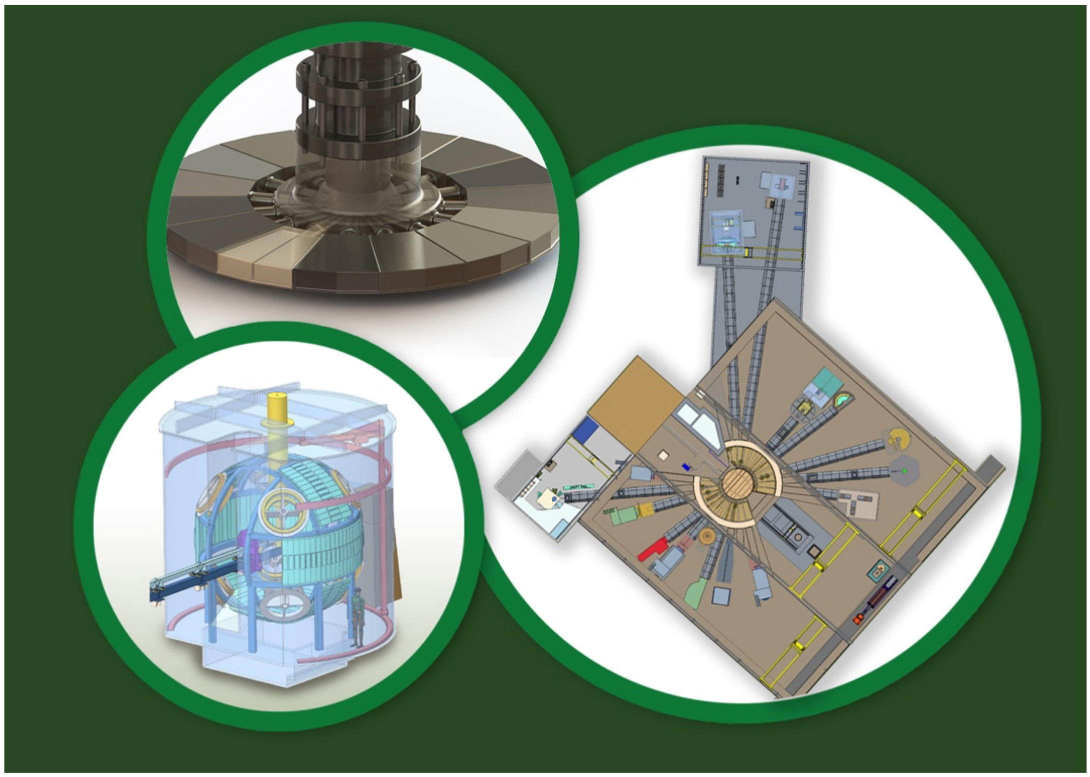
S04030200-TRT10001
ORNL/TM-2022/1829

SECOND TARGET STATION (STS) PROJECT

Analysis of Bunker Shielding–Preliminary Design



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Kumar Mohindroo
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May 2022

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ANALYSIS OF BUNKER SHIELDING–PRELIMINARY DESIGN

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May 2022

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ABBREVIATIONS

BL##	Beamline number at First Target Station
FTS	First Target Station
HD	High density
ORNL	Oak Ridge National Laboratory
SNS	Spallation Neutron Source
STS	Second Target Station Project
ST##	Beamline number at Second Target Station

EXECUTIVE SUMMARY

At the Department of Energy's Oak Ridge National Laboratory, the Second Target Station (STS) beamline sources for preliminary design have been used to perform a shielding analysis of the bunker. The simulations in this report used the ST11 beamline source, primarily the ST11 neutron source, because that source provides conservative prompt total dose rate estimates for all beamlines. Prompt total dose rates (i.e., neutron plus photon dose rates when the beam is on) were calculated on top of the bunker roof, outside the bunker wall, and in the basement below the bunker and instrument floor. Design changes were made to ensure the prompt total dose rate in these areas does not exceed 0.25 mrem/h. This report documents the required shielding thicknesses to meet this dose rate limit. There is one exception to this: for a combination of open and closed beamlines, the prompt total dose rate outside the bunker across from the closed beamline, where there is less shielding due to the lack of beamline shielding, slightly exceeds 0.25 mrem/h. A future analysis will document the shielding modifications required to reduce the calculated prompt total dose rates for this configuration to less than 0.25 mrem/h once more details regarding the STS high density concrete density and composition are known. Finally, prompt total dose rates inside the bunker were simulated. The results of this simulation show that the majority of prompt total dose rate in the bunker is due to neutrons, and a few percent of the total is caused by secondary photons created by the neutrons. The contribution to prompt total dose rate inside the bunker by the primary photons that enter each beamline from the target/moderator area is at least two orders of magnitude less than the neutron contribution. This means prompt total dose rate contributions due to primary photons inside and outside the bunker can be neglected.

1. SCOPE

This report documents the simulation of prompt total dose rates inside and outside the bunker using the beamline sources discussed in Miller and Remec's report *STS Project Generation of Beamline Sources—Preliminary Design* [1]. Configurations analyzed include all beamlines open and operating, all beamlines closed (plugged) during operations, and a combination of open and closed beamlines. This analysis led to some design changes in the bunker shielding to meet the radiation protection requirement that the area outside the bunker be generally accessible. These analyses have been performed during the preliminary design phase of the Second Target Station (STS) Project at the Department of Energy's Oak Ridge National Laboratory. As relevant system design parameters are finalized, select portions of this analysis will be repeated as necessary.

2. ACCEPTANCE CRITERIA

Radiation protection requirements state that the area outside the bunker must be generally accessible. For an area to be generally accessible, the prompt total dose rate must be less than 0.25 mrem/h.

3. ASSUMPTIONS AND LIMITATIONS

This analysis assumes that STS will operate at 700 kW with 1.3 GeV protons. If this power level is increased, the prompt total dose rates discussed in this report will increase.

This report also assumes that activation inside and outside the bunker makes a negligible contribution to dose rates outside the bunker. Therefore, prompt total dose rates in this report do not include any contributions due to the decay of activated materials.

The composition and density, 3.84 g/cm^3, of high density (HD) concrete is the same as that used for the First Target Station (FTS) [2].

All the neutron guides in this report are assumed to have neutron mirrors with an m-value of 3.5.

4. METHODOLOGY AND MODELS

The basic methodology followed for this analysis is to calculate prompt total dose rates inside and outside the bunker with the beamline sources as described in Miller and Remec [1]. These calculations are all performed with MCNP 6.2 [3], table based cross section data based on ENDF/B-VII.1 [4], and the CEM nuclear model providing cross sections above the energy range of the table based cross sections. The standard SNS/STS flux-to-dose conversion factors are used [5], and variance reduction parameters are generated using ADVANTG [6]. More details about the computer hardware and software utilized by this study are provided in APPENDIX A.

Two basic geometry models of the STS bunker were created. The first model focused on just a single beamline but used reflected boundary conditions to simulate the other beamlines surrounding the STS monolith. This is equivalent to the STS monolith being surround by approximately 32.5 neutron beamlines rather than 22 and is a good approximation for dose rates outside the bunker when the beamlines are either all open or all closed. The second model explicitly included 11 beamlines and the surrounding bunker shielding and monolith. This second model has been used for simulations where the configuration of all 11 beamlines on one side of the bunker is not the same. A brief description of these models will begin with the single beamline model and will then describe differences between this model and the explicit 11-beamline model. The full details of these models can be found in the corresponding MCNP files (and to a lesser degree, the relevant SpaceClaim [7] file), but this description points out some of the important details, especially those that changed from the conceptual design. APPENDIX B contains information regarding the location of these SpaceClaim, MCNP, and ADVANTG files.

4.1 SINGLE BEAMLINE WITH REFLECTED BOUNDARY CONDITIONS

V. Graves (STS Instrument Systems) provided K. Gawne (STS Target Systems) a SpaceClaim model of an example neutron beamline, and Gawne imported that into a model of the monolith and bunker. This new SpaceClaim model (circa September 2020) was used as the basis to build an MCNP model for shielding and activation analysis of a single neutron beamline, both inside and outside of the bunker. Figure 1 is a side-by-side comparison of an elevation view of these models. The colors shown in the MCNP portion of Figure 1 correspond to the materials listed in Table 1.

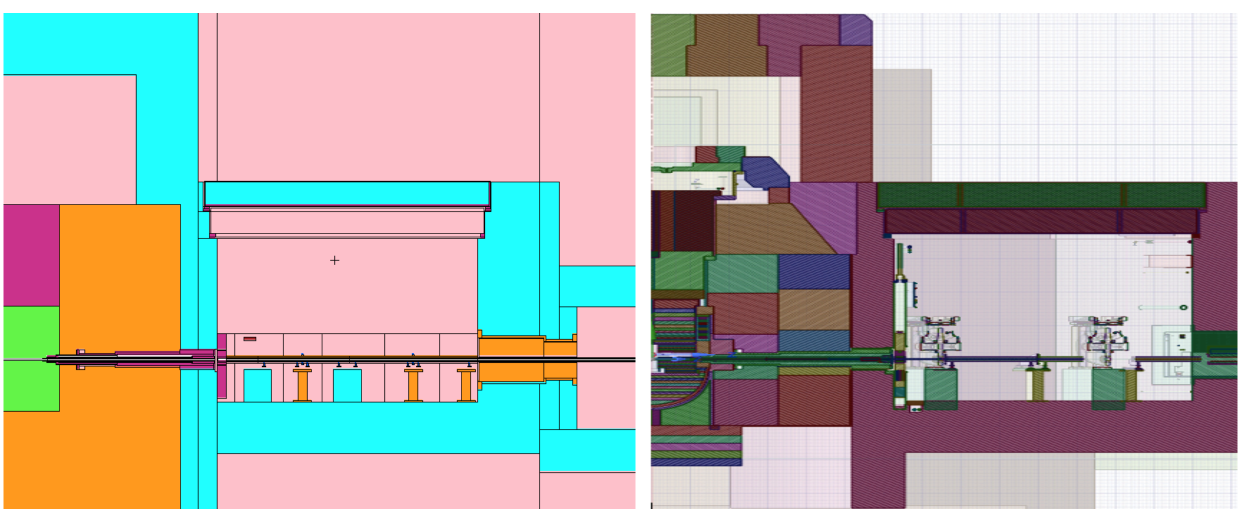

Figure 1. Comparison of MCNP model (left, ZX plane) and SpaceClaim drawing (right) of the monolith, bunker, and neutron beamline.

Table 1. Correlation between colors and materials in the Figure 1 MCNP model.

Green—95% SS316 + 5% Water (7.57 g/cm^3)	**Pink**—Air (1.20e-3 g/cm^3)
Dark pink—SS316 (7.92 g/cm^3)	**Light blue**—HD Concrete (3.84 g/cm^3)
Orange—Carbon steel (7.04 g/cm^3 in the monolith, otherwise 7.82 g/cm^3)	**Brown**—Inconel-718 (8.19 g/cm^3)

The composition and density of HD concrete used in this analysis is the standard composition used in FTS design analyses. When the actual HD concrete composition and density that will be used for STS is known, it will be incorporated into the final design analyses to ensure that all radiation protection requirements are still met. The carbon steel density inside the monolith is 90% of the theoretical value to account for gaps between shielding blocks that are not included in this model. The Inconel (brown) in Figure 1 is small and hard to see. This is the Inconel t_0 chopper, which is easier to see in Figure 2.

The MCNP model in Figure 1 is shown again in Figure 2, but this larger depiction includes labels for key components and dimensions. The actual dimensions are given in Table 2. The MCNP model depicted in Figure 1 and Figure 2 does not exactly match the SpaceClaim model. Rather, this is the final MCNP model that incorporates the dimensions and materials that analysis determined to be necessary to meet the radiation protection limits on dose rates outside the bunker. The beamline shielding outside the bunker is included in this MCNP model. The additional particle attenuation provided by the beamline shielding is required to meet the radiation protection requirements outside the bunker when a beamline is open and operating. The SpaceClaim model in Figure 1 shows both layers of roof panels, but the MCNP model only shows the top layer. See Section 4.1.4 for more details and an explanation.

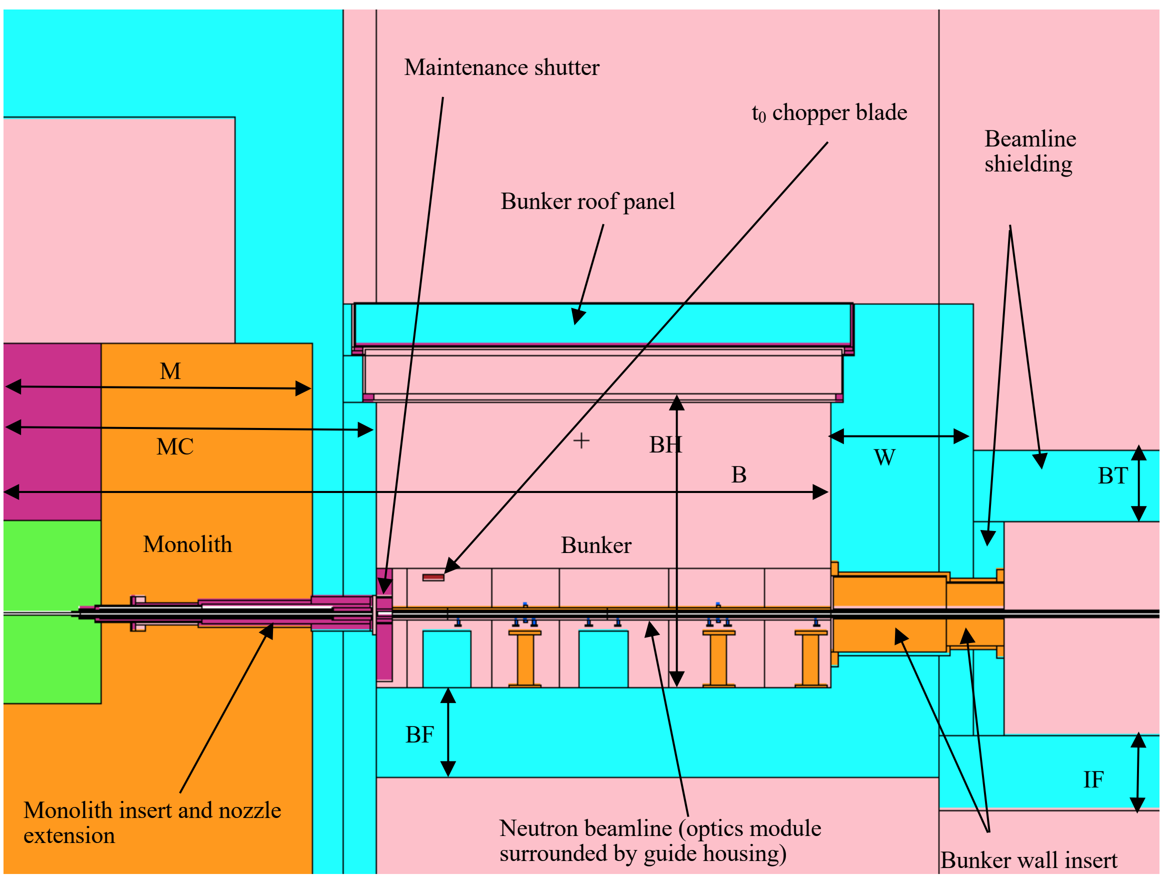

Figure 2. The STS bunker preliminary design (ZX plane).

Table 2. STS bunker preliminary design dimensions for Figure 2.

Figure 2 Label	Dimension (cm)	Figure 2 Label	Dimension (cm)	Figure 2 Label	Dimension (cm)	Figure 2 Label	Dimension (cm)
M	436.853	BF	140	IF	71.5	B	1168.39
MC	526.747	BT	100	W	202	BH	414.02

The MC dimension listed in Table 2, and used throughout this analysis, is smaller than the value provided for conceptual design in Section 4.1.4 of the *STS Conceptual Design Report* [8]. The BT dimension, which applies to the roof the beamline shielding in Figure 2, also applies to the walls of the beamline shielding that are visible in Figure 3. In Figure 3 the walls of the beamline shielding are a little less the BT near the bunker wall and bunker insert. This is due to the shape of this geometry that utilizes reflected boundary conditions. In this model, the walls of the beamline shielding reach the full value of BT about 2 m from the outside of the bunker wall. It is hard to see in Figure 3, but there is a thin air region (pink) outside the beamline shielding at the far right. This is easier to see in Figure 10.

The MCNP model of a single beamline (provided in Figure 3) was constructed as a wedge that is 11° wide. The sides of this wedge have a reflected boundary condition applied in the MCNP simulation. This is equivalent to a model that is a full cylinder with the same beamline geometry and source repeated azimuthally around the axis of this cylinder.

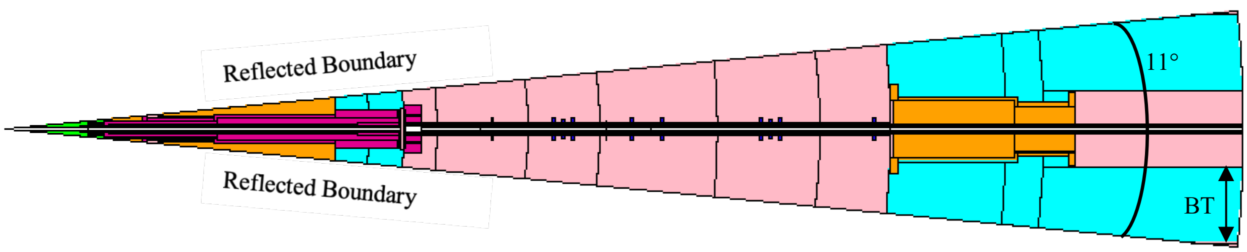

Figure 3. Plan view of the wedge-shaped MCNP model of a single neutron beamline (ZY plane).

4.1.1 Monolith Insert and Nozzle Extension

The optics module, monolith insert, and nozzle extension are important to any analysis of the bunker. These components contain the neutron beamline and surrounding streaming gaps that let radiation from around the moderator, mostly neutrons and photons, travel unshielded from the moderator to the bunker and then to the instrument cave. Figure 4 presents a more detailed view of these components than that presented in Figure 2 and Figure 3. These components are made of long rectangular paralepidids, most of which have 90° rotational symmetry around the axis of the neutron beamline.

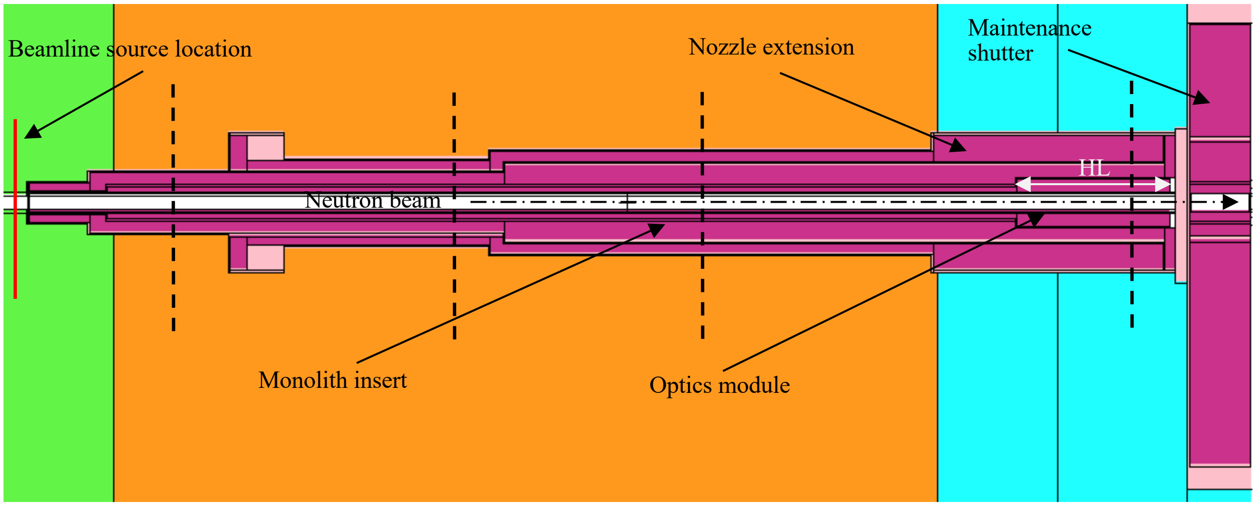

Figure 4. STS monolith insert and nozzle extension preliminary design.

Most of the dimensions in Figure 4 agree with the original SpaceClaim drawings. However, there are two important changes that were made. First, the gap sizes between the optics module and monolith insert and between the monolith insert and the nozzle extension were not consistent. Discussions with Instrument Systems resulted in the decision that these gaps should all be 0.25 in. In reality, Instrument Systems is only responsible for, and only has the authority to dictate the size of, the gaps inside the monolith insert. Target Systems controls the gap between the nozzle extension and the monolith shielding. That said, this MCNP model attempts to model all the gaps close to 0.25 in. The actual dimensions of the gaps in the MCNP model are all between 0.6 and 0.7 cm. Another important change was dictated by the design of a plug that will be used to close a beamline when no instrument is installed. This plug design is documented in Mohindroo, Miller, and Remec's 2022 report [9]. The HL dimension in Figure 4 is 55.029 cm in the preliminary design, for consistency with the plug design [9].

The black dashed vertical lines in Figure 4 indicate locations where views of the monolith insert and nozzle extension perpendicular to the neutron beam are shown in Figure 5. The order of the dashed lines in Figure 4 from left to right corresponds to the order of the images in Figure 5, from left to right and top to bottom. All the void (white) and air (pink) gaps in Figure 5 are nominally 0.25 in. (6.35 mm), with one exception labeled in the top right image of Figure 5. This larger gap accommodates supports for the monolith insert that can be used to adjust the alignment of the neutron guide. The neutron beamline is the white square at the center of each image in Figure 5 (5 × 5 cm), which is surrounded by the aluminum substrate (blue, 0.8 cm) of the supermirror in the neutron guide. The small yellow circles in Figure 5 are cooling channels filled with water, which all have a diameter of 1 cm. Dimensions for the stainless steel (dark pink) monolith insert and nozzle extension are provided in Figure 5. All these regions are square, so only 1 dimension of each square is labeled to conserve space. If a dimension is missing, then it is the same as a previously labeled dimension.

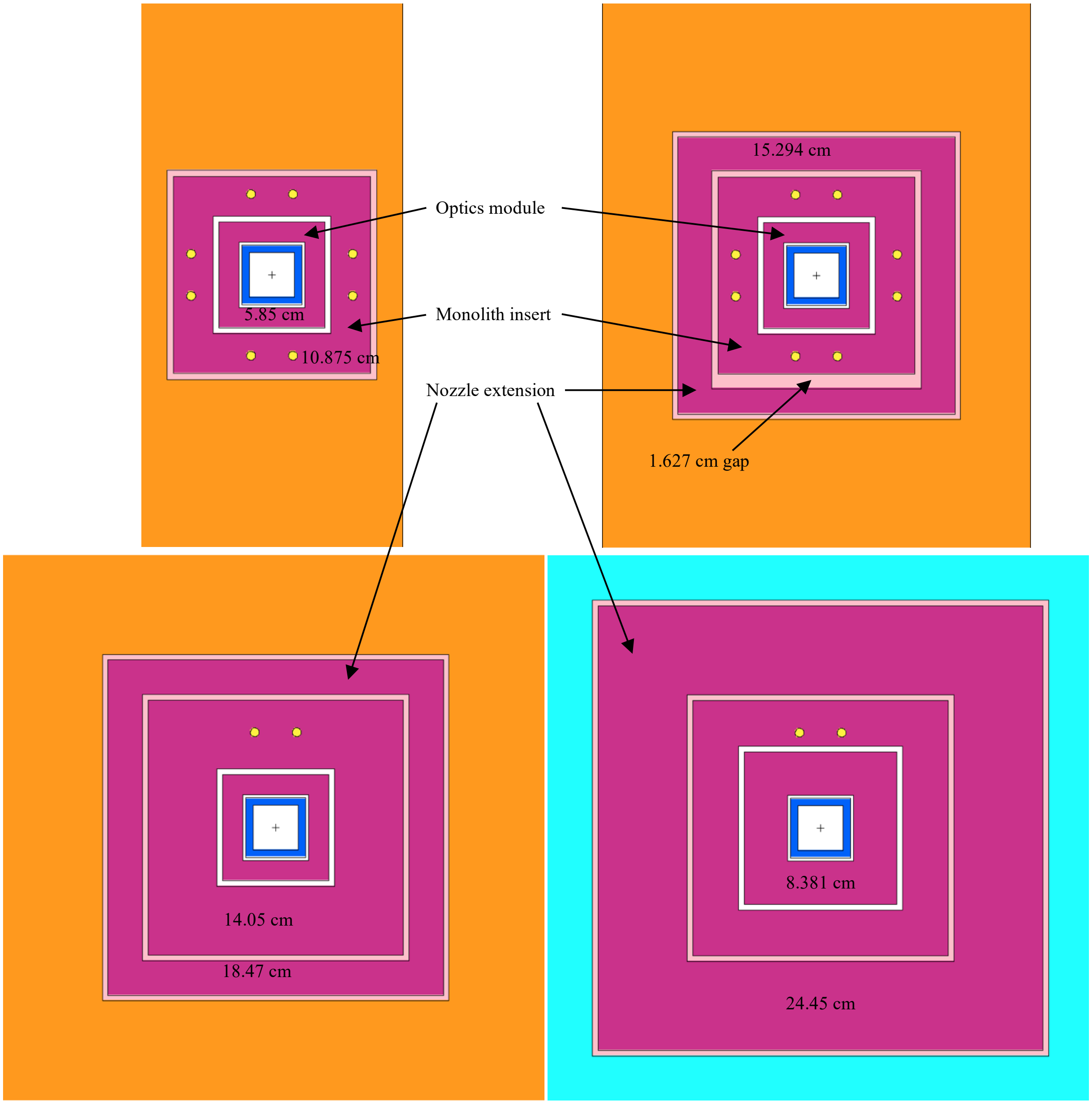

Figure 5. Details of the gaps in the monolith insert and nozzle extension preliminary design.

4.1.2 Neutron Beamline Guide Housing

The generic neutron beamline used in this analysis has a square opening for the neutron beam to pass through. This beamline has an inner cross section of 5 × 5 cm with 0.8 cm thick aluminum walls. Originally the guide housing was also aluminum. Analysis of prompt dose rates in generally accessible areas outside the bunker led to the use of Corelli-style neutron guide housings (identical to beamline 9 [BL09] at FTS), which are 1 in. (2.54 cm) thick carbon steel guide housings with an inner cross section of 10.73 × 10.73 cm. These details of the preliminary design are illustrated in Figure 6.

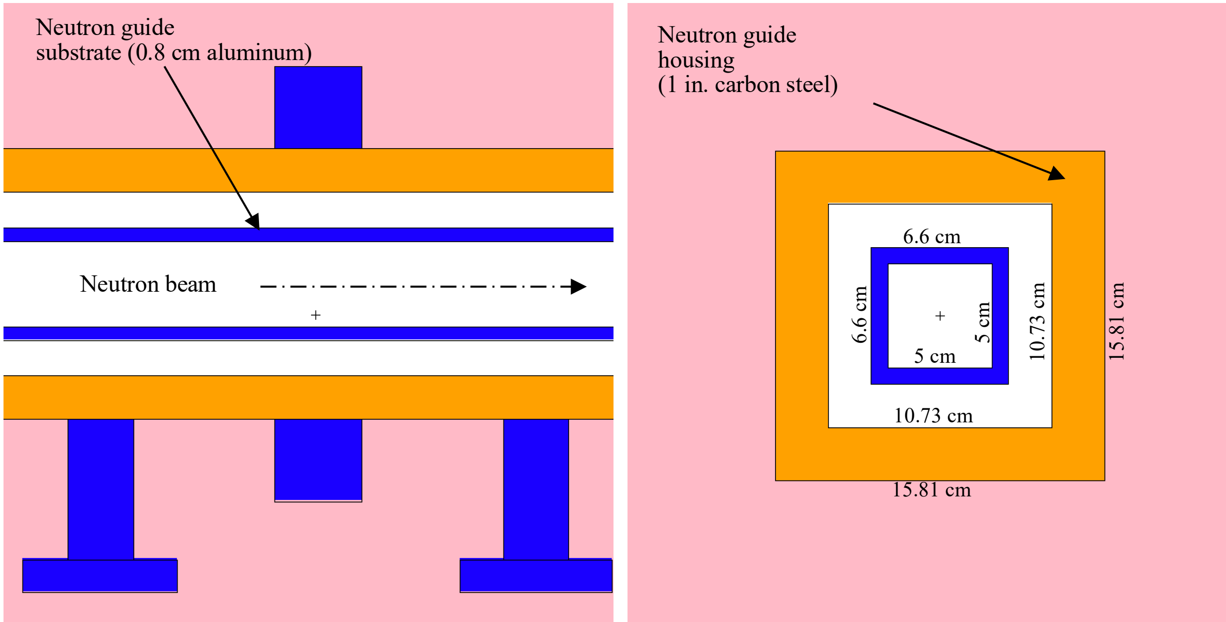

Figure 6. STS Neutron guide housing preliminary design.

4.1.3 Bunker Wall Insert

Many of the highest energy neutrons that enter the neutron beamline near the moderator are traveling in a direction that is almost parallel to the axis of the beamline in the monolith. Those that do scatter in the neutron guide only change direction slightly. This results in most of the highest energy neutrons traveling through the bunker in close proximity to the neutron beamline. However, a penetration is needed in the bunker wall to allow the neutron beamline and guide to pass through the bunker wall and into the instrument cave. The gaps in the bunker wall immediately adjacent to the guide housing represent a significant radiation streaming path. Additionally, the HD concrete of the bunker wall is a less effective shielding material for high-energy neutrons than carbon steel. Therefore, a larger volume of concrete was removed from the bunker wall than would be needed for a simple beam guide penetration and replaced with the large carbon steel plug shown in Figure 7. This plug provides additional shielding for the high-energy neutrons that have escaped the guide but that are still near the guide. Table 3 provides dimensions for the plug depicted in Figure 7.

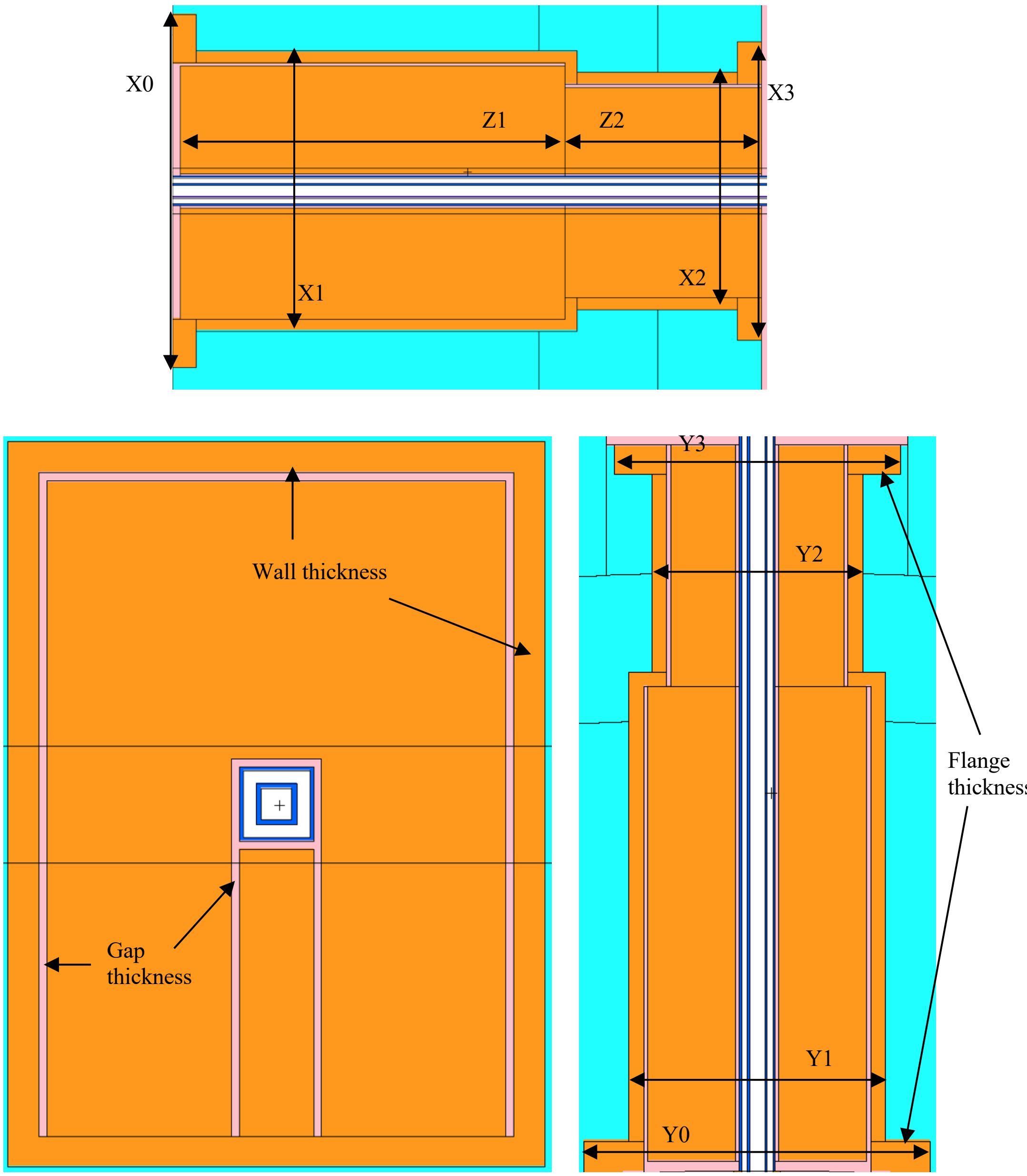

Figure 7. STS Bunker wall insert preliminary design (top ZX plane, bottom left YX plane, bottom right YZ plane).

Table 3. STS bunker wall insert preliminary design dimensions for Figure 7.

Figure 7 Label	Dimension (cm)	Figure 7 Label	Dimension (cm)	Figure 7 Label	Dimension (cm)
X0	147.32	Y0	116.84	Z1	160.14
X1	116.84	Y1	86.36	Z2	81.67
X2	98.9	Y2	70.96	Wall	5
X3	124.46	Y3	96.52	Gap	1.27
				Flange	10

4.1.4 Bunker Roof Panels

The bunker roof is constructed from two layers of wedge-shaped panels The two layers are evident in the SpaceClaim portion of Figure 1, which is slightly offset from the center of the neutron beamline. However, in the MCNP portion of Figure 1, the lower roof panel is not visible because this cut is directly at the center of the neutron beamline, which lines up with a gap between the lower roof panels. Figure 8 shows an elevation view of the MCNP geometry that is perpendicular to the neutron beamline and the view in Figure 1. This view clearly shows the gap between the lower roof panels that is directly above the neutron beamline. There are also gaps between the upper roof panels on the left and right sides of Figure 8, but only half of these gaps are included in the geometry because of the reflected boundary condition, which makes them hard to see in Figure 8. This view also cuts through a simple model of the t_0 chopper in the closed position (i.e., when the chopper is in the neutron beamline).

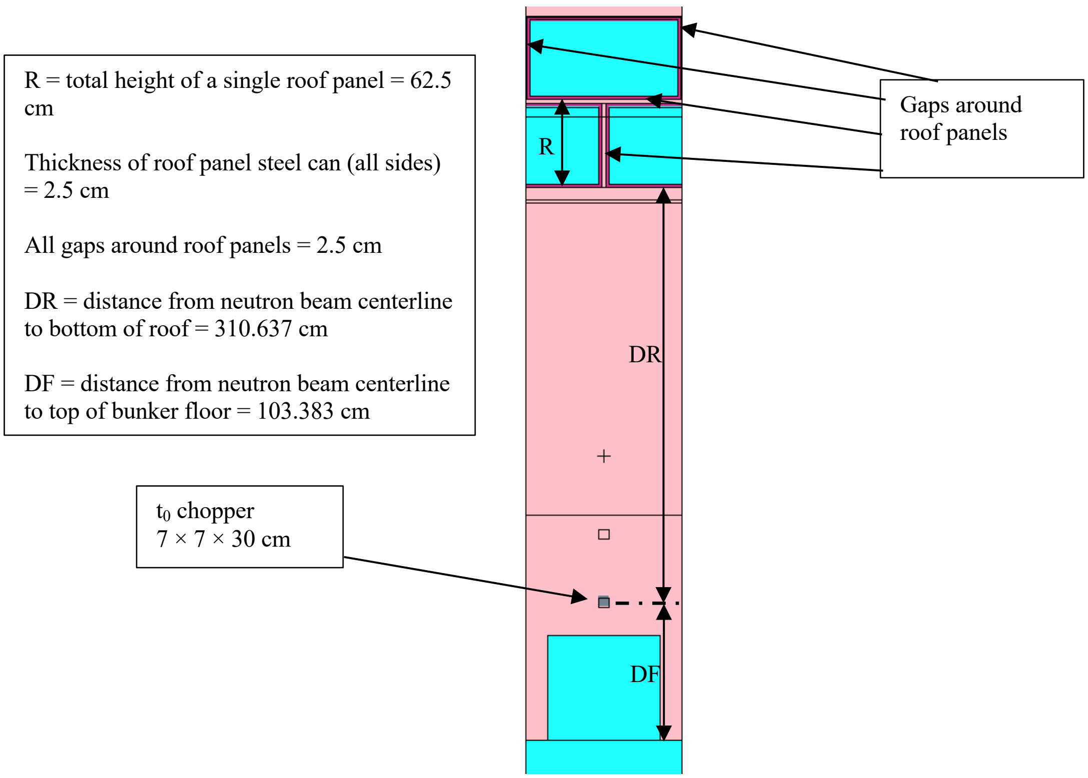

Figure 8. Details of the bunker roof panels in the MCNP geometry of the bunker (YX plane).

Hard to see in Figure 1, and not shown in Figure 8, are gaps between the bunker roof panels and the monolith, gaps between the bunker roof panels and the bunker wall, and also details of the ledges that the bunker roof panels sit on. These details are illustrated in Figure 9.

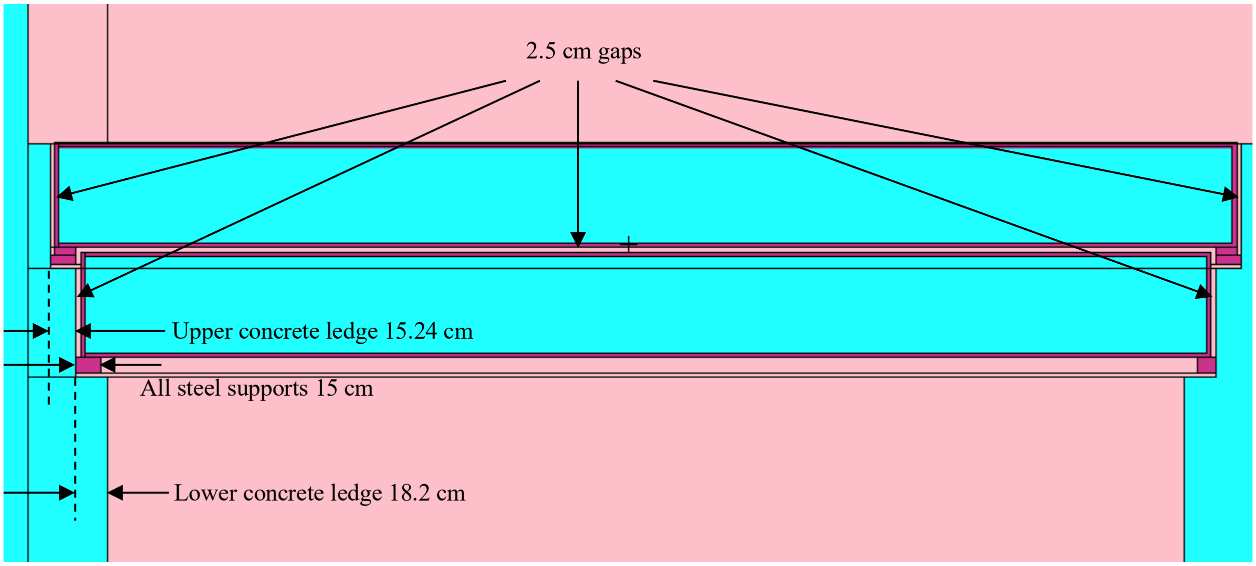

Figure 9. Details of the ledges on the monolith and bunker wall that support the bunker roof panels (ZX plane).

4.2 EXPLICIT BUNKER WITH 11 BEAMLINES

The explicit bunker model does not use any reflected boundary conditions. Rather, it explicitly models 11 of the beamlines on one side of the monolith. A plan view of this model, when all the beamlines are open, is shown in Figure 10. When all the beamlines are open, there is no difference in the elevation view of the MCNP model in Figure 2 and an elevation view of the explicit bunker model that cuts through the centerline of any beamline in the explicit bunker model.

Figure 11 shows the geometry in Figure 10 when the central beamline, ST06, is closed, so there is no neutron guide or beamline shielding outside the bunker, and the plug [9] is inside the monolith insert. Also Figure 11 shows that there is no opening in the bunker wall insert to accommodate the neutron guide for ST06. In fact, none of the streaming gaps illustrated in Figure 7 are included in the ST06 bunker wall insert in Figure 11. Not including the streaming gaps between the permanent bunker wall insert and the temporary plug used to fill the volume of the missing neutron guide inside the bunker wall insert may be considered nonconservative. However, at this stage of design, it is unknown how the opening for the neutron guide will be filled. A straight gap passing through the bunker wall insert without any beamline shielding outside the bunker is unacceptable. The design configuration to fill the opening for the neutron guide in the bunker wall penetration must be analyzed in the future.

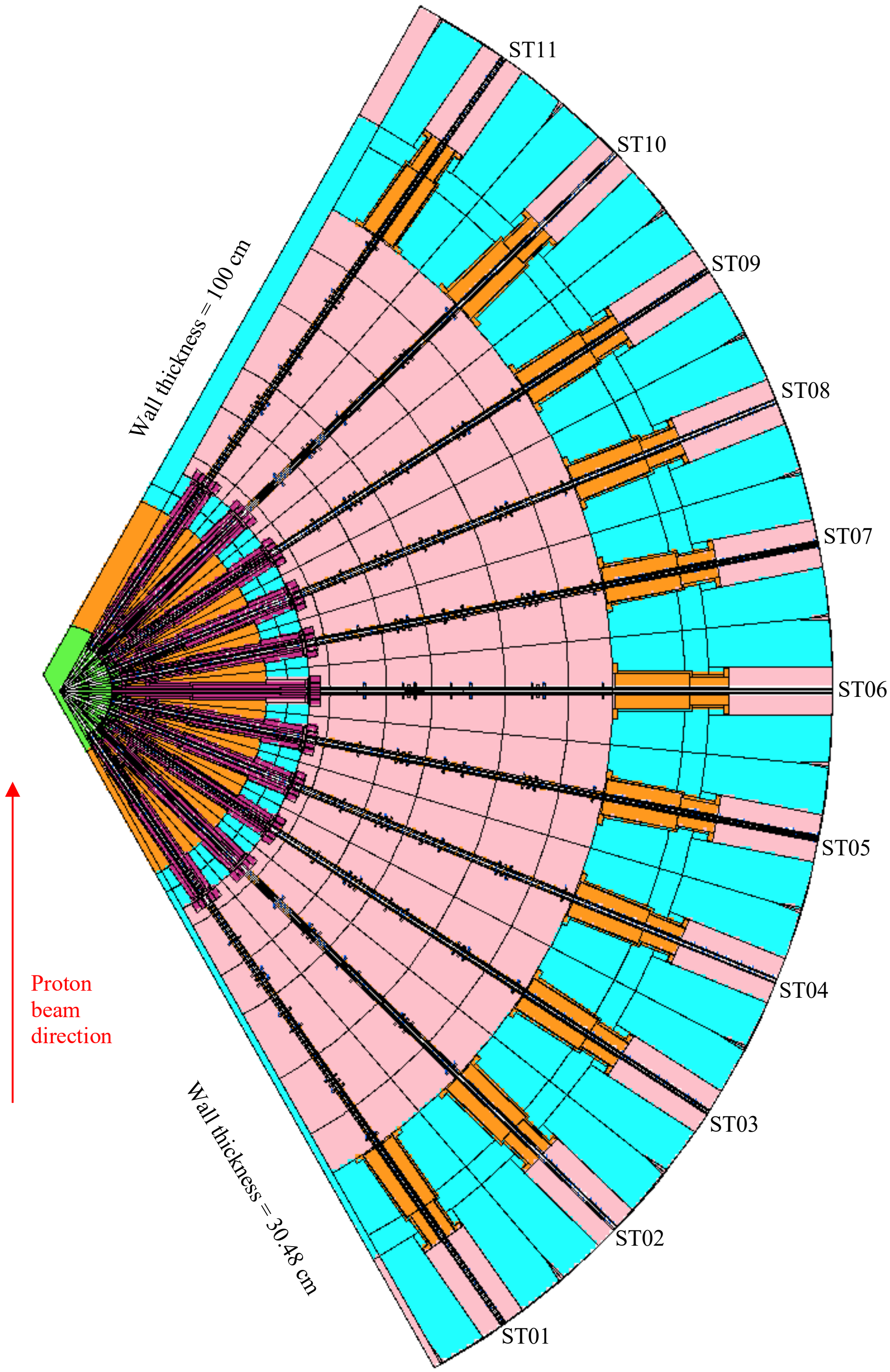

Figure 10. Plan view of the explicit bunker model including 11 open beamlines (ZY plane).

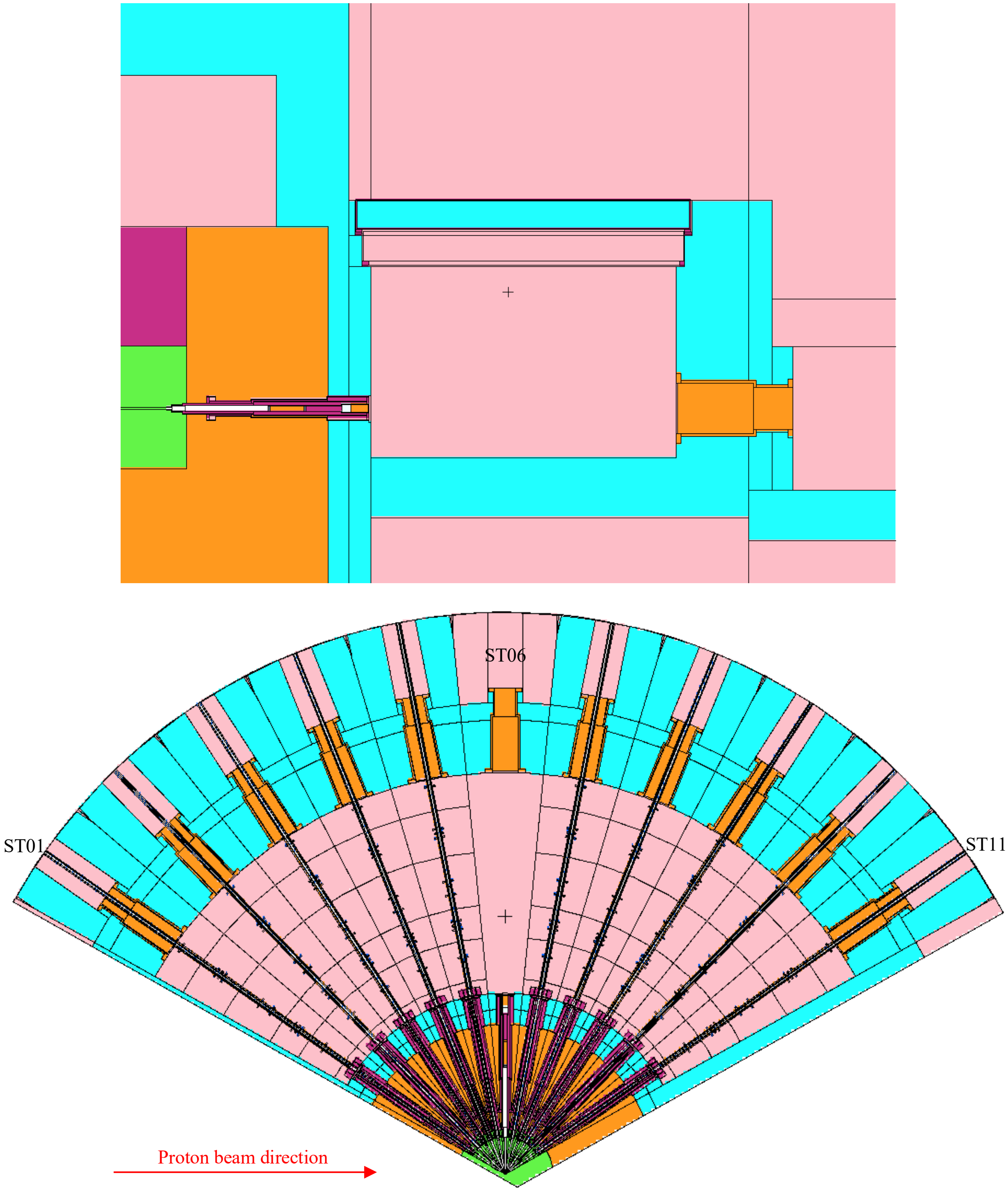

Figure 11. Elevation (top, ZX plane) and plan (bottom, YZ plane) views of the explicit bunker model with one closed beamline surrounded by five open beamlines on each side.

5. ANALYSIS AND RESULTS

The analysis discussed in the following subsections is focused on prompt total dose rate due to neutrons entering beamline 11. ST11 is one of the forward-directed beamlines, with respect to the proton beam direction, so it has the hardest neutron spectrum [1]. The source used in this analysis is referred to as the 19 × 19 cm source in Miller and Remec [1].

5.1 BUNKER ROOF

Analysis of the bunker begins with the roof. The effects of the t_0 chopper above the bunker roof is also evaluated because scattering in the chopper blade increases prompt total dose rates above, below, and to the sides of the neutron beamline. The single-beamline-with-reflected-boundary-conditions MCNP model was used, so the configurations described in the following subsections for a single beamline apply to all beamlines surrounding the monolith.

5.1.1 Bunker Roof with Open Beamlines

The first scenario analyzed regarding bunker shielding is when the proton beam is operating (prompt dose) and all neutron beamlines are open. The source is neutrons entering ST11, and a single beamline is modeled with reflected boundary conditions. A mesh tally is used to tally prompt total dose rate throughout the bunker and above the roof, but the weight windows generated for this analysis only optimize the results above the bunker roof. Figure 12 shows an elevation view of the MCNP geometry and mesh tally results of prompt neutron dose rate at the azimuthal center of beamline 11. Figure 13 shows a plan view of the geometry and prompt neutron dose rate results on the top surface of the bunker roof. It turns out that the maximum prompt neutron dose rates on the bunker roof line up with the center of the neutron beamline/gap in the lower roof panels, which is the plane shown in Figure 12.

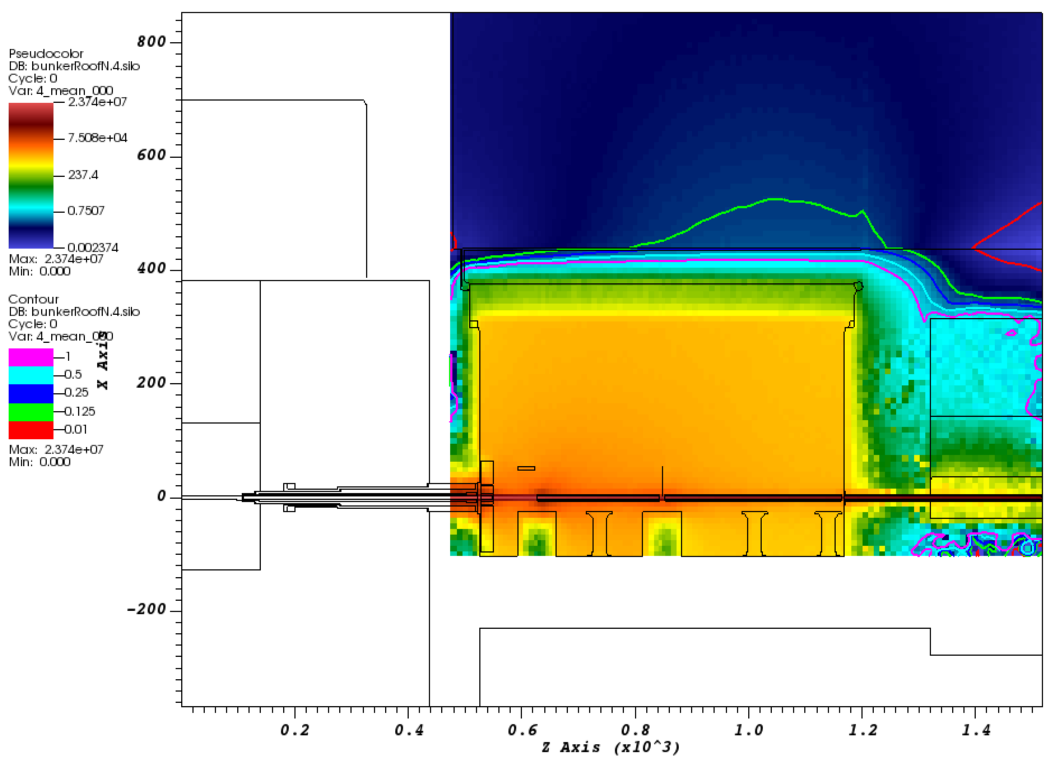

Figure 12. Prompt neutron dose rate contours (mrem/h) along the center of ST11 when the beamline is open.

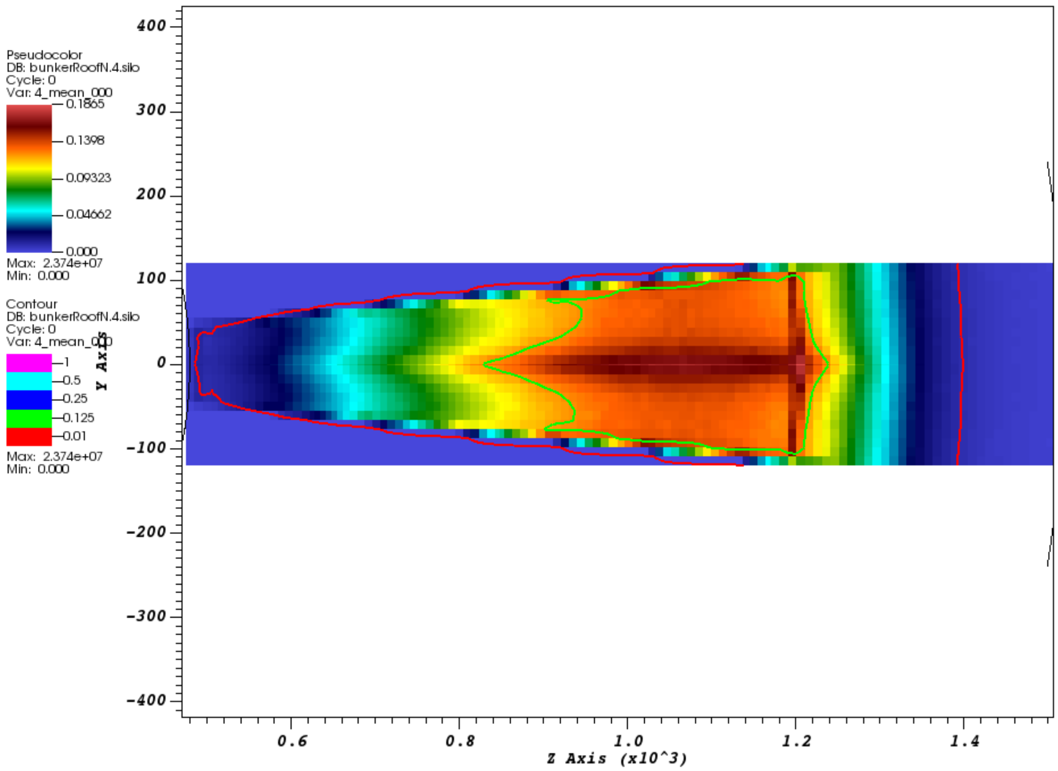

Figure 13. Prompt neutron dose rate contours (mrem/h) on the top surface of the bunker roof above ST11 when the beamline is open, maximum value is 0.186 ± 2.66% mrem/h.

5.1.2 Bunker Roof with Closed t_0 Choppers

The next scenario analyzed is when the t_0 chopper is closed, so the chopper blade is in the neutron beamline. Figure 2 shows a simple model of the t_0 chopper in the open position and Figure 8 shows this simple model of the t_0 chopper in the closed position. The simple representation of the t_0 chopper consists of just the Inconel chopper blade. With the t_0 chopper closed, most of the neutrons and photons entering ST11 have an interaction in the t_0 chopper. This will cause many of these particles to scatter towards the bunker roof and will result in an increase of the prompt total dose rate on top of the bunker. Figure 14 shows an elevation view of the MCNP geometry and mesh tally results of neutron dose rate at the azimuthal center of ST11 when the t_0 chopper is closed. Figure 15 compares the maximum prompt total dose rates on top of the bunker roof when the t_0 chopper is in either the open or closed position. In Figure 15 the peak of the prompt total dose rate profile has shifted to the left when the t_0 chopper is closed, which is closer to the t_0 chopper and monolith. Also, the prompt total dose rate on top of the bunker slightly exceeds the prescribed limit of 0.25 mrem/h when the simple model of the t_0 chopper is closed. In Figure 15 the spike in prompt total dose rate around 1,200 cm is due to a streaming gap between the roof panels and the bunker wall that can be seen better in Figure 2. The other structure in Figure 15 is due to statistical noise in the Monte Carlo solution.

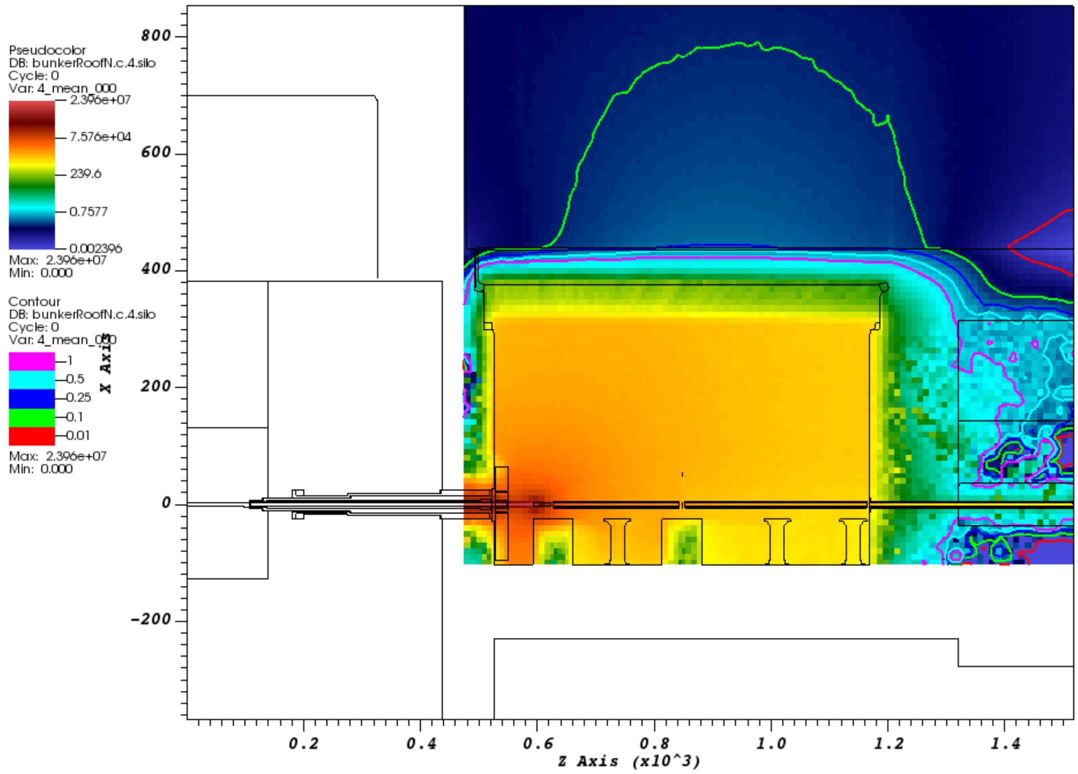

Figure 14. Prompt neutron dose rate contours (mrem/h) along the center of ST11 when the simple t_0 chopper model is closed.

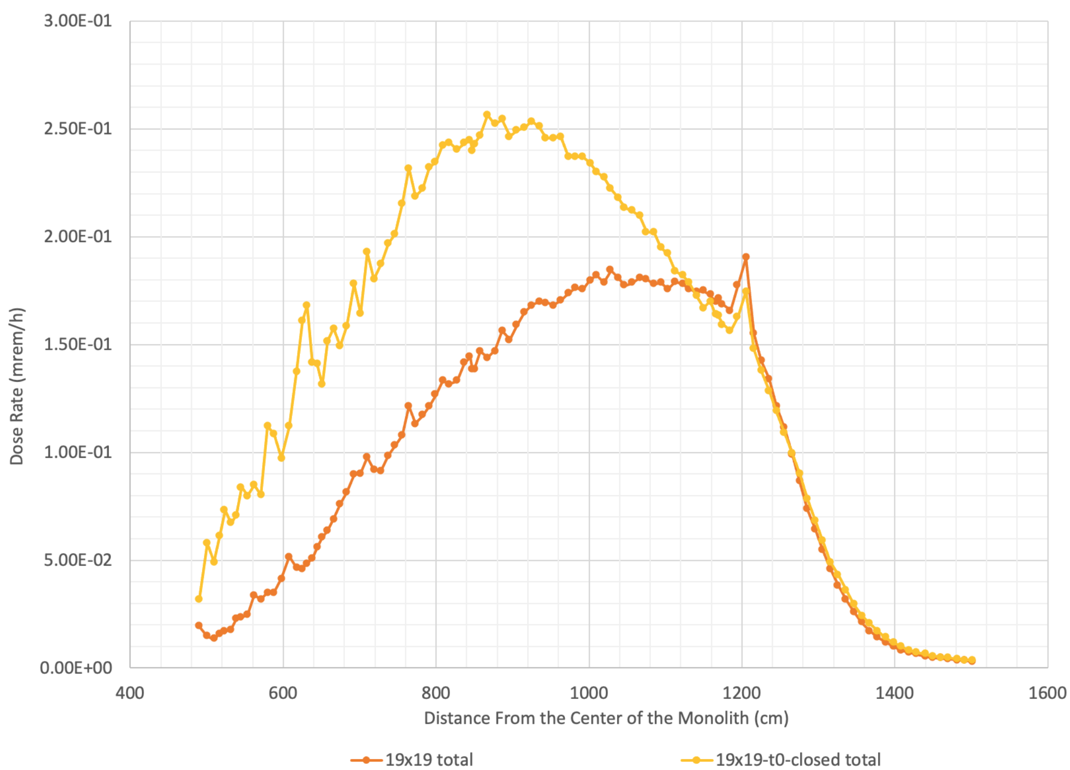

Figure 15. Comparison of the maximum prompt total dose rate (mrem/h) on top of the bunker roof, directly above ST11, when the beamline is open and when the simple t_0 chopper model is closed.

Since calculated prompt total dose rates with the simplified t_0 chopper in the closed position exceed the 0.25 mrem/h prompt total dose rate limit, more detail was added to the t_0 chopper model. The t_0 chopper housing provides additional shielding and will reduce the simulated prompt total dose rate result. Two images of the t_0 chopper housing, which were used as guides to update the MCNP model, are shown in Figure 16. This is followed by an image similar to Figure 14, but Figure 17 shows the prompt neutron dose rate when the t_0 chopper is closed with the addition of the chopper housing. Finally, Figure 18 adds a third curve to the comparison of maximum prompt total dose rate on top of the bunker roof where the additional curve is for the closed t_0 chopper surrounded by the carbon steel housing.

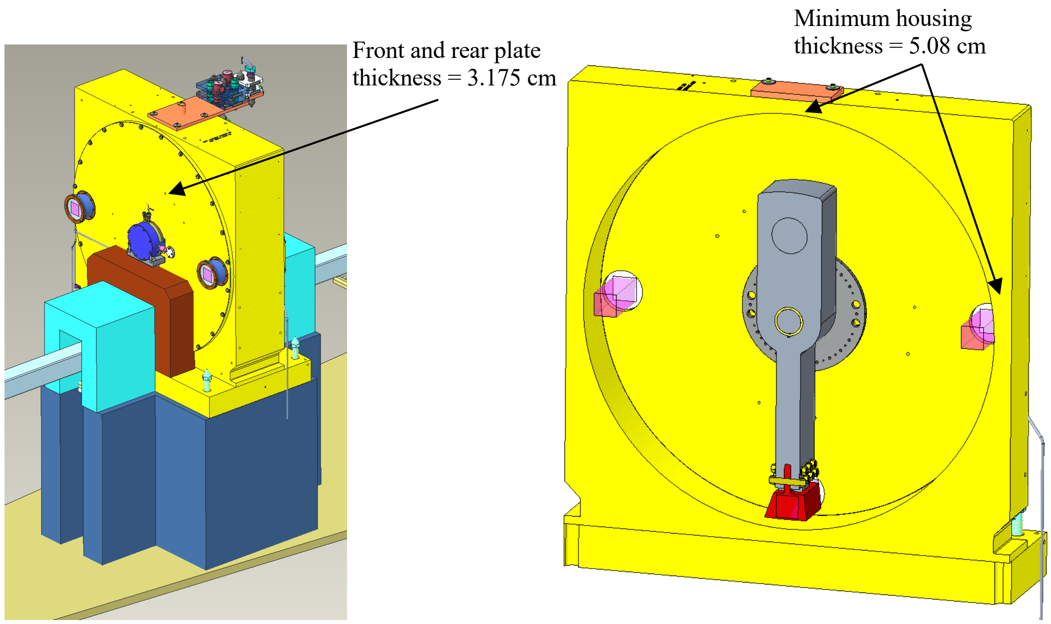

Figure 16. The full t_0 chopper housing (yellow) plus additional shielding (left) and a cross section of the t_0 chopper and housing (right).

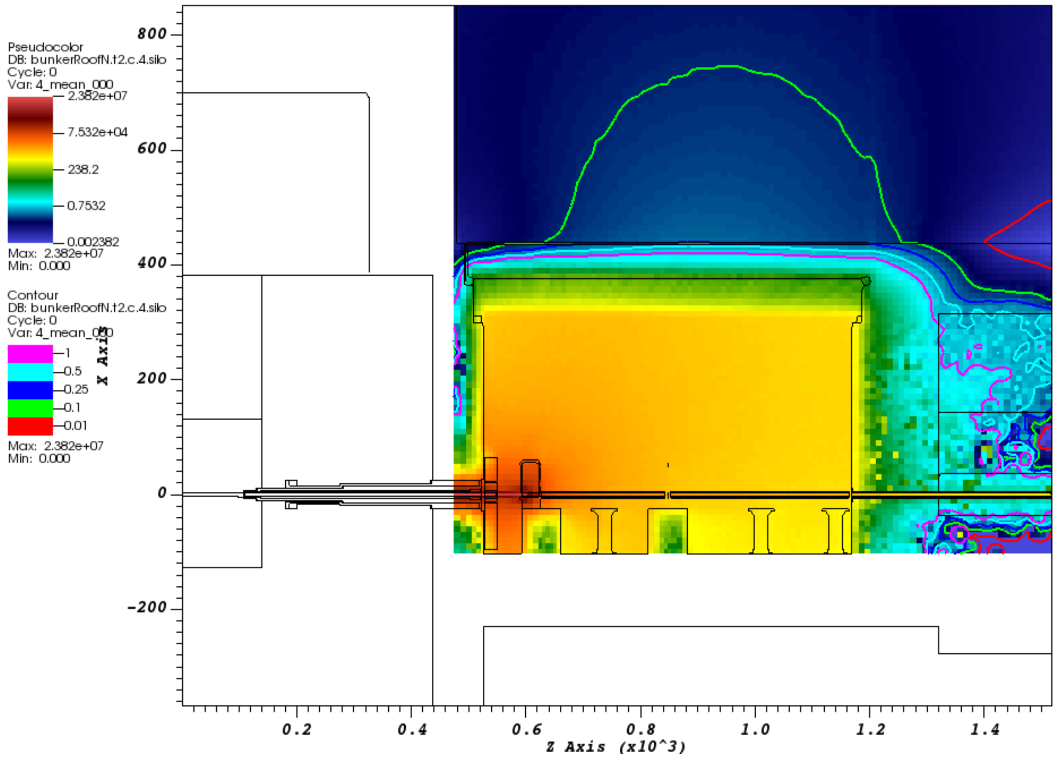

Figure 17. Prompt neutron dose rate contours (mrem/h) along the center of ST11 when the t_0 chopper is closed, and the model includes the t_0 chopper housing.

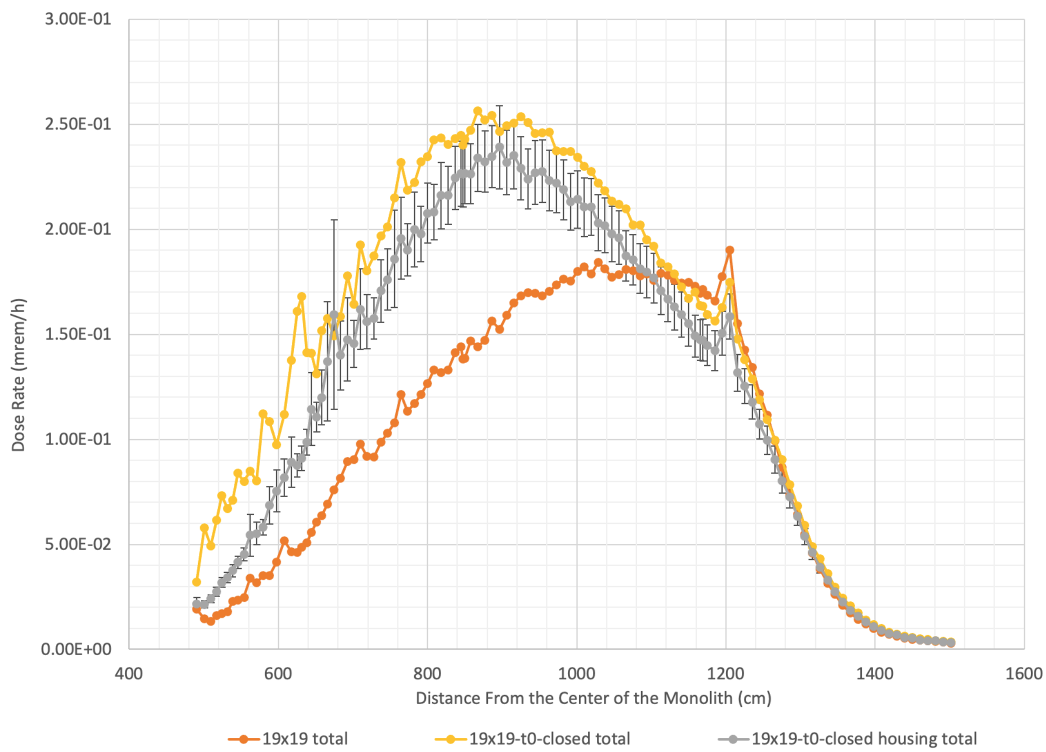

Figure 18. Comparison of maximum total dose rate (mrem/h) on top of the bunker roof, directly above ST11, when the beamline is open, the simple t_0 chopper is closed, and the chopper is closed inside the carbon steel housing. Error bars (two standard deviations) are only included on results with the chopper housing.

5.2 BUNKER WALL

Next the bunker wall is analyzed. First the shielding effectiveness of the conceptual bunker wall design is analyzed. This is followed by analysis of the modified bunker wall design. Again, the single beamline with reflected boundary conditions MCNP model is used, so the configurations described for a single beamline apply to all beamlines surrounding the monolith.

5.2.1 Bunker Wall with No Neutron Guides Installed but All Beamlines Open

During normal operations a neutron guide passes through the bunker wall and the beamline shielding, and eventually ends in an instrument cave (see Figure 2). In this scenario, the 0.25 mrem/h prompt total dose rate limit does not apply inside the beamline shielding and instrument cave. However, when STS begins initial operations, not all the beamlines exiting the monolith will have neutron guide infrastructure inside the bunker and an instrument cave outside the bunker. In this unpopulated beamline scenario, the dose rate on the bunker wall must meet the 0.25 mrem/h limit. Therefore, a simulation was performed of the prompt total dose rate at the bunker wall for ST11 in this unpopulated beamline scenario. The geometry in Figure 2 was modified to remove the neutron guide infrastructure outside the monolith and beamline shielding outside the bunker, but the beamline inside the monolith was left completely open to provide the maximum dose rate on the bunker wall. In this analysis, the bunker wall thickness is 150 cm of HD concrete (component "W" in Figure 2), which matches the conceptual design ([8], section 5.3.2). Figure 19 provides an elevation and plan view of the modified MCNP geometry and mesh tally results of prompt neutron dose at the center of ST11. The contour lines in Figure 19 indicate that the prompt neutron dose rate alone is above 0.25 mrem/h outside the bunker. On the outer surface of the bunker wall, the maximum neutron dose rate is about 500 mrem/h. Clearly some additional shielding is needed for the unpopulated beamline scenario. The result of this analysis is a precursor to the plug design work [9] for unpopulated beamlines.

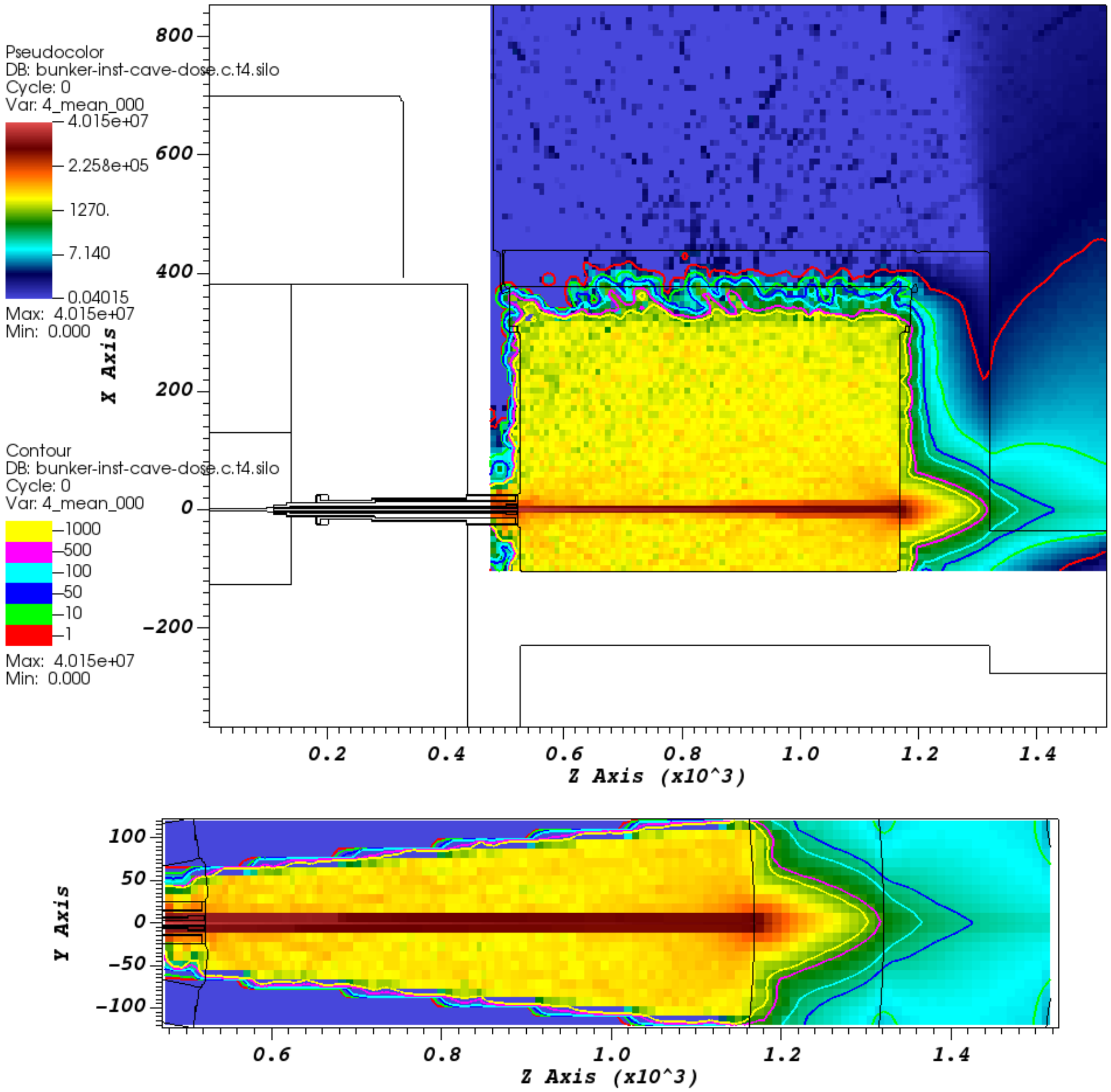

Figure 19. Prompt neutron dose rate contours (mrem/h) along the center of ST11, when it is completely open, for the unpopulated beamline scenario.

5.2.2 Bunker Wall Including Beamline shielding

With the advent of a plug design for unpopulated beamlines, the scenario in Figure 19 is not a realistic operating scenario. What is more realistic is the configuration shown at the top of Figure 11, which is analyzed in Mohindroo, Miller, and Remec [9]. Now this analysis will return to a configuration where the neutron guide infrastructure and penetration in the bunker wall is present, as shown in Figure 2. The neutron guide penetrating the bunker wall makes it difficult to reduce the total dose rate outside the bunker wall to less than 0.25 mrem/h without some additional heavy shielding around the neutron guide outside the bunker. The result shown at the bottom of Figure 19 suggests that the additional shielding needs to cover the full 11° arc between adjacent neutron beamlines. Therefore, the beamline shielding outside the bunker must be included in the shielding analysis of the bunker wall. Multiple configurations containing additional shielding material in and/or around the 150 cm thick bunker wall were analyzed. Several of these configurations produced results that met the prescribed dose rate limit. The simplest solution increased the bunker wall thickness (W in Figure 2) to 222 cm of HD concrete. Other configurations that satisfy the 0.25 mrem/h dose rate limit and keep the bunker wall thickness close to the 150 cm limit were found. However, these configurations with wall thicknesses close to the conceptual design value of 150 cm require a significant amount of the HD concrete to be replaced by carbon steel. In the end, the neutronics group and instrument systems section settled on the configuration shown in Figure 2. A summary of these alternate bunker shielding configurations is provided in APPENDIX C. The major changes to the conceptual design, as shown in Figure 2, are increasing the bunker wall thickness from 150 to 202 cm of HD concrete, adding the carbon steel bunker wall insert depicted in Figure 7, and increasing the wall thickness of the neutron guide housing to 2.54 cm of carbon steel. Figure 20 shows the prompt total dose rate contours for this configuration. In Figure 20 the prompt total dose rate at the location labeled A is 0.18 mrem/h and at B is 0.25 mrem/h. Both these values are the mean plus two sigma (top of the 95% confidence interval). Some additional analysis was performed to determine the energy dependence of the radiation at location A in Figure 20. These results are broken into six coarse energy groups and presented in Table 4.

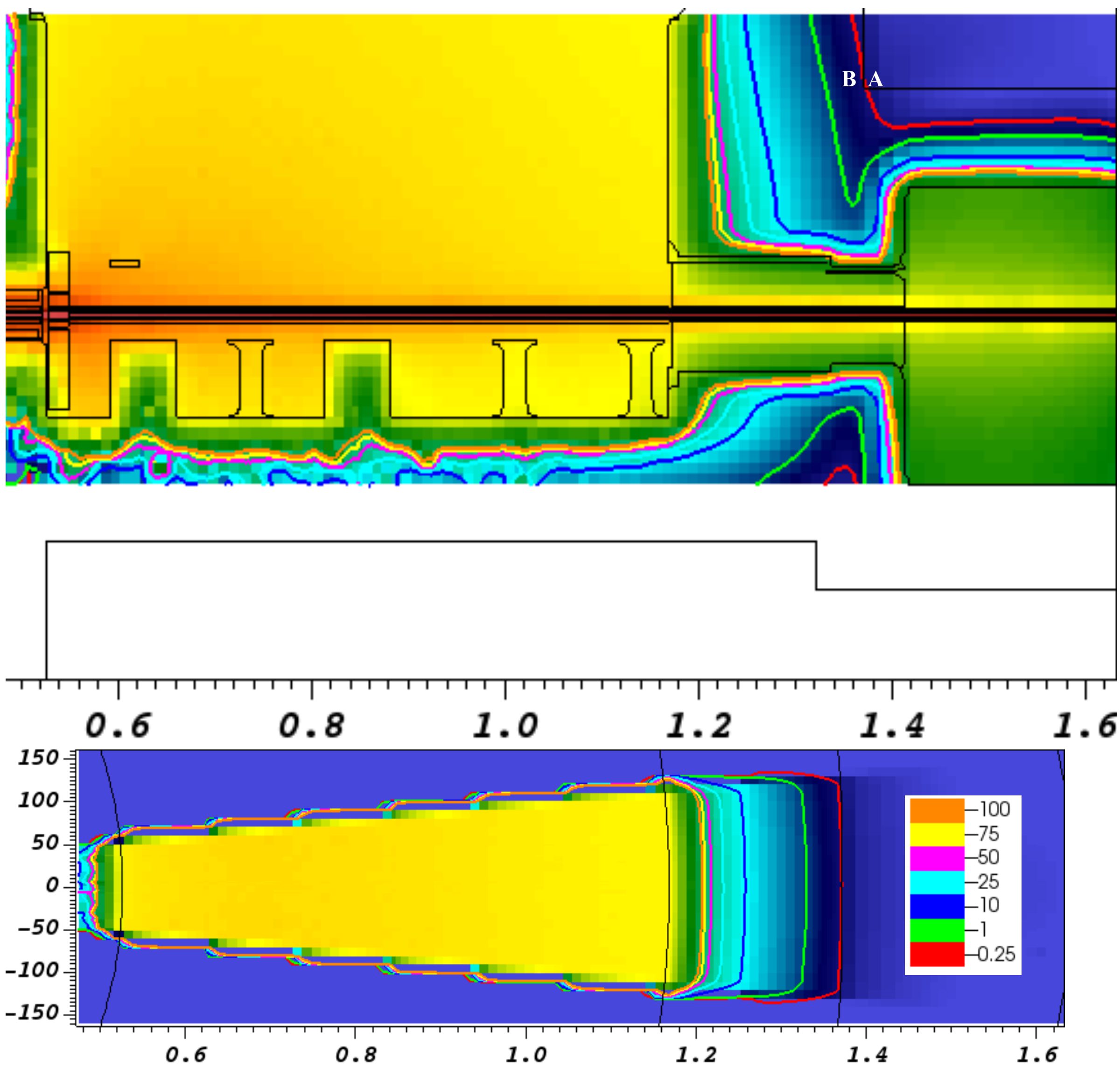

Figure 20. Prompt total dose rate contours (mrem/h) along the center of ST11 when it is completely open (top) and plan view of the contours just above the roof of the beamline shielding (bottom).

Table 4. Energy dependence of radiation at position A in Figure 20.

Neutron Energy Range (MeV)	Percentage of Prompt Total Dose Rate
E > 100 MeV	19.3%
10 MeV < E < 100 MeV	31.4%
1 MeV < E < 10 MeV	34.2%
0.1 MeV < E < 1	11.2%
E < 0.1 MeV	2.3%
All secondary gammas	1.6%

5.3 BUNKER AND INSTRUMENT HALL FLOOR

For the purposes of this shielding analysis the area below the bunker, the basement, is considered generally accessible. This analysis will also use the single beamline with reflected boundary conditions MCNP model, so the configurations described for a single beamline apply to all beamlines surrounding the monolith. In this analysis the bunker floor thickness, BF in Figure 2, was set to 2 m. The prompt total dose rate contours in Figure 21 were used to set the minimum required bunker floor thickness for shielding purposes. In Figure 21 the 0.25 mrem/h total dose rate contour extends deepest into the bunker floor at Z ≈ 830 cm, which is the distance along ST11 from the tube moderator. The top of the bunker floor is at X = –103.383, and the 0.25 mrem/h dose rate is located at X ≈ –243 cm. This results in a minimum required bunker floor thickness for shielding of 140 cm of HD concrete.

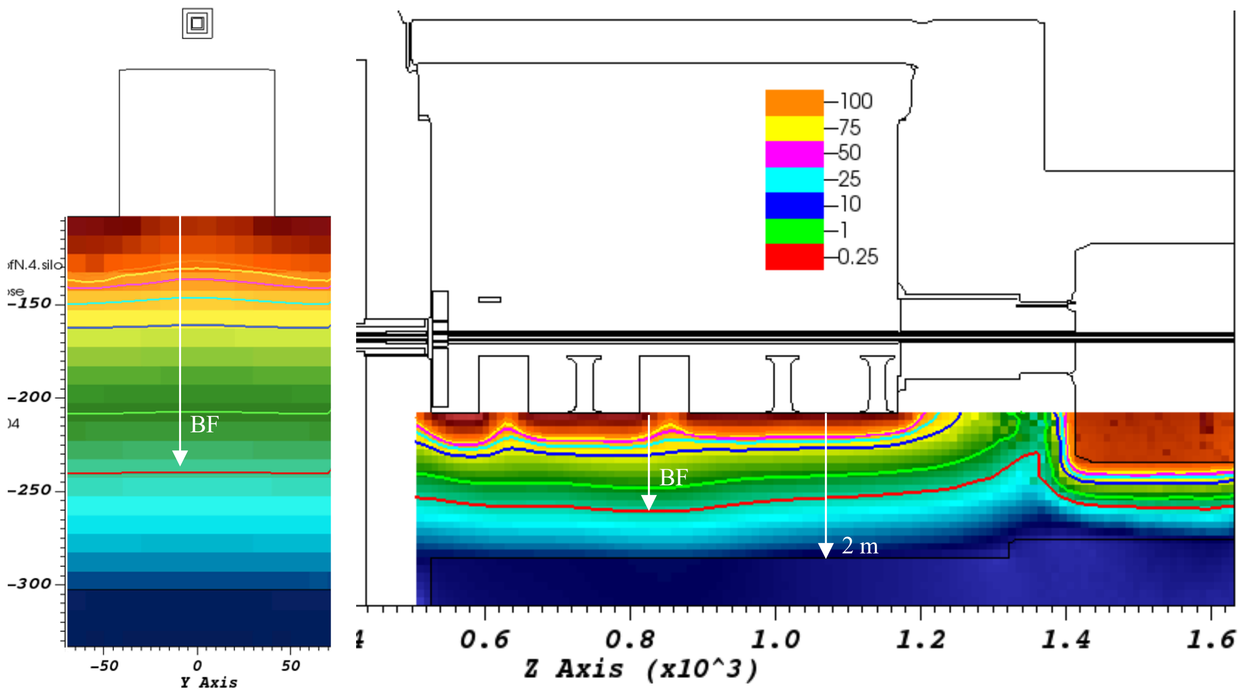

Figure 21. Prompt total dose rate contours (mrem/h) along the center of ST11 when it is open (right) and elevation view of the contours in the bunker floor perpendicular to ST11 at Z = 830 cm (left).

A similar approach was taken outside the bunker for the floor under the beamline shielding and instrument caves (i.e., the instrument floor). The prompt total dose rate contours on the right of Figure 21 show that the 0.25 mrem/h contour is mostly flat within the instrument floor. There is a peak around Z ≈ 1,590 cm, but the model ends at 1,630 cm from the moderator, and there is a vacuum boundary condition on the right side of this model. That means the position of this deepest penetration of prompt total dose rate into the instrument floor may be underestimated. A plot like the left image in Figure 21 is shown in Figure 22 for the instrument floor. In Figure 22 the 0.25 mrem/h contour is at X ≈ –175 cm. This results in a minimum required instrument floor thickness for shielding of 71.5 cm of HD concrete.

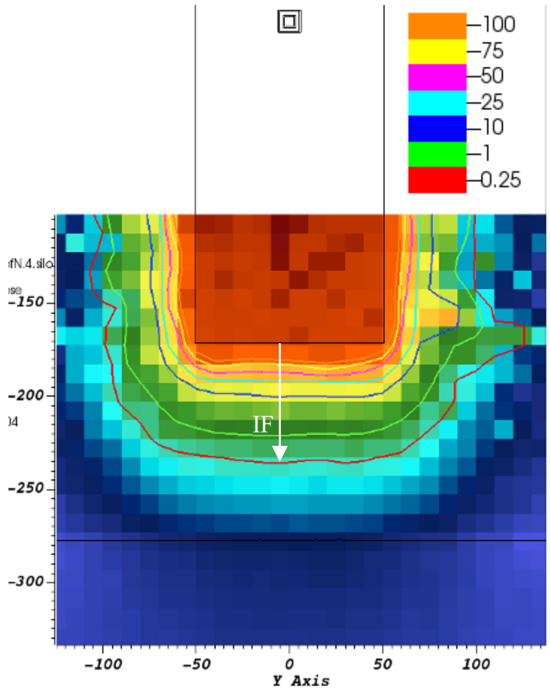

Figure 22. Elevation view of the prompt total dose rate contours (mrem/h) perpendicular to ST11 when it is open, Z = 1,590 cm in right image of Figure 21.

5.4 COMBINING OPEN BEAMLINES WITH BEAMLINE SHIELDING AND CLOSED BEAMLINES WITHOUT BEAMLINE SHIELDING

All the bunker shielding analysis discussed to this point used the single-beamline-with-reflected-boundary-conditions MCNP model, which implies that all the beamlines had the same configuration. Therefore, all the beamlines were open, or all were closed. The previous subsections have shown that the 0.25 mrem/h dose rate limit is met outside the bunker and beamline shielding when all the beamlines are open and operating. The preliminary design of the shield plug [9] shows that the 0.25 mrem/h dose rate limit is met outside the bunker when all the beamlines are closed and unpopulated and the monolith insert plug is installed. Recall if a beamline is closed or unpopulated, there is no beamline shielding for that beamline outside the bunker. This leads to the concern that radiation scattering inside the bunker from an open beamline may increase the dose rate outside a closed beamline that has no beamline shielding installed, so an analysis was performed using the configuration in Figure 11. This analysis started with the ST11 source entering the central beamline, ST06, in the bottom of Figure 11, which is perpendicular to the proton beam direction. Then successive simulations were performed with the ST11 source entering beamlines adjacent to ST06. The adjacent beamlines included in this analysis are ST03 – ST05 and ST07 – ST09. The results of these simulations are summed to give the prompt total dose rate outside the bunker near ST06. The cumulative prompt total dose rate contours outside the bunker for these different simulations are shown in Figure 23. Starting at the top left of Figure 23 is the prompt total dose rate outside the bunker for ST06 when there is no beamline shielding and the shielding plug is in the monolith insert. Then going left to right and top to bottom, the prompt total dose rate from the adjacent beamlines is added to the plot. The bottom right image shows the prompt total dose rate contours for beamlines ST03 – ST09, the closed beamline plus three open beamlines on each side. In Figure 23 it is easy to see which beamlines are included in the simulation because of the high prompt total dose rates inside the neutron guides traversing the bunker. As expected, the prompt total dose rate outside the bunker for the closed beamline is well below 0.25 mrem/h, so the plug design [9] works as expected. The inclusion of ST05 and ST07 makes a large increase in the prompt total dose rate outside the bunker and the beamline shielding of the adjacent beamlines. Adding in ST04 and ST08 makes a small but statistically significant increase in the prompt total dose rate (approximately 10%) outside the bunker and beamline shielding near the central beamline, but beamlines ST03 and ST09 do not make a statistically significant increase. Since these last beamlines added did not make a statistically significant change in the dose rate outside the bunker near the closed beamline, the remaining adjacent beamlines were not simulated. No legend is provided in Figure 23 for the color contours, but a legend is provided for the color isodose lines.

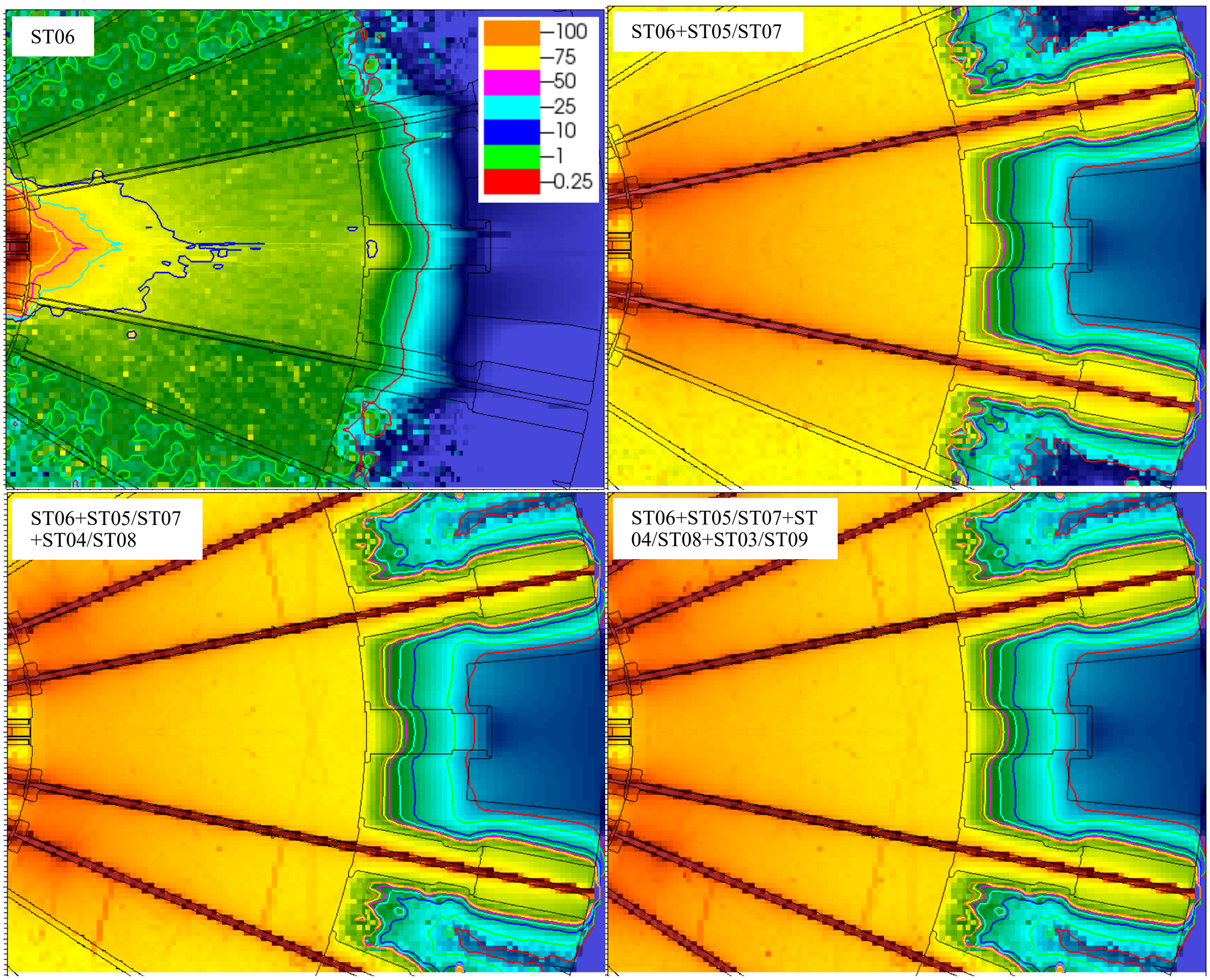

Figure 23. Cumulative prompt total dose rate contours (mrem/h) outside the bunker wall across from the closed beamline and outside the beamline shielding of the adjacent open beamlines.

Figure 23 shows that the dose rate outside the bunker wall, in a region where there is no beamline shielding, is a concern if there is a mix of open and closed beamlines during operations. To evaluate the full extent of this issue, a 3D plot of the prompt total dose rate contours on the outside of the bunker and beamline shielding was created. This 3D plot is shown in Figure 24, and it includes the contributions from beamlines ST03 – ST09. In Figure 24 the prompt total dose rate contours inside the beamline shielding for ST05 and ST07 are clearly visible, similar to Figure 23. The 0.25 mrem/h contours outside the closed beamline, ST06, where there is no beamline shielding, is also evident, and one can see that its extent in the vertical direction is not very large. Most importantly, these contours do not extend above the roof of the adjacent beamline shielding. At this point in the preliminary design, the neutronics group and instrument systems section decided not to investigate mitigating this excessive dose rate.

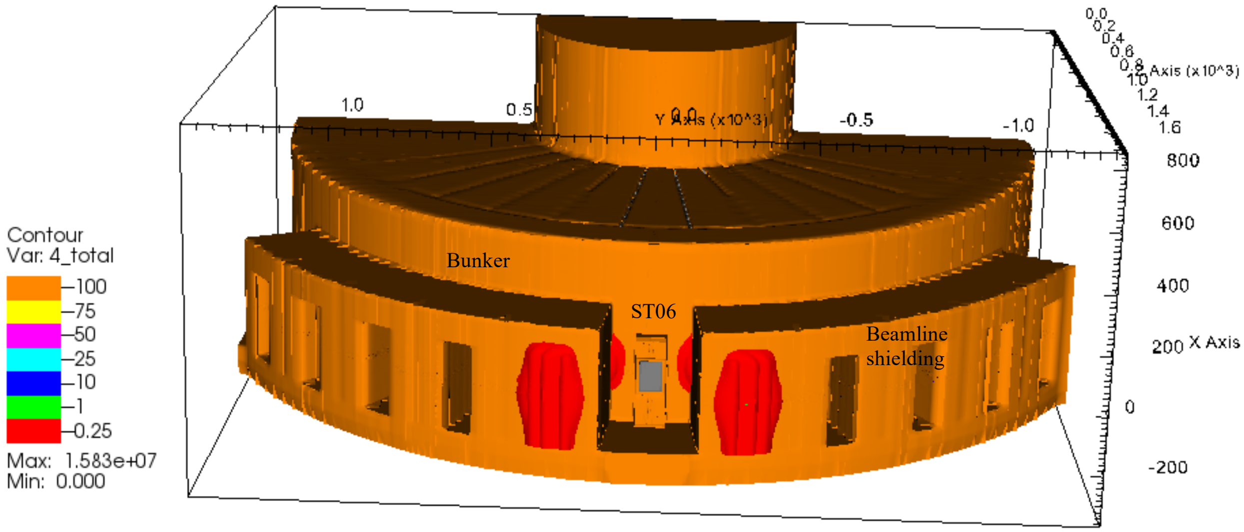

Figure 24. Three-dimensional prompt dose rate contours (mrem/h) outside the bunker and beamline shielding for a closed beamline and three adjacent open beamlines.

5.5 PROMPT TOTAL DOSE RATES INSIDE THE BUNKER

All previous subsections of this report have focused on evaluating prompt total dose rates outside the bunker and beamline shielding, in generally accessible areas. This subsection presents the prompt dose rates inside the bunker. In this analysis all the beamlines are open and operating, so the configuration in Figure 10 is used. Also, like the results presented so far, only the ST11 beamline source is used, so these are conservative results of prompt dose rates inside the bunker. Figure 25 provides the prompt neutron and secondary photon dose rates inside the bunker. The prompt secondary photon dose rates are due to interactions of the ST11 neutrons that resulted in the production of photons. Figure 26 shows the prompt dose rate contours caused by the primary ST11 photons. These are the photons that enter the beamline from the moderator/target area of STS. Details of the primary ST11 photon source are presented in Miller and Remec [1]. No legend is provided in Figure 25 and Figure 26 for the color contours, but a legend is provided in both for the color isodose lines. The prompt secondary photon dose rates are about 10% or less of the prompt neutron dose rates, and the prompt primary photon dose rates are at least two orders of magnitude less than the prompt neutron dose rates. Because the prompt primary photon dose rates inside the bunker are so much lower than the prompt neutron and secondary photon dose rates in the bunker, the prompt primary photon dose rates outside the bunker are certainly negligible.

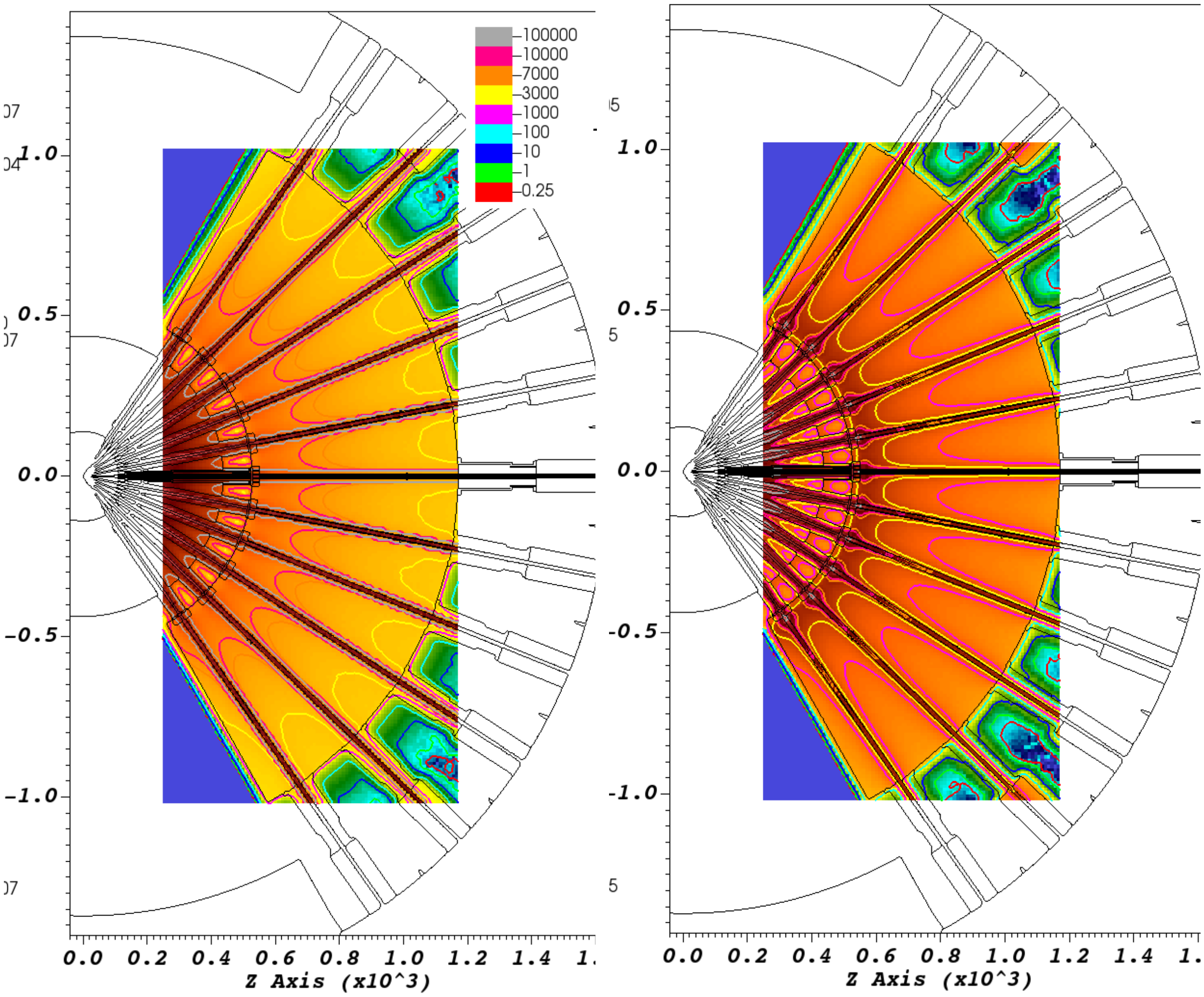

Figure 25. Prompt neutron (left) and secondary photon (right) dose rates (mrem/h) inside the bunker when all beamlines are open and operating and the source entering each beamline is the ST11 neutron source.

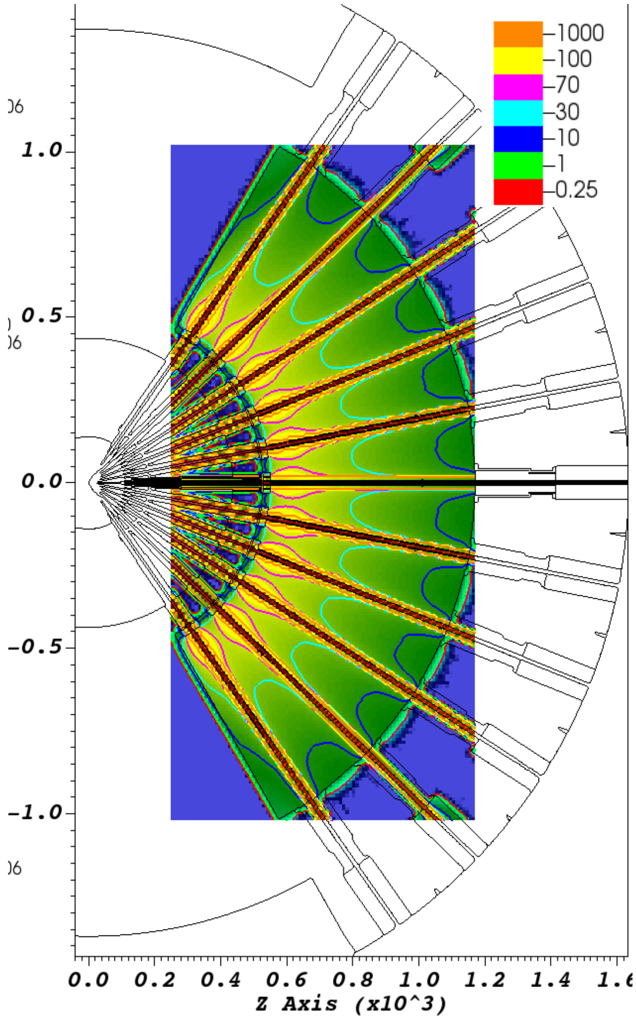

Figure 26. Prompt primary photon dose rates (mrem/h) inside the bunker when all beamlines are open and operating and the source entering each beamline is the ST11 primary photon source.

6. CONCLUSIONS

This report presents the prompt total dose rate analysis of the STS bunker preliminary design. The starting point of the models is the conceptual design [8], which has been updated as needed to meet the radiation protection limit of 0.25 mrem/h in generally accessible areas of the STS. These modifications represent the preliminary design, which was summarized in Section 4.

This analysis began by calculating prompt total dose rates around the outside of the bunker when all the beamlines are open and operating and the ST11 beamline source [1], normalized to a 700 kW proton beam, is used in all beamlines. First, the bunker roof was analyzed, with and without a closed t_0 chopper. It was found that the design of the bunker roof panels, including streaming gaps, met the radiation protection limit of 0.25 mrem/h when the t_0 chopper is open. This limit was also met when the t_0 chopper was closed, but a more realistic model of the t_0 chopper that included the chopper housing was required. This inclusion of the chopper housing shows that 5.08 cm (2 in.) of carbon steel has a meaningful effect on prompt total dose rates outside the bunker caused by neutron scattering when something is placed in the neutron beam. Next, the dose rate outside the bunker wall was analyzed, which showed the estimate provided in the conceptual design, 150 cm of HD concrete, was not adequate. To meet the dose rate requirements beyond the bunker wall, especially with penetrations due to the neutron guides exiting the bunker, additional heavy shielding is needed outside the bunker. Therefore, a portion of the beamline shielding, which shields personnel outside the bunker from the radiation exiting the neutron beamlines in the instrument hall, was added to the model. After adding this portion of the beamline shielding to the model, these additional changes were made to meet the radiation protection limit of 0.25 mrem/h outside the bunker and beamline shielding:

- The bunker wall thickness is increased to 202 cm of HD concrete, W in Figure 2.
- The neutron guide housing inside the bunker is 2.54 cm of carbon steel.
- The bunker wall insert is carbon steel (details in Section 4.1.3).
- The beamline shielding (walls and roof) near the bunker is 100 cm of HD concrete, BT in Figure 2.

The final analysis with all the beamlines open and operating was to evaluate the floor of the bunker and the instrument floor. This analysis showed that the bunker floor should be at least 140 cm of HD concrete and the instrument floor should be at least 71.5 cm of HD concrete. These thicknesses of HD concrete will reduce the dose rates in the basement below the bunker and instruments to 0.25 mrem/h or less.

The analysis in this report first considered all beamlines open, and Mohindroo, Miller, and Remec [9] considered all beamlines closed. This led to the concern that open beamlines next to closed beamlines might increase the prompt total dose rates outside the bunker to greater than 0.25 mrem/h because closed beamlines do not have any beamline shielding installed outside the bunker. The analysis in Section 5.4 indicated that this was true, but the increase above 0.25 mrem/h was not substantial and was limited to a relatively small region. There is more discussion on this topic in Section 6.1.

The last analysis presented in this report evaluated the prompt dose rates inside the bunker when all beamlines are open and operating and the ST11 beamline source, normalized to a 700kW proton beam, is used in all beamlines. These results showed that the neutrons in beamline sources will dominate the prompt total dose rate inside the bunker, and the secondary photons created by neutrons can add a few percent to the prompt total dose rate. The primary photons generated in the proximity of the target, moderators, and reflector structures that enter the beamlines on the ends facing the moderators (at the same location as the neutron beamline sources) make a contribution to the prompt total dose rate inside the bunker that is at least two orders of magnitude less than the neutron contribution. In short, this means that the primary photon beamline sources can be ignored for shielding analysis inside and outside the bunker.

6.1 CONSIDERATIONS FOR FUTURE PRELIMINARY DESIGN WORK AND FINAL DESIGN

Upon completion of this analysis of bunker shielding, there are still a few open issues that will be deferred until a later time. The neutronics group and instrument systems section decided it would be best to consider these on a case-by-case basis when evaluating the specific design of individual neutron beamlines and to wait until more details are known about the STS HD concrete specifications. Examples are:

- Refining the shielding requirements for a mix of open and closed beamlines
- Analyzing beamlines that curve inside the bunker and/or monolith
- Analyzing operations shutters inside the bunker
- Analyzing tapered beamlines that have a 5 × 5 cm opening near the moderator but exit the monolith with a larger opening
- Updating and optimizing gaps in and around the monolith optics, bunker roof panels, and within the bunker wall inserts

Other issues may come up as additional work is performed. At this point, this report provides shielding analysis of the nominal preliminary design of the STS bunker.

7. REFERENCES

1. Miller, T. M. and I. Remec. 2022. *STS Project Generation of Beamline Sources – Preliminary Design*. ORNL/TM-2022/1828, S04030200-TRT10002. Oak Ridge National Laboratory.
2. SNS. 2007. *SNS Specification Section 03300 Cast-in-Place Concrete*. 108000000TS0115R10. Oak Ridge National Laboratory.
3. C. J. Werner, ed. 2017. *MCNP® User's Manual, Code Version 6.2.* LA-UR-17-29981. Los Alamos National Laboratory.
4. Chadwick, M. B., et al. 2011 "ENDF/B-VII.1 Nuclear Data for Science and Technology: Cross Sections, Covariances, Fission Product Yields and Decay Data," *Nuclear Data Sheets*, **112** (12): 2887-2996.
5. Popova, I. I. 2012. *Flux to Dose Conversion Factors*. SNS-NFDD-NSD-TR-0001, R02. Oak Ridge National Laboratory.
6. Mosher, S. W., et. al. 2015. *ADVANTG – An Automated Variance Reduction Parameter Generator*. ORNL/TM-2013/416, Rev. 1. Oak Ridge National Laboratory.
7. SpaceClaim 2020 R2. https://www.ansys.com/products/3d-design/ansys-spaceclaim.
8. *Second Target Station Conceptual Design Report Volume 1: Overview, Technical and Experiment Systems*. 2020. S01010000-TR0001, R00. Oak Ridge National Laboratory.
9. Mohindroo, K., T. M. Miller, and I. Remec. 2022. *Preliminary Design of a Shield Plug for Undeveloped Beamlines*. ORNL/TM-2021/2345, S04030200-TRT10000. Oak Ridge National Laboratory.

APPENDIX A. COMPUTER HARDWARE AND SOFTWARE

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These simulations were performed over several months using different versions of ADVANTG and MCNP. The output files listed in APPENDIX B identify the exact version used for each calculation. Below is a list of the modules on the STS Neutronics Group Linux computational cluster named “Saturn” (saturn.sns.gov) that were used for these simulations and the preferred (latest) version at the time this report was written is identified by an asterisk. If these simulations need to be updated, it is recommended to use the versions with an asterisk or a newer version.

- advantg/advantg3.0.3
- advantg/3.2.0
- advantg/3.2.0-HILO*

- mcnp/mcnp6.2
- mcnp/mcnp6.2mod_20211123*

APPENDIX B. LOCATION OF COMPUTATIONAL INPUT AND OUTPUT FILES

APPENDIX B. LOCATION OF COMPUTATIONAL INPUT AND OUTPUT FILES

Below is the location of all the important files used to generate the computational results discussed in this report. Large intermediate output files, like Denovo fluxes or wwinp files generated by ADVANTG are not included here. These files are located on the Saturn cluster (saturn.sns.gov) in the STS archive. The path to all these files begins will the following:

/home/sts_archive/S.04_Instrument_Sys/S.04.03_Instrument_Bunker/S.04.03.02_Shielding/preliminaryDesign/promptDoseRate/

Filename	Description
drawings/sts-2015-001_asm.3.scdoc	SpaceClaim file of the monolith, bunker, and ST11. K. Gawne combined two models; one of the monolith and bunker and a second of ST11. The ST11 model was provided by V. Graves.
drawings/bunker-rad-study.pdf	2D slice of the geometry through the monolith, bunker, and ST11. Some dimensions are included. Provide by K. Gawne.

roof/19x19/bunkerRoofN.*	MCNP6 input and output files to tally the dose rates on top of the bunker roof without the t_0 chopper in the beam discussed in Section 5.1.1.
roof/19x19/advantgN/bunkerRoof.*5	MCNP5 input files to generate WWs with ADVANTG for the dose rates on top of the bunker roof without the t_0 chopper in the beam discussed in Section 5.1.1.
roof/19x19/advantgN/advantg*in	ADVANTG input files to generate WWs for the dose rates on top of the bunker roof without the t_0 chopper in the beam discussed in Section 5.1.1.
roof/19x19.t0/bunkerRoofN.*	MCNP6 input and output files to tally the dose rates on top of the bunker roof with the simple t_0 chopper in the beam discussed in Section 5.1.2.
roof/19x19.t0/advantgN/bunkerRoof.*5	MCNP5 input files to generate WWs with ADVANTG for the dose rates on top of the bunker roof with the simple t_0 chopper in the beam discussed in Section 5.1.2.
roof/19x19.t0/advantgN/advantg*in	ADVANTG input files to generate WWs for the dose rates on top of the bunker roof with the simple t_0 chopper in the beam discussed in Section 5.1.2.
roof/19x19.t0Housing/bunkerRoofN.t2.*	MCNP6 input and output files to tally the dose rates on top of the bunker roof with the t_0 chopper in the beam, including the housing, discussed in Section 5.1.2.
roof/19x19.t0Housing /advantgN/bunkerRoof.*5	MCNP5 input files to generate WWs with ADVANTG for the dose rates on top of the bunker roof with the t_0 chopper in the beam, including the housing, discussed in Section 5.1.2.
roof/19x19.t0Housing /advantgN/advantg*in	ADVANTG input files to generate WWs for the dose rates on top of the bunker roof with the t_0 chopper in the beam, including the housing, discussed in Section 5.1.2.

wall/noBeamTrnShld/bunker-inst-cave-dose*	MCNP6 input and output files to tally the dose rates outside the bunker wall when there is no beamline shielding installed outside the bunker, discussed in Section 5.2.1.
wall/withBeamTrnShld/0*/bunkerRoofN*	Eight sets of MCNP6 input and output files to tally the dose rates outside the bunker wall when the beamline shielding is installed, discussed in Section 5.2.2.
wall/withBeamTrnShld/bunkerRoofN.comb.msht	Combined mesh tally results for the individual mesh tally results in 0*/bunkerRoofN.msht.

wall/withBeamTrnShld/advantg/bunkeRoof*5	MCNP5 input files to generate WWs with ADVANTG for the dose rates outside the bunker wall when the beamline shielding is installed, discussed in Section 5.2.2.
wall/withBeamTrnShld/advantg/advantg*in	ADVANTG input files to generate WWs for the dose rates outside the bunker wall when the beamline shielding is installed, discussed in Section 5.2.2.

floor/0*/bunkerRoofN*	Seven sets of MCNP6 input and output files to tally the dose rates below the bunker and instrument floor, discussed in Section 5.3.
floor/bunkerRoofN.comb.msht	Combined mesh tally results for the individual mesh tally results in 0*/bunkerRoofN.msht.
floor/advantg/bunkeRoof*5	MCNP5 input files to generate WWs with ADVANTG for the dose rates below the bunker and instrument floor, discussed in Section 5.3.
floor/advantg/advantg*in	ADVANTG input files to generate WWs for the dose rates below the bunker and instrument floor, discussed in Section 5.3.

combined/plug/0*/bunkerFull*	Right sets of MCNP6 input and output files to tally the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in the central plugged beamline, ST06.
combined/plug/bunkerFull.comb.msht	Combined mesh tally results for the individual mesh tally results in 0*/bunkerFull.msht.
combined/plug/advantg/bunkerFull.5	MCNP5 input files to generate WWs with ADVANTG for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in the central plugged beamline, ST06.
combined/plug/advantg/advantg.in	ADVANTG input files to generate WWs for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in the central plugged beamline, ST06.
combined/plug+1/0*/bunkerFull*	Eight sets of MCNP6 input and output files to tally the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST05 and ST07.
combined/plug+1/bunkerFull.comb.msht	Combined mesh tally results for the individual mesh tally results in 0*/bunkerFull.msht.
combined/plug+1/advantg/bunkerFull.5	MCNP5 input files to generate WWs with ADVANTG for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST05 and ST07.
combined/plug+1/advantg/advantg.in	ADVANTG input files to generate WWs for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST05 and ST07.
combined/plug+2/0*/bunkerFull*	Eight sets of MCNP6 input and output files to tally the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST04 and ST08.
combined/plug+2/bunkerFull.comb.msht	Combined mesh tally results for the individual mesh tally results in 0*/bunkerFull.msht.
combined/plug+2/advantg/bunkerFull.5	MCNP5 input files to generate WWs with ADVANTG for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST04 and ST08.
combined/plug+2/advantg/advantg.in	ADVANTG input files to generate WWs for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST04 and ST08.
combined/plug+3/0*/bunkerFull*	Eight sets of MCNP6 input and output files to tally the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST03 and ST09.
combined/plug+3/bunkerFull.comb.msht	Combined mesh tally results for the individual mesh tally results in 0*/bunkerFull.msht.

combined/plug+3/advantg/bunkerFull.5	MCNP5 input files to generate WWs with ADVANTG for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source beamlines ST03 and ST09.
combined/plug+3/advantg/advantg.in	ADVANTG input files to generate WWs for the dose rates outside the bunker when the central beamline is plugged, discussed in Section 5.4. This models the ST11 source in beamlines ST03 and ST09.
combined/totals/bunkerFull.0-*.msht	Cumulative total prompt dose rate mesh tallies for the central plugged beamline plus adjacent beamlines, ST03-ST09, discussed in Section 5.4.

inside/dose.nSrc/bunkerFull*	MCNP6 input and output files to tally the prompt total dose rates inside the bunker when all the beamlines are open and the source in each beamline is the ST11 neutron source, discussed in Section 5.5.
inside/dose.pSrc/bunerkFull*	MCNP6 input and output files to tally the prompt total dose rates inside the bunker when all the beamlines are open and the source in each beamline is the ST11 photon source, discussed in Section 5.5.

APPENDIX C. SUMMARY OF ALTERNATE BUNKER SHIELDING CONFIGURATIONS

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In the process of evaluating the shielding of the bunker wall, many configurations were considered. Several of these configurations were found to meet the 0.25 mrem/h dose rate limit for generally accessible areas at STS. Instrument Systems and STS Neutronics agreed that the configuration described in Section 4 is a simple solution that effectively meets the prescribed dose rate requirements. The remainder of APPENDIX C includes slides from a presentation that was prepared for Instrument Systems by STS Neutronics to summarize the different bunker shielding configurations that were found to meet the generally accessible dose rate requirements. They have been included here to ensure the information is saved for future reference.

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Evaluation of the bunker wall – simple wedge model, beamline 11 (ST11)

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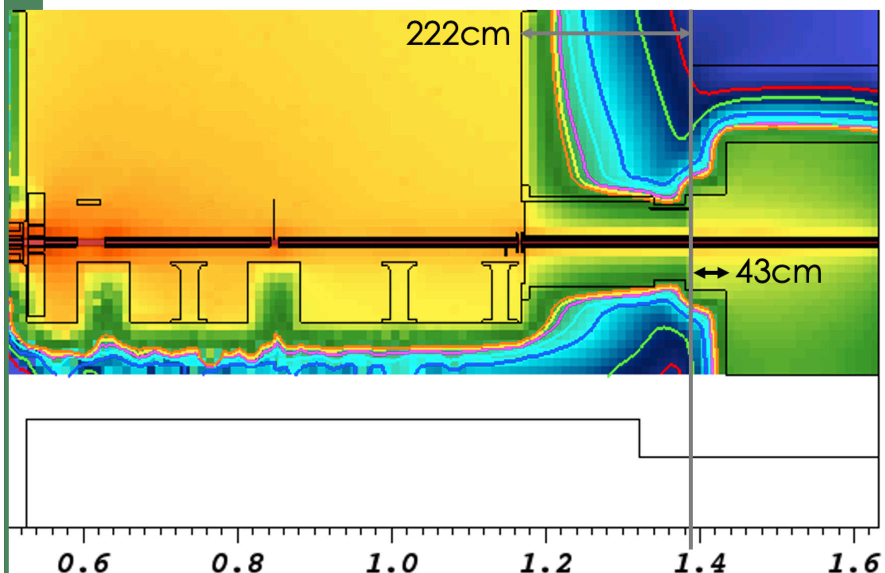
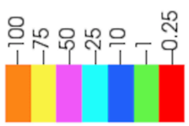
Updated November 4, 2021

Introduction

- This presentation shows results of dose rates outside the bunker wall when ALL beamlines are OPEN
  - Initial simulations without beamline shielding outside the bunker showed that the bunker wall must be closer to 300cm thick rather than 150cm
- The area outside the bunker and outside the beamline shielding is expected to be generally accessible
  - Therefore, the dose rate limit in this area will be 0.25 mrem/h
- The following slides present MCNP results of a couple different shielding configurations that meet the 0.25 mrem/h dose rate limit while trying to minimize the bunker wall thickness

Baseline Configuration





Contour line units mrem/h

The 0.25 mrem/h contour (red line) is just inside the outer bunker wall

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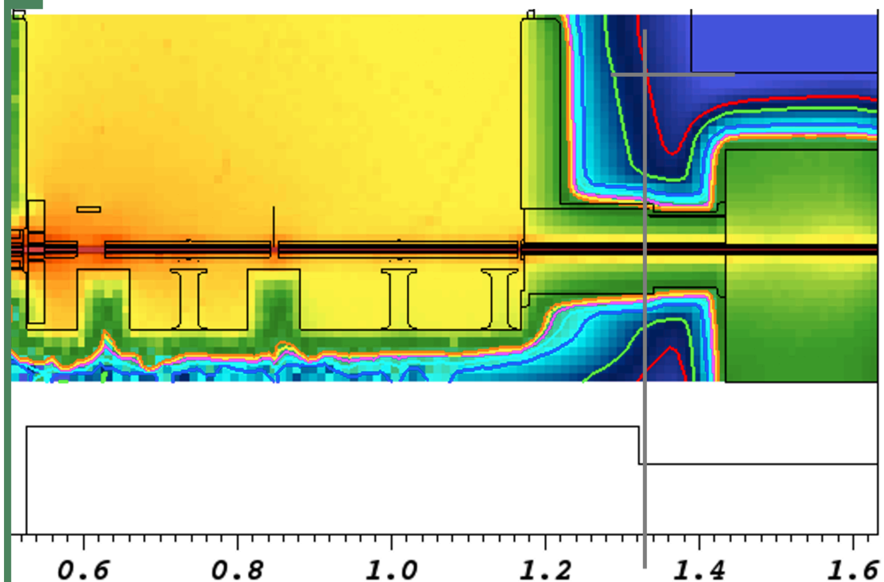
3

- The baseline configuration includes the beamline shielding outside the bunker for 2 reasons
  - This is representative of the real shielding that will be available when a beamline / instrument is installed
  - Without considering this additional shielding the bunker wall needs to be about 3m thick
- Bunker wall is 222cm of HD concrete
- Beamline shielding (HD concrete)
  - Top & sides (not shown here) are 1m thick
  - The vertical portion of the beamline shielding against the bunker wall is 43cm thick
- The guide housing is 6.35mm (0.25”) Al
- There is no liner on the inside surface of the bunker wall
- The bunker wall insert (carbon steel) does not extend into the vertical portion of the beam transport shielding

Modification 1



- Changes from baseline
  - Guide housing is 5.08cm of carbon steel
  - 50cm thick carbon steel liner added to the inside surface of the bunker wall (full azimuthal extent)
  - The bunker wall insert extended into the vertical beam transport shielding (43cm)
- 0.25 mrem/h is the red contour line
- With these changes the bunker wall thickness can be reduced about 60 cm
  - W of Figure 2 in report section 4.1 = 162cm

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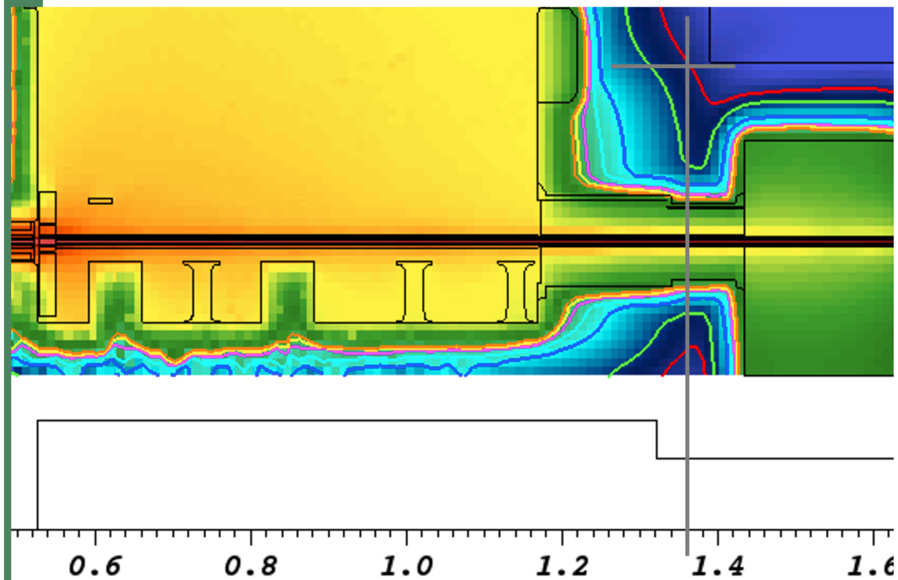
Modification 2



- Changes from baseline
  - Guide housing is 2.54cm of carbon steel
    - This is referred to as a "Corelli" style guide
  - 50cm thick carbon steel liner added to the inside surface of the bunker wall (full azimuthal extent), but only half the height of modification 1 and at the top of the bunker wall
  - The bunker wall insert extended into the vertical beam transport shielding (43cm)
  - Remove gaps / breaks in the neutron beamline
- 0.25 mrem/h is the red contour line
- With these changes the bunker wall thickness can be reduced about 30 cm
  - W of Figure 2 in report section 4.1 = 192cm
- The gaps / breaks were removed from the neutron beamline because any necessary gaps (like a t_0 chopper) would have some shielding surrounding the equipment that requires the gap

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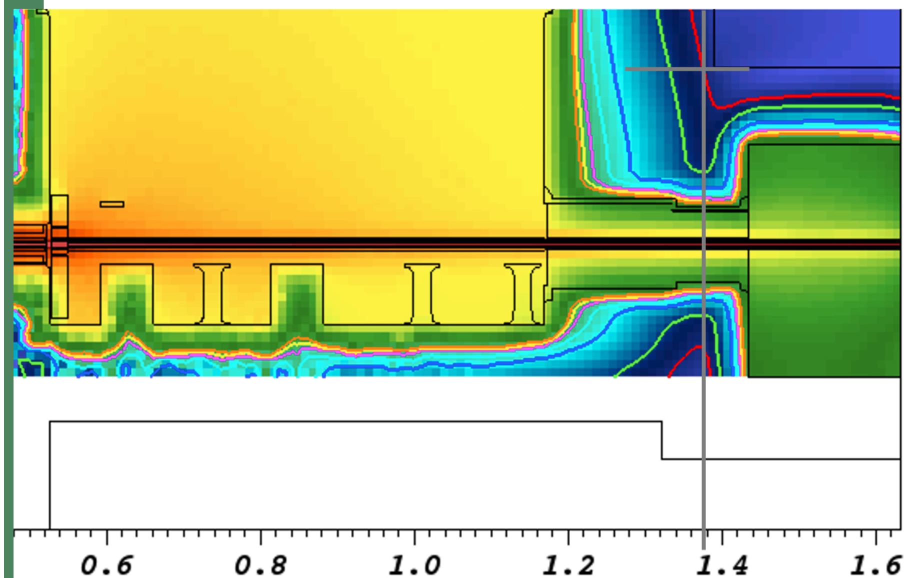
Modification 3



- Changes from baseline
  - Corelli style guide housing (2.54cm of carbon steel)
  - The bunker wall insert extended into the vertical beam transport shielding (43cm)
  - Remove gaps / breaks in the neutron beamline
- 0.25 mrem/h is the red contour line
- With these changes the bunker wall thickness can be reduced about 20 cm
  - W of Figure 2 in report section 4.1 = 202cm
- **This design plus T=202cm was selected for analysis moving forward. This design is simpler than the other modifications and similar to the conceptual design**
- Modifications 1 and 2 and others not discussed here are available if additional shielding is needed in the future

Conclusion: potential solutions to bunker wall shielding

- All these solutions assume the beamline shielding outside the bunker is 100cm thick HD concrete
  - This likely can be relaxed as you move away from the bunker
- Baseline: Al beamline guide housing, no bunker wall liner, bunker wall 222cm HD concrete
- Modification 1, bunker wall 162cm HD concrete
  - 5.08cm carbon steel beamline guide housing, 50cm thick carbon steel bunker wall liner, extended bunker wall insert
- Modification 2, bunker wall 192cm HD concrete
  - 2.54cm carbon steel beamline guide housing, 50cm thick carbon steel bunker wall liner (half height, top), extended bunker wall insert
- Modification 3, bunker wall 202cm HD concrete
  - 2.54cm carbon steel beamline guide housing, extended bunker wall insert
  - This configuration will be used moving forward