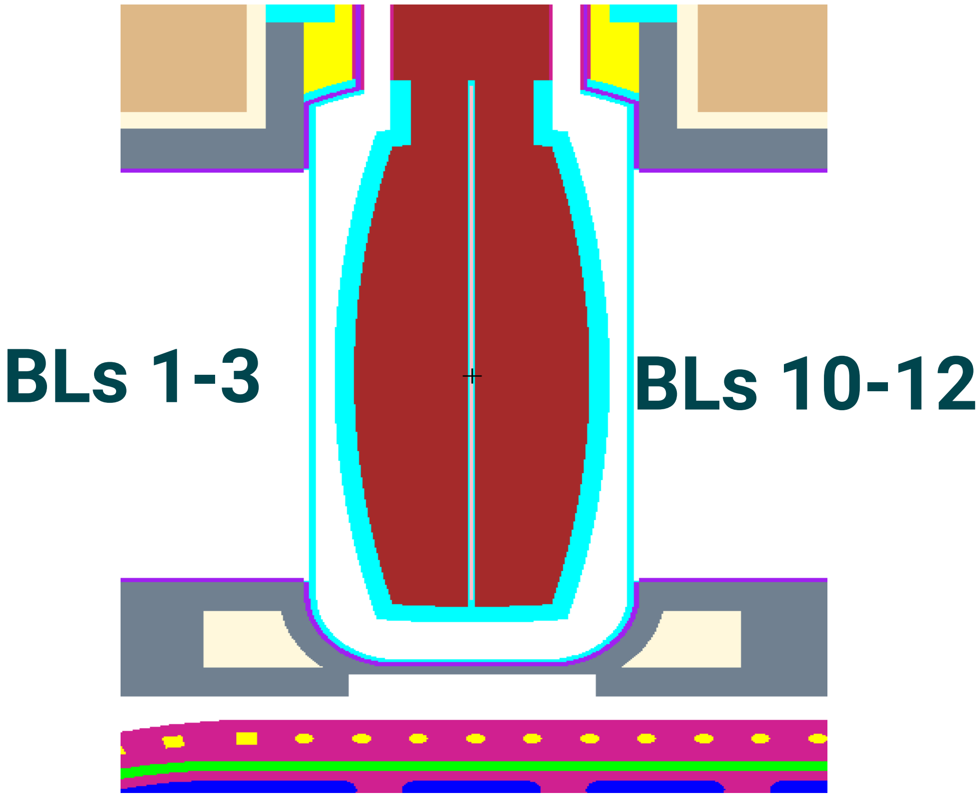
1.139 inch (28.9 mm) space nominally

IRP-3 Moderator component manufacture and processing are unchanged from IPR-2

- Moderator vessels consist of four pieces
- Aluminum fabrications, except for gadolinium inside the poison plate
- Vessel is electron beam welded to reduce distortion



Effects due to distortion of the Gd poison plate in the decoupled hydrogen moderator for IRP-2



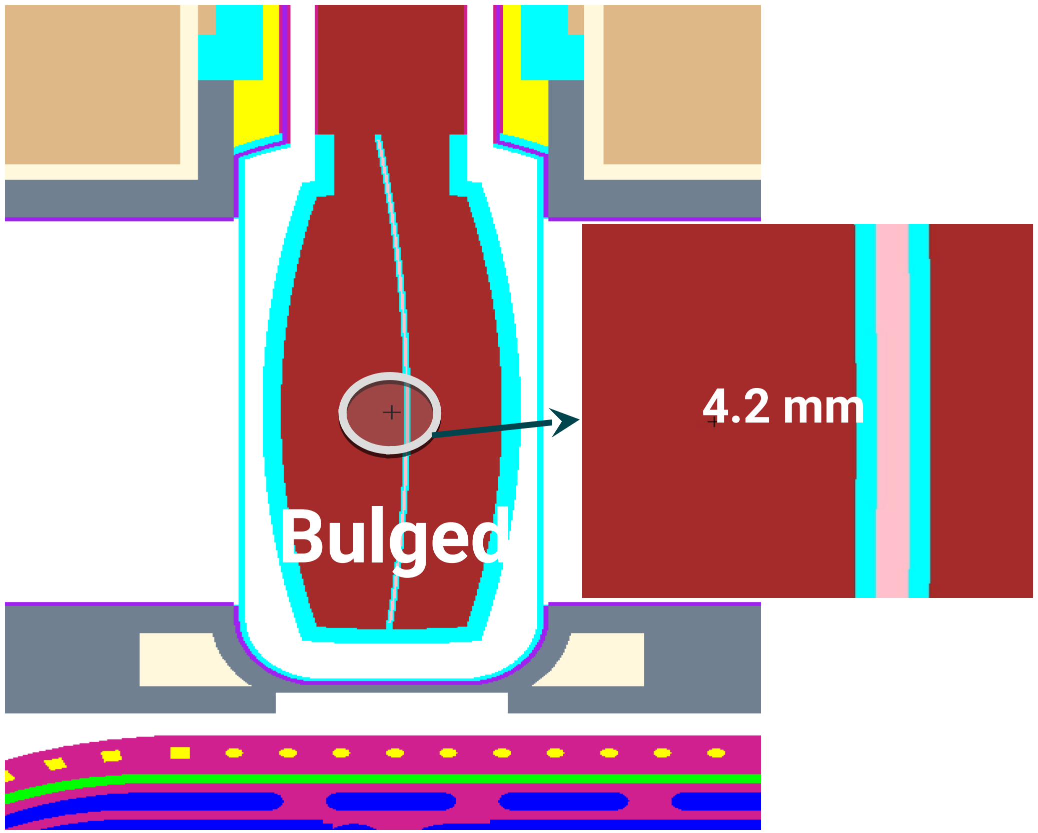


Plate buckled toward POWGEN for IRP-2; flipped for IRP-3
-25% for “thin” side, +35% for “thick” side

Coupled Hydrogen Shows Flux Gain (BL-05 / EQ-SANS)

Expected Changes

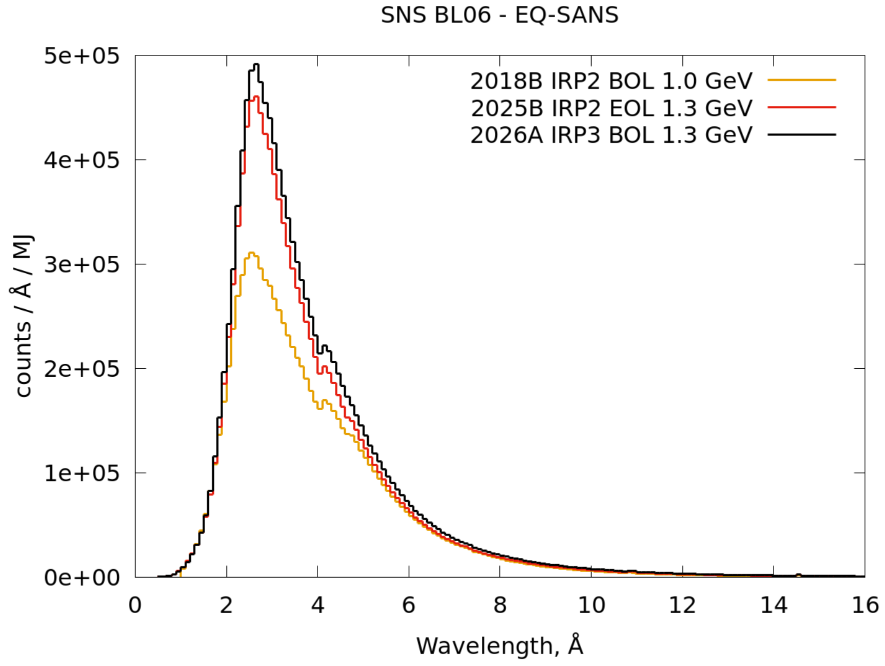
- Decoupler and poison burnup are largely irrelevant for the coupled, unpoisoned moderators
- Installation of orthohydrogen converter during PPU changes spectrum, boosting peak and very long wavelengths
- Increase in energy during PPU boosts intensity slightly by moving neutron production peak toward coupled moderators, which also happen to be the downstream moderators
- Expansion of premoderator coverage in IRP3 boosts intensity

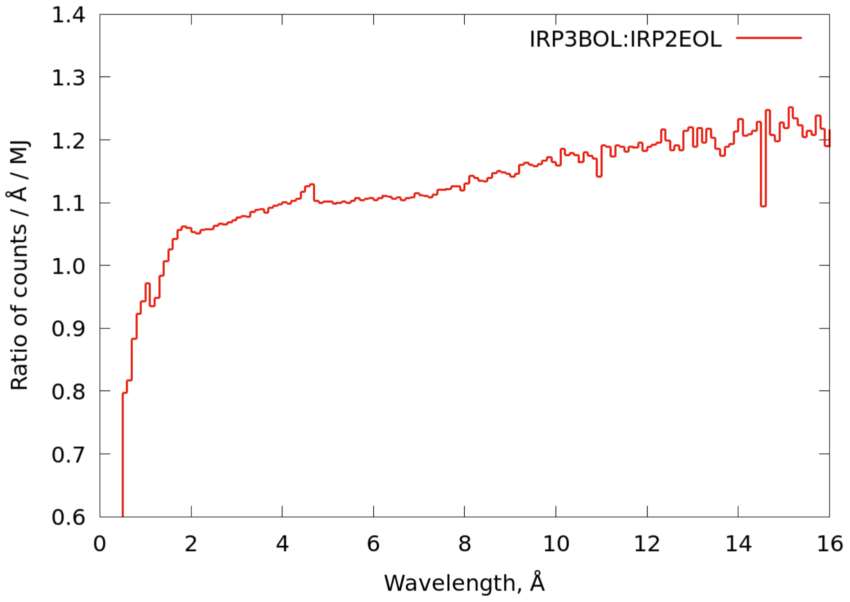
Preliminary Observations

- Small GAIN in intensity relative to IRP2 EOL – around 10% average, more at long wavelengths
  - Attribute to increased premoderator coverage on coupled moderator
- Significant GAIN in intensity relative to IRP1 BOL – around 60% at peak
  - Attribute to PPU changes

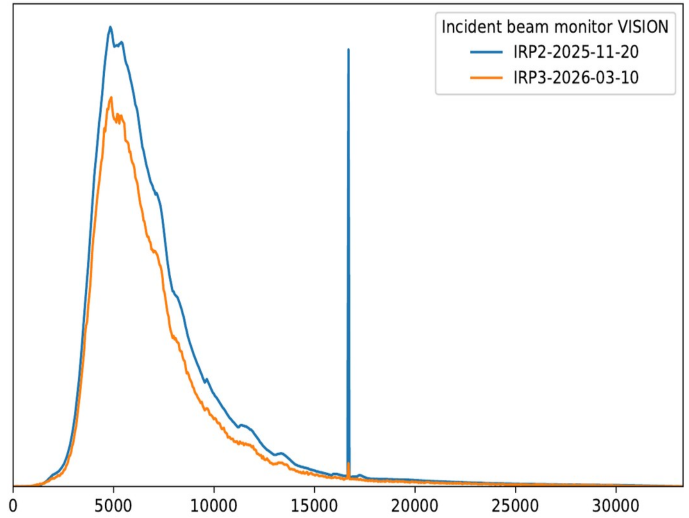
Further work

- Planned measurements at CNCS, HYSPEC will confirm effects





Decoupled Water (thick) Shows Expected Flux Loss (BL-16b / VISION)

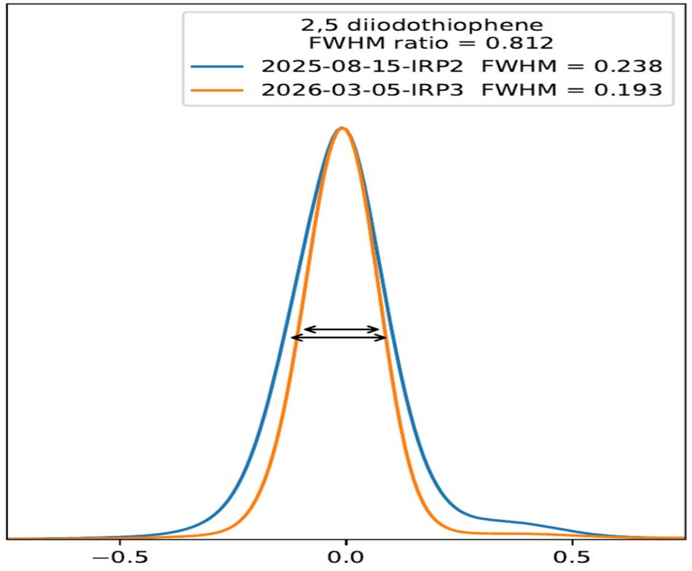


Expected Changes

- Decoupler and poison are new, and will suppress overall intensity by about 20% relative to “burned up” IRP2
- Poison thickness increase (to support longer IRP life) will suppress overall intensity by about 3% relative to IRP2 BOL
- Poison plate repositioning and removal of flow baffle will increase intensity by about 3%
- All reductions in intensity should be accompanied by reductions in pulse width (that is, improvement in resolution)

Preliminary Observations

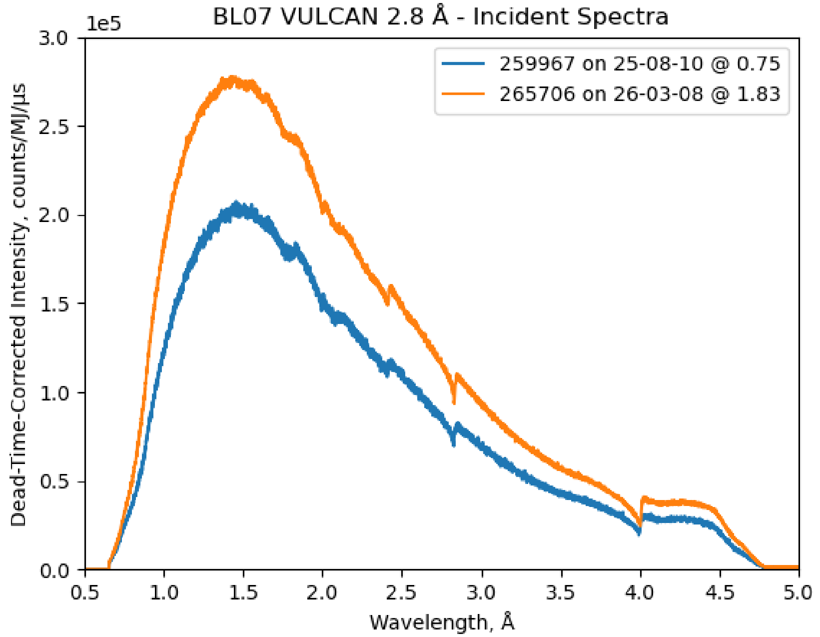
- IRP3 BOL to IRP2 EOL monitor countrate ratio reflects 20% loss in intensity across wavelength range for VISION
- Resolution has improved by 15-20%
- Inconsistent results from ARCS & SEQUOIA suggesting 5-10% GAIN in intensity



Further work

- Additional confirmatory measurements on VISION
- Additional detailed measurements on ARCS and SEQUOIA
- Reconciliation of VISION (flux loss) and ARCS & SEQUOIA (flux gain) observations
- Assessment of resolution effects on ARCS & SEQUOIA using standard samples and downstream beam monitors

Decoupled Water (thin) Shows Unexpected Flux Gain (BL-07 / VULCAN)



Expected Changes

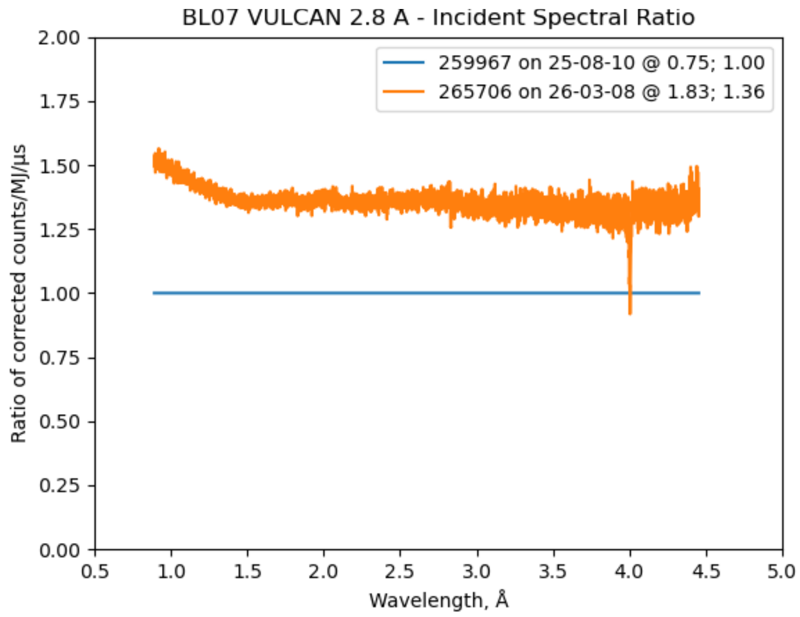
- Decoupler and poison are new, and should suppress overall intensity by about 35% relative to "burned up" IRP2
- Poison thickness increase (to support longer IRP life) will suppress overall intensity by about 8% relative to IRP2 BOL
- Poison plate repositioning and removal of flow baffle will increase intensity by about 8%
- Overall, expect net 35-40% loss
- All reductions in intensity should be accompanied by reductions in pulse width (that is, improvement in potential resolution)

Preliminary Observations

- IRP3 BOL to IRP2 EOL monitor countrate ratio reflects 35% GAIN in intensity across wavelength range
- Instrument calibration data (vanadium), not shown, suggests 25% GAIN in intensity across wavelength range relative to IRP2 EOL
- No apparent change in resolution observed, data not shown (suggesting instrument resolution is not dominated by moderator, but by instrument geometry)

Further work

- Additional confirmatory measurements on VULCAN, including powder standards for line shape, position and resolution
- Confirmation with monitor and scattering measurements on CORELLI



Decoupled H_2 (forward) Shows >Expected Flux Gain (BL-11a / POWGEN)

Expected Changes

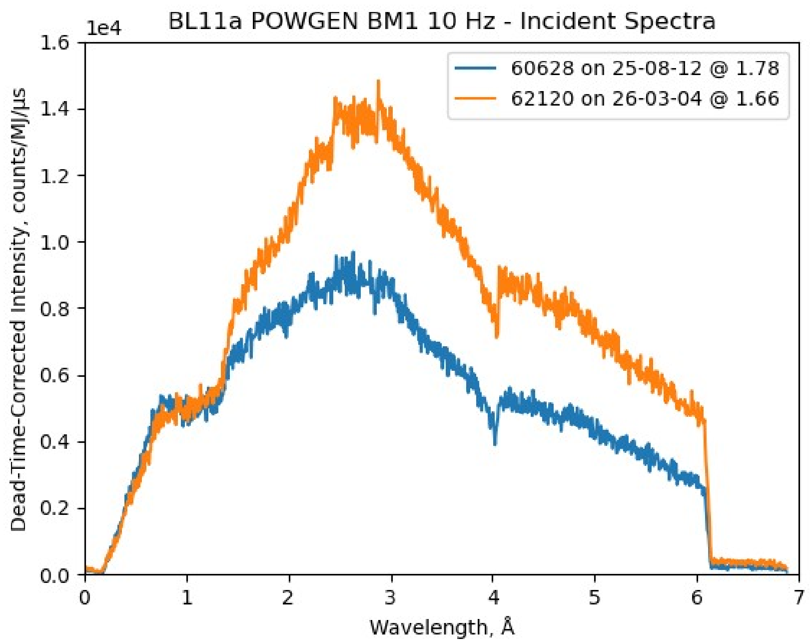
- Decoupler and poison are new, and should suppress overall intensity by about 17% relative to "burned up" IRP2
- Changes in moderator design intended to improve flow patterns, reducing non-linearity in performance with power by reducing potential flow stagnation. Non-linearity reduced intensity at full power by 10-20% depending on wavelength
- Known non-conformances resulted in a bulged poison plate, shifting intensity from POWGEN side to BASIS side, in IRP2. Facility choice to reverse that bulge for IRP3, favoring flux at POWGEN and resolution at BASIS
- Net ~ 25% increase in flux on VENUS, POWGEN, MANDI, and TOPAZ
- All increases in intensity should be accompanied by increases in pulse width (that is, poorer potential resolution)

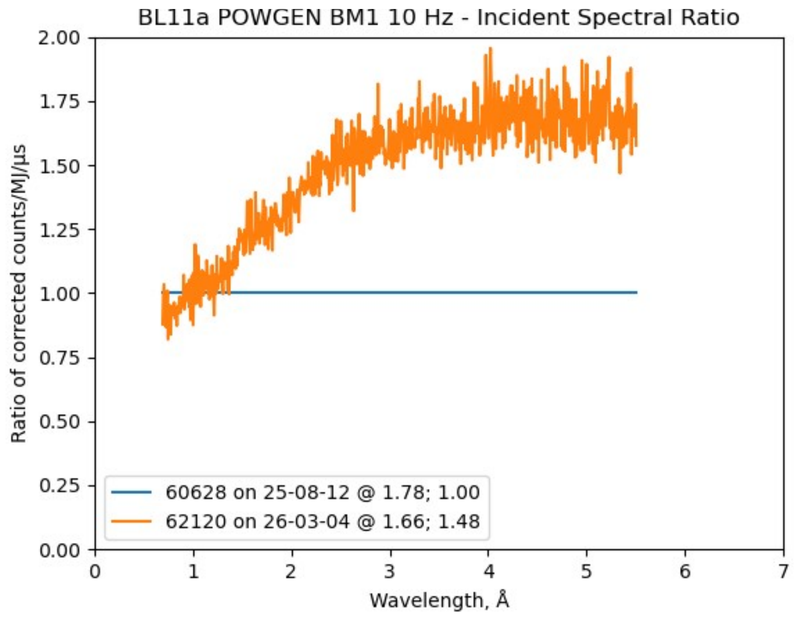
Preliminary Observations

- IRP3 BOL to IRP2 EOL POWGEN monitor countrate ratio reflects 30 to 70% GAIN in intensity depending on wavelength (larger than anticipated)
- Consistent change in incident beam intensity on VENUS (not shown)
- No apparent change in resolution observed, data not shown (suggesting instrument resolution is not dominated by moderator, but by instrument geometry)
- Power dependence reduced; 8%, wavelength independent (next page)

Further work

- Confirmation measurements on all instruments, w/ standards for line shape
- Improved statistics and coverage during upcoming power ramp for non-linearity





Decoupled H_2 (forward): Less Power Non-Linearity (BL-11a / POWGEN)

Expected Changes

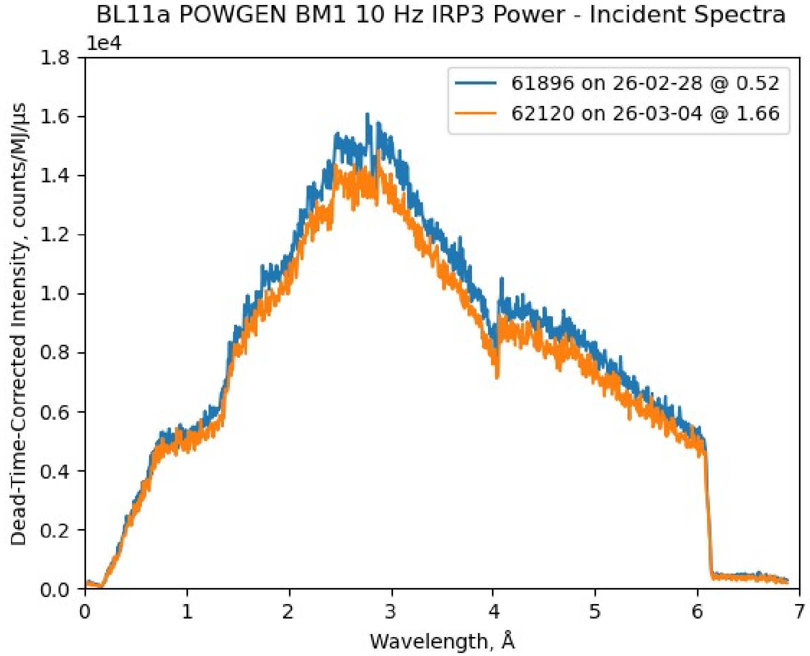
- Changes in moderator design intended to improve flow patterns, reducing non-linearity in performance with power by reducing potential flow stagnation. Non-linearity reduced intensity at full power by 10-20% depending on wavelength
- All increases in intensity should be accompanied by increases in pulse width (that is, poorer potential resolution)

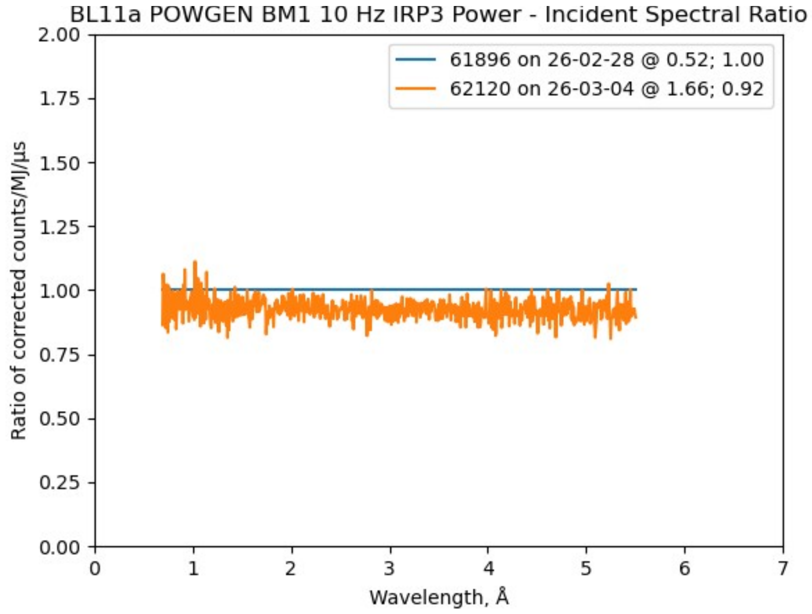
Preliminary Observations

- Power dependence reduced; about -8%, wavelength independent; very different than before

Further work

- Repeat during power ramp, so we get multiple points along curve, and so that everything is continuous, rather than separated by a week





Decoupled H_2 (backward) - Flux Reduction (>expected) (BL-03 / SNAP)

Expected Changes

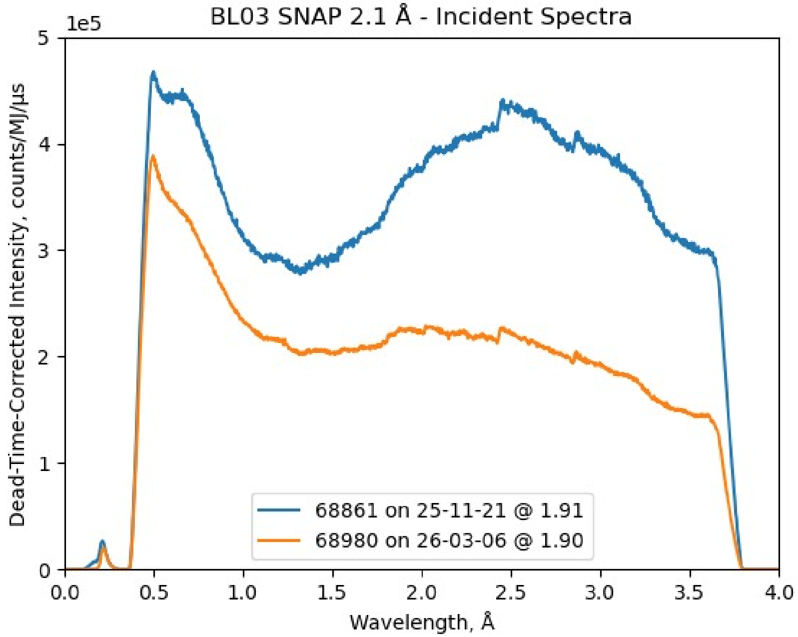
- Decoupler and poison are new, and should suppress overall intensity by about 17% relative to "burned up" IRP2
- Changes in moderator design intended to improve flow patterns, reducing non-linearity in performance with power by reducing potential flow stagnation. Non-linearity reduced intensity at full power by 10-20% depending on wavelength
- Manufacturing issues resulted in a bulged poison plate, shifting intensity from POWGEN side to BASIS side, in IRP2. Facility choice to reverse that bulge for IRP3, favoring flux at POWGEN and resolution at BASIS
- Net effect: 35% reduction on flux for USANS ,NOMAD, BASIS, and SNAP
- All reductions in intensity should be accompanied by reductions in pulse width (that is, improvement in potential resolution)

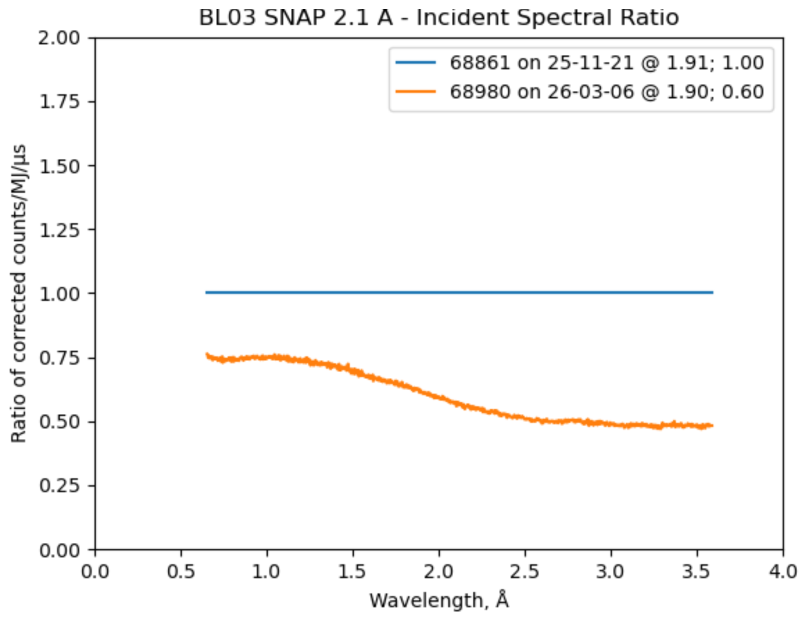
Preliminary Observations

- IRP3 BOL to IRP2 EOL SNAP monitor countrate ratio reflects 50 to 70% LOSS in intensity depending on wavelength (larger than anticipated)
- Consistent change in incident beam intensity on NOMAD and USANS (not shown)
- No apparent change in SNAP resolution observed, data not shown (suggesting instrument resolution is not dominated by moderator, but by instrument geometry)

Further work

- Additional confirmatory measurements on NOMAD and BASIS, including standards for line shape and resolution





Decoupled H_2 (backward) - Reduced Power Non-Linearity (BL-03 / SNAP)

Expected Changes

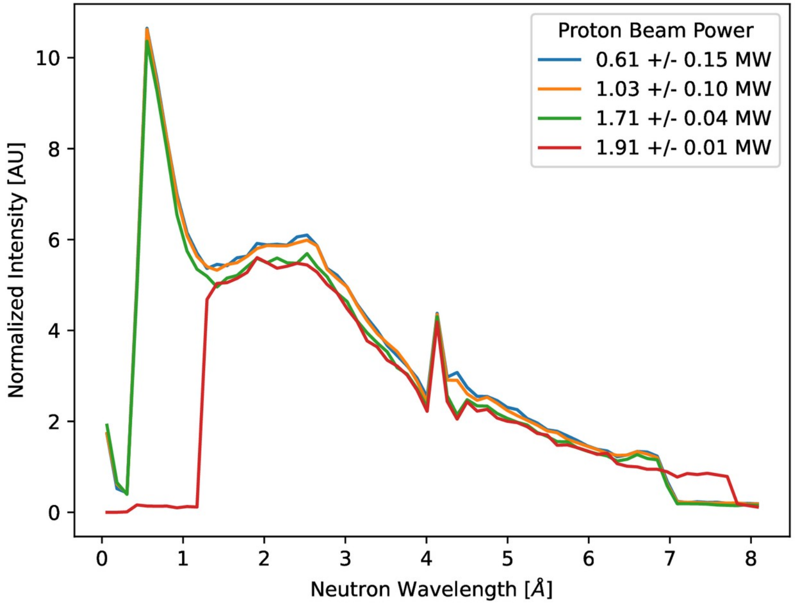
- Changes in moderator design intended to improve flow patterns, reducing non-linearity in performance with power by reducing potential flow stagnation. Non-linearity reduced intensity at full power by 10-20% depending on wavelength
- All increases in intensity should be accompanied by increases in pulse width (that is, poorer potential resolution)

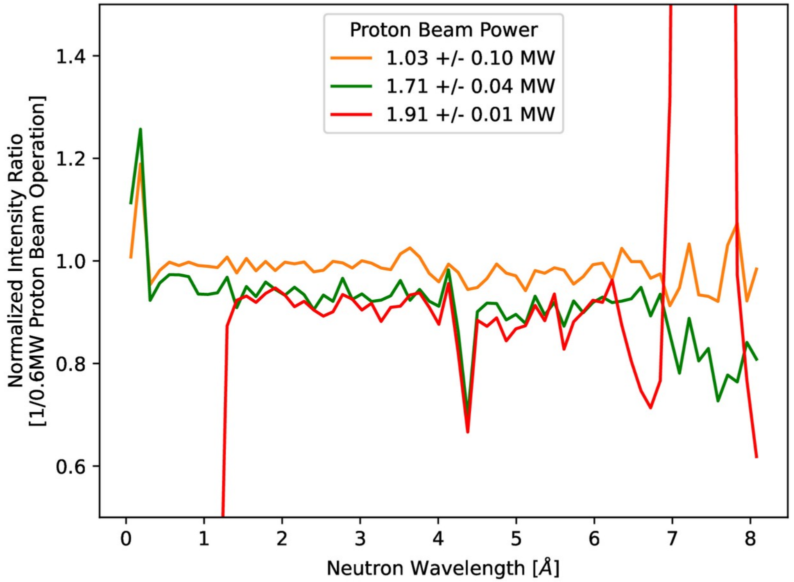
Preliminary Observations

- Power dependence is reduced; about -5-10%, seems wavelength independent; very different than before
- Loss is same on both sides – despite apparent significant bulge – shouldn't that impact a stagnation zone differently?

Further work

- Repeat during power ramp, so we get multiple points along curve, and not separated by some days (start-up power ramp was...rough, and included chopper problems, as evident)
- Better statistics





Expected performance change from IRP-2 EOL to IRP-3

Modification	IRP2 EOL vs. IRP3 BOL analysis	IRP2 EOL vs. IRP3 BOL reality?
DWM poison plate repositioning	1.03 peak DWM thick side 1.08 peak DWM thin side +8% wider pulse widths	
DWM poison thickness increase	0.97 DWM thick side 0.92 DWM thin side	
Beryllium height reduction (15 cm)	0.99	
Poison burnup (fresh vs 40 GWh)	0.80 DWM thick 0.63 DWM thin 0.83 DHM	
DHM Power nonlinearity	1.10 DHM	Reduced, but still present
DHM poison plate bulge expected	1.35 DHM forward 0.74 DHM backward	
CHM modifications	1.08	
Summary	CHM 1.08 DWM thick 0.79 DWM thin 0.62 DHM forward 1.22 DHM backward 0.67	CHM 1.10 (EQSANS) DWM thick 0.80 (VISION) DWM thin 1.35 (VULCAN) DHM forward 1.48 (POWGEN) DHM backward 0.60 (SNAP)

Summary

- Six viewed moderator faces:
- Coupled hydrogen (2) – changed exactly as predicted for IRP-2 to IRP-3 swap
- Decoupled water (thick and thin) – sort of not quite but maybe okay…?
  - VISION (thick side) lost flux and improved resolution exactly as expected, but other beams viewing the same face seem initially to have gone up. Need to keep looking
  - VULCAN (thin side) should have gone down quite a bit – instead went up quite a bit. There is a known optics issue with the instrument (currently under study). Important note – modern instruments have a lot going on. Changes in the source (moderators) during outages are going to be simultaneous with changes on instrument (maintenance and upgrades). We rarely get to look at one change at a time! Need to keep looking
- Decoupled hydrogen (2 faces) – changed as expected, but more sharply – expected +20/-30, got +50/-40. Power-dependent performance changed, but still present.
  - Note – it changed as expected, but not everyone (i.e., instrument teams) really heard that expectation. Communicate and manage expectations on repeat!