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# Ray-Tracing Simulations Characterising the Performance of the Proposed HFIR HB4 Main Shutter


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**August 2021**

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Neutron Technologies Division, Neutron Scattering Sciences Directorate

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## ABBREVIATIONS

| | |
|---|---|
| ORNL | Oak Ridge National Laboratory |
| HFIR | High Flux Isotope Reactor |
| HBRR | HFIR Beryllium Reflector Replacement |
| FOM | Figure of Merit |
| ROI | Region of Interest |
| MCNP | Monte Carlo N-Particle |

## ABSTRACT

The Main Shutter at HB4 will serve two purposes after the HFIR Beryllium Reflector Replacement planned to take place in 2024. First as the primary certified safety control controlling the passage of neutrons from the cold source in the HFIR pressure vessel into the cold guide hall, and second as the first set of reflecting surfaces used to guide neutrons from the source and into the individual guide starts for each instrument in the cold guide hall.


# 1. PURPOSE AND REQUIREMENTS

As stated above, the main shutter will contain the first set of reflecting surfaces serving any of the instruments in the cold hall after 2024. The goal of the reflecting surfaces at this location is to enhance the total cold neutron flux available to any of those instruments. As a result, the guide geometry and coatings are especially tailored to meet the needs of the planned instruments in the cold guide hall upgrade. Furthermore, the positioning and alignment requirements for this multiplexed guide section within the main shutter body will need to meet standards as determined by simulating misalignment of the guide section. This will be the main result of this report.

# 2. NEUTRON BEAM DESIGN

The simulation software utilized to understand the proposed geometry and its alignment requirements is McStas [2]. McStas provides a straightforward means by which to replicate the anticipated performance of the HFIR cold source and the instruments that utilize its neutron flux. This analysis comprises three distinct assemblies: the Cold Source, the Beam Tube and the Main Shutter. Within the Main Shutter assembly are three guide channels, S1, S2, and S3. S1 will feed NB1, NB3, and NB4. S2 will feed NB2 and NB5. S3 will feed NB6. The planned layout at the exit of the shutter is seen in Figure 1. Surface reflectivity will be optimized to accommodate the instrument with the most demanding requirements in each channel.

## 2.1 HB4 Cold Source

The HB4 Cold source is liquid hydrogen at 20K and about 15 atm pressure confined within a volume of 465 $cm^3$ [3]. The viewable surface of the source is nominally an oval with minor radius 3 cm and major radius 4 cm, providing an emission area of approximately 40 $cm^2$. This oval geometry is due to the inlet and outlet ports needed to circulate the hydrogen through the beam tube and into the source volume. As seen in Figure 2, the location of the cold source is at the deepest possible location within the existing beam tube design.

Detailed simulations describing the overall performance of the source can be found in [3] as well as a survey of possible future improvements. The McStas simulation uses the component *Source_gen* in combination with masks to replicate the emission area and spectral shapes of the cold source. As seen in Figure 3, the total emitted area from the source is 39.53 $cm^2$. The spectrum emitted by this area is that of a triple Maxwell-Boltzmann distribution using the parameters in Table 1 to dictate the integrated source brightness and temperature of each. These were determined from [4] and revised downward by 17% in 2020. The details of this revision can be seen in Appendix A. The spectrum used to replicate the measurement is seen in figure 3.

**Table 1. The neutron spectral brightness is defined using a triple Maxwell-Boltzmann Distribution and the following parameters.**

| Brightness [neutrons/(cm$^2$·sr·s)] | Temperature [Kelvin] |
|---|---|
| $6.07 \times 10^{12}$ | 325 |
| $2.61 \times 10^{13}$ | 67.2 |
| $7.95 \times 10^{12}$ | 27.3 |

## 2.2 HB4 Beamtube

The HB4 Beam Tube contains many components, most of which are used to support the cold source volume deep inside the tube and provide initial coarse collimation of the neutron flux in the beam tube. Figure 4 shows an over-head view of the source, beam obstructions and the collimator as described by the McStas simulations provided in Appendix B.

## 2.3 HB4 Main Shutter Guide Channels

The Main Shutter sits approximately 80 cm downstream of the exit of the primary collimator. This shutter will be a large cylinder that rotates about a vertical axis. This will provide both radiological protection when closed and a sturdy housing for the guide channels to reside. Since the shutter will be movable and contain a key optical component, the alignment of the shutter when initially installed will be very important. Additionally, the alignment of the shutter drive end point in the open position is also crucial to the performance of the guide as will be shown in Section 4.

### 2.3.1 Guide Channel Shape and Reflectivity

As described prior, there are three channels in the Main Shutter Guide insert. These are the first reflecting surfaces for the instruments that are proposed for the Cold Guide hall upgrade. The optical requirements within the shutter are determined by what the source can provide through the primary collimator and what the instruments need to meet their science goals. Those needs are dictated by the minimum neutron wavelength and maximum beam divergence on the sample, as noted in [1]. A summary of these requirements is seen in Table 2.

**Table 2. The baseline geometry and reflectivity for the Main Shutter guide channels can be determined via the Wavelength and Divergence requirements for each instrument [1].**

| Instrument | Shutter Channel | Min. Wavelength [Angstroms] | Max. Divergence VxH [FWHM Degrees] |
|---|---|---|---|
| NB1 IMAGINE | S1 | 2.0 | 0.2x0.2 |
| NB2 NSE/Alignment | S2 | 2.4 | 1.5x0.9 |
| NB3 BioSANS | S1 | 3.0 | 0.5x0.5 |
| NB4 Imaging | S1 | 2.4 | 0.4x0.4 (L/D 150) |
| NB5 GPSANS | S2 | 3.0 | 0.5x0.5 |
| NB6 MANTA | S3 | 1.8 | 3.0x2.0 |

Based on these requirements, combined with the location of the Main Shutter and the phase space permitted by the beamtube collimator, one can layout a geometry that will meet almost all of the instrument requirements seen in Table 2. The assignments of each instrument to a certain channel was based on layout in the guide hall and sensitivity to guide curvature disruptions; details regarding this feature of the instrument layout are documented in [1]. One can see the collimator exit flux distribution and source to shutter distance in Figure 5, which dictates the permitted range of guide channels and allowed angular acceptance. From this, an entrance/exit geometry (not-to-scale) is proposed and seen in Figure 6. The geometry permits angles of 1.39, 1.39, and 1.53 degrees of horizontal acceptance for S1, S2 and S3 respectively. S1 and S2 meet their horizontal divergence requirements nicely, and while S3 does not, the flux distribution requirement of 20 mm will provide the flexibility needed to convert the wider space distribution into a wider beam divergence using the right focusing optic design. Vertically, the source is larger and the openings into each guide is equal to or greater than any of the widths, thus any concern trying to fill the required vertical phase space is minimal.

Using these angles, one can then analytically determine the super-reflective coating cut-off, $m$, needed to reflect a given neutron wavelength $\lambda$ at the maximum required angle $\theta$. The equation dictating this is

$$m = 10\frac{\theta[^\circ]}{\lambda[\text{Å}]} \tag{1}$$

Figure 7 plots this equation for each instrument and guide channel.

The geometry used to describe all three guide channels is given in Appendices D, E, and F in the form of OFF geometry files.

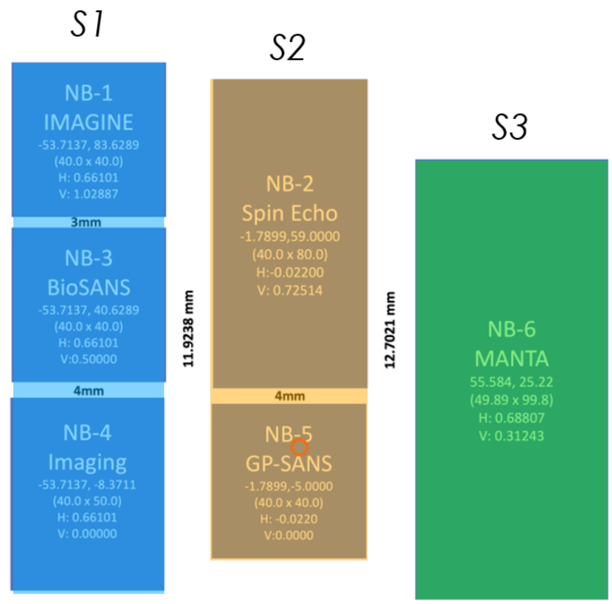


**Figure 1. A schematic layout showing the planned guide start interface geometry at the exit of the Main Shutter.**

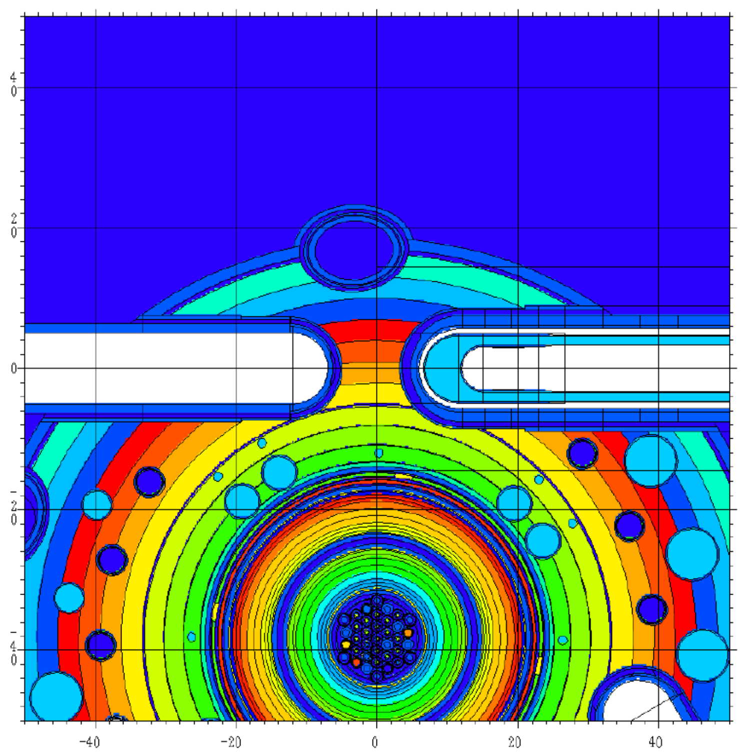


**Figure 2. A cross-cut view of the cold source within the HB4 Beam tube.** The cold source resides at the deepest position possible in the HB4 beamtube and contains 465 $cm^3$ of liquid hydrogen. More details can be found in [3].

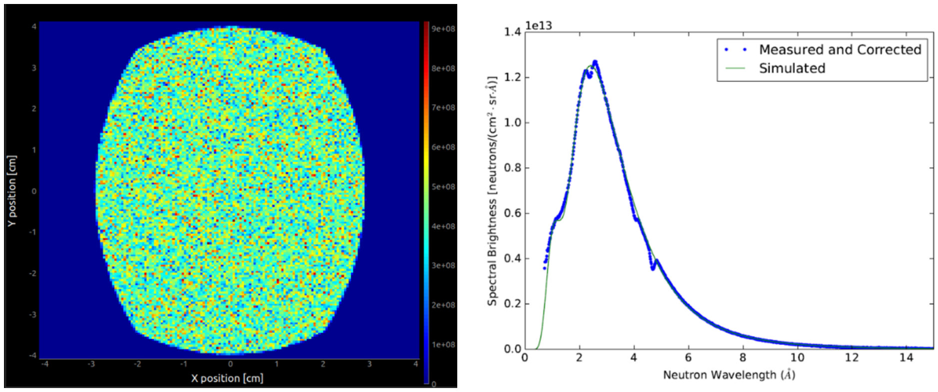


**Figure 3. Plots describing the HB4 cold source used in McStas simulations.** [Left] An image of the cold source flux distribution. [Right] The spectral brightness of the HB4 cold source. The blue dots are measured [4] and the green trace is the simulated spectrum from Triple MB fit using parameters seen in Table 1.

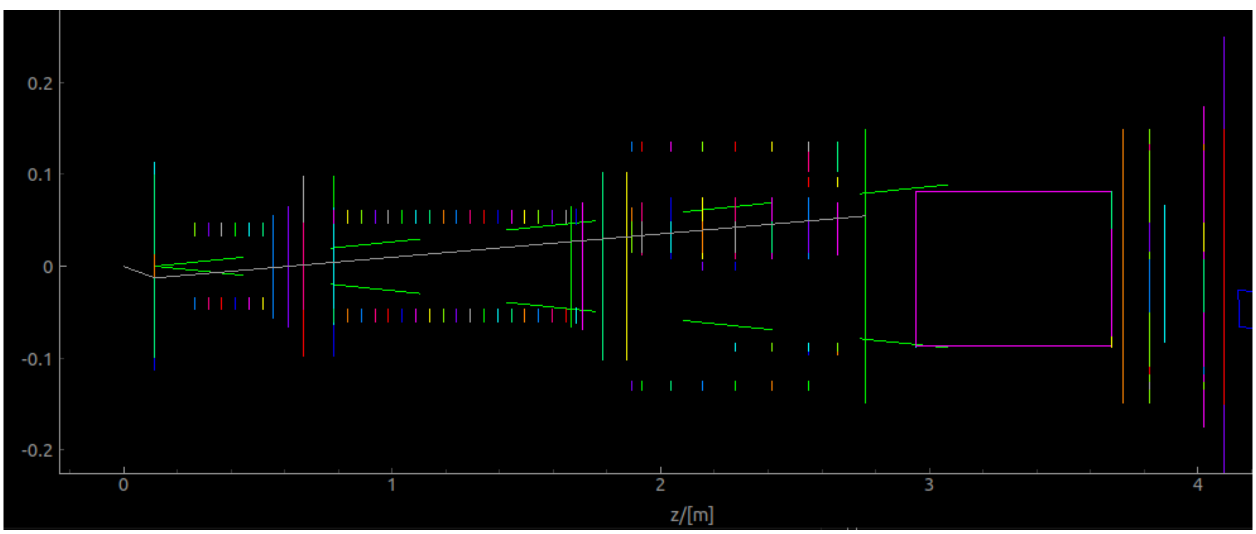


**Figure 4. An overhead view of the simulated beamtube and collimator in McStas.** The neutron flux comes from the left, and is projected on to the entrance of the collimator (magenta).

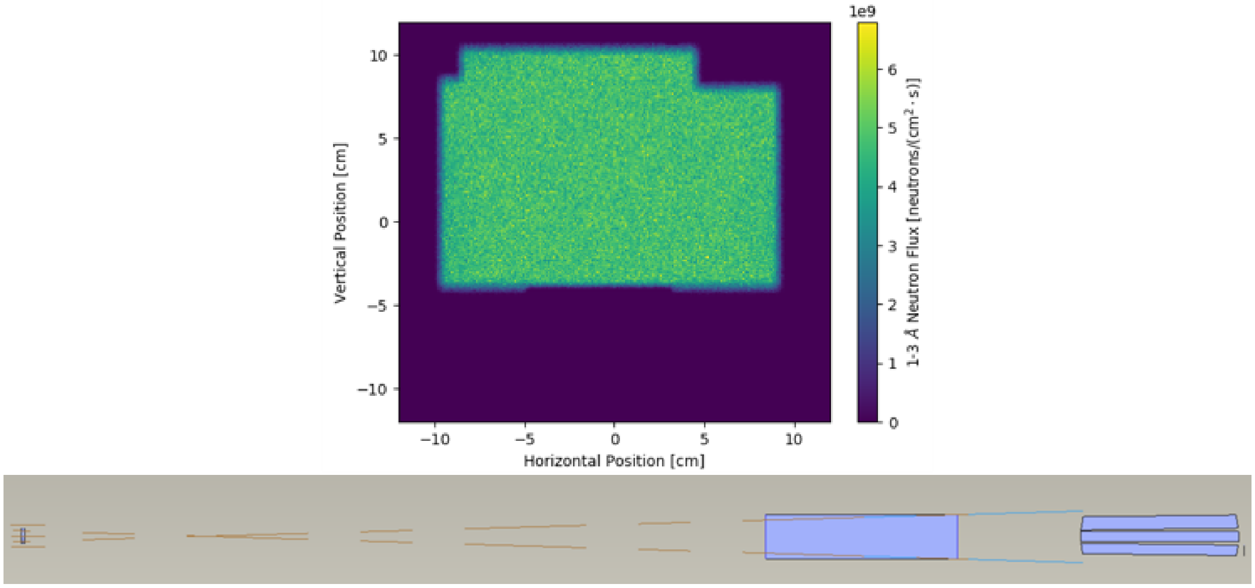


**Figure 5. A view of the available neutron flux at the exit of the internal collimator [Top].** An overhead view of the source, collimator and proposed Main Shutter Guide Channel surfaces [Bottom].

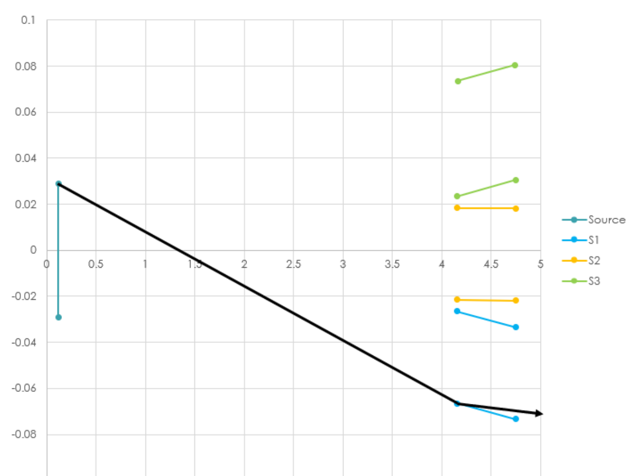


**Figure 6. A not-to-scale over-head view of the proposed Guide Channel geometry for the HB4 Main Shutter.** The black line is an example of a neutron trajectory that would interact with the shutter channel geometry. The source and shutter location combined with their geometry dictate the angular acceptance of the guide channels.

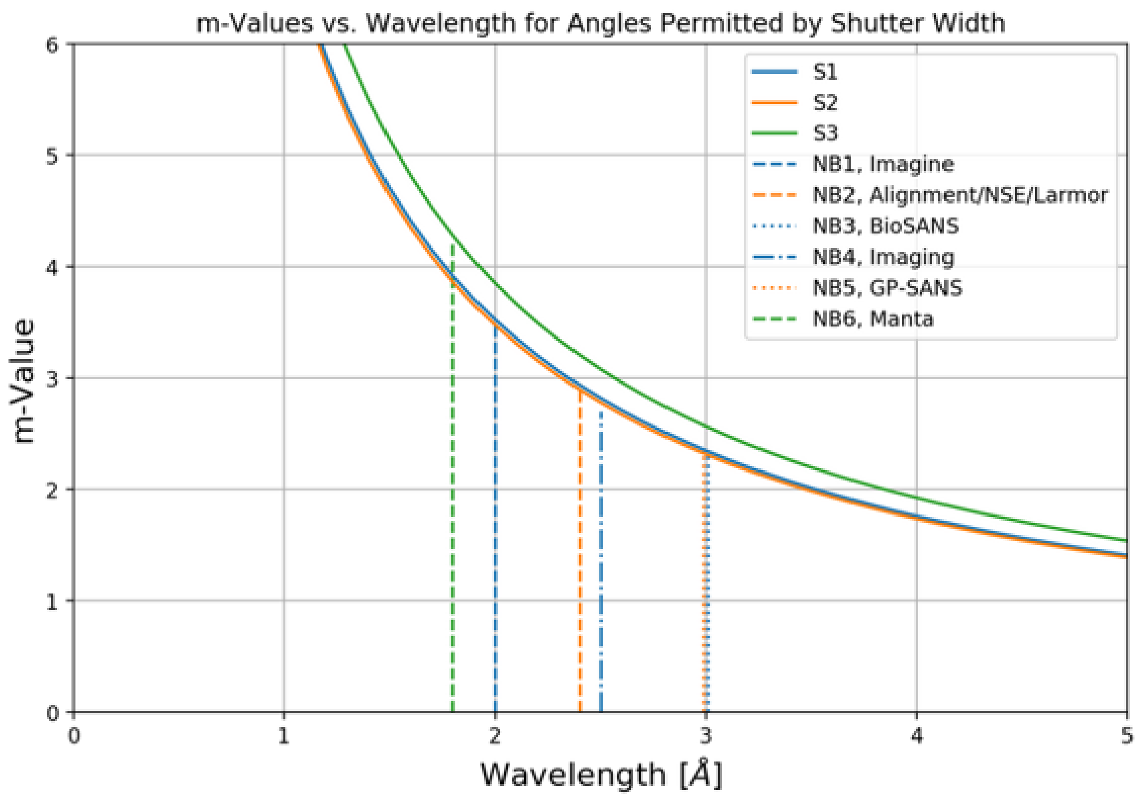


**Figure 7. A plot describing the required reflectivity cutoff for each channel and instrument.** The decay traces are from Equation 1, and the vertical lines represent the minimum required wavelength.

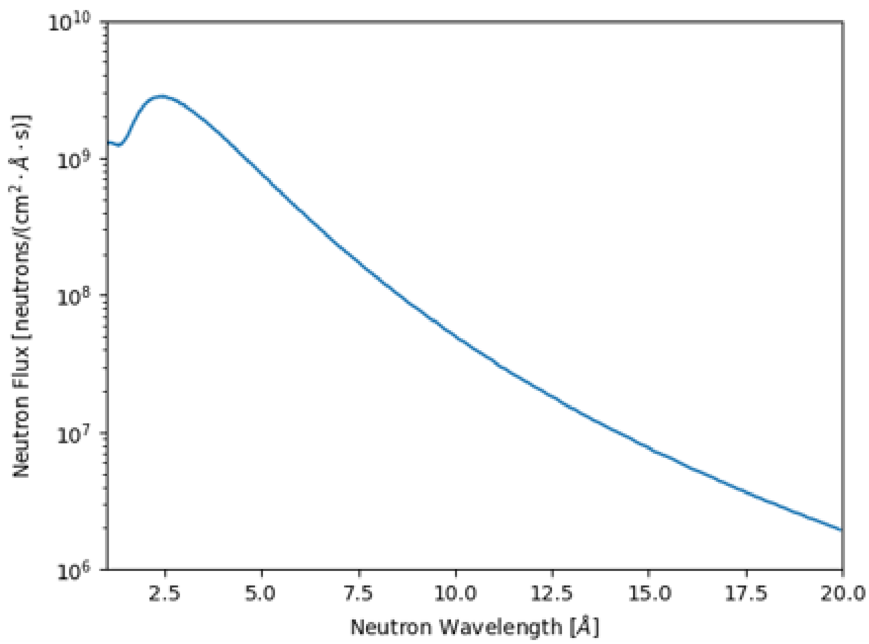


**Figure 8. A plot showing the spectral neutron flux at the entrance to the shutter.**

## 3. PERFORMANCE OF PROPOSED DESIGN

The previous section provided a calculation of the required surface reflectivity based strictly on the horizontal acceptance and minimum wavelength required for the instruments. This section will show that while the analytical calculation is correct, the value added for higher $m$ values on the channels is not substantial in the wavelengths of interest. This will be done using McStas ray-tracing simulations. From neutron wavelengths 1-20 Å there is $8 \times 10^9$ neutrons/(cm$^2$·s) flux available at the entrance to the shutter, and fully illuminates all three channels. An area-normalized spectrum can be seen in Figure 8.

All three guide surfaces provide a significant increase in the flux at the edges of the exit aperture. This is expected, as low angles will reflect and transport better than the higher incident angles, if any. The result is a notable increase in the average flux density with increased super-mirror cutoff, $m$, especially at shorter wavelengths, as seen in Figure 9. Locally, the enhancement in flux can be seen in Figure 10. The same effect is noted across all three guide channels, and even more so in guide channel S3.

While the increase in flux is beneficial, the value added by utilizing higher $m$ values in these guide channels is not immediately obvious. Figures 9 and 10 show this to some extent, but the improvement is better realized with a fine scan of the $m$ value for each guide channel over a shorter wavelength range. Figure 11 shows the change in the average flux for $m$ = 1 to $m$ = 5 for all three channels.

Given Figure 11, it is clear that while the improvement of the flux at the guide exit is notable up to $m$ = 3, it is not substantial for $m$ values beyond for S1 and S2. Thus, $m$ = 3 is the best suited reflectivity cutoff for these channels. S3 does benefit beyond $m$ = 3 in this wavelength range, due mainly to the fact that its geometry permits a wider acceptance and NB6 utilizes a shorter wavelength. The conclusion is the best $m$ value for S3 is $m$ = 3.5. These values, as well as the analytically determined $m$ values from Section 2.3.1 can be seen in Table 3.

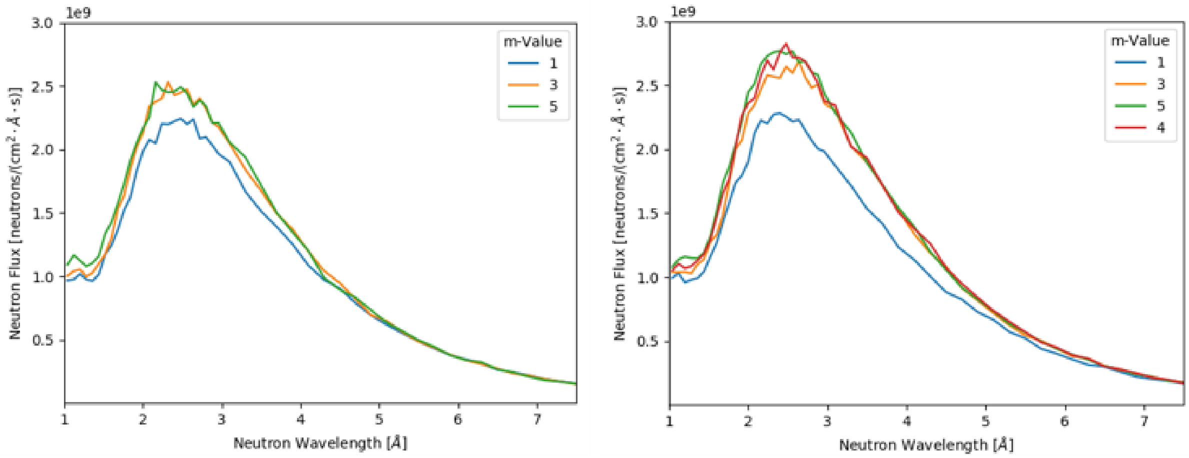


**Figure 9. A plot showing the effect increasing the m-value has on the average exit flux.** [Left] A scan of S1 supermirror coating shows an improvement in average flux, but very little above m=3. [Right] The scan for S3 showing a higher average flux gain and benefit for m-value up to 4.

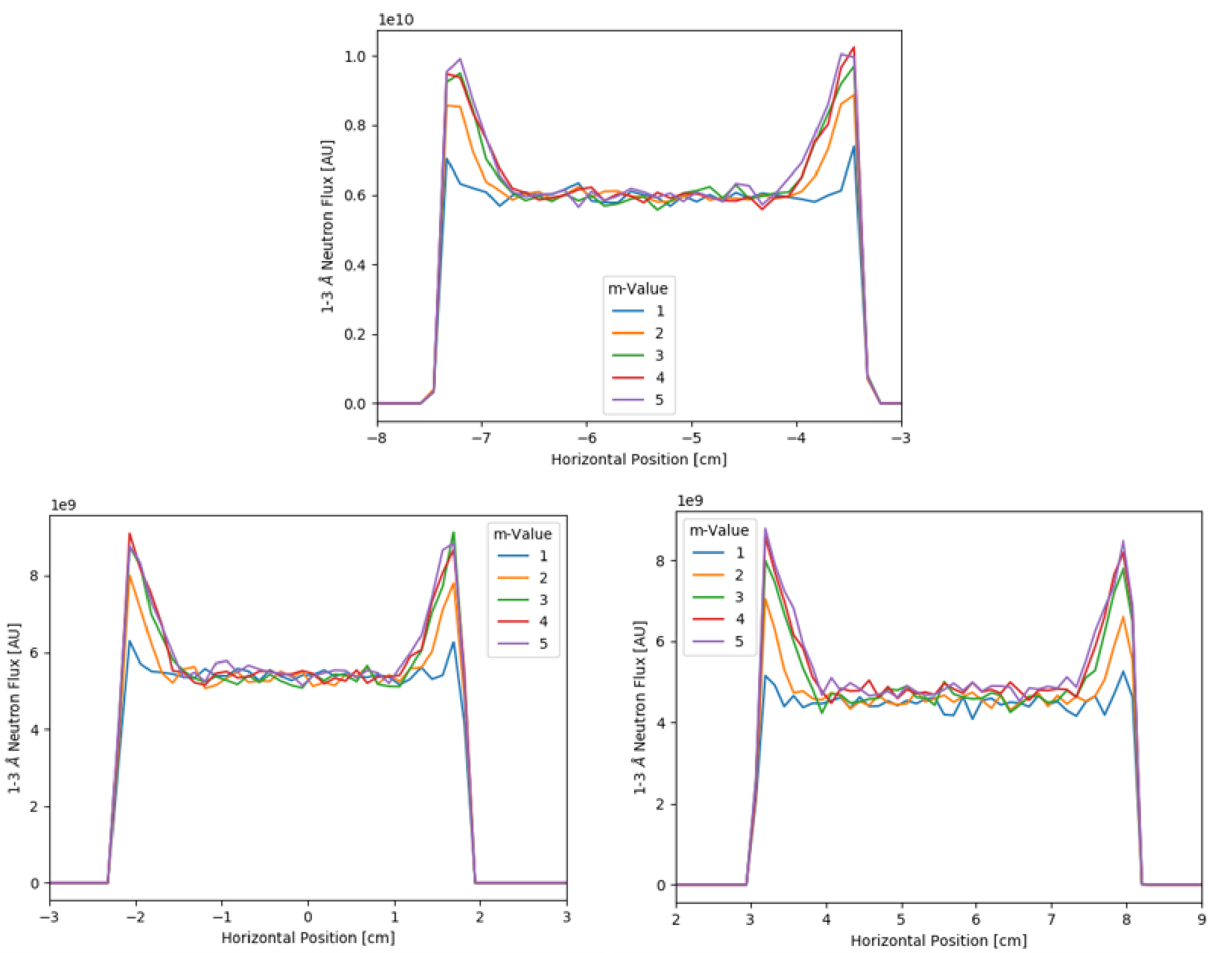


**Figure 10. Three plots describing the horizontal flux from 1-3Å at the exit of the Main Shutter.** The flux is plotted for a range of *m* values for S1 [Top], S2 [Left], and S3 [Right].

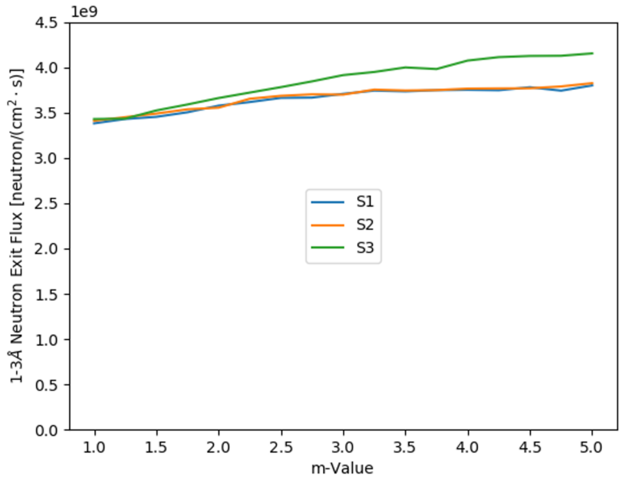


**Figure 11. A scan of the m value for each of the three guide channels.** The improvement in the average 1-3Å flux at the guide channel exit is limited to $m$ = 3 for S1 and S2, and $m$ = 4 for S3.

**Table 3. The analytically determined and proposed m values for the Main Shutter Guide Channels S1, S2, and S3.**

| Guide Channel | Analytical m-value | Optimized m-value |
|---|---|---|
| S1 | 3.5 | 3.0 |
| S2 | 3.0 | 3.0 |
| S3 | 4.2 | 3.5 |

## 4. ALIGNMENT REQUIREMENTS OF PROPOSED DESIGN

It has been shown in the previous sections that the guide channels proposed for the HB4 shutter will provide a notable boost in intensity and beam divergence available to the instrument suite in the cold guide hall. However, their performance is very dependent on the alignment of these initial reflecting features. The guide channels will be inside of a cylinder that rotates about a vertical axis to either a closed or open position.

The closed position will align the channels such that they permit no neutron beam into the guide hall, and the open position will be precisely aligned such that the boost in flux provided by the upstream reflecting surfaces is effectively transported into the rest of the guide system.

Simulations were performed in order to quantify the impact any misalignment would have on the intensity provided to the downstream guide system. These simulations used a modified version of the code found at `https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source-2024`. The modifications added an aperture and spectrum monitor for each proposed guide start just downstream of the guide channel exit. This aperture and monitor replicate the expected acceptance of those guide starts, and will be used as input to the Figure-of-Merit (FOM) to understand the relative impact due to misalignment of the guide channels. The FOM to be used for this simulation will be the relative intensity of the monitor as compared to perfect alignment in two different wavelength regions. As seen in the Figure 13, scanning the pitch of of the guide channel from -0.40° to 0.35° has a substantial effect on the relative intensity, but the impact is different at shorter wavelengths. Thus, the FOM is divided into short and long wavelength FOM's and the performance quantified across the scan range. Each beam guide start was scanned in six degrees of freedom, with each position dimension scanned from +/-4.0 millimeters and rotation dimensions scanned over a range +/-0.4°.

Misalignment in three of the dimensions has the same nominal effect across the whole suite. These are along the z-axis (along the beam), the x-axis (transverse horizontal to the beam), and roll (rotation about the z-axis). The effects can be seen in Figure 14. One notes that misalignment along the beam and around the beam axis is of little consequence, but misalignment along the transverse horizontal direction is substantial, with almost a 3% loss per millimeter of misalignment.

The impact that misalignment has on the rest of the dimensions varies greatly between the guide starts. Plots showing the impact of vertical, pitch and vertical axis rotation misalignment can be seen in Figures 15, 16, 17, 18, 19 and 20 for NB1, 2, 3, 4, 5, and 6 respectively.

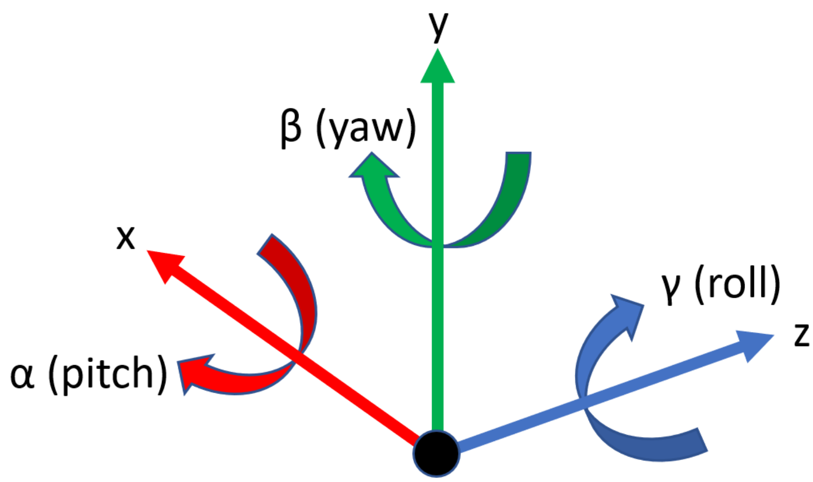


**Figure 12. A diagram showing the typical coordinate system utilized in most neutron ray tracing simulations.**

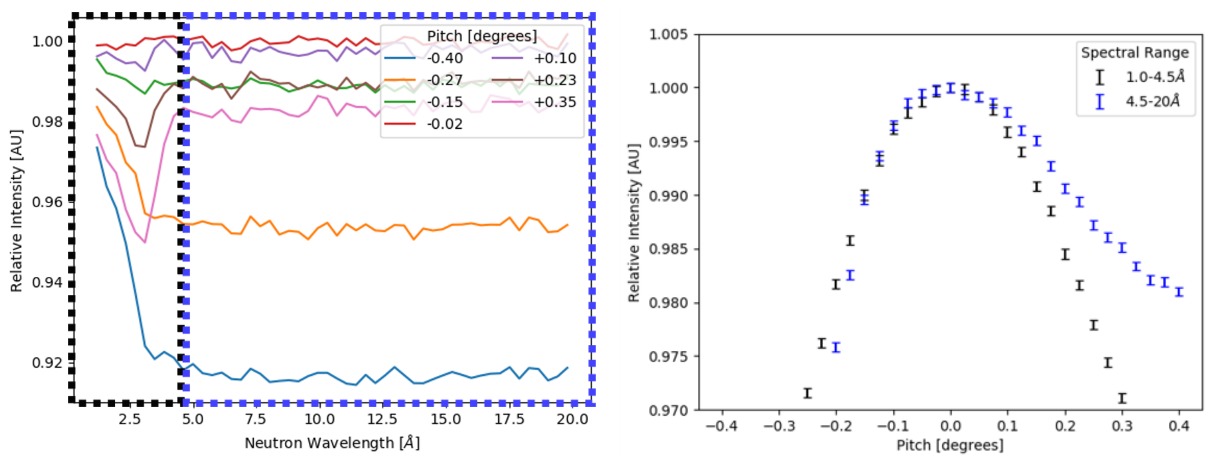


**Figure 13. Plots describing the effect of pitch misalignment on NB6 spectrum.** [Left] The relative spectral intensity across a range of pitch orientations for S3. [Right] The degradation in performance across the short and long wavelength regions of interest versus pitch angle. The ROI's shown the left plot correlate to data points seen in the right plot.

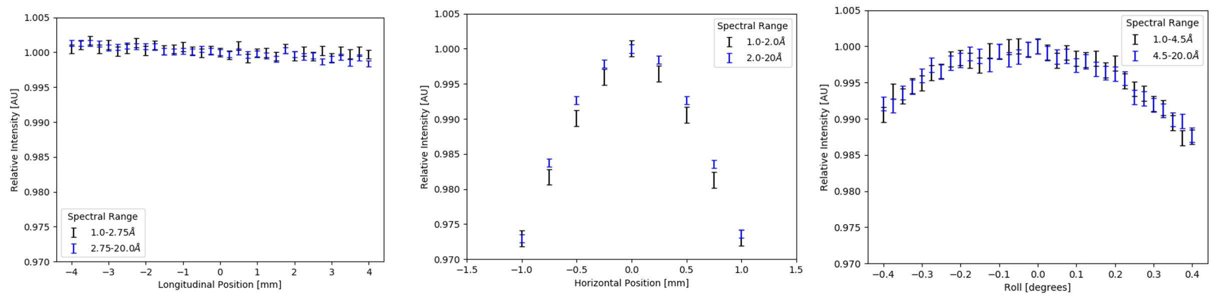


**Figure 14. Plots describing misalignment effects for the whole instrument suite.** [Left] The relative intensity impact of misalignment along the nominal beam trajectory. [Middle] The relative intensity impact of misalignment transverse horizontal to the beam. [Right] The relative intensity impact of angular misalignment around the z-axis.

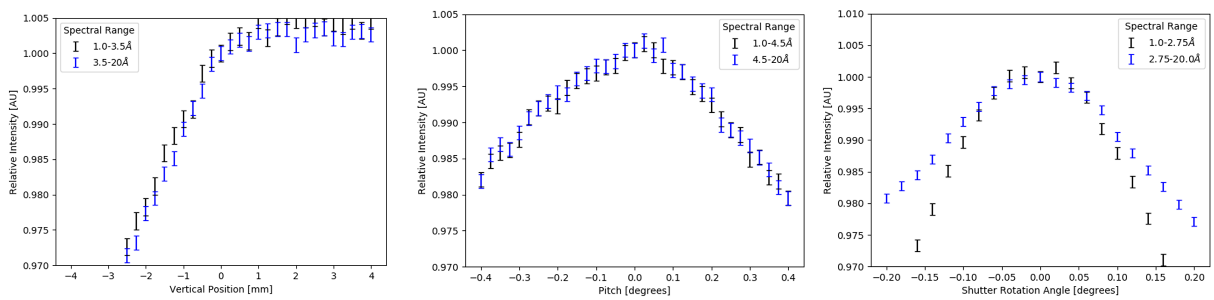


**Figure 15. Plots describing misalignment effects for the NB1 Beam Guide.** [Top] The relative intensity impact of misalignment transverse vertical to the beam. [Middle] The relative intensity impact of misalignment of the guide channel pitch. [Bottom] The relative intensity impact of angular misalignment around the shutter rotation axis.

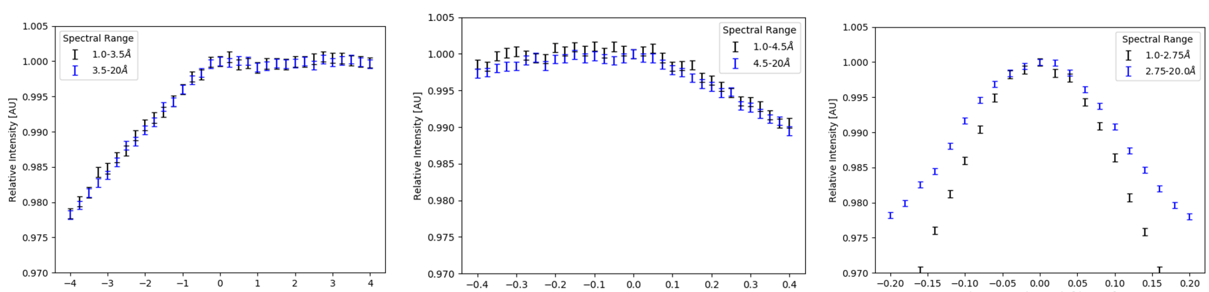


**Figure 16. Plots describing misalignment effects for the NB2 Beam Guide.** [Top] The relative intensity impact of misalignment transverse vertical to the beam. [Middle] The relative intensity impact of misalignment of the guide channel pitch. [Bottom] The relative intensity impact of angular misalignment around the shutter rotation axis.

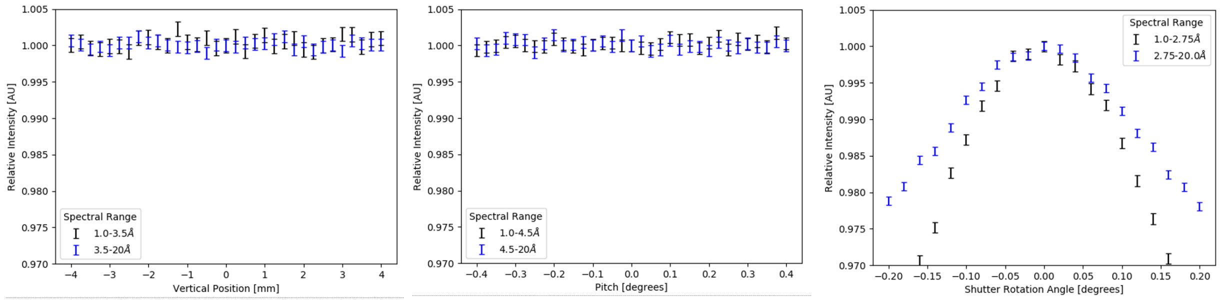


**Figure 17. Plots describing misalignment effects for the NB3 Beam Guide.** [Top] The relative intensity impact of misalignment transverse vertical to the beam. [Middle] The relative intensity impact of misalignment of the guide channel pitch. [Bottom] The relative intensity impact of angular misalignment around the shutter rotation axis.

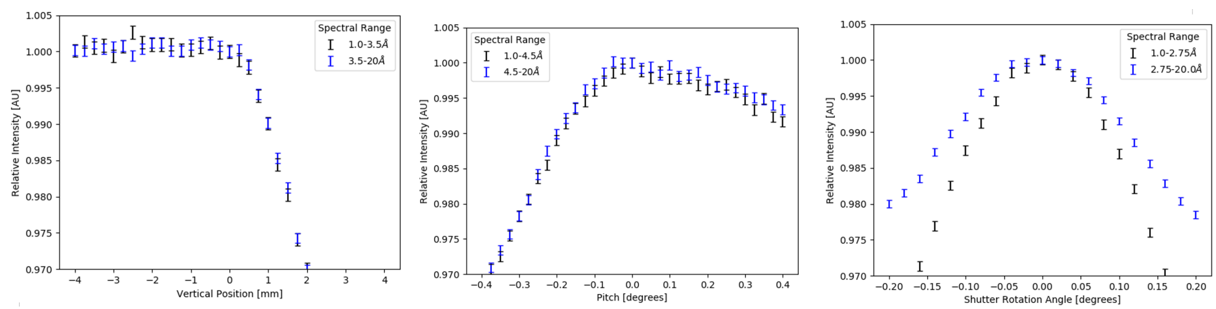


**Figure 18. Plots describing misalignment effects for the NB4 Beam Guide.** [Top] The relative intensity impact of misalignment transverse vertical to the beam. [Middle] The relative intensity impact of misalignment of the guide channel pitch. [Bottom] The relative intensity impact of angular misalignment around the shutter rotation axis.

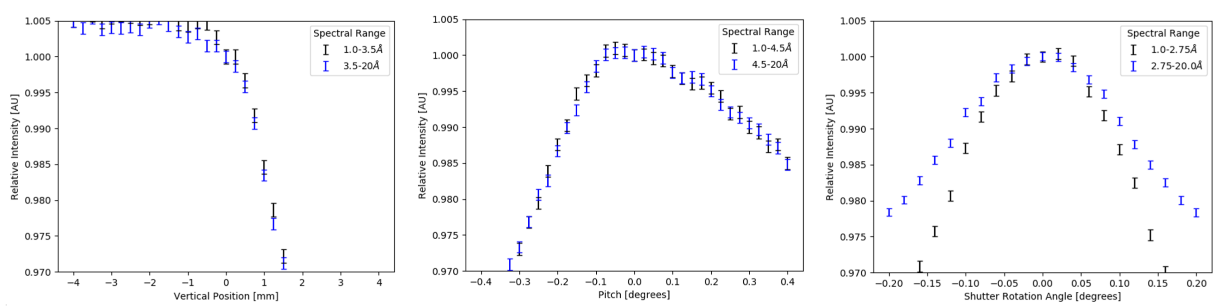


**Figure 19. Plots describing misalignment effects for the NB5 Beam Guide.** [Top] The relative intensity impact of misalignment transverse vertical to the beam. [Middle] The relative intensity impact of misalignment of the guide channel pitch. [Bottom] The relative intensity impact of angular misalignment around the shutter rotation axis.

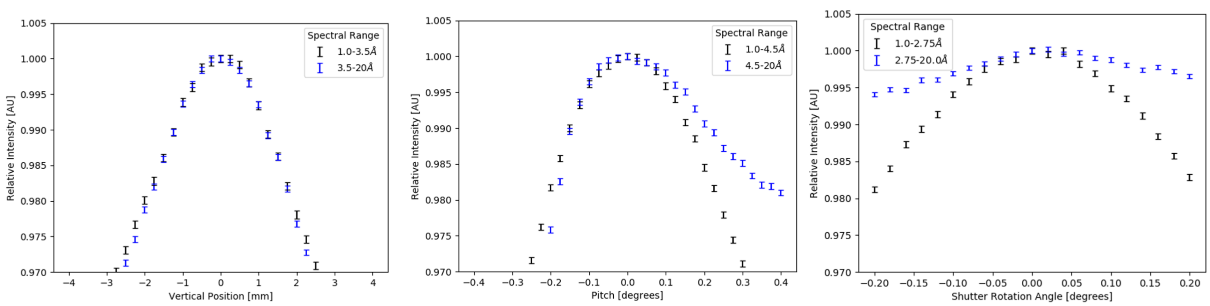


**Figure 20. Plots describing misalignment effects for the NB6 Beam Guide.** [Top] The relative intensity impact of misalignment transverse vertical to the beam. [Middle] The relative intensity impact of misalignment of the guide channel pitch. [Bottom] The relative intensity impact of angular misalignment around the shutter rotation axis.

## 5. SUMMARY

A neutron optic concept of the guide channel insert proposed for the HB4 Main Shutter System was presented and guidelines for its design and alignment requirements were conveyed. Simulations were performed to provide understanding with regards to optimal geometry and coating selection for each surface as well as the impact of misalignment those surfaces can have on the final instrument performance. In general, it seems that alignment of these surfaces to within +/-0.25 millimeters and +/-0.05° across all dimensions will ensure losses are no worse than 1% for any of the guide starts. A more specific quantification showing the impacts on each instrument in terms of relative loss per unit can be seen in Table 4. The inverse of the these values define the alignment range required to maintain losses below 1%.

**Table 4. A table of values interpreting the simulated losses and plots for each beam guide.** Each beam guide simulation provided a plot of intensity losses across each dimension range. Taking the average loss over that scanned range provides a percent-loss-per-unit, where the unit is either millimeters or degrees. This value is then inverted to provide upper and lower misalignment limits for each dimension, assuming a loss of 1% can be tolerated.

| Beam\Dimension | x [%/mm] | | y [%/mm] | | z [%/mm] | | α [%/deg] | | β [%/deg] | | γ [%/deg] | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | lower | upper | lower | upper | lower | upper | lower | upper | lower | upper | lower | upper |
| NB1 | 2.25 | 2.25 | 1.06 | 0.00 | 0.01 | 0.30 | 4.75 | 5.25 | 15.00 | 15.00 | 2.50 | 3.13 |
| NB2 | 2.25 | 2.25 | 0.53 | 0.00 | 0.01 | 0.30 | 0.00 | 0.25 | 18.75 | 18.75 | 2.50 | 3.13 |
| NB3 | 2.25 | 2.25 | 0.01 | 0.01 | 0.01 | 0.30 | 0.01 | 0.01 | 18.75 | 18.75 | 2.50 | 3.13 |
| NB4 | 2.25 | 2.25 | 0.01 | 1.50 | 0.01 | 0.30 | 7.90 | 1.83 | 18.75 | 18.75 | 2.50 | 3.13 |
| NB5 | 2.25 | 2.25 | 1.50 | 0.01 | 0.01 | 0.30 | 9.37 | 3.75 | 18.75 | 18.75 | 2.50 | 3.13 |
| NB6 | 2.25 | 2.25 | 1.00 | 1.00 | 0.01 | 0.30 | 11.00 | 11.00 | 10.00 | 10.00 | 2.50 | 3.13 |
| MAXIMUM | 2.25 | 2.25 | 1.50 | 1.50 | 0.01 | 0.30 | 11.00 | 11.00 | 18.75 | 18.75 | 2.50 | 3.13 |
| **Tolerance** | **x [mm/%]** | | **y [mm/%]** | | **z [mm/%]** | | **α [deg/%]** | | **β [deg/%]** | | **γ [deg/%]** | |
| **(mm or deg) for 1% loss** | **0.44** | **0.44** | **0.67** | **0.67** | **100.00** | **3.33** | **0.09** | **0.09** | **0.05** | **0.05** | **0.40** | **0.32** |

# 6. REFERENCES

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# APPENDIX

## A CORRECTION TO 2007 HB4 COLD SOURCE BRIGHTNESS MEASUREMENT

The first brightness measurement of the refurbished cold source in 2007 utilized a TOF instrument setup that allowed for precise determination of the neutron brightness spectrum from 0.7Å to 10.0 Å [4]. The apparatus used a disk chopper, a neutron detector and a data acquisition system that recorded detector pulses relative to the disk chopper opening trigger time. The result was a well resolved TOF spectrum expected of a 22.5 K cold source. In order to accurately quantify the brightness of the source, determination of the chopper duty cycle, detector efficiency and aperture geometry is required. The aperture geometry (and thus the acceptance correction to determine the true brightness) was “difficult to calculate analytically because the collimation system includes both rectangular and circular apertures.” An estimate of the acceptance was attempted by approximating the round apertures with square apertures of equivalent side-length. Using this estimate the overall acceptance in the detector was determined to be $6.8 \times 10^{-6}$ $cm^2 \cdot sr$. Based on this acceptance, a triple Maxwell-Boltzmann distribution can be used to replicate the cold source spectrum brightness for instrument simulation purposes. The neutron wavelength spectral shape is

$$B(\lambda) = \sum_{i=1}^{3} 2I_i \frac{a_i^2}{\lambda^5} e^{-a_i/\lambda^2} \qquad a_i = \frac{949.0}{T_i} \tag{2}$$

The parameters that best fit this data are seen in Figure 21. Using a McStas simulation replicating the

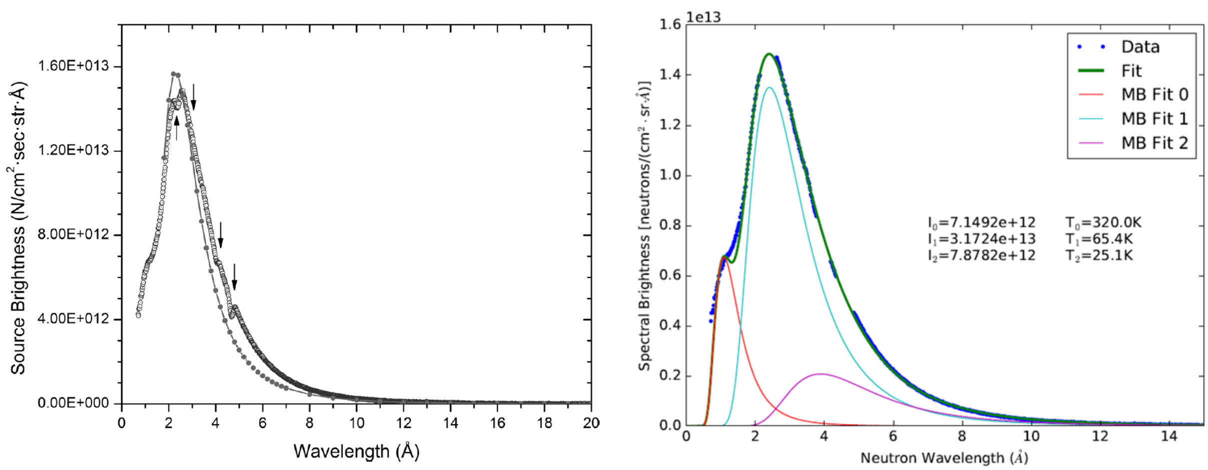


**Figure 21. The simulated, measured and fitted brightness from the HFIR cold source in 2007.** [Left] The spectrum as measured and as simulated using MCNP computer code. [Right] a triple Maxwell-Boltzmann fit to the corrected data taken during the testing.

described 2007 instrument configuration, one should be able to confirm the brightness values provide the expected corrected brightness at the detector based on what is known about the geometry of the apertures in series (acceptance). However, an attempted replication of this result is seen in Figure 22, and the simulated result appears to be about 15% higher than expected when using the parameters fitted to the data provided from 2007.

Maintaining confidence in the standard McStas component *Source_gen*, one assumes that a correction is needed in the acceptance factor of the data normalization, rather than there being an issue with the source component itself. In order to determine the actual acceptance of the instrument used to do the measurement

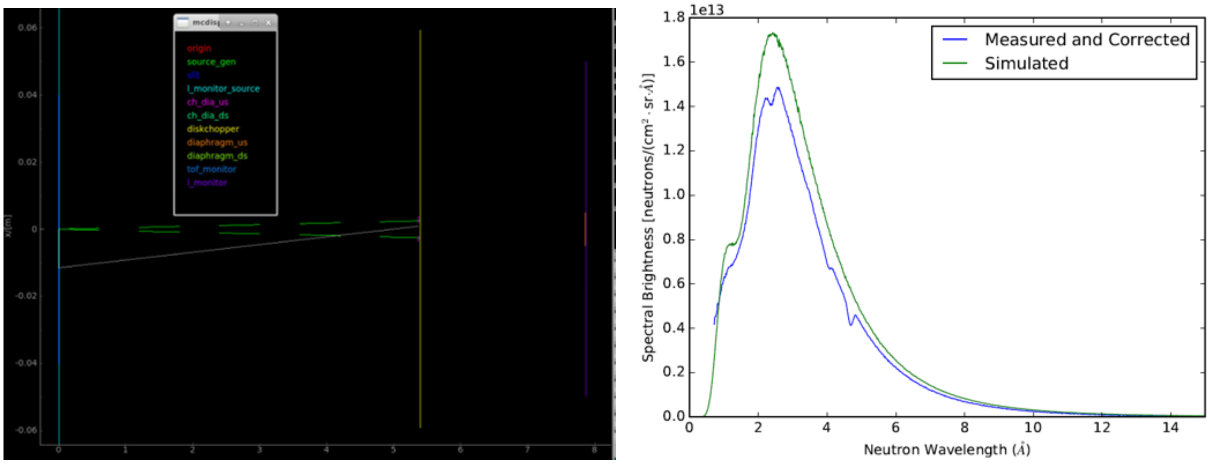


**Figure 22. A schematic describing the layout of the brightness measurement and associated spectrum.** [Left] The simulated TOF instrument to observe the spectrum of the cold source. [Right] The resulting brightness spectrum from the measurement and the simulated one spectrum using the parameters from Figure 21.

a Monte Carlo method much like that could be used to determine the value of $\pi$ is utilized. In this case, one samples the full range of phase space at the source that will fully illuminate the aperture used to define the view of the source at the detector. As seen in figure 23, the whole range of angles $\vec{\theta}$ is sampled across the whole range of positions $\vec{x}$. Only a subset of those positions and trajectories will be transmitted through the aperture system and onto the detector. Thus, if one knows the full phase space emmittance range from the source $E_S$, the acceptance of the system $A$ is the ratio of detected events $N'$ to sampled events $N$ times that source emmitance.

$$A = \frac{N'}{N} E_S \tag{3}$$

Using the McStas instrument definition found at `https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source/-/blob/master/mcstas/chopped_brightness_measurement_2007.instr`, one is able to quantify to a reasonable precision ($\sim 2\%$) the acceptance of the measurement setup to be $7.95 \times 10^{-6}$ $cm^2 \cdot sr$. This is a 17% increase in the acceptance used in the original 2007 report, thus revising the expected brightness values downwards by the same amount.

These new values should be used for any instrument simulation work involving the current HB4 Cold Source design at 85 MW, and can be seen in Table 1.

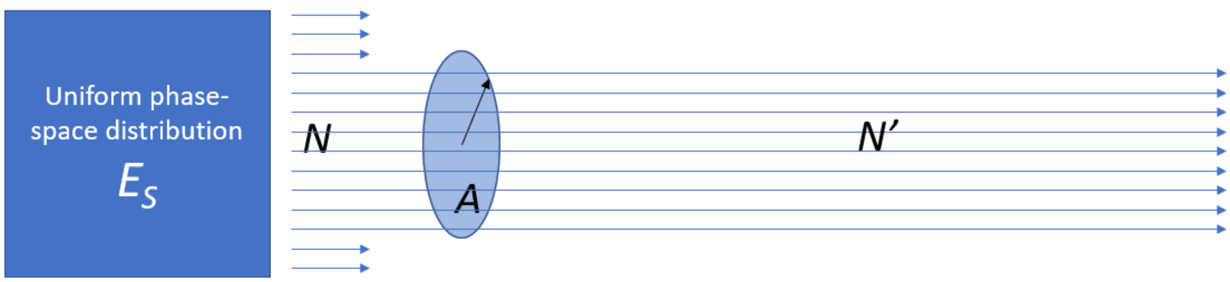


**Figure 23. A schematic describing acceptance determination via Monte Carlo simulation.** The acceptance is the ratio of successful particle trajectories to the number created at the source and times the known emmitance range of the source.

# B MCSTAS CODE REPRESENTING THE COLD SOURCE AND BEAMTUBE AT HB4

https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source-2024/-/blob/master/HB4_Beamtube.instr

```
/*****************************************************************************************************************************************************************************************************************
* Instrument: HB4_Beamtube
*
* %Identification
* Written by: Lee Robertson (robertsonjl@ornl.gov)
* Date Created: 12may2017 (initial testing completed)
* Date Modified: 23apr2018 (implemented internal beamtube collimator final geometry from RRD)
* Date Modified: 25sep2019 (implemented new HB-4 beamline numbering scheme)
* Date Modified: 23oct2019 (Changed the way neutron events (tallies) are stored)
* Date Modified: 30apr2020 (Converted all parameters to constants; Matthew Frost)
*
* Origin: ORNL

* %INSTRUMENT_SITE: ORNL
*
* %Description
* Model of the New HB4 cold source and beamtube obstructions (main modification is the internal beamtube collimator - 2018 design).
* Dimensions are given in inches * IN2M (conversion factor) so that the values can be more easily checked against the drawings.
* The majority of the HFIR drawings use the centerline of the pressure vessel as the absolute coordinate system reference.
* However, the HB-4 beamtube is tangential (not radial) relative to the center of the pressure vessel (also the center of the reactor fuel core, and the center of the Be reflector) so the HB-4 Beamtube Center Line does not intersect the Pressure Vessel Center Line.
* Because they do not intersect, the origin used for the HB-4 beamtube drawings (HB-4 Pressure Vessel Centerline) is defined to be the intersection of the HB-4 Beamtube Center Line and the radial line out from the Pressure Vessel Center Line that is perpendicular to the HB-4 Beamtube Cent
See M11530CS300E-Rev4
*
* Important beamtube dimensions:
*    HB-4 Pressure Vessel Center Line to the tip (closest point to HB-4 PVCL) of the HB-4 Reflector Penetration Tube (M11530CS308E-Rev5) (ignore the HB-4 Sleeve Tube, M11530CS309E-Rev2) = 1.875" (also see M11530CS300E-Rev4)
*    HB-4 Pressure Vessel Center Line to the Viewable Surface of the Cold Source (Source Plane) = 4.685" (M11530CS300E-Rev4)
*    Total length of the HB-4 Reflector Penetration Tube = 64.21" (M11530CS308E-Rev5)
*    Total length of the HB-4 Vacuum Sleeve = 24.40" (M11530CS311E-Rev1)
*    Total length of the HB-4 Vacuum Sleeve Flange = 36.385" (M11530CS312E-Rev4)
*    Total length of the Vacuum Sleeve Assembly = 64.98" (M11530CS310E-Rev4)
*    Total length of the hydrogen line support Ring including weld overlaps = 4.50" (M11530CS313E-Rev4)
*    Length of HB-4 Shield Penetration Tube = 7.00" (M11530CS319E-Rev1)
*    Tip of HB-4 Reflector Penetration Tube to the Downstream End of the HB-4 Shield Penetration Tube = 156.5" (M11530CS304E-Rev11)
*    Total length of the HB-4 Transition Spool No. 1 = 5.430" (M11530CS336E-Rev4) : Minus the weld overlap at the joint with the HB-4 Shield Penetration Tube (M11530CS319E-Rev1) => 5.430" - 0.31" = 5.12" (keep the weld overlap on the upstream end).
*    Downstream End of the HB-4 Collimator Shield (Internal Beamtube Collimator) to upstream end of the HB-4 Transition Spool No. 1 = 6.38" - 5.12" = 1.26" (scaled with ruler off of M11530CS304E-Rev11)
*    Length of HB-4 Collimator Shield (Internal Beamtube Collimator) (not including the "shelf") = 28.750" (M11530CS314E-Rev2)
*    Distance from the Source Plane to the entrance of the HB-4 Collimator Shield (Internal Beamtube Collimator) (not including the "shelf") = 1.875" + 156.5" - 7.00" - 5.12" - 1.26" - 28.75" = 116.245"
*
*
* %Parameters
* Source_Target_Distance[m]:            Distance from the cold source moderator "viewable" surface to the "target". The target is used to eliminate the generation of neutrons that can never enter the beamline optics.  Note: the "target" window must be rectangular centered on the z-axis
* Source_Target_Width[m]:               Width of the "target" window. Nominal value is with of the gross opening of the internal beamtube collimator.  Use 2x3.5"=7.0" from M11530CS314E-Rev2
* Source_Target_Height[m]:              Height of the "target" window. Nominal value is height of the gross opening of the internal beamtube collimator. Use 2x3.7"=7.4" from M11530CS314E-Rev2
* Intensity_1[n/cm^2/str/s]:            Source brightness modeled by 3 Maxwellian distributions. This parameter is the source brightness integrated over wavelength for Maxwellian #1 (units=neutrons/cm^2/str/s). Nominal value is from a fit to the measured source brightness but needs to b
* Temperature_1[K]:                     Source brightness modeled by 3 Maxwellian distributions. This parameter is the characteristic temperature for Maxwellian #1 (in Kelvins). Nominal value is from a fit to the measured source brightness but needs to be adjusted to recover the measure
* Intensity_2[n/cm^2/str/s]:            Source brightness modeled by 3 Maxwellian distributions. This parameter is the source brightness integrated over wavelength for Maxwellian #2 (units=neutrons/cm^2/str/s). Nominal value is from a fit to the measured source brightness but needs to b
* Temperature_2[K]:                     Source brightness modeled by 3 Maxwellian distributions. This parameter is the characteristic temperature for Maxwellian #2 (in Kelvins). Nominal value is from a fit to the measured source brightness but needs to be adjusted to recover the measure
* Intensity_3[n/cm^2/str/s]:            Source brightness modeled by 3 Maxwellian distributions. This parameter is the source brightness integrated over wavelength for Maxwellian #3 (units=neutrons/cm^2/str/s). Nominal value is from a fit to the measured source brightness but needs to b
* Temperature_3[K]:                     Source brightness modeled by 3 Maxwellian distributions. This parameter is the characteristic temperature for Maxwellian #3 (in Kelvins). Nominal value is from a fit to the measured source brightness but needs to be adjusted to recover the measure
* Wavelength_Min[A]:                    Minimum neutron wavelength to be generated.
* Wavelength_Max[A]:                    Maximum neutron wavelength to be generated.
*
*****************************************************************************************************************************************************************************************************************

DEFINE INSTRUMENT HB4_Beamtube()


DECLARE
%{

double Source_Target_Distance = 116.245;          //Distance from the cold source moderator surface to the "target". The target is used to eliminate the generation of neutrons that can never enter the beamline optics.  Nominal value is the entrance to the internal beamtube collimat
double Source_Target_Width = 7.0;                //Width of the "target". Nominal value is with of the gross opening of the internal beamtube collimator.  Use 2x3.5"=7.00" from M11530CS314E-Rev2
double Source_Target_Height = 7.4;                //Height of the "target". Nominal value is height of the gross opening of the internal beamtube collimator. Use 2x3.7"=7.40" from M11530CS314E-Rev2
double Intensity_1=6.07e12;                       //Source brightness modeled by 3 Maxwellian distributions. This parameter is the source brightness integrated over wavelength for Maxwellian #1 (units=neutrons/cm^2/str/s). Nominal value is from a fit to the measured source brightne
Needs to be adjusted.
double Temperature_1=325.0;                       //Source brightness modeled by 3 Maxwellian distributions. This parameter is the characteristic temperature for Maxwellian #1 (in Kelvins). Nominal value is from a fit to the measured source brightness.
Needs to be adjusted.
double Intensity_2=2.61e13;                       //Source brightness modeled by 3 Maxwellian distributions. This parameter is the source brightness integrated over wavelength for Maxwellian #2 (units=neutrons/cm^2/str/s). Nominal value is from a fit to the measured source brightne
Needs to be adjusted.
double Temperature_2=67.2;                       //Source brightness modeled by 3 Maxwellian distributions. This parameter is the characteristic temperature for Maxwellian #2 (in Kelvins). Nominal value is from a fit to the measured source brightness.
Needs to be adjusted.
double Intensity_3=7.95E12;                       //Source brightness modeled by 3 Maxwellian distributions. This parameter is the source brightness integrated over wavelength for Maxwellian #3 (units=neutrons/cm^2/str/s). Nominal value is from a fit to the measured source brightne
Needs to be adjusted.
```

```
double Temperature_3=27.3;                                //Source brightness modeled by 3 Maxwellian distributions. This parameter is the characteristic temperature for Maxwellian #3 (in Kelvins). Nominal value is from a fit to the measured source brightness.
Needs to be adjusted.
double Wavelength_Min=0.0;                               //Minimum neutron wavelength to be generated.
double Wavelength_Max=20.0;                               //Maximum neutron wavelength to be generated.
%}

TRACE

//**********************************************************************************************************************************************************************************************************************************
// Model the super critical moderator as a flat circular source located at the Source Plane of the guide system.
// This will be slightly behind the physical surface of the moderator since it is curved (concave).
// Representing the cold moderator as a flat surface rather than the actual curved surface is OK because Lambert's Law tells us the source brightness along the HB-4_BTCL is uniform, regardless of the curvature.
// Also, the HB-4 beamtube is tangential, so the cold moderator is is illuminated from the side rather than from the rear.
// However, when measuring the source brightness no significant difference was observed between the CG-1 (right) and CG-4 (left) ports in the internal beamtube collimator (original 2006 configuration).
// The shape of the visible area of the moderator is modeled by placing two circular apertures at the source plane (See M11530CS342E-Rev1).
// Placing the two circular apertures right against the source potentially causes a error in the statistical weighting of the neutrons so the source parameters must be adjusted in order to recover the observed cold source brightness.

COMPONENT Source = Source_gen_tally(radius   = 1.566 * IN2M,                       // Radius of inner "viewable" surface of cold source moderator vessel.  See M11530CS341E-Rev1
                                    dist     = Source_Target_Distance * IN2M,      // Distance from the guide focal plane to the internal beamtube collimator entrance.
                                    focus_xw = Source_Target_Width * IN2M,         // Target window is the entrance to the internal beamtube collimator
                                    focus_yh = Source_Target_Height * IN2M,        // Target window is the entrance to the internal beamtube collimator
                                    verbose  = 1,                                  // Include source parameters in the output
                                    I1       = Intensity_1,                        // Source brightness integrated over wavelength for Maxwellian #1 (units=neutrons/cm^2/str/s)
                                    T1       = Temperature_1,                      // Characteristic temperature for Maxwellian #1 (in Kelvins).
                                    I2       = Intensity_2,                        // Source brightness integrated over wavelength for Maxwellian #2 (units=neutrons/cm^2/str/s)
                                    T2       = Temperature_2,                      // Characteristic temperature for Maxwellian #2 (in Kelvins).
                                    I3       = Intensity_3,                        // Source brightness integrated over wavelength for Maxwellian #3 (units=neutrons/cm^2/str/s)
                                    T3       = Temperature_3,                      // Characteristic temperature for Maxwellian #3 (in Kelvins).
                                    Lmin     = Wavelength_Min,                     // Minimum wavelength of neutrons generated
                                    Lmax     = Wavelength_Max)                     // Maximum wavelength of neutrons generated
  AT (0.0, 0.0, 4.685 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System  // See M11530CS300E-Rev4
  EXTEND
%{
    if (tally_flag == 1)
    {  // OK, we are at the source so initialize a neutron tally for this neutron.
       tally_neutron_index++;
       tally_number_of_events = 0;
       tally_event_component_index[tally_number_of_events] = INDEX_CURRENT_COMP;
       tally_event_component_type[tally_number_of_events] = 0;
       tally_event_position[tally_number_of_events][0] = x;
       tally_event_position[tally_number_of_events][1] = y;
       tally_event_position[tally_number_of_events][2] = z;
       tally_event_velocity[tally_number_of_events][0] = vx;
       tally_event_velocity[tally_number_of_events][1] = vy;
       tally_event_velocity[tally_number_of_events][2] = vz;
       tally_event_weight[tally_number_of_events] = p;
       tally_reflection_q[tally_number_of_events] = 0.0;
       tally_reflection_mirror_index[tally_number_of_events] = 0;
    }
%}

//  Add the circular apertures to model the actual shape of the cold moderator.

COMPONENT Left_Side_Source_Mask = Slit(radius = 2.804 * IN2M)                // See M11530CS341E-Rev4
  AT (-1.66 * IN2M, 0.0, 0.0) RELATIVE Source                                // See M11530CS341E-Rev4

COMPONENT Right_Side_Source_Mask = Slit(radius = 2.804 * IN2M)               // See M11530CS341E-Rev4
  AT ( 1.66 * IN2M, 0.0, 0.0) RELATIVE Source                                // See M11530CS341E-Rev4

// Take an image and spectrum of the source just as a sanity check.

COMPONENT Source_Image = PSD_monitor(nx = 400, ny = 400, filename = "Source_Image", xwidth=0.2, yheight=0.2)
  AT (0.0, 0.0, 0.0) RELATIVE Source

COMPONENT Source_Wavelength_monitor = L_monitor(nL=200, filename="Source_Spectrum", xwidth=0.2, yheight=0.2, Lmin=Wavelength_Min, Lmax=Wavelength_Max)
  AT (0.0, 0.0, 0.0) RELATIVE Source

COMPONENT source_BT_l_monitor = L_monitor(
    nL=300,
    filename="BT_source_spectrum",
    xwidth=0.0254,
    yheight=0.0254,
    Lmin=Wavelength_Min,
    Lmax=Wavelength_Max,
    restore_neutron=1)
AT (0, 0, 0) RELATIVE Source

COMPONENT source_BT_divergence_monitor = Divergence_monitor(
    nh=300,
    nv=300,
    filename="BT_Source_Divergence",
    xwidth=0.0254,
    yheight=0.0254,
    maxdiv_h=3,
```

```
    maxdiv_v=3,
    restore_neutron=1)
AT (0, 0, 0) RELATIVE PREVIOUS


//*****************************************************************************************************************************************************************


//*****************************************************************************************************************************************************************
// Model all the beamtube components that might block part of the beam depending on what is modeled downstream.
// Once the model is stable, components that do not block the beam should be commented out.
// Be sure to put them back in and check for shadows if you make any changes to the beamtube configuration.
//
// Model the hydrogen supply and return lines through the first section of the beamtube thimble (the part that is inside the pressure vessel).
// The lines are modeled by placing circular beamstops with the same radius (0.563" / 2 = 0.2815") as the hydrogen lines every 2 inches along the length of the thimble (vacuum sleeve).
// This is definitely overkill, but the beamstop component takes very negligible time to execute relative to most of the other components.
//
// Distance from the HB-4 Pressure Vessel Center Line to the start of the hydrogen lines is 4.685"(HB-4 Pressure Vessel Center Line to Source Plane) + 0.465"(depth of concave moderator surface, M11530CS341E-Rev1) + 5.375"(length of moderator "wings", M11530CS341E-Rev1) = 10.525"

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_1 = Beamstop(radius = (0.563 / 2.0) * IN2M)   // See M11530CS311E-Rev1 and M11530CS341E-Rev4
  AT ( 1.59 * IN2M, 0.0, 10.525 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System        // See M11530CS300E-Rev4

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_1 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, 10.525 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_2 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( 1.59 * IN2M, 0.0, (10.525 + 2.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_2 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, (10.525 + 2.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_3 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( 1.59 * IN2M, 0.0, (10.525 + 4.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_3 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, (10.525 + 4.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_4 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( 1.59 * IN2M, 0.0, (10.525 + 6.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_4 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, (10.525 + 6.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_5 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( 1.59 * IN2M, 0.0, (10.525 + 8.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_5 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, (10.525 + 8.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_6 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( 1.59 * IN2M, 0.0, (10.525 + 10.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_6 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, (10.525 + 10.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// The distance from the HB-4 Pressure Vessel Center Line to the frist step in the beamtube diameter (HB-4 Vacuum Sleeve M11530CS311E-Rev1) is given by:
// 1.875"(HB-4 Pressure Vessel Center Line to tip (closest point to HB-4 Pressure Vessel Center Line) of the HB-4 Reflector Penetration Tube) + (2.875" - 2.4375")(thickness of the Reflector Penetration Tube, M11530CS308E-Rev3) + 19.75" (first step in diameter of Vacuum Sleeve, M11530CS311
// The final beamstop components for modeling the hydrogen transfer lines are at the start of the first transition in the beamtube diameter.

COMPONENT Hydrogen_Supply_Line_Through_First_Section_of_Thimble_7 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( 1.59 * IN2M, 0.0, 22.0625 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Return_Line_Through_First_Section_of_Thimble_7 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-1.59 * IN2M, 0.0, 22.0625 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the end of the first section of the HB-4 Vacuum Sleeve as a circular aperture at the point when the diameter begins the transition from 4.435" to 5.186"  See M11530CS311E-Rev1

COMPONENT End_of_First_Section_of_Vacuum_Sleeve = Slit(radius = (4.435 / 2.0) * IN2M)
  AT (0.0, 0.0, 22.0625 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System  //See M11530CS341E-Rev1, M11530CS311E-Rev1, M11530CS300E-Rev4

// Model the end of the transition section of the HB-4 Vacuum Sleeve as a circular aperture.  See M11530CS311E-Rev1
// During the transition in the beamtube diameter increases from 4.435" to 5.186", the beamtube tappers by 10 degrees (see M11530CS311E-Rev1)
// The change in the beamtube radius is then (5.186" /2) - (4.435" /2) = 0.3755"
// So at a slope of 10 degrees, the length of the beamtube diameter transition is given by 0.3755" / tan(10) = 2.1296"

COMPONENT End_of_Vacuum_Sleeve_Transition = Slit(radius = (5.186 / 2.0) * IN2M)
  AT (0.0, 0.0, (22.0625 + 2.1296) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the hydrogen line support ring just after the transition in the beamtube diameter using a pair of circular apertures and a series of rectangular beam blocks.  See M11530CS313E-Rev4
// The hydrogen line clamp assembly begins 24.40" from the start of the HB-4 Vacuum Sleeve minus the weld overlap of 0.25" = 24.40" - 0.25" = 24.15"
// So the distance from the HB-4 Pressure Vessel Center Line to the start of the hydrogen line support ring is 1.875"(HB-4_PVCL to the tip of the HB-4 Reflector Penetration Tube) + (2.875" - 2.4375")(thickness of the Reflector Penetration Tube, M11530CS308E-Rev3) + 24.15" = 26.4375"
// The final beamstop components for modeling the hydrogen transfer lines are at the start of the first transition in the beamtube diameter.
```

```
COMPONENT Hydrogen_Line_Support_Ring_Assembly_Start = Slit(radius = (5.05 / 2.0) * IN2M)
  AT (0.0, 0.0, 26.4375 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_and_Support_Clamp_Left_1 = Beamstop(xwidth = 2.0 * IN2M, yheight = 6.0 * IN2M)
  AT ( (1.857 + 1.0) * IN2M, 0.0, 26.4375 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_and_Support_Clamp_Right_1 = Beamstop(xwidth = 2.0 * IN2M, yheight = 6.0 * IN2M)
  AT (-(1.857 + 1.0) * IN2M, 0.0, 26.4375 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_and_Support_Clamp_Left_2 = Beamstop(xwidth = 2.0 * IN2M, yheight = 6.0 * IN2M)
  AT ( (1.857 + 1.0) * IN2M, 0.0, (26.4375 + 4.50) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_and_Support_Clamp_Right_2 = Beamstop(xwidth = 2.0 * IN2M, yheight = 6.0 * IN2M)
  AT (-(1.857 + 1.0) * IN2M, 0.0, (26.4375 + 4.50) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Support_Ring_Assembly_End = Slit(radius = (5.05 / 2.0) * IN2M)
  AT (0.0, 0.0, (26.4375 + 4.50) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the hydrogen supply and return lines through the final section of the vacuum sleeve flange.

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_1 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_1 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_2 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 2.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_2 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 2.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_3 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 4.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_3 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 4.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_4 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 6.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_4 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 6.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_5 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 8.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_5 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 8.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_6 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 10.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_6 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 10.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_7 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 12.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_7 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 12.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_8 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 14.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_8 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 14.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_9 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 16.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_9 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 16.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_10 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 18.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_10 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 18.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_11 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 20.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_11 = Beamstop(radius = (0.563 / 2.0) * IN2M)
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  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 20.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_12 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 22.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_12 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 22.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_13 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 24.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_13 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 24.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_14 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 26.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_14 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 26.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_15 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 28.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_15 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 28.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_16 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 30.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_16 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 30.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_17 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 32.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_17 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 32.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_left_18 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT ( (4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 34.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Hydrogen_Line_Through_Vacuum_Sleeve_Flange_right_18 = Beamstop(radius = (0.563 / 2.0) * IN2M)
  AT (-(4.25 / 2.0) * IN2M, 0.0, (26.4375 + 4.50 + 34.0) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the end of the 5.186" diameter section of the vacuum sleeve flange as a circular aperture.  See M11530CS312E-Rev4

COMPONENT Downstream_End_of_Vacuum_Sleeve_Flange_1 = Slit(radius = (5.186 / 2.0) * IN2M)  // See M11530CS312E-Rev4
  AT (0.0, 0.0, (26.4375 + 4.50 + 36.385 - 1.63) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the connectors on the hydrogen line at the end of the Vacuum Sleeve Flange.  See M11530CS313E-Rev4 and M11530CS347E-Rev1

COMPONENT Hydrogen_Supply_Line_Connector = Beamstop(radius = (0.688 / 2.0) * IN2M)
  AT ( 2.125 * IN2M, 0.0, (26.4375 + 4.50 + 36.385 - 0.815) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System  // See M11530CS300E-Rev4, M11530CS313E-Rev4 and M11530CS310E-Rev4

COMPONENT Hydrogen_Return_Line_Connector = Beamstop(radius = (0.688 / 2.0) * IN2M)
  AT (-2.125 * IN2M, 0.0, (26.4375 + 4.50 + 36.385 - 0.815) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the end of the 5.46" diameter section of the vacuum sleeve flange as a circular aperture.  See M11530CS312E-Rev4

COMPONENT Downstream_End_of_Vacuum_Sleeve_Flange_2 = Slit(radius = (5.46 / 2.0) * IN2M)
  AT (0.0, 0.0, (26.4375 + 4.50 + 36.385) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the double loop in the hydrogen supply and return lines just past the end of the Vacuum Sleeve Flange as a pair of circular apertures.
// The loop is taken to be centered lengthwise in the HB-4 Vacuum Tube Access Sleeve (see Section UU on M11530CS305E-Rev5)
// The length of the HB-4 Vacuum Tube Access Sleeve (M11530CS321E-Rev1) is 7.55" and it overlaps the end of the Vacuum Sleeve Bell (M11530CS312E-Rev4) by 0.33"
// So the distance from the HB-4_PVCL to the center of the loop is 1.875"(HB-4 Pressure Vessel Cemter Line to the tip of the HB-4 Reflector Penetration Tube) + 66.58"(length of HB-4 Refelctor Penetration Tube including Vacuum Sleeve Bell) + ((7.55" - 0.33") / 2) = 72.065"
// The length of the hydrogen line loop along the beamtube axis is 3.465" (see M11530CS346E-Rev2)
// There is no need to model the He or vacuum lines between the Vacuum Tube Window and the end of the Vacuum sleeve since they cannot be in the neutron beam.
// There is no need to model the HB-4 Collimator Cavity Supply And Drain Line (used when flooding the beamtube) since it is normally empty and will not significantly attenuate the neutrons.

COMPONENT Hydrogen_Supply_Line_Loop_Start = Slit(radius = ((8.624 - 0.563) / 2.0) * IN2M)
  AT (0.0, 0.0, (72.065 - (3.465 / 2.0)) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System  // See M11530CS345E-Rev3

COMPONENT Hydrogen_Supply_Line_Loop_End = Slit(radius = ((8.624 - 0.563) / 2.0) * IN2M)
  AT (0.0, 0.0, (72.065 + (3.465 / 2.0)) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Ignore the pair of Al windows, but model nested hydrogen supply/return and other lines  See M11530CS304E-Rev11 and M11530CS337E-Rev0
// Model lines at HB-4 Vacuum Tube Window (M11520CS338E-Rev0) which is 1.875" (HB-4_PVCL to tip of HB-4 Beamtube Assembly, M11530CS300E-Rev4) + 156.5"(Total length of HB-4Beamtube Assembly, M11530CS304E-Rev11) - 7.000"(Length of HB-4 Shield Penetration Tube, M11530CD319E-Rev1) + 0.310"(HE
COMPONENT Nested_Hydrogen_Line_at_Vacuum_Tube_Window = Beamstop(radius = (1.781 / 2.0) * IN2M) // See M11530CS338E-Rev0
  AT (1.625 * IN2M, -4.188 * IN2M, 74.575 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Vacuum_Line_at_Vacuum_Tube_Window: R = 4.875" and rotation = 15 deg from top so x = R*sin(15) = 1.262" and y = R*cos(15) = 4.709"   See M11530CS338E-Rev0
COMPONENT Vacuum_Line_at_Vacuum_Tube_Window = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 74.575 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System
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COMPONENT Helium_Line_1_at_Vacuum_Tube_Window = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, 74.575 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_Vacuum_Tube_Window = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, 74.575 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model lines at HB-4 Transition Spool No. 2 (M11530CS337E-Rev1)
// It is 1.55" downstream from the HB-4 Vacuum Tube Window (See M11520CS304E-Rev11): 74.575" + 1.55" = 76.125"
COMPONENT Nested_Hydrogen_Line_at_Transition_Spool_No2 = Beamstop(radius = (2.274 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 76.125 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Vacuum_Line_at_Transition_Spool_No2: R = 4.875" and rotation = 15 deg from top so x = R*sin(15) = 1.262" and y = R*cos(15) = 4.709"   See M11530CS337E-Rev1
COMPONENT Vacuum_Line_at_Transition_Spool_No2 = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 76.125 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_Transition_Spool_No2 = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, 76.125 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_Transition_Spool_No2 = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, 76.125 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the lines at the step up to 2.625" OD in the nested hydrogen supply line around the bimetal fitting assembly
// The step is located 10.045" - 4.333" - 1.5" = 4.212" (see M11530CS363E-Rev1) downstream from HB-4 Transition Spool No. 2

COMPONENT Nested_Hydrogen_Line_at_2625_Step_in_OD = Beamstop(radius = (2.625 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, (76.125 + 4.212) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_at_2625_Step_in_OD_of_Nested_Hydrogen_Line = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, (76.125 + 4.212) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_2625_Step_in_OD_of_Nested_Hydrogen_Line = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, (76.125 + 4.212) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_2625_Step_in_OD_of_Nested_Hydrogen_Line = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, (76.125 + 4.212) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the nested hydrogen, helium, and vacuum lines at the start of the HB-4 Collimator Cavity Supply And Drain Line
// The position of the start of the drain line is referenced from the turn inside the internal beamtube collimator (see M11530CS304E-Rev11, M11530CS332E-Rev3, and M11530CS314E-Rev2)
// Distance to the start of the collimator is 108.928" pressure vessel center line (value provided by Troy Jensen).
// So the start of the drain line is at 108.928"(pressure vessel center line to the start of collimator) + 36.00"(total length of collimator) - (15.88" - 1.5")(distance from downstream end of collimator to where lines turn) - (65.50" - 3.0" - 17.00")(distance from turn inside the collimat

COMPONENT Nested_Hydrogen_Line_at_start_of_Drain_Line = Beamstop(radius = (2.625 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 85.048 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_at_start_of_Drain_Line = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 85.048 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_start_of_Drain_Line = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, 85.048 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_start_of_Drain_Line = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, 85.048 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Location not clear from the drawings but assumed to be at the bottom of the beamtube since it is a drain line.
// Inner diameter of beam tube (HB4 Spool) is 11.75" and the outer diameter of the drain line is 0.375"
COMPONENT Drain_Line_at_start_of_Drain_Line = Beamstop(radius = (0.375 / 2.0) * IN2M)
  AT (0.0, -((11.75 / 2.0) - (0.375 / 2.0)) * IN2M, 85.048 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the nested hydrogen, helium, and vacuum lines at the turn in the drain line
// The position of the in the drain line is referenced from the start of the drain line (see M11530CS304E-Rev11, M11530CS332E-Rev3)
// Distance from the pressure vessel center line to the turn in the drain line is 85.048" + (65.5" - 3.0" - 57.71") = 89.838"

COMPONENT Nested_Hydrogen_Line_at_turn_in_drain_line = Beamstop(radius = (2.625 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 89.838 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_at_turn_in_drain_line = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 89.838 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_turn_in_drain_line = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, 89.838 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_turn_in_drain_line = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, 89.838 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Drain_Line_at_turn_in_drain_line_1 = Beamstop(radius = (0.375 / 2.0) * IN2M)
  AT (0.0, -((11.75 / 2.0) - (0.375 / 2.0)) * IN2M, 89.838 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Ignore the transverse section of the drain line here, it is too thin to attenuate the beam very much (0.049" x 2 of Al)
// This turn in the drain line rotates it up from the bottom (-90 degrees) to -52.5 degrees measured from vector (-1, 0, 0) out from the beamtube center line
// This puts it on the -x side of the beamtube across from the nested hydrogen line
// So x = -((11.75 / 2.0) - (0.375 / 2.0)) * cos(52.5) = -3.462" and y = -((11.75 / 2.0) - (0.375 / 2.0)) * sin(52.5) = -4.512"

COMPONENT Drain_Line_at_turn_in_drain_line_2 = Beamstop(radius = (0.375 / 2.0) * IN2M)
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  AT (-3.462 * IN2M, -4.512 * IN2M, 89.838 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model all the lines at the half way point between the turn in the drain line and the turns in the vacuum and helium lines
// The vacuum and helium lines make all their turns at the same distace from the core centerline
// We model the lines at this point to eliminate neutrons that might completely pass through one of the lines between the turn in the drain line and the turns in the other lines
// The turns in the vacuum and helium lines are referenced from their turns inside the internal beamtube collimator
// These position of the turns upstream of the collimators are at 108.928"(pressure vessel center line to the start of collimator) + 36.00"(total length of collimator) - (15.88" - 1.5")(distance from downstream end of collimator to where lines turn) - 30.0"(distance from turns inside coll
// So the half way point is at 89.838" + (100.548 - 89.838) / 2 = 95.193"

COMPONENT Nested_Hydrogen_Line_halfway_between_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (2.625 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 95.193 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_halfway_between_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 95.193 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_halfway_between_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, 95.193 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_halfway_between_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, 95.193 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Drain_Line_halfway_between_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (0.375 / 2.0) * IN2M)
  AT (-3.462 * IN2M, -4.512 * IN2M, 95.193 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Now model all the lines at the point where the Vacuum and Helium lines turn upstream of the internal beamline collimator

COMPONENT Nested_Hydrogen_Line_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (2.625 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns_1 = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Ignore the transverse section of the Vacuum line -- not much attenuation
// This turn in the Vacuum Line rotates it counterclockwise (looking back toward the source) from 15 degrees from the vertical to 75 degrees from the vertical (see M11530CS314E_Rev2)
// It remains on the +x side of the beamtube on the same side as the nested hydrogen line
// So x = 4.875 * cos(15.0) = 4.709" and y = 4.875 * sin(15) = 1.262"
COMPONENT Vacuum_Line_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns_2 = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (4.709 * IN2M, 1.262 * IN2M, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns_1 = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT ((10.250 / 2.0) * IN2M, 0.0, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Ignore the transverse section of Helium Line 1 -- not much attenuation
// This turn in Helium Line 1 rotates it counterclockwise (looking back toward the source) by 45 degrees (see M11530CS314E_Rev2)
// It remains on the +x side of the beamtube on the same side as the nested hydrogen line
// So x = (10.25 / 2.0) * cos(45.0) = 3.624" and y = -(10.25 / 2.0) * sin(45) = -3.624"
COMPONENT Helium_Line_1_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns_2 = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (3.624 * IN2M, -3.624 * IN2M, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns_1 = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-(10.250 / 2.0) * IN2M, 0.0, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Ignore the transverse section of Helium Line 2 -- not much attenuation
// This turn in Helium Line 2 rotates it counterclockwise (looking back toward the source) by 45 degrees (see M11530CS314E_Rev2)
// It remains on the -x side of the beamtube on the opposite side from the nested hydrogen line
// So x = -(10.25 / 2.0) * cos(45.0) = 3.624" and y = (10.25 / 2.0) * sin(45) = 3.624"
COMPONENT Helium_Line_2_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns_2 = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-3.624 * IN2M, 3.624 * IN2M, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Drain_Line_at_Drain_Line_turn_and_Vacuum_Line_Helium_Lines_turns = Beamstop(radius = (0.375 / 2.0) * IN2M)
  AT (-3.462 * IN2M, -4.512 * IN2M, 100.548 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model all the lines halfway between the point where the Vacuum and Helium lines turn and the upstream end of the internal beamline collimator
// The position will be at 100.548" + ((108.928" - 100.548") / 2) = 104.738"

COMPONENT Nested_Hydrogen_Line_halfway_between_Vacuum_and_Helium_Line_turns_And_upstream_end_of_collimator = Beamstop(radius = (2.275 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 104.738 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_halfway_between_Vacuum_and_Helium_Line_turns_And_upstream_end_of_collimator = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (4.709 * IN2M, 1.262 * IN2M, 104.738 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_halfway_between_Vacuum_and_Helium_Line_turns_And_upstream_end_of_collimator = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (3.624 * IN2M, -3.624 * IN2M, 104.738 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_halfway_between_Vacuum_and_Helium_Line_turns_And_upstream_end_of_collimator = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-3.624 * IN2M, 3.624 * IN2M, 104.738 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Drain_Line_halfway_between_Vacuum_and_Helium_Line_turns_And_upstream_end_of_collimator = Beamstop(radius = (0.375 / 2.0) * IN2M)
  AT (-3.462 * IN2M, -4.512 * IN2M, 104.738 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model all the lines at the upstream end of the internal beamline collimator -- 108.928" from the pressure vessel center line

COMPONENT Nested_Hydrogen_Line_at_upstream_end_of_collimator = Beamstop(radius = (2.275 / 2.0) * IN2M)
  AT (1.625 * IN2M, -4.188 * IN2M, 108.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System
```

```
COMPONENT Vacuum_Line_at_upstream_end_of_collimator = Beamstop(radius = (1.281 / 2.0) * IN2M)
  AT (4.709 * IN2M, 1.262 * IN2M, 108.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_upstream_end_of_collimator = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (3.624 * IN2M, -3.624 * IN2M, 108.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_upstream_end_of_collimator = Beamstop(radius = (0.397 / 2.0) * IN2M)
  AT (-3.624 * IN2M, 3.624 * IN2M, 108.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Drain_Line_at_upstream_end_of_collimator = Beamstop(radius = (0.375 / 2.0) * IN2M)
  AT (-3.462 * IN2M, -4.512 * IN2M, 108.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

//Model the upstream end of the internal beamtube collimator shelf as a rectangular beamstop (see M11530CS314E-Rev2)

COMPONENT Internal_Beamtube_Collimator_Shelf_Start = Beamstop(xwidth = 11.73 * IN2M, yheight = 8.0 * IN2M)
  AT (0.0, (-2.38 - (8.0 / 2.0)) * IN2M, 108.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System  //Distance to the start of the collimator (108.928") provided by Troy Jensen.

// The actual entrance to the collimator penetration is located at 108.928" + 7.25" = 116.178" (see M11530CS314E-Rev2)

COMPONENT Internal_Collimator_Entrance_Image = PSD_monitor(nx = 700, ny = 700, filename = "Internal_Collimator_Entrance_Image", xwidth=0.35, yheight=0.35)
  AT (0.0, 0.0, 116.178 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model internal beamtube collimator as a guide with two beamstops for the "steps" at the top.  Not really considering guide here but maybe the inner surface can be polished and coated with Ni if it helps improves performance a lot. (see M11530CS314E-Rev2)
// This is a crude model because it does not consider reflections from the stepped surfaces.  Need a better "Custom" component.

COMPONENT Internal_Collimator_Penetration_Shadow_1 = Beamstop(xmin = 1.6 * IN2M, xmax = 3.25 * IN2M, ymin = 2.83 * IN2M, ymax = 3.8 * IN2M)
  AT (0.0, 0.0, 116.178 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Internal_Collimator_Penetration_Shadow_2 = Beamstop(xmin = -3.5 * IN2M, xmax = -3.0 * IN2M, ymin = 3.0 * IN2M, ymax = 3.8 * IN2M)
  AT (0.0, 0.0, 116.178 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Internal beamtube collimator penetration adjusted to match M11530CS314E-Rev2 9/6/2018
// Using m=1 here not worth the cost/effort.  Use m=0 instead. Lee Robertson 10/12/2018

COMPONENT Internal_Collimator_Penetration = Guide_custom_tally(w1 = 6.61 * IN2M, h1 = 5.02 * IN2M, l = 28.75 * IN2M, R0 = 0.99, Qc = 0.0219, alpha1 = 0.0, alpha2 = 0.0, alpha3 = 0.0, alpha4 = 0.0, m1 = 0.0, m2 = 0.0, m3 = 0.0, m4 = 0.0, W1 = 0.0, W2 = 0.0, W3 = 0.0, W4 = 0.0)
  AT (-0.095 * IN2M, 1.13 * IN2M, (108.928 + 7.25) * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

//  The downstream end of the internal beamtube collimator is located at 108.928" + 36.00" = 144.928" (see M11530CS314E-Rev2)

COMPONENT Internal_Collimator_Penetration_Shadow_3 = Beamstop(xmin = 1.6 * IN2M, xmax = 3.25 * IN2M, ymin = 2.83 * IN2M, ymax = 3.8 * IN2M)
  AT (0.0, 0.0, 144.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Internal_Collimator_Penetration_Shadow_4 = Beamstop(xmin = -3.5 * IN2M, xmax = -3.0 * IN2M, ymin = 3.0 * IN2M, ymax = 3.8 * IN2M)
  AT (0.0, 0.0, 144.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Internal_Collimator_Exit_Image = PSD_monitor(nx = 700, ny = 700, filename = "Internal_Collimator_Exit_Image", xwidth=0.35, yheight=0.35)
  AT (0.0, 0.0, 144.928 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the downstream end of the HB-4 Spool section of the beamtube by a circular aperture.  See M11530CS318E-Rev1
// Position is 62.245" HB-4 Pressure Vessel Center Line to Flange Surface of Reflector Penetration Tube) + 96.130" (from there out to the downstream end of the HB-4 Shield Penetration Tube M11530CS319E-Rev1, M11530CS304E-Rev11) - 7.00" (length of the HB-4 Shield Penetration Tube M11530CS3

COMPONENT Spool_Section = Slit(radius = (11.73 / 2.0) * IN2M)
  AT (0.0, 0.0, 146.656 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model the spool transition assembly. Use a circular aperture for the step in the beamtube diameter
// Position is 62.245" HB-4 Pressure Vessel Center Line to Flange Surface of Reflector Penetration Tube) + 96.130" (from there out to the downstream end of the HB-4 Shield Penetration Tube M11530CS319E-Rev1, M11530CS304E-Rev11) - 7.00" (length of the HB-4 Shield Penetration Tube M11530CS3

COMPONENT Transition_Spool_No1_Step_in_Beamtube_Diameter = Slit(radius = (11.73 / 2.0) * IN2M)
  AT (0.0, 0.0, 150.418 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model all the lines at the step in th beamtube diameter in HB4 Transition Spool No1 -- 150.418" from the pressure vessel center line

COMPONENT Nested_Hydrogen_Line_at_Transition_Spool_No1_Step_in_Beamtube_Diameter = Beamstop(radius = (2.275 / 2.0) * IN2M)
  AT (-0.812 * IN2M, -4.188 * IN2M, 150.418 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

//  x = 4.875" * sin(15) = 1.262" and y = 4.875" * cos(15) = 4.709"  see M11530CS336E-Rev4
COMPONENT Vacuum_Line_at_Transition_Spool_No1_Step_in_Beamtube_Diameter = Beamstop(radius = (1.266 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 150.418 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_Transition_Spool_No1_Step_in_Beamtube_Diameter = Beamstop(radius = (0.277 / 2.0) * IN2M)  //see M11530CS336E-Rev4
  AT ((10.25 / 2.0) * IN2M, 0.0, 150.418 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_Transition_Spool_No1_Step_in_Beamtube_Diameter = Beamstop(radius = (0.277 / 2.0) * IN2M)  //see M11530CS336E-Rev4
  AT (-(10.25 / 2.0) * IN2M, 0.0, 150.418 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// x = (10.25 / 2) * cos(29.5) = 4.461 and y = (10.25 / 2) * sin(29.5) = 2.524"  see M11530CS36E-Rev4
COMPONENT Drain_Line_at_Transition_Spool_No1_Step_in_Beamtube_Diameter = Beamstop(radius = (0.277 / 2.0) * IN2M)
  AT (-4.461 * IN2M, -2.524 * IN2M, 150.418 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// There is a wicked evil coupling on the hydrogen line here.
// It is so bad we had to eliminate and entire guide and instrument because of it.
// The coupling is hexagonal and is offset from the center of the nested hydrogen line.
// The center of the hexagonal coupling is at x = -0.812" + 0.501" = -0.311" and y = -4.188" + 0.206" = -3.982"  see M11530CS336E-rev4 and M11530CS378E-Rev2
```

```
// Model the hexagonal shape of the coupling by three rectangular beamstops rotated by 60 degrees
// The length of the rectangles is 2.0 * 2.569" = 5.138" and the width is 2.0 * 2.569" * tan(30) = 2.966"
// One of the rectangular beamstops is vertical, one at +60 degrees, and one at -60 degrees   see M11530CS378E-Rev2
// The position of the Hexagonal Coupling is at z = 150.418" (Transition Spool No1 step in beamtube diameter) + 2.276" (length of HB-4 Hydrogen Transfer Line and Bellows Assembly, M11530CS375E-Rev1) = 152.694"

COMPONENT Nested_Hydrogen_Line_Hexagonal_Coupling_1 = Beamstop(xwidth = 2.966 * IN2M, yheight = 5.138 * IN2M)
  AT (-0.311 * IN2M, -3.982 * IN2M, 152.694 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Nested_Hydrogen_Line_Hexagonal_Coupling_2 = Beamstop(xwidth = 2.966 * IN2M, yheight = 5.138 * IN2M)
  AT (0.0, 0.0, 0.0) RELATIVE PREVIOUS
  ROTATED (0.0, 0.0, 60.0) RELATIVE PREVIOUS

COMPONENT Nested_Hydrogen_Line_Hexagonal_Coupling_3 = Beamstop(xwidth = 2.966 * IN2M, yheight = 5.138 * IN2M)
  AT (0.0, 0.0, 0.0) RELATIVE PREVIOUS
  ROTATED (0.0, 0.0, 60.0) RELATIVE PREVIOUS

// Model the shield penetration tube by a circular aperture at the downstream end.  See M11530CS319E-Rev1
// Position at 62.245" (Pressure Vessel Center Line to Vacuum Sleeve Seal Flange) + 89.470" (Vacuum Sleeve Seal Flange to downstream end of Transition Spool No1 including overlap tab) - 0.31" (overlap tab) + 7.000" (length of HB-4 Beam Tube Access Sleeve) = 158.405"

COMPONENT Shield_Penetration_Tube = Slit(radius = (13.75 / 2.0) * IN2M)
  AT (0.0, 0.0, 158.405 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Model all the lines at the downstream end of the HB-4 Shield Penetration Tube -- 158.405" from the pressure vessel center line

COMPONENT Nested_Hydrogen_Line_at_downstream_end_of_Shield_Penetration_Tube = Beamstop(radius = (2.275 / 2.0) * IN2M)
  AT (-0.812 * IN2M, -4.188 * IN2M, 158.405 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Vacuum_Line_at_downstream_end_of_Shield_Penetration_Tube = Beamstop(radius = (1.266 / 2.0) * IN2M)
  AT (1.262 * IN2M, 4.709 * IN2M, 158.405 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_1_at_downstream_end_of_Shield_Penetration_Tube = Beamstop(radius = (0.277 / 2.0) * IN2M)  //see M11530CS336E-Rev4
  AT ((10.25 / 2.0) * IN2M, 0.0, 158.405 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Helium_Line_2_at_downstream_end_of_Shield_Penetration_Tube = Beamstop(radius = (0.277 / 2.0) * IN2M)  //see M11530CS336E-Rev4
  AT (-(10.25 / 2.0) * IN2M, 0.0, 158.405 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

COMPONENT Drain_Line_at_downstream_end_of_Shield_Penetration_Tube = Beamstop(radius = (0.277 / 2.0) * IN2M)
  AT (-4.461 * IN2M, -2.524 * IN2M, 158.405 * IN2M) RELATIVE Pressure_Vessel_CL_Coordinate_System

// Generate a beam image and spectrum at the exit of the beamtube

//**********************************************************************************************************************************

END
```

# C MCSTAS CODE REPRESENTING THE MAIN SHUTTER AT HB4

https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source-2024/-/blob/master/HB4_Main_Shutter.instr

```
/*******************************************************************************
*         McStas instrument definition URL=http://www.mcstas.org
*
* Instrument: New HB4 Main Shutter
*
* %Identification
* Written by: Matthew Frost (frostmj@ornl.gov)
* Date Created: 28may2020
* Origin: ORNL
* %INSTRUMENT_SITE: ORNL
*
* %Description
* The main shutter consists of the rotating drum with a vertical rotation axis.
* There are three beam path penetrations for S1 (NB-1, NB-3, NB-4), S2 (NB-2A, NB-2B, NB-5), and S3 (NB-6).
* This module models the location of the Main Shutter Rotation Axis
* The the shutter penetration to be used is determined by the
* The penetration has a straight guide.
*
* %Parameters
* There are no parameters
*
* %Link
*
* %End
*******************************************************************************/

DEFINE INSTRUMENT HB4_Main_Shutter()

TRACE

//*****************************************************************************************************************************
//
//  Because the S1 penetration has an irregular shape, we will use the Guide_anyshape component to model it.
//
//  To generate the vetices of the S1 guide section, run the puthon scripts NB1_calc_shutter_penetration.py, NB3_calc_shutter_penetration.py, and NB4_calc_shutter_penetration.py
//  These scripts should be in the HB4_Main_Shutter folder
//
//  Output from NB1_calc_shutter_penetration.py:
//
// These coordinates are relative to the center of the source in the McSTAS model, NOT the core centerline
// NB-1 : Guide coordinate system origin:
//      x poisiton at source =  0.0
//      y poisiton at source =  8.855115
//      z poisiton at source =  0.0
//      x-axis rotation = -0.91976359
//      y-axis rotation = -0.66101
//      z-axis rotation = 0.0
//      Position where the guide in the common casing begins : (-53.726756789, 83.6213911526, 4656.78255604)
//
// McSTAS code for the origin of the NB-1 guide system:
// COMPONENT NB1_Beam_Coordinate_System = Arm()
//   AT (-53.726756789, 83.6213911526, 4656.78255604 RELATIVE Source
//   ROTATED (-0.91976359, -0.66101, 0.0) RELATIVE Source
//
// NB-1:centerline
// enter: -46.5614121675, 73.6500813859, 4035.72418893
// exit: -53.4149285694, 83.1874502976, 4629.75475276
//
```

```
// NB-1:x = 20.0, y = 28.855114999999998
// enter: -26.5318180762, 93.6096232442, 4033.27448159
// exit: -33.4471845867, 103.233062907, 4632.6659219
//
// NB-1:x = -20.0, y = 28.855114999999998
// enter: -66.6070026422, 93.7179545983, 4039.56038754
// exit: -73.3666761687, 103.124731553, 4625.45709235
//
// NB-1:x = 20.0, y = -11.144885
// enter: -26.5318180762, 53.6044687768, 4033.27448159
// exit: -33.4471845867, 63.2279084393, 4632.6659219
//
// NB-1:x = -20.0, y = -11.144885
// enter: -66.6070026422, 53.712800131, 4039.56038754
// exit: -73.3666761687, 63.1195770852, 4625.45709235
//
//
//
// Output from NB3_calc_shutter_penetration.py:
//
// These coordinates are relative to the center of the source in the McSTAS model, NOT the core centerline
// NB-3 : Guide coordinate system origin:
//      x poisiton at source =  0.0
//      y poisiton at source =  0.0
//      z poisiton at source =  0.0
//      x-axis rotation = -0.5
//      y-axis rotation = -0.66101
//      z-axis rotation = 0.0
//      Position where the guide in the common casing begins : (-53.726756789, 40.6418303355, 4656.78255604)
//
// McSTAS code for the origin of the NB-3 guide system:
// COMPONENT NB3_Beam_Coordinate_System = Arm()
//   AT (-53.726756789, 40.6418303355, 4656.78255604 RELATIVE Source
//   ROTATED (-0.5, -0.66101, 0.0) RELATIVE Source
//
// NB-3:centerline
// enter: -46.5614121675, 35.2215753674, 4035.72418893
// exit: -53.4149285694, 40.4059465719, 4629.75475276
//
// NB-3:x = 20.0, y = 20.0
// enter: -26.5318180762, 55.1989435482, 4033.27448159
// exit: -33.4471845867, 60.4301015266, 4632.6659219
//
// NB-3:x = -20.0, y = 20.0
// enter: -66.6070026422, 55.2578308533, 4039.56038754
// exit: -73.3666761687, 60.3712142215, 4625.45709235
//
// NB-3:x = 20.0, y = -20.0
// enter: -26.5318180762, 15.1974204128, 4033.27448159
// exit: -33.4471845867, 20.4285783911, 4632.6659219
//
// NB-3:x = -20.0, y = -20.0
// enter: -66.6070026422, 15.2563077179, 4039.56038754
// exit: -73.3666761687, 20.369691086, 4625.45709235
//
//
//
// Output from NB4_calc_shutter_penetration.py:
//
// These coordinates are relative to the center of the source in the McSTAS model, NOT the core centerline
// NB-4 : Guide coordinate system origin:
//      x poisiton at source =  0.0
//      y poisiton at source =  -8.3711
//      z poisiton at source =  0.0
//      x-axis rotation = 0.0
//      y-axis rotation = -0.66101
```

```
//      z-axis rotation = 0.0
//      Position where the guide in the common casing begins : (-53.726756789, -8.3711, 4656.78255604)
//
// McSTAS code for the origin of the NB-4 guide system:
// COMPONENT NB4_Beam_Coordinate_System = Arm()
//   AT (-53.726756789, -8.3711, 4656.78255604 RELATIVE Source
//   ROTATED (0.0, -0.66101, 0.0) RELATIVE Source
//
// NB-4:centerline
// enter: -46.5614121675, -8.3711, 4035.72418893
// exit: -53.4149285694, -8.3711, 4629.75475276
//
// NB-4:x = 20.0, y = 16.6289
// enter: -26.5318180762, 16.6289, 4033.27448159
// exit: -33.4471845867, 16.6289, 4632.6659219
//
// NB-4:x = -20.0, y = 16.6289
// enter: -66.6070026422, 16.6289, 4039.56038754
// exit: -73.3666761687, 16.6289, 4625.45709235
//
// NB-4:x = 20.0, y = -33.3711
// enter: -26.5318180762, -33.3711, 4033.27448159
// exit: -33.4471845867, -33.3711, 4632.6659219
//
// NB-4:x = -20.0, y = -33.3711
// enter: -66.6070026422, -33.3711, 4039.56038754
// exit: -73.3666761687, -33.3711, 4625.45709235
//
//
//  The top of the S1 Shutter penetration is defined by NB-1 and the bottom by NB-4
//
//  So in the source cordinate system, the OFF File Would look like:
//
// # OFF File for the S1 penetration through the HB-4 Main Shutter
// # First line needs to be "OFF"
// OFF
// #
// # This OFF file contains 8 vertices and 4 surfaces
// # The next line indicates the number of vertices followed by the number of surfaces
// 8 4
// #
// # This is the list of vertices:
// -0.066607  -0.033371  4.039560   #vertex #0
// -0.026532  -0.033371  4.033274   #vertex #1
// -0.033447  -0.033371  4.632666   #vertex #2
// -0.073367  -0.033371  4.625457   #vertex #3
// -0.066607   0.093718  4.039560   #vertex #4
// -0.026531   0.093610  4.033274   #vertex #5
// -0.033447   0.103233  4.632666   #vertex #6
// -0.073367   0.103125  4.625457   #vertex #7
// #
// # This is the list of reflecting surfaces
// # The first number is the number of vertices from the list above needed to define this surface
// # It is followed by the list of vertices (number in order from the vertex list above starting with 0)
// # Finally there is the reflectivity parameters for that surface (m, R0, Qc, alpha, W)
// 4    5  1  2  6      3.000  0.990  0.0219  2.511  0.0025    #surface #0 (right vertical mirror)
// 4    4  0  3  7      3.000  0.990  0.0219  2.511  0.0025    #surface #1 (left vertical mirror)
// 4    0  1  2  3      3.000  0.990  0.0219  2.511  0.0025    #surface #3 (lower horizontal mirror, bottom)
// 4    4  5  6  7      3.000  0.990  0.0219  2.511  0.0025    #surface #4 (upper horizontal mirror, top)
// #
// # End of OFF file# OFF File for the S1 penetration through the HB-4 Main Shutter

//      # First line needs to be "OFF"
//      OFF
//      #
//      # This OFF file contains 8 vertices and 4 surfaces
```

```
//      # The next line indicates the number of vertices followed by the number of surfaces
//      8 4
//      #
//      # This is the list of vertices:          BASED ON SOURCE POSITION
//      #-0.066607  -0.033371  4.039560   #vertex #0
//      #-0.026532  -0.033371  4.033274   #vertex #1
//      #-0.033447  -0.033371  4.632666   #vertex #2
//      #-0.073367  -0.033371  4.625457   #vertex #3
//      #-0.066607   0.093718  4.039560   #vertex #4
//      #-0.026531   0.093610  4.033274   #vertex #5
//      #-0.033447   0.103233  4.632666   #vertex #6
//      #-0.073367   0.103125  4.625457   #vertex #7
//      # This is the list of vertices:          BASED ON SHUTTER DRUM ROTATION AXIS
//      -0.066607  -0.033371  -0.293756   #vertex #0
//      -0.026532  -0.033371  -0.300042   #vertex #1
//      -0.033447  -0.033371   0.299350   #vertex #2
//      -0.073367  -0.033371   0.292141   #vertex #3
//      -0.066607   0.093718  -0.293756   #vertex #4
//      -0.026531   0.093610  -0.300042   #vertex #5
//      -0.033447   0.103233   0.299350   #vertex #6
//      -0.073367   0.103125   0.292141   #vertex #7
//      #
//      # This is the list of reflecting surfaces
//      # The first number is the number of vertices from the list above needed to define this surface
//      # It is followed by the list of vertices (number in order from the vertex list above starting with 0)
//      # Finally there is the reflectivity parameters for that surface (m, R0, Qc, alpha, W)
//      4    5  1  2  6      1.000  0.990  0.0219  2.511  0.0025    #surface #0 (right vertical mirror)
//      4    4  0  3  7      1.000  0.990  0.0219  2.511  0.0025    #surface #1 (left vertical mirror)
//      4    0  1  2  3      0.500  0.990  0.0219  2.511  0.0025    #surface #3 (lower horizontal mirror, bottom)
//      4    4  5  6  7      0.500  0.990  0.0219  2.511  0.0025    #surface #4 (upper horizontal mirror, top)
//      #
//      # End of OFF file


COMPONENT Shutter_Entrance_Image = PSD_monitor(nx = 100, ny = 100, filename = "Shutter_Entrance_Image", xmin = -.25, xmax = .25, ymin = -.25, ymax = .25)
//  AT (0.0, 0.0, 4.029) RELATIVE Source
  AT (0.0, 0.0, 4.13146) ABSOLUTE

COMPONENT Shutter_Mask = Slit_anyshape(geometry = shutter_filename, vertices = "4 0 1 5")
//  AT (0.0, 0.0, 0.0) RELATIVE Source
  AT (0.0, 0.0, 4.452315) ABSOLUTE // POSITION OF ROTATION AXIS IN HB4 COORDINATE SYSTEM PER DRAWING 2020520-HB4_SHUTTER_INFO_3XH - sht1.pdf PROVIDED BY MIKE HOFFMANN ON MAY 20, 2020.

COMPONENT Shutter_Guide_Section = Guide_anyshape_tally(geometry = shutter_filename, center=0)
//  AT (0.0, 0.0, 0.0) RELATIVE Source
  AT (0.0, 0.0, 4.452315) ABSOLUTE // POSITION OF ROTATION AXIS IN HB4 COORDINATE SYSTEM PER DRAWING 2020520-HB4_SHUTTER_INFO_3XH - sht1.pdf PROVIDED BY MIKE HOFFMANN ON MAY 20, 2020.

COMPONENT Shutter_Exit_Image = PSD_monitor(restore_neutron=1, nx = 100, ny = 100, filename = "Shutter_Exit_Image", xmin = -.25, xmax = .25, ymin = -.25, ymax = .25)
  AT (0.0, 0.0, 4.77299) ABSOLUTE //CHANGED ON 2020MAY27 TO ACCOMODATE MAIN SHUTTER GUIDE INTERFACE PLANE VALUE Z = 4.77299 IN HB4 ORIGIN SYSTEM

//Transition Building Bulkhead Opening - defined by a slit that fits inside points defined by M Hoffmann

COMPONENT TT_Center = Arm()
  AT (-0.615500,-0.328000,20.602500) ABSOLUTE
  ROTATED (0.0, -15.085775, 0.0) ABSOLUTE

COMPONENT TT_BS_01 = Beamstop(xwidth=3.323538,yheight=1.000000)
  AT (0.000000,1.232000,0.000000) RELATIVE TT_Center
  ROTATED (0.0, 0.0, 0.0) RELATIVE TT_Center

COMPONENT TT_BS_02 = Beamstop(xwidth=1.000000,yheight=3.464000)
  AT (2.161769,0.000000,0.000000) RELATIVE TT_Center
  ROTATED (0.0, 0.0, 0.0) RELATIVE TT_Center

COMPONENT TT_BS_03 = Beamstop(xwidth=3.323538,yheight=1.000000)
  AT (0.000000,-1.232000,0.000000) RELATIVE TT_Center
  ROTATED (0.0, 0.0, 0.0) RELATIVE TT_Center
```

```
COMPONENT TT_BS_04 = Beamstop(xwidth=1.000000,yheight=3.464000)
  AT (-2.161769,0.000000,0.000000) RELATIVE TT_Center
  ROTATED (0.0, 0.0, 0.0) RELATIVE TT_Center

//Column based on output from cg_hall_column_01.py

COMPONENT column_01_1 = Beamstop(xwidth=1.146907,yheight=1.0)
   AT (-8.764254,0.0,47.219349) ABSOLUTE
   ROTATED (0.0,-104.329132,0.0) ABSOLUTE
COMPONENT column_01_2 = Beamstop(xwidth=0.519726,yheight=1.0)
   AT (-9.157958,0.0,47.710648) ABSOLUTE
   ROTATED (0.0,165.670844,0.0) ABSOLUTE
COMPONENT column_01_3 = Beamstop(xwidth=0.396137,yheight=1.0)
   AT (-9.360716,0.0,47.454428) ABSOLUTE
   ROTATED (0.0,75.670807,0.0) ABSOLUTE
COMPONENT column_01_4 = Beamstop(xwidth=0.761584,yheight=1.0)
   AT (-9.156837,0.0,46.914639) ABSOLUTE
   ROTATED (0.0,66.003893,0.0) ABSOLUTE
COMPONENT column_01_5 = Beamstop(xwidth=0.391839,yheight=1.0)
   AT (-8.812154,0.0,46.615246) ABSOLUTE
   ROTATED (0.0,-14.329144,0.0) ABSOLUTE


END
```

# D MAIN SHUTTER GUIDE CHANNEL S1 OFF FILE

https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source-2024/-/blob/master/main_shutter_S1.off

```
# OFF File for the S1 penetration through the HB-4 Main Shutter
# First line needs to be "OFF"
OFF
#
# This OFF file contains 8 vertices and 4 surfaces
# The next line indicates the number of vertices followed by the number of surfaces
8 4
#
# This is the list of vertices:         BASED ON SOURCE POSITION
#-0.066607  -0.033371  4.039560   #vertex #0
#-0.026532  -0.033371  4.033274   #vertex #1
#-0.033447  -0.033371  4.632666   #vertex #2
#-0.073367  -0.033371  4.625457   #vertex #3
#-0.066607   0.093718  4.039560   #vertex #4
#-0.026531   0.093610  4.033274   #vertex #5
#-0.033447   0.103233  4.632666   #vertex #6
#-0.073367   0.103125  4.625457   #vertex #7
# This is the list of vertices:         BASED ON SHUTTER DRUM ROTATION AXIS
-0.066607  -0.033371  -0.293756   #vertex #0
-0.026532  -0.033371  -0.300042   #vertex #1
-0.033447  -0.033371   0.299350   #vertex #2
-0.073367  -0.033371   0.292141   #vertex #3
-0.066607   0.093718  -0.293756   #vertex #4
-0.026531   0.093610  -0.300042   #vertex #5
-0.033447   0.103233   0.299350   #vertex #6
-0.073367   0.103125   0.292141   #vertex #7
#
# This is the list of reflecting surfaces
# The first number is the number of vertices from the list above needed to define this surface
# It is followed by the list of vertices (number in order from the vertex list above starting with 0)
# Finally there is the reflectivity parameters for that surface (m, R0, Qc, alpha, W)
4    5  1  2  6      3.000  0.990  0.0219  2.511  0.0025    #surface #0 (right vertical mirror)
4    4  0  3  7      3.000  0.990  0.0219  2.511  0.0025    #surface #1 (left vertical mirror)
4    0  1  2  3      0.000  0.990  0.0219  2.511  0.0025    #surface #3 (lower horizontal mirror, bottom)
4    4  5  6  7      0.000  0.990  0.0219  2.511  0.0025    #surface #4 (upper horizontal mirror, top)
#
# End of OFF file
```

# E Main Shutter Guide Channel S2 OFF File

https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source-2024/-/blob/master/main_shutter_S2.off

```
# OFF File for the S2 penetration through the HB-4 Main Shutter
# First line needs to be "OFF"
OFF
#
# This OFF file contains 8 vertices and 4 surfaces
# The next line indicates the number of vertices followed by the number of surfaces
8 4
#
# This is the list of vertices:
#-0.021549  -0.025000  4.032875   #vertex #0
# 0.018452  -0.025000  4.032669   #vertex #1
# 0.018221  -0.025000  4.633977   #vertex #2
#-0.021779  -0.025000  4.633740   #vertex #3
#-0.021549   0.091046  4.032875   #vertex #4
# 0.018452   0.091044  4.032669   #vertex #5
# 0.018221   0.098654  4.633977   #vertex #6
#-0.021779   0.098651  4.633740   #vertex #7
-0.021549  -0.025000  -0.300441 #vertex #0
 0.018452  -0.025000  -0.300647 #vertex #1
 0.018221  -0.025000   0.300661 #vertex #2
-0.021779  -0.025000   0.300424 #vertex #3
-0.021549   0.091046  -0.300441 #vertex #4
 0.018452   0.091044  -0.300647 #vertex #5
 0.018221   0.098654   0.300661 #vertex #6
-0.021779   0.098651   0.300424 #vertex #7
#
# This is the list of reflecting surfaces
# The first number is the number of vertices from the list above needed to define this surface
# It is followed by the list of vertices (number in order from the vertex list above starting with 0)
# Finally there is the reflectivity parameters for that surface (m, R0, Qc, alpha, W)
4    5  1  2  6      3.000  0.990  0.0219  2.511  0.0025    #surface #0 (right vertical mirror)
4    4  0  3  7      3.000  0.990  0.0219  2.511  0.0025    #surface #1 (left vertical mirror)
4    0  1  2  3      0.000  0.990  0.0219  2.511  0.0025    #surface #3 (lower horizontal mirror, bottom)
4    4  5  6  7      0.000  0.990  0.0219  2.511  0.0025    #surface #4 (upper horizontal mirror, top)
#
# End of OFF file
```

# F MAIN SHUTTER GUIDE CHANNEL S3 OFF FILE

https://code.ornl.gov/sns-neutronics/mcstas-wg/hb4-cold-source-2024/-/blob/master/main_shutter_S3.off

```
# OFF File for the S3 penetration through the HB-4 Main Shutter
# First line needs to be "OFF"
OFF
#
# This OFF file contains 8 vertices and 4 surfaces
# The next line indicates the number of vertices followed by the number of surfaces
8 4
#
# This is the list of vertices:
# 0.023433  -0.027895 4.033017   #vertex #0
# 0.073535  -0.027911 4.041218   #vertex #1
# 0.080529  -0.025773 4.623564   #vertex #2
# 0.030639  -0.025790 4.632966   #vertex #3
# 0.023433   0.071895 4.033017   #vertex #4
# 0.073535   0.071911 4.041218   #vertex #5
# 0.080529   0.076213 4.623564   #vertex #6
# 0.030639   0.076230 4.632966   #vertex #7
 0.023433  -0.027895  -0.300299 #vertex #0
 0.073535  -0.027911  -0.292098 #vertex #1
 0.080529  -0.025773   0.290248 #vertex #2
 0.030639  -0.025790   0.299650 #vertex #3
 0.023433   0.071895  -0.300299 #vertex #4
 0.073535   0.071911  -0.292098 #vertex #5
 0.080529   0.076213   0.290248 #vertex #6
 0.030639   0.076230   0.299650 #vertex #7
#
# This is the list of reflecting surfaces
# The first number is the number of vertices from the list above needed to define this surface
# It is followed by the list of vertices (number in order from the vertex list above starting with 0)
# Finally there is the reflectivity parameters for that surface (m, R0, Qc, alpha, W)
4    5  1  2  6      3.500  0.990  0.0219  2.511  0.0025    #surface #0 (right vertical mirror)
4    4  0  3  7      3.500  0.990  0.0219  2.511  0.0025    #surface #1 (left vertical mirror)
4    0  1  2  3      3.500  0.990  0.0219  2.511  0.0025    #surface #3 (lower horizontal mirror, bottom)
4    4  5  6  7      3.500  0.990  0.0219  2.511  0.0025    #surface #4 (upper horizontal mirror, top)
#
# End of OFF file
```