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Second Target Station (STS) Project

Moderator Reflector Assembly Thickness vs. Size Curves

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OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE US DEPARTMENT OF ENERGY

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1. PURPOSE

For the conceptual design of the Second Target Station (STS) Moderator Reflector Assembly (MRA), a parametric optimization study was completed by varying the dimensions of the hydrogen, premoderator water, and beryllium geometries in order to find the combination which produced the optimum neutron beams to the beamlines [1]. The characteristic beam size was fixed at 30mm for both moderators, fixing the height of the cylinder and diameter of the tube moderator to 30mm for the study. This study included the aluminum structures which enclose and separate these materials; however, the aluminum wall thicknesses were assumed constant regardless of the size of vessel. While the mechanical engineering team was able to minimize the aluminum thicknesses for the optimum conceptual design configuration, no feedback for the engineering reality that, in general, as vessels increase in size their thicknesses must increase, was included in the optimization. This report aims to provide guidance for capturing the effects of required aluminum thickness for various component sizes for the preliminary MRA optimization study.

2. SCOPE

To provide guidance for the preliminary MRA optimization study, thickness vs. size curves were created for the relevant structures of the MRA. To create these curves, many static structural finite element analysis (FEA) cases were run for the hydrogen vessel and reflector structures in order to optimize the wall thicknesses for various component sizes. These analyses optimized the wall thicknesses for the internal pressure loads only (19 bar Maximum Allowable Working Pressure (MAWP) for the hydrogen and 5 bar MAWP for the reflector) and did not consider thermal stresses or thermal hydraulic requirements. In the conceptual design, the other requirements were straightforward to meet once the vessels were optimized for the required pressure. The other requirements are assumed to be capable of fulfillment with minimal impact to neutronic performance for the preliminary design as well. Therefore, the thickness vs. sized curves will be created based solely on the optimizations of the vessels for the required internal pressure loads.

3. METHODS

The vessel wall thickness optimizations were performed so that the wall thicknesses were minimized while still meeting the stress allowables of the ASME BPVC Section VIII Div. 2 [2]. Note that in many cases, multiple solutions were possible by adding wall thickness to adjacent structures to minimize thickness in other areas compared to the listed configurations; however, the listed configurations strike a reasonable compromise between the wall thicknesses of adjacent structures and additional configurations can be considered during final design if it appears that additional performance gains are possible. The FEA analyses were performed using ANSYS 2019r3. In general, ¼ or ½ symmetry models were built using Solid187 10 node Tetrahedral elements, although the cylinder hydrogen vessel was built using Plane183 8 node Axisymmetric elements. Example meshes are shown in figures 3.1 & 3.2. No significant effort was exerted to ensure mesh independence; however, since the meshes were similar across the comparison, no bias should exist from any mesh dependence and the general trends should be correct. The internal pressure loads were applied as shown in figures 3.3 and 3.4. The wall thicknesses were then adjusted so that the maximum von Mises Stress was 121 MPa, which is the membrane plus bending limit for stresses for Al 6061-T6. No attempt to analyze weld stresses, which have a maximum membrane plus pending limit of 81 MPA, was made; however, in general locations for welding in regions within these limits is possible for all configurations. Sample von Mises contour plots can be seen in figures 3.5 and 3.6.

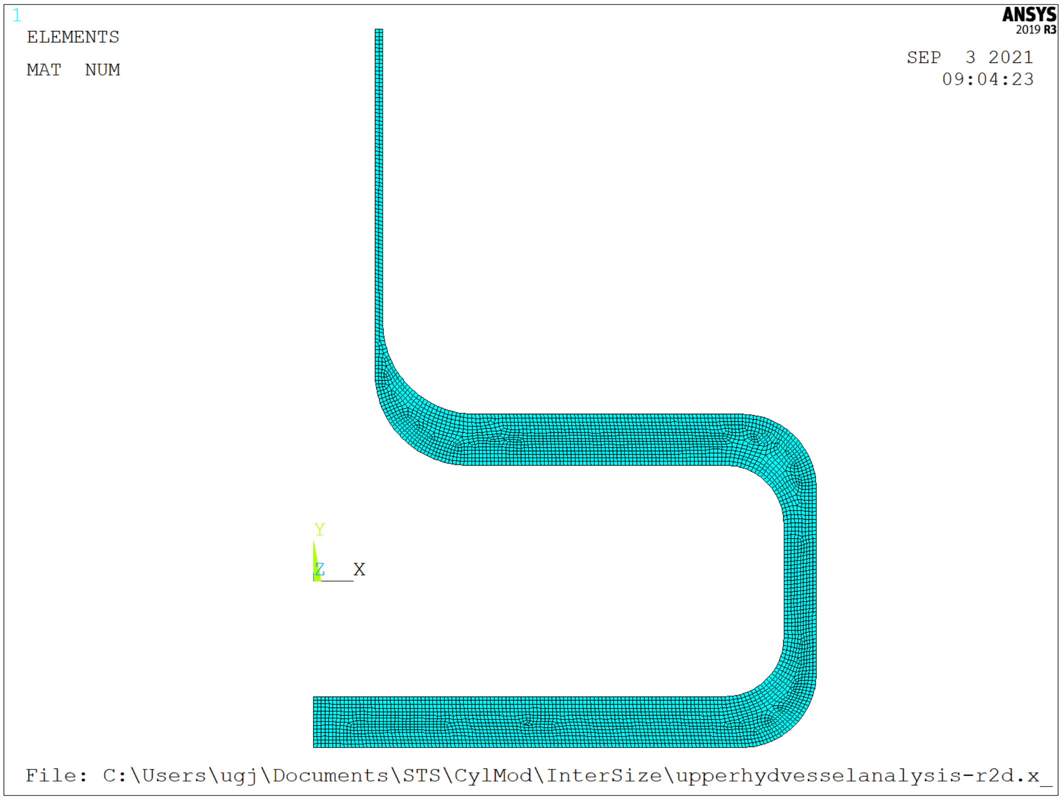

Figure 3.1. Cylinder Hydrogen Vessel Mesh comprised of Axisymmetric 8 node quad elements.

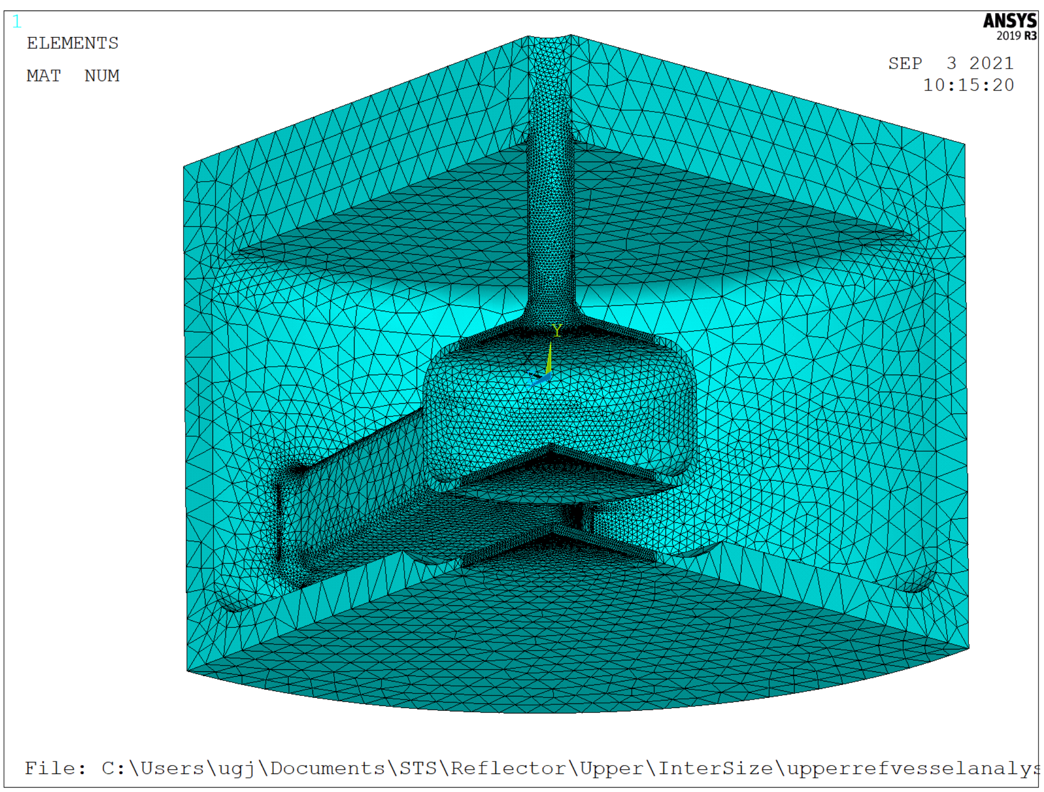

Figure 3.2. Cylinder Reflector Vessel Mesh comprised of 10 node tetrahedral elements.

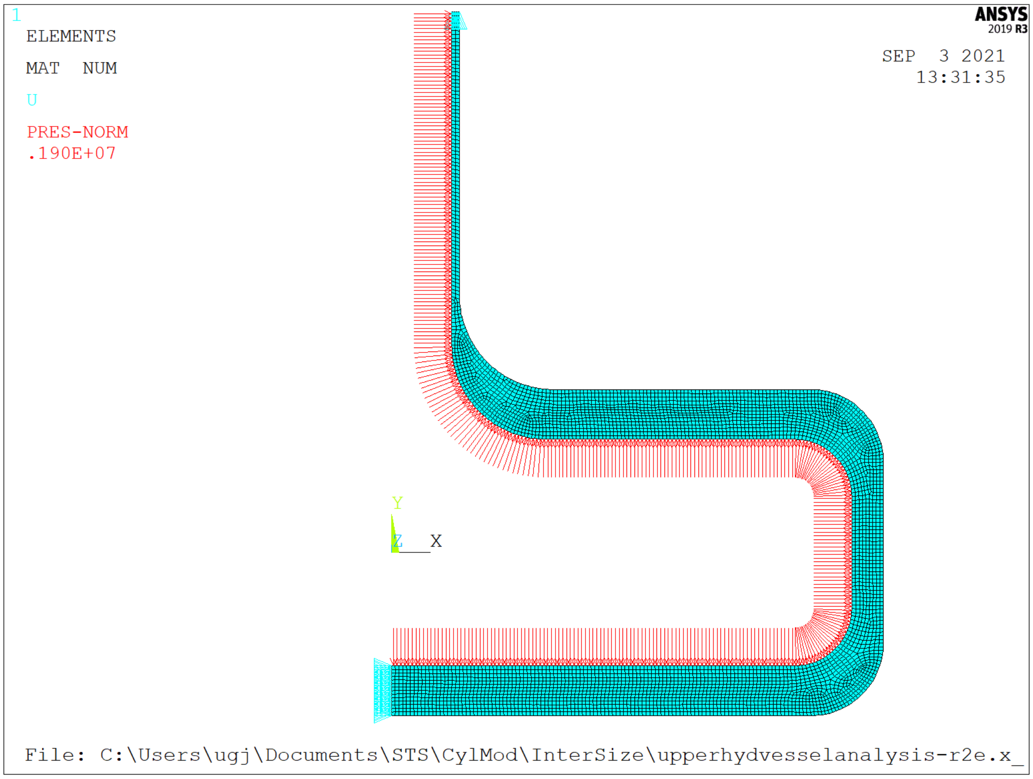

Figure 3.3. Cylinder Hydrogen Vessel with 19 Bar Internal Pressure Loading.

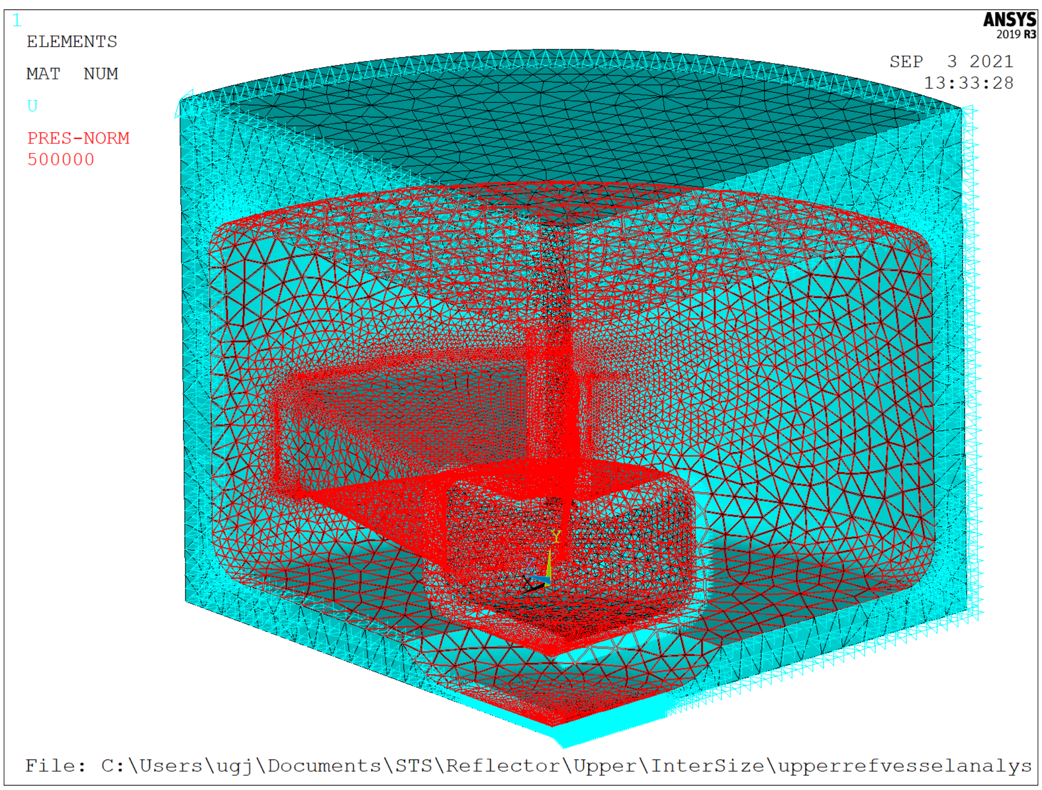

Figure 3.4. Cylinder Reflector Vessel with 5 Bar Internal Pressure Loading.

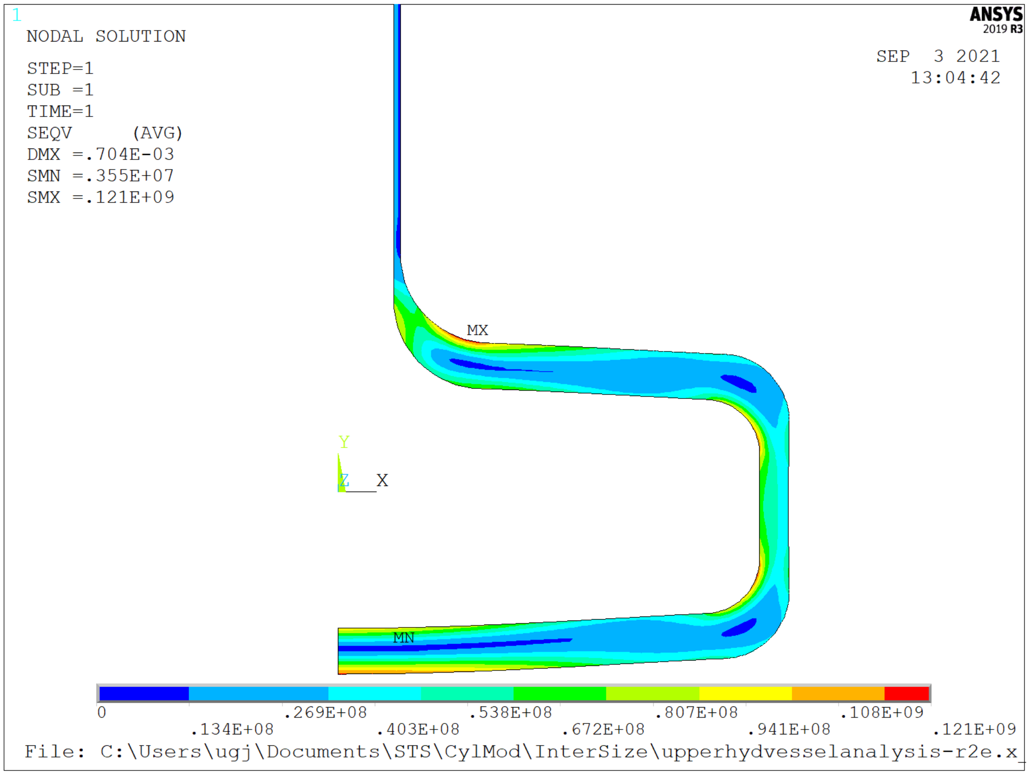

Figure 3.5. Cylinder Hydrogen Vessel Von Mises Contour Plot (Pa) with Maximum of 121 MPa.

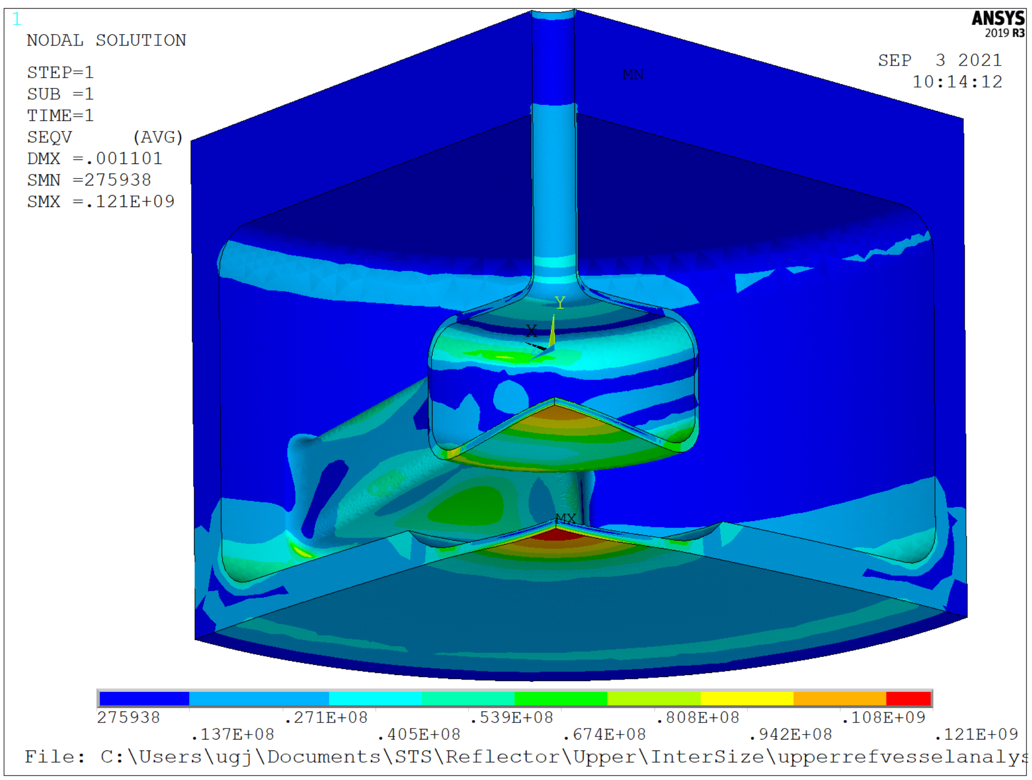

Figure 3.6. Cylinder Reflector Vessel Von Mises Contour Plot (Pa) with Maximum of 121 MPa.

4. RESULTS

4.1 CYLINDER MODERATOR AND REFLECTOR

In general, the cylinder moderator and reflector proved to be quite sensitive to vessel sizes in the resulting required thicknesses, especially for flat structures. The results of the FEA optimizations were plotted against the relevant independent variables to show the dependency. Figure 4.1.1 shows the cylinder moderator geometry with parameter names shown in order to help understand the following graphs. As in the previous study, the hydrogen height was fixed at 30mm. As seen in the graphs of figures 4.1.2, 4.1.3, and 4.1.4, the hydrogen vessel flat and cylindrical walls, vacuum vessel flat walls, and premoderator flat wall all depended heavily on hydrogen vessel radius over the range of study, which was determined by the results of the conceptual design optimization. Note that while there may be some additional uncertainty extrapolating outside the studied range, the trends are expected to continue and extrapolation outside the range is reasonable for the preliminary neutronics study. Additionally, the reflector vessel flat wall thickness depended on the beryllium radius as shown in figure 4.1.5. The vacuum vessel cylindrical wall and reflector vessel cylindrical wall were chosen to be 2 mm and 15 mm, respectively, for robustness considerations, and these thicknesses are sufficient to support the required load over the size ranges studied. The hydrogen and vacuum supply tubes as well as the neutron beam extraction tubes were not examined. The neutron beam extraction tubes will likely show some small sensitivity, but it is likely a complicated relationship between hydrogen radius and beryllium radius and it is not considered here. Note that the premoderator thicknesses and hydrogen and beryllium height do not affect the thickness of any vessel walls.

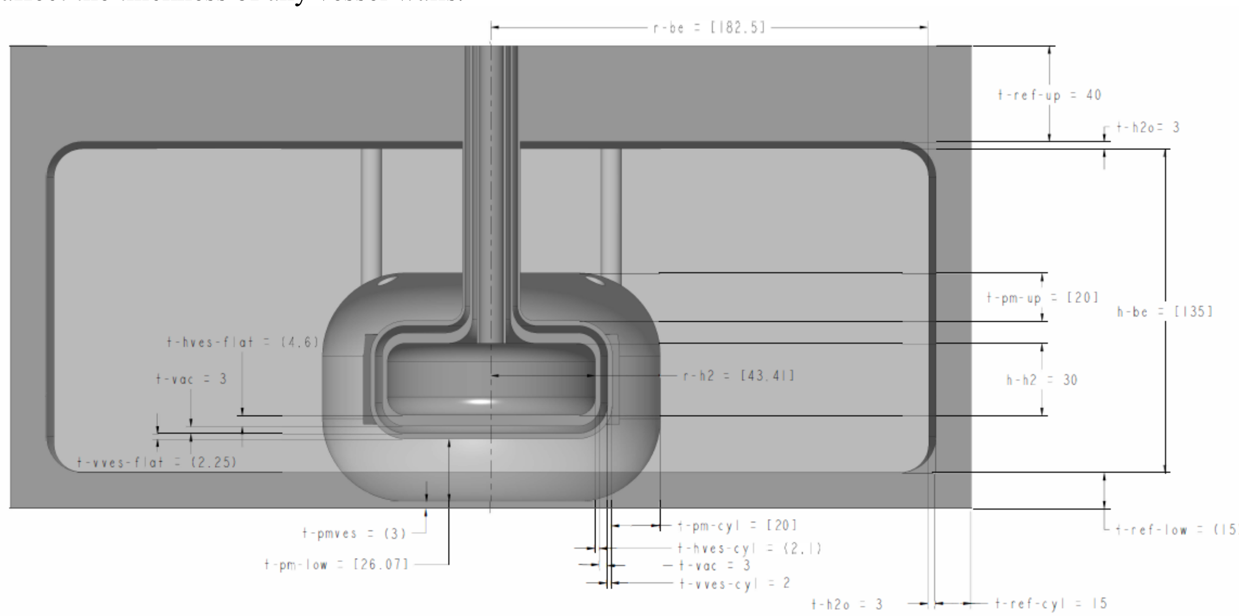

Figure 4.1.1. Cylinder Moderator and Reflector Geometry. Dimensions shown as [x.xx] are independent variables, dimensions shown as (x.xx) are dependent variables, and dimension shown as x.xx are fixed or constant across the range of the independent variables considered.

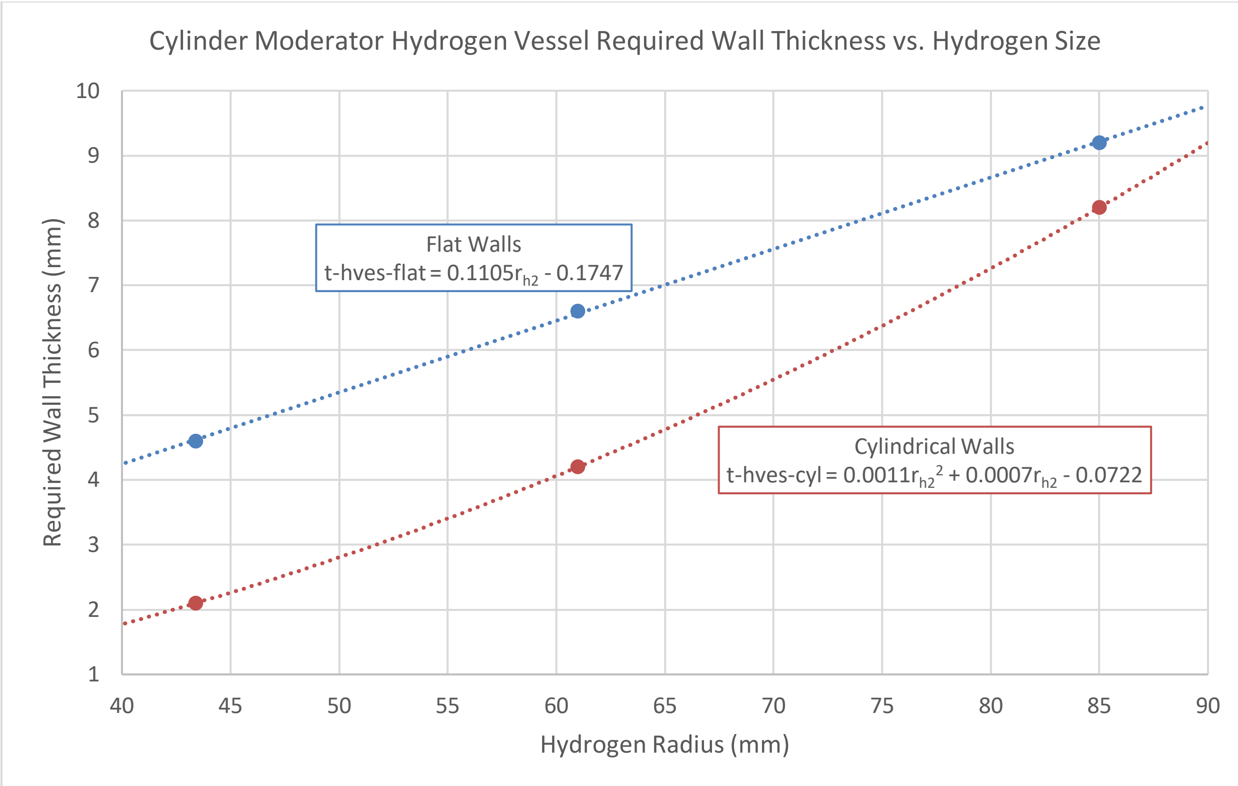

Figure 4.1.2.

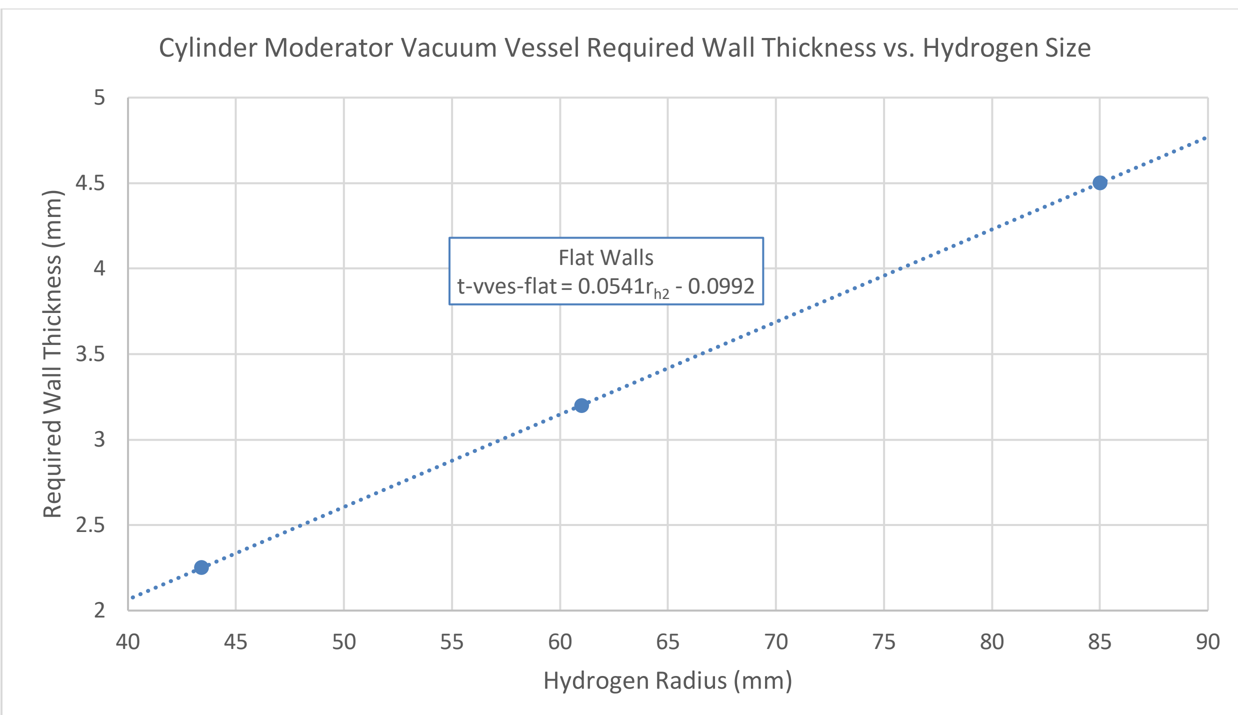

Figure 4.1.3.

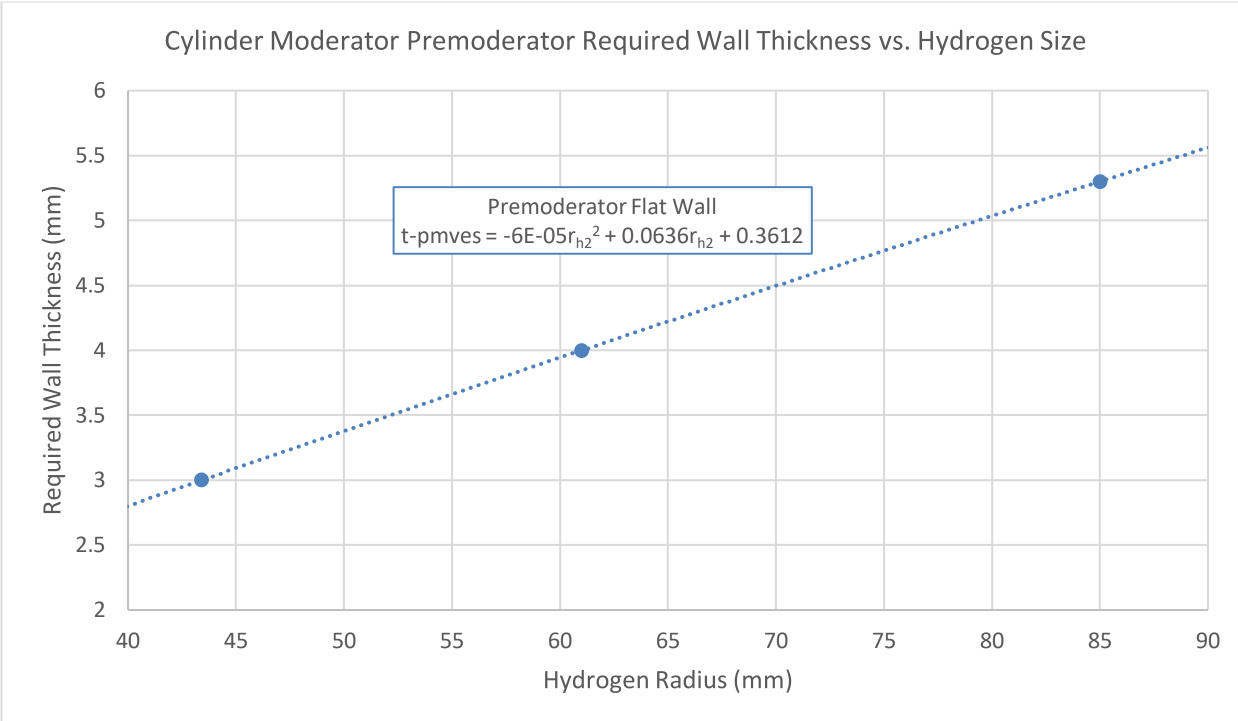

Figure 4.1.4.

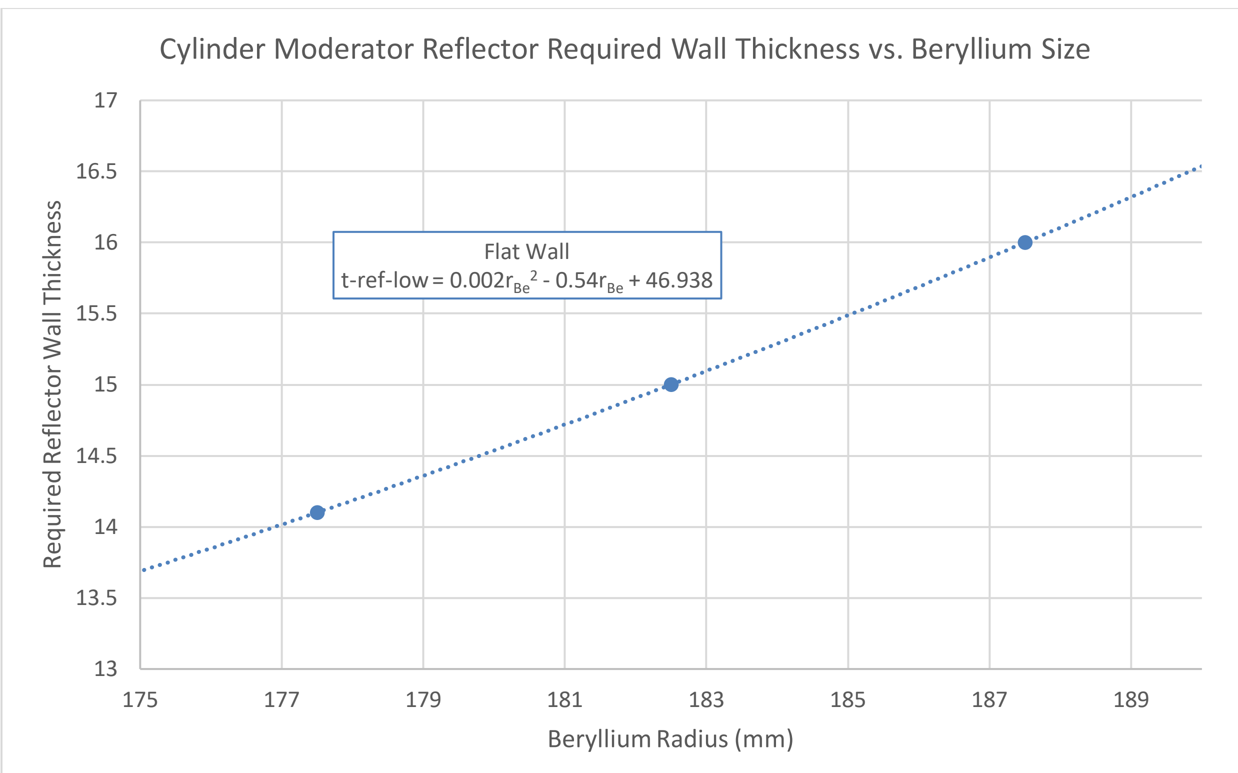

Figure 4.1.5.

4.2 TUBE MODERATOR AND REFLECTOR

The tube moderator proved to be much less sensitive to the vessel sizes in the resulting required thicknesses. Figures 4.2.1 & 4.2.2 show the tube moderator with parameter names shown. The hydrogen and vacuum vessel wall thicknesses were shown to be insensitive to the hydrogen tube length and the hydrogen diameter is a fixed parameter equal to 30mm. The premoderator wall thickness was shown to be insensitive to tube length and premoderator thickness of the size ranges considered, although there may be some small sensitivity if these ranges are pushed outside the range from the conceptual optimization. The only wall thickness for the tube moderator that was shown to be sensitive to the vessel size was the reflector vessel flat wall to the beryllium size, as shown in figure 4.2.3. It should be noted that because of the geometry is more complicated for the tube reflector vessel, the relationship between reflector wall thickness and beryllium radius is more complicated so the simple curve fit to the data is not as representative. Again, it is expected that the general trend will continue outside the studied range, so extrapolation outside the range for the preliminary neutronics study is reasonable. The reflector vessel cylindrical wall was chosen to be 15 mm for robustness considerations, and this thickness is sufficient to support the required load over the size range studied. The hydrogen and vacuum supply tubes as well as the neutron beam extraction tubes were not examined, but no sensitivity is expected in either.

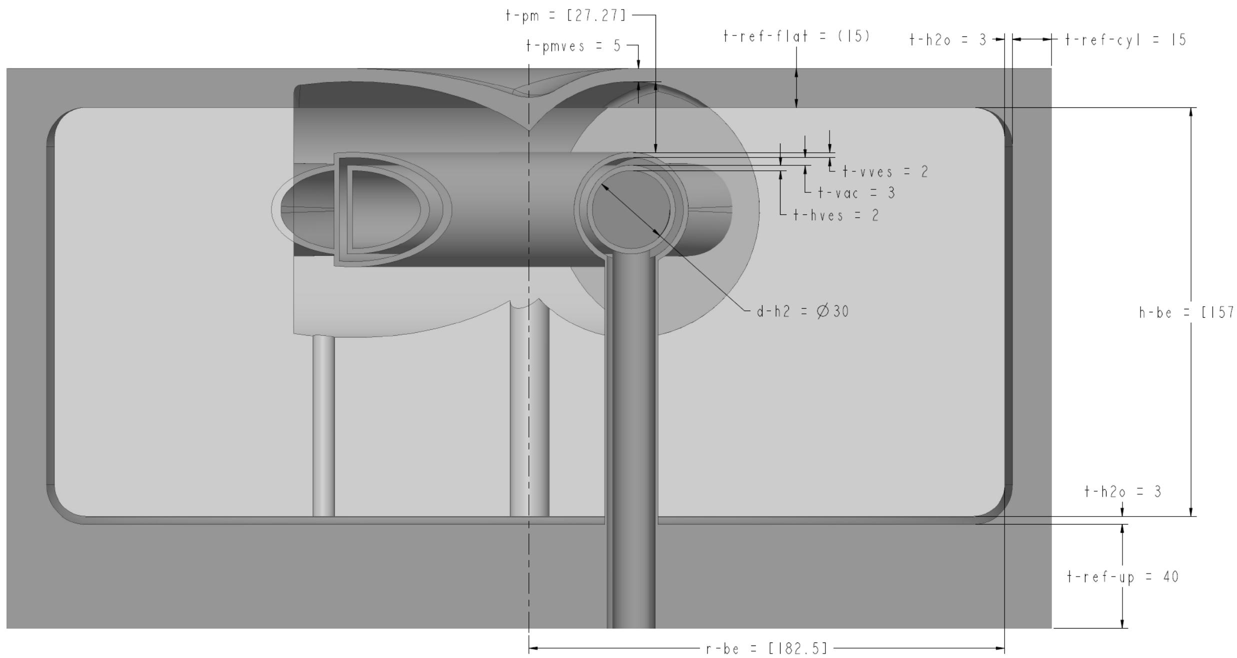

Figure 4.2.1. Tube Moderator and Reflector Vertical Cross Section. Dimensions shown as [x.xx] are independent variables, dimensions shown as (x.xx) are dependent variables, and dimension shown as x.xx are fixed or constant across the range of the independent variables considered.

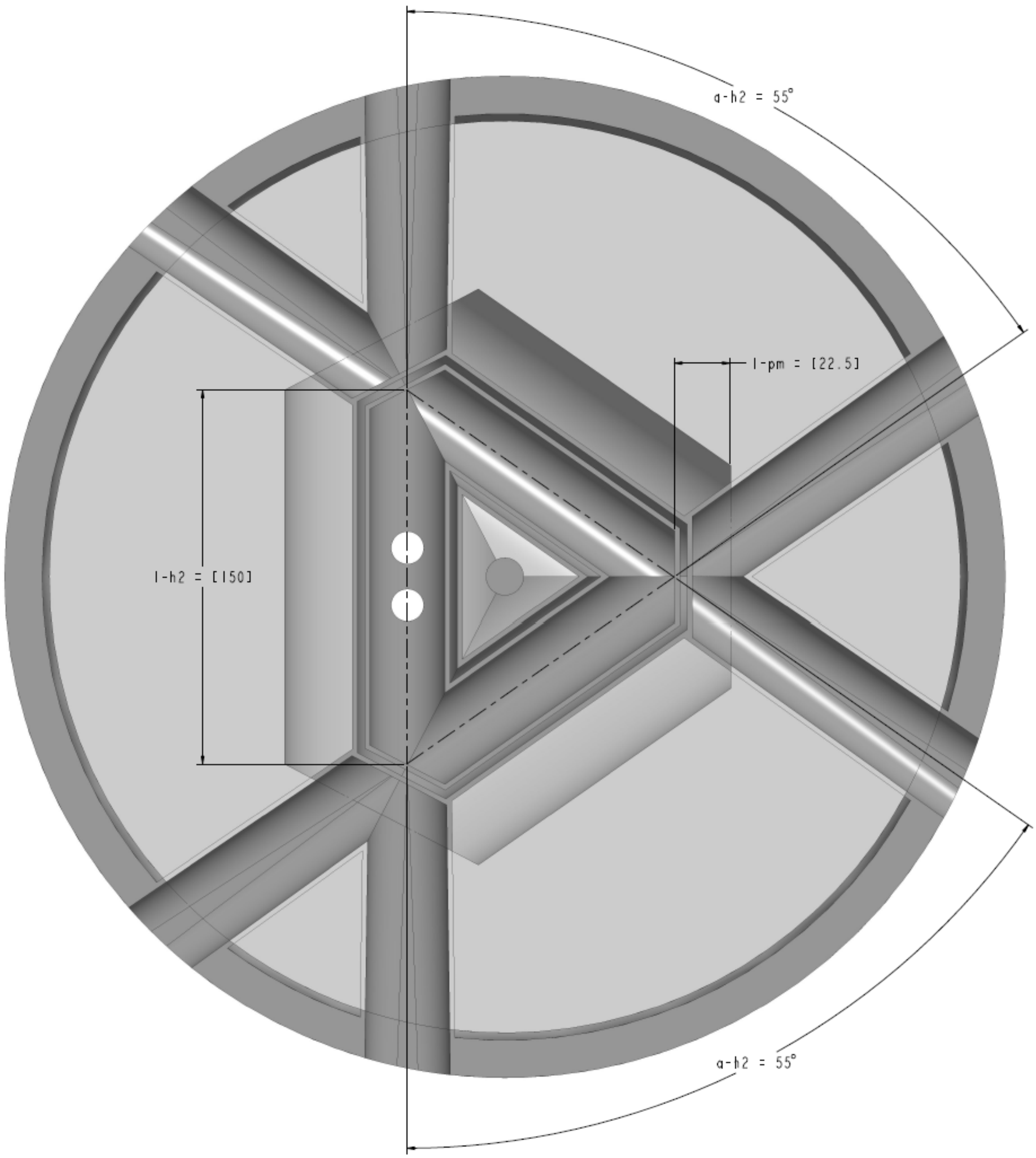

Figure 4.2.2. Tube Moderator and Reflector Horizontal Cross Section. Dimensions shown as [x.xx] are independent variables, dimensions shown as (x.xx) are dependent variables, and dimension shown as x.xx are fixed or constant across the range of the independent variables considered.

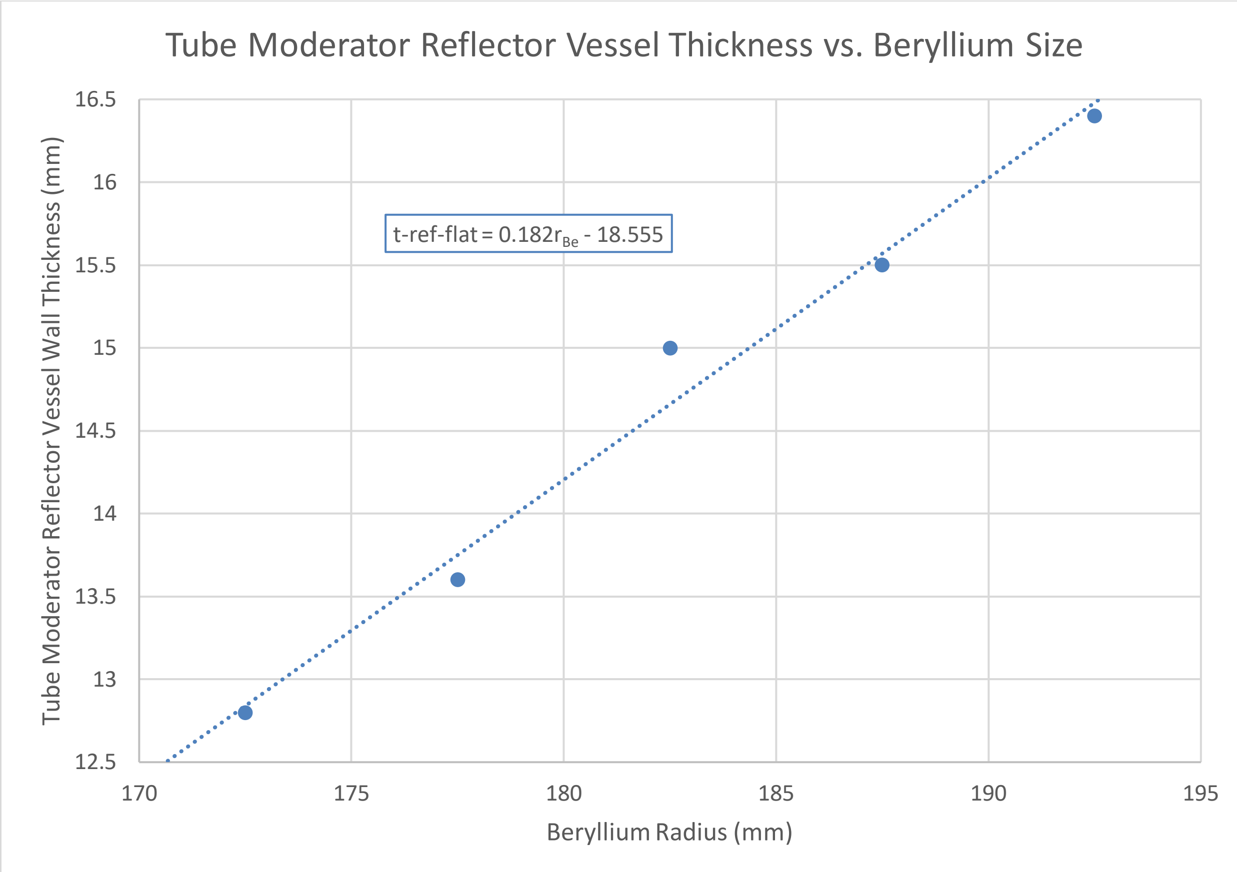

Figure 4.2.3.

The complicated tube moderator geometry features some parameters that were not studied in the conceptual design, specifically relating to the premoderator geometry. One such parameter is the length of the premoderator from the hydrogen viewed face, labeled l-pm in Figure 4.2.2. It is likely that reducing this number would allow for a slightly thinner premoderator wall, but it has not been studied. Another area that has not been studied is offsetting or distorting the premoderator such that the thickness of premoderator around the tube is not constant above, below and to the sides of the vacuum vessel. The results of the cylinder moderator optimization show that optimal premoderator geometry is thicker between the target and hydrogen vessel and thinner on the opposite side and around the sides. It is possible a similar configuration would be optimal for the tube moderator as well; however, this has not been studied. Non-constant premoderator thickness around the tube would be unlikely to change the required wall thickness or the complexity of fabrication of the reflector vessel.

5. CONCLUSION

Curves of required wall thickness vs. size of components have been presented for both tube and cylinder moderators and reflectors based on a series of wall thickness optimization FEA studies. These curves are intended to be used in the preliminary moderator physics optimization in order to add engineering reality to the optimization and include feedback based on engineering reality. While it is anticipated that additional engineering optimization of the final configuration will be required, the results of these curves should provide a reasonable representation of the final required thicknesses.

6. REFERENCES

1. Remec, Igor and Gallmeier, Franz X., Neutronics analyses for the conceptual design of the SNS Second Target Station, Journal of Neutron Research 22 (2020) p265-273.

2. American Society of Mechanical Engineers, Boiler Pressure Vessel Code, Section VIII, Division 2, 2021.