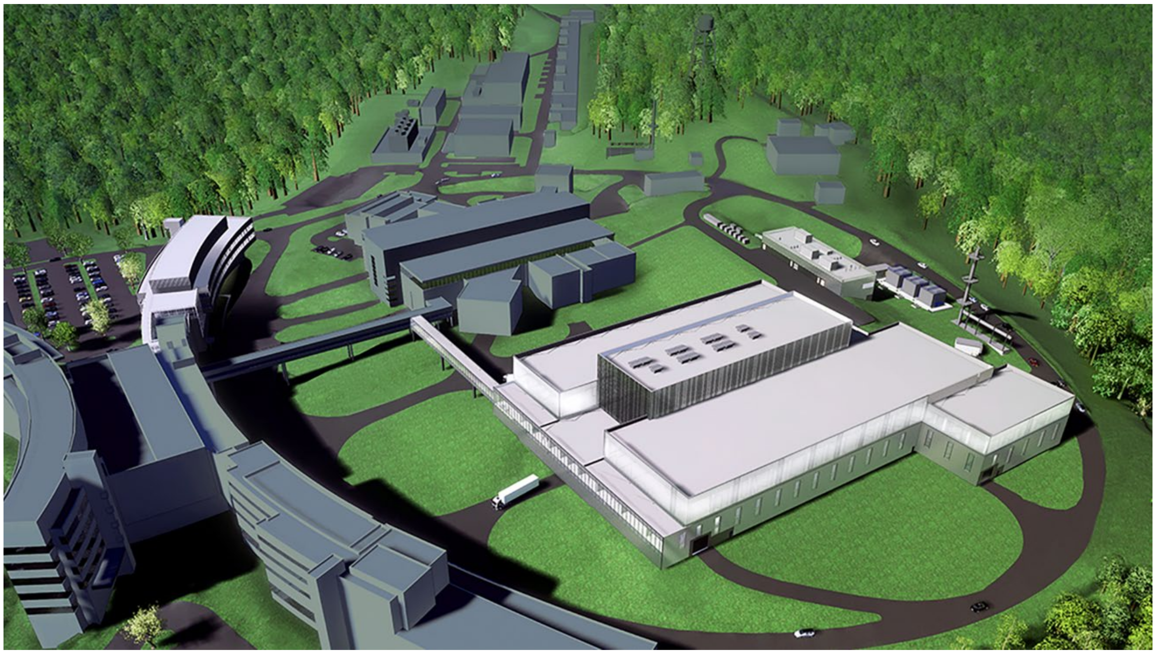
S03070000-DES10000

# Second Target Station Project: Target Station Shielding – Design Description




Chris Anton
Cam Eiland
Darren Dugan
Hogan Knott
Lukas Bearden
Mike Strong


**April 2025**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# Second Target Station Project

## TARGET STATION SHIELDING – DESIGN DESCRIPTION

Chris Anton
Cam Eiland
Darren Dugan
Hogan Knott
Lukas Bearden
Mike Strong

April 2025

Prepared by
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, TN 37831
managed by
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for the
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| 00 | Initial Release |
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| | |

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| **AIC** | Accelerator Interface Components |
| **BPVC** | Boiler and Pressure Vessel Code |
| **CAD** | Computer-Aided Design |
| **CF** | Conventional Facilities |
| **CFD** | Computational Fluid Dynamics |
| **COTS** | Commercial Off The Shelf |
| **CTE** | Coefficient of Thermal Expansion |
| **CV** | Core Vessel |
| **DAC** | Design Analysis Calculation |
| **DFMEA** | Design Failure Modes and Effects Analysis |
| **DOE** | US Department of Energy |
| **DPA** | Displacements Per Atom |
| **EOL** | End of Life |
| **ESH&Q** | Environmental Safety Health and Quality |
| **FEA** | Finite Element Analysis |
| **FEM** | Finite Element Model |
| **FTS** | First Target Station |
| **HA** | Hazzard Analysis |
| **ICS** | Integrated Control System |
| **KPP** | Key Performance Parameter |
| **LINAC** | Linear Accelerator |
| **LOF** | Life of Facility |
| **MPS** | Machine Protection System |
| **MRA** | Moderator Reflector Assembly |
| **NPH** | Natural Phenomena Hazzard |
| **ORNL** | Oak Ridge National Laboratory |
| **PB** | Proton Beam |
| **PBTA** | Proton Beam Tube Assembly |
| **PBW** | Proton Beam Window |
| **PHAR** | Preliminary Hazzard Analysis and Report |
| **PS** | Process Systems |
| **SAD** | Safety Assessment Document |
| **SNS** | Spallation Neutron Source |
| **STS** | Second Target Station |
| **TDR** | Target Drive Room |
| **TPS** | Target Protection System |
| **TS** | Target Systems |
| **TSS** | Target Station Shielding |
| **TVP** | Target Viewing Periscope |
| **WBS** | Work Breakdown Structure |

# 1. SCOPE

This document provides the preliminary design description for the Target Station Shielding (TSS) scope within the Target Systems (TS) group of the Second Target Station (STS) project. The decomposition of requirements from the TS to TSS is outlined. Additional requirements are derived from interfaces with other systems within TS as well as with other level 2 systems within the project. The design of all TSS components is described. Requirements verification is discussed, and particular emphasis is placed on requirements that have yet to be verified during preliminary design. Plans for meeting all unverified requirements during final design are discussed.

# 2. TARGET STATION CONTEXT

The purpose of the STS Project is to build the world's brightest source of cold wavelength neutrons for cutting-edge science. To achieve this goal, a solid rotating tungsten target will receive 1.3 GeV proton pulses at a rate of 15 Hz from the existing FTS LINAC, totaling 700 KW beam power and providing neutrons via spallation of the tungsten target. Two compact liquid hydrogen moderators will be located adjacent to the tungsten target, providing cold wavelength neutrons to 18 discrete instrument beamlines. Neutron guide optics facilitate transport of cold neutrons from the moderator down the neutron beamlines to beamline instrument end stations. Samples are placed in the instrument end stations in the path of the neutron beam, where detector arrays are utilized to perform cutting-edge scientific research.

The primary function of TSS is to provide radiation shielding within the monolith as necessary to protect personnel and instrumentation both inside and outside of the target monolith. Secondary functions within TSS include leak collection around the utility piping at the top of the monolith, leak collection at the bottom of the monolith, and physical protection of the target system from physical impact.

# 3. TARGET STATION SHIELDING SCOPE

The Target Station Shielding WBS element (S.03.07) will deliver five primary subsystems:

- Bulk Shielding
- Removable Shielding
- Bulk Shielding Liner
- Core Vessel Baseplate
- Pipe Pans

The complete system must meet all the requirements outlined in S0307000-SRD10000 Target Station Shielding Requirements (1) and derived sub-assembly requirements. Evidence and closure of the project are met by completion and passage of the verification in S03070000-TAC10000 Target Station Shielding Verification Plan (2).

The scope of work associated with this WBS and its components include:

- Design Engineering
- Procurement
- Fabrication Oversight
- Subsystem Acceptance Testing
- Shipment

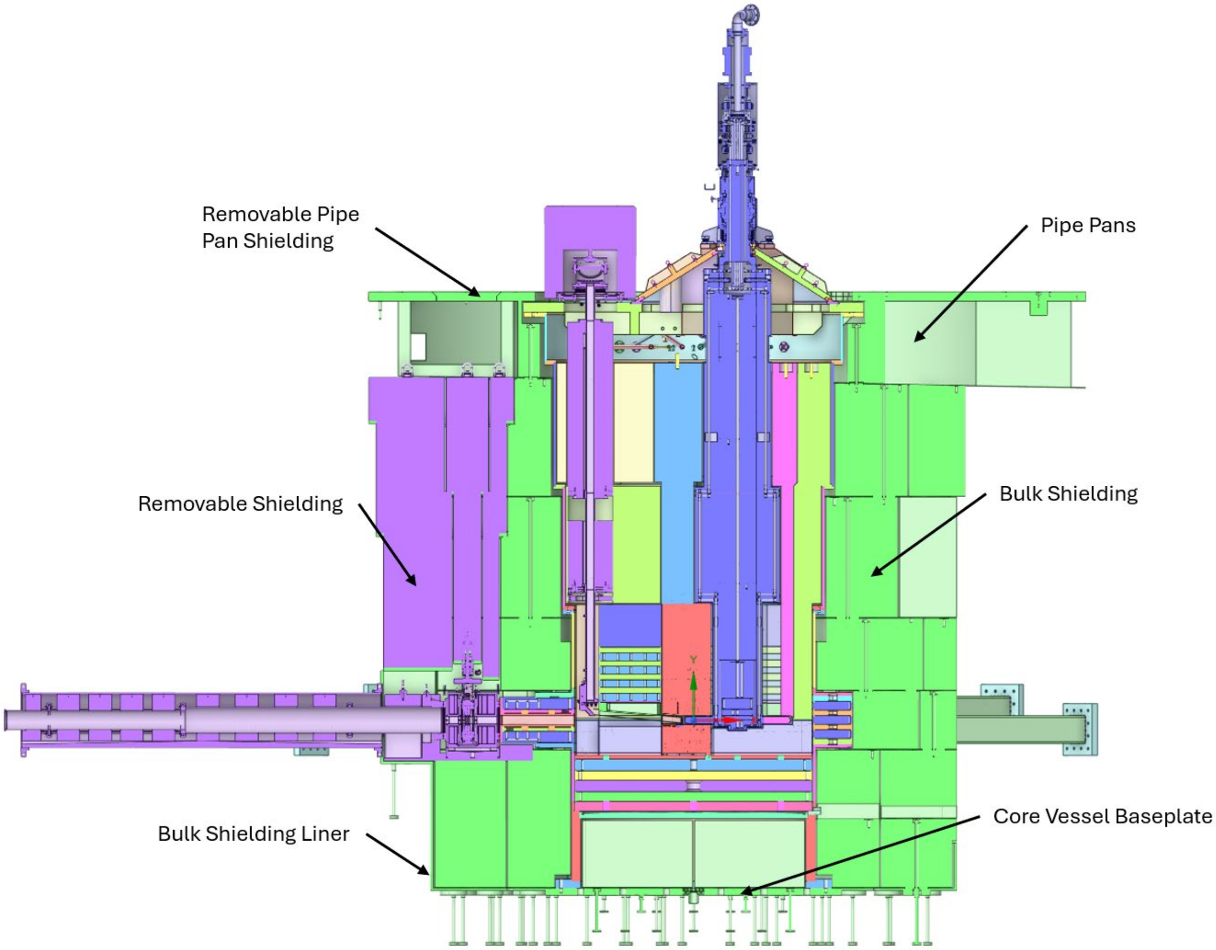



*Figure 1: Overall layout of Target Station Shielding with other Target Systems technical components included*

The scope of WBS S.03.07 ends upon receipt of all associated technical components at the STS facility but does not mark the completion of the STS capitol project. It is expected that while the TSS scope may have formally ended, the project team will continue supplying technical oversight throughout installation and commissioning. The project team must document the design such that activities related to the TSSS but outside the formal scope of S.03.07 can be performed successfully.

WBS Scope S.03.07 does not include the following:

- System engineering and integration into Target Systems
- Installation of the VS components
- Operations and planning
- Facility testing

The following subsections describe each subsystem within Target Station Shielding in greater detail.

### 3.1 Bulk Shielding Scope

The Bulk Shielding consists of all permanent target station shielding blocks. The bulk shielding fills the majority of space in between the outside profile of the Core Vessel (CV) and the inside profile of the monolith concrete. Bulk shielding blocks will be made from carbon steel painted with an anti-corrosion coating. Because the mechanical requirements for the shield blocks is not stringent, cobble or secondary plate carbon steel will be utilized to reduce the bulk shielding cost. A similar approach was utilized at the first target station (FTS) with success. All mechanical fasteners required to secure the shielding is also included in this scope of work. The bulk shielding assembly can be seen in Figure 2 below.

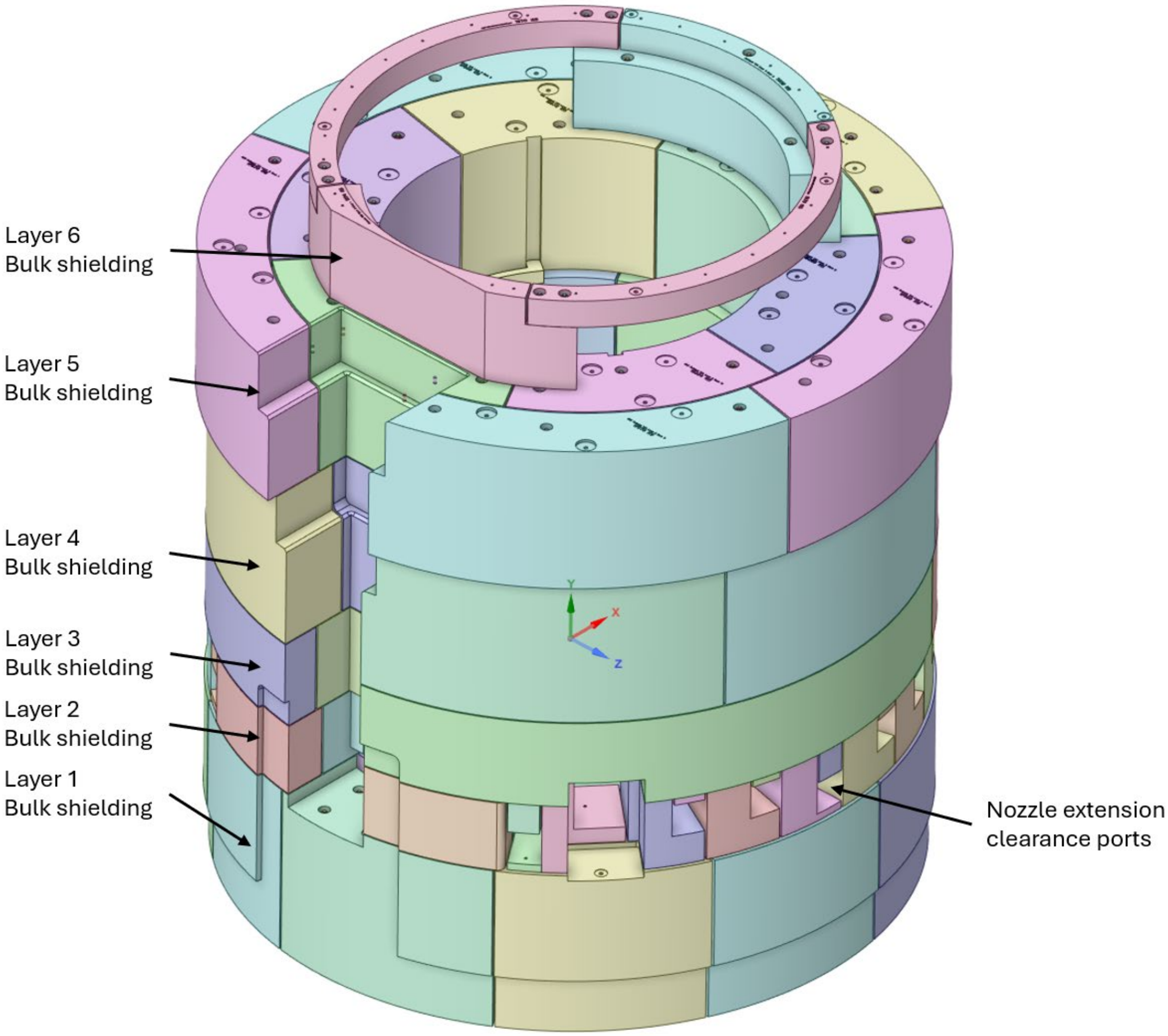



*Figure 2: Basic layout of the Bulk Shielding assembly*

### 3.2 REMOVABLE SHIELDING

The TSS removable shielding is comprised of two sets of shield blocks. The first set of shield blocks consist of three shield blocks that reside above the Proton Beam Window (PBW), PBW shielding, and Proton Beam Tube Assembly (PBTA) remote clamp. These blocks are removed vertically in order to gain access to these technical components for maintenance or repairs. The second set of removable shield blocks are a series of flat plates that reside directly above the pipe pan and form a portion of the target drive room (TDR) floor. These shield blocks shield the TDR from radiation coming from the water lines when the proton beam is on. All associated mounting hardware for the removable shield blocks are included in this scope of work. See Figure 3 below for a detailed view of the removable shielding.

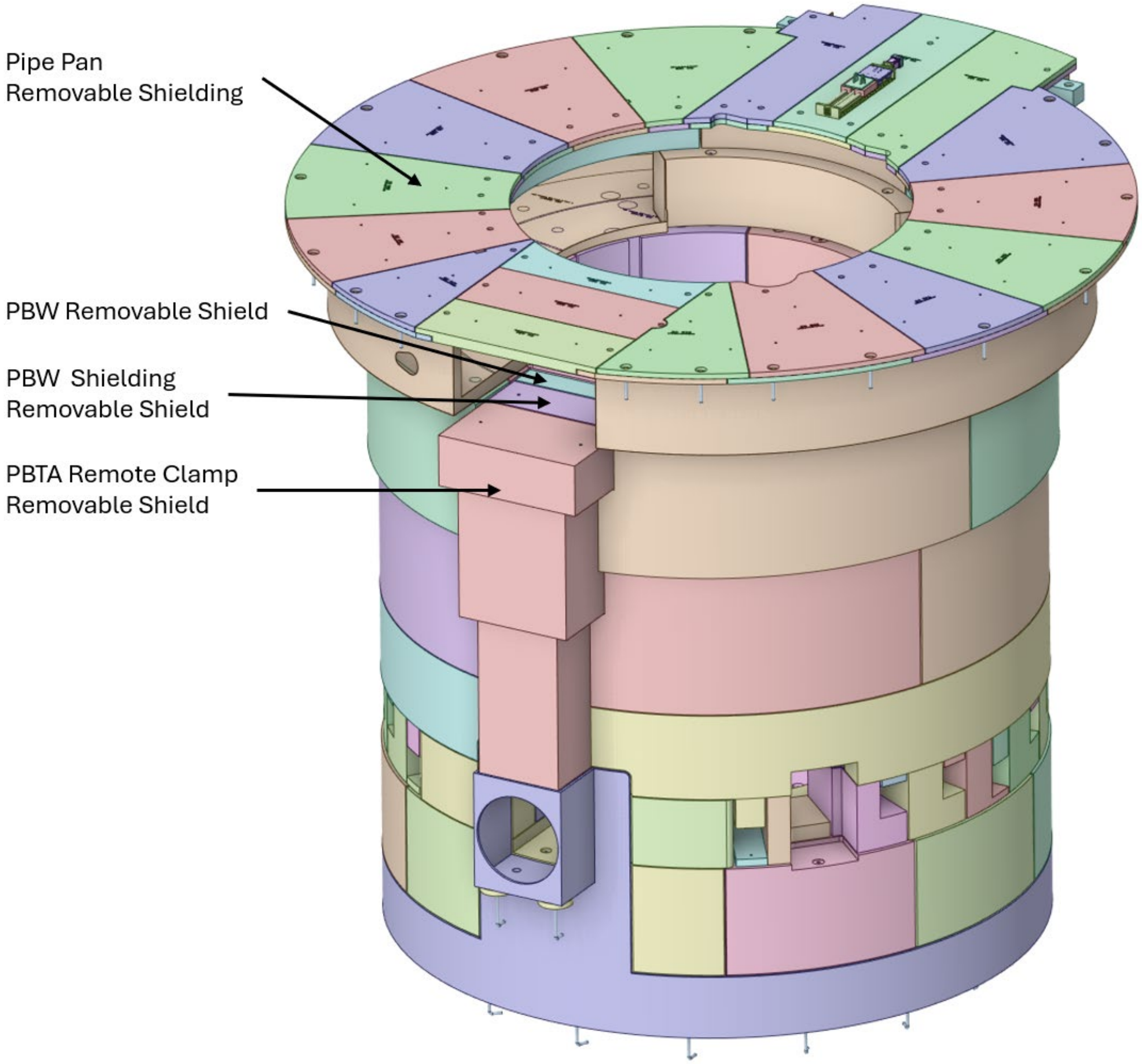



*Figure 3: CAD view of the TSS highlighting the removable shielding*

### 3.3 BULK SHIELDING LINER

The bulk shielding liner is a carbon steel liner located at the bottom of the monolith. The bulk shielding liner forms part of a leak collection system at the bottom of the monolith that prevents the concrete base of the monolith from being exposed to irradiated water from the Target System. The bulk shielding liner is welded to the CV base plate and extends to the vertical wall of the monolith concrete. The liner extends vertically upward in order to provide additional leak containment. The bulk shielding liner also extends upward to surround a cutout in the monolith concrete around the PBW and PBTA remote clamp. All required mounting and installation hardware is included in this scope of work. The Bulk shielding Liner can be seen in Figure 4 below.

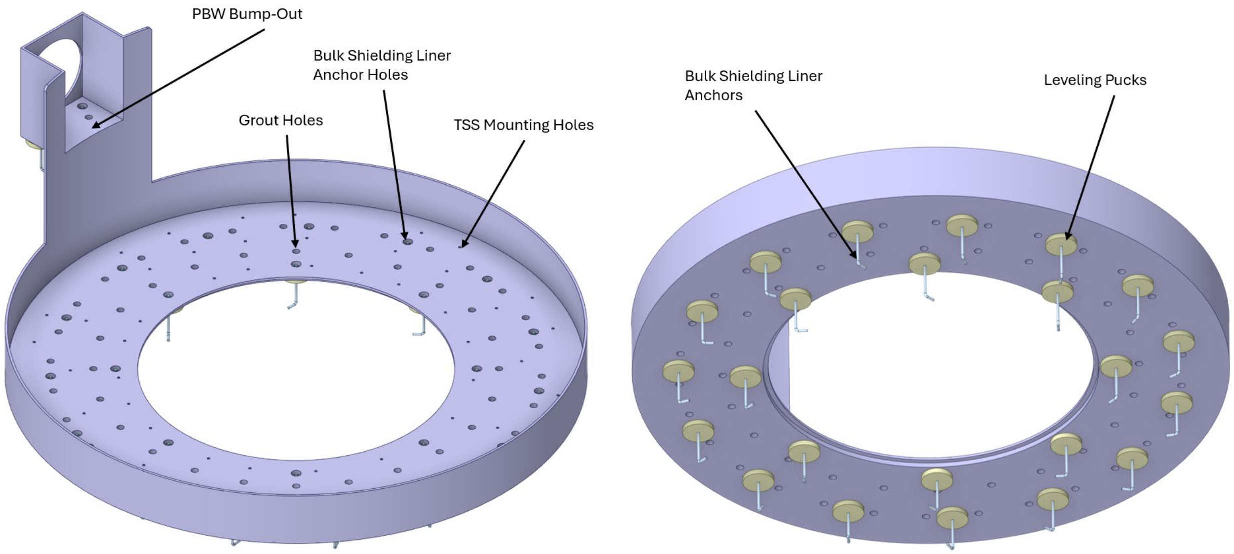



*Figure 4: CAD image showing the bulk shielding liner with anchors and shim pucks*

## 3.4 CORE VESSEL BASEPLATE

The CV Baseplate is a thick carbon steel plate that resides under the CV. The CV base is mounted to this plate, and the alignment and leveling of the CV baseplate is critical during monolith installation. The CV baseplate is welded to the bulk shielding liner, which together provide leak collection at the bottom of the monolith. A central hole for a sleeved drain pipe is located at the center of the CV baseplate, and will be welded directly to the Process Systems drain line for the monolith. Associated mounting and alignment hardware are included in this scope of work. An image of the CV baseplate can be seen in Figure 5 below.

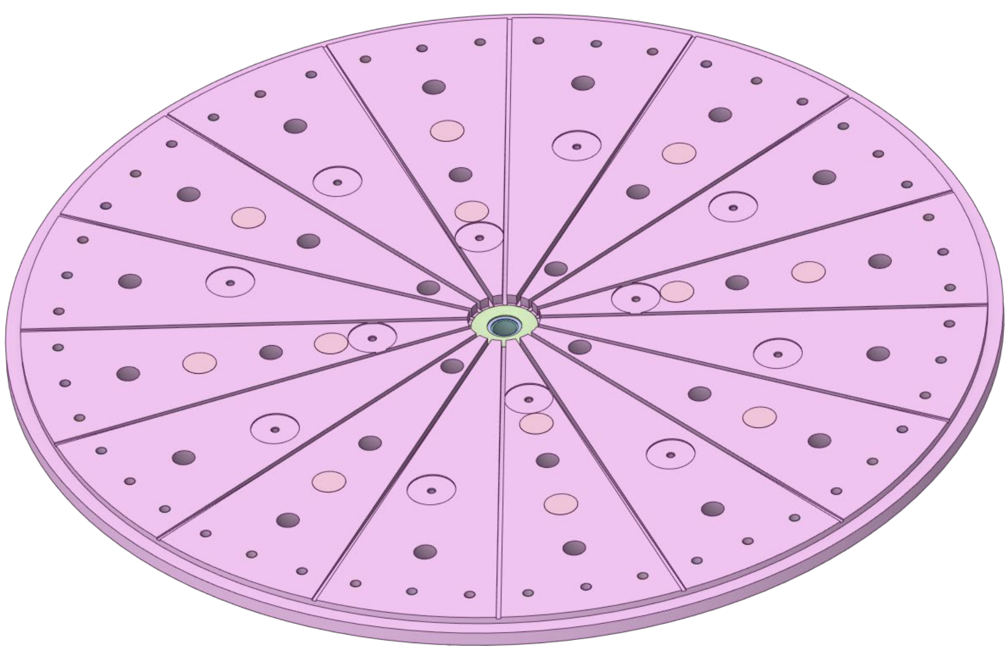


*Figure 5: CAD image showing the CV Baseplate*

### 3.5 PIPE PANS

The Pipe Pans are thin stainless steel structures at the top of the bulk shielding stack that line the recessed areas below the TDR floor that contain the water pipes and other utilities that enter the top of the CV. The pipe pans surround the outside of the CV and extend across the bulk shielding and over the concrete recess in the TDR floor. The function of the pipe pan is to provide leak collection the utility pipes residing inside the pipe pans. A pipe pan drain hole will be welded to the Process Systems leak collection pipe, which will route any leaks to the leak collection system. The pipe pan can be seen in Figure 6 below.

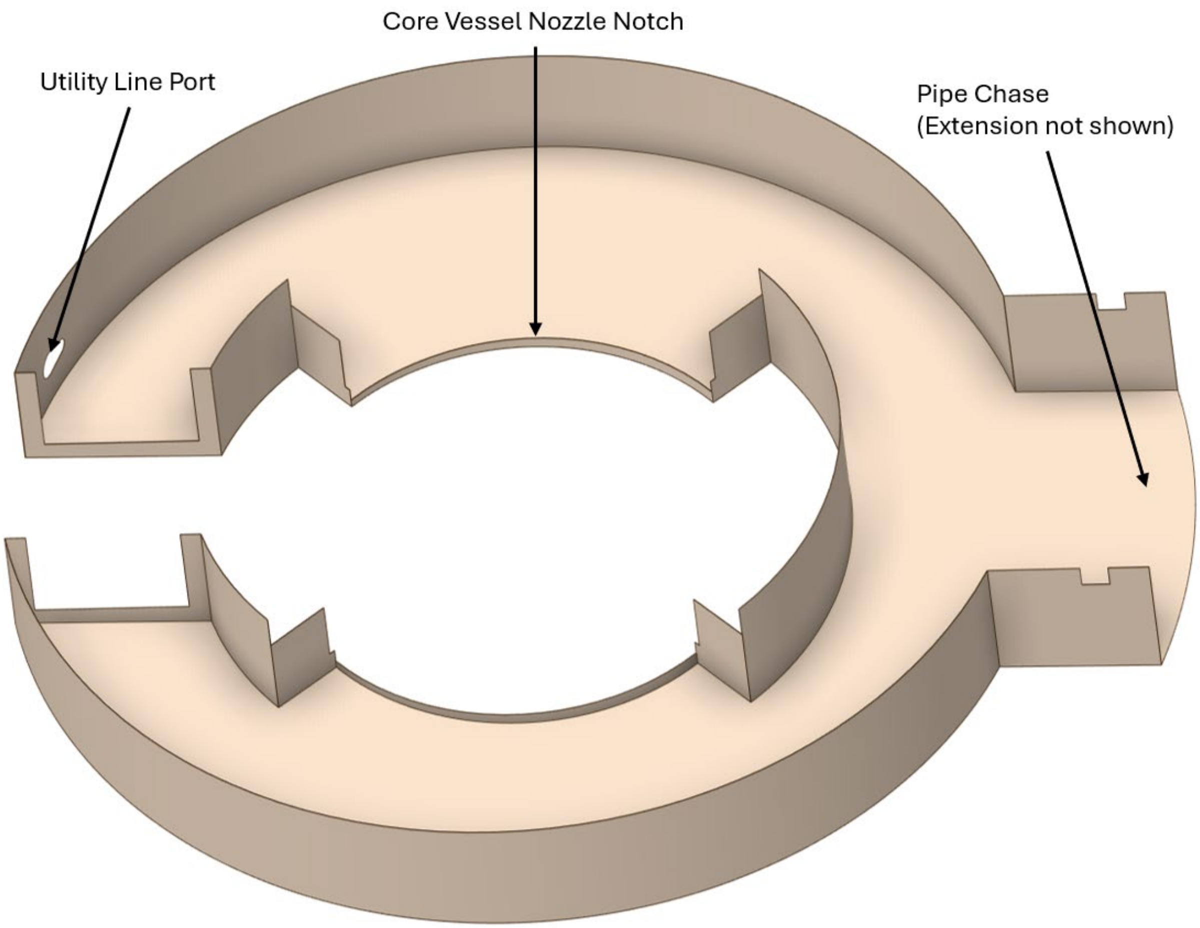



*Figure 6: CAD image showing the Pipe Pan*

## 4. INTERFACES

### 4.1 INSTRUMENT SYSTEMS INTERFACES

TSS interfaces with the monolith inserts of Instrument Systems via the monolith ports. The monolith ports consist of steel structures embedded into the monolith concrete that form openings for the nozzle extensions. The monolith port assemblies also form a depression in the outside surface of the monolith concrete to provide clearance for the downstream flanges of the nozzle extensions, monolith inserts, and monolith insert utility connections. The overall design, fabrication and installation of the monolith ports are the responsibility of Conventional Facilities (CF), with the internal profile being defined by Vessel

Systems. The interface between VS and Bunker ensures that the VS inside profile design provides the necessary clearance for the monolith insert utility lines. Interface details are described in detail in S01020500-IS0025 (3).

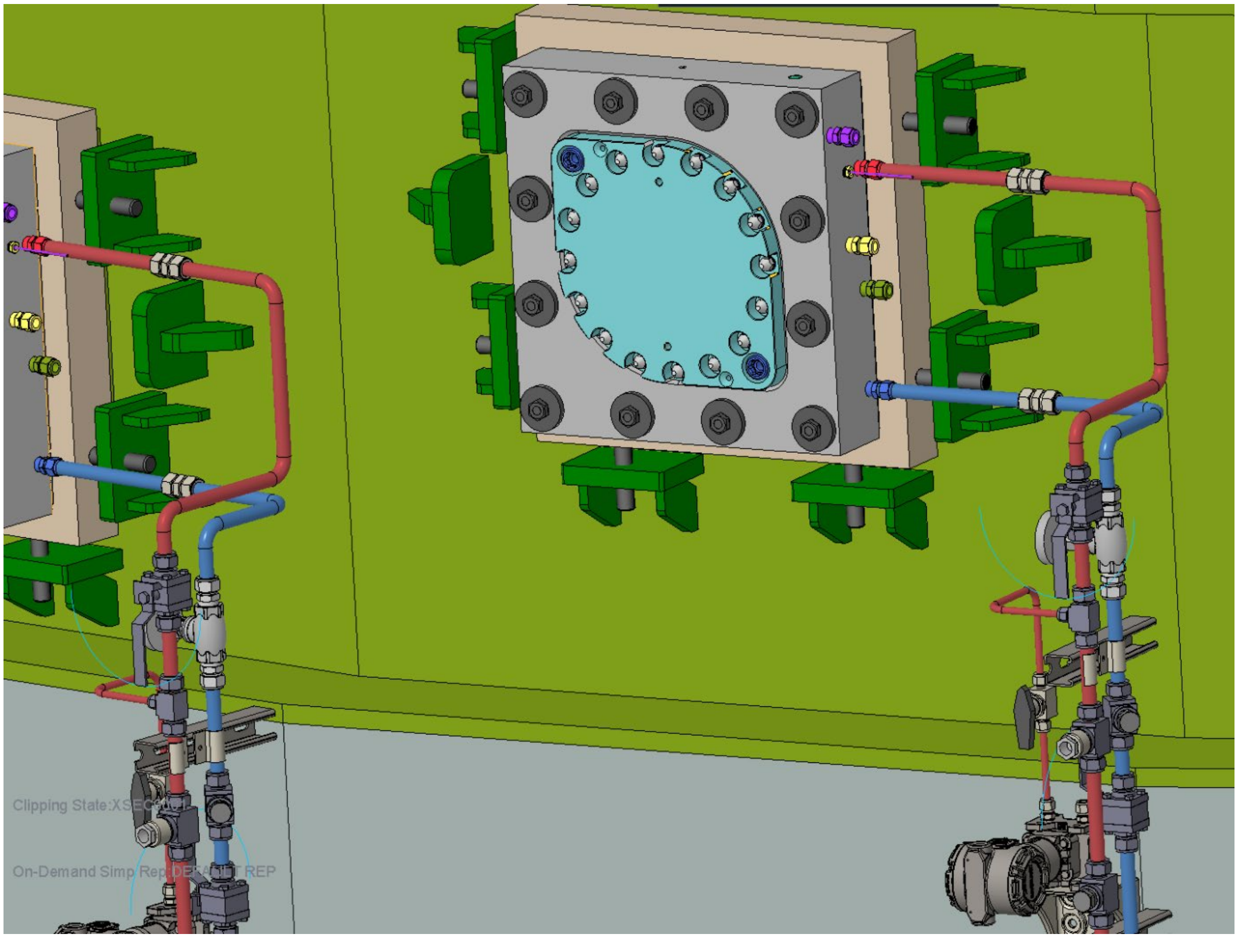


*Figure 7: CAD image of monolith port assembly, nozzle extensions and monolith inserts showing clearances for monolith insert utility lines*

## 4.2 CONVENTIONAL FACILITIES INTERFACES

The TSS to CF interface is the most involved within the TSS scope. The following list summarizes the specific interfacing areas between TSS and CF.

1. Internal monolith concrete geometry
    a. An interface drawing was generated by TSS that specifies the required geometry and tolerances of the monolith inside concrete provided by CF
2. Monolith port internal geometry
    a. An interface drawing was generated by TSS that specifies the required inside profile, position and installed tolerances of the monolith port assemblies
    b. CF is responsible for the overall design, procurement and installation of the monolith ports based on the inside profile requirements provided by TSS
3. Core vessel baseplate geometry

a. TSS has provided an interface drawing that shows the size, location and positional tolerance of the CV baseplate concrete anchors

b. The maximum loading of the concrete anchors due to bolt pretension and seismic activity is provided to CF to facilitate proper anchor design

c. Grout hole sizes and locations are provided by TSS

4. Bulk shielding liner geometry

   a. TSS has provided an interface drawing that shows the size, location and positional tolerance of the bulk shielding liner concrete anchors

   b. The maximum loading of the concrete anchors due to bolt pretension and seismic activity is provided to CF to facilitate proper anchor design

   c. Grout hole sizes and locations are provided by TSS

5. Pipe pan geometry

   a. TSS has provided interface drawings that define the concrete profile that mates to the pipe pan, as well as embedded anchor details for mounting of the pipe pan covers

The fully details of the interfaces are described in Interface Sheet S01020500-IST10064 (4).

## 4.3 INTEGRATED CONTROL SYSTEMS

TSS and ICS share an interface for instrumentation cable routing. TSS does not have any active monitoring or controls associated with its hardware, however it will be necessary to accommodate cable routing coming out of the pipe pan. Thermocouples located inside the CV are connected to ICS cabling inside the pipe pan. These cables need to safely pass through the monolith structure to reach signal processing cabinets located outside of the monolith. It is anticipated that conduit will be run underneath the TDR floor level to route these cables. Clearance around the cabling conduit will be provided in the pipe pan and top layer of the bulk shielding (if necessary). Interface details can be seen in Interface Sheet S01020500-IST10220 (5).

## 4.4 TARGET SYSTEMS INTERFACES

Target Station Shielding has a variety of interfaces with other technical component groups within Target Systems. In order to manage these interfaces, interface sheets have been developed between Target Systems level 3 groups. These interfaces are summarized below.

### 4.4.1 TSS to AIC Interfaces

TSS has interfaces with Accelerator Interface Components (AIC) Proton Beam Window (PBW), Proton Beam Window Shielding (PBWS), Proton Beam Tube Assembly (PBTA) and Target Viewing Periscope (TVP). Vertical access to the PBW, PBWS and PBTA remote clamp is required in order to carry out maintenance activities on these components. Utility line galleries will be provided between the bulk and removable TSS shielding that allow the PBW and PBWS utility lines to run up the shield stack. TSS will design, procure and install removable shield blocks that allow for vertical access to these components when removed. The PBW, PBWS and PBTA remote clamp all reside on an alignment plate that will mechanically interface with the TSS bulk shielding below this plate. Interface details are described in S01020500-IST10217 (6).

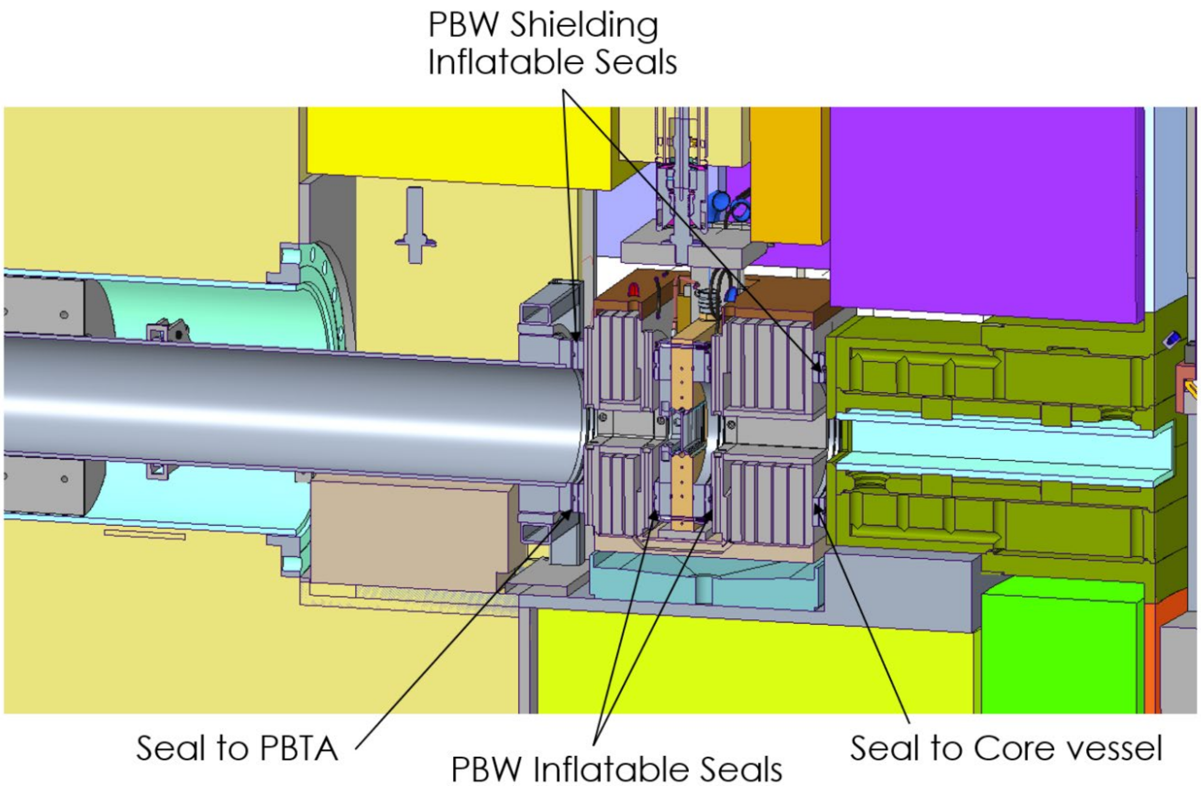



*Figure 8: Cross sectional view cut down the proton beam line showing the PBW/PBWA to Vessel Systems interfacing hardware*

### 4.4.2 TSS to Cryogenic Moderator Systems Interfaces

The Cryogenic Moderator System (CMS) has a single interfacing component with TSS, the cryogenic transfer line. The transfer line connects the CMS system to the MRA at an interfacing point at the top of the CV. The transfer line will penetrate the side wall of the pipe pan, and a clearance hole must be provided. A trench in the monolith concrete will be provided by CF, and cover plates over the trench providing an even TDR floor as well as drop protection for the transfer line will be provided by TSS. The sizing and location of the pipe pan sidewall penetration, concrete trench and trench cover are detailed in interface sheet S03000000-IST10011 (7).

### 4.4.3 TSS to Process Systems Interfaces

Process Systems is responsible for providing cooling water and gasses to all of the technical components within Target Systems. The majority of the utility lines run in and out of the TDR via the pipe pan. TSS is responsible for the design of the pipe pan space, which is defined by the profile of the top layer of bulk shielding blocks as well as the monolith concrete profile. The pipe pan lines this utility clearance space, and is designed and provided by TSS. The physical layout of the pipe pan, pipe pan covers, and pipe pan drainage connections are all interfaces between TSS and PS. The large target water supply and return lines are supported by structures designed by Process Systems, and may require attachment features located on the pipe pan covers. These interfaces are formally defined in interface sheet S03000000-IST10005 (8).

### 4.4.4 TSS to Remote Handling Interfaces

TSS contains a number of removable components that require removal via remote handling in order to limit radiation dosage to workers. The TSS components that require remote handling include the removable shield blocks above the AIC components (Qty 3) and the pipe pan removable hatches. Interface details are described in Interface Sheet S03000000-IST10007 (9).

# 5. REQUIREMENTS

## 5.1 GENERAL REQUIREMENTS

*General Target Station Shielding Requirements*

### 5.1.1 Carbon Steel Temperature Limit (CodeBeamer reference: 6138)

*Target Station Shielding carbon steel structures should have a maximum operating temperature of 200 C.*

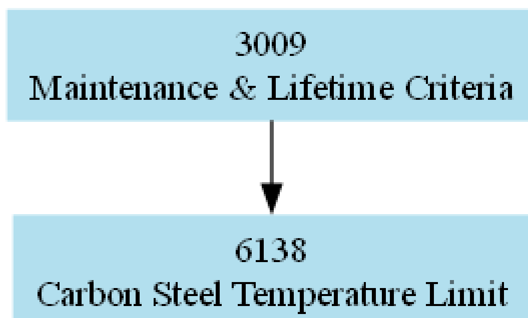



*Figure 9: Requirement 6138 source and elaboration*

A carbon steel maximum operating temperature was selected based on the STS materials handbook (10).

## 5.2 SAFETY REQUIREMENTS

*Requirements derived from the Preliminary Hazzard Analysis Report* (11).

### 5.2.1 Non-Flammable Shielding (CodeBeamer reference: 6982)

*Target Station Shielding components shall be made of non-flammable materials.*

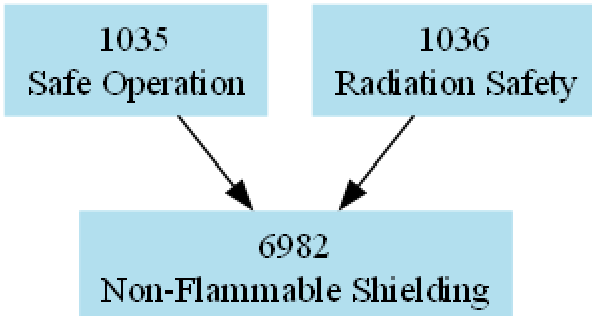



*Figure 10: Requirement 6982 source and elaboration*

The use of non-flammable materials within the monolith significantly reduces the impact of internal or external fires on the overall target system.

### 5.2.2 Protect Cryogenic Transfer Lines (CodeBeamer reference: 6983)

*Target Station Shielding shall not permit motion of the shielding to cause the cryogenic transfer lines to release Hydrogen under SDC2 seismic conditions.*

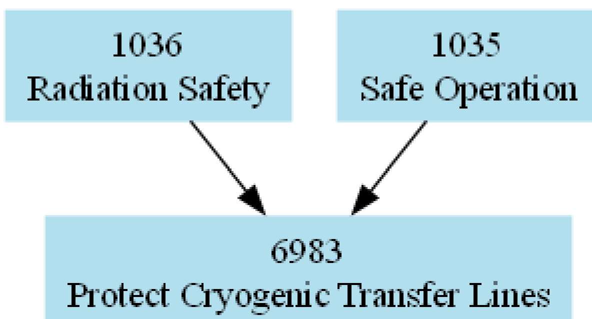



*Figure 11: Requirement 6983 source and elaboration*

One of the primary hazards within the monolith is a release of hydrogen into the TDR due to a seismic event. Target Station Shielding must help ensure that the cryogenic transfer lines will not be damaged by moving or shifting shield blocks or other hardware during a seismic event in order to prevent an unexpected release of hydrogen into the TDR.

### 5.2.3 Shielding Anchoring (CodeBeamer reference: 6984)

*The Target Station Shielding shall be anchored in such a way to limit motion of the bulk shielding relative to the monolith floor or relative to different shielding layers to < 0.1 mm under SDC Level 2 seismic loads.*

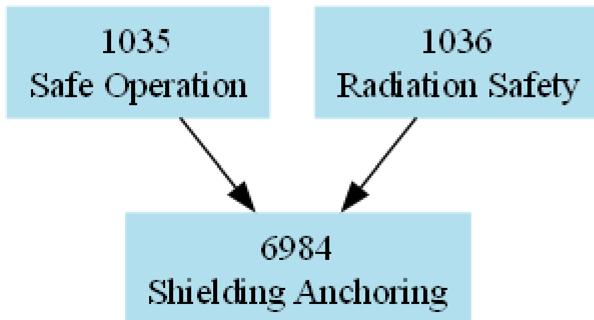



*Figure 12: Requirement 6984 source and elaboration*

Proper alignment of the Target Station Shielding is important to proper operation of the target system. The Proton Beam Window is supported off of the target station shielding, so shifts in position of the shielding could result in reduced system performance. Significant shifts of the target station shielding within the monolith also run the risk of permanent damage to the CV, Proton Beam Window, Proton Beam Window Shielding, Proton Beam Tube Assembly or nozzle extensions. For all of these reasons, it is critical that the design limits seismic motion of the target station shielding components to the greatest extent possible.

### 5.2.4 Radiation Shielding Performance (CodeBeamer reference: 6986)

*Target Station Shielding, along with the other Target Systems components in the Monolith and Target Drive Room, shall not prevent necessary operations in the high bay due to radiation dose.*

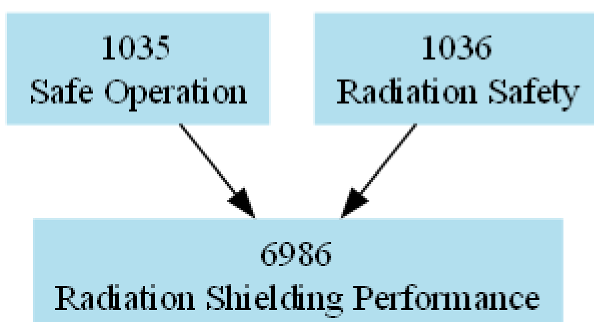



*Figure 13: Requirement 6986 source and elaboration*

Target Station Shielding forms part of a radiation shielding strategy that limits radiation exposure to workers during facility operations. Acceptable radiation limits in the high bay, instrument bunker and hot process vault are described in the STS radiation safety policy and plan (12). The design of TSS components contributes significantly to the overall radiation shielding of the monolith. A variety of design aspects including shielding material selection, shielding thickness, shielding geometry and gaps between hardware impact the radiation levels seen in the target building both when the facility is active and when the facility is shut down. The overall efficacy of the radiation shielding of TSS components in combination with other monolith components will be validated through neutronics analysis.

### 5.2.5 Target protection during LOCA (CodeBeamer reference: 6987)

*Target Station Shielding hardware shall assist in keeping the target temperature below 800C under loss of cooling event.*

*Note: The shielding acts as a thermal sink that helps maintain target temperatures of < 800 C during a loss of cooling event.*

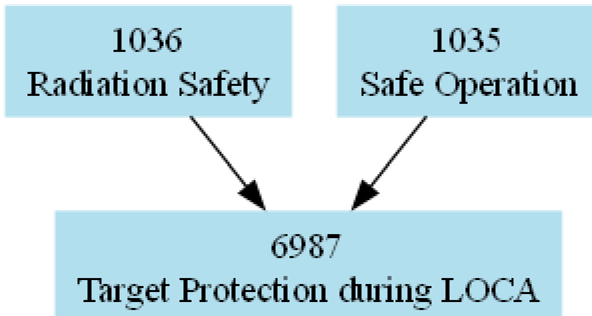



*Figure 14: Requirement 6987 source and elaboration*

By maintaining a low shield block temperature adjacent to the target during a loss of cooling event, the shield block acts as a heat sink that protects the target from overheating.

### 5.2.6 Target Temperature Limit During Facility Fire (CodeBeamer reference: 6977)

*Monolith shielding shall assist in keeping target temperature below 800C under reasonable fire conditions.*

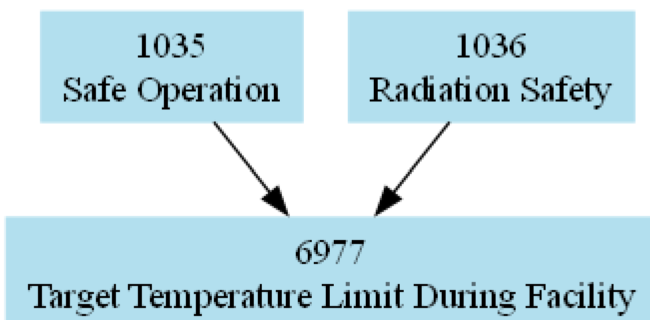



*Figure 15: Requirement 6977 source and elaboration*

The target must remain below 800C in order to avoid melting of the target and release of radioactive products throughout the CV. The large thermal mass of the Target Station Shielding help keep the target assembly under this temperature.

#### 5.2.7 Impact Damage Protection (CodeBeamer reference: 6978)

*The Monolith steel shielding shall protect the Target Feet and Moderator Reflector Assembly from physical impact damage when installed and in the operational configuration.*

*Note: Monolith steel shielding does not protect Moderator Reflector Assembly or Target feet that have been removed from their home positions within the monolith.*
*Note: Monolith steel shielding provides less protection when removable shielding is not in place during maintenance activities.*

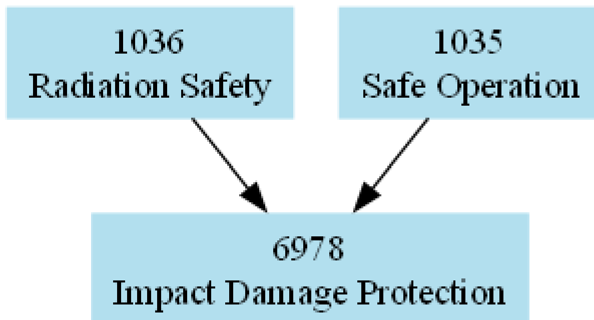



*Figure 16: Requirement 6978 source and elaboration*

Target Station Shielding provides a substantial amount of carbon steel shielding between the target feet and MRA and the exterior of the monolith. This shielding provides physical impact protection from aircraft, vehicles and tornado borne missiles that could strike the monolith. Full protection is only offered when the Target System is in operational configuration with all shielding in place. When shielding is removed for maintenance activities including proton beam window changeout, the protection offered is reduced. Target Station Shielding is not responsible for protecting components that have been removed from their home position within the monolith from physical impact damage.

#### 5.2.8 Bulk Shielding Liner Leak Collection (CodeBeamer reference: 6979)

*A bulk shielding liner shall capture water leaks at the bottom of the Monolith and drain to a connected leak collection system.*

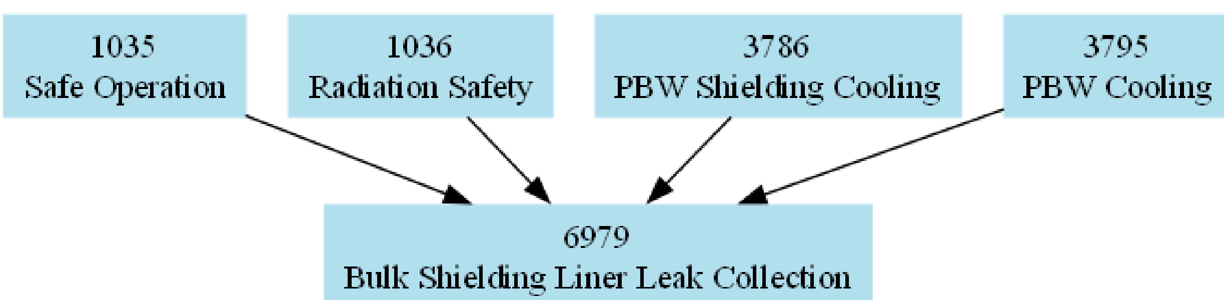



*Figure 17: Requirement 6979 source and elaboration*

All water that enters the monolith becomes radioactive through the production of tritium in the water as well as suspended particles that can become radioactive when exposed to the spallation environment. Any water that leaks from a water cooled component inside the monolith and outside the CV and pipe pans must be collected and routed to an appropriate drainage tank that can handle the activated nature of the water.

#### 5.2.9 Pipe Pan Drain (CodeBeamer reference: 6980)

*Pipe Pans shall capture water leaks in the Target Drive Room and drain to a connected leak collection system.*

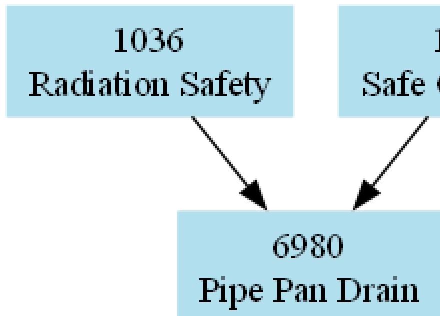



*Figure 18: Requirement 6980 source and elaboration*

All water that enters the monolith becomes radioactive through the production of tritium in the water as well as suspended particles that can become radioactive when exposed to the spallation environment. Any water that leaks from the water feed and return lines that connect to the Core Vessel must be collected and routed to an appropriate drainage tank that can handle the activated nature of the water.

### 5.3 TSS-CMA INTERFACE

*Requirements derived from Interface Sheet S03000000-IST10011* (7).

#### 5.3.1 Transfer Line Clearance (CodeBeamer reference: 7201)

*Target Station Shielding shall provide an unobstructed path through the pipe pan for the hydrogen transfer line per Interface Sheet S03000000-IST10011* (7).

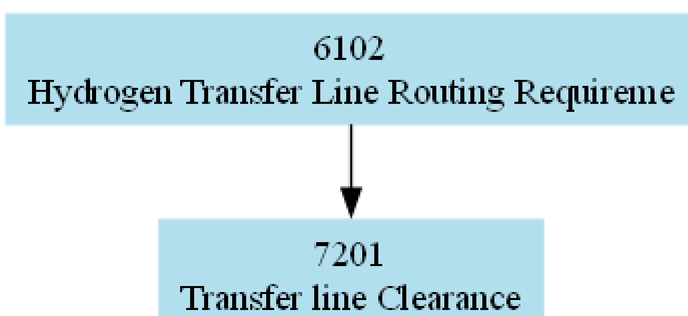



*Figure 19: Requirement 7201 source and elaboration*

The hydrogen transfer line must be protected from physical damage during the life of the facility in order to avoid accidental discharge of flammable hydrogen. Physical clearance of all hardware surrounding the transfer line is one way of ensuring that the line is not damaged during both normal operations.

### 5.3.2 Transfer Line Seismic Protection (CodeBeamer reference: 7202)

*Target Station Shielding shall prohibit the pipe pan from damaging the hydrogen transfer line during a seismic event per Interface Sheet S03000000-IST10011* (7).

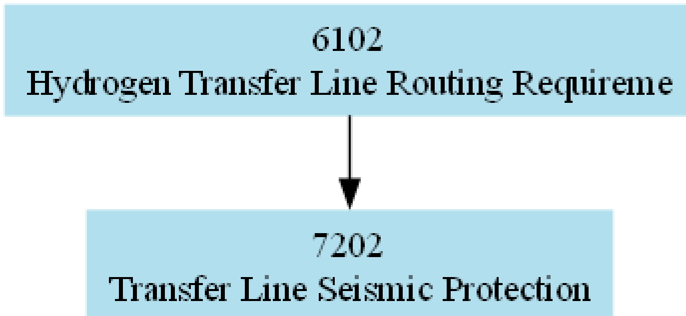



*Figure 20: Requirement 7202 source and elaboration*

The hydrogen transfer line must be protected from physical damage during a seismic event to avoid accidental discharge of flammable hydrogen. All hardware surrounding the transfer line must be designed to avoid motion that causes damaged to the transfer line during a seismic event.

### 5.3.3 Transfer Line Drop Damage Protection (CodeBeamer reference: 7203)

*Target Station Shielding shall provide removable covers above the hydrogen transfer line to protect it from damage due to falling objects within the target drive room per Interface Sheet S03000000-IST10011* (7).

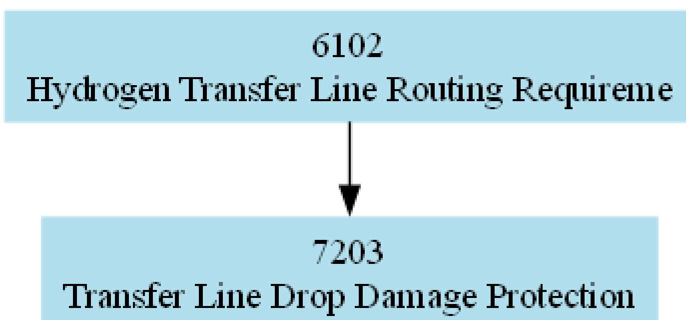



*Figure 21: Requirement 7203 source and elaboration*

The hydrogen transfer line must be protected from physical damage due to falling objects to avoid accidental discharge of flammable hydrogen. Target Station Shielding shall protect the exposed portion of the transfer line that resides within the pipe pan via protective covers over the pipe pan area.

#### 5.3.4 Transfer Line Support Features (CodeBeamer reference: 7204)

*Target Station Shielding shall provide features in the pipe pan for mounting of transfer line supports per S03000000-IST10011* (7).

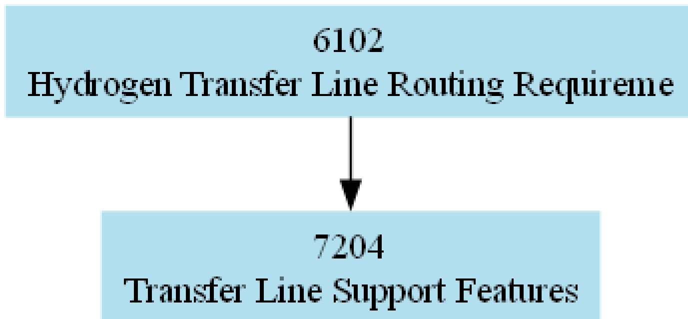



*Figure 22: Requirement 7204 source and elaboration*

The hydrogen transfer line requires support at regular intervals. It may be necessary to locate one of these supports inside the pipe pan. If this is the case, TSS will provide the necessary mounting features to accommodate this support. The CMS team will design and procure the support.

### 5.4 TSS-AIC INTERFACE

*Requirements derived from Interface sheet IST01020500-IST10217*

#### 5.4.1 AIC Support (CodeBeamer reference: 7207)

*Target Station Shielding shall align and support the baseplate that the Proton Beam Window, Proton Beam Window Shielding and Proton Beam Tube Assembly remote clamp are mounted to. Gravitational and seismic loads will be supported while maintaining the alignment tolerances specified in Interface Sheet S01020500-IST10217* (6).

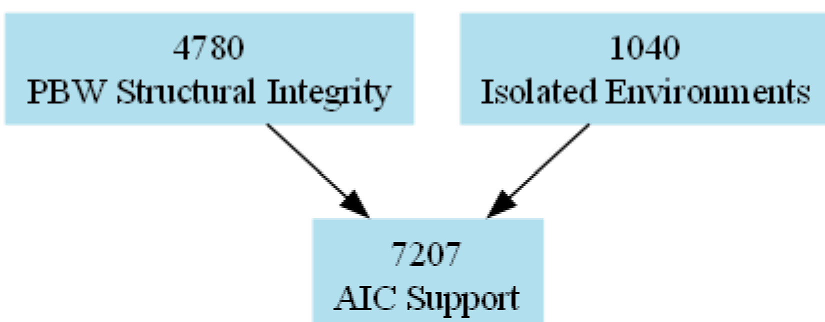



*Figure 23: Requirement 7207 source and elaboration*

Alignment of the proton beam window assembly is critical to the successful operation of the Target system. The PBW is designed to maximize the amount of protons that impact the target while maintaining an environmental seal between the CV and the accelerator environments. Misalignment of the PBW could reduce the amount of protons impacting the target, reducing the overall brightness of the target system. The TSS provides both mechanical support and alignment of the PBW and associated hardware.

### 5.4.2 Proton Beam Window Access (CodeBeamer reference: 7211)

*Target Station Shielding shall allow access to the Proton Beam Window within 8 hours per Interface Sheet S01020500-IST10217* (6).

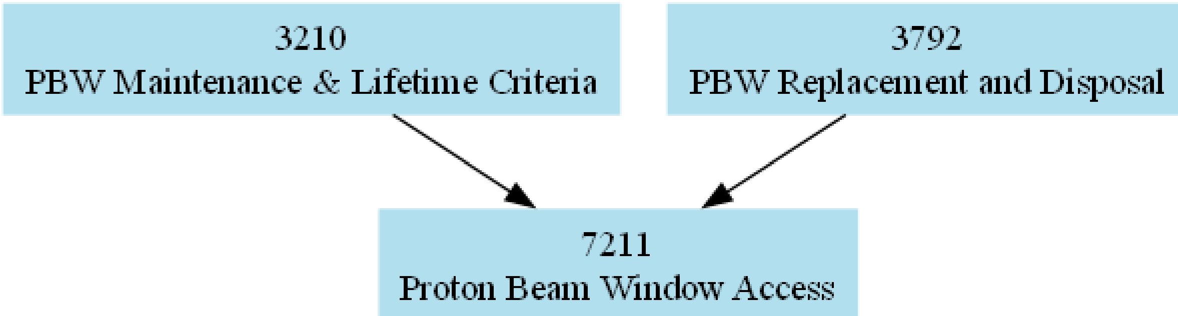



*Figure 24: Requirement 7211 source and elaboration*

The PBW is not a life of facility component and will need to be changed periodically. PBW removal is a relatively involved process that will be performed during a long outage of the STS, but where possible steps should be taken to reduce the overall time required to perform the PBW change out. In order to gain access to the PBW, the PBW removable shield block is vertically removed. The removal of this component is straight forward and should be accomplished in a single 8 hour shift.

### 5.4.3 Proton Beam Window Shielding Access (CodeBeamer Reference: 7212)

*Target Station Shielding shall allow access to the Proton Beam Window Shielding Assembly within 24 hours per Interface Sheet S01020500-IST10217* (6).

*Note: The clock starts when the removable shielding removal above the Proton Beam Window Shielding assembly begins.*

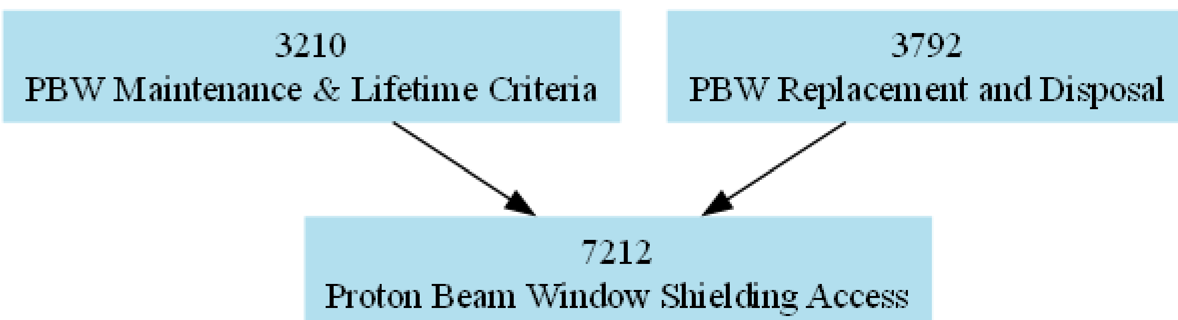



*Figure 25: Requirement 7212 source and elaboration*

The PBW shielding is not a life of facility component and will need to be changed periodically. PBW shielding removal is a relatively involved process that will be performed during a long outage of the STS, but where possible steps should be taken to reduce the overall time required to perform the PBW shielding change out. In order to gain access to the PBW shielding, the PBW and PBW shielding removable shield blocks are vertically removed. The removal of these components is straight forward and should be accomplished in three 8 hour shifts.

#### 5.4.4 Utility Line Clearance (CodeBeamer reference: 7213)

*Target Station Shielding shall provide clearance for Proton Beam Window and Proton Beam Window Shielding utility lines per Interface Sheet S01020500-IST10217* (6).

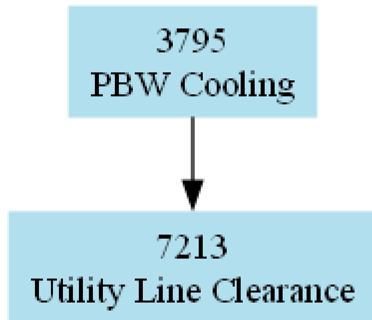



*Figure 26: Requirement 7213 source and elaboration*

Vertical extraction of the PBW and PBW shielding is required during planned maintenance events or in the event of a premature component failure. TSS must provide a clear path of vertical extraction and reinstallation of all PBW and PBW shielding hardware once the corresponding TSS removable shield blocks are removed.

#### 5.4.5 Proton Beam Tube Assembly Remote Clamp Access (CodeBeamer reference: 7214)

*Target Station Shielding shall allow access to the Proton Beam Tube Assembly remote clamp within 24 hours per Interface Sheet S01020500-IST10217* (6).

*Note: The clock starts when the removable shielding removal above the Proton Beam Tube Assembly begins.*

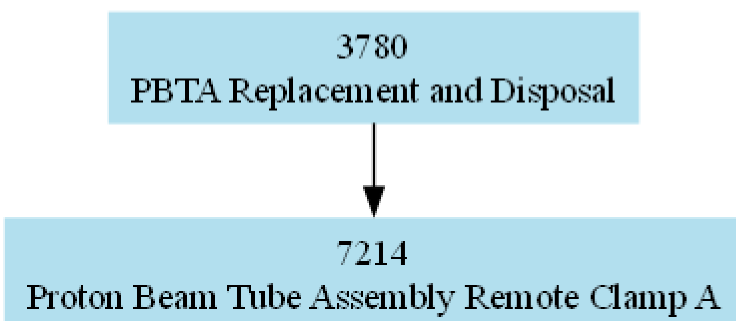



*Figure 27: Requirement 7214 source and elaboration*

The PBTA shielding is nominally a life of facility component. However, a significant proton beam excursion could damage the PBTA in a way that would require its replacement. Access to the PBTA remote clamp on the downstream side of the PBTA is required for PBTA removal. Access to the remote clamp must be provided via a removable TSS shield block. Removal of this shield block requires the removal of the PBW and PBW shielding shield blocks. The removal of these components is straight forward and should be accomplished in three 8 hour shifts.

### 5.4.6 Proton Beam Tube Assembly Clearance (CodeBeamer reference: 7215)

*Target Station Shielding shall provide clearance in the bulk shielding liner for the Proton Beam Tube Assembly per Interface Sheet S01020500-IST10217* (6).

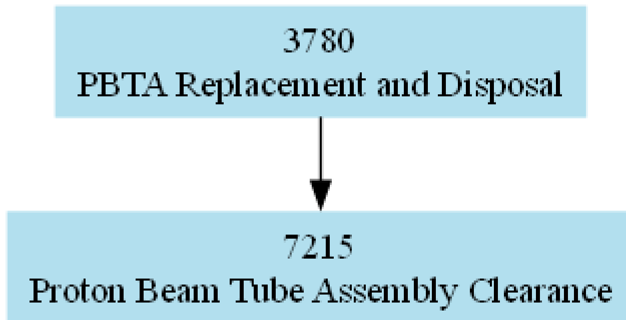



*Figure 28: Requirement 7215 source and elaboration*

The PBTA penetrates the bulk shielding liner. Sufficient clearance around the PBTA is required to protect the PBTA from physical damage during normal thermal expansion during facility operation as well as during a seismic event.

### 5.4.7 Target Viewing Periscope Clearance (CodeBeamer reference: 7813)

*Target Station Shielding shall provide appropriate clearance around the Target Viewing Periscope assembly per Interface Sheet S01020500-IST10217* (6).

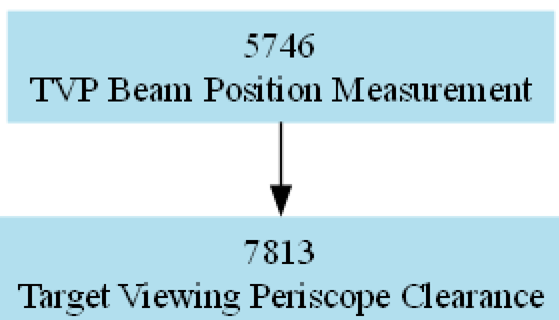



*Figure 29: Requirement 7813 source and elaboration*

The TVP optical tubes travel across the TSS removable shield blocks above the pipe pan. TSS must ensure that no TSS hardware encroaches on the keep out zones surrounding the TVP optical tubes.

## 5.5 TSS-PROCESS SYSTEMS INTERFACE

*Requirements derived from Interface Sheet S03000000-IST10005* (8).

### 5.5.1 Utility Pipe Clearance (CodeBeamer reference: 7217)

*Target Station Shielding shall supply sufficient clearance for utility piping inside the pipe pan per Interface Sheet S03000000-IST10005* (8).

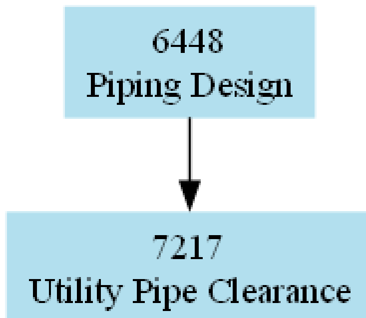



*Figure 30: Requirement 7217 source and elaboration*

The majority of water-cooled components residing inside the CV are cooled via Process Systems' water lines that penetrate the side wall of the CV from the pipe pan. Several gas lines are also ran through the pipe pan to serve technical systems residing inside the CV. The pipe pan geometry is a combination of the CV, TSS and concrete geometries and is defined by TSS. TSS must ensure that sufficient space is allotted within the pipe pans to accommodate the utility supply and return lines designed by Process Systems.

### 5.5.2 Pipe Pan Drainage (CodeBeamer reference: 7218)

*Target Station Shielding shall slope the bottom of the pipe pan a minimum of 1 degree downward slope towards the hot process vault and provide an interfacing feature for water routing to the leak collection system per Interface Sheet S03000000-IST10005* (8).

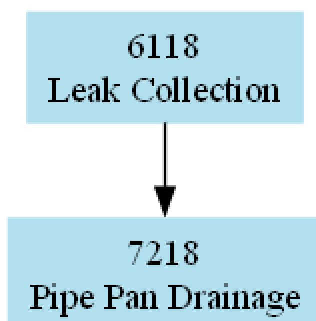



*Figure 31: Requirement 7218 source and elaboration*

Any water that is collected in the pipe pan must be routed in the downstream direction to a drainage pipe at the far end of the pipe pan. A small slope will be incorporated into the pipe pan to route the majority of any water leaks to the drainage pipe for proper collection by Process Systems.

### 5.5.3 Pipe Pan Supports (CodeBeamer reference: 7219)

*Target Station Shielding shall provide features within the pipe pan for mounting of pipe supports designed and provided by Process Systems per Interface Sheet S03000000-IST10005* (8).

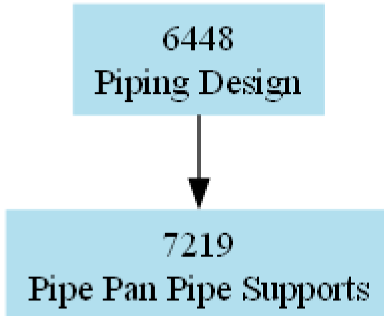



*Figure 32: Requirement 7219 source and elaboration*

The utility lines running through the pipe pan will require supports at periodic intervals. Process Systems will design and install any required pipe supports. Target station shielding will provide any required mounting interface hardware needed to secure the pipe supports to the pipe pan.

### 5.5.4 Utility Pipe Access (CodeBeamer reference: 7220)

*Target Station Shielding shall allow for access to the utility pipes contained within the pipe pan per Interface Sheet S03000000-IST10005* (8).

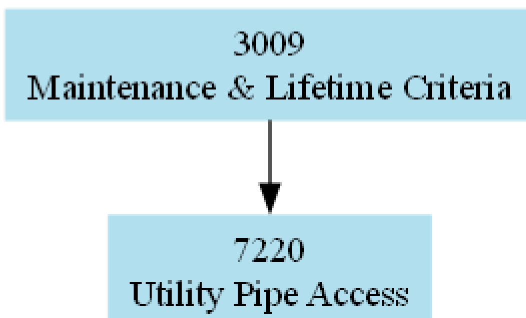



*Figure 33: Requirement 7220 source and elaboration*

The Process Systems utility pipes are expected to be life of the facility components, however access shall be provided to allow for repairs of any leaking utility lines that occur in the future. The utility lines will be accessed via removable cover plates that reside on top of the pipe pan area. These removable plates sit partially on target station shielding and partially on a ledge in the monolith concrete.

#### 5.5.5 Utility Pipe Clearance (CodeBeamer reference: 7221)

*Target Station Shielding shall allow for utility pipes to pass through the pipe pan covers into the target drive room per Interface Sheet S03000000-IST10005* (8).

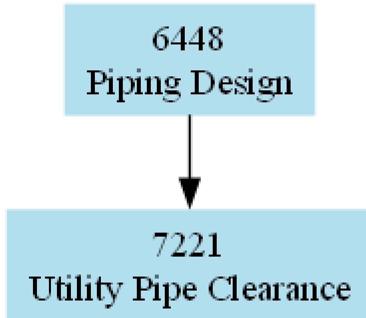



*Figure 34: Requirement 7221 source and elaboration*

A number of Process Systems utility pipes need to be routed out of the top of the pipe pan and across the Core Vessel lid to supply utilities to the target assembly and TVP assembly. Openings in the removable shield plates above the pipe pan will be provided to allow the utility lines to pass through the shield plates.

#### 5.5.6 Bulk Shielding Liner Drain (CodeBeamer reference: 7222)

*Target Station Shielding shall provide a connection pipe to the bulk shielding liner drain per Interface Sheet S03000000-IST10005* (8).

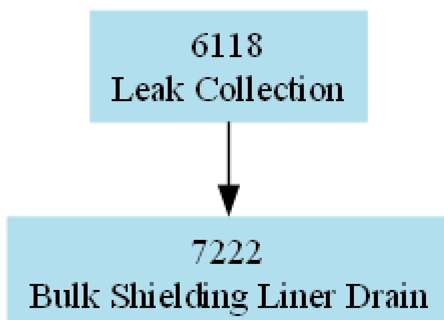



*Figure 35: Requirement 7222 source and elaboration*

The bulk shielding liner drain is located at the center of the monolith floor. This drain connects to the drain port in the center of the Core Vessel Baseplate. The drain line is a part of Process Systems scope, and will be case in place in the concrete floor of the monolith. TSS shall design the CV baseplate and associated adapter rings to allow for welded connection to the drain pipe to be made.

### 5.5.7 Target Water Line Support (CodeBeamer reference: 7223)

*Target Station Shielding shall support target water line support assemblies per Interface Sheet S03000000-IST10005* (8).

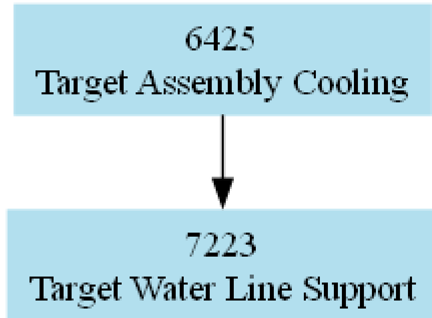



*Figure 36: Requirement 7223 source and elaboration*

The target assembly is supplied water via large supply and return lines that run near the roof of the target drive room. Process Systems will design pipe supports for the supply and return lines. TSS will provide the necessary mounting features in the CV lid to properly mount and secure the pipe supports.

### 5.5.8 Core Vessel Drain Line Clearance (CodeBeamer reference: 7815)

*Target Station Shielding shall provide clearance around the Core Vessel drain line per Interface Sheet S03000000-IST10005* (8).

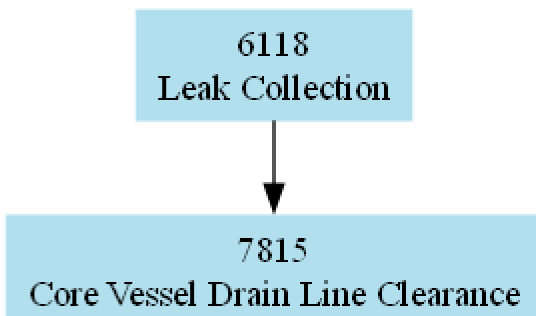



*Figure 37: Requirement 7815 source and elaboration*

The CV drain line exits the sidewall of the CV below the proton beam elevation and is routed through the TSS and monolith concrete into the instrument bunker. TSS shall be designed to allow for proper clearance of the CV drain pipe.

## 5.6 TSS-REMOTE HANDLING INTERFACE

*Requirements derived from Interface Sheet S03000000-IST10007* (9).

### 5.6.1 Removable Component Lifting Interfaces (CodeBeamer reference: 7225)

*Target Station Shielding shall provide lifting interfaces for all removable Target Station Shielding components per Interface Sheet S03000000-IST10007* (9).

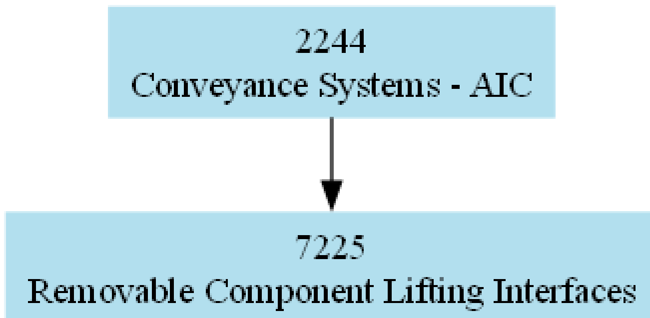



*Figure 38: Requirement 7225 source and elaboration*

A number of TSS components are designed to be removed to accommodate maintenance activities within the monolith. All removable components include lifting interfaces that allow removal of these components by the Remote Handling team. The method of lifting each component has been identified and the mass of removable components has been kept well below the lifting limit of the identified lifting device.

## 5.7 TSS-INSTRUMENT SYSTEMS INTERFACE

*Requirements derived from Interface Sheet S01020500-IS0025* (3).

### 5.7.1 Monolith Port Clearance (CodeBeamer reference: 7228)

*Target Station Shielding shall provide appropriate physical clearance between the monolith insert rear flanges, utility connections and the monolith ports per Interface Sheet S01020500-IS0025* (3).

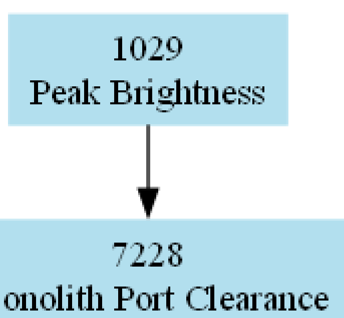



*Figure 39: Requirement 7228 source and elaboration*

The monolith ports provide a steel form work through the monolith concrete that form the openings for the CV nozzle extensions. The design, procurement and installation of the monolith ports is part of CF scope. TSS will provide CF with the required inside profile and dimensional accuracy required for the monolith ports. The bunker side portions of the monolith ports are designed to provide proper clearance for the nozzle extension rear flange and monolith insert utility connections.

## 5.8 TSS-CONVENTIONAL FACILITIES INTERFACE

*Requirements derived from Interface Sheet S01020500-IST10064* (4).

### 5.8.1 Monolith Internal Concrete Profile (CodeBeamer reference: 7230)

*Target Station Shielding shall supply the required monolith internal concrete profile to Conventional Facilities per Interface Sheet S01020500-IST10064* (4).

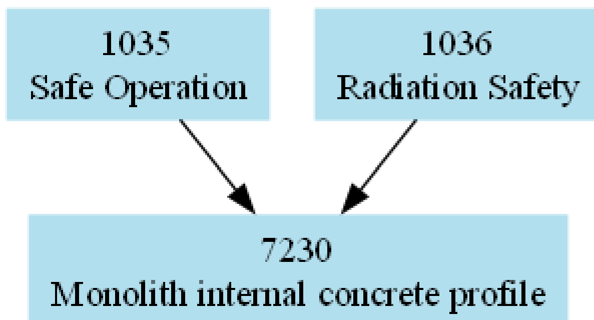



*Figure 40: Requirement 7230 source and elaboration*

The monolith concrete will be designed and poured by the CF team. The inside profile of the monolith concrete is defined by TSS via an interface sheet and associated drawing. The proper concrete profile is important to ensure that the bulk shielding liner and target station shielding fit properly inside the monolith and gaps between the shielding and the concrete are properly managed.

### 5.8.2 Concrete Anchor Details (CodeBeamer reference: 7232)

*Target Station Shielding shall supply the location, size, connection type and mechanical loading of the concrete anchors required by Target Station Shielding per Interface Sheet S01020500-IST10064* (4).

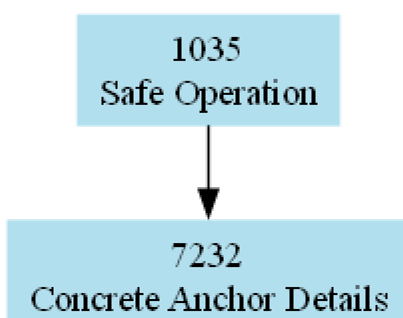



*Figure 41: Requirement 7232 source and elaboration*

Concrete anchors secured in the monolith concrete are required to properly secure the CV baseplate, bulk shielding liner and removable shielding above the pipe pans. The anchors at the bottom of the monolith concrete will be cast in place. These anchors are used to secure the bulk shielding liner and CV baseplate during initial installation and the grouting process. Anchors at the top of the monolith concrete will be drilled and installed after the monolith concrete has set, as these anchors do not see significant mechanical loads. Installation of all anchors is part of CF scope, and TSS will provide the anchor locations and type to the CF team.

#### 5.8.3 Mechanical Loading Details (CodeBeamer reference: 7233)

*Target Station Shielding shall supply the mechanical loads imparted on the concrete by the monolith interior components per Interface Sheet S01020500-IST10064* (4).

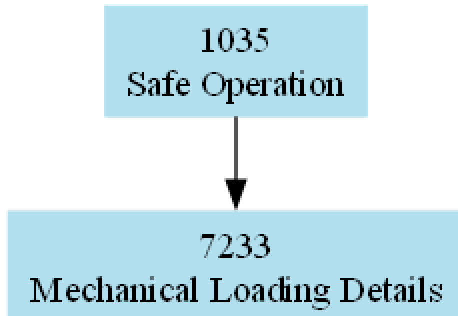



*Figure 42: Requirement 7233 source and elaboration*

The monolith concrete and anchor system must support the full mass of the fully assembled monolith. TSS will provide the CF team with the gravitational and seismic loading on the monolith concrete and concrete anchor system. CF will ensure proper design of the monolith concrete structure to support these loads.

#### 5.8.4 Grout Holes (CodeBeamer reference: 7234)

*Target Station Shielding shall include features that allow grouting of Target Station Shielding hardware per Interface Sheet S01020500-IST10064* (4).

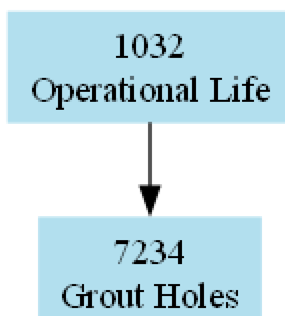



*Figure 43: Requirement 7234 source and elaboration*

The CV baseplate and bulk shielding liner will be installed on top of leveling shims that provide a gap in between the TSS hardware and the poured concrete. This allows for greater positional accuracy of the CV baseplate and bulk shielding liner as the shims can be adjusted to compensate for variations in the monolith concrete floor. After the TSS hardware is located and bolted in place the CF team will fill the gap with grout. TSS will provide grout holes in the CV baseplate and bulk shielding liner of the size and spacing specified by the CF team to allow for proper grout filling.

#### 5.8.5 Monolith Port Geometry (CodeBeamer reference: 7235)

*Target Station Shielding shall supply the required interior profile of the monolith ports per Interface Sheet S01020500-IST10064* (4).

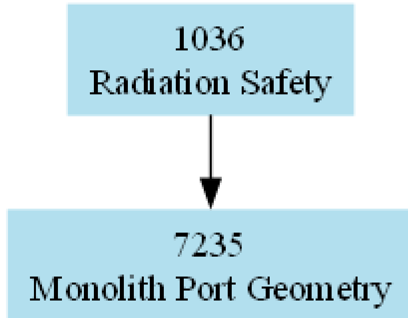



*Figure 44: Requirement 7235 source and elaboration*

The monolith ports provide a steel form work through the monolith concrete that form the openings for the CV nozzle extensions. The design, procurement and installation of the monolith ports is part of CF scope. TSS will provide CF with the required inside profile and dimensional accuracy required for the monolith ports. Proper inside port geometry is important to ensure that the nozzle extensions fit properly through the monolith ports and that reasonable gaps between the monolith ports and the nozzle extensions are provided. The bunker side portions of the monolith ports are designed to provide proper clearance for the nozzle extension rear flange and monolith insert utility connections. Brackets have been specified to align and support the rear flange of each nozzle extension.

#### 5.8.6 Concrete Temperature (CodeBeamer reference: 7236)

*Target Station Shielding shall ensure that the monolith concrete temperature does not exceed 65 C for prolonged periods due to radiation heating per Interface Sheet S01020500-IST10064* (4).

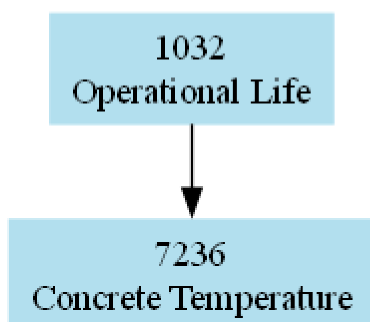



*Figure 45: Requirement 7236 source and elaboration*

The spallation process generates significant neutronic energy that is converted into heat as the radioactive products interact with solid material. CV shielding and target station shielding absorb the majority of this energy, which in turn protects the concrete structure from overheating. The monolith concrete temperature must be kept below a threshold to protect the concrete from structural degradation.

## 5.9 TSS – INTEGRATED CONTROLS

*Requirements derived from interface sheet S01020500-IST10220* (5).

### 5.9.1 Pipe Pan Side Wall Penetrations (CodeBeamer reference: 7410)

*Target Station Shielding shall provide penetrations in the pipe pan side wall for instrumentation wiring per Interface Sheet S01020500-IST10220* (5).

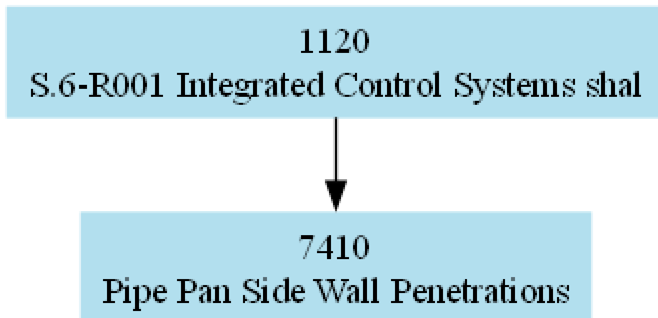



*Figure 46: Requirement 7410 source and elaboration*

All instrumentation cables inside the CV are routed through the CV sidewall into the pipe pan. From there, the cables are routed under the TDR floor and out of the monolith to control cabinets via conduit runs. Openings will be provided in the pipe pan that align with the cable conduit runs through the TDR.

### 5.9.2 Instrumentation Wire Pipe Chase (CodeBeamer reference: 7411)

*Target Station Shielding shall provide a pipe chase through the bulk shielding for instrumentation wiring per Interface Sheet S01020500-IST10220* (5).

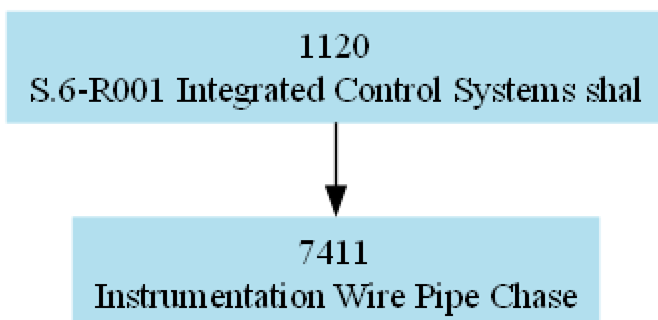



*Figure 47: Requirement 7411 source and elaboration*

All instrumentation cables inside the CV are routed through the CV sidewall into the pipe pan. From there, the cables are routed under the TDR floor and out of the monolith to control cabinets via conduit runs. If any instrument conduit run intersects target station shielding, clearance will be provided in the shielding to accommodate the conduit.

# 6. DESIGN

Target Station Shielding is comprised of five subsystems; Bulk Shielding, Removable Shielding, Core Vessel Baseplate, Bulk Shielding Liner and Pipe Pans. The current configuration of these subsystems is shown in Figure 48 below.

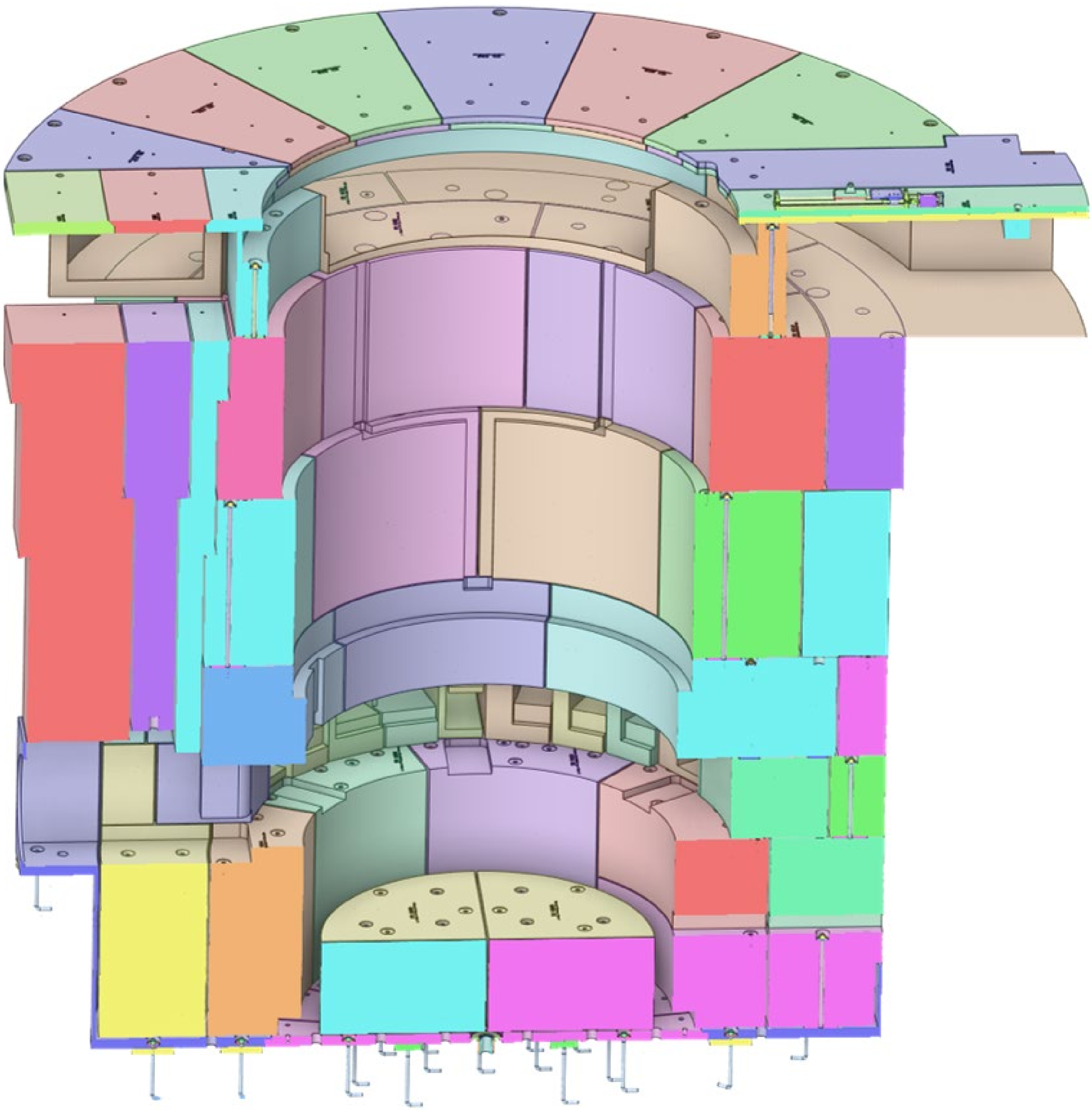


*Figure 48: Cross-section view of Target Station Shielding hardware*

## 6.1 BULK SHIELDING DESIGN

The TSS Bulk Shielding is comprised of an interlocked stack of carbon steel shielding that fills the space in between the Core Vessel and the monolith concrete within the Target Systems monolith. While it is possible to remove bulk shielding blocks after the monolith is fully constructed, all bulk shielding blocks are considered life of the facility components that we do not expect to remove until the facility is decommissioned. The inside profile of the bulk shielding is driven by the CV geometry. Piping galleries are provided in the bulk shielding to allow the water lines cooling the CV beltline to be routed along the outside of the CV and up into the pipe pan. The outside profile of the Bulk Shielding was determined by performing a Neutronics study to determine the required amount of steel in the radial direction. The general layout of the Bulk Shielding assembly is show in Figure 49 below.

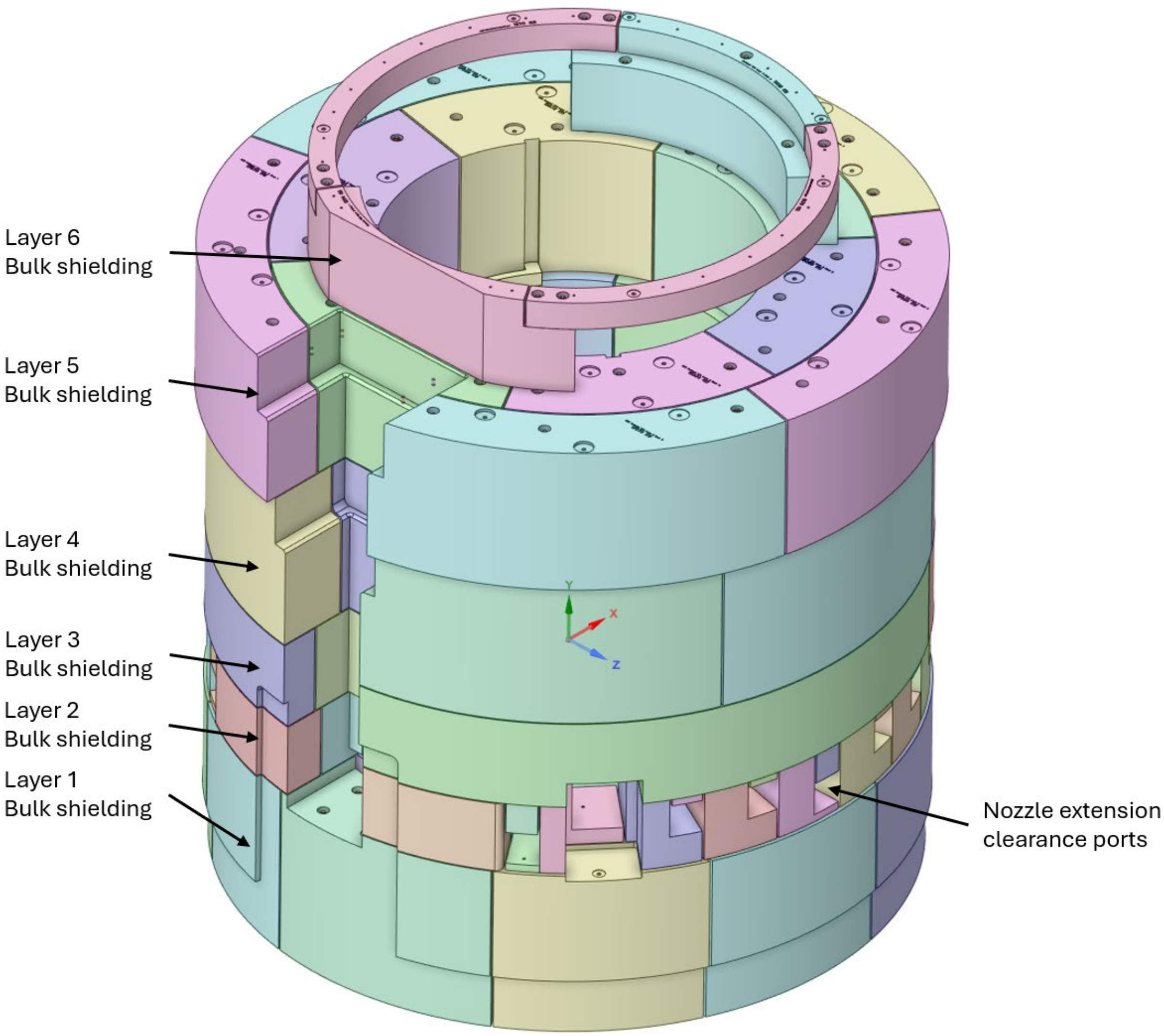



*Figure 49: Basic layout of the TSS Bulk Shielding*

### 6.1.1 Bulk Shielding Layer 1 Design

Individual bulk shielding blocks vary significantly in size and shape. Each shield block will be constructed from carbon steel and coated with an anti-corrosive coating. The maximum size of a bulk shielding block is limited by the capacity of the high bay crane, as this crane will be used to install the shield blocks during monolith construction. Four Layer 1 shield blocks reside inside the bottom skirt of the CV. The remaining Level 1 blocks surround the outside of the CV. The shield blocks are split into two concentric rings to allow for the inner ring of shielding to be installed by first bringing the blocks vertically down into the monolith and then shifting towards the CV. This horizontal shift is required to clear the CV beltline which protrudes from the CV shells and does not allow vertical installation. Notches in the shielding are also required to accommodate the PBW alignment plate and CV nozzle extension mounting brackets. A detailed image showing layer 1 shielding clearance around the CV beltline and nozzle extensions can be seen in Figure 50 below.

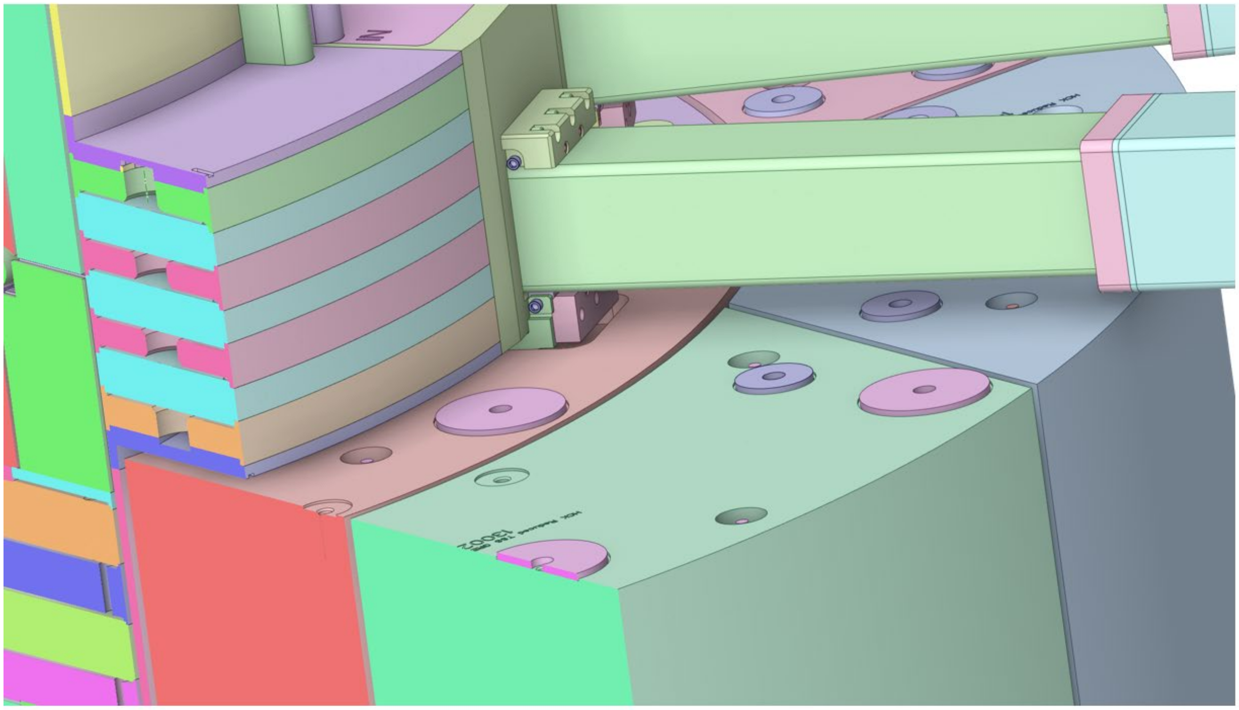


*Figure 50: Detailed view of bulk shielding layer 1 and CV with nozzle extensions installed*

Layer 1 shield blocks are secured to the bulk shielding liner and CV baseplate using tie rods as seen in Figure 51 below. The tie rods will be tensioned during installation to impart a compressive force in between the shield blocks and the underlying layer. This approach was selected to mitigate block shifting during a seismic event. This arrangement also allows relatively loose tolerances to be applied to each shield block by utilizing generous vertical hole clearance around the tie rods, which will reduce the overall cost of each shield block. The survey and alignment team will position each shield block in its nominal position prior to attaching the tie rods and locking the blocks in place. Each shield block layer also rests on shim pucks that will be modified as necessary to ensure that each shield layer is as level as possible and at nominal height before the next layer is installed. This installation approach should avoid unwanted tolerance stackup as the bulk shielding is installed.

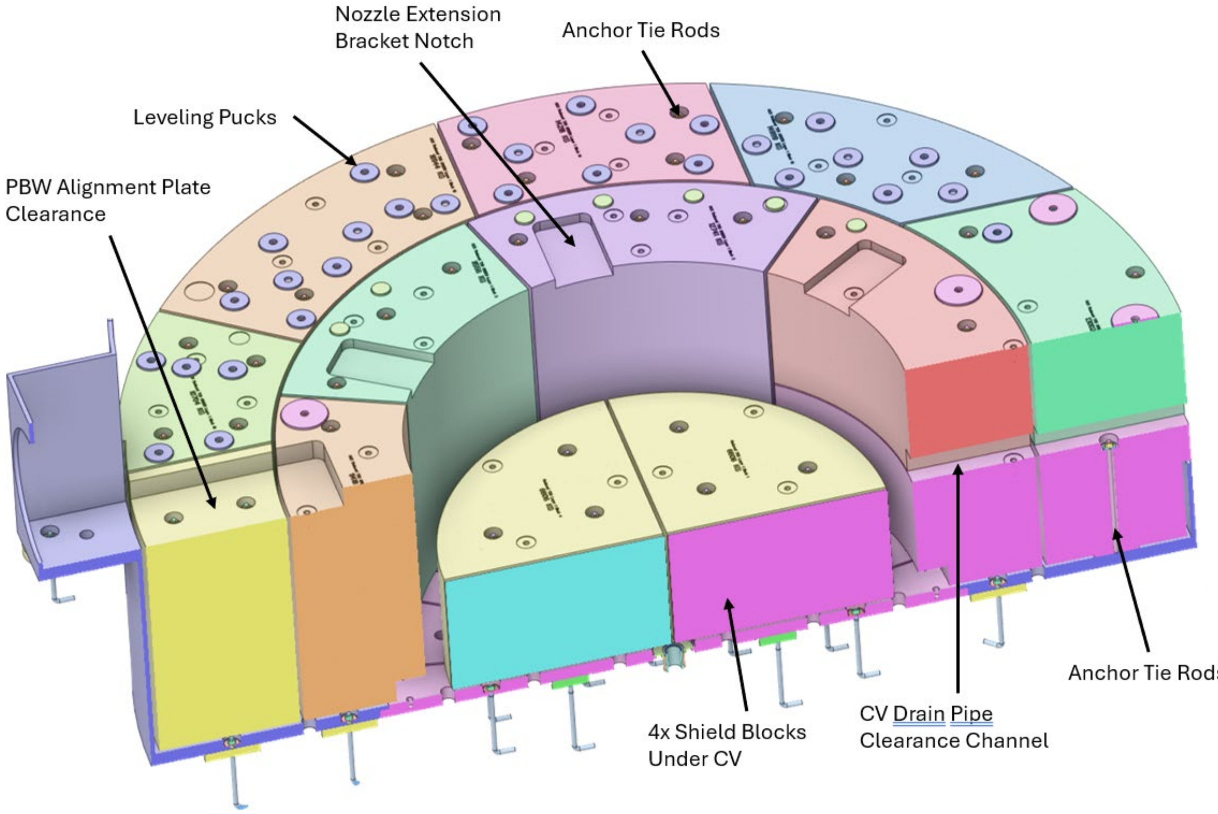
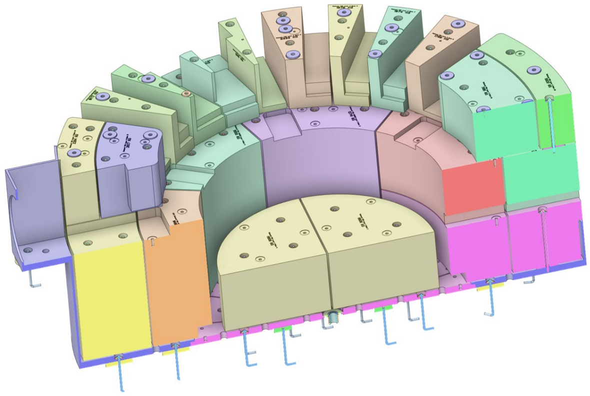



*Figure 51: Cross section view of bulk shielding layer 1 including mounting hardware*

### 6.1.2 Bulk Shielding Layer 2 Design

The second layer of bulk shielding is installed around the CV nozzle extensions. The nozzle extensions will be installed sequentially, with adjacent layer 2 shield blocks being installed as part of this sequence. Once a nozzle extension is welded in place the shield blocks below and around the nozzle extension will not be able to be removed without cutting the nozzle extension seal weld. The shield blocks that surround the nozzle have an L-shaped cross section as can be seen in Figure 52 below. Because this layer of shielding does not need to fit beneath the CV beltline single blocks can be utilized on this layer. Each shield block will be horizontally slid into place prior to being precision aligned and locked into place. The shield blocks will be secured in place with tie rods and shim pucks as was described for the layer 1 shield blocks. Layer 2 shield block tie rods are threaded into holes in the tops of the layer 1 shield blocks and tensioned to fix their position and ensure they do not slip out of position in a seismic event.



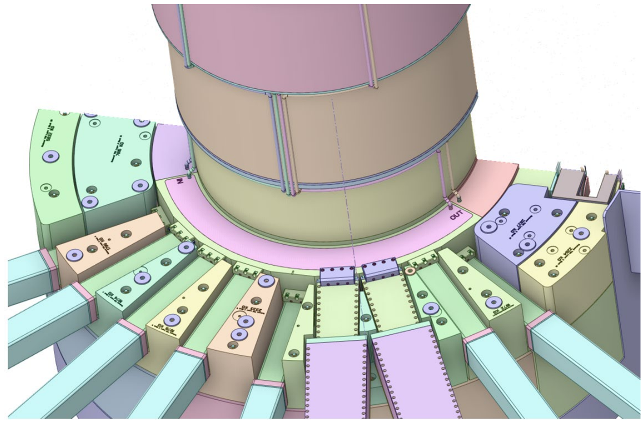


*Figure 52: Cross section views of the bulk shielding assembly up to Layer 2 both with (right) and without (left) the CV*

### 6.1.3 Bulk Shielding Layer 3 Design

The layer 3 shield blocks are supported off of the layer 2 shield blocks. It is important that the bulk shielding does not interact with the CV nozzle extensions in order to avoid damaging the nozzle extensions. Small shield blocks are bolted onto the main shield blocks that fill the voids left on top of each nozzle extension and can be seen in Figure 53 below. This layer of shielding is once again broken up into inner and outer rings of shielding in order to allow for vertical installation that can clear the top flange of the CV without interfering with the monolith concrete wall. This layer of shielding will be locked in place using the same method as layer 2, anchoring into tapped holes in the top of the layer 2 shield blocks.

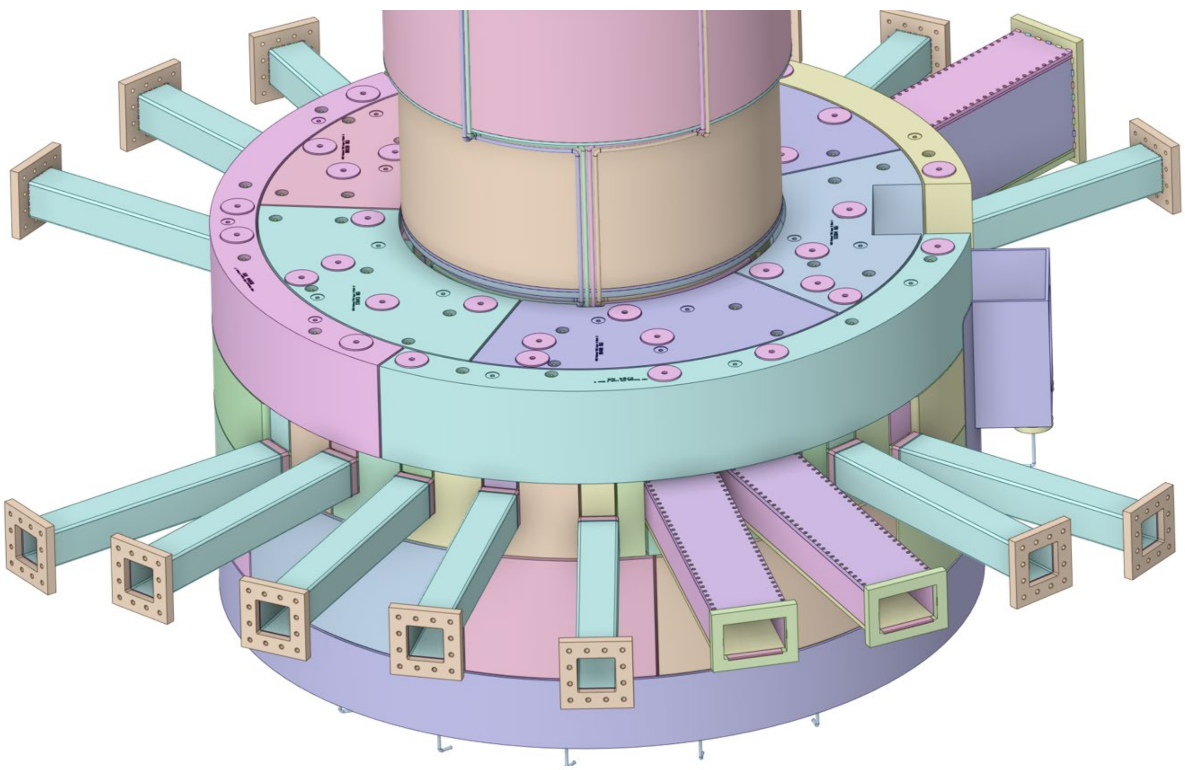


*Figure 53: Bulk shielding installed up to layer 3 with CV installed*

### 6.1.4 Bulk Shielding Layer 4 Design

The layer 4 shield blocks are supported off of the layer 3 shield blocks as can be seen in Figure 54 below. This layer of shielding is once again broken up into inner and outer rings of shielding in order to allow for vertical installation that can clear the top flange of the CV without interfering with the monolith concrete wall. The gaps in between individual shield blocks has been staggered throughout the shield assembly to minimize neutronic streaming through these gaps. The splitting of shield blocks has been designed to ensure that each shield block is well supported off of the layer below. This layer of shielding will be locked in place using the same method as the other shielding layers.

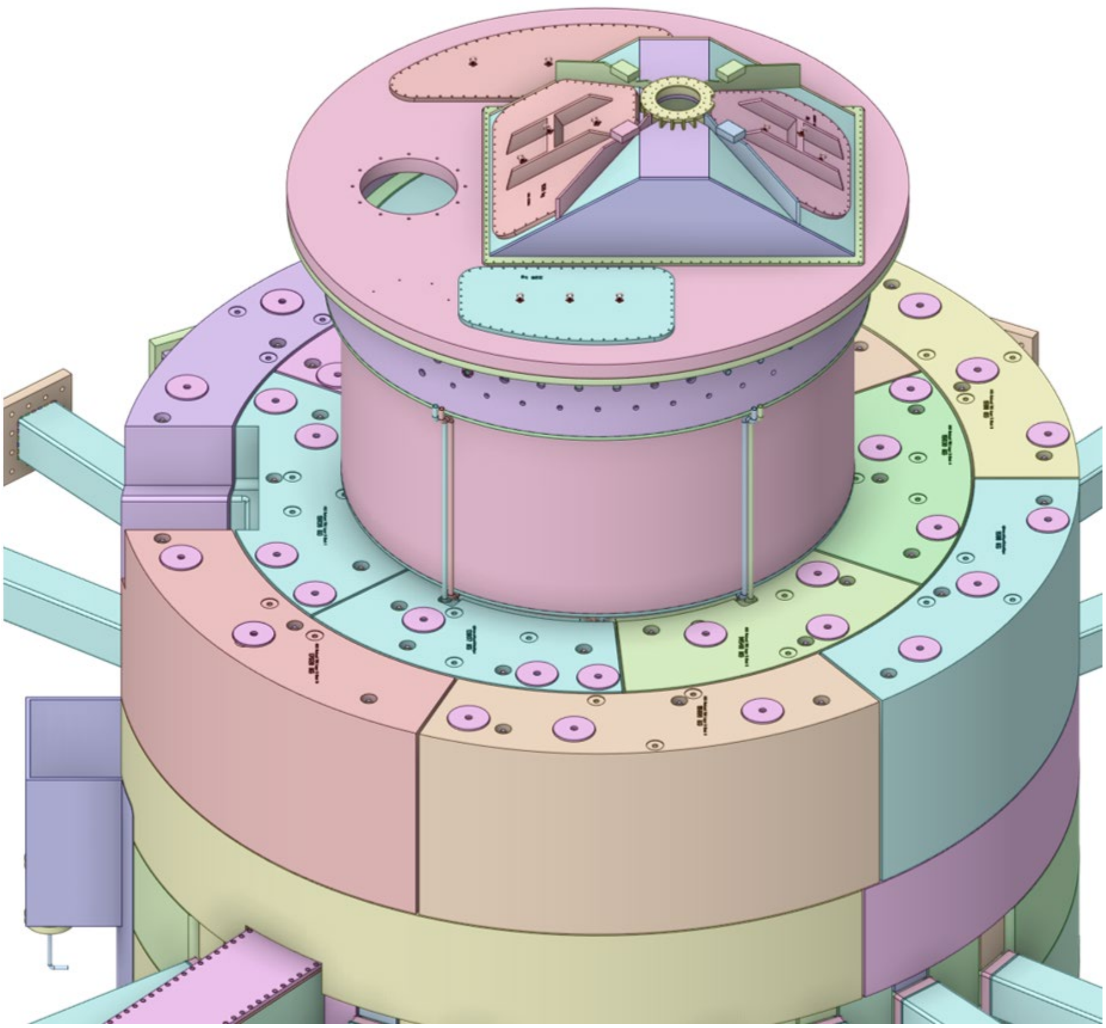


*Figure 54: Bulk shielding installed up to layer 4 with CV installed*

### 6.1.5 Bulk Shielding Layer 5 Design

Bulk shielding layer 5 is the final layer of bulk shielding to be installed. This layer supports the floor of the pipe pans, and surrounds the OD of the core vessel as shown in Figure 55 below. This layer of shielding is once again broken up into inner and outer rings of shielding in order to allow for vertical installation that can clear the top flange of the CV without interfering with the monolith concrete wall.  This layer of shielding will be locked in place using the same method as the other shielding layers.

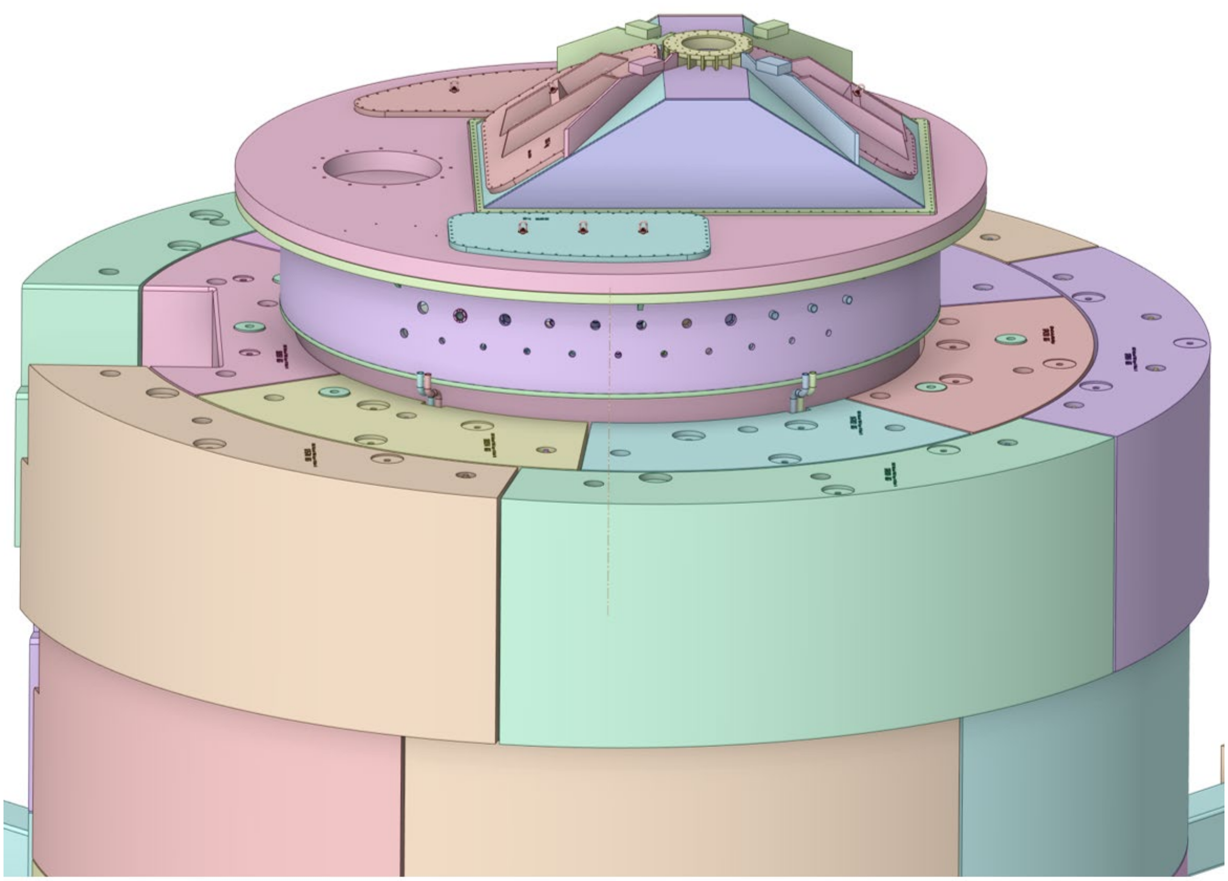


*Figure 55:  Bulk shielding installed up to layer 5 with CV installed*

### 6.1.6 Bulk Shielding Layer 6 Design

Layer 6 bulk shielding blocks surround the OD of the Core Vessel.  Two blocks rest on the layer 5 shield blocks, while an additional two bridge blocks span across CV.  The bridge blocks are required to provide clearance for the utility piping that attaches to the nozzles of the CV.  The purpose of the Layer 6 shield blocks is to provide support for the removable shielding plates located above the pipe pan.  The layer 6 shield blocks can be seen in Figure 56 below.

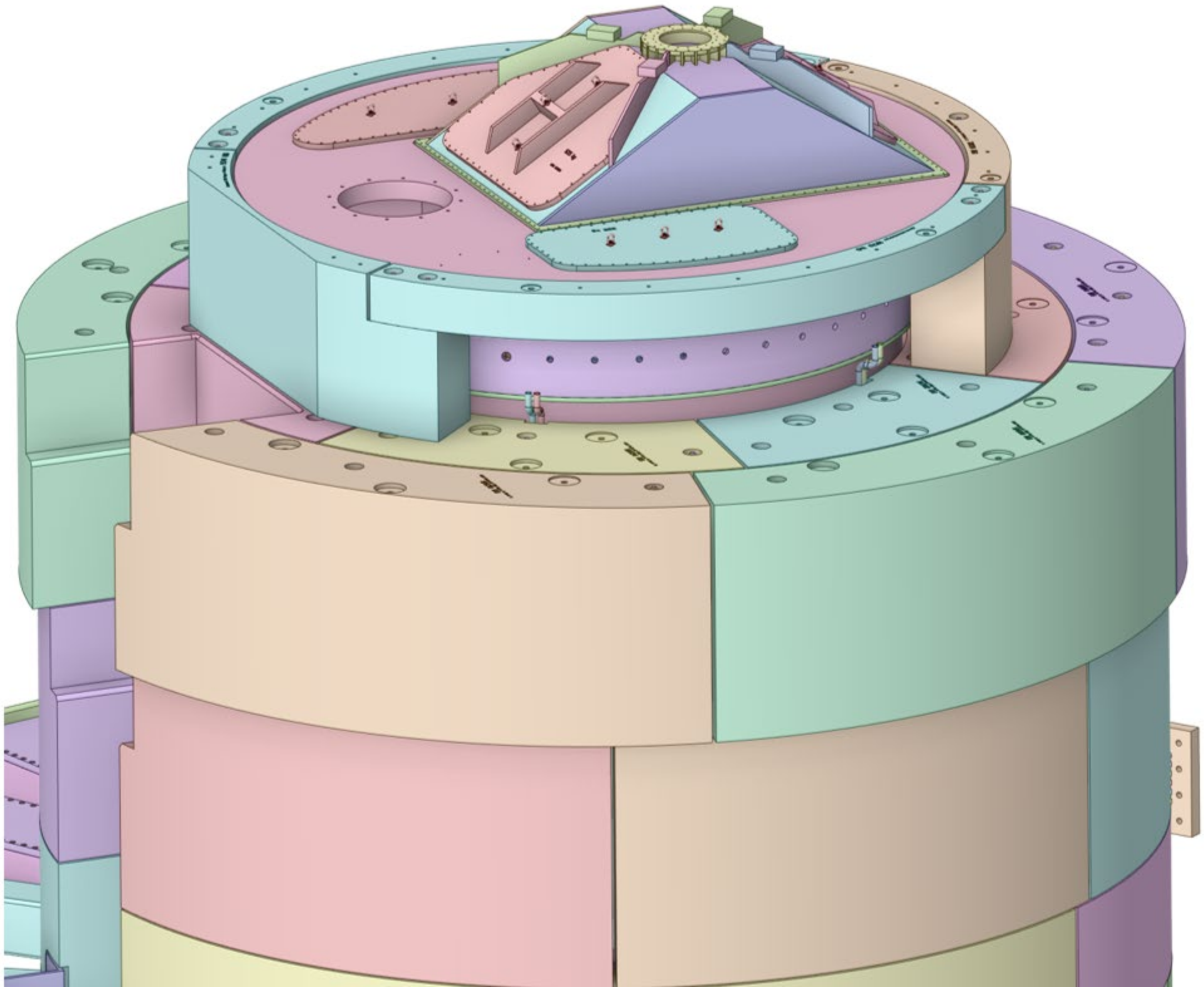


*Figure 56: Bulk shielding installed up to layer 6 with CV installed*

### 6.2 REMOVABLE SHIELDING DESIGN

The removable shielding consists of two collections of shield blocks; the AIC removable shield blocks above the PBW, PBW shielding and PBTA remote clamp and the steel plates that reside above the pipe pans and form a portion of the target drive room floor. Both of these sets of shield blocks are supported partially off of the bulk shielding and partially off of the monolith concrete.

#### 6.2.1 AIC Removable Shield Block Design

The AIC removable shield block group consists of three shield blocks that are installed vertically above the AIC components residing inside the TSS. These shield blocks are unique as they are much taller than they are wide, and span bulk shielding layers 3, 4 and 5. This shield block configuration allows for a single shield block to be removed in order to access the PBW, which is the most frequently serviced component. In order to gain access to the PBW shielding or PBTA remote clamp the PBW shield block must be removed, followed by the desired second shield block. Each of the AIC removable shield blocks are supported off of the bulk shielding via ledges. Shim pads will be installed on these ledges to help precisely locate the removable shield blocks in the vertical direction. Alignment pins on the bulk shielding ledges ensure that the blocks are properly located during installation.

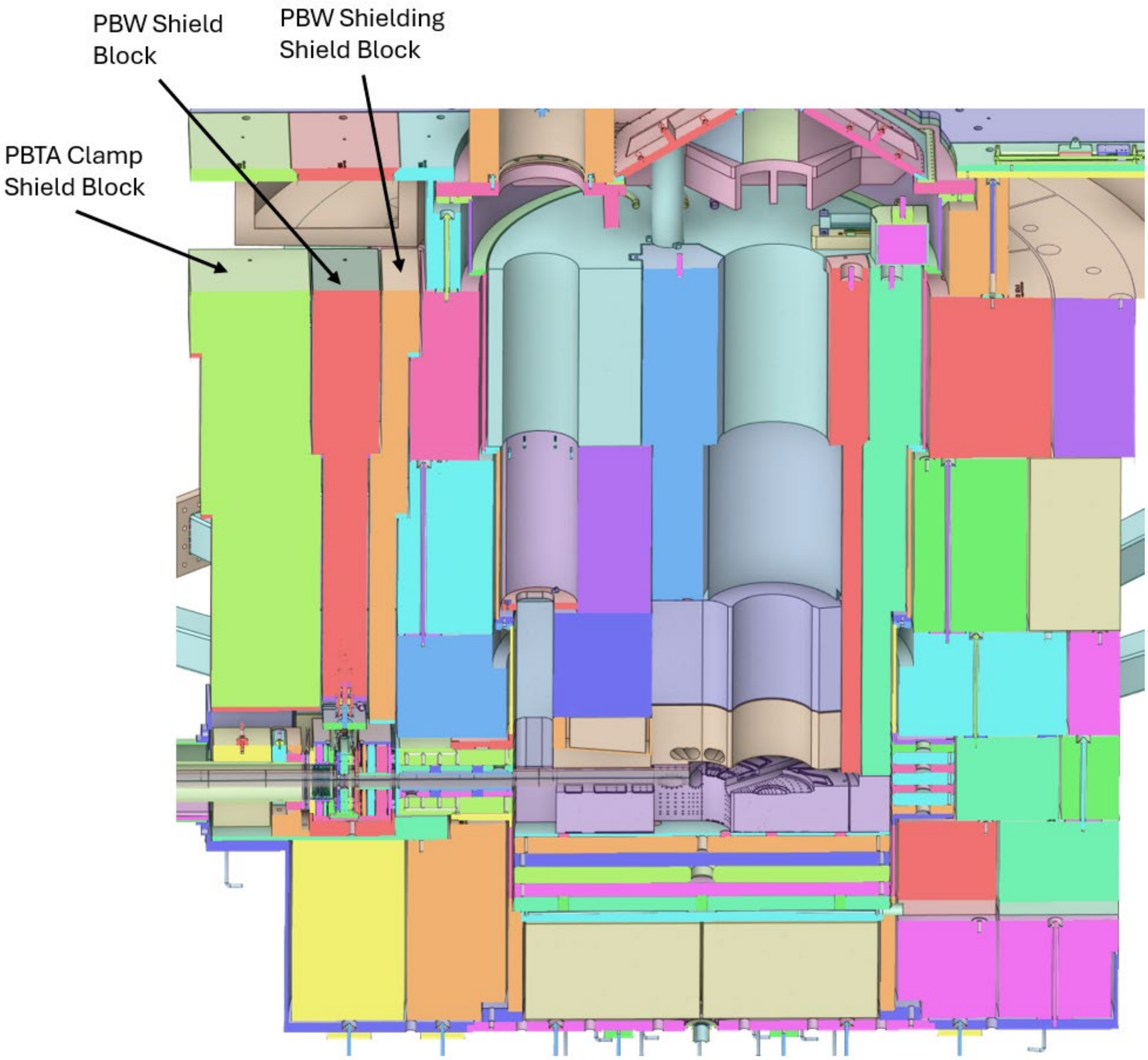



*Figure 57: CAD section view of TSS and CV with AIC removable shielding installed*

### 6.2.2 Pipe Pan Cover Shield Plate Design

The pipe pan cover shield plates reside above the pipe pans and form a portion of the TDR floor. The pipe pan cover plates consist of two layers of 50 mm thick plates installed with staggered gaps to minimize neutronics streaming effects. These plates provide radiation shielding during beam on operations when the return water lines are filled with highly activated water that represent a significant source of radiation. The plates bolt to the layer 6 bulk shielding near the CV and sit on and are secured to ledges in the monolith concrete on the outside perimeter of the shielding. Two layers of plates was selected to keep the weight of individual cover plates below the 1 ton crane limit of the jib cranes located inside the TDR. Removal of the upstream cover plates will be required to gain access to the AIC removable shield blocks. The remaining cover plates will only be removed if there is an issue with one of the utility lines inside the pipe pan or some supplemental hardware is being installed inside of the pipe pan. The pipe pan cover plates are shown in Figure 58 below.

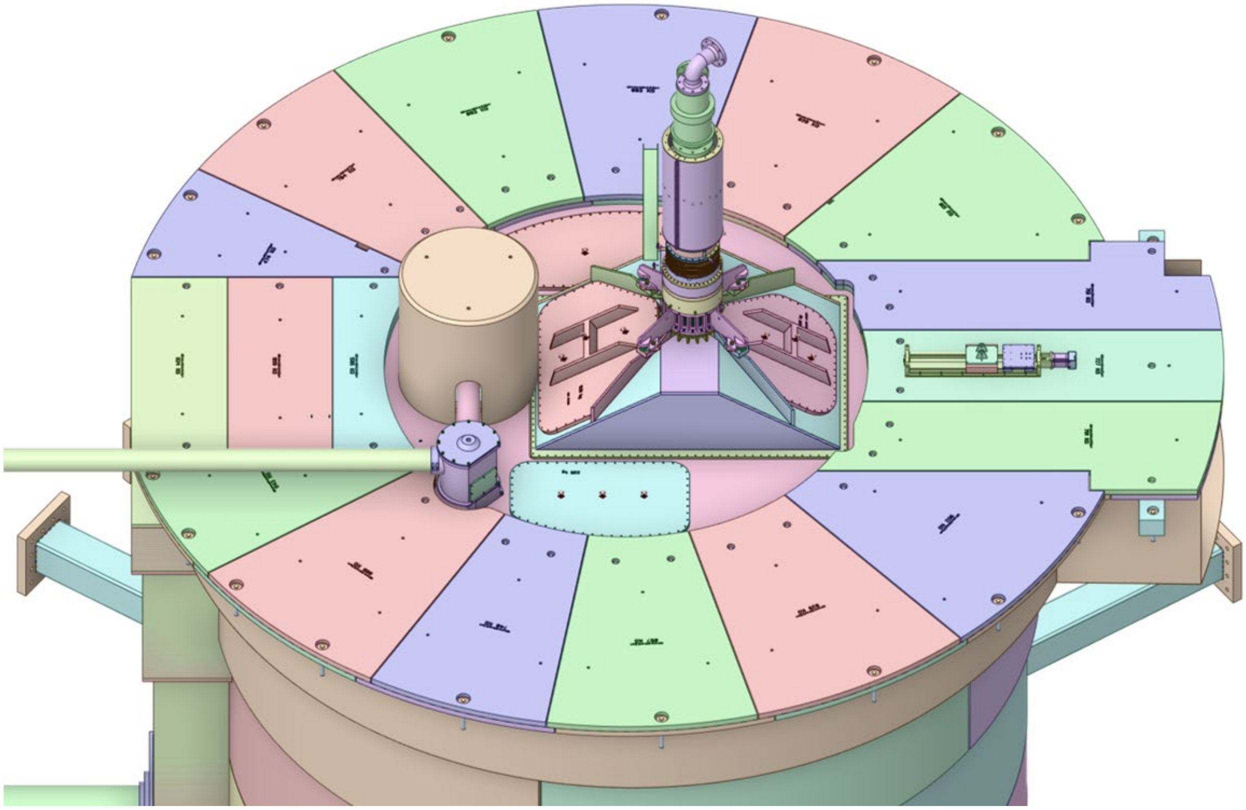


*Figure 58: CAD model view of pipe pan cover removable shielding*

### 6.3 CORE VESSEL BASEPLATE DESIGN

The CV Baseplate is a 75 mm thick carbon steel plate with a variety of features machined into the top and bottom of the plate. The primary purpose of the CV baseplate is to provide a stable and accurate mounting interface for the Core Vessel. The CV bottom flange bolts directly into the CV baseplate, making the installed accuracy of the baseplate critical. In an approach similar to that used at FTS, the CV baseplate will be supported off of leveling pucks threaded into embedded anchors in the monolith concrete. Survey and alignment will determine the proper level of each leveling puck prior to the CV Baseplate installation. The baseplate will be brought down onto the leveling pucks and secured in place via additional anchors that penetrate through clearance holes to the top of the CV baseplate.

After the baseplate has been locked in place the bulk shielding liner will be similarly located within the monolith and the two parts will be welded together to form a water tight seal for leak collection. Following the welding step the CF team will grout the void space under the baseplate and bulk shielding liner. A secondary purpose of the anchor bolts is to keep the baseplate in place during the grouting process. Cover plates will be fitted and welded over the CV baseplate anchors. Radial grooves are machined in the baseplate that route water leaks to a central drain port. The double-walled drain line will be cast in place in the concrete prior to the CV baseplate installation, and will be field welded to the CV baseplate during installation. The basic layout of the CV baseplate is show in Figure 59 below.

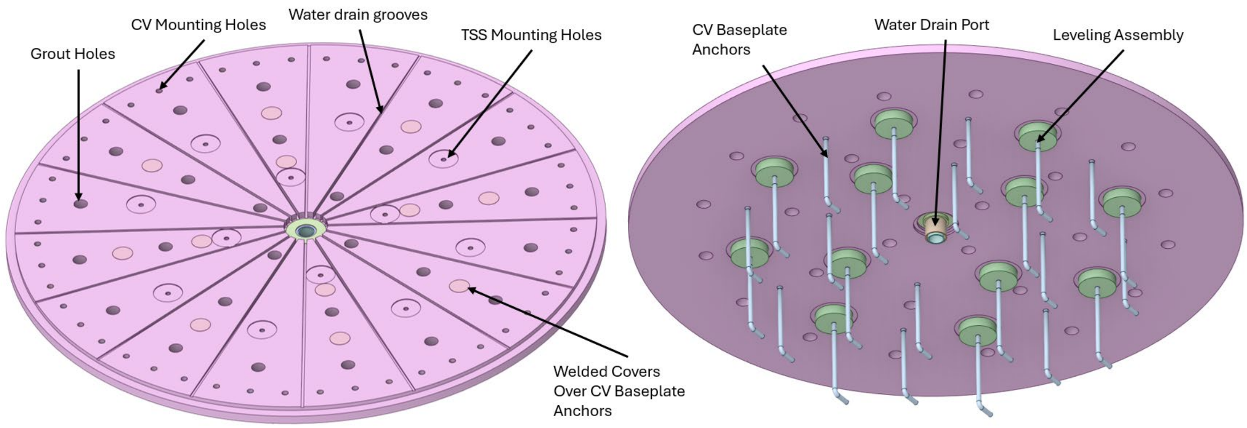



*Figure 59: CAD images of the top and bottom of the Core Vessel Baseplate*

## 6.4 BULK SHIELDING LINER DESIGN

The bulk shielding liner is a carbon steel liner located at the bottom of the monolith. The bottom of the bulk shielding liner is 75 mm thick, while the side walls are 25 mm thick. The bulk shielding liner forms part of a leak collection system at the bottom of the monolith that prevents the concrete base of the monolith from being exposed to irradiated water from the Target System. The bulk shielding liner is welded to the CV base plate and extends to the vertical wall of the monolith concrete. The liner extends vertically upward in order to provide additional leak containment. The bulk shielding liner also extends upward to surround a cutout in the monolith concrete around the PBW and PBTA remote clamp. Due to its large size, it is expected that the bulk shielding liner will be purchased in pieces and welded together onsite prior to installation.

Like the CV Baseplate, the bulk shielding liner will be supported off of leveling pucks threaded into embedded anchors in the monolith concrete. Survey and alignment will determine the proper level of each leveling puck prior to the Bulk Shielding Liner installation. The liner will be brought down onto the leveling pucks and secured in place via additional anchors that penetrate through clearance holes to the top of the liner. After the liner has been locked in place it will be welded to the CV baseplate to form a water tight seal for leak collection. Following the welding step the CF team will grout the void space under the baseplate and bulk shielding liner. A secondary purpose of the anchor bolts is to keep the liner in place during the grouting process. Cover plates will be fitted and welded over the liner anchors. The basic layout of the CV baseplate is show in Figure 60 below.

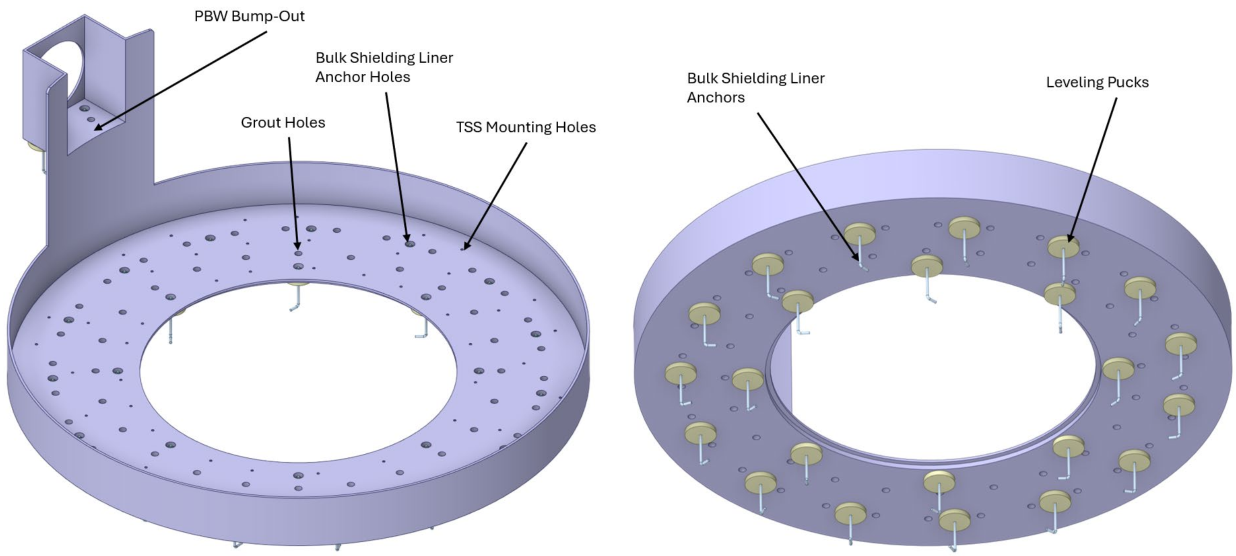



*Figure 60: CAD images of the top and bottom of the Bulk Shielding Liner*

## 6.5 PIPE PAN DESIGN

The Pipe Pans are fabricated from 3 mm thick stainless steel and are located at the top of the bulk shielding stack that line the recessed areas below the TDR floor that contain the water pipes and other utilities that enter the top of the CV. The pipe pans surround the outside of the CV and extend across the bulk shielding and over the concrete recess in the TDR floor. The function of the pipe pan is to provide leak collection for the utility pipes residing inside the pipe pans. The pipe pans will extend further downstream than is shown in Figure 61. A pipe pan drain hole will be welded to the Process Systems leak collection pipe, which will route any leaks to the leak collection system. The pipe pans will be purchased in sections and field welded together in-situ after the bulk shielding is fully installed.

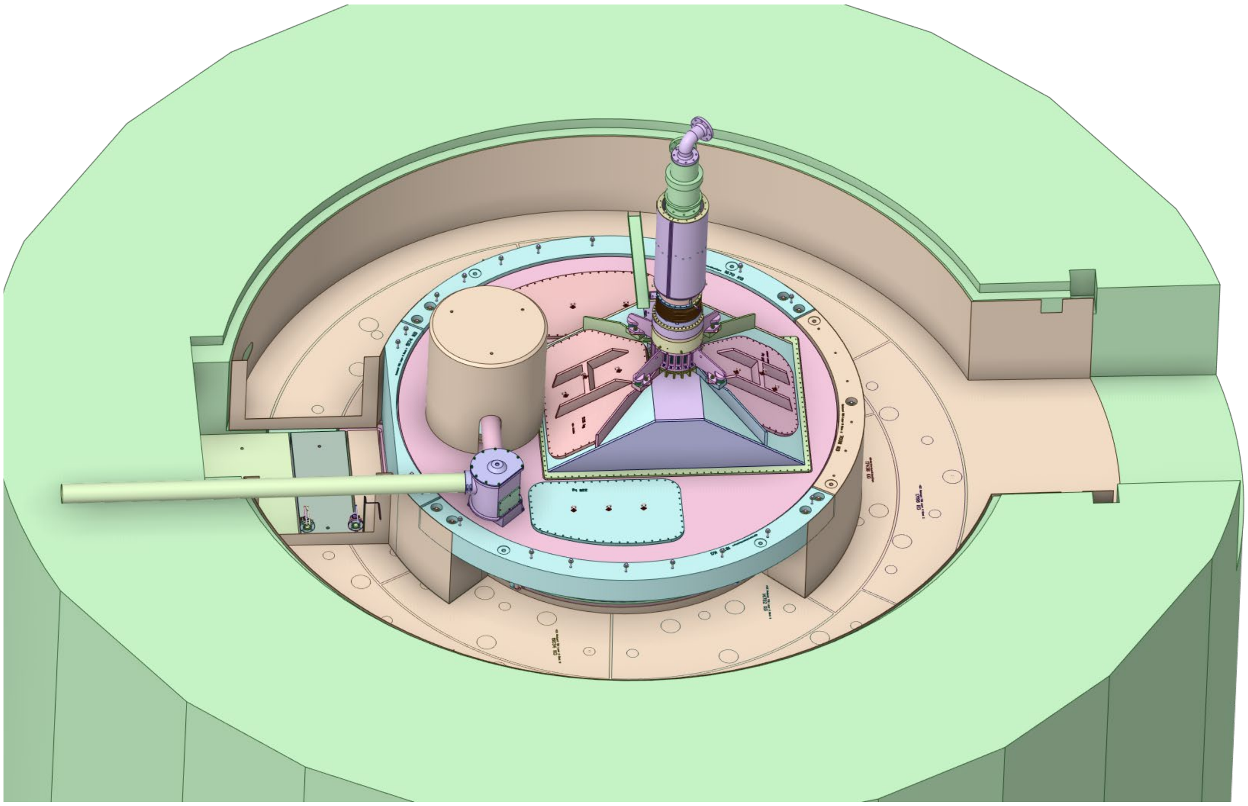


*Figure 61: Pipe pan (tan) configuration within the monolith*

## 6.6 TARGET STATION SHIELDING NEUTRONICS ANALYSIS

The original design of the monolith called for the carbon steel Target Station Shielding to extend to 8.65 meters from the center of the monolith. In early 2023 a significant cost optimization effort was undertaken by the project, and the required volume of target station shielding was reconsidered. The original volume of steel was based on the first target station. Because the STS design contains an instrument bunker that will not be accessible during beam-on operations a greater amount of radiation could be allowed to leave the monolith in the radial direction. A neutronics study was performed to evaluate the viability of reducing the outside diameter of the Target Station Shielding to 5.8 meters and to replace the removed steel shielding volume with concrete. Radiation levels with the reduced volume steel were found to be acceptable both inside the instrument bunker and in the high bay and instrument halls.

Another consideration that required evaluation was the impact of reducing the steel volume on the neutronic heating of the monolith concrete. A simplified quarter symmetry model was developed and analyzed by the Neutronics team to determine the amount of energy deposited into the steel and concrete structures. The results of this analysis are shown in Figure 62 below. A full summary of the neutronics analysis is presented in (13).

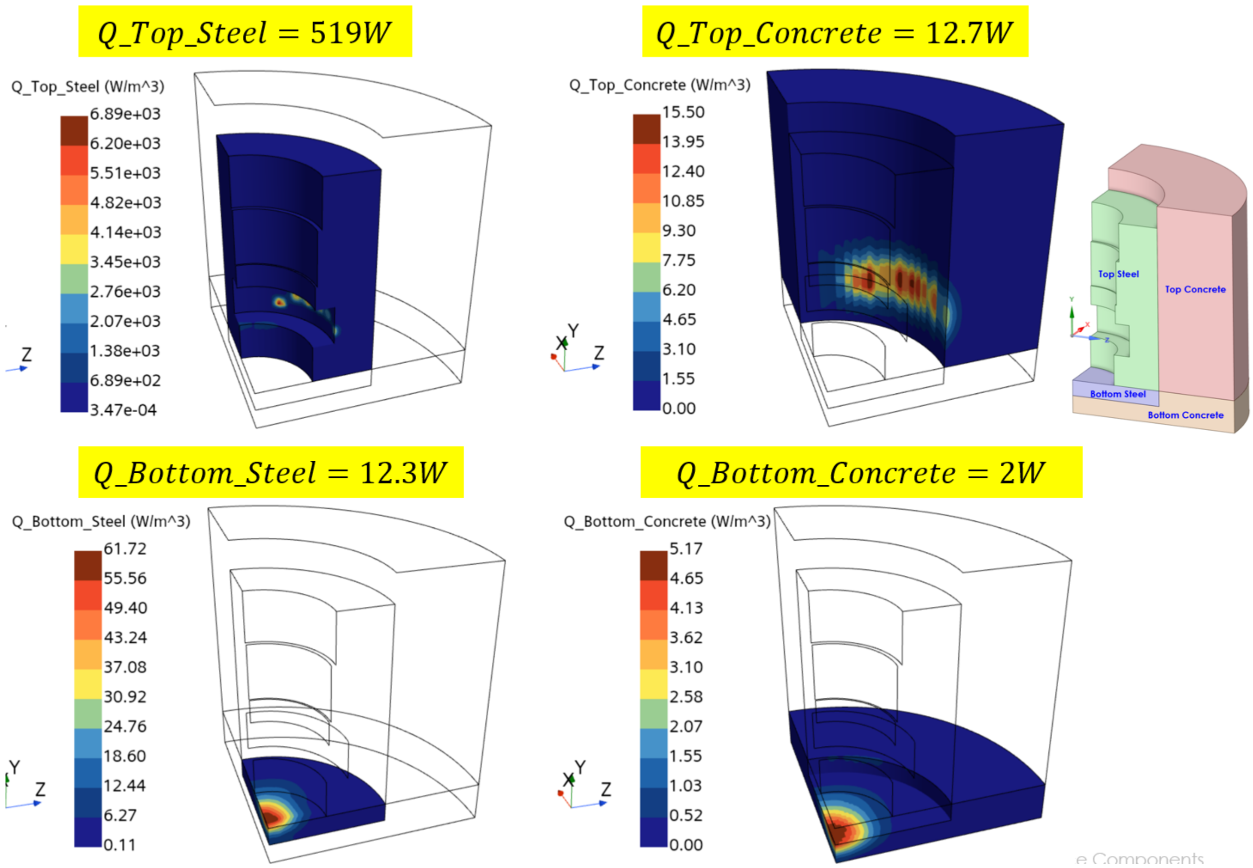



*Figure 62: Neutronics energy deposition analysis of Target Station Shielding and monolith concrete from late 2023*

## 6.7 TARGET STATION SHIELDING THERMAL ANALYSIS

The neutronics energy deposition data above was utilized to evaluate the temperature of both the simplified bulk shielding as well as the monolith concrete. It is important not to heat the concrete to a steady state temperature greater than 65 C to avoid a loss of strength in the concrete. The thermal analysis showed a maximum carbon steel temperature of 47 C and a peak concrete temperature of 46.1 C. These results provided further validation that the reduction in TSS volume was an acceptable solution to reduce overall project cost while maintaining good shielding performance. It should be noted that this analysis used a homogeneous carbon steel block to represent the target station shielding as opposed to a number of smaller blocks. A more detailed neutronics analysis of the full TSS volume as well as an analysis of the thermal performance of the target station shielding using the as-designed stacked block design is planned during final design. A full summary of the thermal analysis and results are presented in (13).

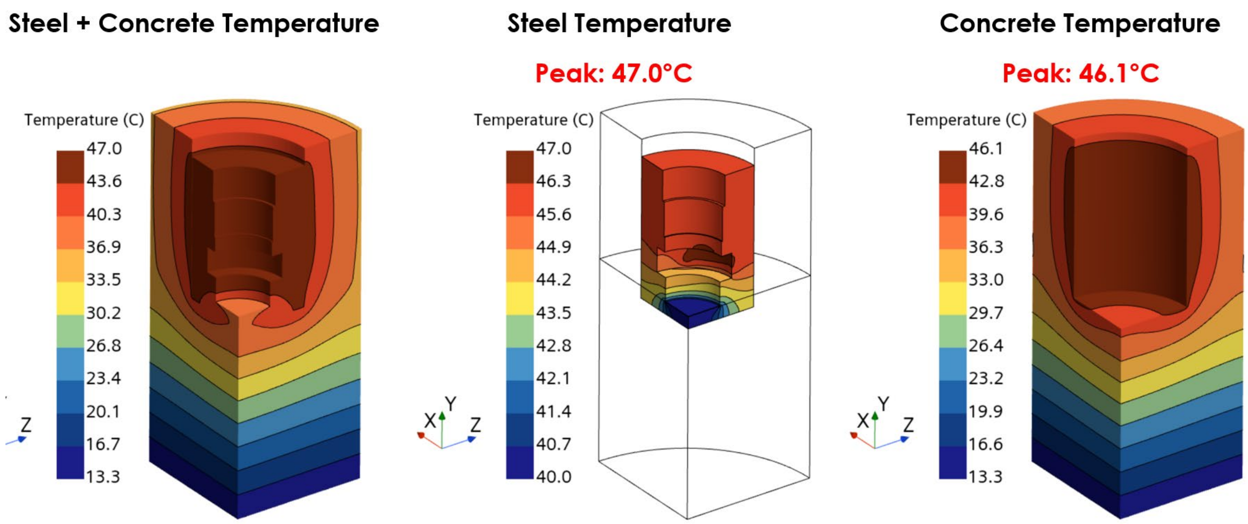



*Figure 63: Results of thermal analysis of a simplified TSS and concrete Model*

## 6.8 TARGET STATION SHIELDING STRUCTURAL ANALYSIS

Structural analysis of the target station shielding components was performed to determine the amount of stress and deflection the various components would experience under both gravity and seismic loading. Gravitational loading showed minimal vertical deflections, with the peak deflections located at the bridge shielding that supports the removable shield plates above the pipe pan as shown in Figure 64 below. Radial displacements of less than 0.07mm were seen and are a good indication of the overall stability of the bulk shielding stack.

A series of seismic calculations was also performed at each shield block layer within the bulk shielding to determine the efficacy of the tie rod interlocking method employed. The seismic analysis determined the required coefficient of friction between mating shield blocks that would be required to resist seismic displacement. The maximum coefficient of friction required to resist seismic motion under the most conservative calculations and only taking into account gravity without the seismic restraints was 0.62. When the tie rod restrain system was also taken into account the most conservative calculations showed a required coefficient of friction of only 0.19. We intend to use a class B coating that provides a 0.5 coefficient of friction in combination with the tie-rod restraints. This solution provides significant margin in a seismic event.

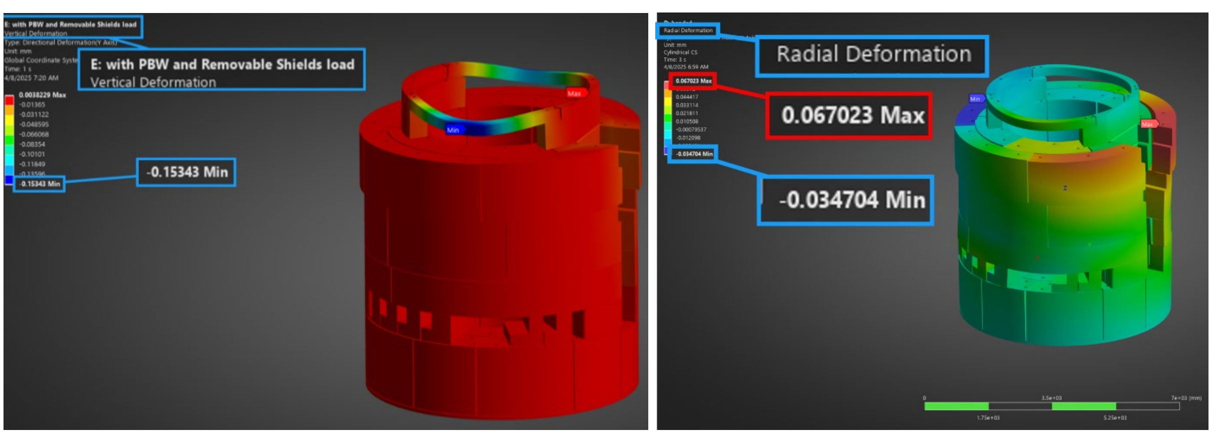



*Figure 64: Vertical (left) and radial (right) deflections of the TSS bulk shielding under gravitational loading*

## 6.9 TARGET STATION SHIELDING MANUFACTURING

### 6.9.1 Bulk Shielding Manufacturing

The bulk shielding will be constructed from low cost carbon steel. Cobble or secondary plate steel similar to what was used on the FTS bulk shielding will be utilized. This type of steel offers a very low cost per pound price while still providing excellent radiation shielding performance. All bulk shielding blocks will be fabricated completely by an outside vendor. The method of construction of each shield block will be determined in collaboration with the shielding vendor. Stacked and welded plates is the most likely construction method to be employed. Each shield block will require final machining to produce drilled thru holes, blind tapped holes and outside profile features. Efforts will be made to minimize the tolerance requirements of these shield blocks to keep costs down as much as possible. Each shield block will be coated with an anti-corrosive coating to minimize rusting over the life of the facility. The Target Station Shielding manufacturing and fabrication strategy details all steps necessary to fabricate the bulk shielding (15).

### 6.9.2 Removable Shielding Manufacturing

The AIC removable shield blocks will be constructed from the same low cost steel to fabricate the bulk shielding components. The form factor of these blocks may necessitate a different fabrication strategy from the bulk shielding blocks. Details of the manufacturing approach will be determined in collaboration with the selected shielding vendor during the procurement process. The pipe pan cover plates will also be fabricated from low cost carbon steel, likely secondary plate steel. These plates are 50mm thick, and contain basic features that are not technically challenging to machine. The Target Station Shielding manufacturing and fabrication strategy details all steps necessary to fabricate the removable shielding (15).

### 6.9.3 Core Vessel Baseplate Manufacturing

The CV Baseplate will be constructed carbon steel plate with a finished thickness of 75mm. Low cost secondary plate or conventional A36 plate may be used depending on the form factors available. A large mill will be required to machine the CV baseplate, however the machined features are all straight forward and should not pose a machining challenge. The Target Station Shielding manufacturing and fabrication strategy details all steps necessary to fabricate the CV Baseplate (15).

### 6.9.4 Bulk Shielding Liner Manufacturing

The bulk shielding liner will be constructed from carbon steel with a combination of 75mm and 25mm finished thicknesses. Low-cost secondary plate steel will be employed where possible to save costs. The bottom section of the liner is constructed from 75mm thick plate and will likely be fabricated in sections and assembled/field welded together on site due to its large size. The side walls of the bulk shielding liner are 25 mm thick and will be rolled to the proper diameter and welded to the bottom section. Grout and anchor holes will be machined into the bottom plate prior to installation. Anchor holes for mounting the first layer of bulk shielding will be located via survey and alignment and drilled/tapped in place using magnetic base drills to ensure accurate anchor hole locations. The Target Station Shielding manufacturing and fabrication strategy details all steps necessary to fabricate the Bulk Shielding Liner (15).

### 6.9.5 Pipe Pan Manufacturing

The pipe pans will be constructed from stainless steel sheet. They will be constructed in pieces and fit/field welded together in place after the bulk shielding is installed. The Target Station Shielding manufacturing and fabrication strategy details all steps necessary to fabricate the pipe pans (15).

## 6.10 TARGET STATION SHIELDING REMOTE HANDLING

All removable TSS components were designed to allow for remote handling removal and reinstallation after operation of the STS. The AIC removable shield blocks include zip lift studs over the centers of gravity of each block for hands free attachment and release from the overhead crane. The removable plates above the pipe pans include swivel hoist rings and are sized to be lifted either by the high bay crane or the 1 ton Jib crane located inside the target drive room. Additional details can be found in Interface Sheet S03000000-IST10007 (9).

## 6.11 TARGET STATION SHIELDING INSTALLATION

Installation of the TSS components into the monolith is intertwined with the installation of other Target Systems components. Installation of TSS components happens early in construction of the monolith structure, following installation of the monolith concrete. The bulk shielding liner and CV baseplate are the first components installed, followed by a portion of bulk shielding and then the CV. Bulk shielding is sequentially installed around each CV nozzle extension as they are installed onto the CV. The remaining TSS is free to be installed once all of the CV nozzle extensions are in place. Care must be taken to install and test components in the proper order to ensure proper installation is achieved. Installation details are described in greater detail in the TSS installation plan (16).

## 7. REFERENCES

| Ref | Document Title | Document Number |
|---|---|---|
| (1) | Target Station Shielding Requirements | S03070000-SRD10000 |
| (2) | Target Station Shielding Verification Plan | S03070000-TAC10000 |
| (3) | Interface Sheet for S.03.06 Vessel Systems and S.03.07 Target Station Shielding to S.04.03 Bunker | S01020500-IS0025 |
| (4) | Interface Sheet for Vessel Systems and Target Station Shielding and Conventional Facilities | S01020500-IST10064 |
| (5) | Interface Sheet – Target Station Shielding to Integrated Control Systems | S01020500-IST10220 |
| (6) | Interface Sheet for Core Vessel, Target Station Shielding and Accelerator Interface Components | S01020500-IST10217 |
| (7) | Interface Sheet for Cryogenic Moderator System and Target Station Shielding | S03000000-IST10011 |
| (8) | Interface Sheet - Target Station Shielding to Process Systems | S03000000-IST10005 |
| (9) | Interface Sheet – Target Station Shielding to Remote Handling | S03000000-IST10007 |
| (10) | Materials Handbook:  Second Target Station Project | S03010300-TDO10000 |
| (11) | STS Preliminary Hazzard Analysis Report | S01030000-ES0002 |
| (12) | STS Radiation Safety Policy and Plan | S01030100-PN0001 |
| (13) | Neutronics Monolith Energy Deposition and Thermal Analysis | N/A |
| (14) | Target Station Shielding Structural Analysis | S03070000-DAC10000 |
| (15) | Target Station Shielding Manufacturing and Fabrication Strategy | S03070000-MFP10001 |
| (16) | Vessel Systems and Target Station Shielding Installation Plan | S03060000-TDO10000 |