HTTF Ceramic Component Fabrication

Mold and Construction Document for Procurement of all Ceramic Components Used in the HTTF Internals

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This document contains the necessary instructions for the casting and handling of the ceramic components for the HTTF.

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1 INTRODUCTION

The High Temperature Test Facility (HTTF) is a facility designed to produce code validation data for the Nuclear Regulatory Commission for High Temperature Gas-Cooled Reactor system codes. The Reactor Pressure Vessel (RPV) is basically a stainless steel shell containing a large volume of ceramic materials. There are two regions within the RPV that are composed of an assembly of ceramic components. These two regions are the Core Region and the Lower Plenum Region. The thermal energy is input into the Core Region and the largest temperature gradients are expected to reside within components of this region. There are three basic ceramic component shapes: core block; the core support post; and the permanent reflector block, as shown in Figure 1-1. The remainder of this document describes the fabrication and mold handling requirements to produce the ceramic components for the HTTF.

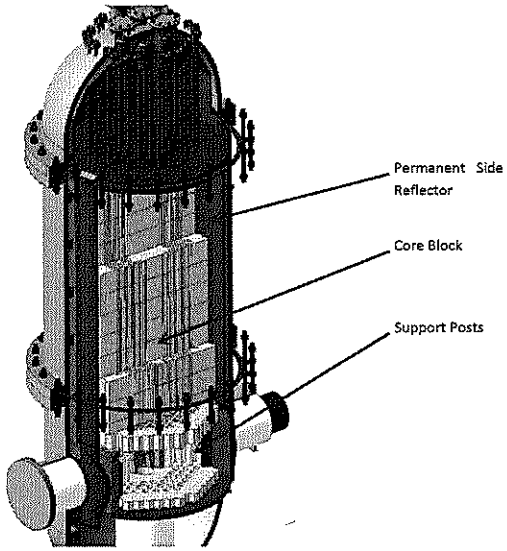

FIGURE 1-1: CUT-AWAY RENDERING OF THE HTTF RPV, WHERE THE CERAMIC COMPONENTS ARE BEIGE IN COLOR.

The ceramic blocks are arranged such that there is a ring of reflector blocks surrounding the central core stack. In the lower plenum region there is a network of core support posts that separate the Lower Plenum Floor from the Lower Plenum Roof. In total there are 252 cast ceramic components needed to compose the reactor internal assembly. The following diagram provides a cross-section of the core stack to provide a relative location for each component, see Figure 1-2.

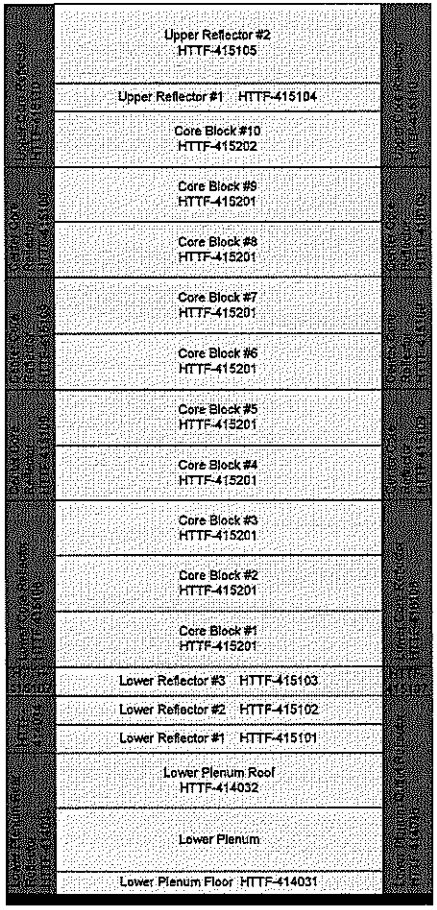

FIGURE 1-2: SIDE VIEW OF THE BLOCK ARRANGEMENT WITHIN THE REACTOR INTERNALS.

1.1 CASTING EXPECTATIONS

The subsequent sections contain details about each general shape's casting requirements, including refractory material type and cure temperature. Data sheets for each material are included as attachments in section 5.5 and 5.6. The manufacturer's recommended firing schedule is included in attachments 5.7 and 5.8. It is expected that the component firing schedule use the manufacturer's recommendations as bound for the maximum ramp rates and temperatures. Slower ramp rates are acceptable, since they provide a more conservative firing schedule.

OSU will provide:

- Refractory material
- Casting structures and configuration components
- Cast component handling fixtures

OSU will not provide:

- Consumable components, such as extra LLDPE tubing
- Component handling equipment, such as cranes and forklifts

Upon completion the casting entity will provide:

- Delivery of all materials to Radiation Center, Oregon State University Corvallis Campus
- All complete cast and fired ceramic blocks
- All unused refractory material
- All OSU provided casting equipment, forms and handling fixtures
- Completed form assembly and disassembly check lists for each casting operation
- Firing records for each cast component including date, time, ramp rate, and temperature

2 Component #1- Core and Reflector Blocks

In the central region of the ceramic components, reside the upper and lower reflector, the core blocks and the lower plenum roof and floor. These 17 ceramic blocks all possess a similar stepped hexagonal perimeter. These blocks are roughly 44 inches across the hexagonal shape and vary in thickness from 3.125 inches to 11 inches. This change in thickness drives a large variation in block mass with the thinnest block weighing 509 lbm and the thickest block weighing 1,880 lbm. All of these blocks will require a high temperature firing during the casting process to ensure dimensional stability during use. Table 2-1 contains the specific data about each of the blocks in the core stack. Figure 2-1 through Figure 2-9 display renders of the each components for visual comparison. Sections 2.1, 2.2 and 2.3 will discuss the handling and casting processes for the core stack components.

TABLE 2-1: BREAKDOWN OF THE NEEDED CORE STACK BLOCKS.

Part Number	Description	Qty	Material	Volume in^3	Mass lbm	Cure Temperature
HTTF-414031	Lower Plenum Floor	1	Greencast-94F Plus	4,803	509	1600 °C
HTTF-414032	Lower Plenum Roof	1	Greencast-94F Plus	8,689	920	1600 °C
HTTF-415101	Lower Reflector #1	1	Greencast-94F Plus	6,060	642	1600 °C
HTTF-415102	Lower Reflector #2	1	Greencast-94F Plus	5,682	601	1600 °C
HTTF-415103	Lower Reflector #3	1	Greencast-94F Plus	5,777	612	1600 °C
HTTF-415104	Upper Reflector #1	1	Greencast-94F Plus	6,041	640	1600 °C
HTTF-415105	Upper Reflector #2	1	Greencast-94F Plus	17,748	1,880	1600 °C
HTTF-415201	Core Block – Basic	9	Greencast-94F Plus	11,259	1,192	1600 °C
HTTF-415202	Core Block – Upper	1	Greencast-94F Plus	10,839	1,148	1600 °C

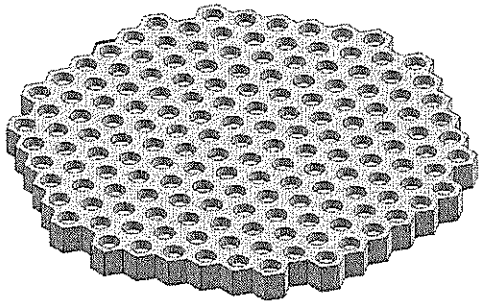

FIGURE 2-1: RENDER OF THE LOWER PLENUM FLOOR, PART NUMBER HTTF-414031.

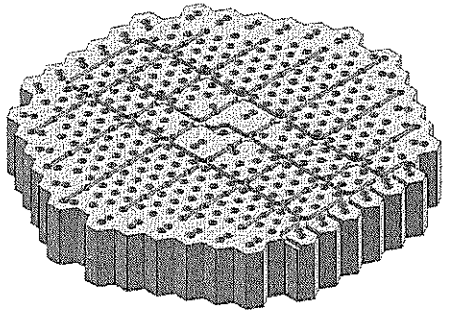

FIGURE 2-2: RENDER OF THE LOWER PLENUM ROOF, PART NUMBER HTTF-414032.

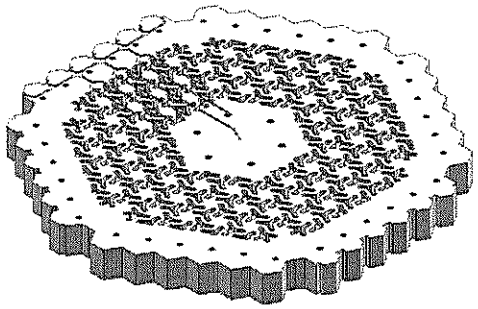

FIGURE 2-3: RENDER OF LOWER REFLECTOR #1, PART NUMBER HTTF-415101.

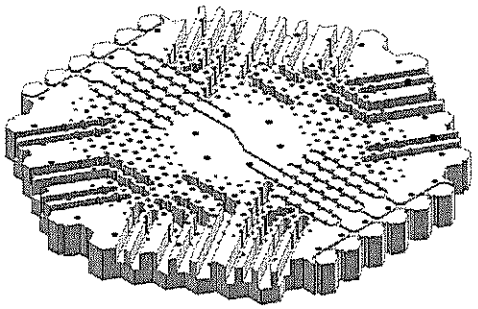

FIGURE 2-4: RENDER OF LOWER REFLECTOR #2, PART NUMBER HTTF-415102.

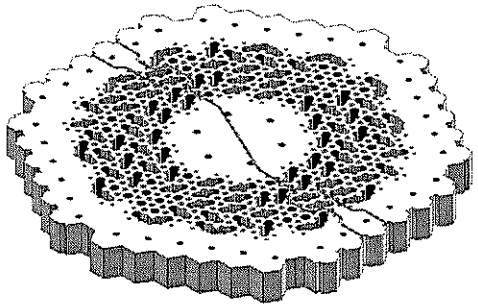

FIGURE 2-5: RENDER OF LOWER REFLECTOR #3, PART NUMBER HTTF-415103.

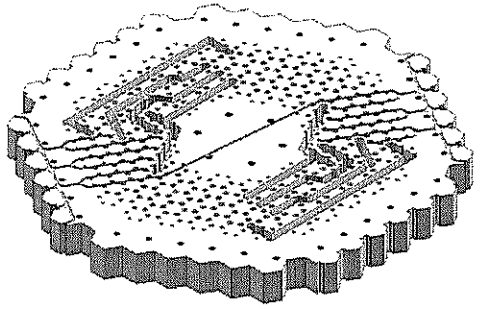

FIGURE 2-6: RENDER OF UPPER REFLECTOR #1, PART NUMBER HTTF-415104.

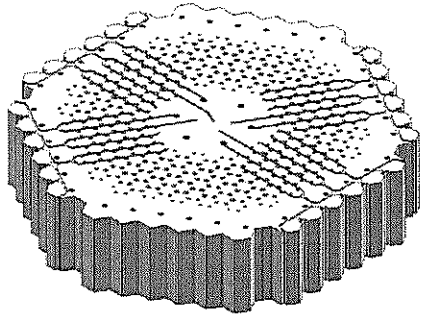

FIGURE 2-7: RENDER OF UPPER REFLECTOR #2, PART NUMBER HTTF-415105.

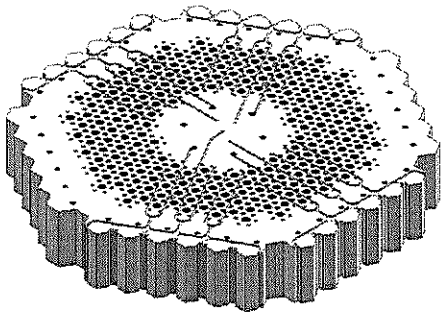

FIGURE 2-8: RENDER OF CORE BLOCK # 1-9, PART NUMBER HTTF-415201.

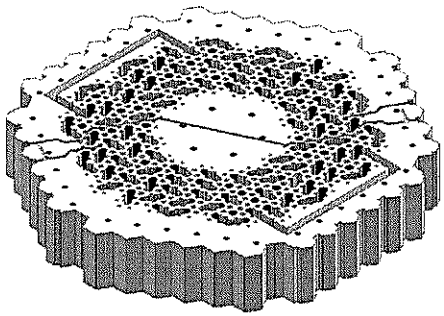

FIGURE 2-9: RENDER OF CORE BLOCK #10, PART NUMBER HTTF-415202.

2.1 Core Block Handling

The 17 blocks in the center stack of the HTTF vary in thickness from 3.125" to 11.000" and have varying hole patterns. A fixture is needed to provide an attachment point for the handling of theses plates. A few of the gas bypass channels are modified slightly to allow the lifting fixture to engage the block. This choice allows for minimal modifications to the desired block geometry to accommodate the block handling. This fixture is designed to engage the plates in 12 locations, which is intended to minimize the local stresses induced from the lifting anchors, and renders of the fixture can be seen in Figure 2-10 and Figure 2-11.

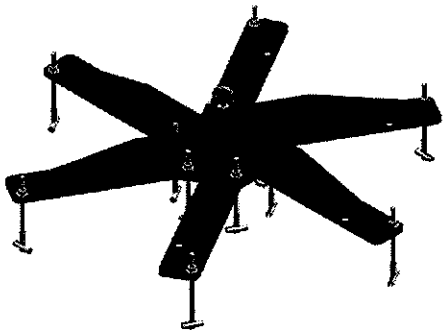

FIGURE 2-10: RENDER OF THE CORE BLOCK LIFTING FIXTURE, WHERE THE CENTRAL GREEN LIFTING EYE WILL BE USED TO CONNECT THE HOIST CONNECTION TO THE FIXTURE AND THE GOLD COLORED TOGGLE ANCHORS WILL CONNECT THE CORE BLOCKS TO THE FIXTURE.

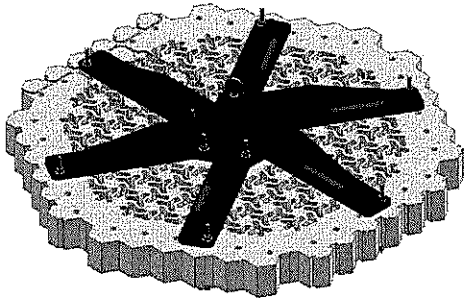

FIGURE 2-11: RENDER OF THE CORE BLOCK LIFTING JIG SHOWN ATTACHED TO THE LOWER REFLECTOR BLOCK #1.

The toggle bolts are used to slide through a 5/8" diameter hole and then rotate 90° to engage the lifting void that is cast into the block.

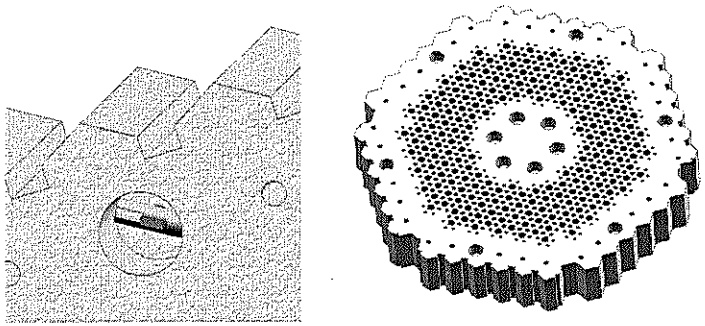

FIGURE 2-12: RENDER OF THE TOGGLE ANCHOR ENGAGED IN A CORE BLOCK (LEFT) AND THE 12 CAST VOIDS (RIGHT).

2.1.1 Toggle Anchor Mockup

To ensure an operator's ability to actuate the toggle anchor from only the top surface of the lifting assembly, a simple demonstration unit was made to test the process. This unit consisted of a block of wood, measuring 4" x 4" x 4", a toggle anchor, and bolting hardware. A visual representation of the components is shown in Figure 2-13. The toggle anchor passes through lifting holes that are cast into the core blocks. At the base of the lifting holes is a 2.0" diameter, 2.0" tall cylindrical void that is cast into the block, which provides space for the toggle bolt to rotate 90° to properly engage the core block. The toggle bolt is attached to a grade 8 fully threaded bolt and a nut and washer are used to transfer the load from the bolt to the lifting jig. The nut and washer provide the needed positional variability to accommodate various block thicknesses. This arrangement is demonstrated in the photographs shown in Figure 2-14. Once the toggle bolt is inserted into the core block and properly engaged at the top of the lifting void, the nut should be tightened to 20 ft-lbs of torque. By torqueing all 12 bolts to this modest amount the load applied to each toggle bolt should be uniform during lifting operations.

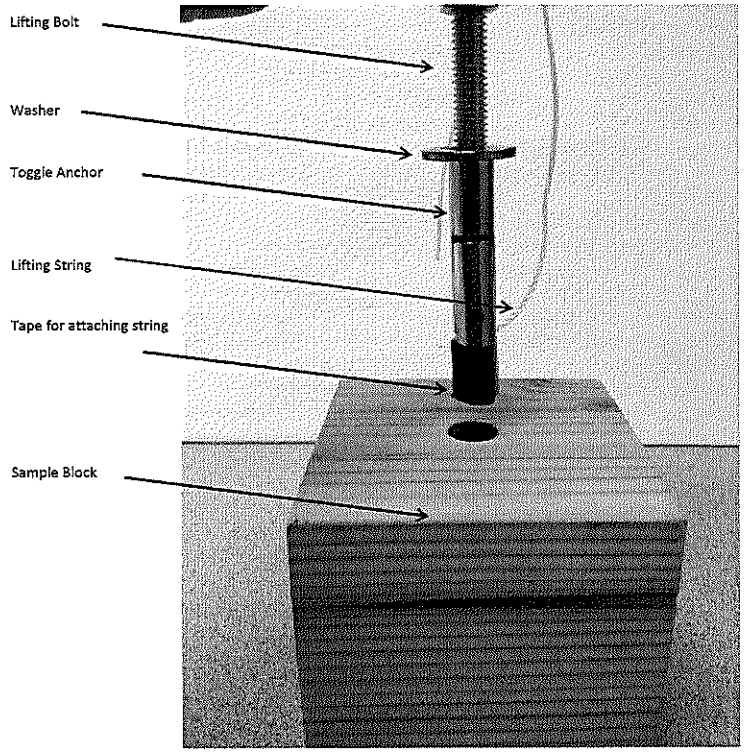

FIGURE 2-13: PHOTOGRAPH OF THE TOGGLE BOLT MOCKUP MATERIALS. IT SHOULD BE NOTED THAT THE STRING PASSES THROUGH THE TOGGLE ANCHOR JUST BELOW THE PIVOT, BEFORE BEING ATTACHED TO THE LOWER ANCHOR SECTION.

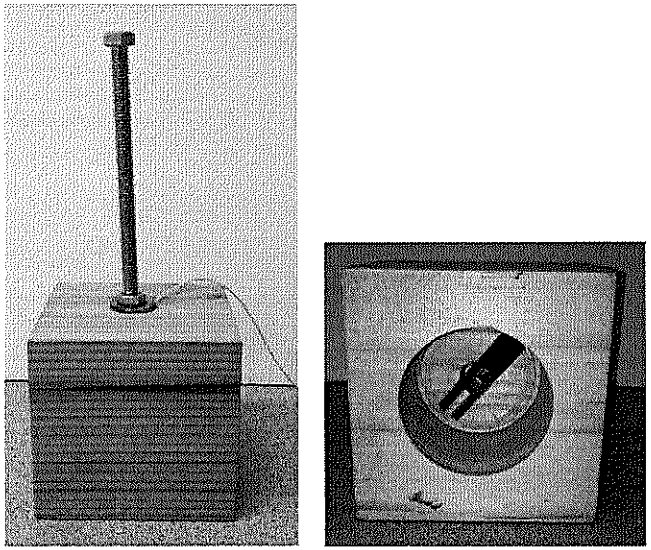

FIGURE 2-14: IMAGE OF THE INSTALLED TOGGLE BOLT: SIDE VIEW (LEFT) AND BOTTOM VIEW (RIGHT).

To actuate the toggle anchor from a remote location, a simple modification is needed. A string must be connected to the lower section of the toggle anchor, in this case using electrical tape. The simplicity of this connection method is that the string performs no function during the actual lifting process and is simply replaced if damaged when tensioning the lifting bolt. As shown in Figure 2-15, the toggle anchor hangs vertically with no lifting load applied. This function is essential for removing the anchor once the lifting operation is completed. To actuate the toggle anchor, simply insert the anchor and bolt assembly into the lifting channel, lift up on the string to rotate the toggle anchor and lift to bolt to properly engage the lifting void ceiling. With the anchor properly seated, torque the nut and repeat for the remaining lifting locations on the core block.

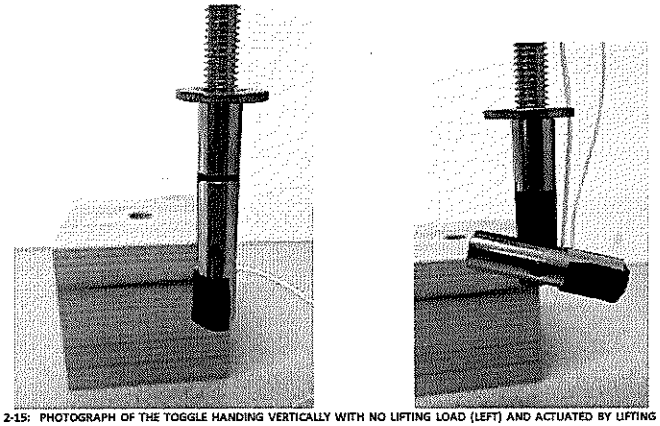

FIGURE 2-15: PHOTOGRAPH OF THE TOGGLE HANDING VERTICALLY WITH NO LIFTING LOAD (LEFT) AND ACTUATED BY LIFTING ON THE STRING THAT IS TAPED TO THE LOWER SECTION OF THE TOGGLE ANCHOR (RIGHT).

2.2 Core Stack Mold Configurations and Handling

The core block mold is designed to accommodate all nine core block geometries. The steel components of the mold provide the structure for the mold while all the UHMW components will be exchanged to accommodate the various configurations. A diagram depicting the basic mold components is shown in Figure 2-16. The specific components for each block geometry configuration are detailed in Table 2-2. Renders of each of the geometric configurations are shown in Figure 2-17 through Figure 2-25.

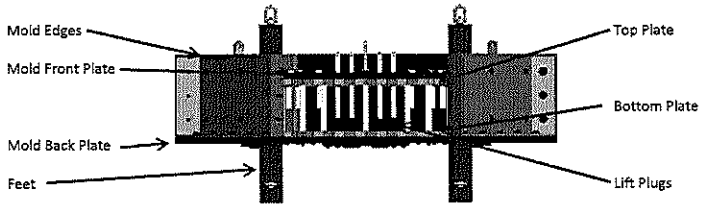

FIGURE 2-16: TOP VIEW OF THE CORE BLOCK MOLD.

TABLE 2-2: TABULATION OF THE MOLD CONFIGURATIONS FOR EACH BLOCK DESIGN.

Part Number	Description	Block Height	Top Plate	Bottom Plate	Spacer Posts	Edge Plates	Lift Plug Type
HTTF-414031	Lower Plenum Floor	3.125"	414031 Top	414031 Bottom	414031 Spacer	5 Edge Plain	12 Long
HTTF-414032	Lower Plenum Roof	7.800"	414032 Top	4140332 Bottom	415201 Spacer	5 Edge Plain	12 Flush
HTTF-415101	Lower Reflector #1	4.000"	415101 Top	415101 Bottom	415101 Spacer	1 Edge Plain 4 Edge Inst	12 Long
HTTF-415102	Lower Reflector #2	4.000"	415102 Top	415102 Bottom	415101 Spacer	3 Edge Plain 2 Edge Inst	4 Flush 8 long
HTTF-415103	Lower Reflector #3	4.000"	415103 Top	415103 Bottom	415101 Spacer	1 Edge Plain 4 Edge Inst	12 Long
HTTF-415104	Upper Reflector #1	4.000"	415104 Top	415104 Bottom	415101 Spacer	1 Edge Plain 4 Edge Inst	12 Long
HTTF-415105	Upper Reflector #2	11.000"	415105 Top Gas Sleeve	415102 Bottom	415105 Spacer	1 Edge Plain 4 Edge Inst	12 Long
HTTF-415201	Core Block – Basic	7.800"	415201 Front Gas Sleeve	415201 Back	415201 Spacer	1 Edge Plain 4 Edge Inst	12 Long
HTTF-415202	Core Block – Upper	7.800"	415202 Top	415201 Back	415201 Spacer	1 Edge Plain 4 Edge Inst	12 Long

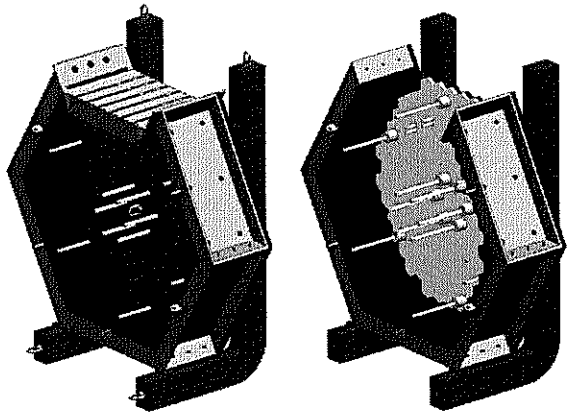

FIGURE 2-17: RENDER OF THE CORE MOLD SHOWN IN THE "414031 LOWER PLENUM FLOOR" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

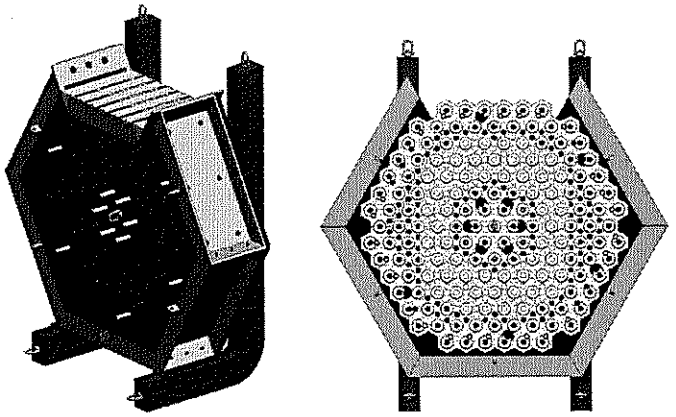

FIGURE 2-18: RENDER OF THE CORE MOLD SHOWN IN THE "414032 LOWER PLENUM ROOF" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

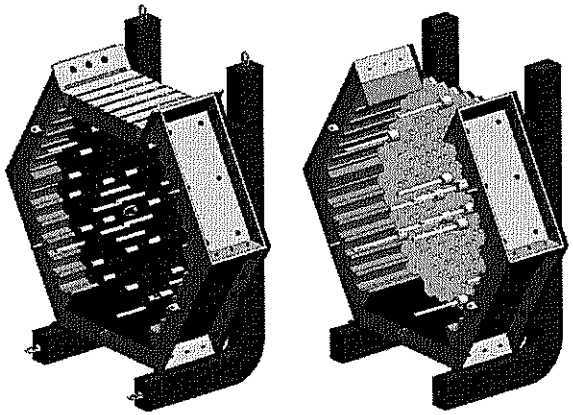

FIGURE 2-19: RENDER OF THE CORE MOLD SHOWN IN THE "415101 LOWER REFLECTOR #1" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

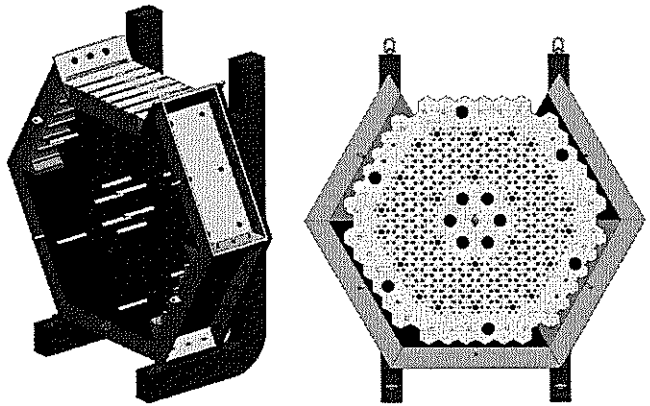

FIGURE 2-20: RENDER OF THE CORE MOLD SHOWN IN THE "415102 LOWER REFLECTOR #2" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT). LIFT PLUG LOCATIONS NOTED BY COLOR: PURPLE = FLUSH LIFT PLUG AND RED = LONG LIFT PLUG.

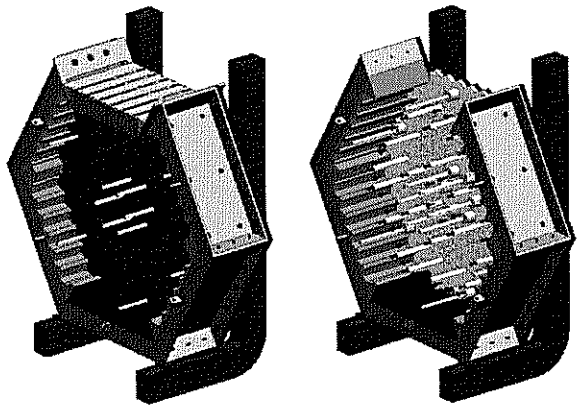

FIGURE 2-21: RENDER OF THE CORE MOLD SHOWN IN THE "415103 LOWER REFLECTOR #3" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

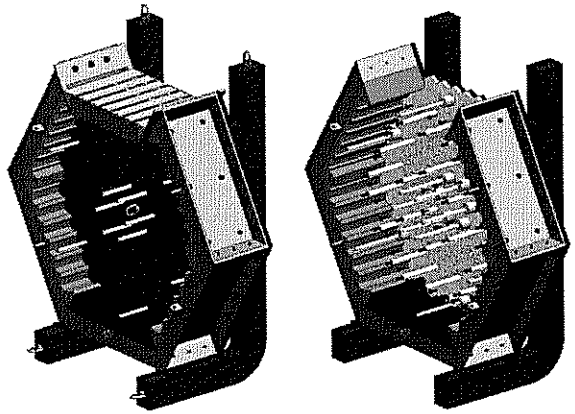

FIGURE 2-22: RENDER OF THE CORE MOLD SHOWN IN THE "415104- UPPER REFLECTOR #1" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

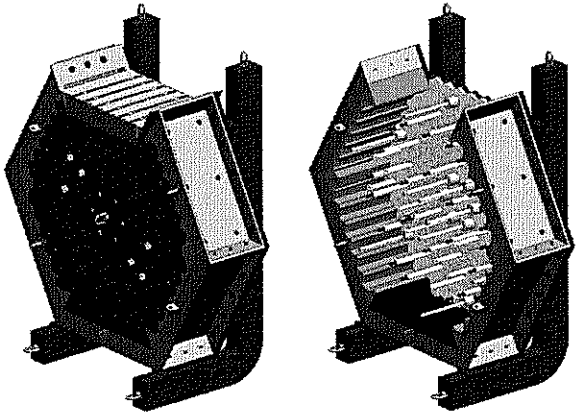

FIGURE 2-23: RENDER OF THE CORE MOLD SHOWN IN THE "415105 UPPER REFLECTOR #2" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

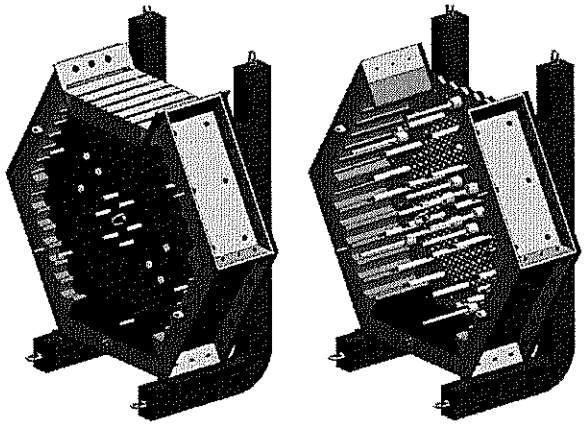

FIGURE 2-24: RENDER OF THE CORE MOLD SHOWN IN THE "415201 CORE BLCOK #1-9" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

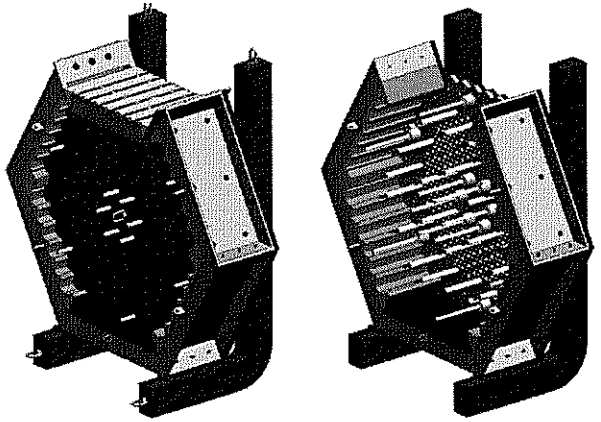

FIGURE 2-25: RENDER OF THE CORE MOLD SHOWN IN THE "415202 CORE BLOCK #10" CONFIGURATION: FULL ASSEMBLY (LEFT) AND WITH THE FRONT PLATE, TOP AND CAP REMOVED FOR CLARITY (RIGHT).

2.2.1 Core Block Mold Handling

The Core Block Mold is designed with multiple lifting points. To move the entire mold or switch between the upright and horizontal configurations, there are four hoist rings installed on the feet. An adjustable chain sling is intended to provide the connection between the hoist rings and lifting device. To lift the front plate with the attached top plate there is a separate hoist ring attached to the front plate. Each edge plate is fitted with a lifting eye to provide an attachment point when handling the edges. These locations are depicted in Figure 2-26. The Core Block mold is designed to be cast in the "Vertical" position, where the resultant part is rotated 90° from its operational orientation. The mold will be rotated onto its back in the "Horizontal" position during mold disassembly. These two orientations are shown in Figure 2-27.

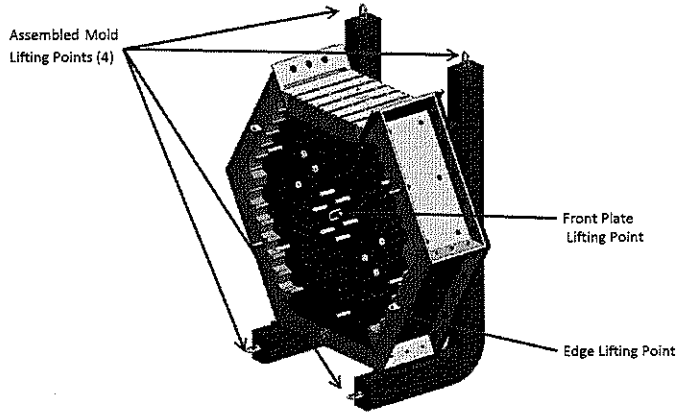

FIGURE 2-26: RENDER OF THE ASSEMBLED MOLD DENOTING THE LIFTING POINTS.

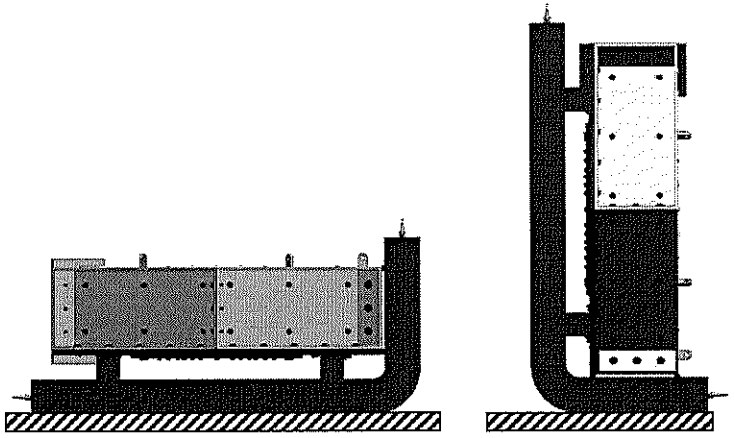

FIGURE 2-27: RENDER OF THE CORE BLOCK MOLD, SHOWN IN THE "HORIZONTAL" (LEFT) AND "VERTICAL" (RIGHT) CONFIGURATIONS.

2.3 Core Stack Mold Assembly and Disassembly

The assembly of the Core Block mold will vary slightly with each selected block geometry since there are different combinations of void assemblies and top and bottom plates used, shown in Figure 2-28. The assembly begins with the steel structure consisting of the back plate and the feet in the vertical orientation. The lift plugs, bottom plate, and spacer posts are then installed, shown in Figure 2-29. The mold then should be rotated into the Horizontal orientation. After the orientation change, the mold edges and edge plates should be installed, as shown in Figure 2-30. Following the edges, the front plate / top plate assembly should be installed, as shown in Figure 2-31. It should be noted that the spacer posts installed in a previous step provide threaded portions that maintain the separation between the top and bottom plates, as shown in Figure 2-32. With the front and back plates properly engaged the void assemblies are to be installed. Once this task is done, rotate the mold into the vertical position and install the Mold Edge Cap to complete the full mold assembly, as shown in Figure 2-33. The cap installation can be delayed until the majority of the refractory material has been poured into the mold allow a larger opening.

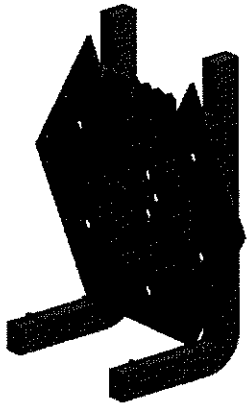

FIGURE 2-28: RENDER OF THE MOLD BACK PLATE AND FEET IN THE VERTICAL POSITION.

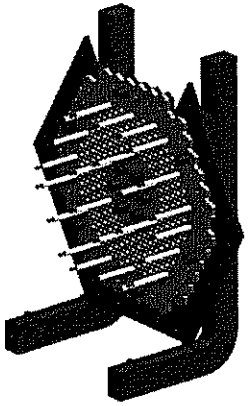

FIGURE 2-29: RENDER OF THE BOTTOM PLATE, LIFTING PLUGS, AND SPACERS INSTALLED.

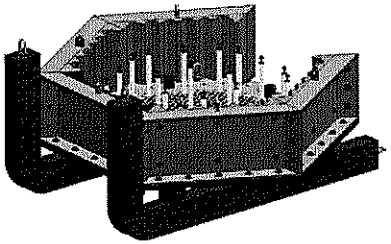

FIGURE 2-30: RENDER OF THE MOLD PLACED IN THE HORIZONTAL POSITION AND HAVING THE MOLD EDGES AND EDGE PLATES INSTALLED.

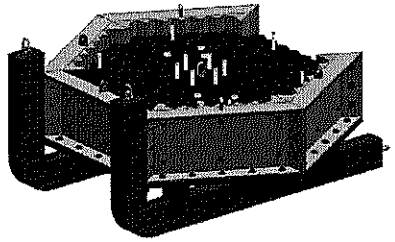

FIGURE 2-31: RENDER OF THE MOLD WITH THE TOP PLATE, FRONT PLATE, AND GAS SLEEVES INSTALLED. AT THIS STEP, ALL VOID ASSEMBLIES WOULD BE INSTALLED.

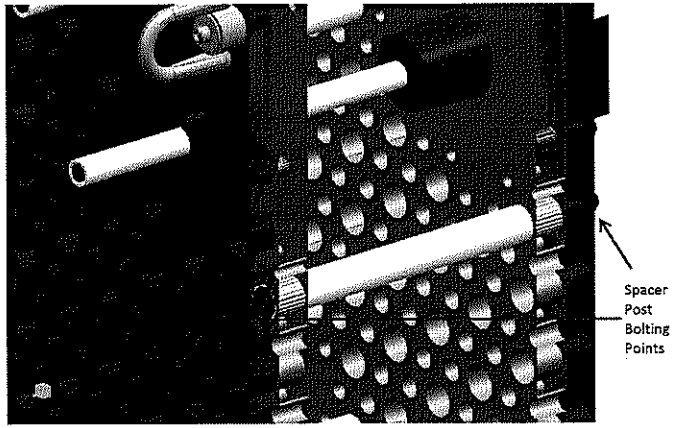

FIGURE 2-32: DETAIL OF THE SPACER POST COMPONENTS ENGAGING THE FRONT AND BACK PLATES.

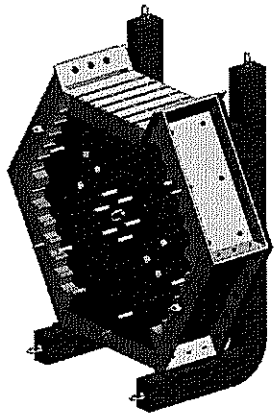

FIGURE 2-33: RENDER OF THE FULLY ASSEMBLED CORE BLOCK MOLD, IN THE VERTICAL POSITION.

2.3.1 Lift Port

The lift plugs are designed to be removed from the back plate of the mold. The removal of the plugs allows the core block lifting jig to engage the cast components to remove them from the mold. There are 12 plugs in total, all of which are bolted to the back plate of the core mold. The attachment locations can be seen in Figure 2-34. In components 414032 and 415102 the characteristics of the top face features interfere with the cast lifting void. In these two blocks some or all of the "long" lifting plugs will be exchanged with plugs in the "flush" configuration. The Lift Plug mounting plate bolts to the back plate using two bolts. There is a center bolt to attach the plastic plugs to the mounting plate. The plate is fitted with two threaded locations to aid in the removal of the lift plugs. These bolt locations are detailed in Figure 2-35. During the core block mold assembly, the lift plug should be fitted with the proper end piece to provide either the long or flush configuration. The two configurations can be seen in Figure 2-36 and Figure 2-37.

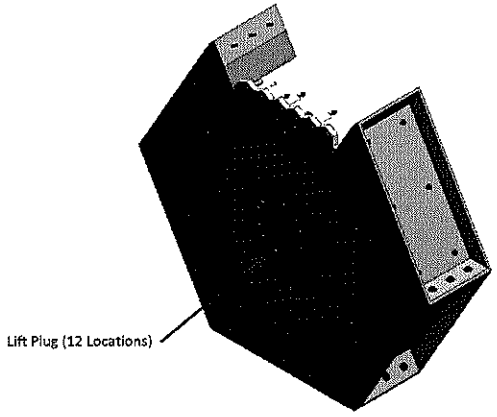

FIGURE 2-34: RENDER OF THE BACK OF THE CORE BLOCK MOLD DENOTING THE LIFT PLUG LOCATIONS, SHOWN IN BLACK, NOTE THE CORE BLOCK FEET HAVE BEEN REMOVED FOR CLARITY.

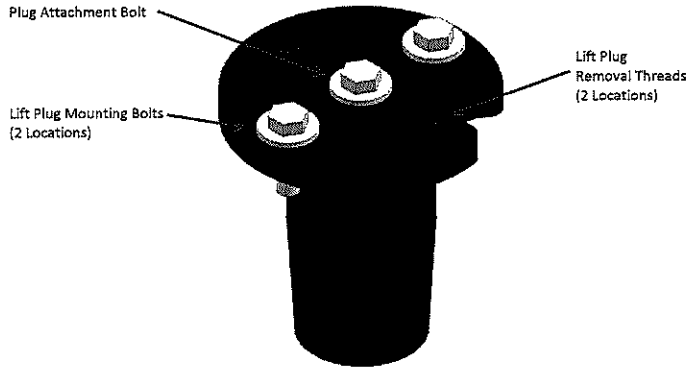

FIGURE 2-35: RENDER OF THE LIFT PLUG MOUNTING PLATE.

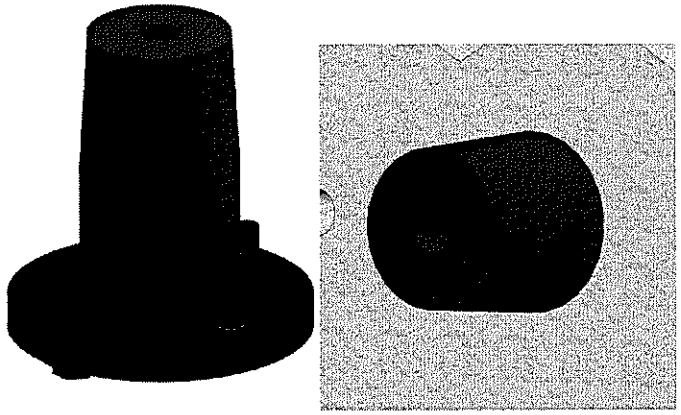

FIGURE 2-36: RENDER OF THE "LONG" LIFTING PLUG CONFIGURATION ASSEMBLED (LEFT) AND INSTALLED IN THE MOLD (RIGHT).

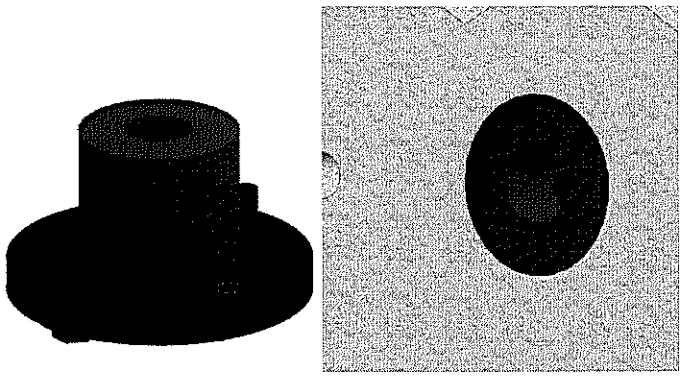

FIGURE 2-37: RENDER OF THE "FLUSH" LIFTING PLUG CONFIGURATION ASSEMBLED (LEFT) AND INSTALLED IN THE MOLD (RIGHT).

2.3.2 Core Mold Edge Configurations

Certain blocks require raceways be cast into their sides. To accomplish this, two edge molds have been developed, one with raceways and one without. The casting details specify which edge plate is required for each block, and the associated renders include the appropriate color coding to designate which edge is used. Both edges are fastened to the Mold Edges in a similar manner. Also the top and bottom plates will contain the mating interface to provide further confirmation of the proper face installation. For comparison, the two edge plates are shown in Figure 2-38.

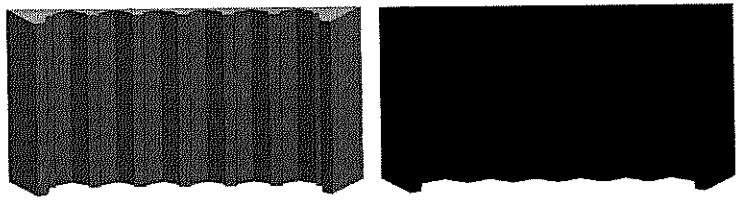

FIGURE 2-38: RENDER OF THE "INSTRUMENT EDGE PLATE" (LEFT) AND THE "PLAIN EDGE PLATE" (RIGHT).

2.3.3 Core Mold Voids

The core blocks require up to 700 cylindrical holes to pass through the block from the top to the bottom face. Due to the hole proximity and quantity, it is not practical to apply a taper to each cylindrical face. Instead, the mold is designed to use a two component system to form these voids. A steel rod surrounded by a thin-walled piece of plastic tubing is inserted into the mold through holes drilled in the top and bottom plates of the mold. The steel rod provides the structural means to create the void during casting, while the plastic tube makes the mold assembly and disassembly of the mold easier. Each of the voids cast through the core block will use this configuration. A render of the components can be seen in Figure 2-39. The void rods are threaded on one end to aid in void removal.

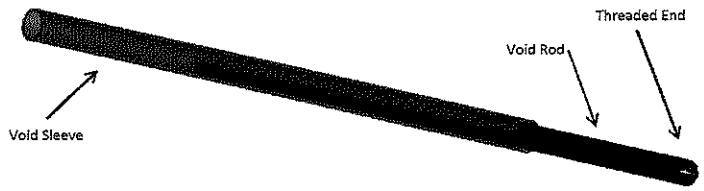

FIGURE 2-39: RENDER OF A VOID ASSEMBLY DISPLAYING THE CENTER ROD (BLUE) AND THE PLASTIC SLEEVE (RED).

2.3.4 Core Block Mold Assembly Check List (to be completed before each casting operation)

Mold Configuration: _____ Part #: _____

Operator Names: _____ _____

Date: _____ Time: _____

- ☐ Remove all residual refractory material and clean all surfaces.
- ☐ Orient Steel Structure in the "Vertical Orientation" using lifting mounts on the feet.
- ☐ Assemble Lift Ports with proper spacer: Flush or Long.
- ☐ Install Lift ports into back plate.
- ☐ Install appropriate bottom plate onto back plate.
- ☐ Install plate spacers
- ☐ Orient Steel Structure in the "Horizontal Orientation" using lifting mounts on the feet.
- ☐ Assemble Mold Edges with the appropriate edge plates.
- ☐ Install Mold Edges.
- ☐ Bolt appropriate Top Plate onto the Front Plate.
- ☐ Install Front Plate, ensuring proper Top Plate orientation.
- ☐ Install Gas Sleeves, if appropriate.
- ☐ Install all void assemblies.
- ☐ Install Edge Cap (Note: This can be completed during the casting process to allow a larger opening for the majority of the mold filling.
- ☐ Double check all hardware correctly installed and tightened.
- ☐ Note any problems in assembly below:

Signature _____

Signature _____

2.3.5 Core Block Mold Disassembly Check List (to be completed after each casting operation)

Mold Configuration: _____ Part #: _____

Operator Names: _____ _____

Date: _____ Time: _____

- ☐ Begin with the mold in the "Vertical Orientation."
- ☐ Remove Mold Cap and Lift Plugs.
- ☐ Remove all void assemblies
- ☐ Rotate mold in to the "Horizontal Orientation."
- ☐ Remove Mold Edges.
- ☐ Remove Mold Front with the Top plate still attached.
- ☐ Attach the Core Block Lifting Jig.
- ☐ Lift finished core block out of the mold.
- ☐ Note any problems in the disassembly below:

Signature _____

Signature _____

3 Component #2- Permanent Side Reflector Blocks

The Upper Reflector, Core, and Lower Reflector blocks are surrounded by the Permanent Side Reflector which is an assembly of 36 blocks with the general shape of a trapezoidal-prism measuring roughly 29" wide by 7" deep and up to 24" tall, and with a maximum calculated weight of 321 lbm. The Lower Plenum is surrounded by seven Permanent Side Reflector blocks measuring up to 29" wide by 7" deep and 28" tall, and with a calculated maximum weight of 415 lbm. Table 3-1 contains quantities, material types, and cure temperatures for each of the reflector block geometries. Renders of the nine block geometries can be seen in Figure 3-1 through Figure 3-5.

TABLE 3-1: BREAKDOWN OF THE NEEDED 43 REFLECTOR BLOCKS.

Part Number	Description	Qty	Material	Volume in^3	Mass lbm	Cure Temperature
HTTF-414033	Lower Plenum Lower Rear	1	Greencast-94F Plus	2987	316	1000 °C
HTTF-414034	Lower Plenum Upper Rear	1	Greencast-94F Plus	1204	128	1000 °C
HTTF-414035	Lower Plenum Outlet	1	Greencast-94F Plus	3303	350	1000 °C
HTTF-414036	Lower Plenum - 6 Heater	2	Greencast-94F Plus	3920	415	1000 °C
HTTF-414037	Lower Plenum - 9 Heater	2	Greencast-94F Plus	3763	399	1000 °C
HTTF-415107	Instrument Path Core Outer Reflector	6	Thor 80 Castable	590	53	1000 °C
HTTF-415108	Lower Core Outer Reflector	6	Thor 80 Castable	3578	321	1000 °C
HTTF-415109	Center Core Outer Reflector	18	Thor 80 Castable	2382	214	1000 °C
HTTF-415110	Upper Core Outer Reflector	6	Thor 80 Castable	3486	313	1000 °C

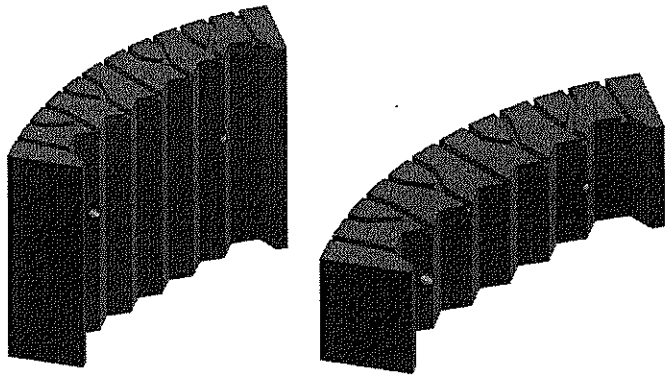

FIGURE 3-1: RENDER OF THE LOWER PLENUM LOWER REAR REFLECTOR, HTTF-414033 (LEFT) AND THE LOWER PLENUM UPPER REAR REFLECTOR, HTTF-414034 (RIGHT).

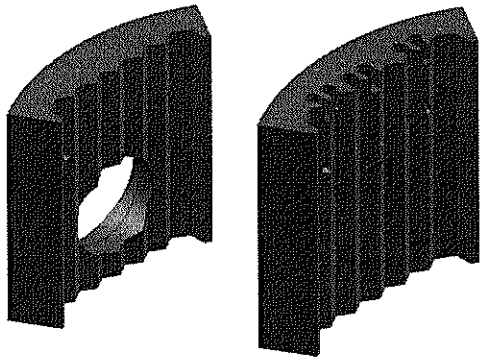

FIGURE 3-2: RENDER OF THE LOWER PLENUM OUTLET REFLECTOR, HTTF-414035 (LEFT), AND THE LOWER PLENUM - 6 HEATER REFLECTOR, HTTF-414036 (RIGHT).

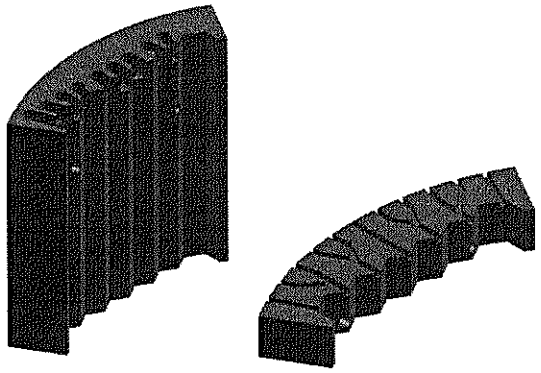

FIGURE 3-3: RENDER OF THE LOWER PLENUM - 9 HEATER REFLECTOR, HTTF-414037 (LEFT), AND THE INSTRUMENT PATH CORE OUTER REFLECTOR BLOCK, HTTF-415107 (RIGHT).

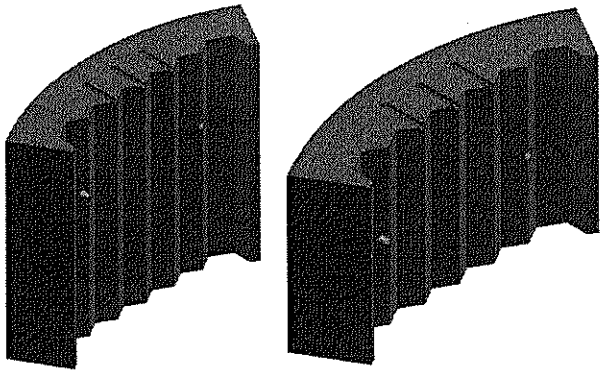

FIGURE 3-4: RENDER OF THE LOWER CORE OUTER REFLECTOR BLOCK, HTTF-415108 (LEFT), AND THE CENTER CORE OUTER REFLECTOR BLOCK, HTTF-415109 (RIGHT).

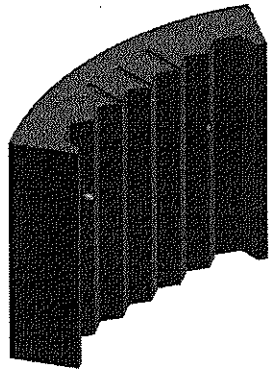

FIGURE 3-5: RENDER OF THE UPPER CORE OUTER REFLECTOR BLOCK: HTTF-415110.

3.1 Reflector Block Handling

A steel jig will be utilized to lift the reflector blocks with an overhead crane. This jig is designed to engage the lifting ports that are cast into the reflector blocks. These lifting ports are cylinders 1.000" in diameter on a 14.700" spacing and no more the 8.000" on center below the upper face of the block. The jig is designed with a central lifting eye, where a clevis and sling can be used to connect to the hoist eye. A render of this jig can be found in Figure 3-6. During general handling, the reflector blocks can be engaged from either the cylindrical face or the sawtooth face as shown in Figure 3-7 and Figure 3-8.

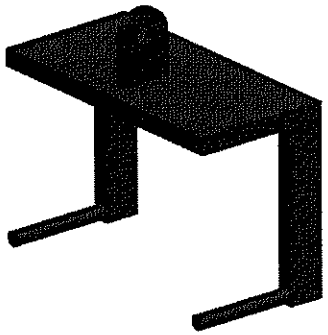

FIGURE 3-6: RENDER OF THE SIDE REFLECTOR LIFING JIG.

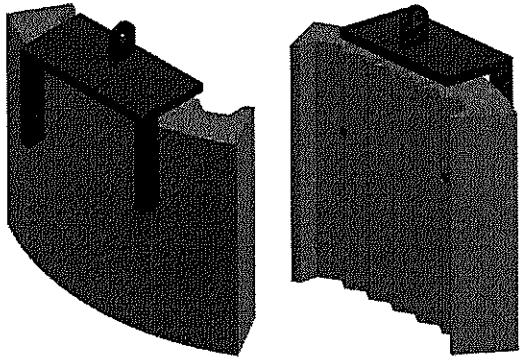

FIGURE 3-7: RENDER OF THE LIFTING JIG SUPPORTING A CORE REFLECTOR BLOCK FROM THE OUTER FACE.

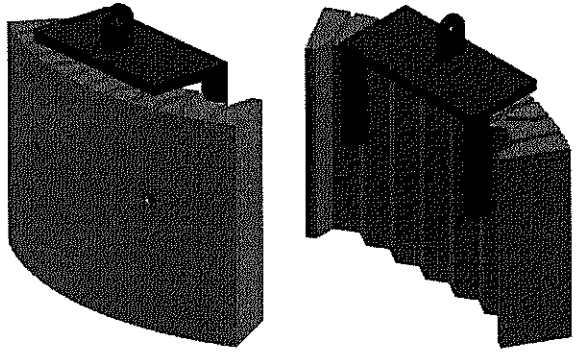

FIGURE 3-8: RENDER OF THE LIFTING JIG SUPPORTING A LOWER PLENUM REFLECTOR BLOCK FROM THE INNER SAWTOOTH FACE.

3.2 Reflector Block Mold Configurations and Handling

The PSR mold is designed to provide a form for all 9 different outer reflector geometries. The steel components of the mold, in addition to the inner and outer UHMW plates, are intended to be used in every casting, while the spacer plates, heater void rods, top plates and bottom plates will change based on the desired shape. The mold is designed to allow the top and bottom plates to move toward the center of the mold, which allows the height of the finished block to be reduced. There is only one upper spacer that is needed, while there is a need for six different thicknesses of lower spacers. The lower spacers are numbered 1 through 6 where number Lower Plate #1 is touching the metallic frame. The plates are labeled in Figure 3-9 where the mold is shown in the "Instrument Path Core Outer Reflector" configuration. Table 3-2 outlines the specific top, bottom, and spacer plates to use for each configuration. Figure 3-10 through Figure 3-18 provide renders of the mold in each configuration. Similar to the technique discussed in Section 2.3.3, the lifting voids and heater voids used in the PSR mold will use a plastic jacketed steel rod assembly to great the necessary cast voids.

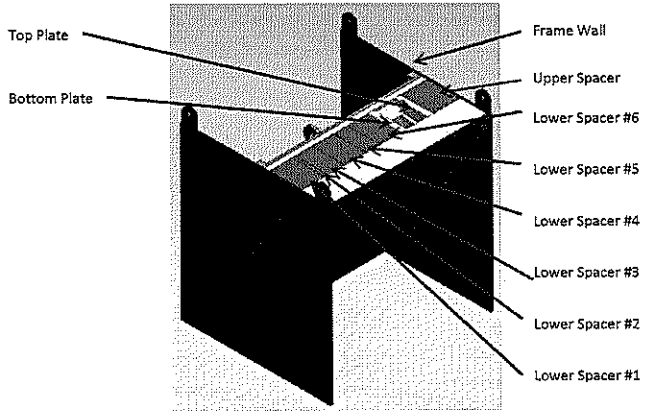

FIGURE 3-9: RENDER OF THE PSR MOLD IN THE "INSTRUMENT PATH CORE OUTER REFLECTOR" CONFIGURATION, WHERE THE SPACER PLATES ARE COLORED GREY AND THE TOP AND BOTTOM PLATES ARE COLORED WHITE.

TABLE 3-2: TABLE LISTING THE MOLD PLATES USED IN EACH BLOCK.

Part Number	Description	Block Height	Top Plate	Bottom Plate	Spacer Plates
HTTF-414033	Lower Plenum Lower Rear	19.625"	Instrument Inlet Top	Basic Bottom Plate	Lower Plate #1 Lower Plate #2 Lower Plate #3
HTTF-414034	Lower Plenum Upper Rear	8.000"	Instrument Inlet Top	Basic Bottom Plate	Lower Plate #1 Lower Plate #2 Lower Plate #3 Lower Plate #4 Lower Plate #5 Upper Plate
HTTF-414035	Lower Plenum Outlet	27.625"	Instrument Channel Top	Basic Bottom Plate	Outlet Plug
HTTF-414036	Lower Plenum - 6 Heater	27.625"	6 Heater Top	6 Heater Bottom	6 Heater Rod Assemblies
HTTF-414037	Lower Plenum - 9 Heater	27.625"	9 Heater Top	9 Heater Bottom	9 Heater Rod Assemblies
HTTF-415107	Instrument Path Core Outer Reflector	4.000"	Instrument Inlet Top	Basic Bottom Plate	Lower Plate #1 Lower Plate #2 Lower Plate #3 Lower Plate #4 Lower Plate #5 Lower Plate #6 Upper Plate
HTTF-415108	Lower Core Outer Reflector	23.400"	Instrument Channel Top	Basic Bottom Plate	Lower Plate #1
HTTF-415109	Center Core Outer Reflector	15.600"	Instrument Channel Top	Basic Bottom Plate	Lower Plate #1 Lower Plate #2 Lower Plate #3 Lower Plate #4
HTTF-415110	Upper Core Outer Reflector	22.800"	Instrument Channel Top	Basic Bottom Plate	Lower Plate #1 Lower Plate #2

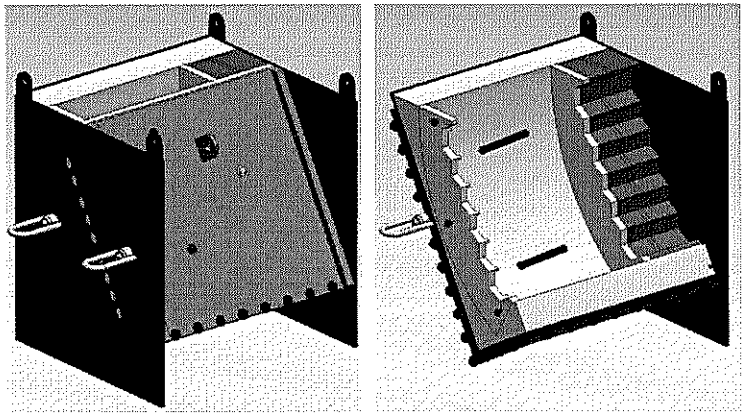

FIGURE 3-10: RENDER OF THE PSR MOLD IN THE "LOWER PLENUM LOWER REAR" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

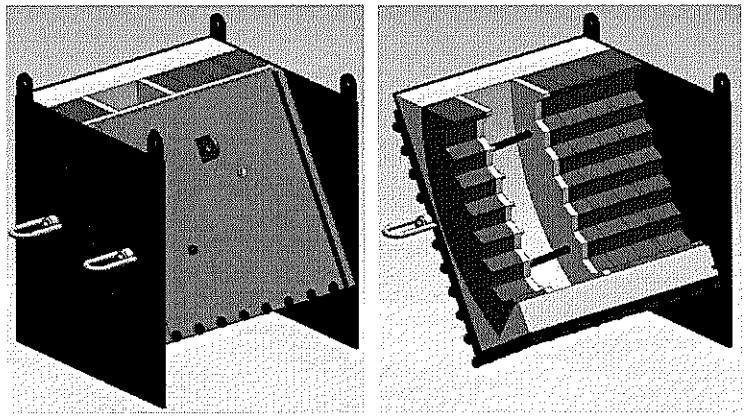

FIGURE 3-11: RENDER OF THE PSR MOLD IN THE "LOWER PLENUM UPPER REAR " CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

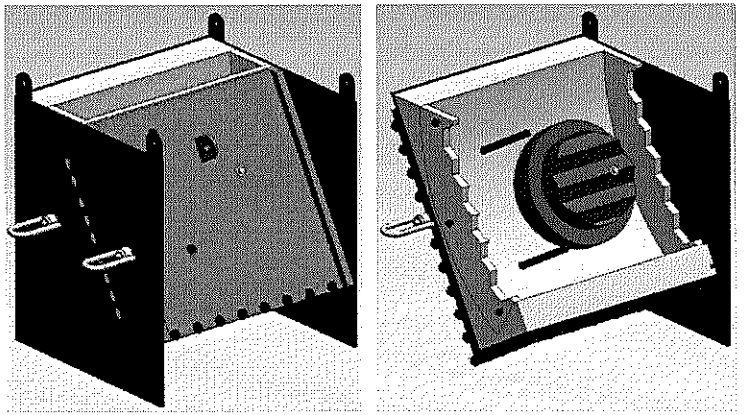

FIGURE 3-12: RENDER OF THE PSR MOLD IN THE "LOWER PLENUM OUTLET" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

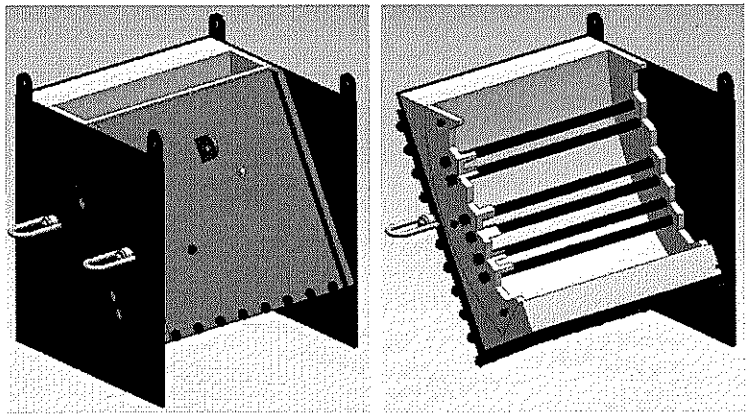

FIGURE 3-13: RENDER OF THE PSR MOLD IN THE "6 HEATER" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

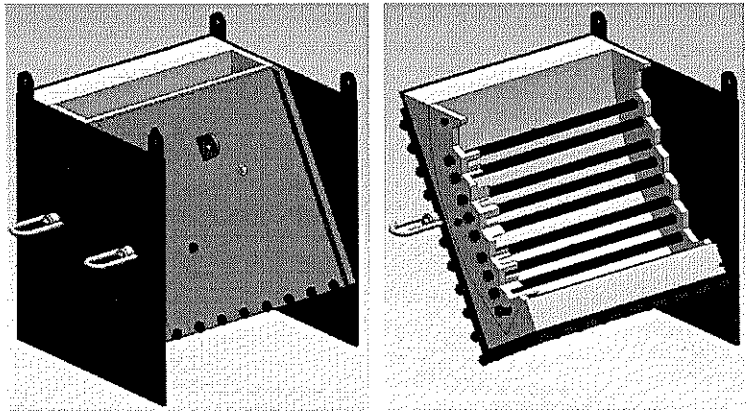

FIGURE 3-14: RENDER OF THE PSR MOLD IN THE "9 HEATER" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

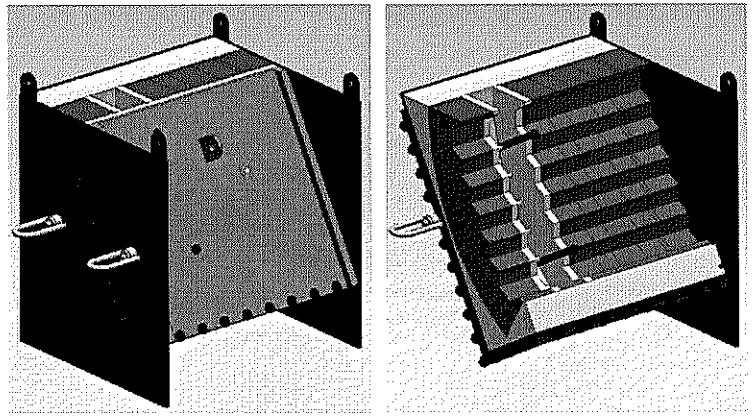

FIGURE 3-15: RENDER OF THE PSR MOLD IN THE "INSTRUMENT PATH CORE OUTER REFLECTOR" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

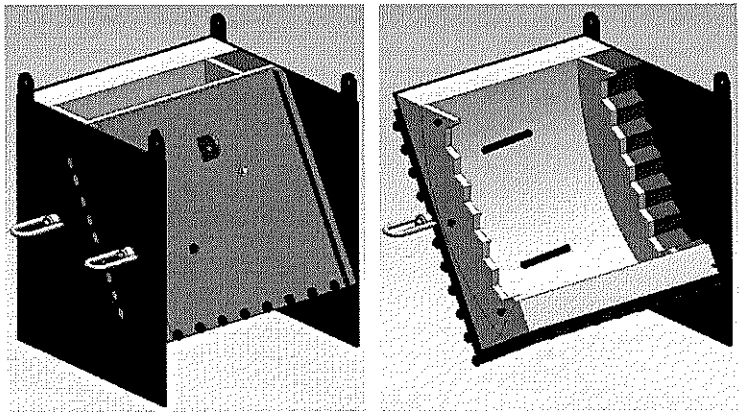

FIGURE 3-16: RENDER OF THE PSR MOLD IN THE "LOWER CORE OUTER REFLECTOR" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

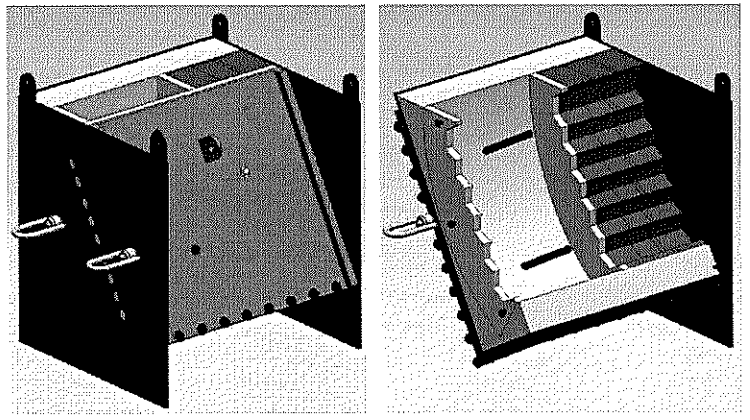

FIGURE 3-17: RENDER OF THE PSR MOLD IN THE "CENTER CORE OUTER REFLECTOR" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

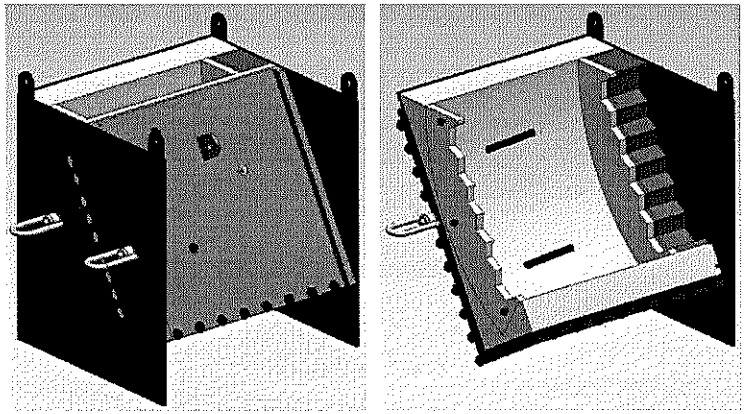

FIGURE 3-18: RENDER OF THE PSR MOLD IN THE "UPPER CORE OUTER REFLECTOR" CONFIGURATION: FULL ASSEMBLY (LEFT) AND FRAME WALL, MOLD CAP, AND INSIDE PLATE REMOVED FOR CLARITY (RIGHT).

3.2.1 Reflector Block Mold Handling

The Reflector mold in its heaviest configuration has a calculated mass of 1155 lbm without any refractory material and roughly 1500 lbm when filled with refractory. To move this mold, lifting eyes and hoist ring mounting locations have been incorporated into the mold. It is intended that the mold is normally stored and moved in the upright position, where the opening in the mold is on the top face as shown in Figure 3-19. It is intended that the mold be moved using a four point lifting sling at the locations denoted in the figure.

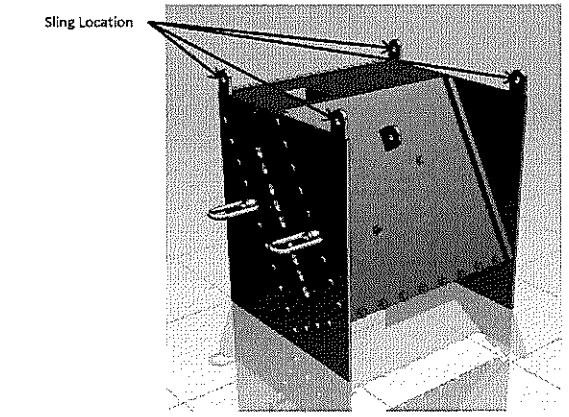

FIGURE 3-19: RENDER OF THE MOLD IN THE NORMAL ORIENTATION WITH THE CONNECTION POINTS FOR THE LIFTING SLING.

During the filling of the mold, an air pocket is formed in the lower corner, shown in the left image of Figure 3-20. To alleviate this problem, it is expected that the mold be lifted on by the rear two lifting points as shown in the right image of Figure 3-20.

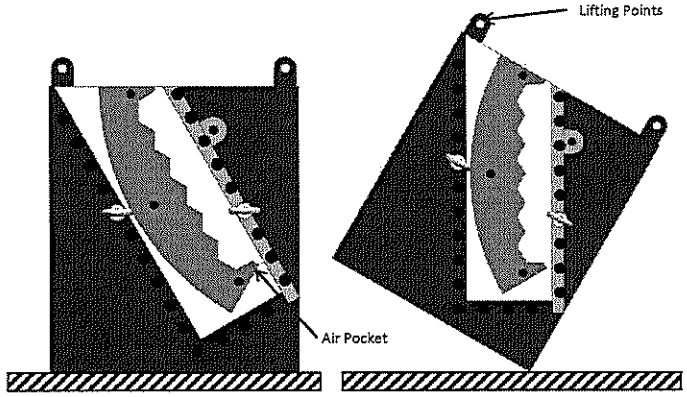

FIGURE 3-20: SIDE VIEW OF THE MOLD DENOTING THE AIR POCKET (LEFT) AND THE MOLD ROTATED TO REMOVE THE AIR POCKET DURING THE INTIAL FILLING STAGE OF THE CASTING PROCESS (RIGHT). THE FRAME WALL PLATE HAS BEEN REMOVED FOR CLARITY.

After the casting process is completed the mold must be rotated 90° to rest on the side of the frame. This rotation is completed by lifting from the anchors that are attached to the Frame Wall plate. This operation must occur before any bolts are removed from the mold.

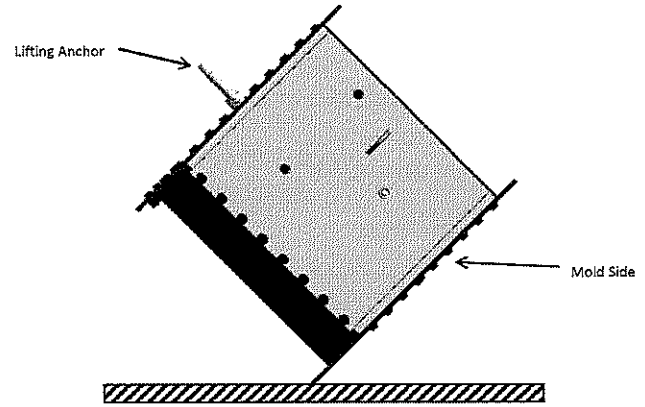

FIGURE 3-21: RENDER OF THE PSR MOLD BEING LIFTED FROM THE SIDE LIFTING EYES TO ORIENT THE MOLD FOR DISASSEMBLY.

3.3 Reflector Block Mold Assembly and Disassembly

Assembly of the PSR Mold begins with the mold frame and outside plate oriented in the casting position as shown in Figure 3-22.

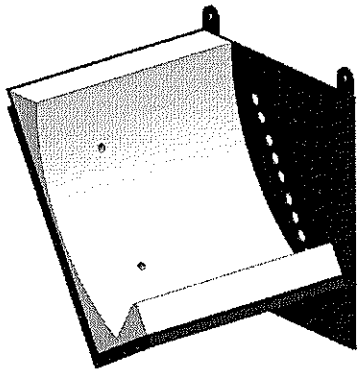

FIGURE 3-22: RENDER OF THE PSR MOLD FRAME AND OUTSIDE PLATE ORIENTED TO BEGIN MOLD ASSEMBLY.

The first step of assembly is to install the lower spacers and bottom plate. Three bolts are then passed through the side of the frame to attach the lower spacers and bottom plate, as shown in Figure 3-23. After installing the lower plates, install the frame front, upper spacer plate, and the appropriate top plate for the desired PSR block, as depicted in Figure 3-24. If casting either of the PSR Heater geometries, install the heater void rods, as shown in Figure 3-25. If casting the Lower Plenum Outlet block, attached the outlet plug to the inside plate / mold cap assembly, as shown in Figure 3-26. The Outlet cap contains a threaded insert to allow attaching to the mold cap. Lastly install the mold cap, lifting void rods and all bolts. Uniformly tighten all fasteners. The full assembly is shown in Figure 3-27. A check list to assembly is included in 3.3.1.

To disassemble the mold, rotate the mold onto its side as shown in Figure 3-21. Then reverse the process described above. A disassembly check list is included in 3.3.2.

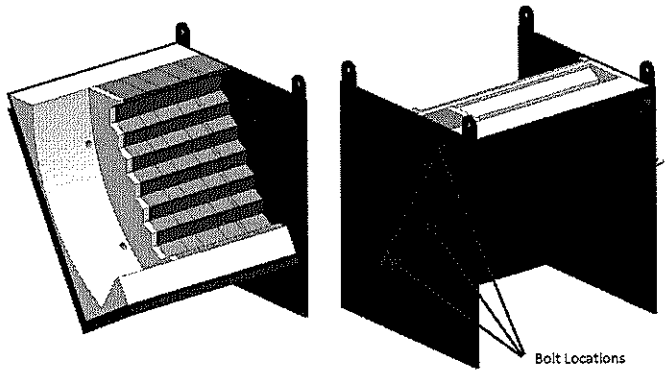

FIGURE 3-23: RENDER OF THE MOLD DISPLAYING THE INSTALLATION OF THE LOWER SPACERS AND THE BOTTOM PLATE (LEFT). RENDER SHOWING THE BOLT LOCATIONS TO RETAIN THE LOWER AND BOTTOM PLATES (RIGHT).

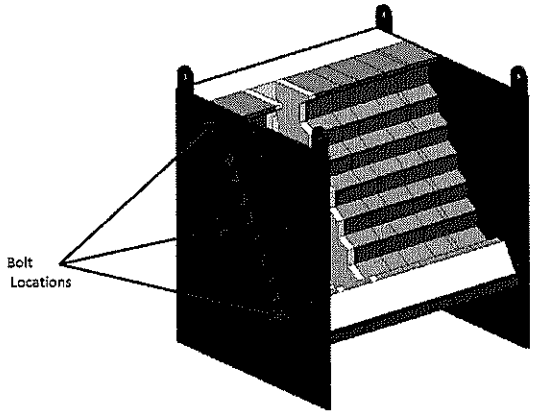

FIGURE 3-24: RENDER OF THE MOLD DISPLAYING THE ADDITION OF THE FRAME FRONT, UPPER SPACER AND THE TOP/INSTRUMENT PLATES. NOTE THE LOACTIONS OF THE BOLTS USED TO RETAIN THE UPPER SPACER AND TOP PLATES.

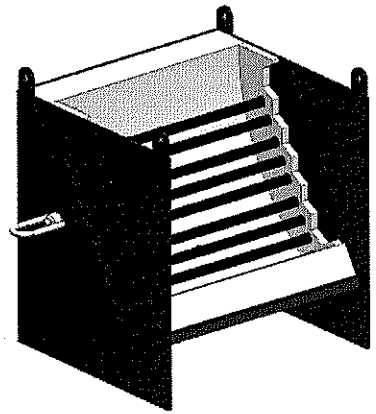

FIGURE 3-25: RENDER OF THE MOLD SHOWING THE INSTALLATION OF THE HEATER RODS, IF APPROPRIATE FOR THE PARTICULAR PSR BLOCK.

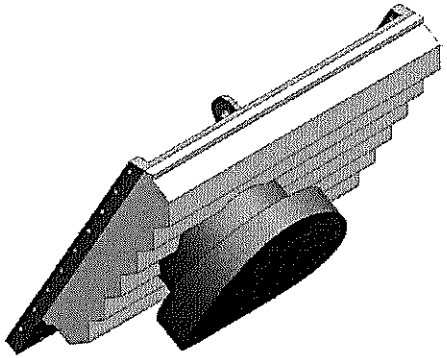

FIGURE 3-26: RENDER OF THE OUTLET PLUG ATTACHED TO THE INSIDE PLATE / MOLD CAP ASSEMBLY. THIS STEP IS COMPLETED BEFORE ATTACHING TO THE MOLD FRAME.

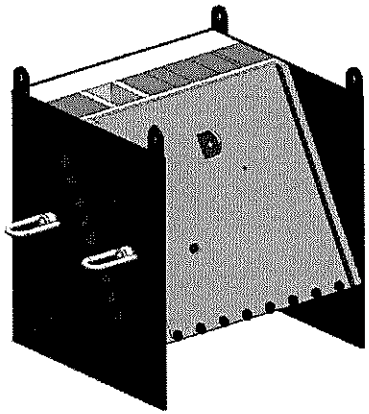

FIGURE 3-27: RENDER OF THE COMPLETELY ASSEMBLED MOLD.

3.3.1 PSR Mold Assembly Check List (to be completed before each casting operation)

Mold Configuration: _____ Part #: _____

Operator Names: _____ _____

Date: _____ Time: _____

- ☐ Remove all residual refractory material and clean all surfaces.
- ☐ Orient the frame into the upright orientation.
- ☐ Install appropriate lower spacers.
- ☐ Install appropriate bottom plate.
- ☐ Attach bolts for lower spacers and bottom plate.
- ☐ Attach Frame Wall using bolts and 1 lifting anchor
- ☐ Install Upper Spacer Plate, if appropriate.
- ☐ Install appropriate top plate.
- ☐ Install Heater Void Rods, if appropriate.
- ☐ Attach outlet plug to mold cap, if appropriate; else plug attachment hole.
- ☐ Install mold cap.
- ☐ Install Lift Void Rods.
- ☐ Install all remaining hardware.
- ☐ Double check all hardware correctly installed and tightened.
- ☐ Attach lifting slings to frame lifting locations.
- ☐ Note any problems in assembly below:

Signature _____

Signature _____

3.3.2 PSR Mold Disassembly Check List (to be completed after each casting operation)

Mold Configuration: _____ Part #: _____

Operator Names: _____ _____

Date: _____ Time: _____

- ☐ Remove Lift Void rods and sleeves
- ☐ Remove Heater Rod Voids, if applicable.
- ☐ Rotate PSR Mold onto side.
- ☐ Remove bolt that retains the outlet plug, if applicable.
- ☐ Remove Frame Wall and associated hardware.
- ☐ Remove mold cap and associated bolts.
- ☐ Remove top plate and upper spacer, if applicable.
- ☐ Remove PSR Block from mold using lifting jig.
- ☐ Remove outlet plug from block, if applicable.
- ☐ Remove applicable lower spacers and bottom plate.

  Rotate frame back into casting orientation.
- ☐ Note any problems in the disassembly below:

Signature _____

Signature _____

4 Component #3: Support Column

The support column is a simple cylinder measuring 14.000" in length and 2.250" in diameter and weighing roughly 6 lbm each. These cylinders are installed in the lower plenum and used to support the load of the core blocks, upper reflector and lower reflector, while allowing the coolant to exit the core and redistribute as the flow moves into the outlet duct. In addition to the basic cylinder, there are two additional shapes needed to incorporate the instrumentation in the lower plenum. A breakdown of the quantities of each cylinder type can be found in Table 4-1 and a render of the three desired shapes can be found in Figure 4-1.

TABLE 4-1: BREAKDOWN OF THE DESIRED POST GEOMETRIES, QUANTITIES, REFRACTORY MATERIAL, AND FINAL CURE TEMPERATURE.

Part Number	Description	Quantity	Material	Cure Temperature
HTTF-414022	Basic Cylinder	160	Greencast-94F Plus	1000 °C
HTTF-414023	TC Void Cylinder	16	Greencast-94F Plus	1000 °C
HTTF-414024	Hollow Cylinder	16	Greencast-94F Plus	1000 °C

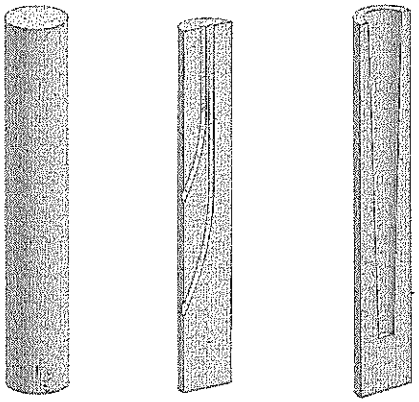

FIGURE 4-1: RENDER OF THE BASIC SUPPORT COLUMN (LEFT), TC VOID COLUMN (MIDDLE), AND HOLLOW COLUMN (RIGHT).

4.1 Post Handling

Due to the minimal weight of each of the posts, 6 lbm, no additional lifting equipment is needed for the operator to install the posts in the lower plenum.

4.2 Post Mold Layout and Handling

The mold will contain 12 voids in total to cast 10 basic columns and 1 TC Void column and 1 Hollow column with each casting operation. It is intended that the mold be reused in the typical configuration for all 16 casting operations. Unlike the Core Block and Reflector molds, the various posts are created at the same time. The mold is constructed to have a stiff steel structure that supports the plastic casting plates. The steel structure, Figure 4-2, is a welded assembly of steel plates and the attached steel studs are used to attach the UHMW plates to the structure. The full assembly is shown in Figure 4-3 with each form labeled and a full set of drawings of the Post Mold can be found attached to this document.

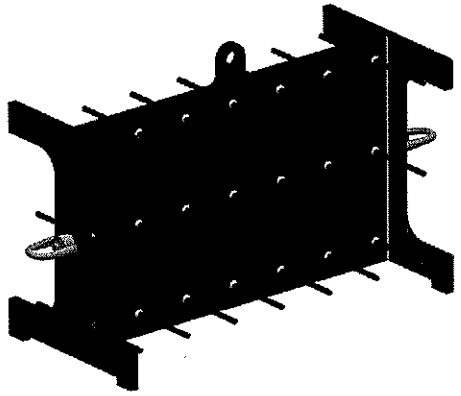

FIGURE 4-2: RENDER OF THE POST MOLD STEEL STRUCTURE. THE YELLOW DETAILS ARE THE WELDS CONNECTING THE STEEL COMPONENTS AND THE GREEN COMPONENTS ARE THE LIFTING EYES USED FOR ROTATING THE FORMS.

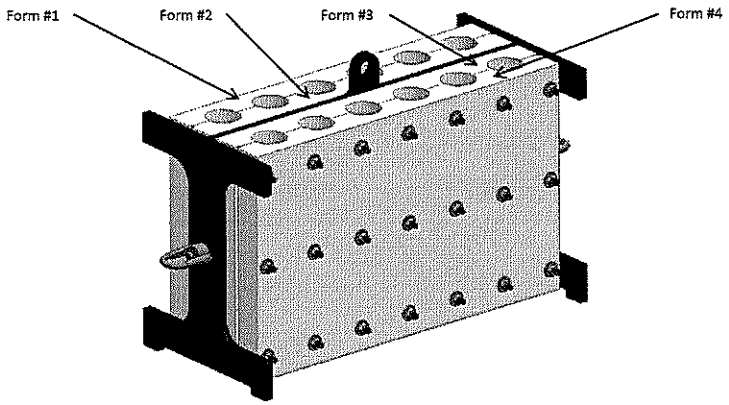

FIGURE 4-3: RENDER OF THE ASSEMBLED POST MOLD. THE WHITE BLOCKS ARE THE POST MOLD FORMS WHERE THE VOID FOR THE FINAL PRODUCT RESIDES.

The dry mass of the mold is calculated to be 182 LBM and when filled with the refractory the total mass is calculated to be about 260 LBM. The mold is designed to be moved using a lifting aid such as an overhead crane. For general transportation there is a center lifting eye to attach the lifting device to as shown in Figure 4-4. It is intended that the mold is in this orientation during all casting, curing, and storage operations. During the mold assembly and subsequent disassembly operations the mold will need to be rotated onto its side. It is intended that this operation be conducted through the use of lifting eyes that are attached to the side of the mold. To connect to these attachment points, it is intended that a lifting bar with two slings be utilized, as shown in Figure 4-5 and Figure 4-6.

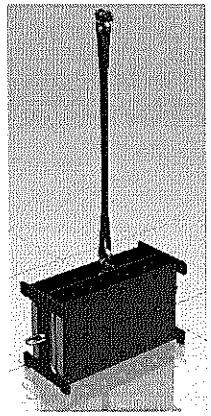

FIGURE 4-4: RENDER OF THE POST MOLD BE LIFTED USING THE CENTER LIFTING EYE.

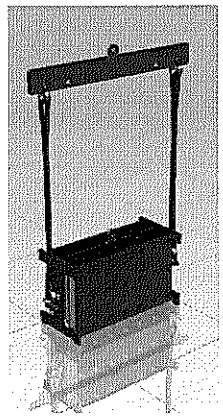

FIGURE 4-5: RENDER OF THE POST MOLD BEING LIFTED USING THE SIDE LIFTING LOCATIONS, FOR USE WHEN ASSEMBLING AND DISASSEMBLING THE MOLD.

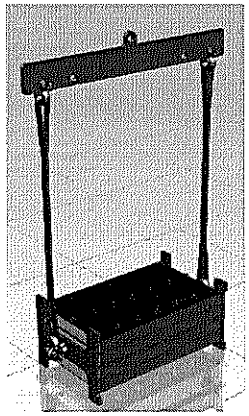

FIGURE 4-6: RENDER OF THE POST MOLD SHOWN ROTATED ON ITS SIDE USING THE SIDE LIFTING ARRANGEMENT.

4.3 Post Mold Assembly and Disassembly

The mold is designed to create 10 simple cylinders, a hollow cylinder, and a cylinder with two pathways for thermocouples. To create the hollow cylinder and the TC voids, extra components will be installed in specific cavities to create the appropriate void. For the hollow cylinder, a conical component is bolted to the floor of one of the voids formed by Form #1 and Form #2. A render of this can be seen in Figure 4-7, where the conical insert is colored green and the associated bolt that retains the cone is colored blue. As directed in the assembly procedure in the following sub-section, the cone is installed into the void after Form #1 and #2 have been mated together and attached to the mold structure.

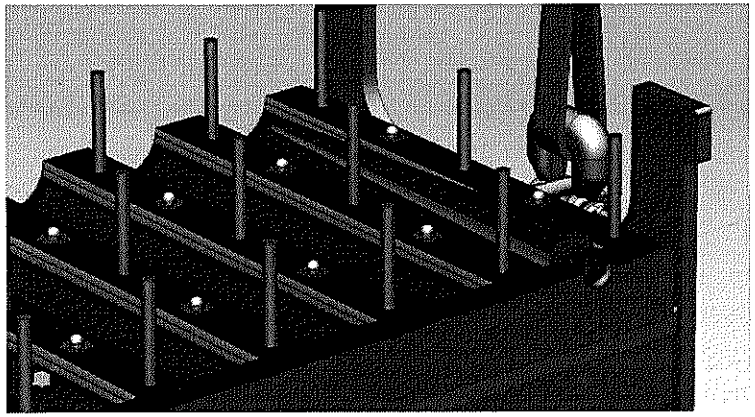

FIGURE 4-7: RENDER OF THE MOLD SHOWNING THE CONICAL INSERT INSTALLED IN THE MOLD, NOTE FORM #1 REMOVED FOR CLARITY.

To create the thermocouple voids, two pieces of LLDPE tubing will be attached to Form #3. Both Form #3 and #4 had voids that are machined into the mold to retain the tubing during the casting process, as shown in Figure 4-8. #10 wood screws are used to retain the tubing in Form #3 ensuring that the tubing does not move during the Mold assembly process, as shown in Figure 4-9. As directed in the assembly procedure in the following subsection, the tubing is installed onto Form #3 before the Forms #3 and #4 are attached to the structure.

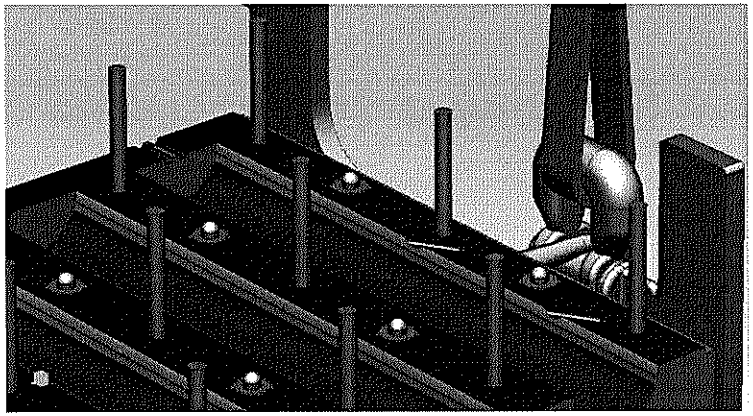

FIGURE 4-8: RENDER OF THE MOLD SHOWING THE INDENTATIONS MACHINED IN FORM #3, WHERE THE TC VOID TUBES WILL RESIDE, SHOWN IN BLUE.

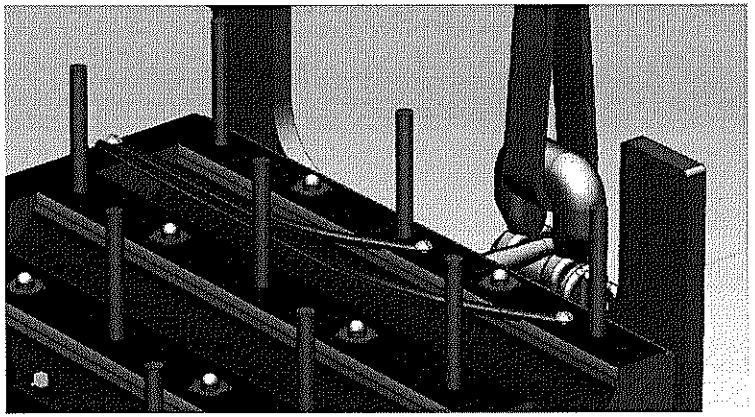

FIGURE 4-9: RENDER OF THE TC VOID TUBES, SHOWN IN GREEN, INSTALLED ONTO FORM PLATE #3 USING THREE WOOD SCREWS, SHOWN IN YELLOW.

4.3.1 Post Mold Assembly Check List (to be completed before each casting operation)

Casting Number: _____

Operator Names: _____ _____

Date: _____ Time: _____

- ☐ Remove all residual refractory material and clean all surfaces.
- ☐ Orient Steel Structure on side using side lifting mounts.
- ☐ Attach TC Void guide tubes to Form #3 using the wood screws to retain the tubes.
- ☐ Place Form #3 onto Post Mold Structure.
- ☐ Place Form #4 onto Post Mold Structure assuring the Form 3 and Form 4 correctly engage.
- ☐ Attach all nuts and washers to the bolts protruding through the face of Form #4.
- ☐ Evenly tighten all nuts.
- ☐ Lift mold and rotate onto other side.
- ☐ Place Form #2 onto Post Mold Structure.
- ☐ Place Form #1 onto Post Mold Structure assuring that Form #1 and Form #2 correctly engage.
- ☐ Attach all nuts and washers to the bolts protruding through the face of Form #1.
- ☐ Evenly tighten all nuts.
- ☐ Insert conical insert into void and bolt into place.
- ☐ Tighten the bolt.
- ☐ Return mold to the casting orientation.
- ☐ Move lifting connection from side lifting eyes to center eye.
- ☐ Double check all hardware correctly installed and tightened.
- ☐ Note any problems in assembly below:

Signature _____

Signature _____

4.3.2 POST MOLD DISASSEMBLY CHECK LIST (TO BE COMPLETED AFTER EACH CASTING OPERATION)

Casting Number: _____

Name: _____ _____

Date: _____ Time: _____

- ☐ Place mold on flat surface with Form #1 oriented up.
- ☐ Remove bolt that retains the conical void for the Hollow Cylinder.
- ☐ Remove all nuts and washers retaining Form #1.
- ☐ Remove Form #1, using grooves in the side of the form to pry the plates apart.
- ☐ Remove all 6 ceramic components.
- ☐ Remove the conical plug from the Hollow Cylinder.
- ☐ Remove Form #2 from structure.
- ☐ Lift the mold and rotate such that Form #4 is oriented up.
- ☐ Remove all nuts and washers from Form #4.
- ☐ Remove Form #4, using grooves in the side of the form to pry the plates apart.
- ☐ Remove wood screws.
- ☐ Remove all 6 ceramic components.
- ☐ Remove the tubes from the TC Void Cylinder.
- ☐ Note any problems in the disassembly below:

Signature _____

Signature _____

5 ATTACHMENTS

The following sections comprise the supplemental information that is needed to complete this document.

5.1 CORE BLOCK MOLD DRAWINGS

See drawings in "CBM_Collection.pdf"

5.2 REFLECTOR BLOCK MOLD DRAWINGS

See drawings in "PSR_Mold_Dwg.pdf"

5.3 POST MOLD DRAWINGS

See drawings in "Post_Mold_Dwg.pdf"

5.4 CERAMIC HANDLING EQUIPMENT

See "Ceramic_Handling.pdf"

5.5 GREEN CAST DATA SHEET

GREENCAST®-94 F PLUS

Product Data 2/11. 6778

Description: High-Alumina, Low-Silica Castable for Severe Abrasion

Features:
- Free-flowing characteristics. Minimal vibration is suggested for tight or intricate areas to ensure complete filling.
- High temperature resistance for hydrogen service.

Uses:
- Hydrogen transfer lines and secondary ammonia reformer linings.
- High temperature burner blocks and high temperature thermal combustors.

Chemical Analysis: Approximate (Calcined Basis)	
Silica (SiO_2)	0.1%
Alumina (Al_2O_3)	96.5%
Iron Oxide (Fe_2O_3)	0.1%
Lime (CaO)	3.0%
Magnesia (MgO)	0.1%
Alkalies (Na_2O+K_2O)	0.2%

Physical Data (Typical)	
Maximum Service Temperature	3400°F (1870°C)
Material Required	182 lb/ft³ (2.92 g/cm³)
Bulk Density	lb/ft³ (g/cm³)
After 220°F (105°C)	189 (3.03)
After 1500°F (816°C)	182 (2.92)
After 3000°F (1649°C)	183 (2.93)
Modulus of Rupture	lb/in.² (MPa)
After 220°F (105°C)	3,400 (23.4)
After 1500°F (816°C)	2,400 (16.6)
After 3000°F (1649°C)	7,100 (49.0)
Hot Modulus of Rupture	lb/in.² (MPa)
At 1500°F (816°C)	2,500 (17.2)
At 2500°F (1371°C)	2,800 (19.3)
At 2700°F (1482°C)	3,400 (23.4)
Cold Crushing Strength	lb/in.² (MPa)
After 220°F (105°C)	16,500 (113.8)
After 1500°F (816°C)	13,800 (95.2)
After 3000°F (1371°C)	20,000 (137.9)
Permanent Linear Change	
After 220°F (105°C)	None
After 1500°F (816°C)	0.0%
After 3000°F (1371°C)	+0.2%
Abrasion Loss	
After 1500°F (815°C)	9.5 cc

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GREENCAST®-94 F PLUS

Product Data

Thermal Conductivity	Btu·in./hr·ft²·°F (W/m·°C)
At 400°F (205°C)	36.4 (5.25)
At 800°F (425°C)	24.8 (3.58)
At 1200°F (650°C)	19.6 (2.83)
At 1600°F (870°C)	17.3 (2.49)
At 2000°F (1095°C)	17.1 (2.47)

Note: The data given above are based on averages of the results on samples selected from initial or limited plant production. Variation from the above data may occur in individual tests and in large scale plant production. The test data cannot be taken as minimum or maximum values for specification purposes. ASTM test procedures used when applicable.

Mixing and Using Information (Water calculated at 8.337 lb/gallon)	55 lb bag	1000 lb bag	1500 lb bag
Water Required—Free-Flowing (Weight 6.0%)			
Pounds	3.3	60.0	90.0
Gallons	0.4	7.2	10.8
Liters	1.5	27.2	40.8
Working Time		20 minutes	
Mixing Time		5 to 6 minutes	

For detailed mixing and using instructions, contact your ANH representative or visit www.anhrefractories.com.

Heatup/Dryout Schedule

See ANH Dryout Schedule 2—PLUS Rated Castables and Gunning Castables.

Installation Guidelines

See ANH Installation Guidelines CC-1—Conventional Castables—Standard.

Shelf Life (Under Proper Storage Conditions) 180 days

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5.6 THOR 80 CASTABLE DATA SHEET

THOR 80 CASTABLE

Product Data

Description: Silicon-Carbide, Low-Moisture Castable		
Chemical Analysis: Approximate (Calcined Basis)		
	Silicon Carbide (SiC)	78.0%
	Alumina (Al_2O_3)	12.9%
	Silica (SiO_2)	7.7%
	Lime (CaO)	1.1%
	Iron Oxide (Fe_2O_3)	0.1%
	Alkalies (Na_2O+K_2O)	0.1%
Physical Data (Typical)		
Maximum Service Temperature		3000°F (1649°C)
Material Required		154 lb/ft³ (2.47 g/cm³)
Bulk Density		lb/ft³ (g/cm³)
	After 230°F (110°C)	155 (2.48)
	After 1500°F (816°C)	154 (2.47)
	After 2000°F (1093°C)	154 (2.47)
	After 2500°F (1371°C)	155 (2.48)
Modulus of Rupture		lb/in² (MPa)
	After 230°F (110°C)	1,200 (8.3)
Hot Modulus of Rupture		lb/in² (MPa)
	At 1500°F (816°C)	3,100 (21.4)
	At 2000°F (1093°C)	4,800 (33.1)
	At 2500°F (1371°C)	400 (2.8)
Cold Crushing Strength		lb/in² (MPa)
	After 1500°F (816°C)	8,000 (55.2)
Permanent Linear Change		
	After 1500°F (816°C)	-0.2%
Abrasion Loss		
	After 1500°F (816°C)	15.0 cc
	After 2000°F (1093°C)	6.0 cc
Apparent Porosity		
	After 230°F (110°C)	16.0%
	After 1500°F (816°C)	18.0%
	After 2000°F (1093°C)	18.0%
	After 2500°F (1371°C)	14.0%
Thermal Conductivity		Btu·in/hr·ft²·°F (W/m·°C)
	At 392°F (200°C)	52.4 (7.56)
	At 752°F (400°C)	45.6 (6.58)
	At 1112°F (600°C)	46.7 (6.73)
	At 1472°F (800°C)	48.2 (6.95)

Page 1 of 2

THOR 80 CASTABLE

Product Data

Thermal Shock Test, Strength Loss			
Samples Fired at 2000°F (1093°C) and After 5 Cycles to 2000°F (1093°C)			0.0%

Note: The test data shown are based on average results on production samples and are subject to normal variation on individual tests. The test data cannot be taken as minimum or maximum values for specification purposes. ASTM test procedures used when applicable.

Mixing and Using Instructions (Water calculated at 8.337 lb/gallon)	55 lb bag	1000 lb bag	1500 lb bag
Water Required—Vibration Casting (Weight 6.0%)			
Pounds	3.3	60.0	90.0
Gallons	0.4	7.2	10.8
Liters	1.5	27.2	40.8

For detailed mixing and using instructions, contact your ANH representative or visit www.anhrefractories.com.

Heatup/Dryout Schedule

See ANH Dryout Schedule 1—Standard Castables and Gunning Castables.

Installation Guidelines

See ANH Installation Guidelines LCC-2—Low Cement Castables—Pumpable.

Shelf Life (Under Proper Storage Conditions)	90 days

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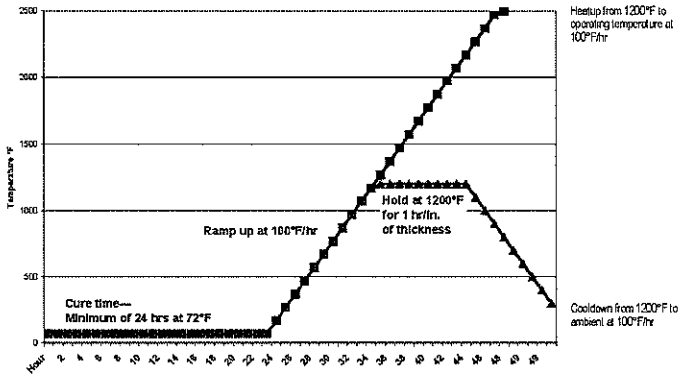
5.7 Firing Schedule for Greencast-94F PLUS

ANH Schedule 2—PLUS Rated Castables and Gunning Castables

Curing and Dryout General Guidelines – Field Use – One Sided Dryout 5/12/11

Example: 9-Inch Lining Schedule
Total Curing and Dryout Time—48 Hours



Curing and Dryout Schedule (heated from the hot face)	Hours
Cure Time	
Minimum ambient cure time (range of 70°F to 100°F)	24
Dryout Heat Sequence	
Heat from ambient to service temperature at 100°F/hr	~25
Total Dryout Time	~25
Total Curing and Dryout Time	~49

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