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Baseline Assessment of TREAT for Modeling and Analysis Needs

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SUMMARY

TREAT is an air-cooled, graphite moderated, thermal, heterogeneous test facility designed to evaluate reactor fuels and structural materials under conditions simulating various types of nuclear excursions and transient undercooling situations that could occur in a nuclear reactor. After 21 years in a standby mode, TREAT is being re-activated to revive transient testing capabilities. Given the time elapsed and the concurrent loss of operating experience, current generation and advanced computational methods are being applied to begin TREAT modeling and simulation prior to renewed at-power operations. Such methods have limited value in predicting the behavior of TREAT without proper validation. Hence, the U.S. DOE has developed a number of programs to support development of benchmarks for both critical and transient operations.

Extensive effort has been expended at INL to collect detailed descriptions, drawing and specification for all aspects of TREAT, and to resolve conflicting data found through this process. This report provides a collection of these data, with updated figures that are significantly more readable than historic drawings and illustrations, compositions, and dimensions based on the best available sources. This document is not nor should it be considered to be a benchmark report. Rather, it is intended to provide one stop shopping, to the extent possible, for other work that seeks to prepare detailed, accurate models of the core and its components. Given the nature of the variety of historic documents available and the loss of institutional memory, the only completely accurate database of TREAT data is TREAT itself. Unfortunately, disassembly of TREAT for inspection, assay, and measurement is highly unlikely. Hence the data provided herein is intended serve as a best-estimate substitute.

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ACRONYMS

ANL	Argonne National Laboratoy
β_{eff}	Effective Delayed Neutron Fraction
BOL	Beginning of Life
DOE	Department of Energy
DWG#	INL drawing no.
EALF	Energy Corresponding to the Average Neutron Lethargy Causing Fission
EGMPEBV	Expert Group on Multi-physics Experimental Data, Benchmarks and Validation
EOL	End of Life
HEU	High enrichment uranium
HFEF	Hot Fuel Examination Facility
ICW	Inadvertent Control Rod Withdrawal
IGR	Impulse Graphite Reactor
INL	Idaho National Laboratory
k_{eff}	Effective Core Multiplication Factor
LEU	Low enrichment uranium
LWR	Light Water Reactor
MCNP	Monte Carlo N-Particle
MFC	Materials and Fuels Complex
NE	Office of Nuclear Energy
NEA	Nuclear Energy Agency
NEAMS	Nuclear Energy Advanced Modeling and Simulation Program
NEUP	Nuclear Energy University Program
NNSA	National Nuclear Security Administration
NSRR	Nuclear Safety Research Reactor
OECD	Organization for Economic Cooperation and Development
RERTR	Reduced Enrichment for Research and Test Reactors
S/A	Subassembly
TREAT	Transient Reactor Test Facility

Baseline Assessment of TREAT for Modeling and Analysis NeedsError! Bookmark not defined.

1. INTRODUCTION

The Transient Reactor Test Facility (TREAT) located at Idaho National Laboratory (INL) is an air-cooled, thermal, heterogeneous test facility designed to evaluate reactor fuels and structural materials under conditions simulating various types of nuclear excursions and transient undercooling situations the could occur in a nuclear reactor. Transient testing involves placing fuel or material into the core of a nuclear reactor and subjecting it to short bursts of intense, high-power radiation. Fuel meltdowns, metal-water reactions, thermal interaction between overheated fuel and coolant, and the transient behavior of ceramic fuel for high temperature systems can be investigated [Freund 1958]. The contribution by TREAT to reactor safety includes the following: 1) provision of basic data to predict the safety margin of fuel designs and the severity of potential accidents, 2) service as a proving ground for fuel concepts designed to reduce or prevent consequent hazards, and 3) provision of nondestructive test data via neutron radiography of fuel samples irradiated in other test reactors [Sachs 1974].

The major unique features of TREAT include large flux integral absorption due to its high heat capacity; inherent, rapid instantaneous, temperature-dependent shutdown mechanism; rapid transient rod movement; and visual access to the core center [MacFarlane 1958]. The TREAT core is driven by highly enriched uranium (HEU) dispersed in a graphite matrix (~1:10000 ^{235}U/C atom ratio). At the center of the core, fuel is removed allowing for the insertion of an experimental test vehicle. TREAT's design provides experimental flexibility and inherent safety during neutron pulsing. This safety stems from the graphite in the driver fuel having a strong negative temperature coefficient of reactivity resulting from a thermal Maxwellian shift with increased leakage, as well as graphite acting as a temperature sink. Air cooling is available, but is generally used post-transient for heat removal.

TREAT's primary purpose was to simulate accident conditions leading to fuel damage, including melting or vaporization of test specimens, while leaving undamaged the reactor's fuel. During steady-state operation, TREAT could also be utilized as a large neutron-radiography facility and could examine assemblies up to 15 ft. in length. Unique shielded viewing slots allowed for both optical and gamma camera systems to record reactive mechanisms occurring during the experiment on film for detailed study. A fast-neutron hodoscope was a key diagnostic instrument that by collimating and detecting fission neutrons emitted by experiment fuel samples could provide time and spatial resolution of fuel motion during transients and in-place measurement of fuel distribution before and after an experiment. Many of these features are illustrated in Figures 1.1 through 1.3.

The reactor was operated from February 1959 until April 1994, generating over 720 MWh of energy in 6604 reactor startups and 2884 transient irradiations. The reactor underwent a major upgrade in 1988, which included installation of new instrumentation and control systems, with refurbishment of the rod drive systems. The only major difference, in-core, between the pre-upgrade core and the upgraded core was the change in the number and locations of the control rods. Changes in the control rods were made to adjust the shape of the spatial flux to improve energy delivery to the core. However, physically, no changes were made within the core that affected the neutronic response of the core during steady state or transient operation post-upgrade.

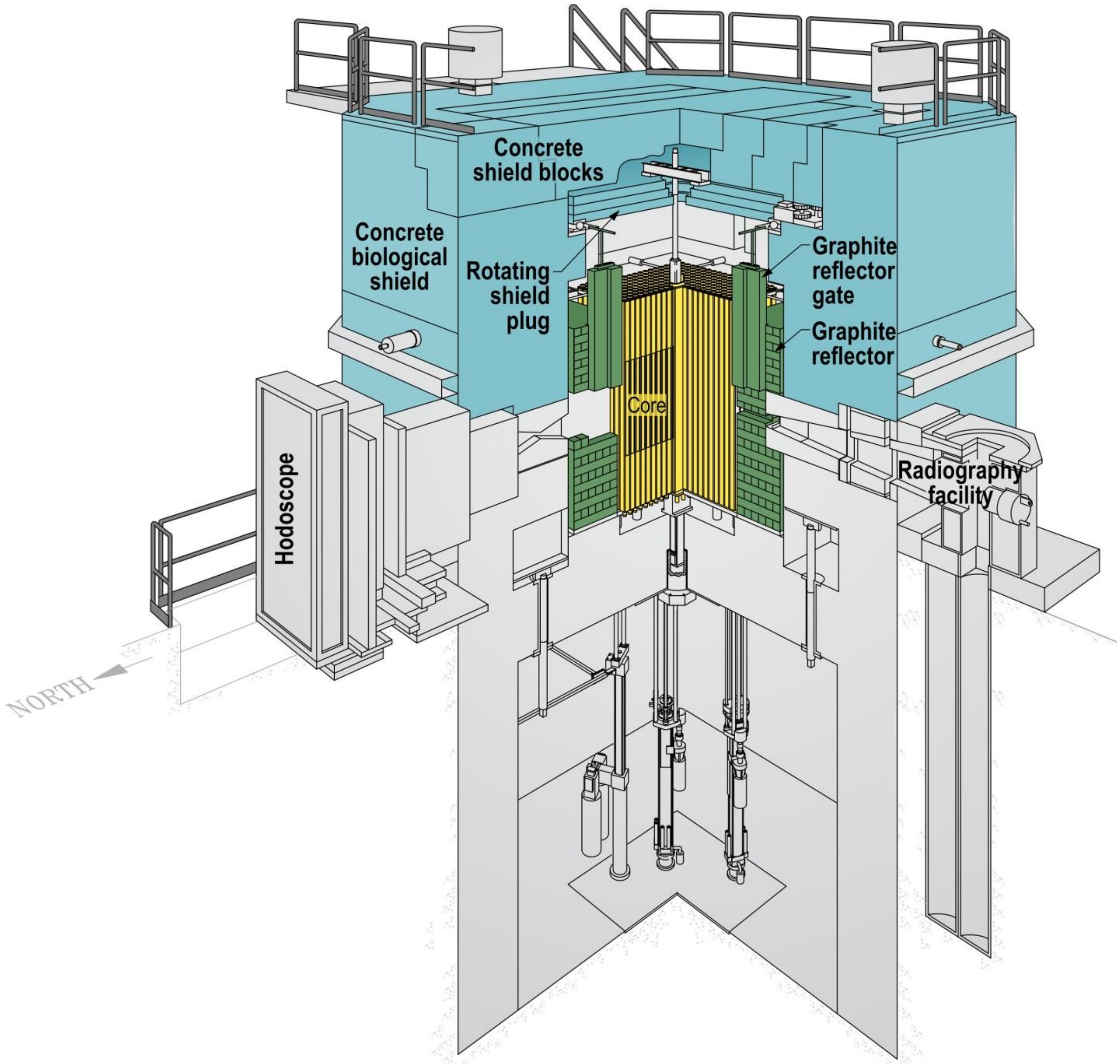


Figure 1.1. Key components of the full TREAT facility.

The U.S. Department of Energy (DOE) is preparing to restart TREAT. The pulsed reactor, built in 1959 and operated continuously for 35 years, has not operated since 1994. Based on ongoing efforts is expected that the facility will become operational in 2018 or sooner, and resume transient testing before the end of the decade. Transient testing of nuclear fuels is needed to improve current nuclear power plant performance and sustainability, to make next generation reactors more affordable, to develop nuclear fuels that are easier to recycle, and to improve the proliferation resistance of fuel designs.

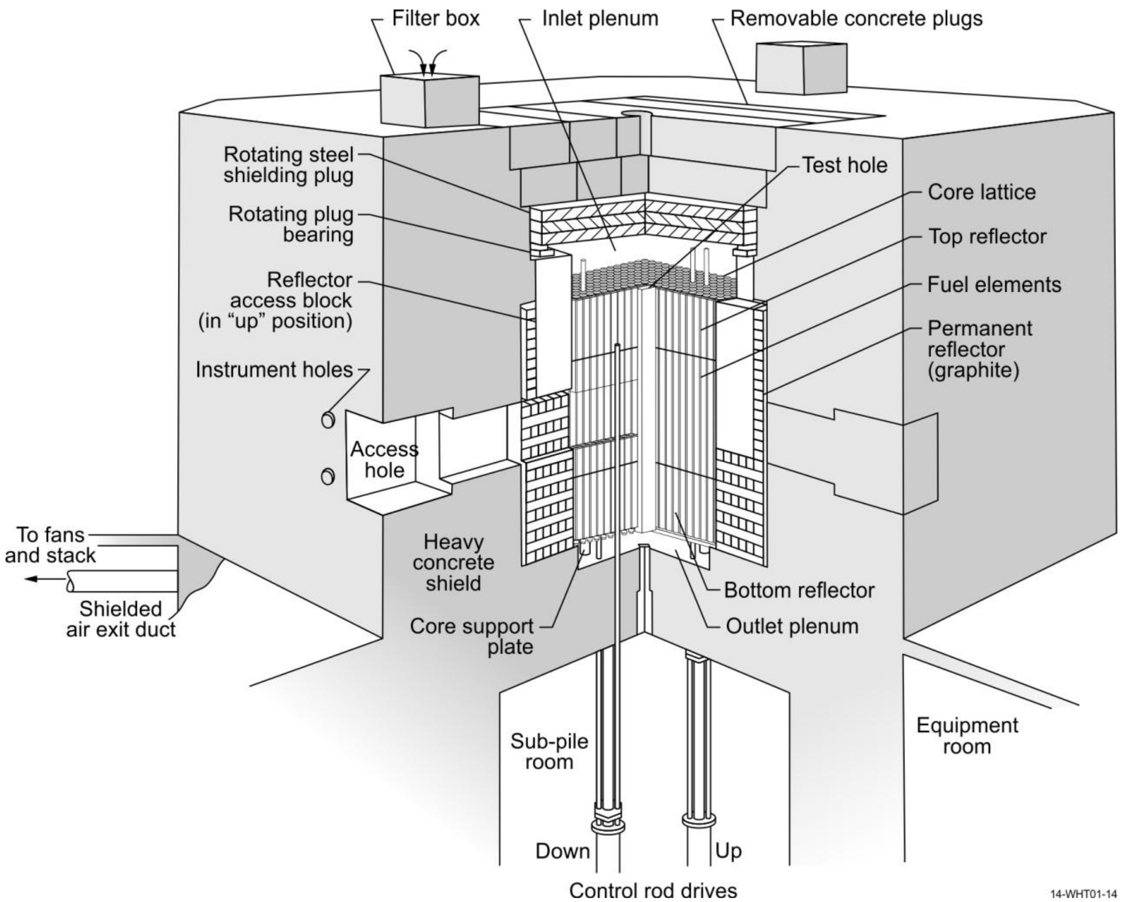


Figure 1.2. Cutaway Showing Internal Components within TREAT.

TREAT is one of four such transient facilities worldwide, along with the Nuclear Safety Research Reactor (NSRR) facility in Japan, the Impulse Graphite Reactor (IGR) facility in Kazakhstan, and the CABRI facility in France [INL 2009]. NSRR transient facility is dedicated to the study of LWR fuel systems in transient experiments. It is a pool-type pulse reactor utilizing water for coolant. Along with TREAT, the IGR is one of the oldest research reactors in the world and is most similar to TREAT as an air-cooled graphite-moderated reactor; it relies on forced air flow during operation. CABRI is similar to but larger than NSRR; it has conducted significant transient tests on a variety of nuclear fuel systems and is currently configured with a light-water reactor (LWR) coolant loop experimental capability. Each of these reactors has more or less the same mission, but capabilities and experiment workload vary by facility. TREAT is perhaps the most versatile because of its relatively open design and support for numerous experiment types. TREAT's design is based on a cartridge experiment concept, in which an experiment (or set of experiments) is isolated from the reactor core by placement within a self-contained system inside a pressure vessel (test vehicle). A number of test vehicle designs are possible and have historically been used, including both static fluid/moderator and recirculating coolant systems. This allows the experiment to use essentially any working fluid (water, sodium, helium, etc.) at desired pressures, temperatures and flow rates. Experiments and test packages are assembled at the nearby Hot Fuel Examination Facility (HFEF) at the INL Materials and Fuels Complex (MFC), transported to TREAT and loaded into the core using an appropriate test vehicle transportation and handling cask. Post-irradiation, the process is reversed and the test rig is returned to HFEF for extraction and examination. Within the core, the test vehicle typically replaced one or two standard fuel elements. Each element is nominally 4 in. square and 8 ft tall, with a 4 ft active fuel region in the center, or approximately 10 cm x 10 cm with a 1.22 m. active height. The irradiated portion of an experiment is thus typically no more than 10 cm x 20 cm x 1.22 m, although the test rig, flow loops, and instrumentation usually extend above and below the fueled region of the core.

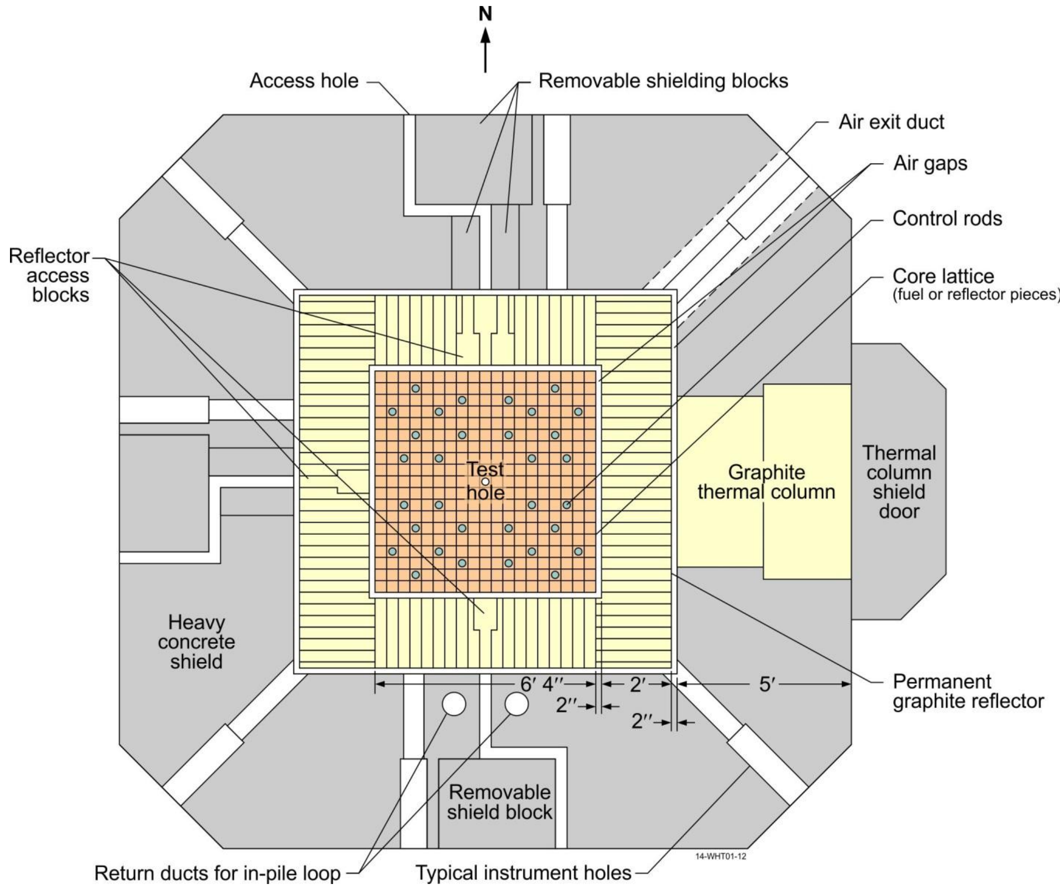


Figure 1.3. Top View of the TREAT Core, Permanent Reflector, and Biological Shielding.

And although the core is relatively simple, its small size relative to the mean free path of neutrons in the graphite fuel can challenge many analysis methods. Relatively crude methods supplemented by extensive experimental calibration were used to estimate power deposition in an experiment, still with significant uncertainty. For obvious reasons, modern analysis methods for TREAT have not been pursued since it was last operated in 1994, and there was no need for maintenance and usage of the formerly applied methods. Hence, the knowledge and experience to simulate the performance of TREAT and the power deposition in an in-core experiment has largely been lost.

In modern analysis terms, full three-dimensional time-dependent transport calculations with spatially distributed temperature feedback experienced by TREAT under both steady state and transient operation, are considered to be a strongly coupled multi-physics problem. An irradiated experiment with structural mechanics within the fuel and clad, and single or multi-phase coolant with or without flow, driven by the transient pulse provided by the core, is an even more complex multi-physics scenario. Computational methods capable of solving problems of this nature have only become available in the last decade.

Although resumption of transient testing is not expected to begin for a few more years, calculational tools are needed today. The DOE National Nuclear Security Administration (NNSA) is funding analysis to evaluate and support potential conversion of the currently high enrichment uranium (HEU) fuel design to a low enrichment uranium (LEU) design [Kontogeorgakos 2014]. LEU fuel studies, design of new static and transient flow test vehicles and candidate fuel experiments, and activities in preparation for safety analysis and training in support of the resumption of testing are using a number of existing methods to predict core performance and to study historical operations. Yet these methods remain primitive, and are largely unvalidated.

To address these modeling and simulation challenges, the U.S. DOE is currently sponsoring a number of efforts related to modeling the TREAT core, primarily through the Office of Nuclear Energy. These include development of modeling capabilities under the Nuclear Energy Advanced Modeling and Simulation (NEAMS) program and development of core benchmarks from historical data at multiple universities under the Nuclear Energy University Program (NEUP). Other efforts to build models of TREAT are ongoing elsewhere.

Beginning with the LEU conversion program and followed shortly by preliminary calculations to validate other codes for TREAT transport calculations, efforts began at INL to identify the appropriate modeling parameters for TREAT. Much of this work was done in cooperation with LEU conversion analysts at Argonne National Laboratory (ANL), pulling from published reports on the original TREAT design [Freund 1960], kinetics measurements [Okrent 1960], and the last series of experiments performed in TREAT, the M8 calibration series [Robinson 1994]. These reports provided a far from complete description of the various TREAT elements and the core itself. Efforts to locate missing data were sometimes challenging, and often providing conflicting data from data that had already been collected. Given the broad number of sources required to select these data, and to document rationale for selection of specific data when conflicts were identified, it was decided to compile the best set of TREAT data into a single document, to be used as a guide for future modeling, benchmark development and validation efforts. This report is the culmination of that effort.

Note that while this document is perhaps the most complete collection of specifications, drawings and descriptions of TREAT and its constituent components, the only completely accurate database of TREAT data is TREAT itself. Unfortunately, disassembly of TREAT for inspection, assay, and measurement is highly unlikely (although this has been completed for selected components, as discussed in this text). As new information becomes available on aspects of TREAT, it will be disseminated through future reports and shared within the modeling community. If it is found that significant changes in data provided herein are necessary, a revision of this report will be provided at a future date.

2. CORE COMPONENTS AND GEOMETRIES

The TREAT facility reactor core can be arranged to contain variable arrangements of assemblies, often historically referred to as elements, adapted to achieve desired experimental conditions. Peering in through the top of the core (see Figure 2.1) one can see that the primary assemblies utilized are the red-capped fuel assemblies. Various other assemblies also exist, and known information regarding these assemblies is summarized in Table 2.1. The intent of this section is to summarize available dimensional details regarding the various core assemblies and other core components such as control rods, support structure, the permanent reflector, and reactor shielding. It can be noticed that quite a bit of similarity exists between the different types of assemblies, which is useful when developing models of TREAT.

A general description of the reactor is that it consists of a right cylindrical core fully reflected by graphite (~2 ft.) on all sides. In its normal operation as a pulsed engineering test reactor, there is typically a vertical central hole containing a test sample, with possibly one or more large slots running horizontally from the core center out through the reflector. The size of the core is adjusted to provide the necessary excess reactivity to run the various transients required for test operations [Okrent 1960].

The reactor cavity is designed to accommodate a total of 361 assemblies arranged in a 4-in.-square lattice up to a maximum active core size of 6 ft. 4 in. square by 4 ft. high [Freund 1960].

Whereas the primary focus of this report is to provide sufficient information to model the TREAT reactor core, detailed information is provided for the numerous assemblies and permanent reflector. Additional information is provided for some of the core support structure, shielding, and experimental fixtures, but not in as much detail.

Figure 2.1. Top View of Northeast Section of TREAT Reactor Core Assemblies.

Table 2.1. Assemblies Used in TREAT Facility Reactor Core.

Identification Series	**Identification Coloring**	**Assembly Type**
100, 200, 300, 400	Red	Standard Fuel Assembly
500	Red	Thermocouple Fuel Assemblies
600	Yellow	Access Hole (24-inch) Assembly
700	Green	Control Rod Fuel Assembly
X-725	Magenta	Vertical Access Hole Fuel Assembly
0-1 to 0-…	Black	Zircaloy-Clad Dummy Assembly
A-1 to A-…	Blue	Access Hole (24-inch) Dummy Assembly
X-1 to X-…	Silver	Aluminum-Clad Dummy Assembly
--	--	Access Hole (24-inch) Dummy Assembly
H-1 to H-20	--	Access Hole (48- and 49-inch) Dummy Assembly
--	Black (notched)	Control Rod Dummy Assembly
--	--	Vertical Access Hole Dummy Assembly
--	--	Source Dummy Assembly
H-22	--	Dummy Half Assembly
H-21	--	Access Hole (48-inch) Dummy Half Assembly
--	--	Dummy Three-Quarter Assemblies
--	--	Shielding Assembly

2.1 Standard Fuel Assembly

A standard fuel assembly is shown in Figure 2.2 with a list of applicable drawings and materials provided in Table 2.2. Individual component drawings for the standard fuel assembly are provided in Figures 2.3 through 2.13.

Table 2.2. Standard TREAT Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.2	RE-1-21094	Standard Fuel Assembly	--
1	2.3	RE-1-21880	Top Fuel Fitting	Al-1100
1	2.4	RE-1-21768	Long Plug Part #1	CP-2 Graphite
1	2.4	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.5	RE-1-22736	End Tube Part #1	Al-6063
1	2.5	RE-1-22736	End Tube Part #2	Al-6063
1	2.6	RE-1-21767	Short Plug	CP-2 Graphite
1	2.7	RE-1-22739	Short Plain Plug	CP-2 Graphite
1	2.8	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.9	RE-1-21717	Fuel Section	Zr-3
6	2.10	RE-1-21578	Fuel Block Part #1	Graphite Fuel
8	2.11	RE-1-22699	Tab	Zr-3
2	2.12	RE-1-24160	Spacer	Zr-3
1	2.13	Z0012-0314 to -316	Fuel Identification Tag	Al-6061

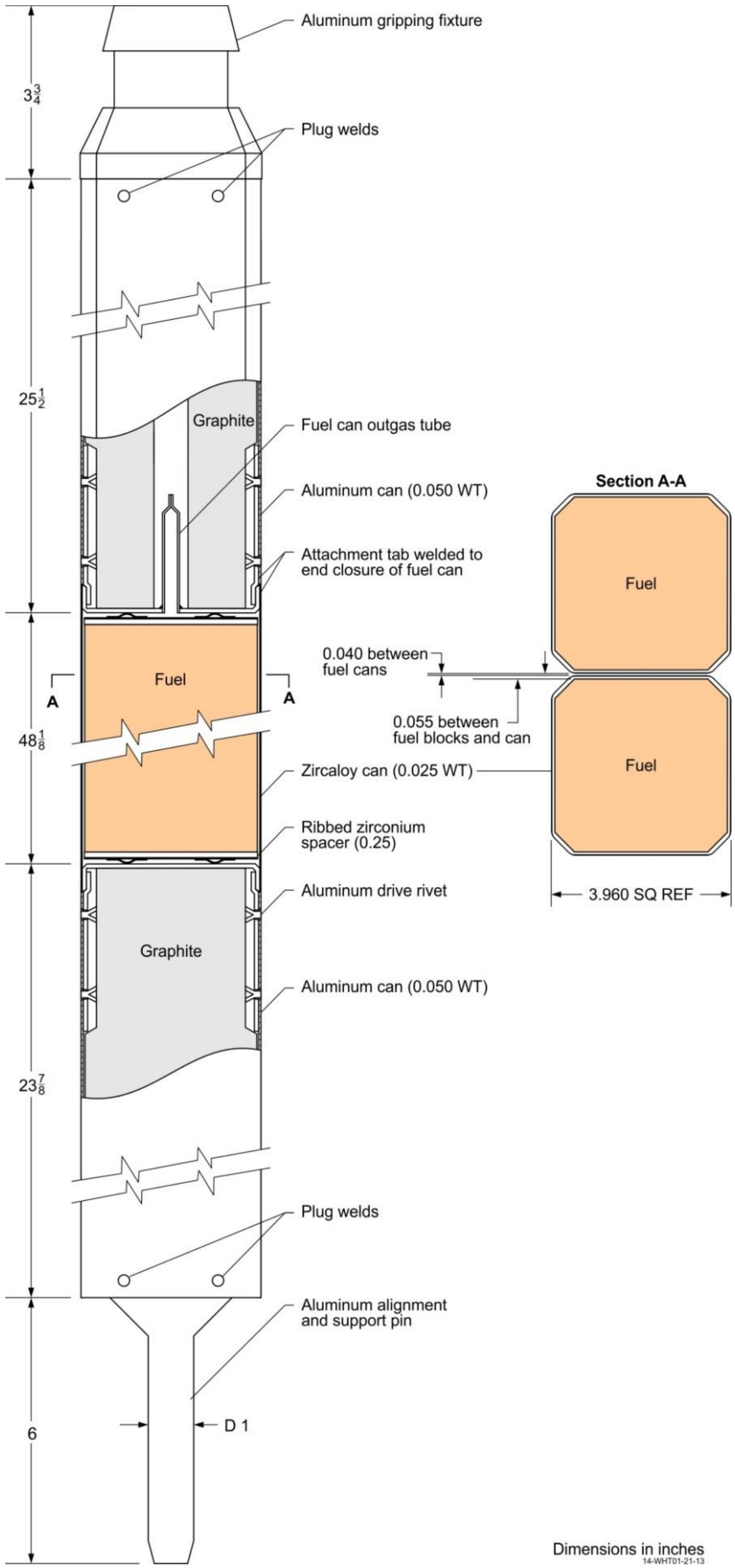


Figure 2.2. Standard Fuel Assembly (DWG# RE-1-21094).

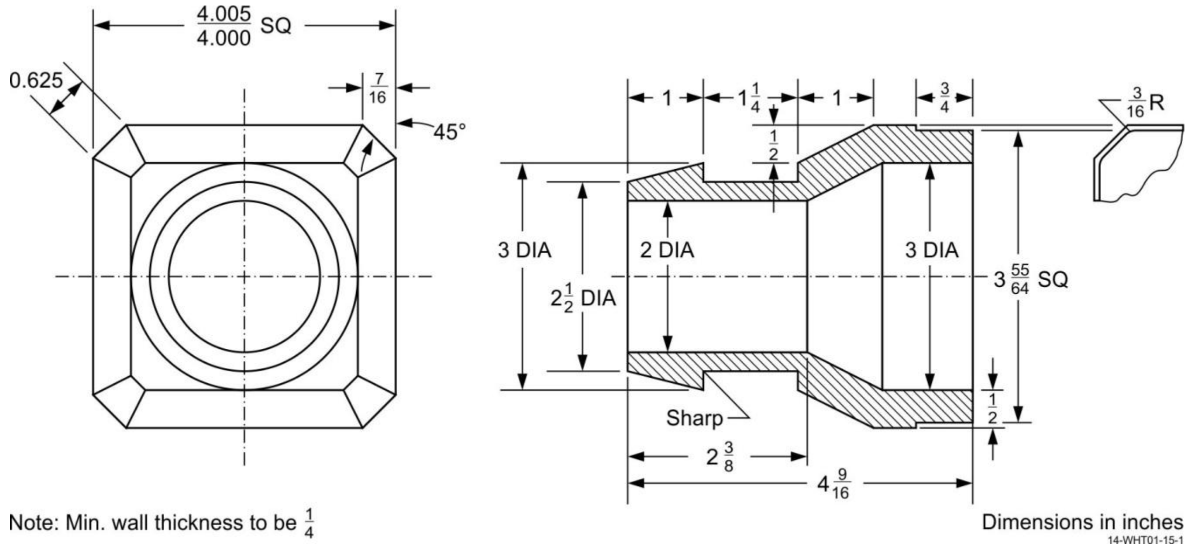


Figure 2.3. Top Fuel Fitting (DWG# RE-1-21880).

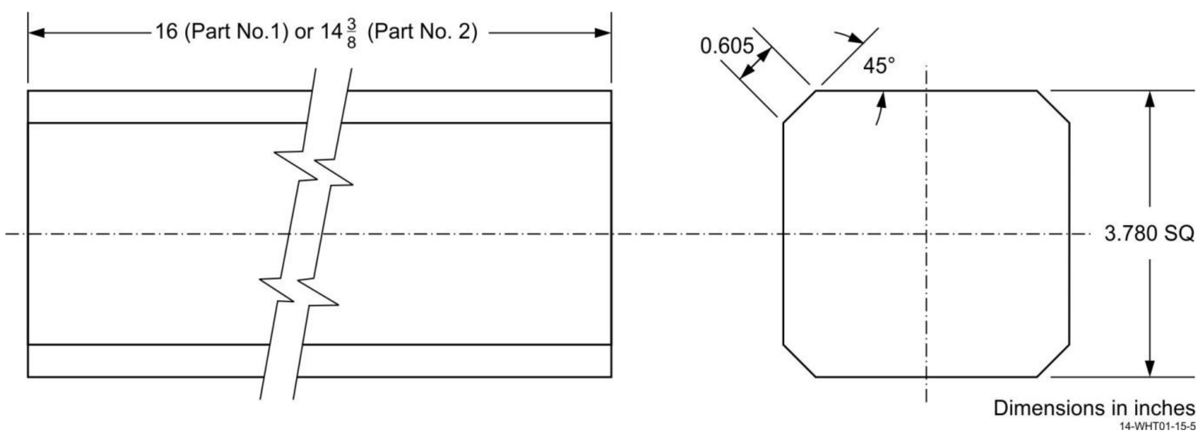


Figure 2.4. Long Plug (DWG# RE-1-21768).

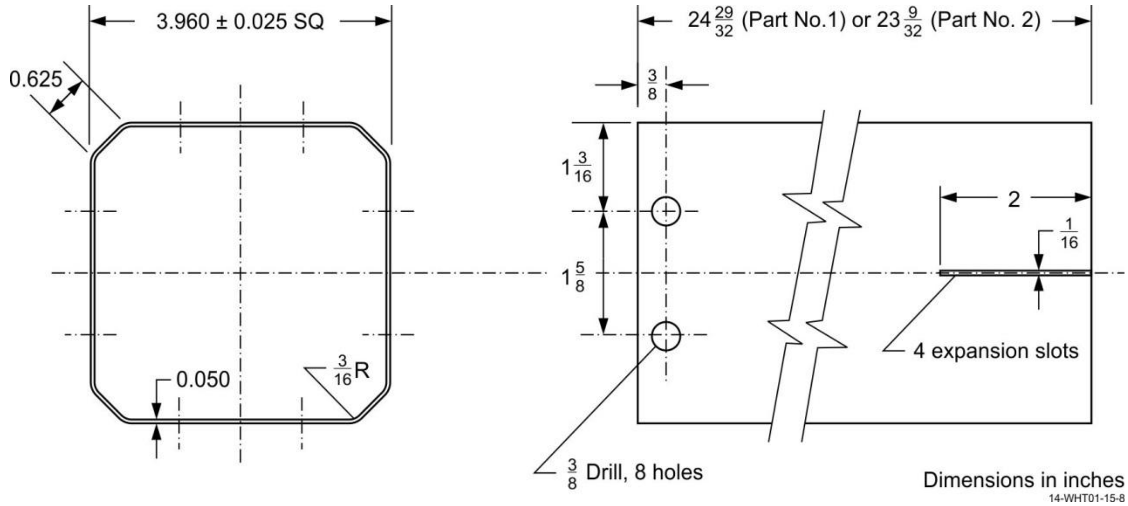


Figure 2.5. End Tube (DWG# RE-1-22736).

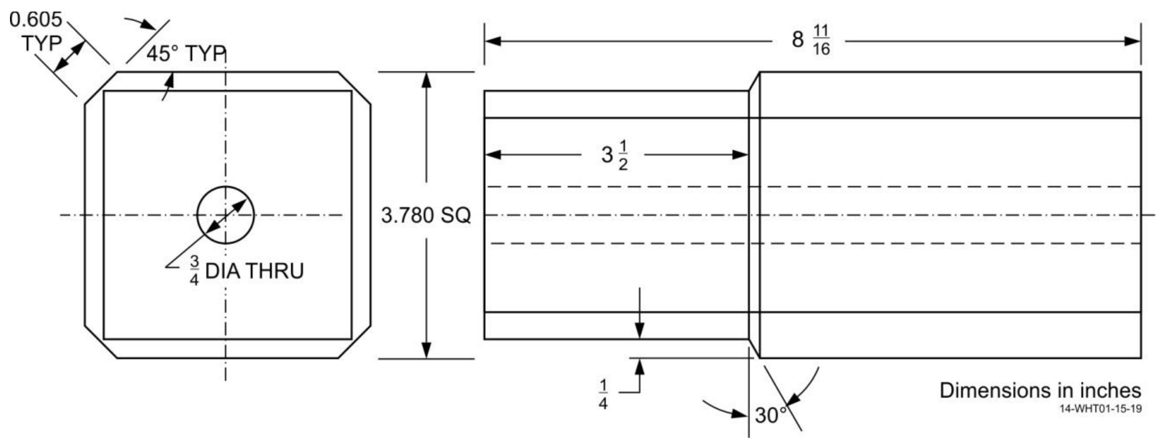


Figure 2.6. Short Plug (DWG# RE-1-21767).

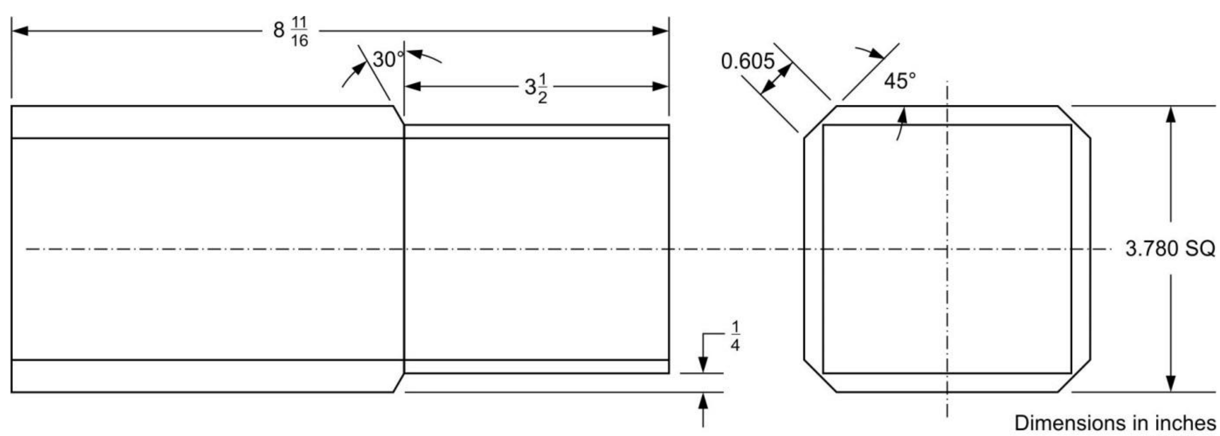


Figure 2.7. Short Plain Plug (DWG# RE-1-22739).

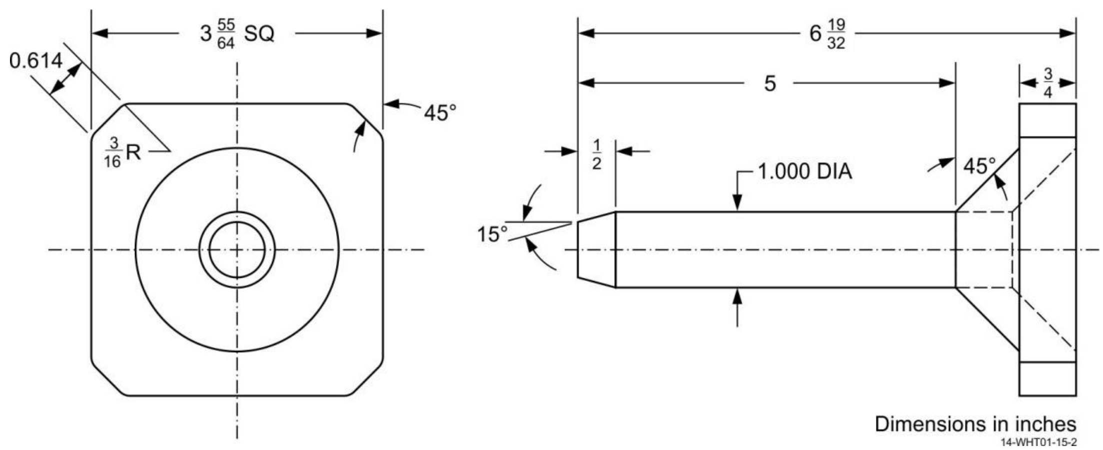


Figure 2.8. Bottom Fuel Fitting (DWG# RE-1-21881).

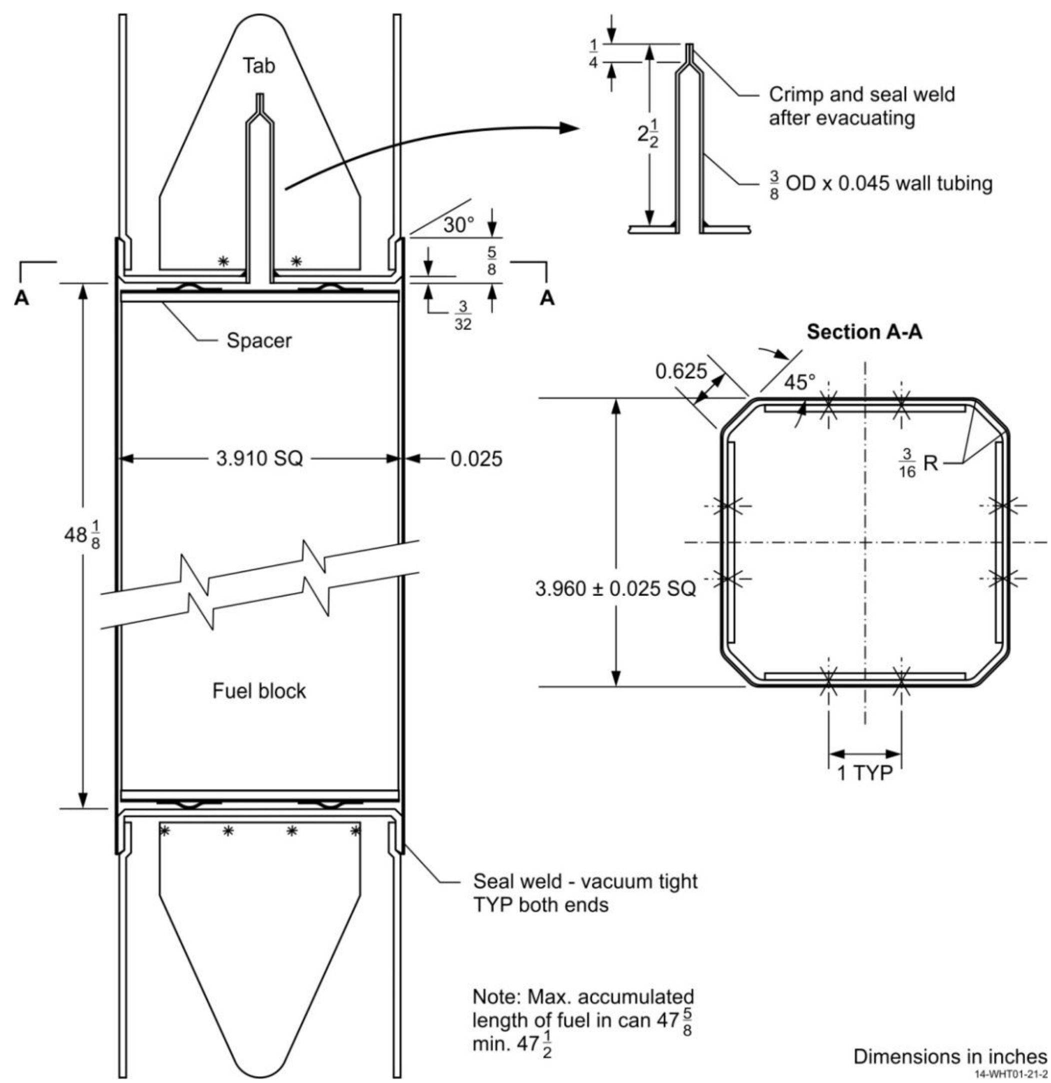


Figure 2.9. Fuel Section (DWG# RE-1-21717).

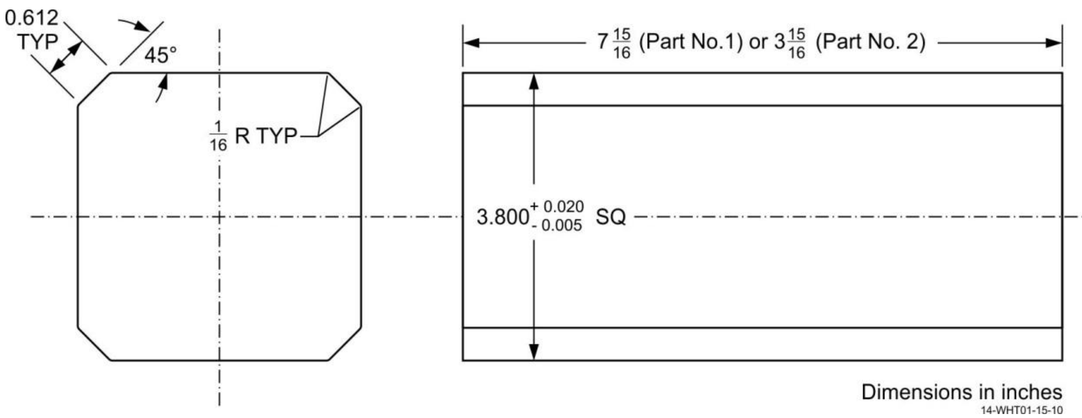


Figure 2.10. Fuel Block (DWG# RE-1-21578).

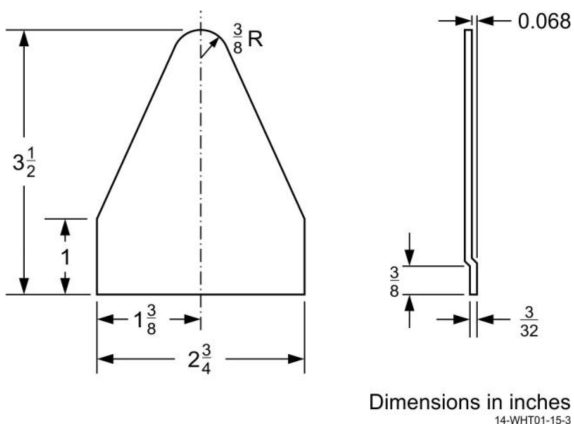


Figure 2.11. Tab (DWG# RE-1-22699).

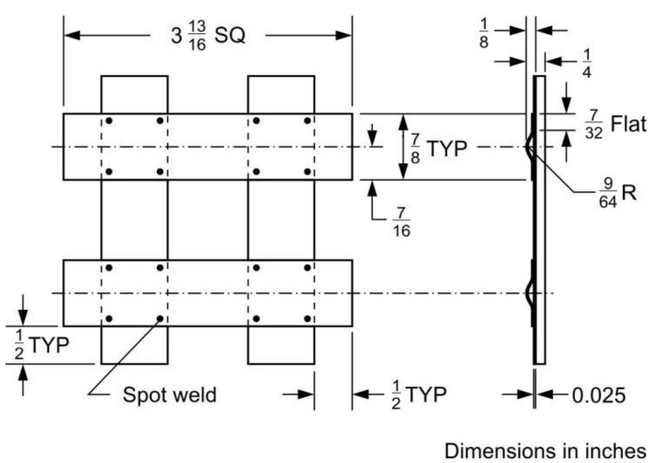


Figure 2.12. Spacer (DWG# RE-1-24160).

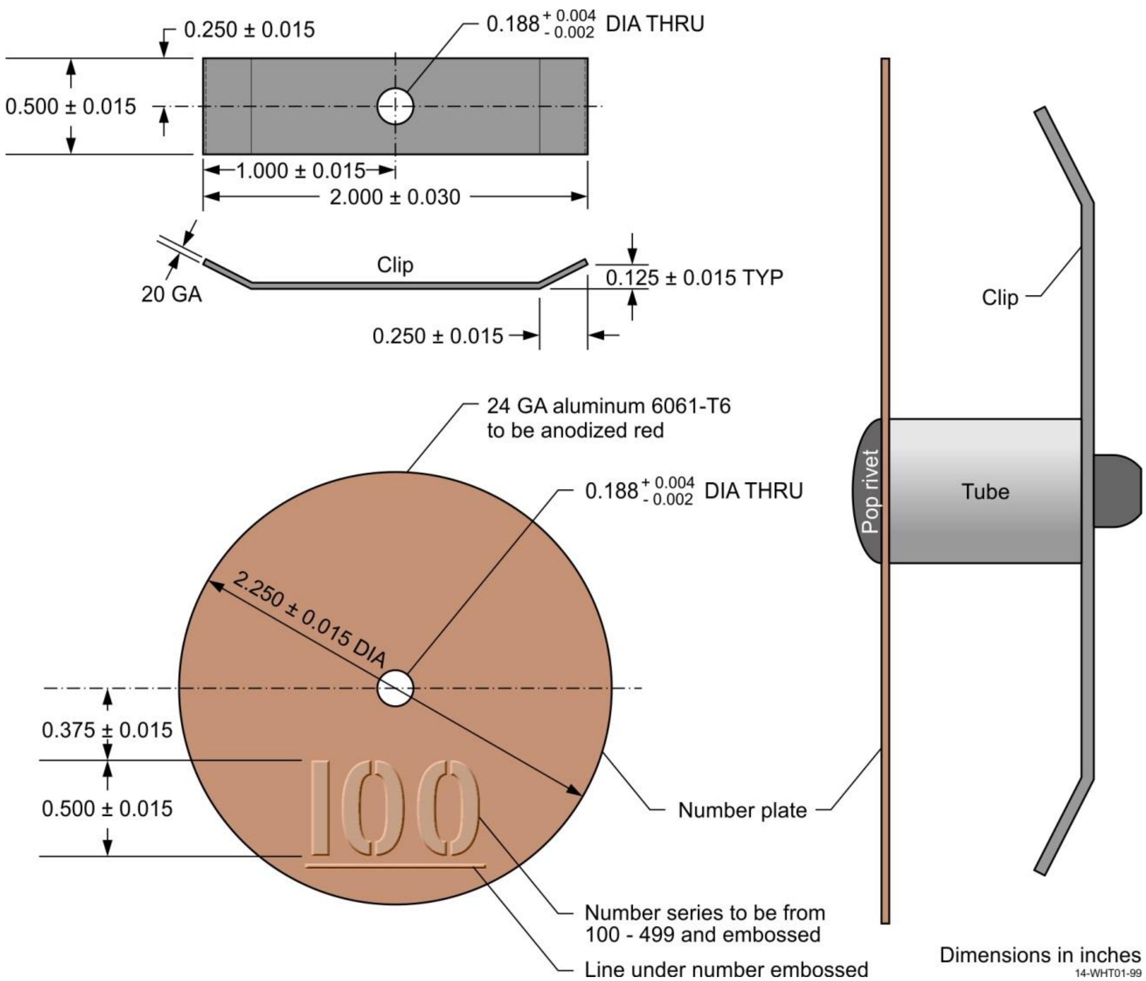


Figure 2.13. Fuel Identification Tag (DWG# Z0012-0314 through -0316).

2.2 Control Rod Fuel Assembly

The control rod fuel assembly is a standard fuel assembly with a hole down to center to allow for vertical movements of control rods. The assembly is shown in Figure 2.14 with a list of applicable drawings and materials provided in Table 2.3. Individual component drawings are provided in Figures 2.14 through 2.28.

Table 2.3. Control Rod Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.14	RE-1-22602	Control Rod Fuel Assembly	--
1	2.15	RE-1-22603	Head	Al-1100
1	2.16	RE-1-22604	Upper Long Plug	CP-2 Graphite
1	2.17	RE-1-22605	Upper Short Plug	CP-2 Graphite
1	2.18	RE-1-22606	Lower Short Plug	CP-2 Graphite
1	2.19	RE-1-22607	Lower Long Plug	CP-2 Graphite
1	2.20	RE-1-22736	End Tube Part #1	Al-6063
1	2.20	RE-1-22736	End Tube Part #2	Al-6063
1	2.21	RE-1-22608	Base	Al-1100
1	2.22	RE-1-22609	Bearing Tube	Al-1100
1	2.23	RE-1-22610	Carbon Graphite Bushing	Graphitar
1	2.24	RE-1-22611	Bushing Retainer	Al-1100
1	2.25	RE-1-22612	Control Rod Element Fuel Section	Zr-3
6	2.26	RE-1-22613	Fuel Block	Graphite Fuel
8	2.27	RE-1-22699	Tab	Zr-3
2	2.28	RE-1-24150	Spacer	Zr-3

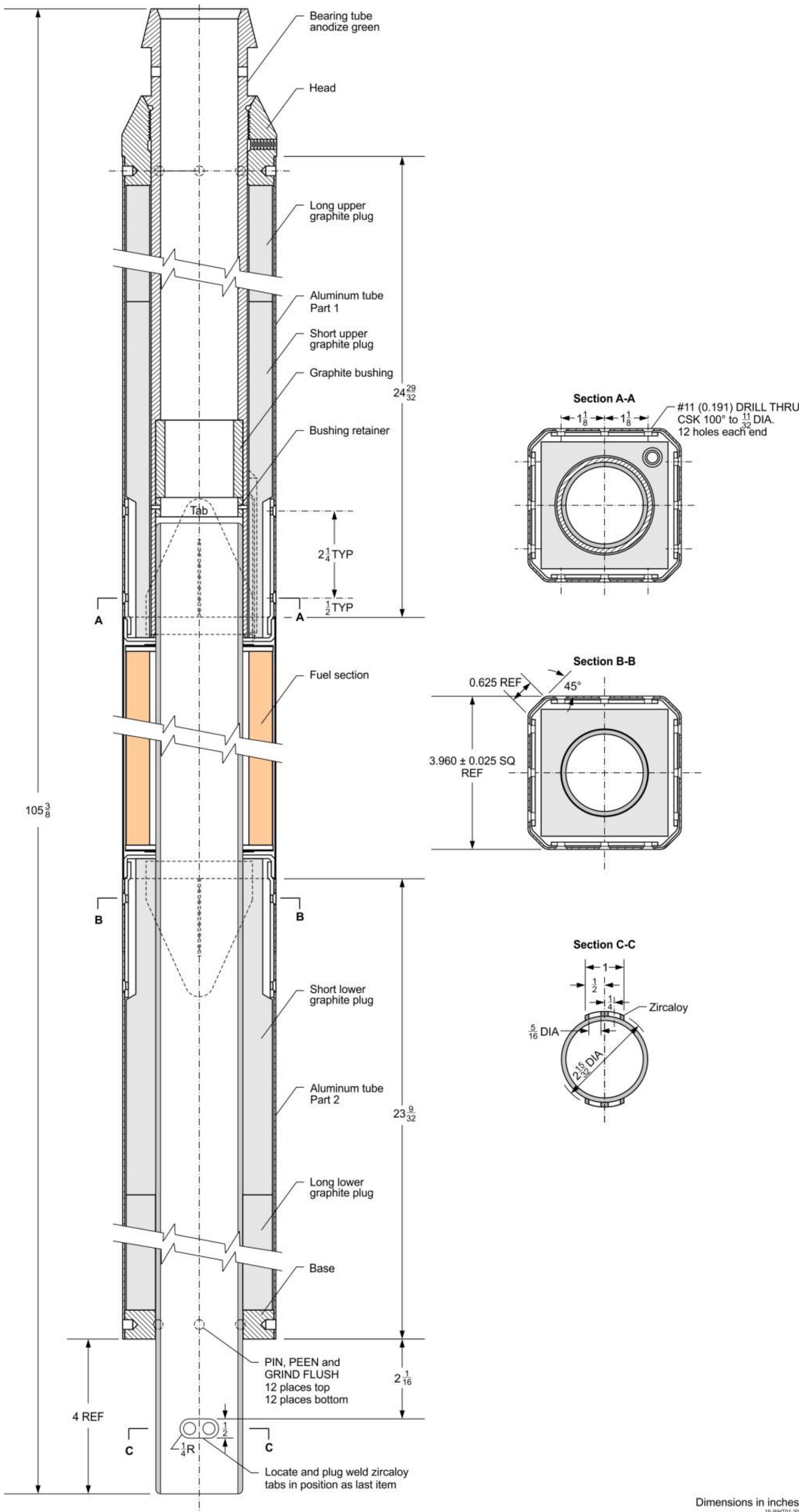


Figure 2.14. Control Rod Fuel Assembly (DWG# RE-1-22602).

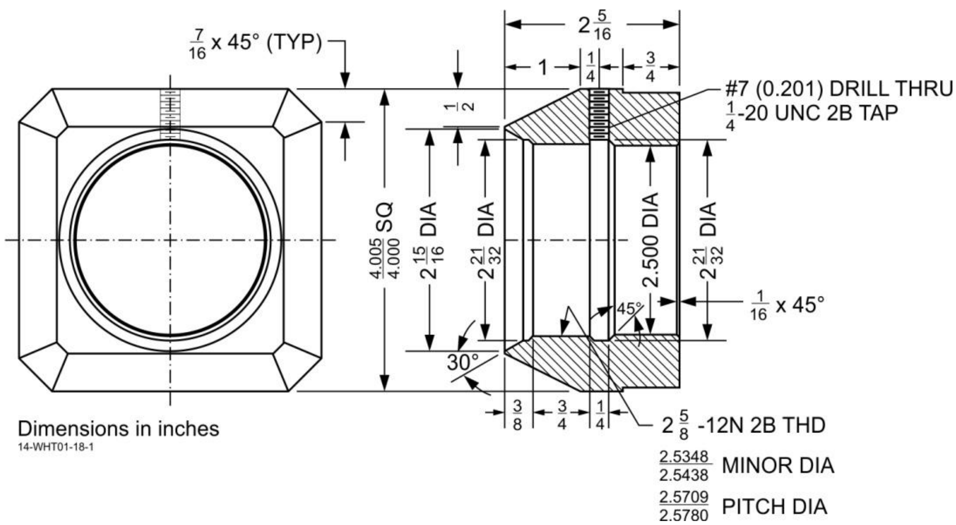


Figure 2.15. Head (DWG# RE-1-22603).

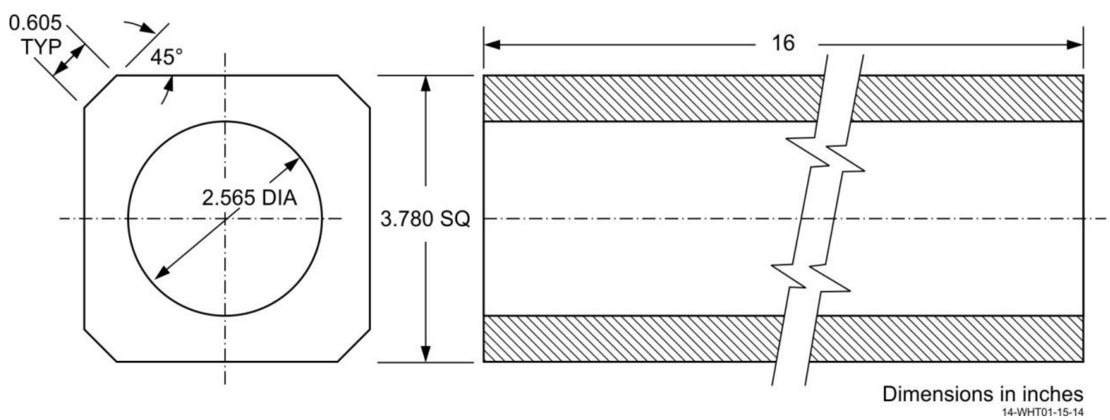


Figure 2.16. Upper Long Plug (DWG# RE-1-22604).

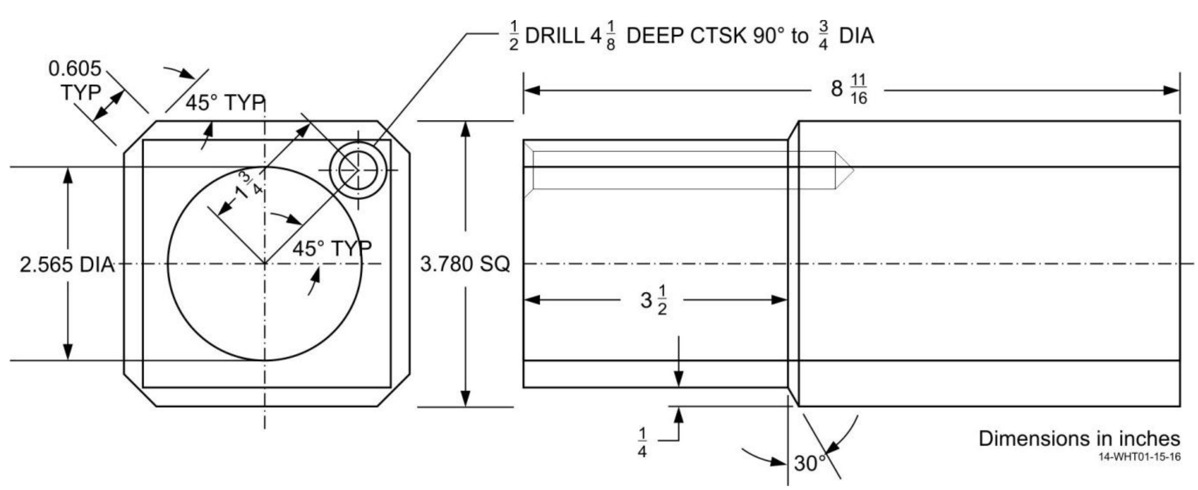


Figure 2.17. Upper Short Plug (DWG# RE-1-22605).

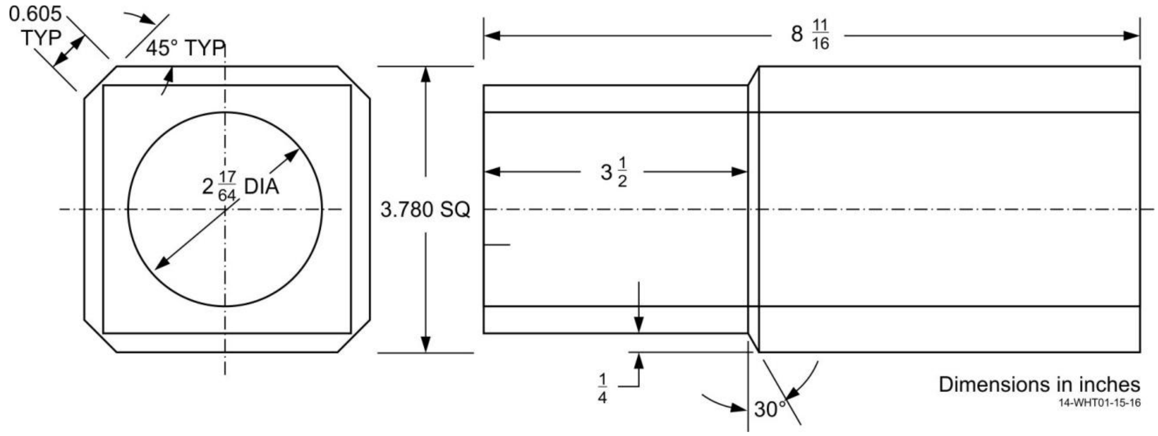


Figure 2.18. Lower Short Plug (DWG# RE-1-22606).

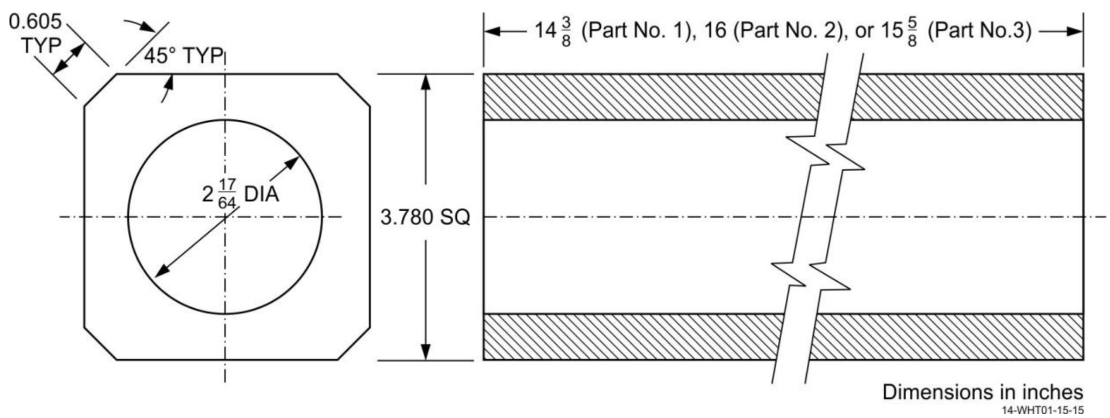


Figure 2.19. Lower Long Plug (DWG# RE-1-22607).

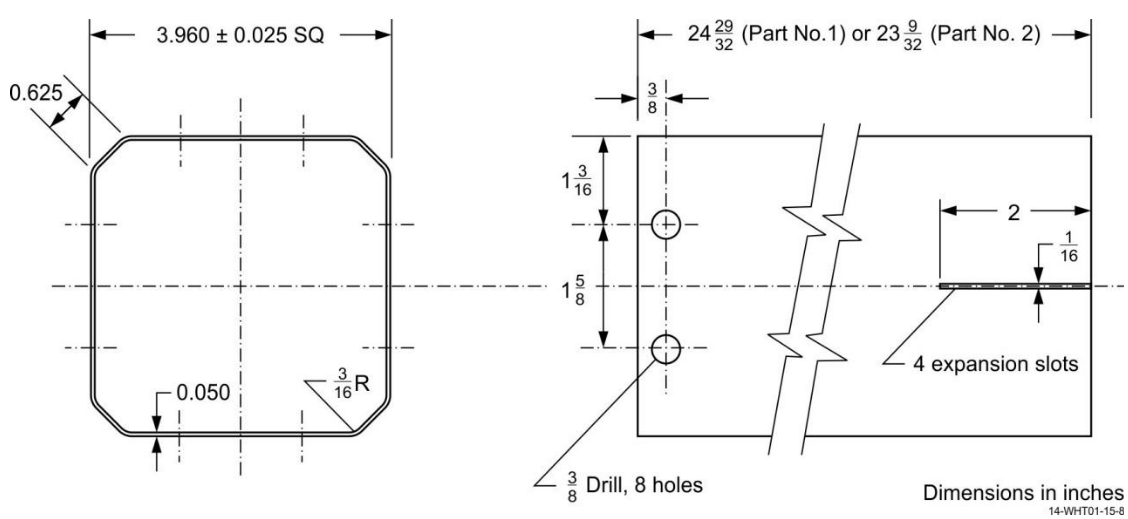


Figure 2.20. End Tube (DWG# RE-1-22736).

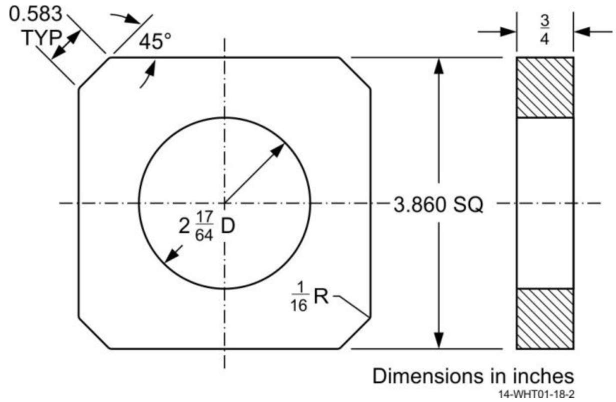


Figure 2.21. Base (DWG# RE-1-22608).

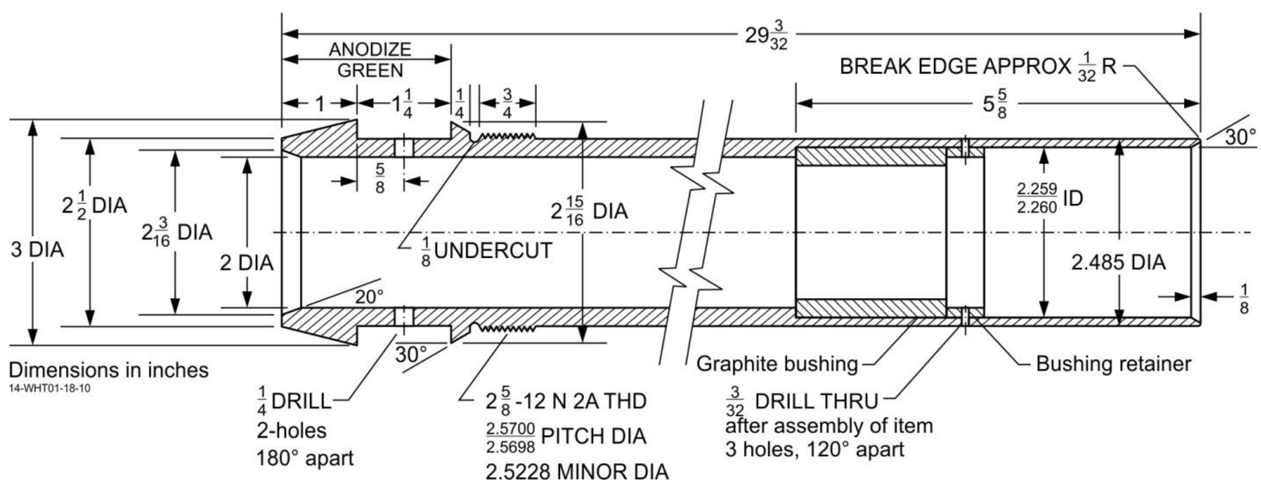


Figure 2.22. Bearing Tube (DWG# RE-1-22609).

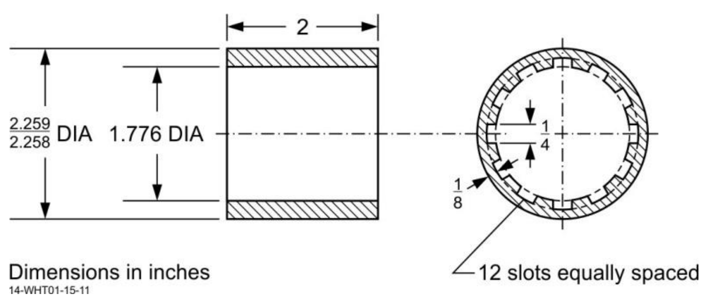


Figure 2.23. Carbon Graphite Bushing (DWG# RE-1-22610).

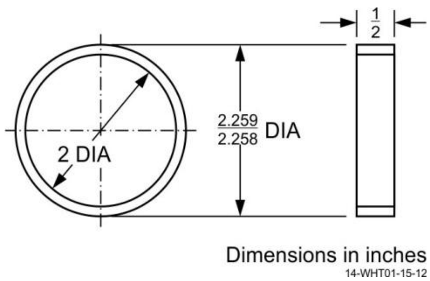


Figure 2.24. Bushing Retainer (DWG# RE-1-22611).

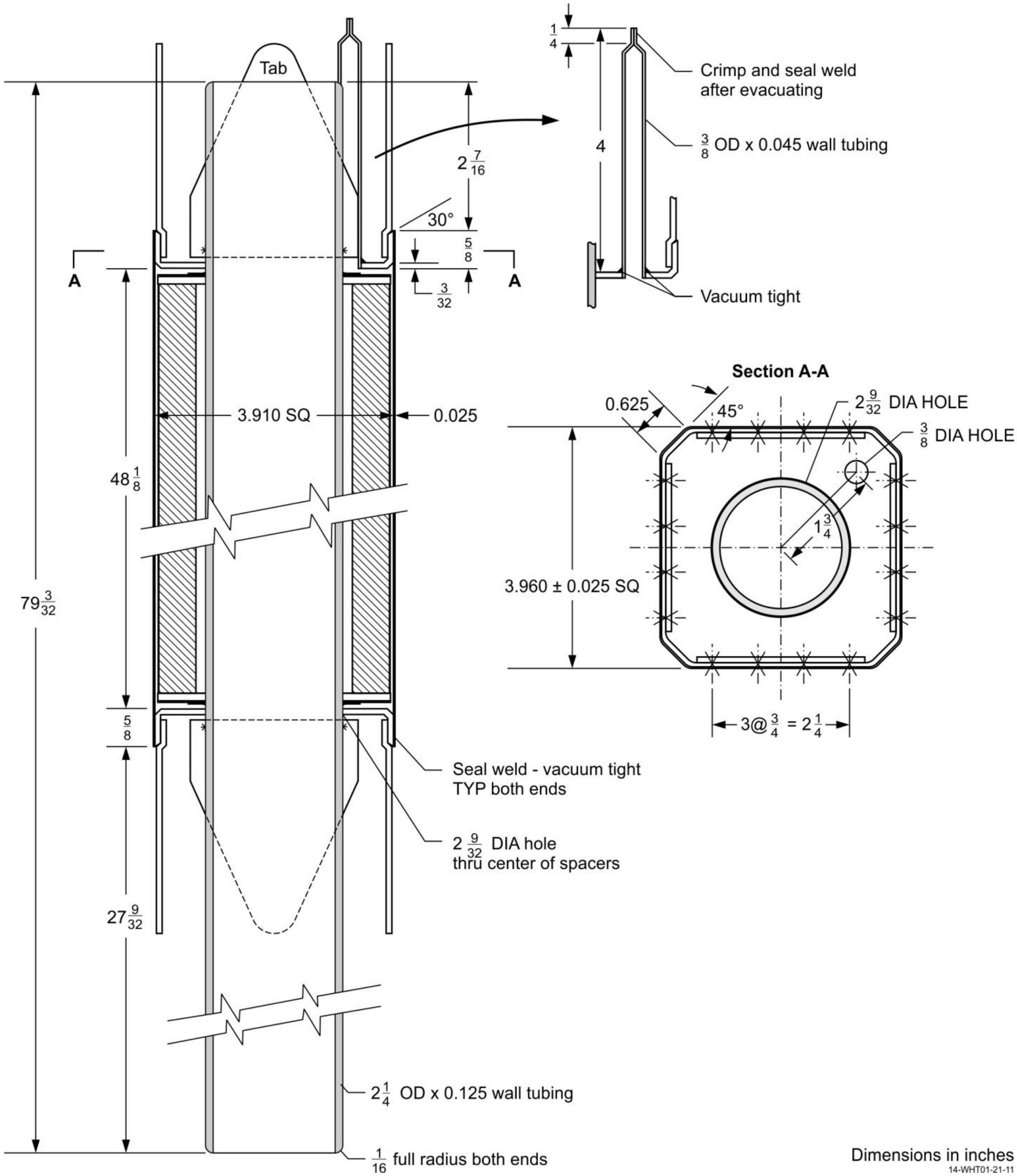


Figure 2.25. Control Rod Element Fuel Section (DWG# RE-1-22612).

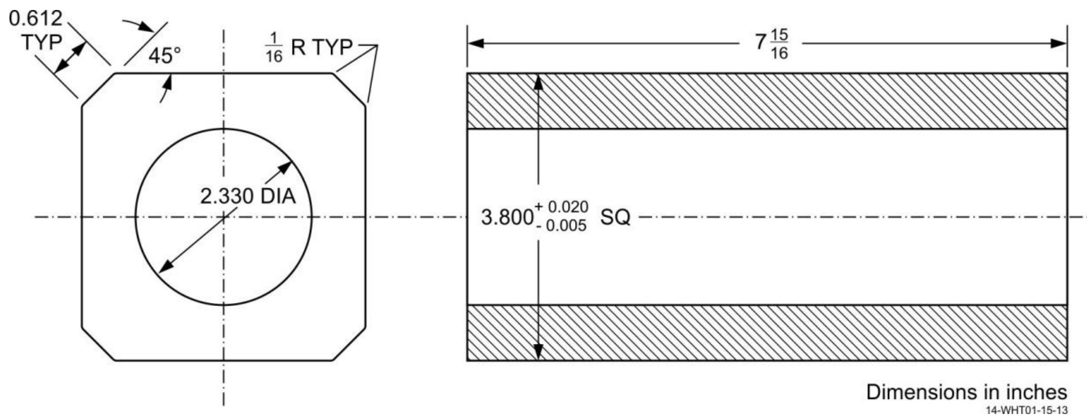


Figure 2.26. Fuel Block (DWG# RE-1-22613).

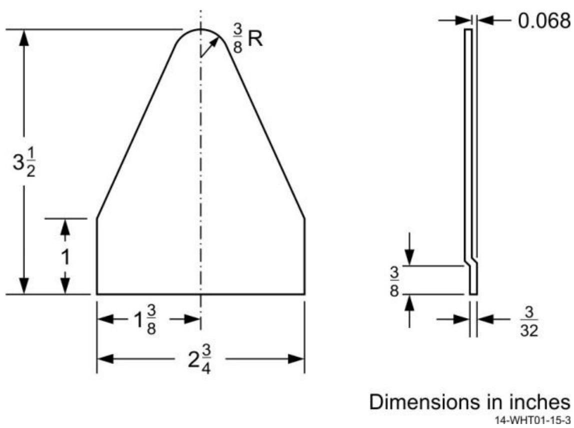


Figure 2.27. Tab (DWG# RE-1-22699).

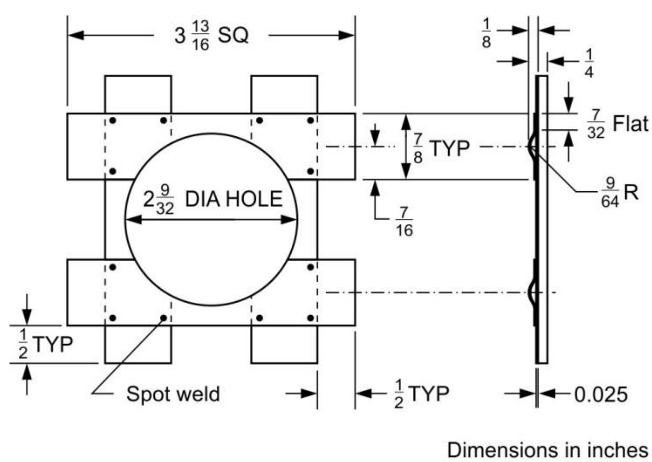


Figure 2.28. Spacer (DWG# RE-1-24150).

2.2.1 Vertical Access Hole Fuel Assembly

The vertical access hole fuel assembly is a control rod fuel assembly with the rod guide bushing removed and the lower end of the guide tube cut short and replaced with a standard element alignment pin. The assembly is shown in Figure 2.29 with a list of applicable drawings and materials provided in Table 2.4. Individual component drawings are provided in Figures 2.29 through 2.41.

Table 2.4. Vertical Access Hole Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.29	--	Vertical Access Hole Fuel Assembly	--
1	2.30	RE-1-22603	Head	Al-1100
1	2.31	RE-1-22604	Upper Long Plug	CP-2 Graphite
1	2.32	RE-1-22605	Upper Short Plug	CP-2 Graphite
1	2.33	RE-1-22606	Lower Short Plug	CP-2 Graphite
1	2.34	RE-1-22607	Lower Long Plug	CP-2 Graphite
1	2.35	RE-1-22736	End Tube Part #1	Al-6063
1	2.35	RE-1-22736	End Tube Part #2	Al-6063
1	2.36	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.37	RE-1-22609	Bearing Tube	Al-1100
1	2.38	--	Vertical Access Element Fuel Section	Zr-3
6	2.39	RE-1-22613	Fuel Block	Graphite Fuel
8	2.40	RE-1-22699	Tab	Zr-3
2	2.41	RE-1-24150	Spacer	Zr-3

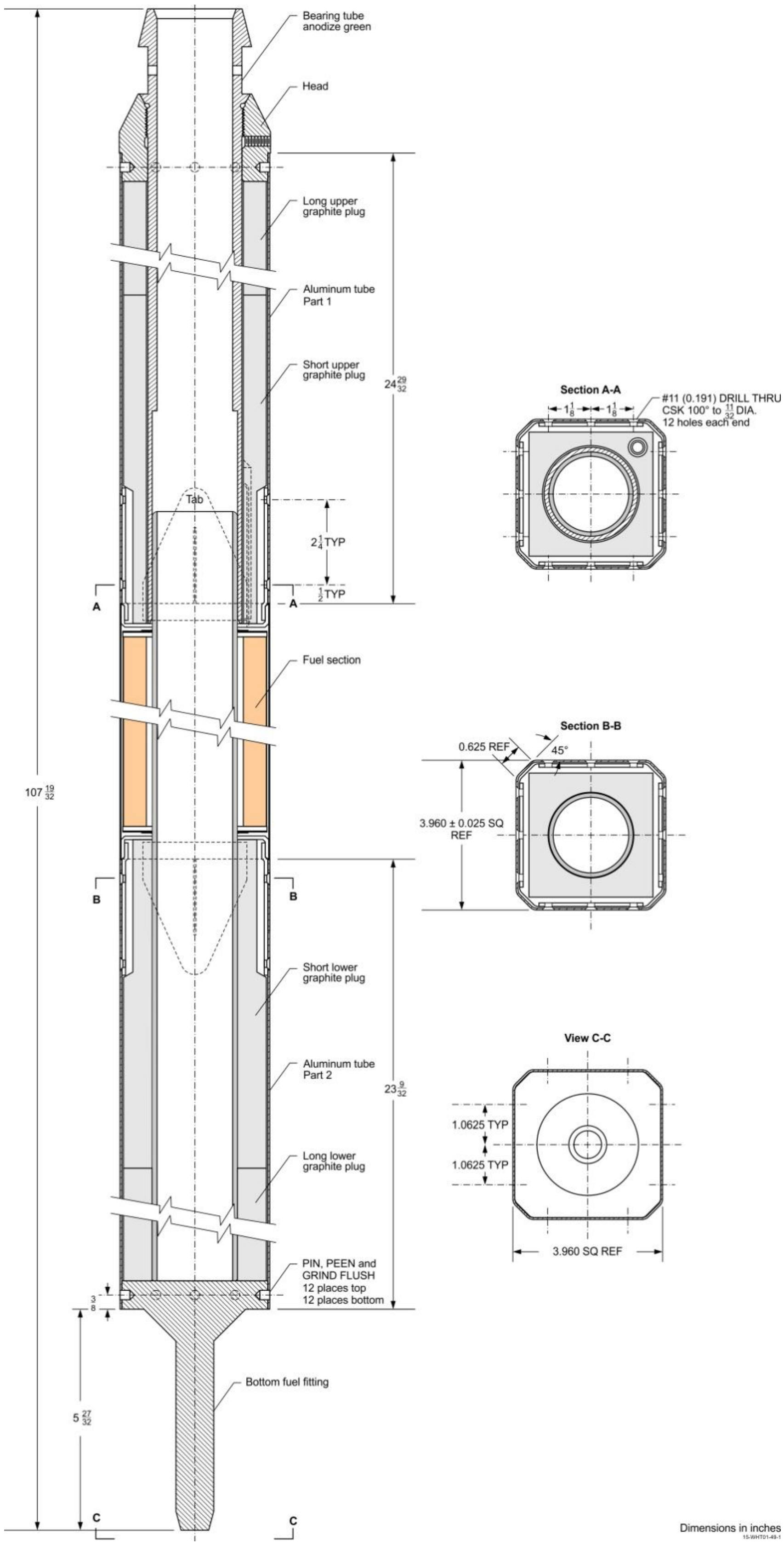


Figure 2.29. Vertical Access Hole Fuel Assembly.

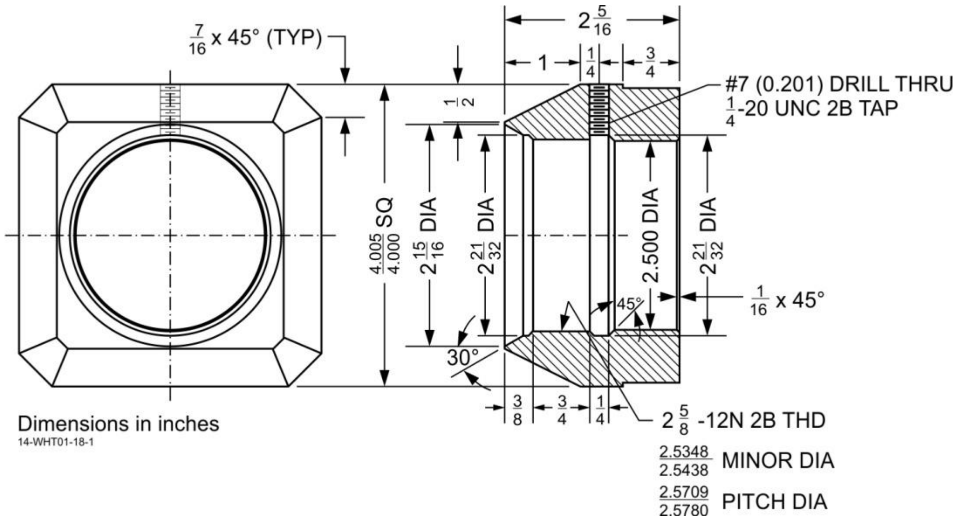


Figure 2.30. Head (DWG# RE-1-22603).

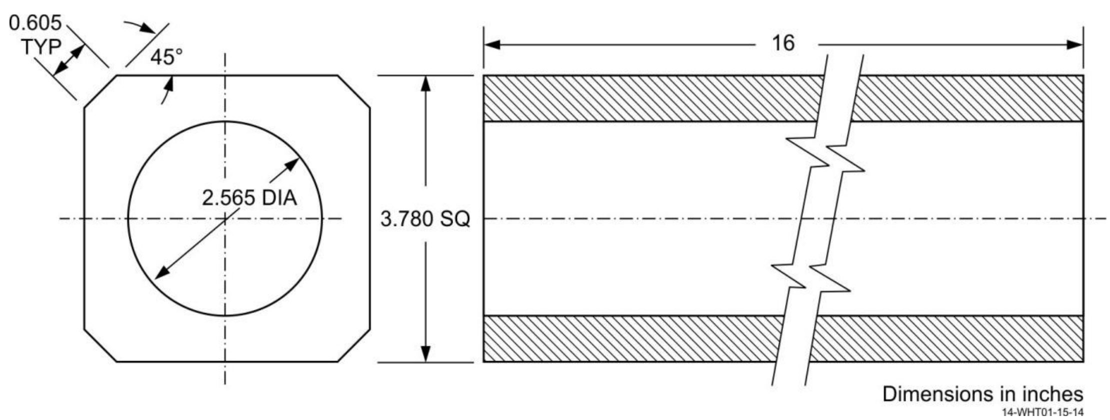


Figure 2.31. Upper Long Plug (DWG# RE-1-22604).

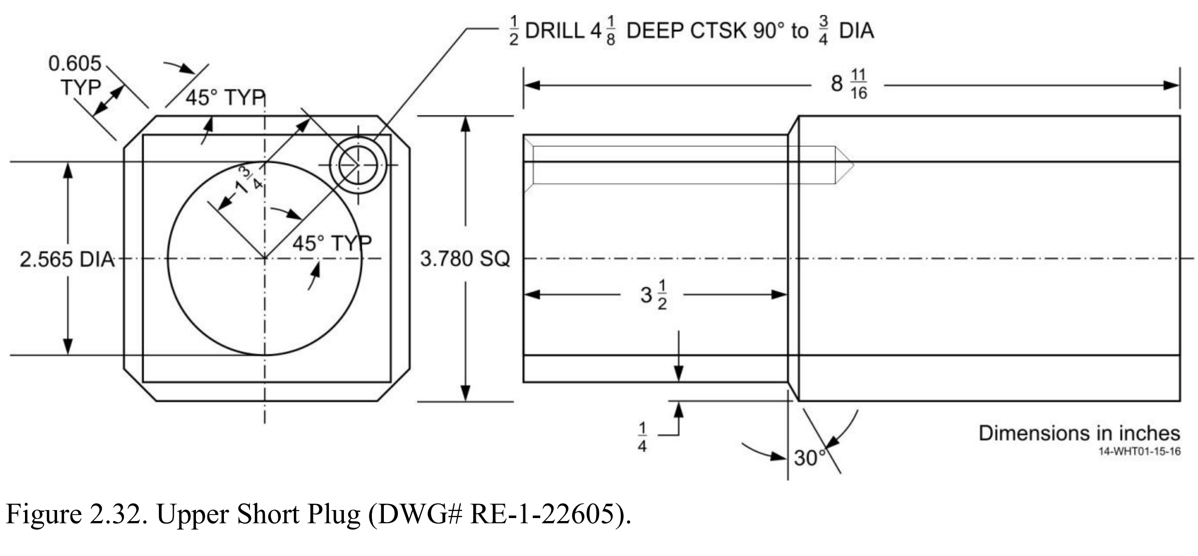


Figure 2.32. Upper Short Plug (DWG# RE-1-22605).

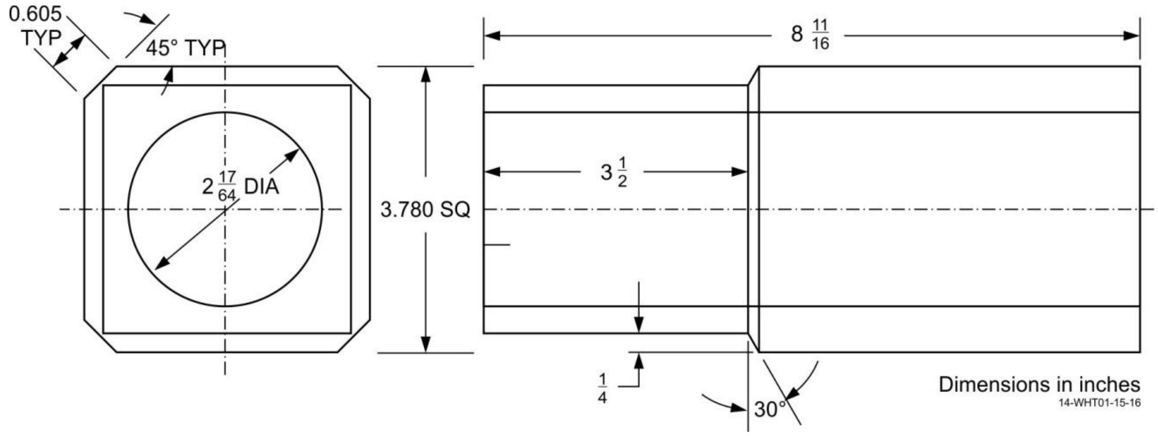


Figure 2.33. Lower Short Plug (DWG# RE-1-22606).

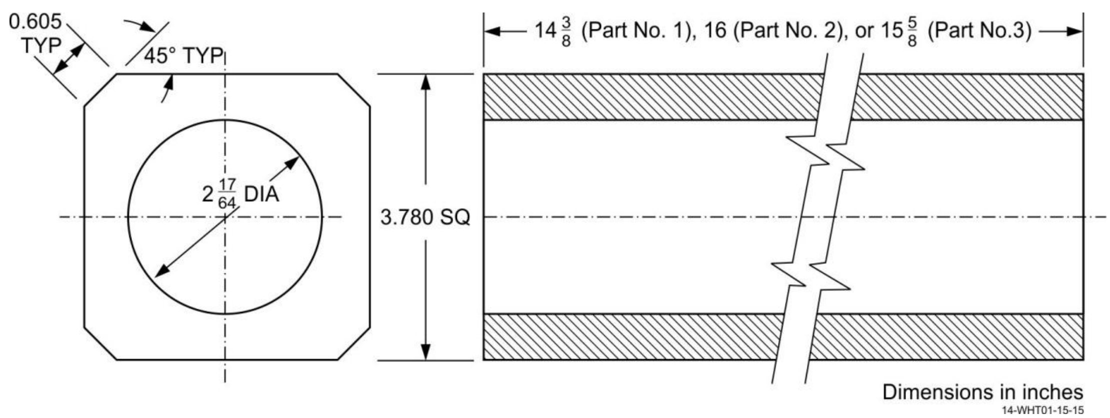


Figure 2.34. Lower Long Plug (DWG# RE-1-22607).

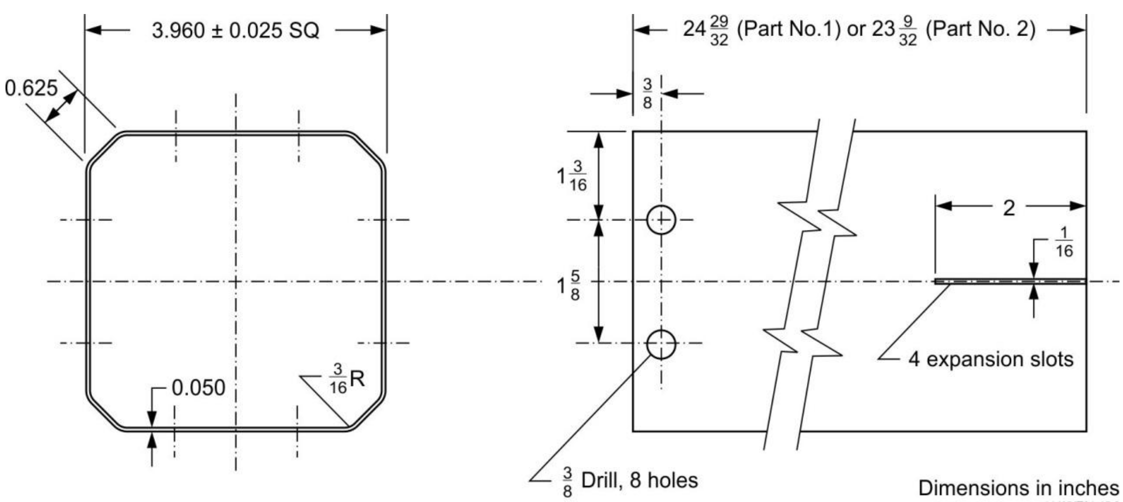


Figure 2.35. End Tube (DWG# RE-1-22736).

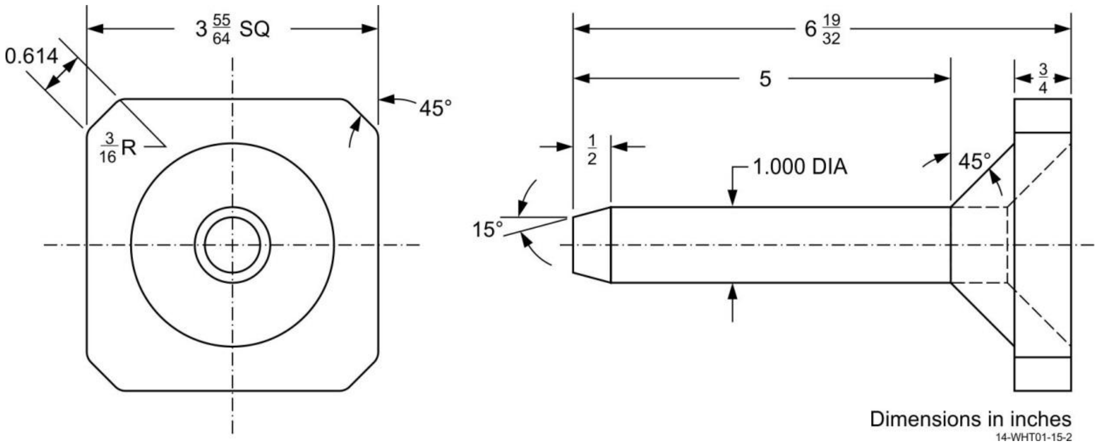


Figure 2.36. Bottom Fuel Fitting (DWG# RE-1-21881).

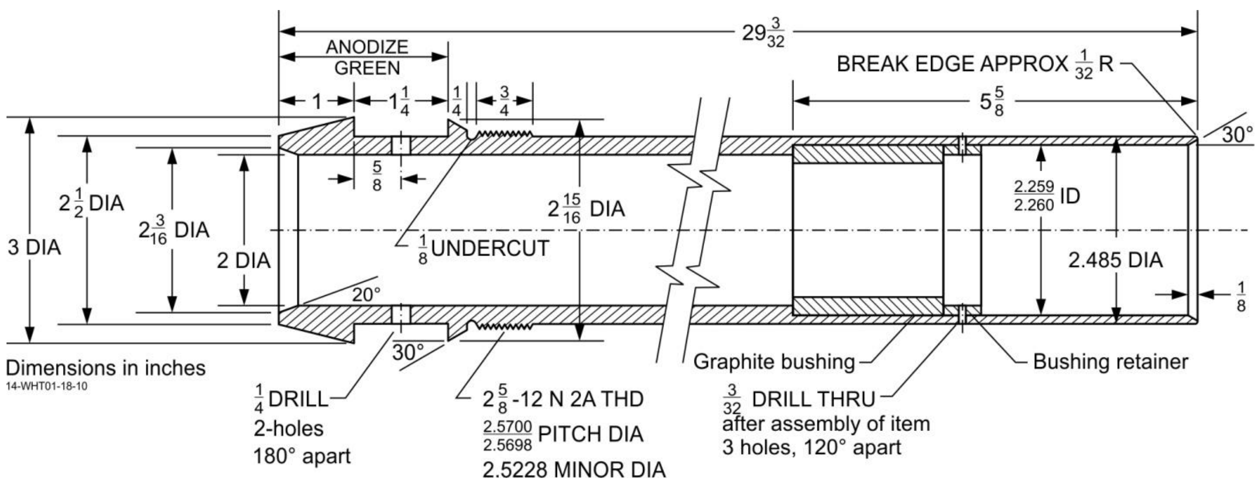


Figure 2.37. Bearing Tube (DWG# RE-1-22609).

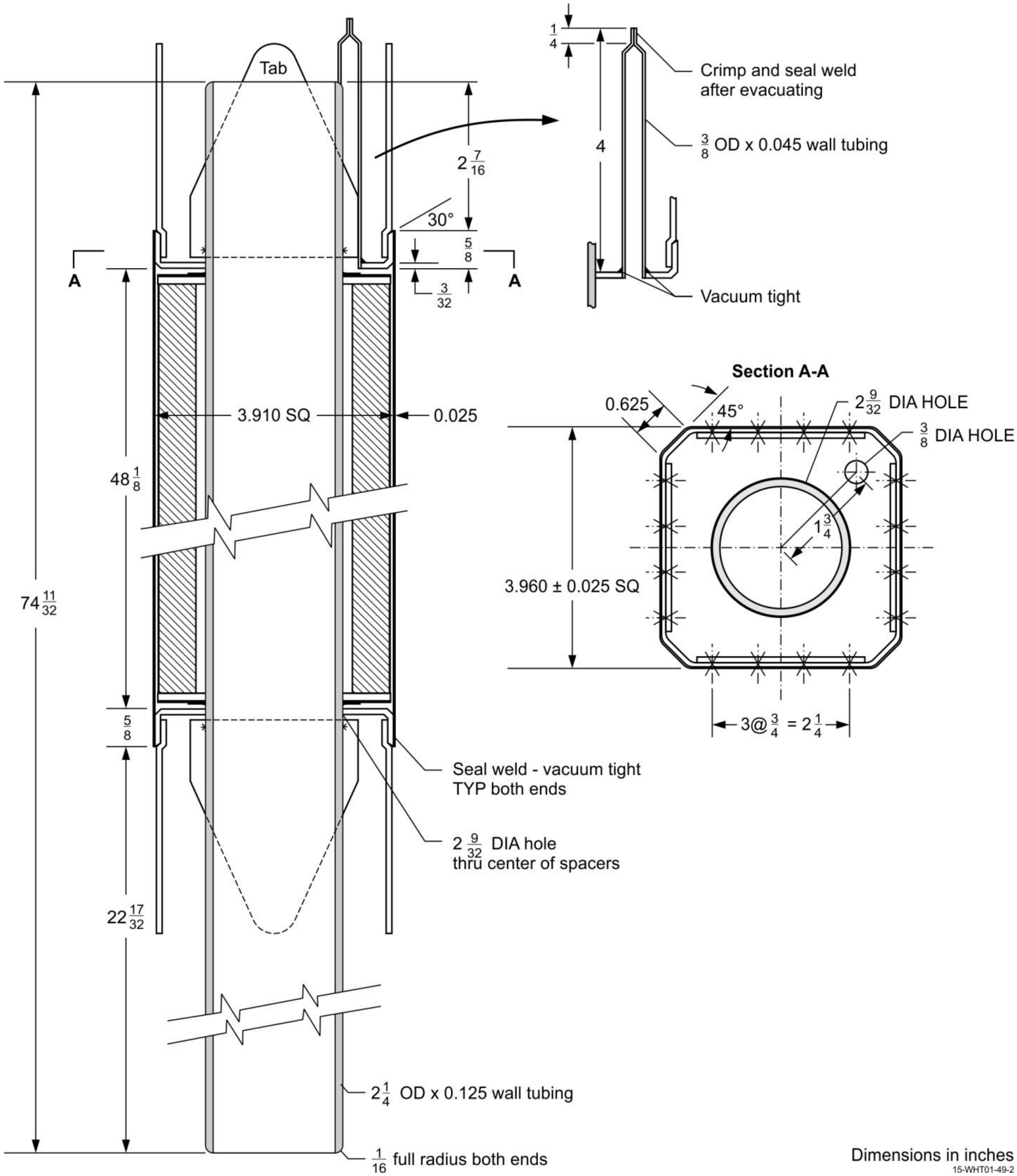


Figure 2.38. Vertical Access Element Fuel Section.

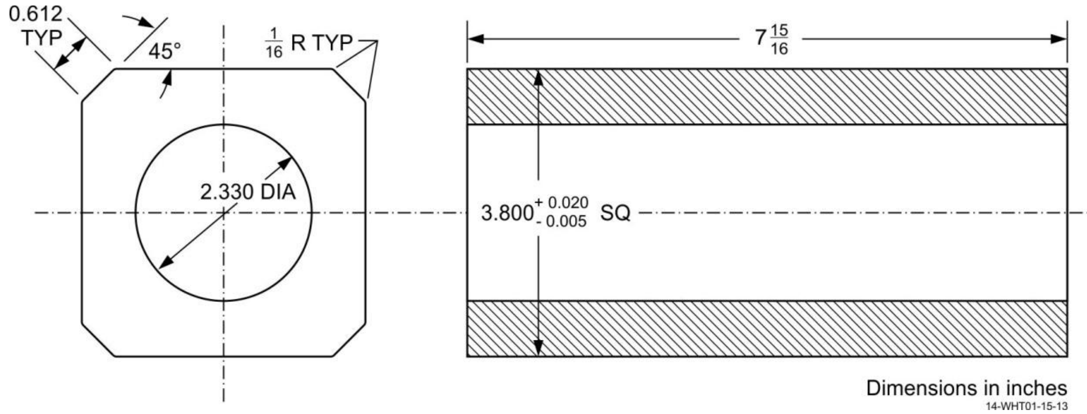


Figure 2.39. Fuel Block (DWG# RE-1-22613).

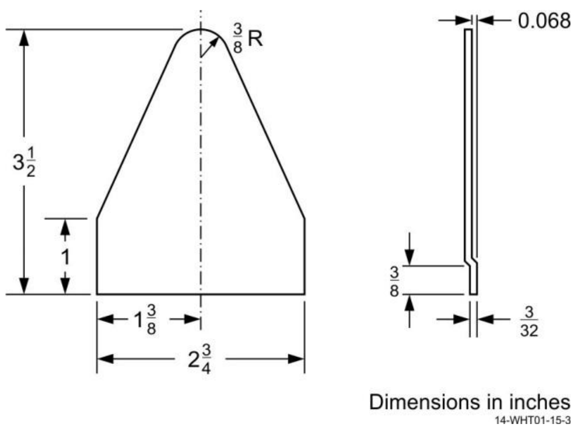


Figure 2.40. Tab (DWG# RE-1-22699).

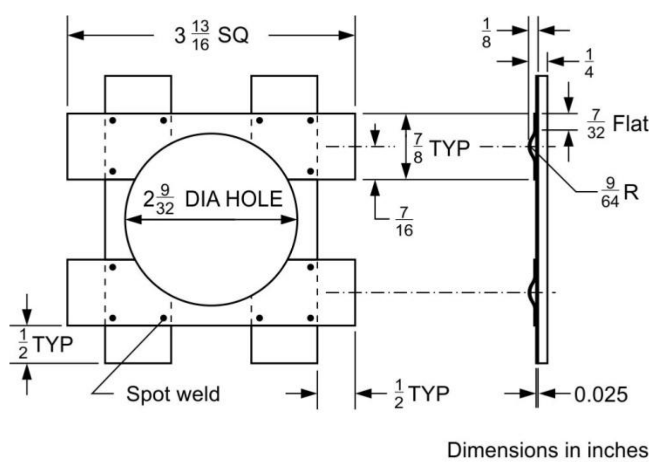


Figure 2.41. Spacer (DWG# RE-1-24150).

2.3 Access Hole (24-inch) Fuel Assembly

The access hole (24-inch) fuel assembly, or slotted fuel assembly, is a standard fuel assembly with a 24-inch-high window created in the center to allow for horizontal access through portions of the core. These assemblies were primarily utilized between an experiment and the hodoscope. Some of the slotted assemblies included a roller assembly (see Figures 2.56 and 2.57). The assembly is shown in Figure 2.42 with a list of applicable drawings and materials provided in Table 2.5. Individual component drawings are provided in Figures 2.42 through 2.57.

Table 2.5. Access Hole (24-inch) Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.42	RE-1-22718	Access Hole Fuel Assembly	--
1	2.43	RE-1-21880	Top Fuel Fitting	Al-1100
1	2.44	RE-1-21768	Long Plug Part #1	CP-2 Graphite
1	2.44	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.45	RE-1-22736	End Tube Part #1	Al-6063
1	2.45	RE-1-22736	End Tube Part #2	Al-6063
2	2.46	RE-1-21767	Short Plain Plug	CP-2 Graphite
1	2.47	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.48	RE-1-21717	Access Hole Fuel Section	Zr-3
2	2.49	RE-1-21578	Fuel Block Part #1	Graphite Fuel
2	2.49	RE-1-21578	Fuel Block Part #2	Graphite Fuel
8	2.50	RE-1-22699	Tab	Zr-3
2	2.51	RE-1-24160	Spacer	Zr-3
4	2.52	RE-1-24660	Anchor Tab	Zr-3
2	2.53	RE-1-24659	Side Frame	Zr-3
2	2.54	RE-1-24661	Guide	Zr-3
1	2.55	Z0012-0314 to -316	Fuel Identification Tag	Al-6061
--	--	--	Optional Additional Parts	--
1	2.56	RE-1-22718	Access Hole Roller Fuel Assembly	--
1	2.57	ID-IC-13441	Access Hole Roller Assembly	--
1	2.57	ID-IC-13442	Housing	Mild Steel
2	2.57	ID-IC-13443	Roller	Mild Steel
2	2.57	ID-IC-13444	Pin	Brass B16

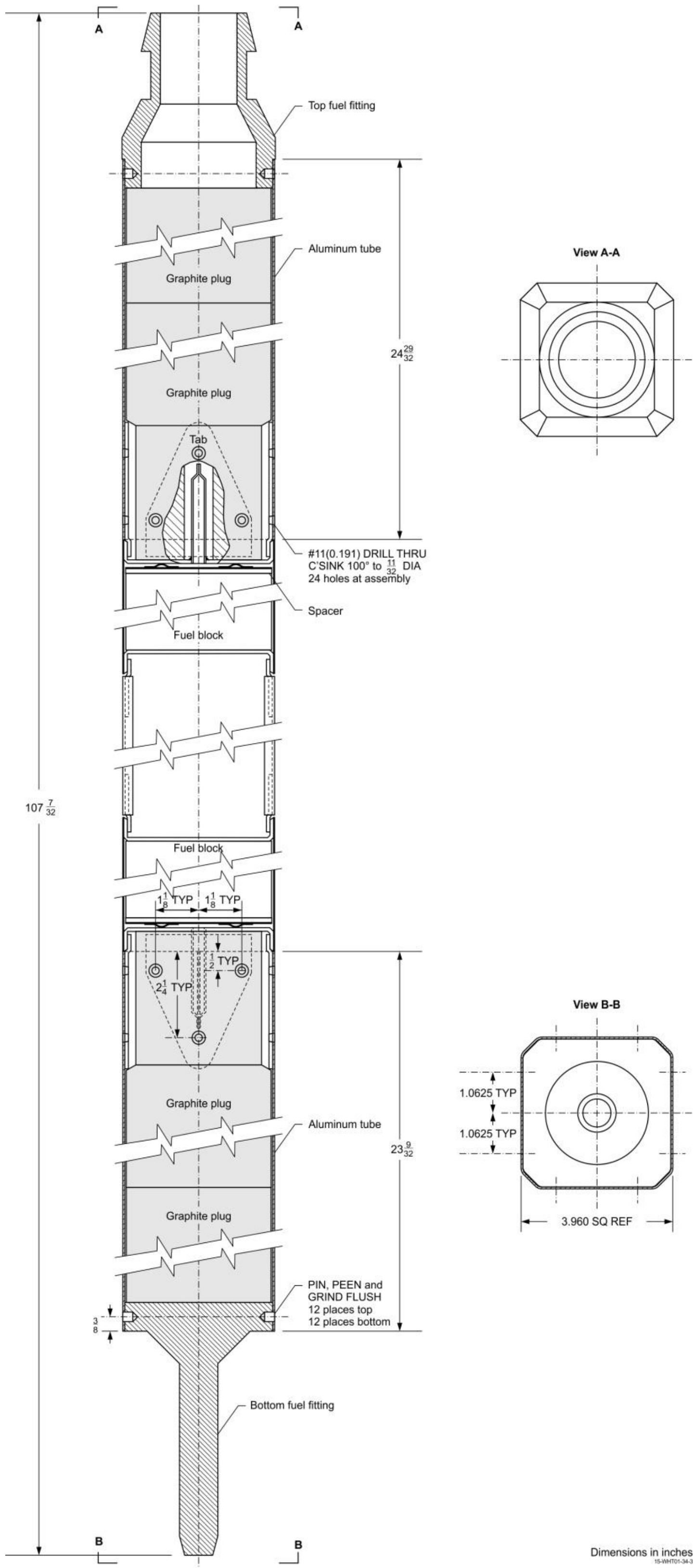


Figure 2.42. Access Hole Fuel Assembly (DWG# RE-1-22718).

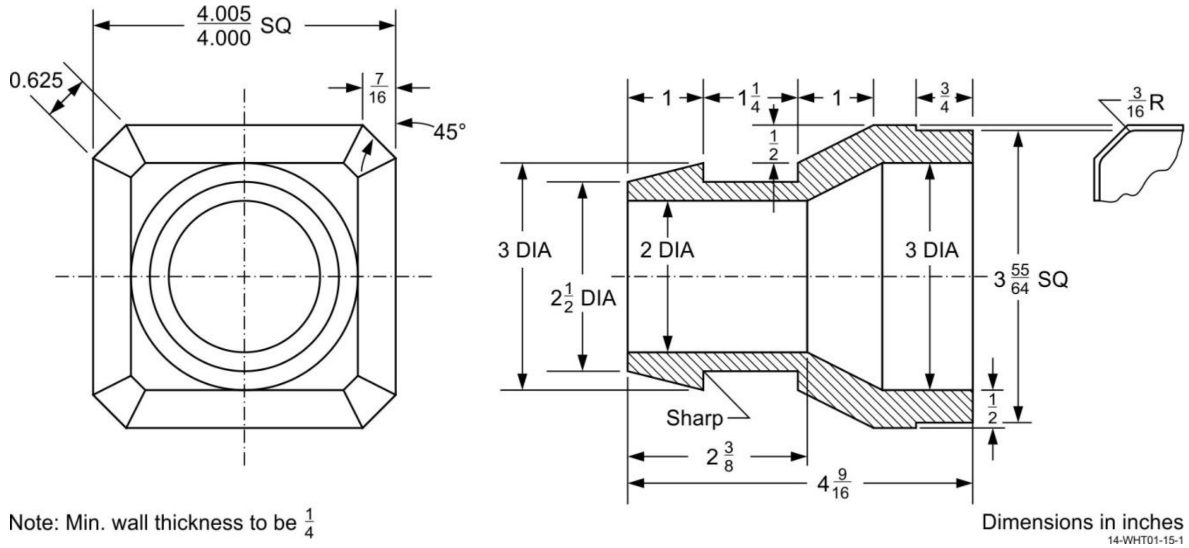


Figure 2.43. Top Fuel Fitting (DWG# RE-1-21880).

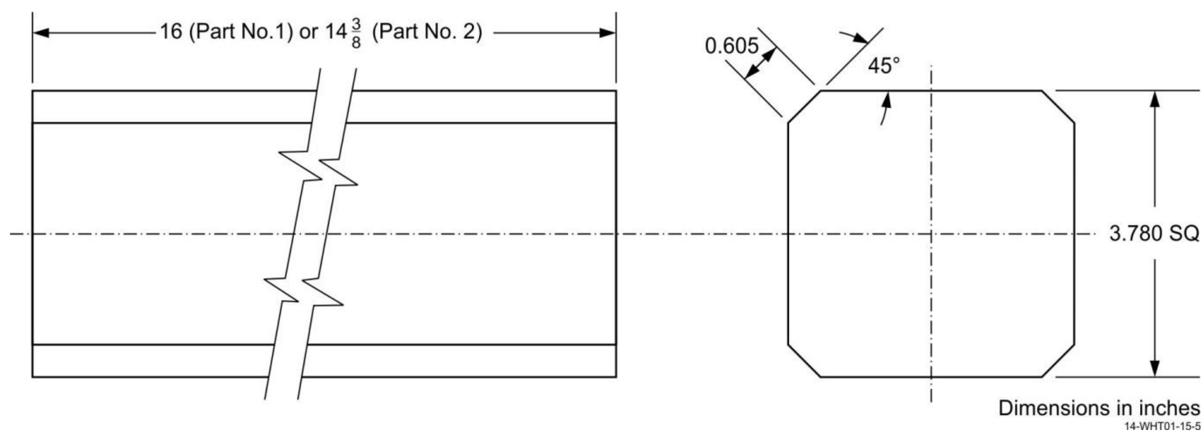


Figure 2.44. Long Plug (DWG# RE-1-21768).

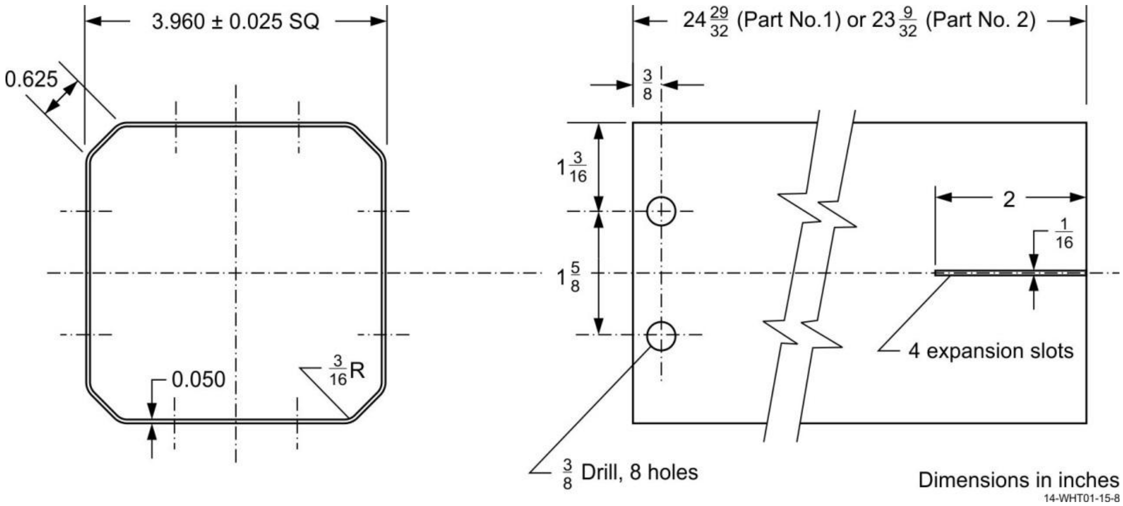


Figure 2.45. End Tube (DWG# RE-1-22736).

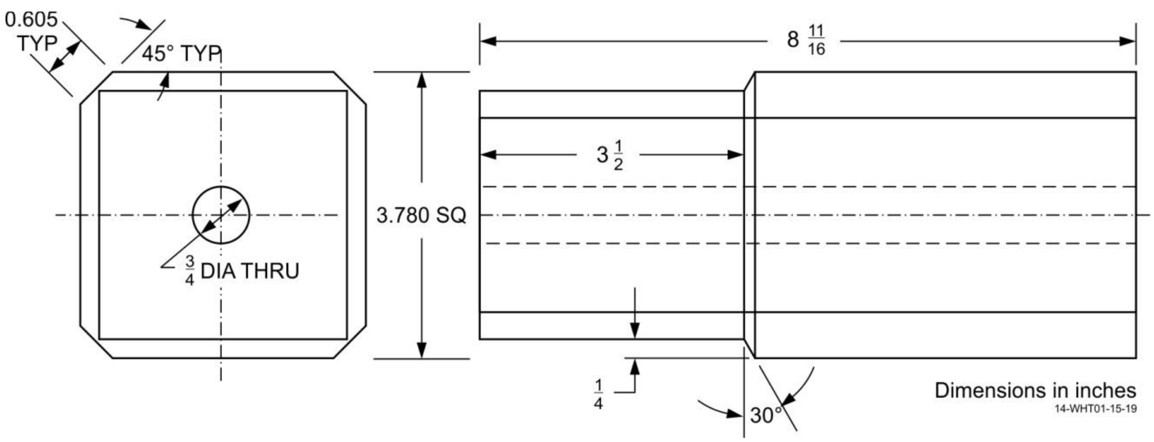


Figure 2.46. Short Plug (DWG# RE-1-21767).

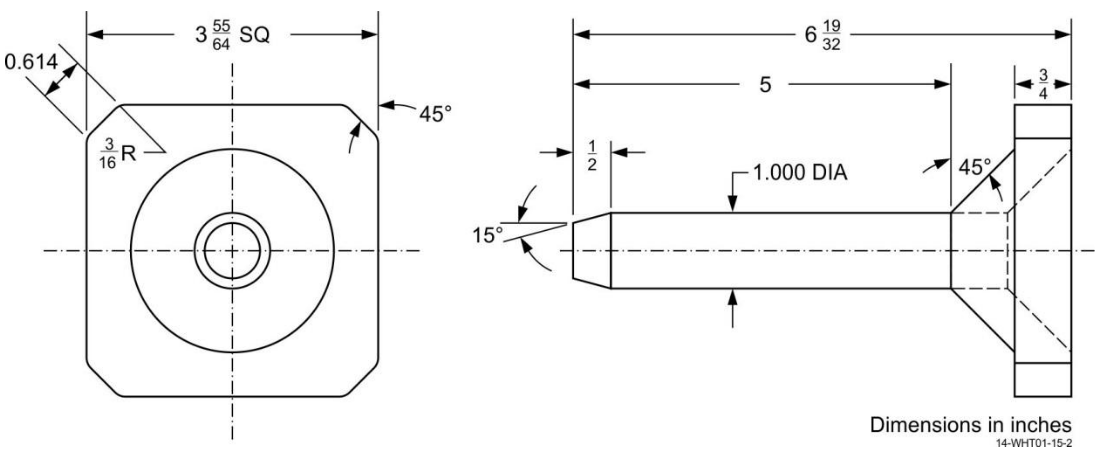


Figure 2.47. Bottom Fuel Fitting (DWG# RE-1-21881).

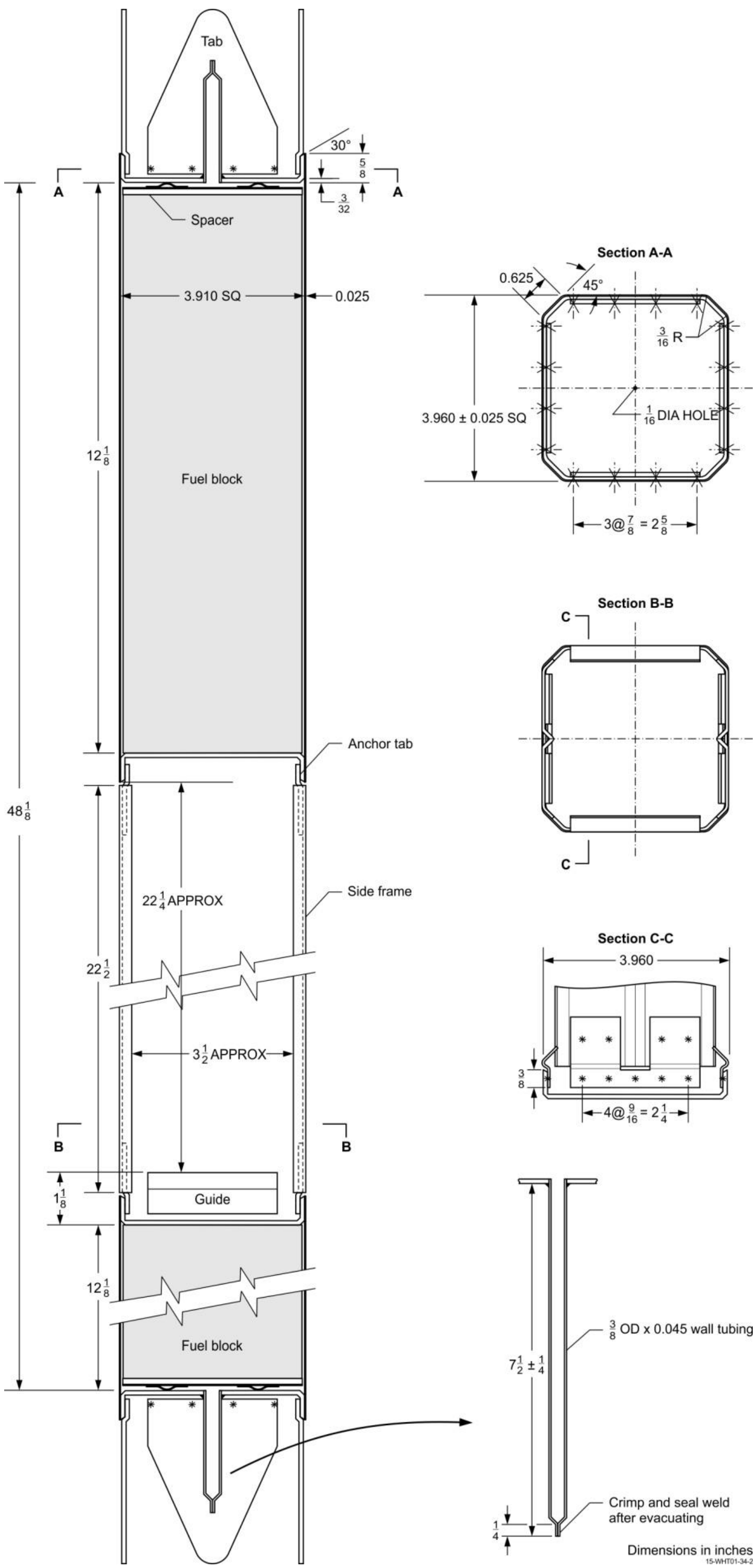


Figure 2.48. Access Hole Fuel Section (DWG# RE-1-21716).

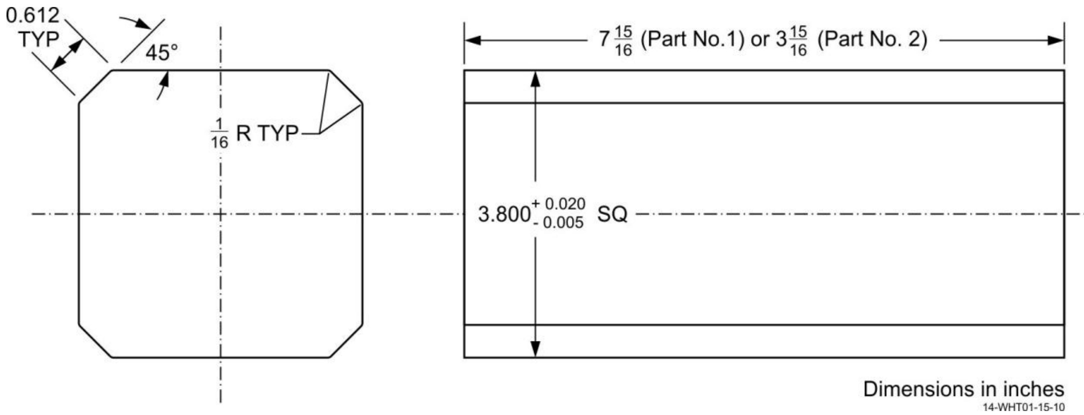


Figure 2.49. Fuel Block (DWG# RE-1-21578).

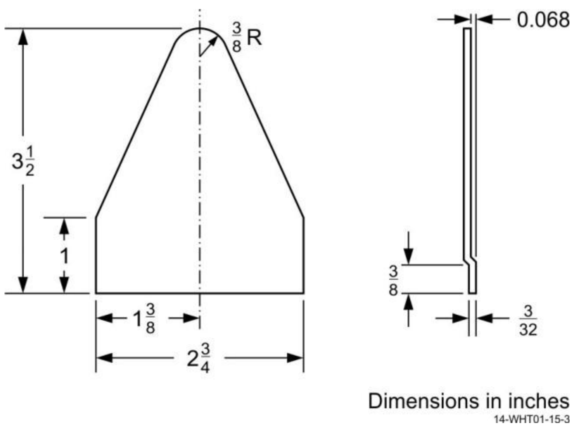


Figure 2.50. Tab (DWG# RE-1-22699).

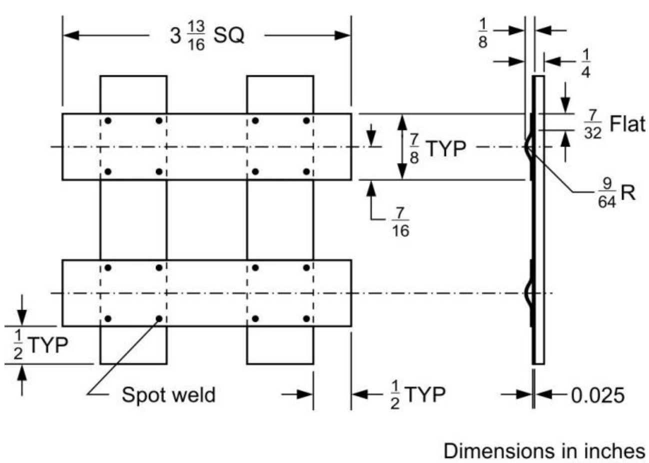


Figure 2.51. Spacer (DWG# RE-1-24160).

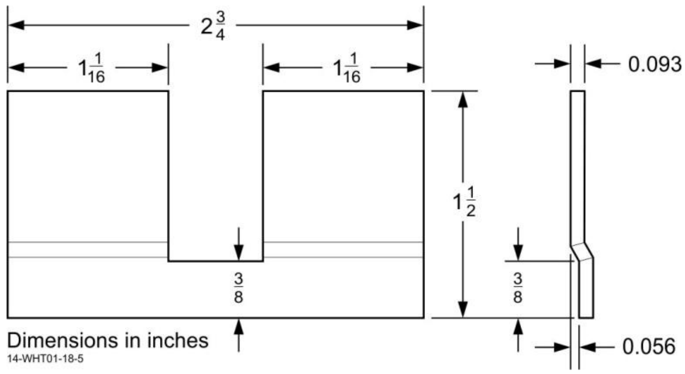


Figure 2.52. Anchor Tab (DWG# RE-1-24660).

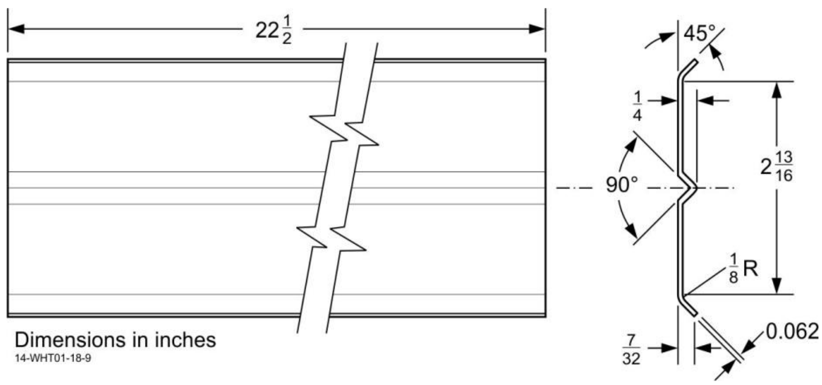


Figure 2.53. Side Frame (DWG# RE-1-24659).

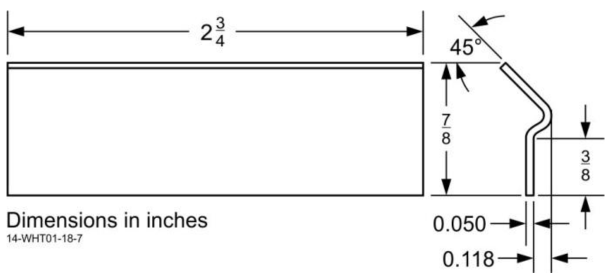


Figure 2.54. Guide (DWG# RE-1-24661).

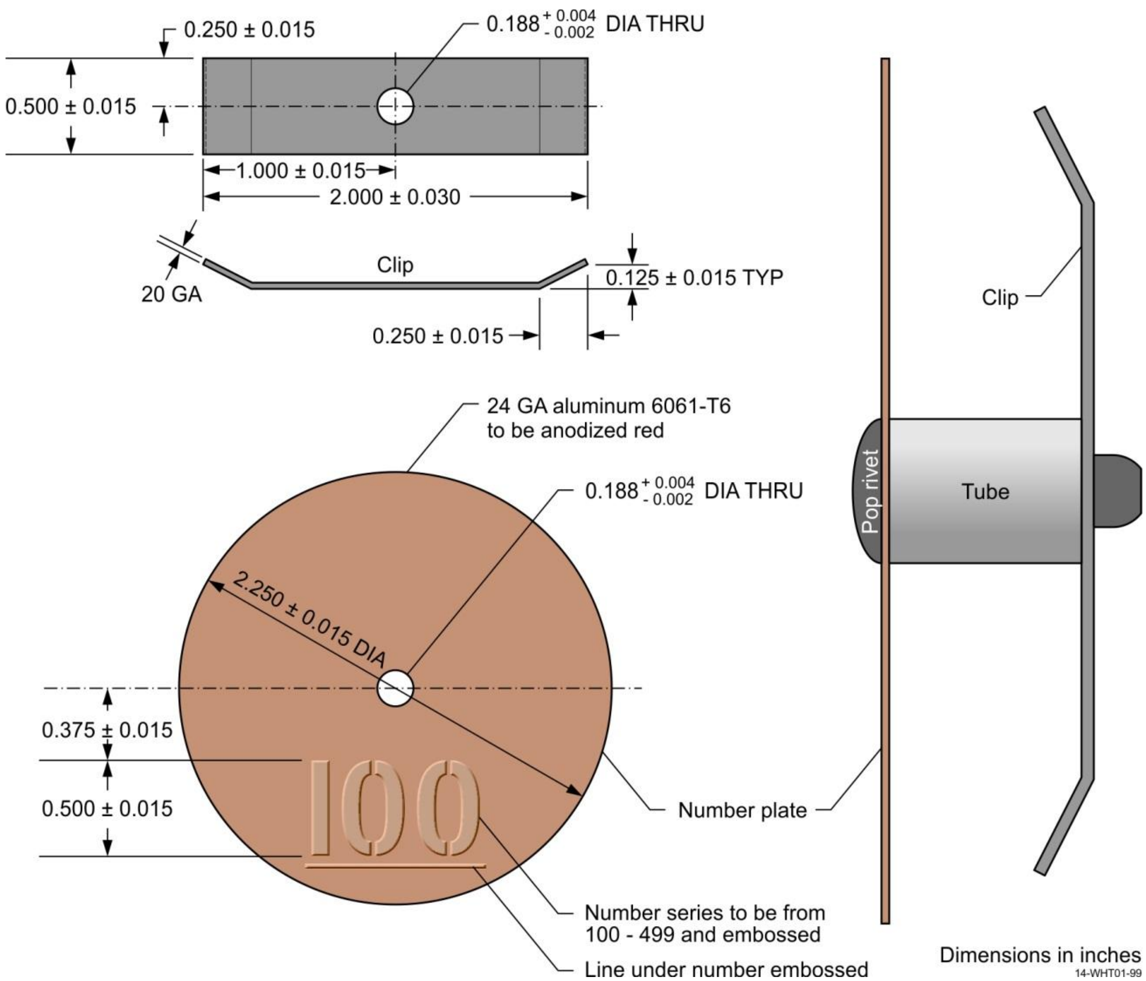


Figure 2.55. Fuel Identification Tag (DWG# Z0012-0314 through -0316).

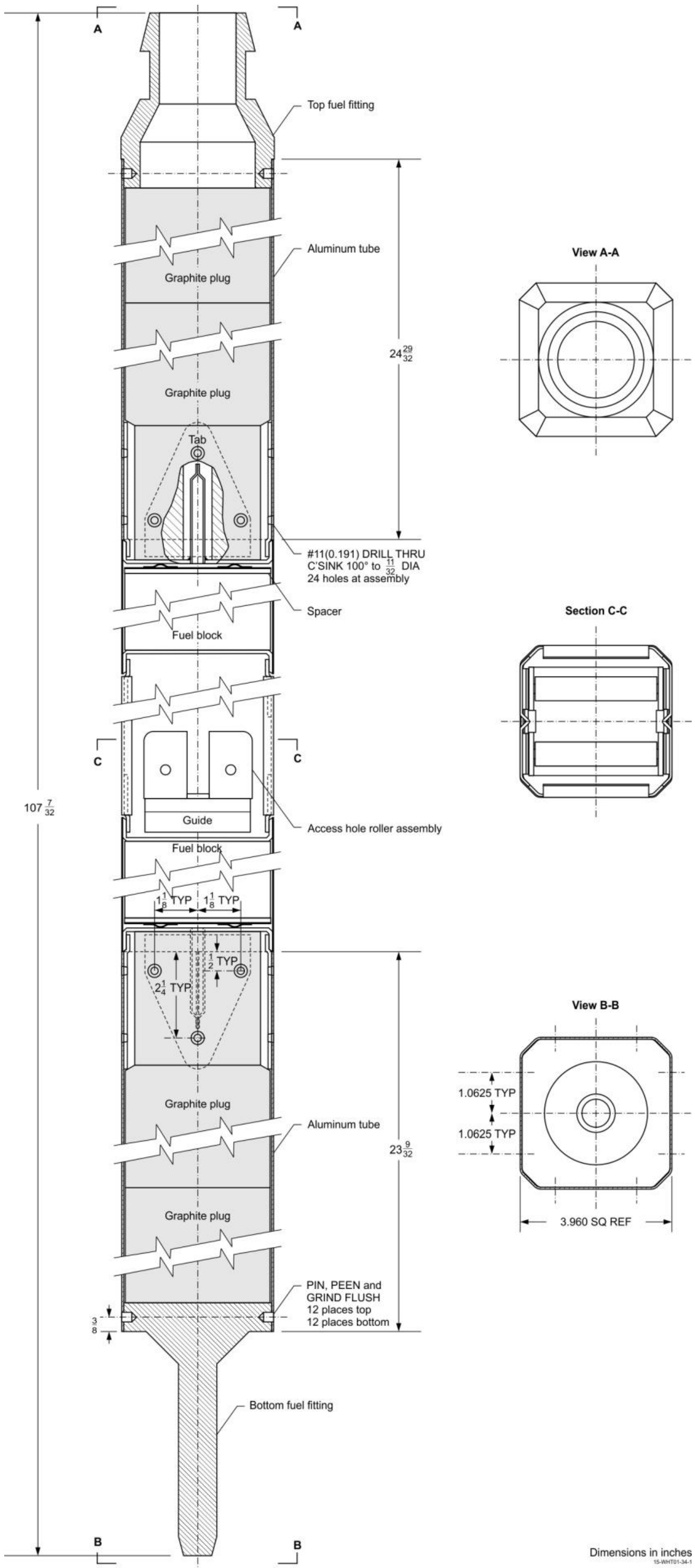


Figure 2.56. Access Hole Roller Fuel Assembly (DWG# RE-1-22718).

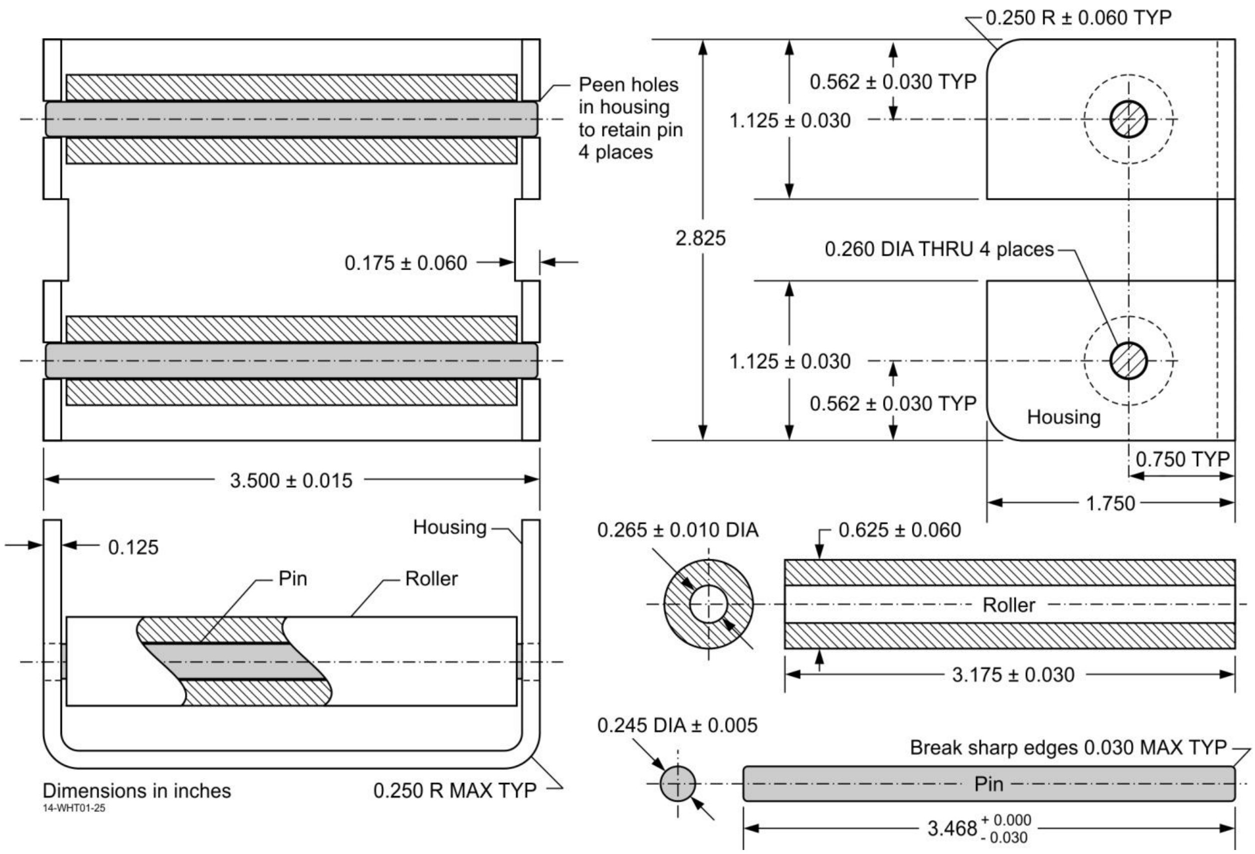


Figure 2.57. Fuel Identification Tag (DWG# ID-IC-13441 through -13444).

2.4 Thermocouple Fuel Assemblies

The thermocouple fuel assemblies are standard fuel assemblies fitted with various arrangements of thermocouples for measuring temperature throughout the core. A summary of the various types of TREAT thermocouple fuel, and dummy, assemblies is provided in Table 2.6.

It should be noted that components such as thermocouples and amphenols would have been purchased from standard off-the-shelf vendors during the construction of TREAT and then modified, as necessary, for adaptation into the facility. The intent was to reduce costs and adhere to practiced ASTM standards of the time period for thermocouple components. As such, detailed drawings of the thermocouples themselves, aside from placement within the thermocouple assemblies, are not available.

The thermocouple assemblies are used to monitor temperature at various points of interest in the fuel and reflector sections. There are a limited number of thermocouples that can be installed within a single assembly; therefore, five types of thermocouples assembly designs incorporating three types of thermocouple installations are employed. Type A thermocouples are chromel-alumel couple sheathed in SS304 (0.062 in. diameter) with MgO insulation. Type B thermocouples are chromel-alumel couple using 28-gauge wire in asbestos-glass insulation (i.e. asbestos overbraid with fiberglass). Type C thermocouples are fast-response chromel-alumel couple with 28-gauge wire attached individually to the fuel blocks by means of small conical wedges. The thermocouples are attached to an 8-pin chromel-alumel Amphenol connector located in the upper end fitting of the assembly. Chromel-alumel lead wires are attached by means of an aluminum holder which contains the male half of the Amphenol plug. The lead wires extend through the reactor coolant inlet ducts and terminate at a junction panel mounted on the outer surface of the concrete shield [Freund 1960].

See ASTM E235 2012 and ASTM E585 2012 for additional information regarding standard nuclear grade thermocouples.

Table 2.6. Types of Thermocouple Assemblies in TREAT.

Identification Numbering	Identification Coloring	Section	Assembly Type
500-503	Red	2.4.1	Four Thermocouple Fuel Assembly
504-505	Red	2.4.4	Reflector Fuel Gradient Thermocouple Fuel Assembly
506-519	Black	2.6.8	Zircaloy-Clad Four Thermocouple Dummy Assembly
520-549	Red	2.4.2	Mid Fuel, Reflector and Skin Thermocouple Fuel Assembly
550-579	Red	2.4.3	Transient Thermocouple Fuel Assembly
620-621	Yellow	2.4.5	Access Hole (24-inch) Thermocouple Fuel Assembly

2.4.1 Four Thermocouple Fuel Assembly

The four thermocouple fuel assembly is shown in Figure 2.59 with a list of applicable drawings and materials provided in Table 2.7. Individual component drawings are provided in Figures 2.59 through 2.74.

Table 2.7. Four Thermocouple Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.59	RE-1-23252	4 Thermocouple Fuel Assembly	--
1	2.59	--	Straight Amphenol Plug	Al-6061
4	2.59	--	Chromel-Alumel Thermocouples	--
1	2.60	RE-1-23270	Special Plug	CP-2 Graphite
1	2.61	RE-1-22739	Short Plain Plug	CP-2 Graphite
1	2.62	RE-1-23269	Top Plug	CP-2 Graphite
1	2.63	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.64	RE-1-22736	End Tube Part #1	Al-6063
1	2.64	RE-1-22736	End Tube Part #2	Al-6063
1	2.65	RE-1-22881	Bottom Fuel Fitting	Al-1100
1	2.66	RE-1-23253	Plug Holder	Al-6061
1	2.67	RE-1-23254	Socket Holder	Al-6061
1	2.68	RE-1-23255	Top Fuel Fitting Rework	Al-1100
4	2.69	RE-1-24159	Thermocouple Well Part #1	Zr-3
1	2.70	RE-1-23256	4 Thermocouple Fuel Section	Zr-3
6	2.71	RE-1-21578	Fuel Block Part #1	Graphite Fuel
8	2.72	RE-1-22699	Tab	Zr-3
2	2.73	RE-1-24160	Spacer	Zr-3
1	2.74	RE-1-23257	Plug Rework Box Receptacle	Al-6061

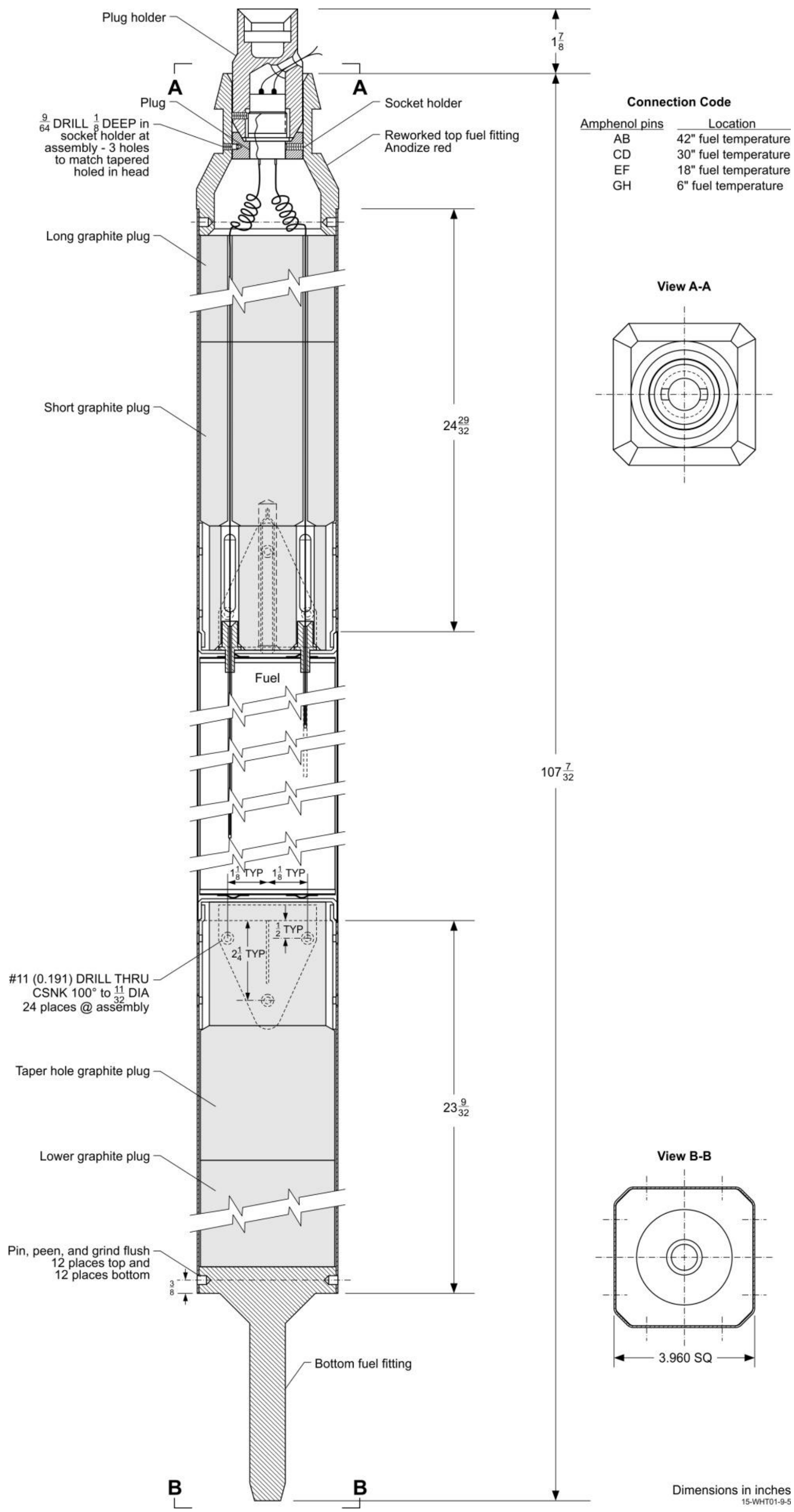


Figure 2.59. 4 Thermocouple Fuel Assembly (DWG# RE-1-23252).

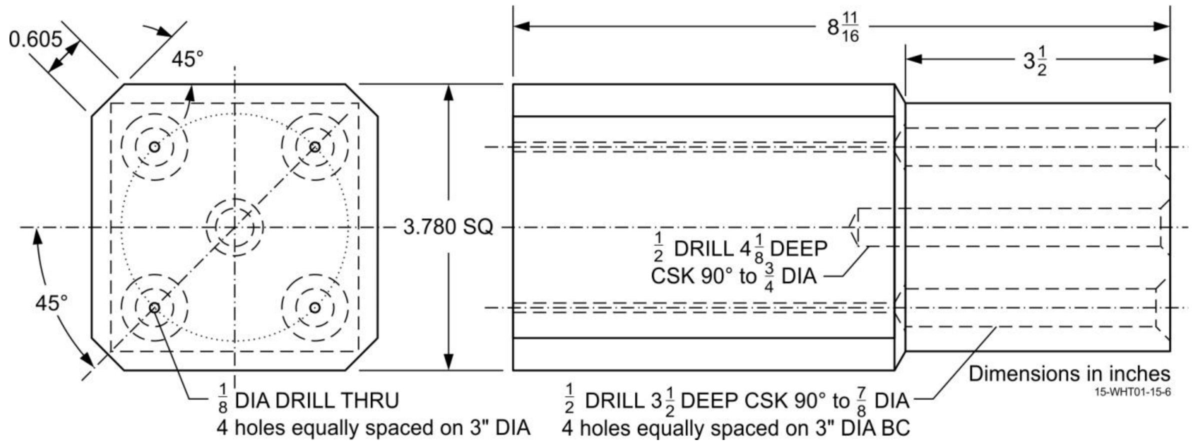


Figure 2.60. Special Plug (DWG# RE-1-23270).

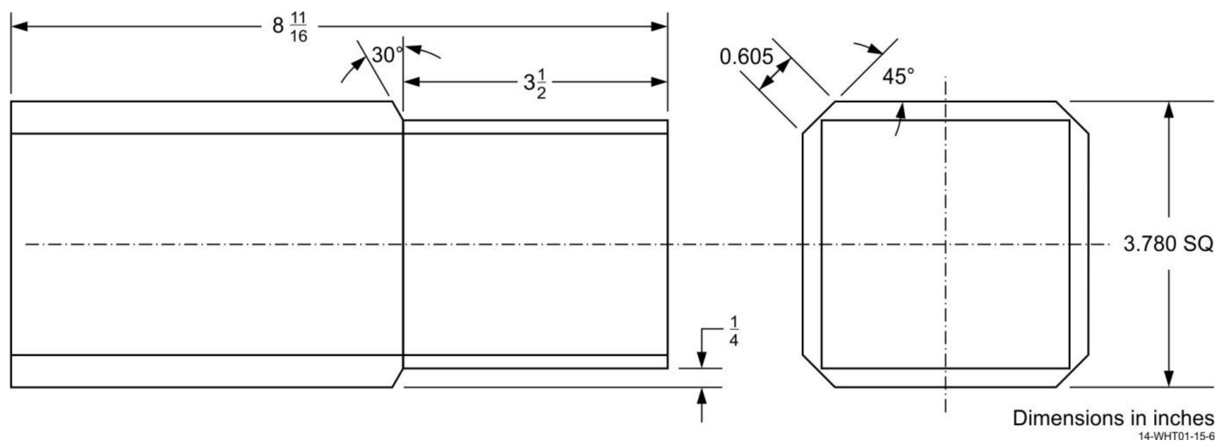


Figure 2.61. Short Plain Plug (DWG# RE-1-22739).

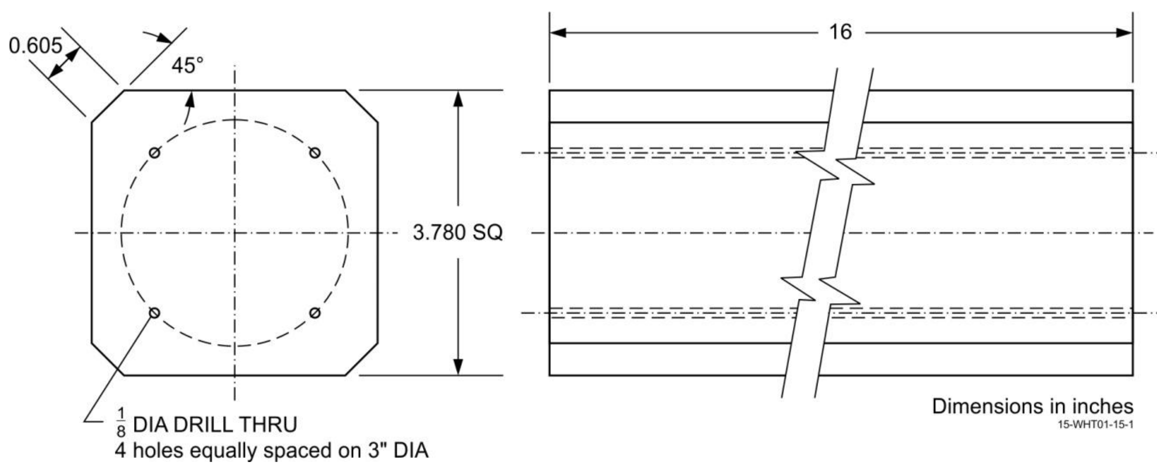


Figure 2.62. Top Plug (DWG# RE-1-23269).

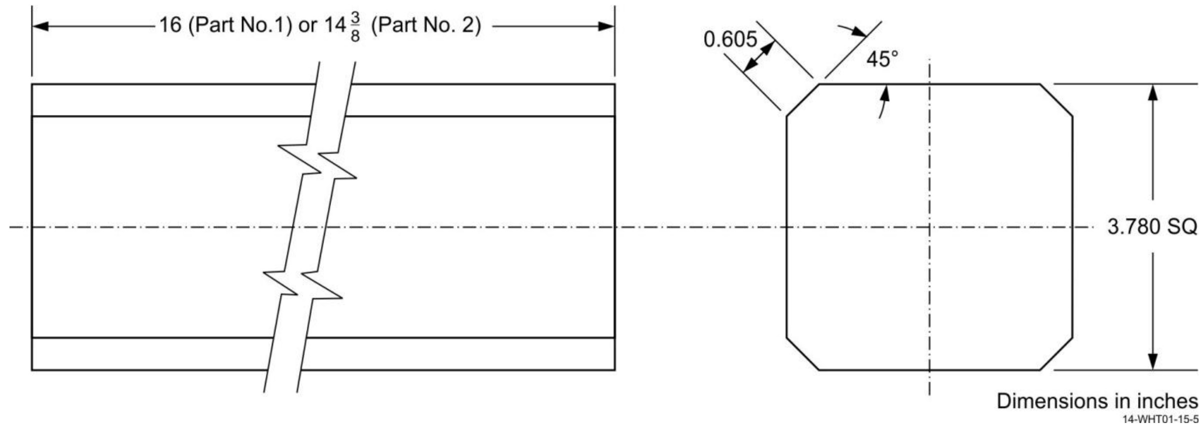


Figure 2.63. Long Plug (DWG# RE-1-21768).

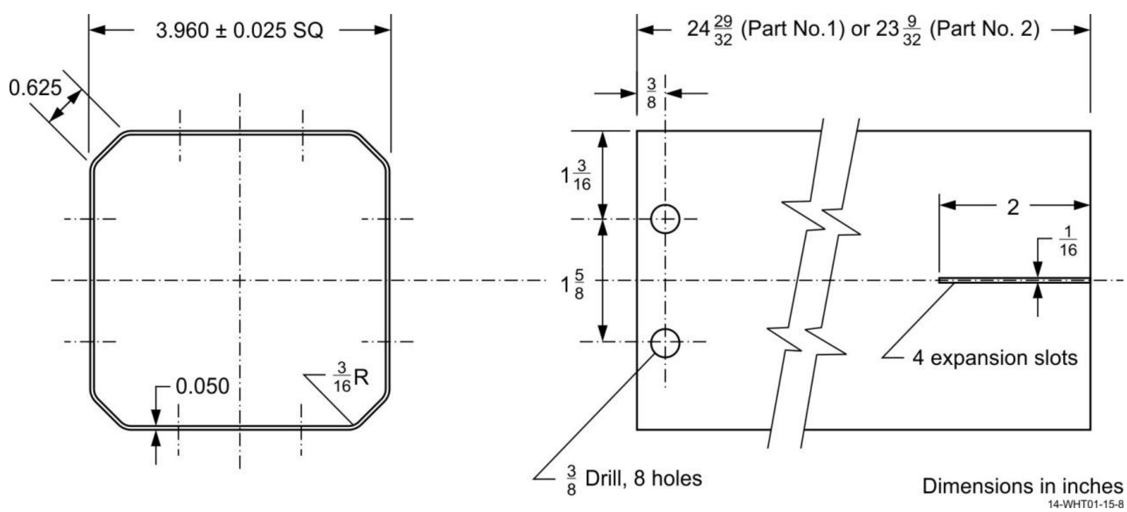


Figure 2.64. End Tube (DWG# RE-1-22736).

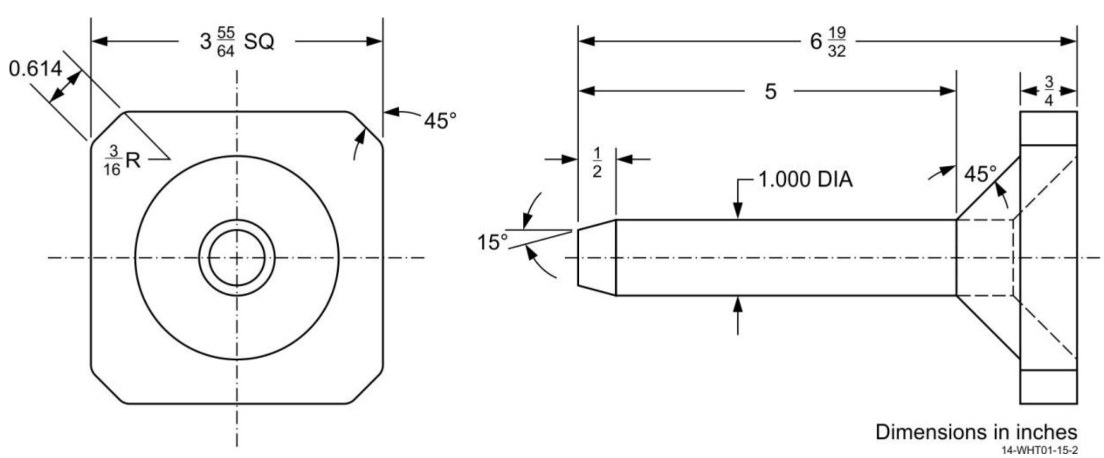


Figure 2.65. Bottom Fuel Fitting (DWG# RE-1-21881).

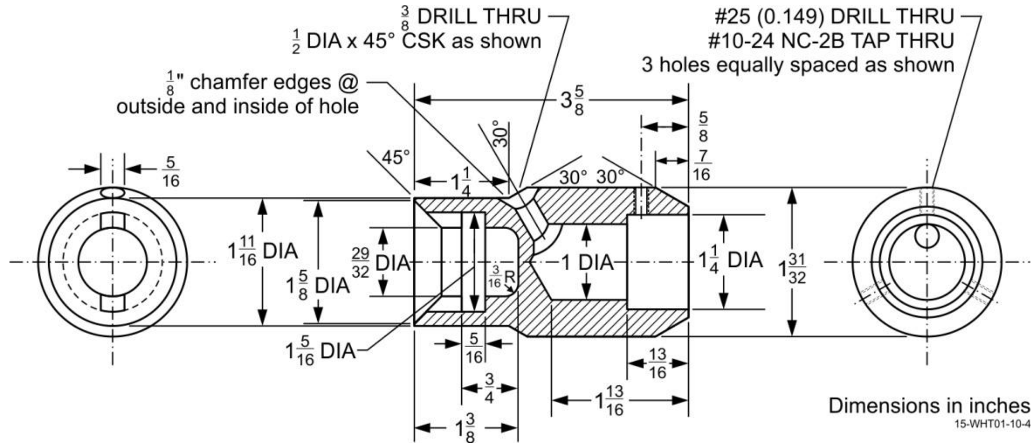


Figure 2.66. Plug Holder (DWG# RE-1-23253).

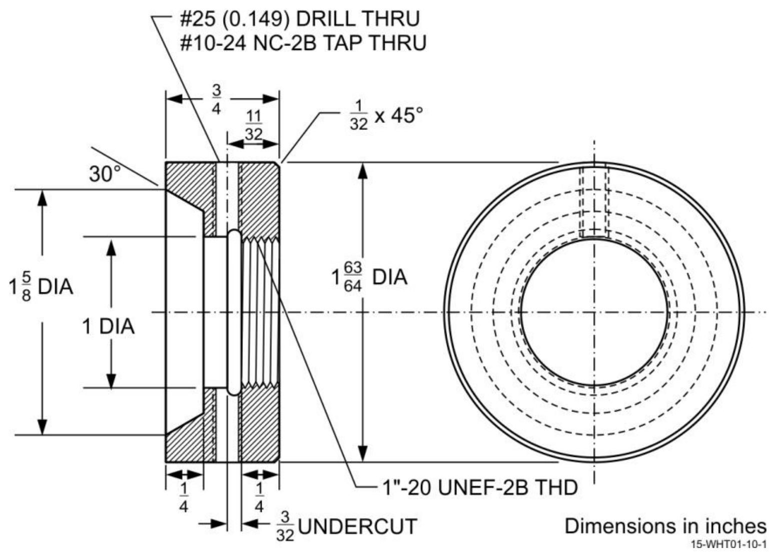


Figure 2.67. Socket Holder (DWG# RE-1-23254).

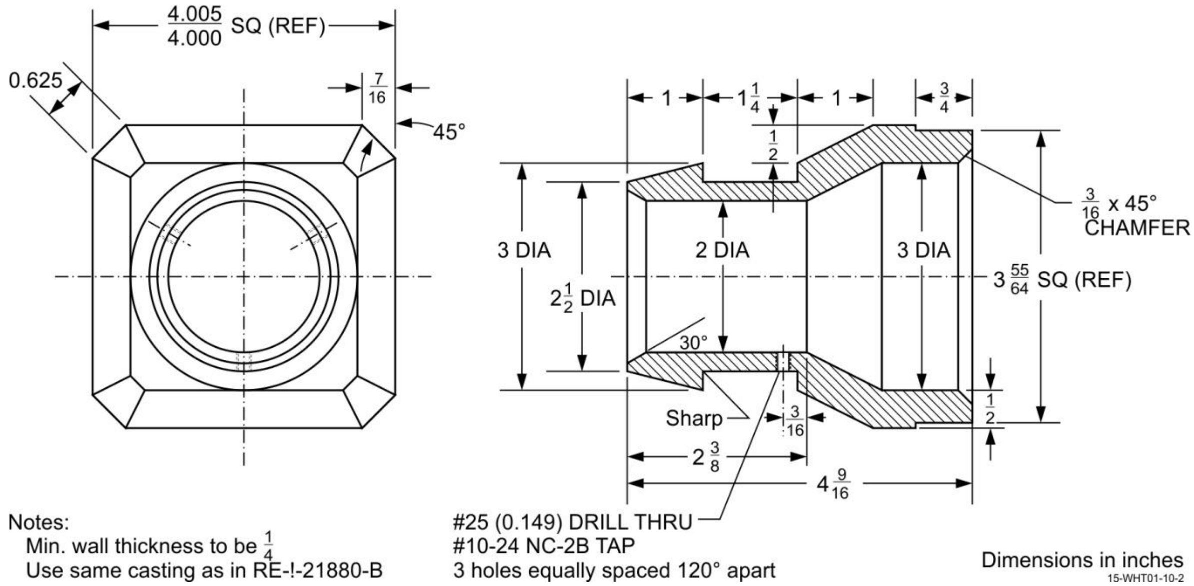


Figure 2.68. Top Fuel Fitting Rework (DWG# RE-1-23255).

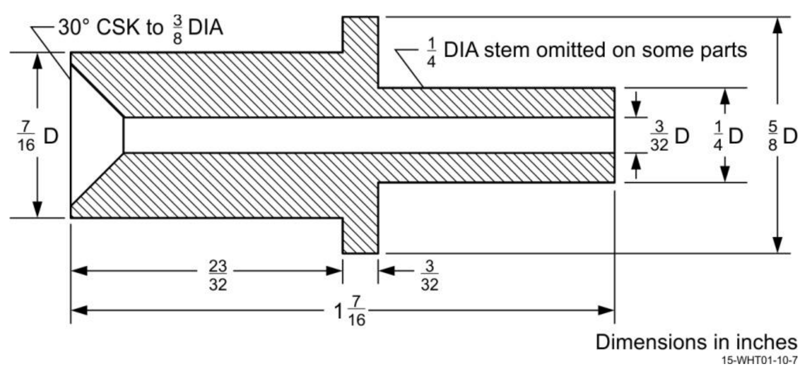


Figure 2.69. Thermocouple Well (DWG# RE-1-24159).

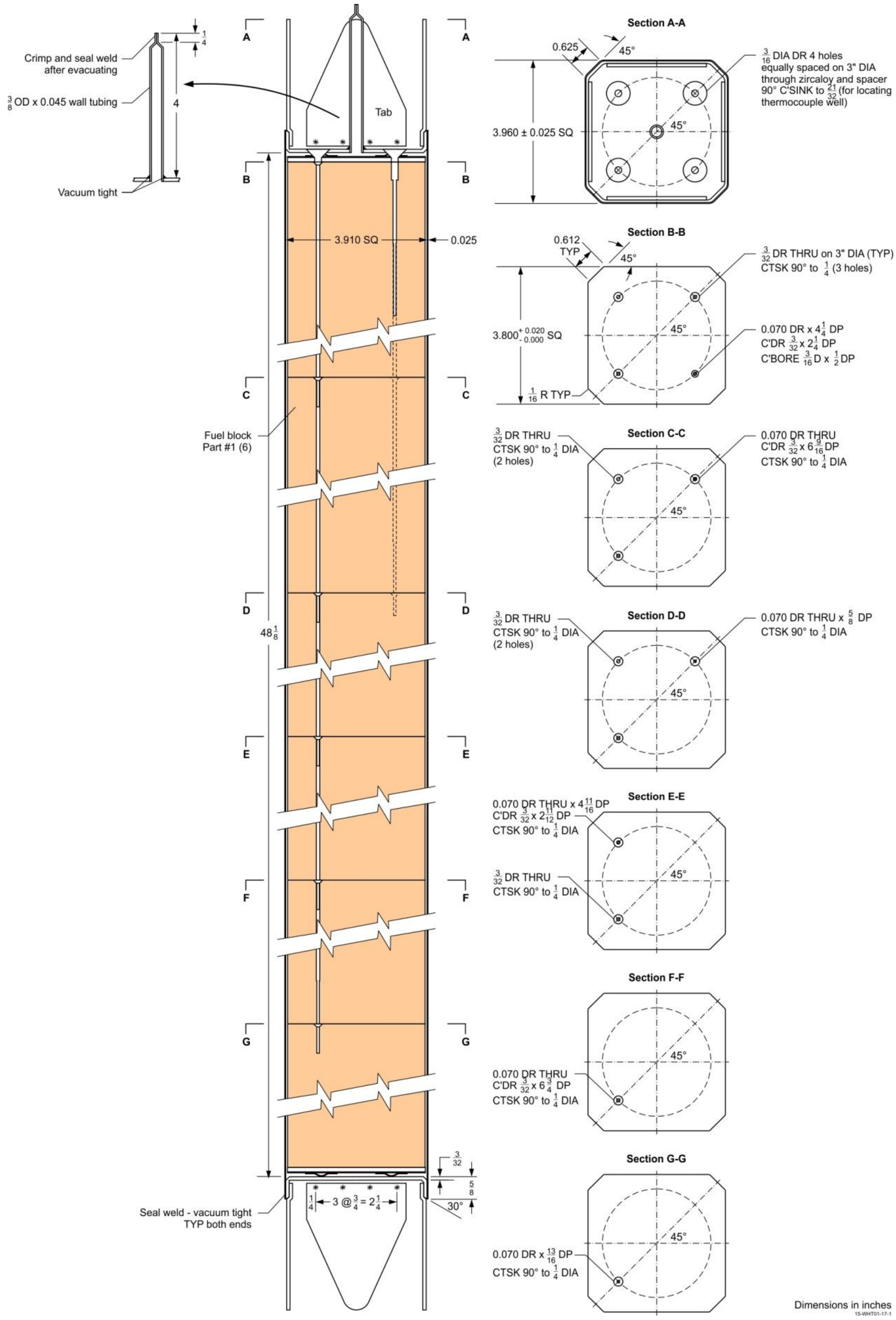


Figure 2.70. 4 Thermocouple Fuel Section (DWG# RE-1-23256).

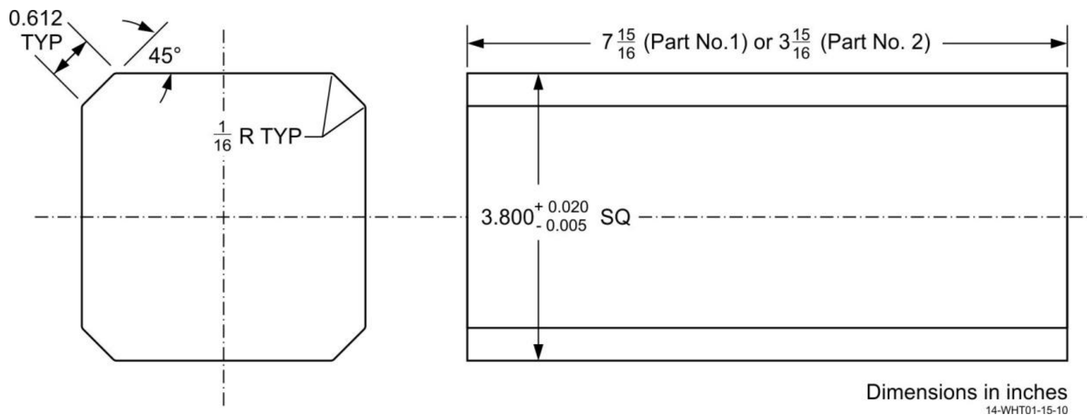


Figure 2.71. Fuel Block (DWG# RE-1-21578).

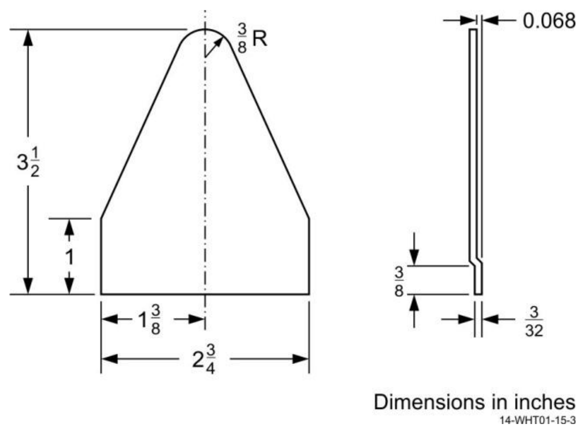


Figure 2.72. Tab (DWG# RE-1-22699).

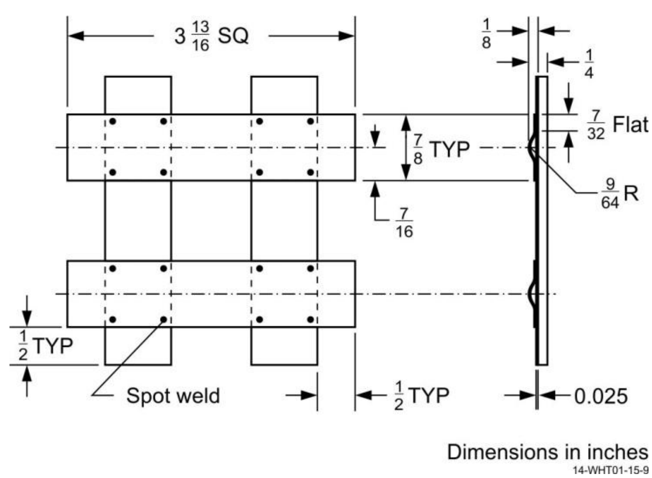


Figure 2.73. Spacer (DWG# RE-1-24160).

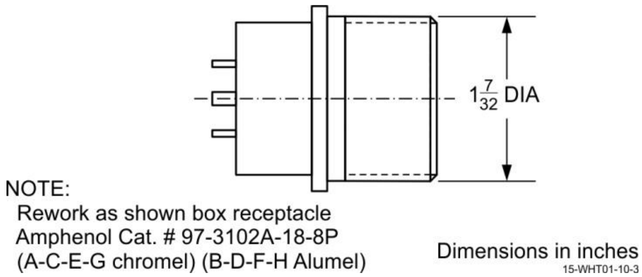


Figure 2.74. Plug Rework Box Receptacle (DWG# RE-1-23257).

2.4.2 Mid Fuel Reflector and Skin Thermocouple Fuel Assembly

The mid fuel reflector and skin thermocouple fuel assembly is shown in Figure 2.75 with a list of applicable drawings and materials provided in Table 2.8. Individual component drawings are provided in Figures 2.75 through 2.92.

Table 2.8. Mid Fuel Reflector and Skin Thermocouple Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.75	RE-1-23271	Mid Fuel Reflector & Skin Thermocouple Fuel Assembly	--
1	2.75	--	Straight Amphenol Plug	Al-6061
4	2.75	--	Chromel-Alumel Thermocouples	--
1	2.76	RE-1-23274	Slotted Plug	CP-2 Graphite
1	2.77	RE-1-24422	Taper Hole Plug	CP-2 Graphite
1	2.78	RE-1-23273	Top Plug	CP-2 Graphite
1	2.79	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.80	RE-1-22736	End Tube Part #1	Al-6063
1	2.80	RE-1-22736	End Tube Part #2	Al-6063
1	2.81	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.82	RE-1-23253	Plug Holder	Al-6061
1	2.83	RE-1-23254	Socket Holder	Al-6061
1	2.84	RE-1-23255	Top Fuel Fitting Rework	Al-1100
1	2.85	RE-1-23275	Thermocouple Shield	Zr-3
2	2.86	RE-1-24225	Pin	CP-2 Graphite
1	2.87	RE-1-24159	Thermocouple Well Part #1	Zr-3
1	2.88	RE-1-23272	Thermocouple Fuel Section	Zr-3
6	2.89	RE-1-21578	Fuel Block Part #1	Graphite Fuel
8	2.90	RE-1-22699	Tab	Zr-3
2	2.91	RE-1-24160	Spacer	Zr-3
1	2.92	RE-1-23257	Plug Rework Box Receptacle	Al-6061

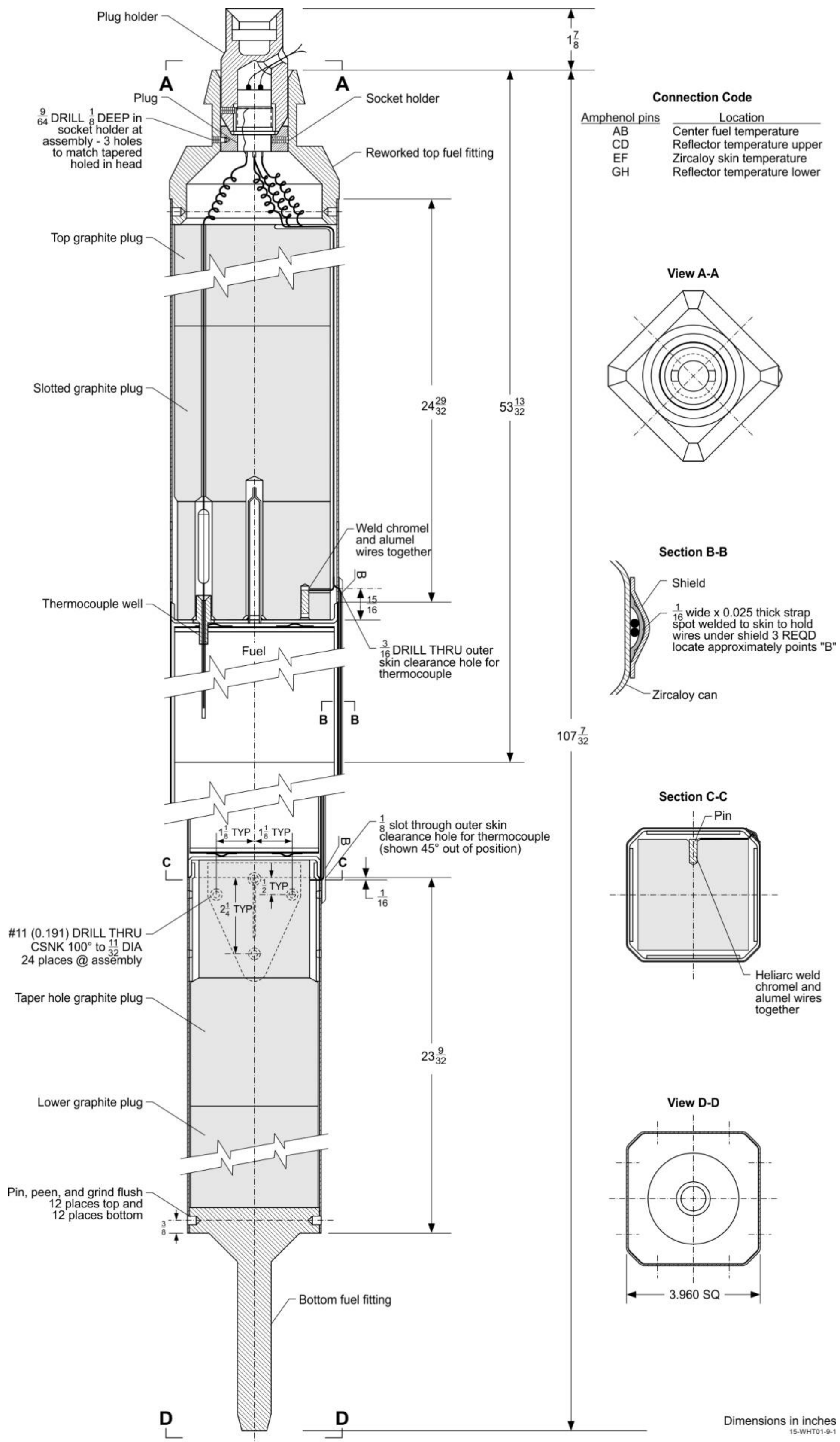


Figure 2.75. Mid Fuel Reflector & Skin Thermocouple Fuel Assembly (DWG# RE-1-23271).

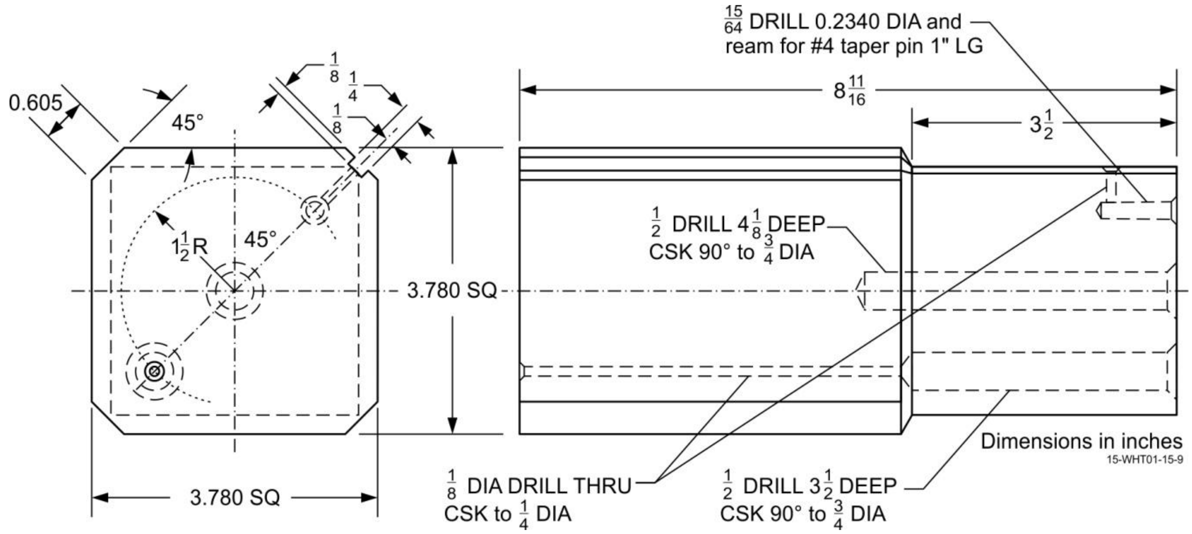


Figure 2.76. Slotted Plug (DWG# RE-1-23274).

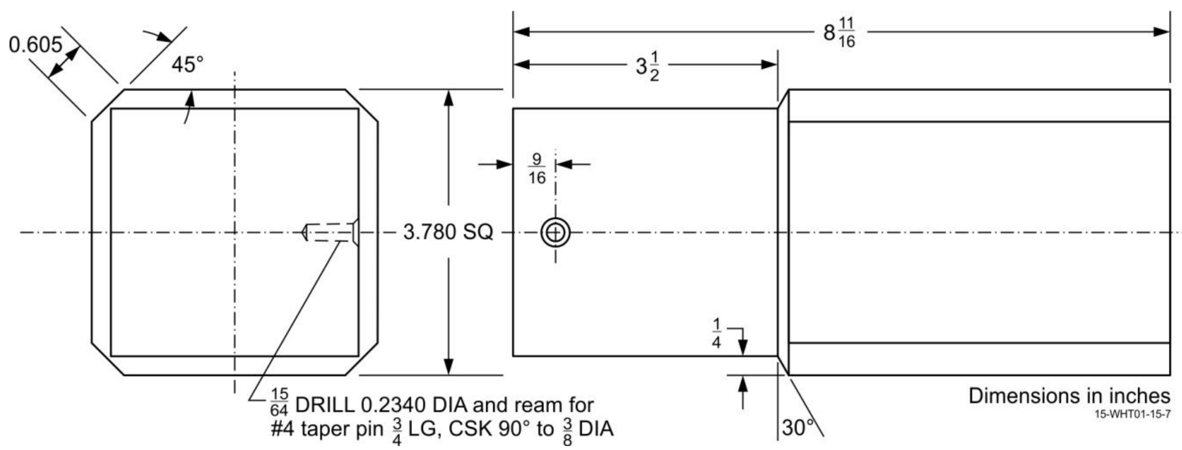


Figure 2.77. Taper Hole Plug (DWG# RE-1-24422).

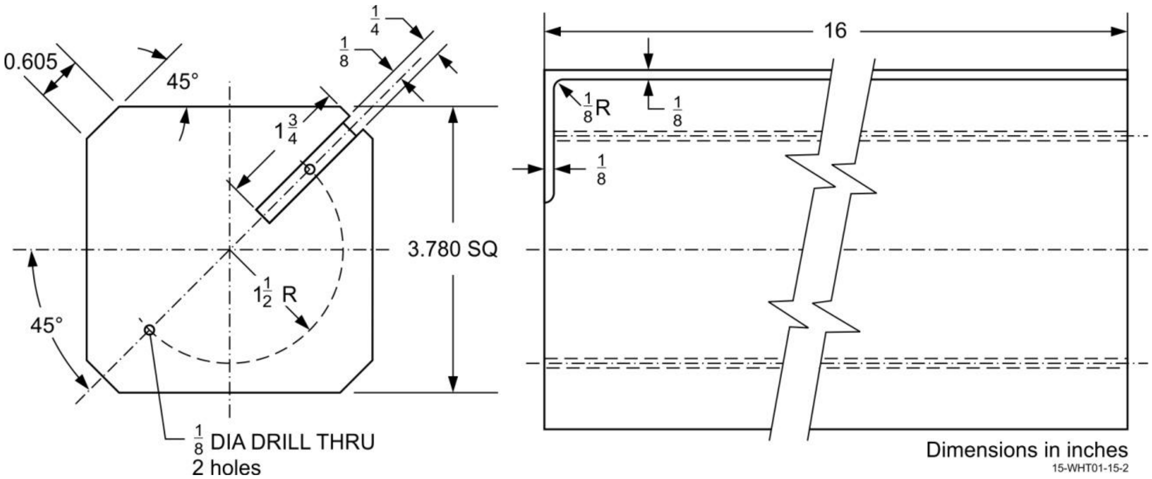


Figure 2.78. Top Plug (DWG# RE-1-23273).

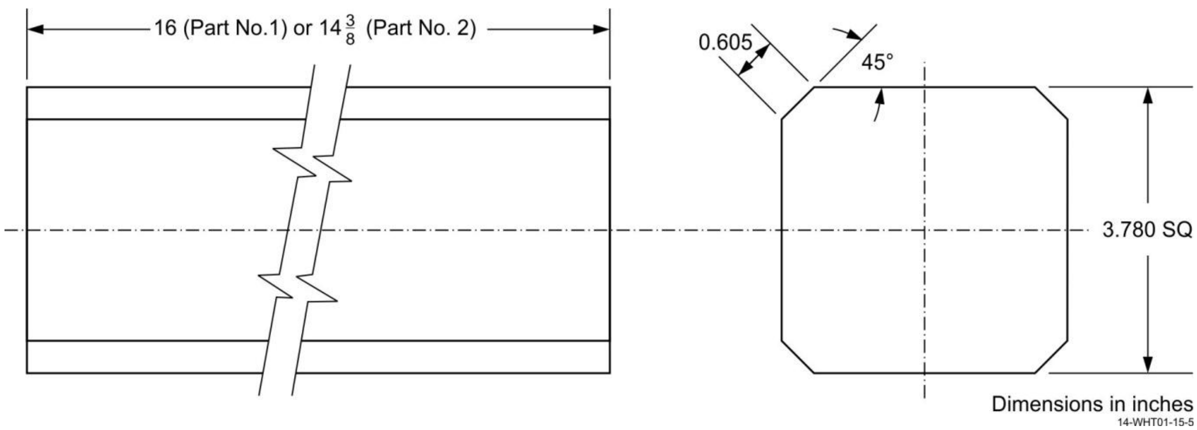


Figure 2.79. Long Plug (DWG# RE-1-21768).

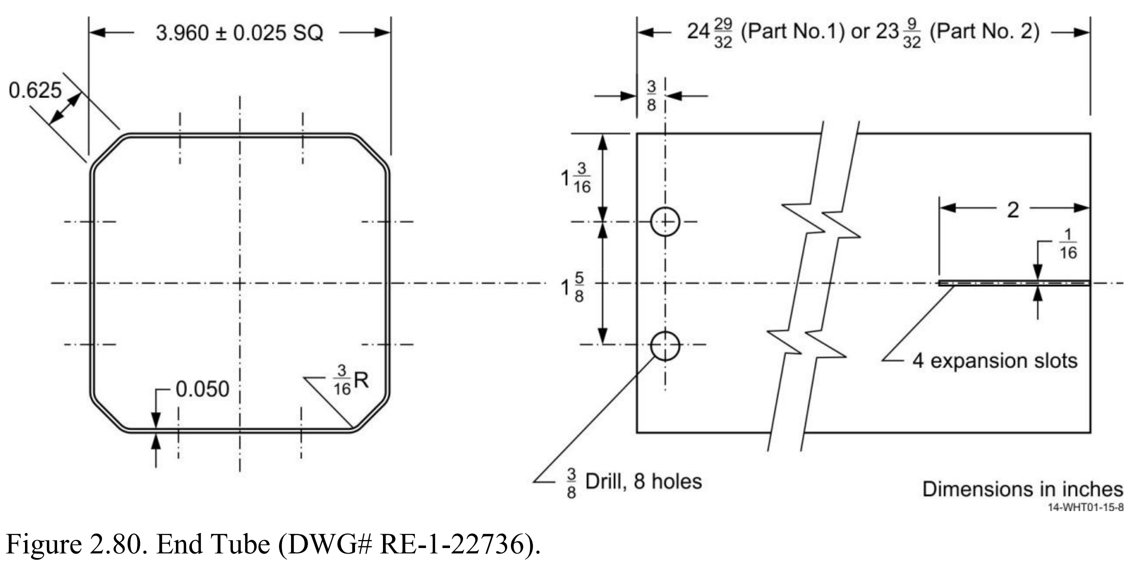


Figure 2.80. End Tube (DWG# RE-1-22736).

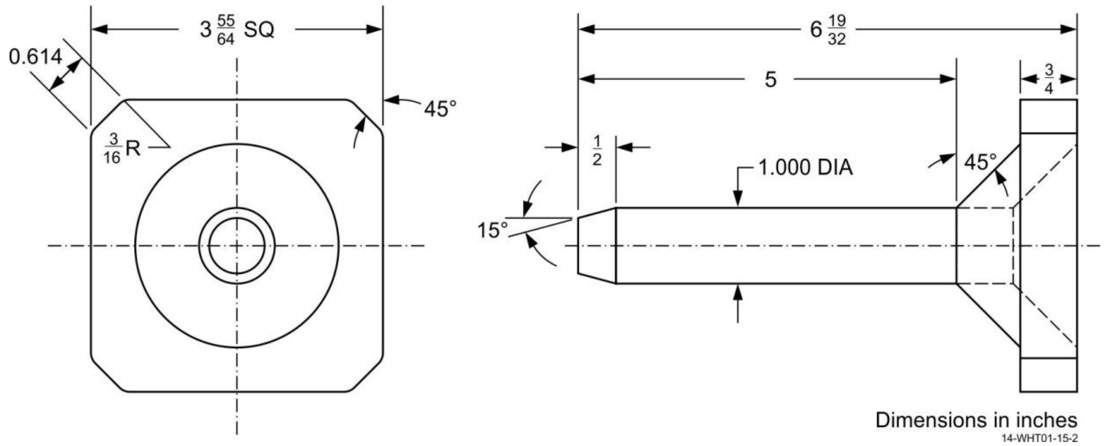


Figure 2.81. Bottom Fuel Fitting (DWG# RE-1-21881).

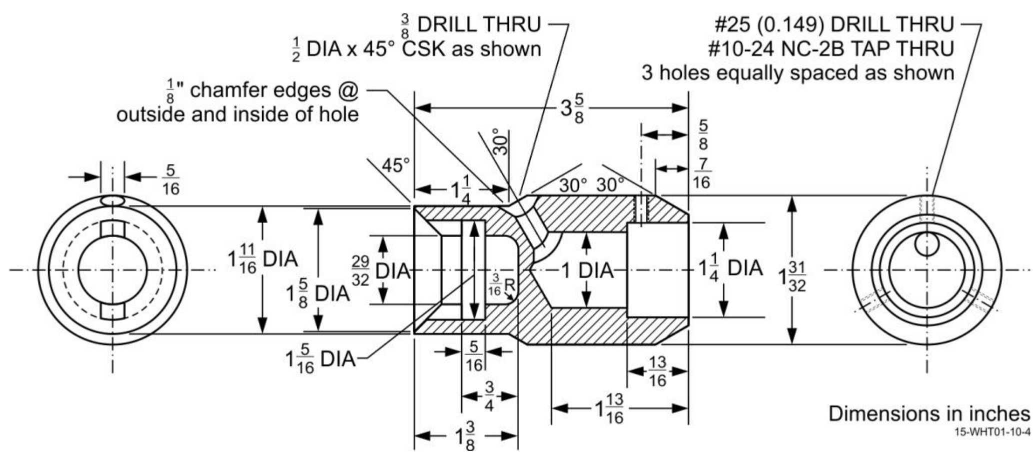


Figure 2.82. Plug Holder (DWG# RE-1-23253).

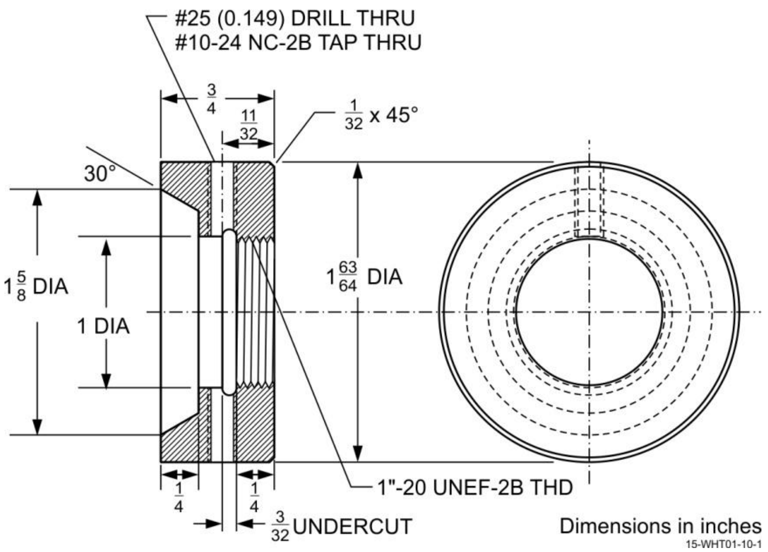


Figure 2.83. Socket Holder (DWG# RE-1-23254).

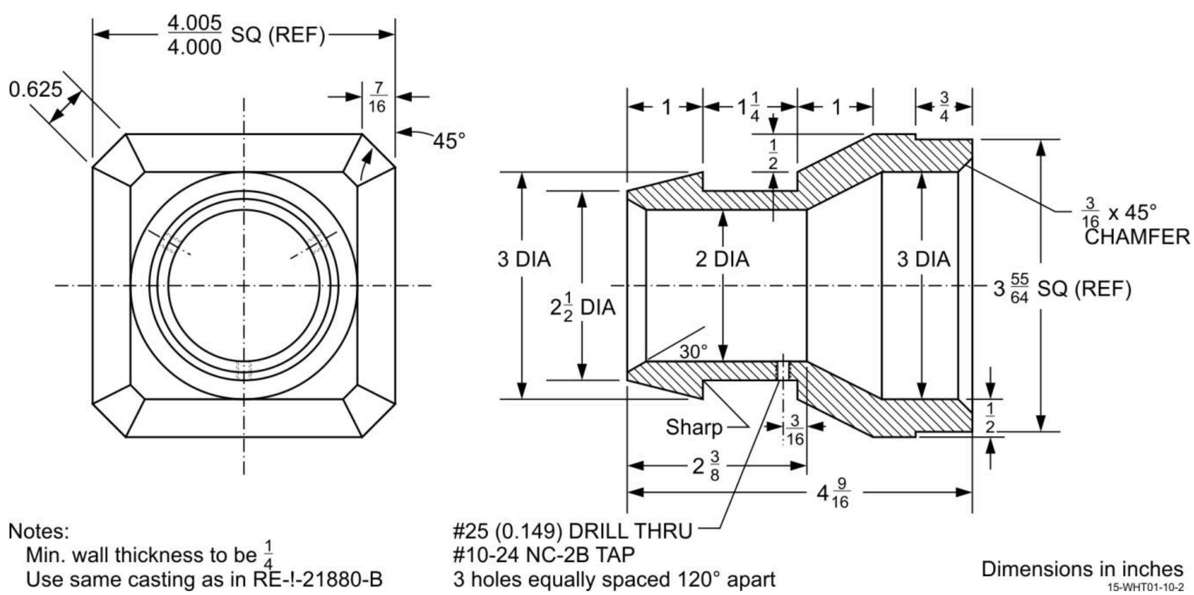


Figure 2.84. Top Fuel Fitting Rework (DWG# RE-1-23255).

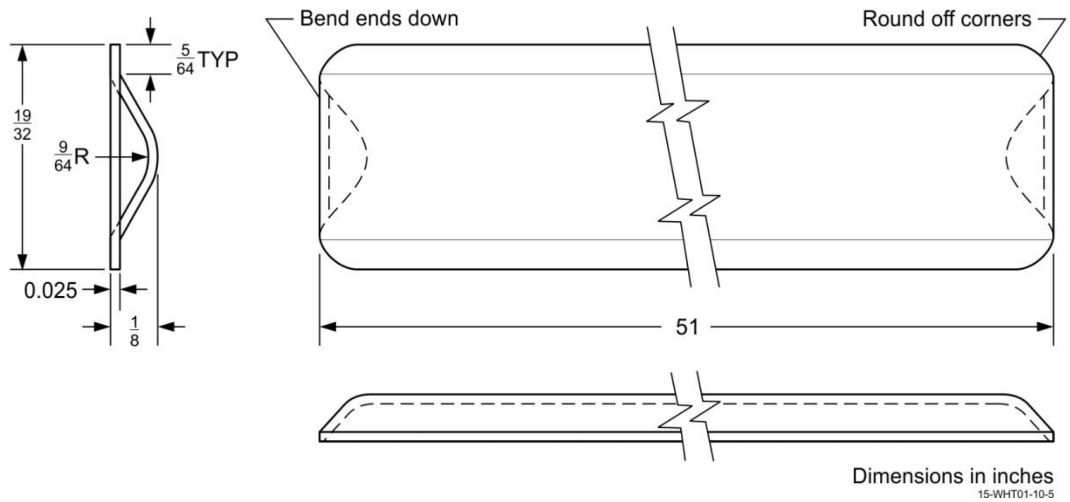


Figure 2.85. Thermocouple Shield (DWG# RE-1-23275).

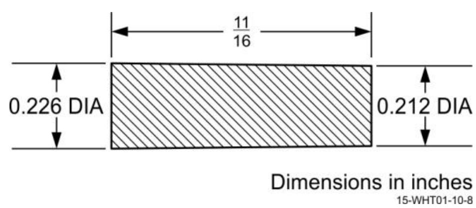


Figure 2.86. Pin (DWG# RE-1-24225).

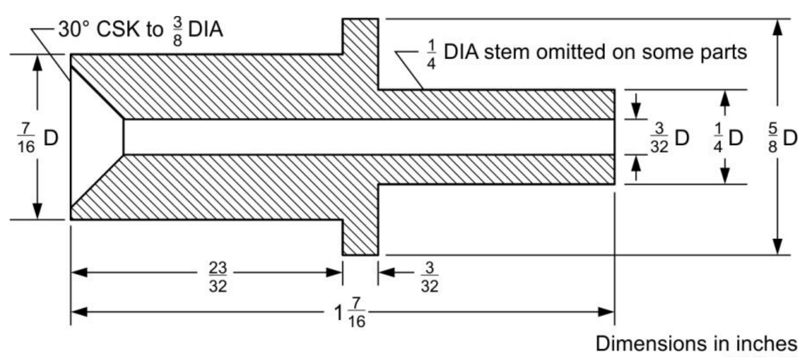


Figure 2.87. Thermocouple Well (DWG# RE-1-24159).

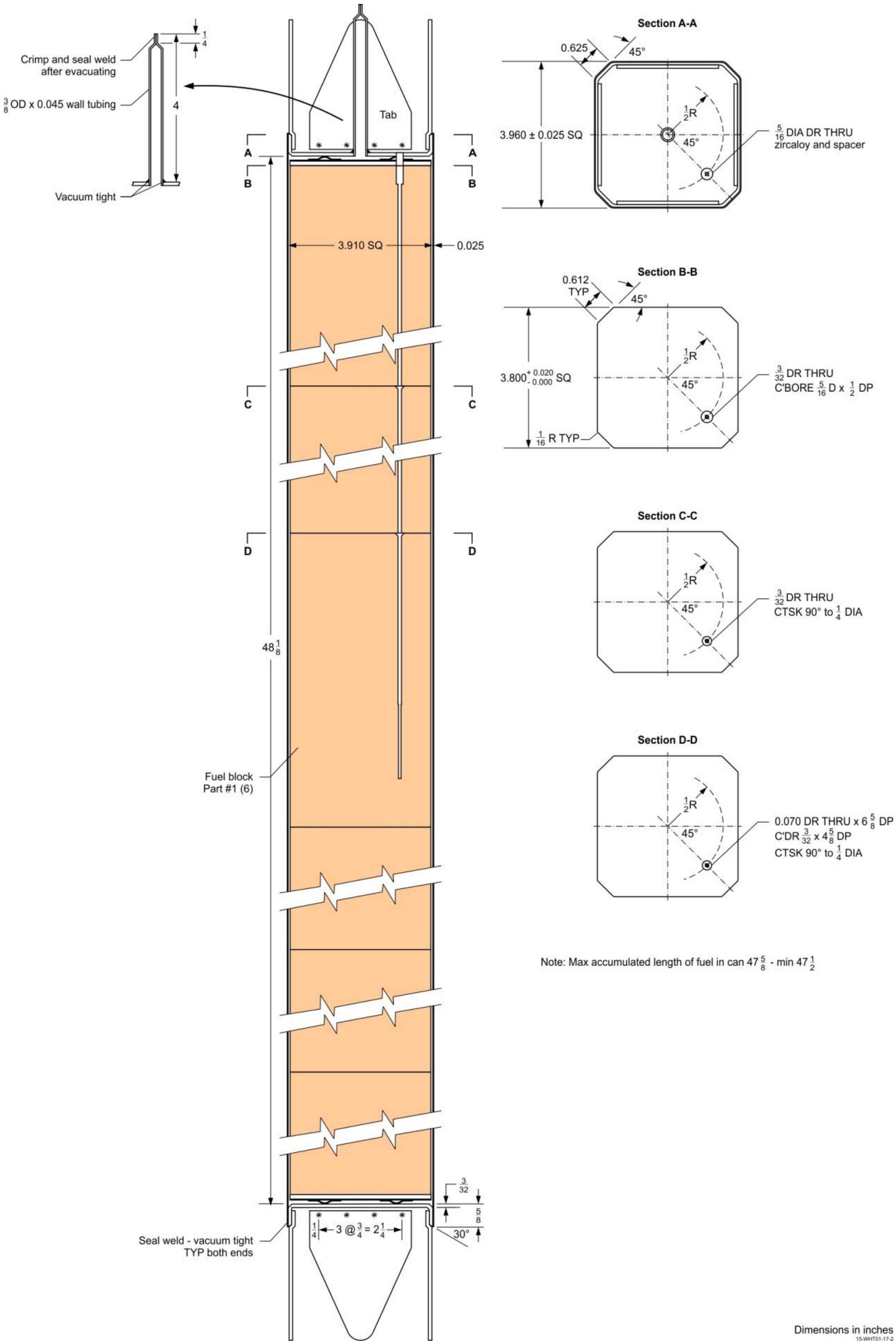


Figure 2.88. Thermocouple Fuel Section (DWG# RE-1-23272).

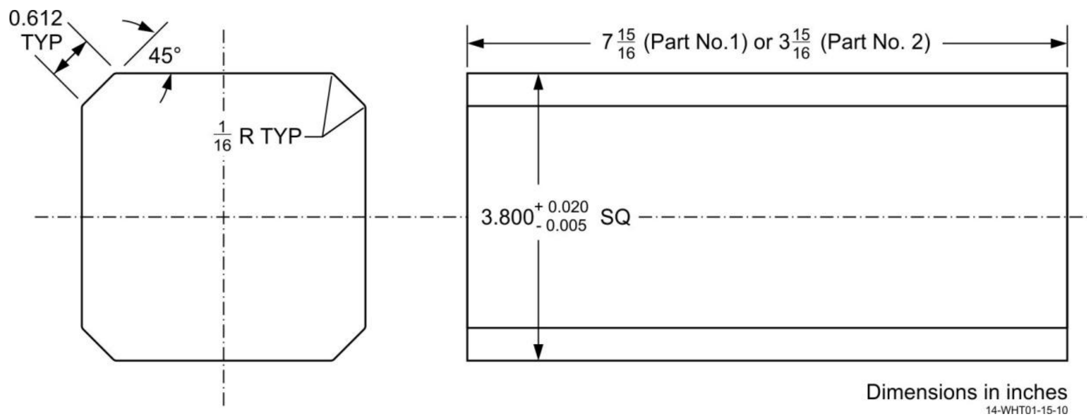


Figure 2.89. Fuel Block (DWG# RE-1-21578).

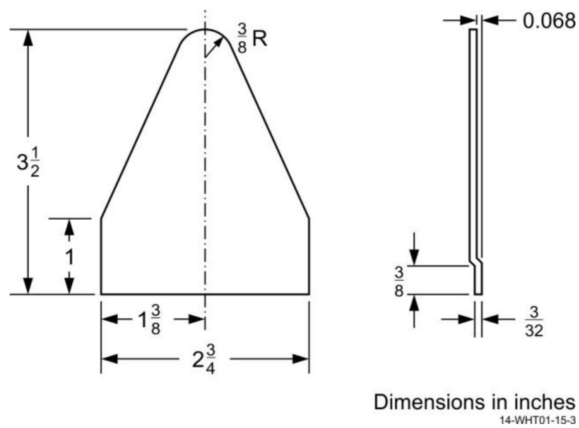


Figure 2.90. Tab (DWG# RE-1-22699).

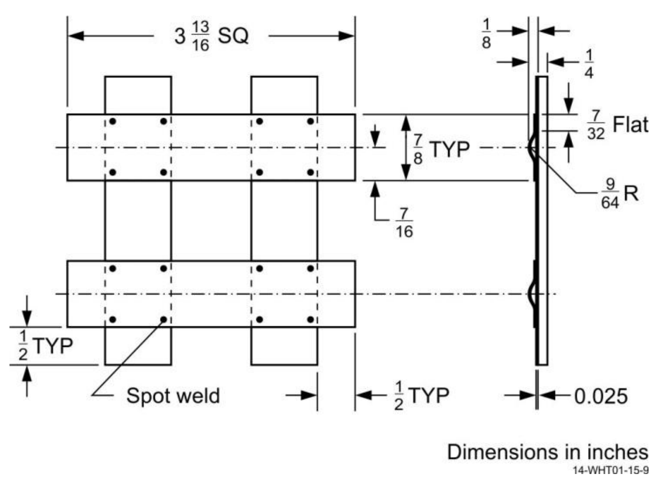


Figure 2.91. Spacer (DWG# RE-1-24160).

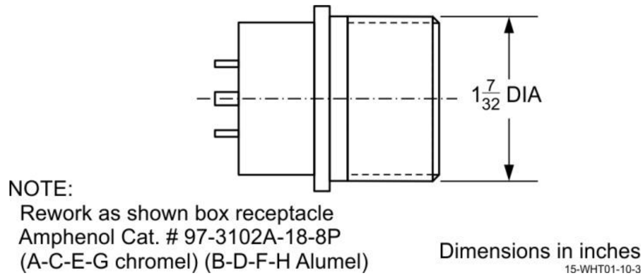


Figure 2.92. Plug Rework Box Receptacle (DWG# RE-1-23257).

2.4.3 Transient Thermocouple Fuel Assembly

The transient thermocouple fuel assembly is shown in Figure 2.93 with a list of applicable drawings and materials provided in Table 2.9. Individual component drawings are provided in Figures 2.93 through 2.111.

Table 2.9. Transient Thermocouple Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.93	RE-1-24218	Transient Thermocouple Fuel Assembly	--
1	2.93	--	Straight Amphenol Plug	Al-6061
4	2.93	--	Chromel-Alumel Thermocouples	--
1	2.94	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.95	RE-1-22736	End Tube Part #2	Al-6063
1	2.96	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.97	RE-1-22739	Plain Short Plug	CP-2 Graphite
1	2.95	RE-1-22736	End Tube Part #1	Al-6063
1	2.98	RE-1-24219	Slotted Short Plug	CP-2 Graphite
1	2.99	RE-1-24220	Slotted Long Plug	CP-2 Graphite
1	2.100	RE-1-23255	Top Fuel Fitting Rework	Al-1100
1	2.101	RE-1-23254	Socket Holder	Al-6061
1	2.102	RE-1-23257	Plug Rework Box Receptacle	Al-6061
1	2.103	RE-1-23253	Plug Holder	Al-6061
1	2.104	RE-1-24221	Transient Thermocouple Fuel Section	Zr-3
1	2.105	RE-1-24222	Fuel Block "V" Cut	Graphite Fuel
1	2.106	RE-1-24223	Slotted Fuel Block	Graphite Fuel
1	2.107	RE-1-24224	Taper Hole Fuel Block	Graphite Fuel
8	2.108	RE-1-22699	Tab	Zr-3
2	2.109	RE-1-24225	Pin	CP-2 Graphite
3	2.110	RE-1-21578	Fuel Block Part #1	Graphite Fuel
2	2.111	RE-1-24160	Spacer	Zr-3

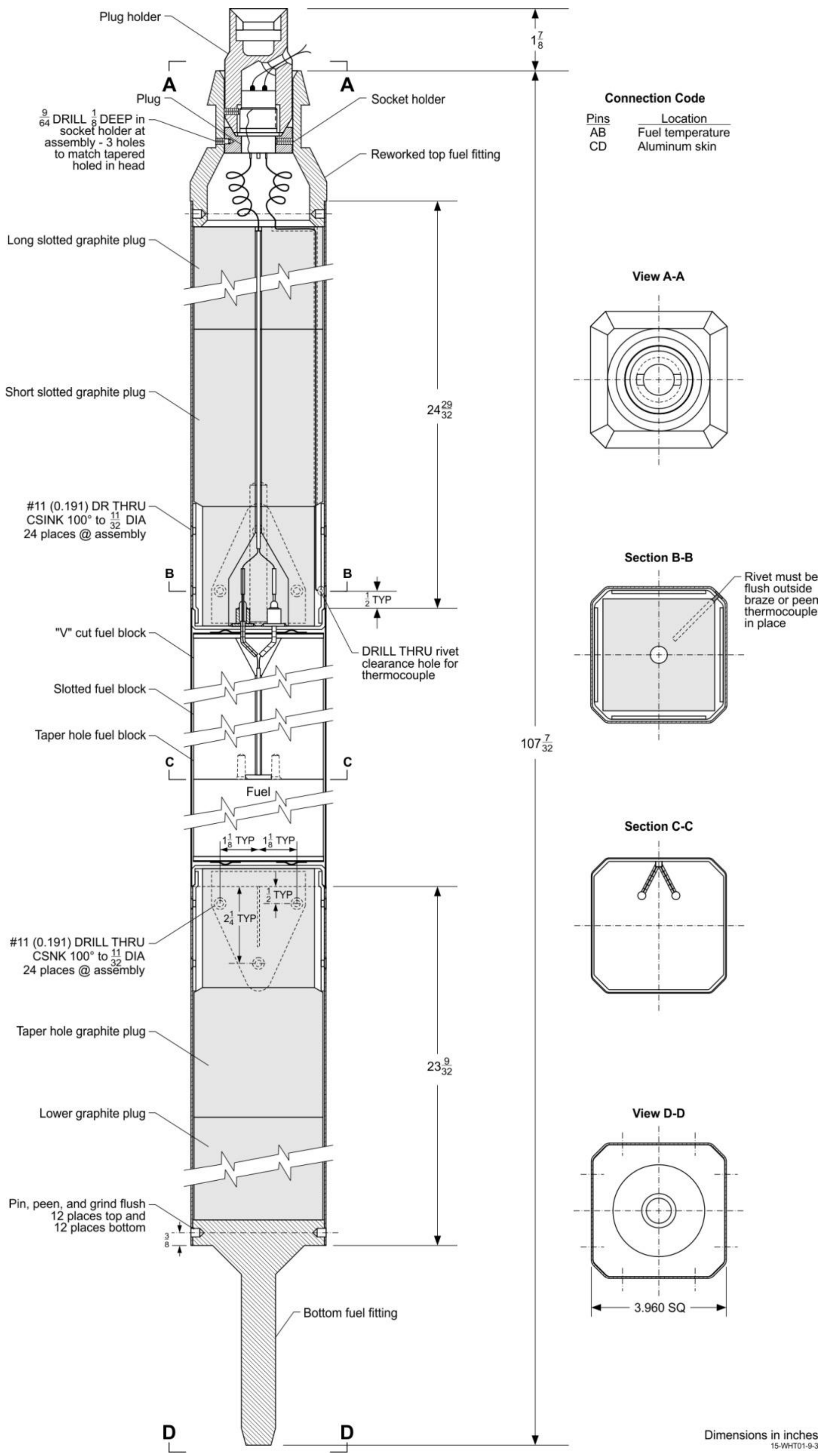


Figure 2.93. Transient Thermocouple Fuel Assembly (DWG# RE-1-24218).

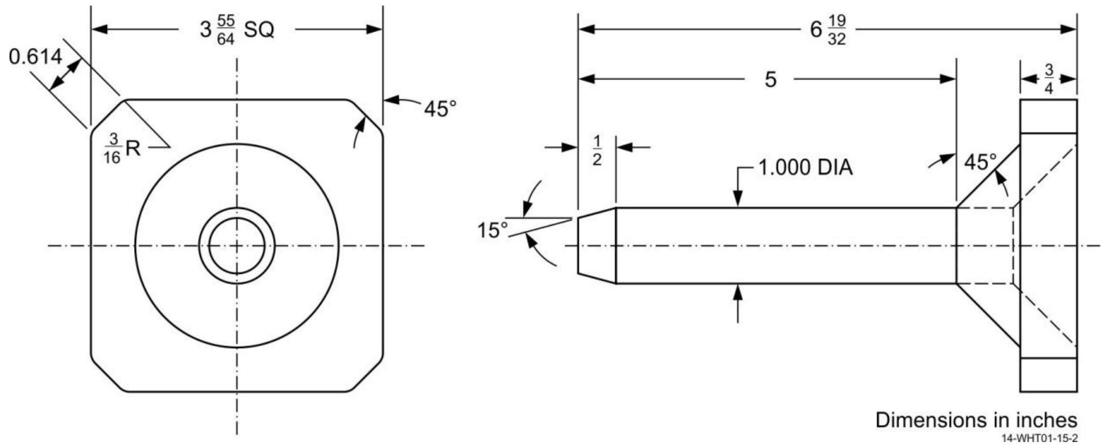


Figure 2.94. Bottom Fuel Fitting (DWG# RE-1-21881).

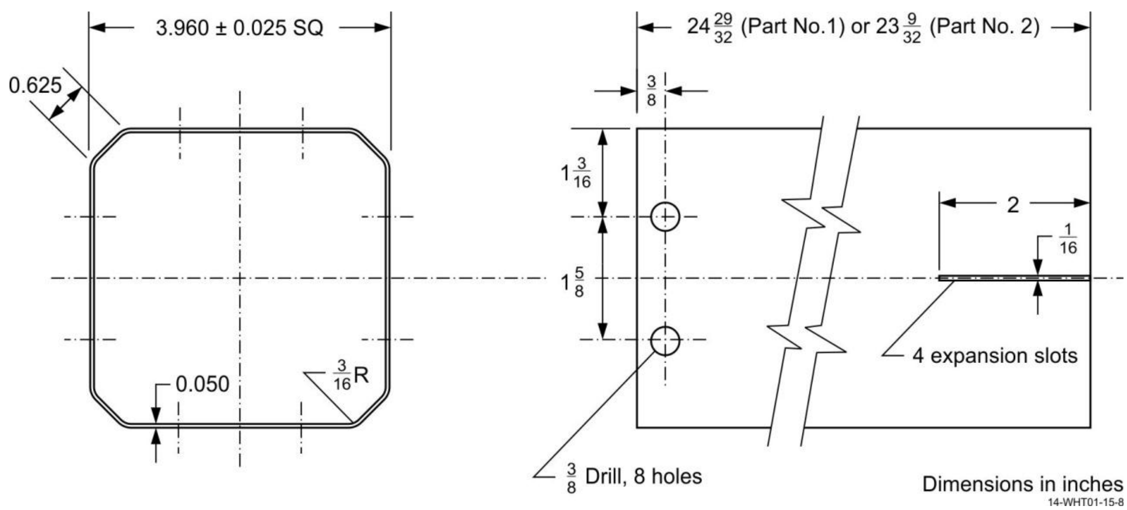


Figure 2.95. End Tube (DWG# RE-1-22736).

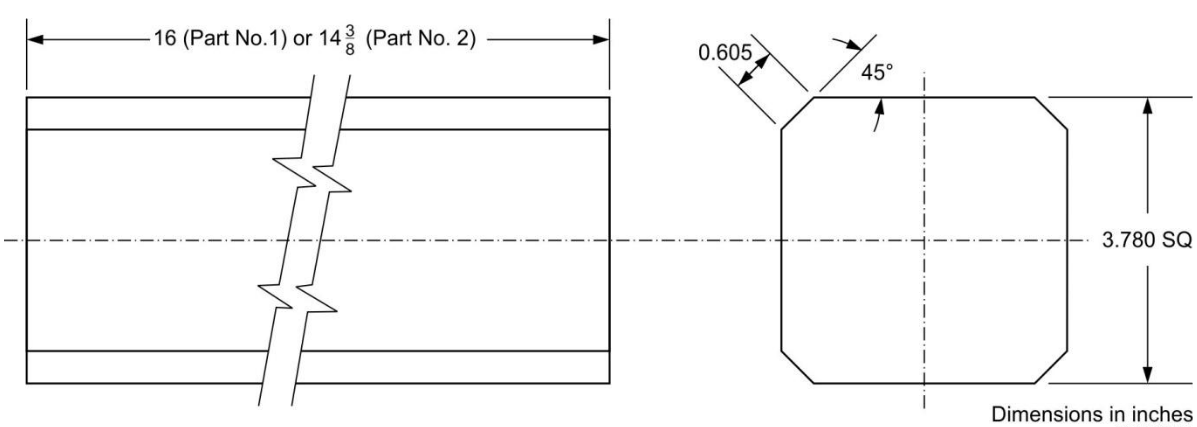


Figure 2.96. Long Plug (DWG# RE-1-21768).

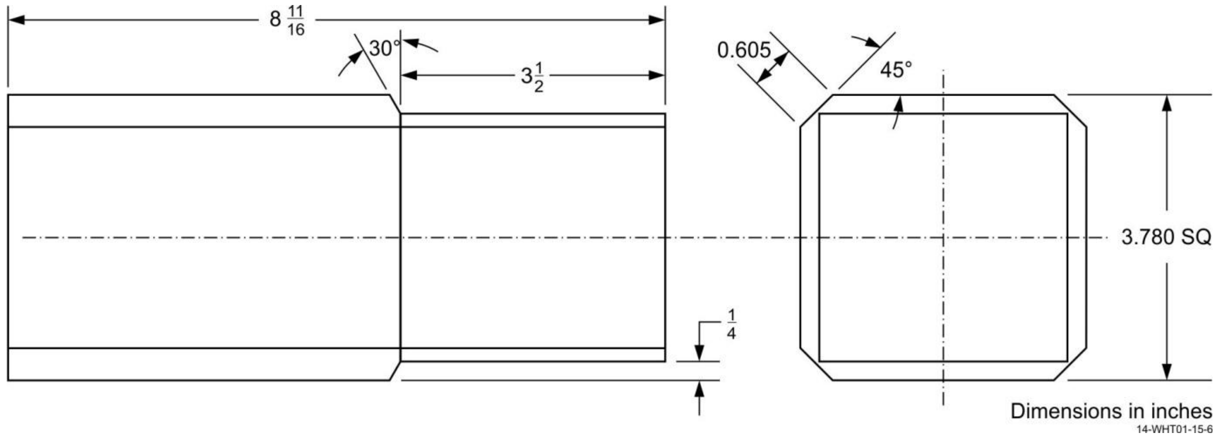


Figure 2.97. Plain Short Plug (DWG# RE-1-22739).

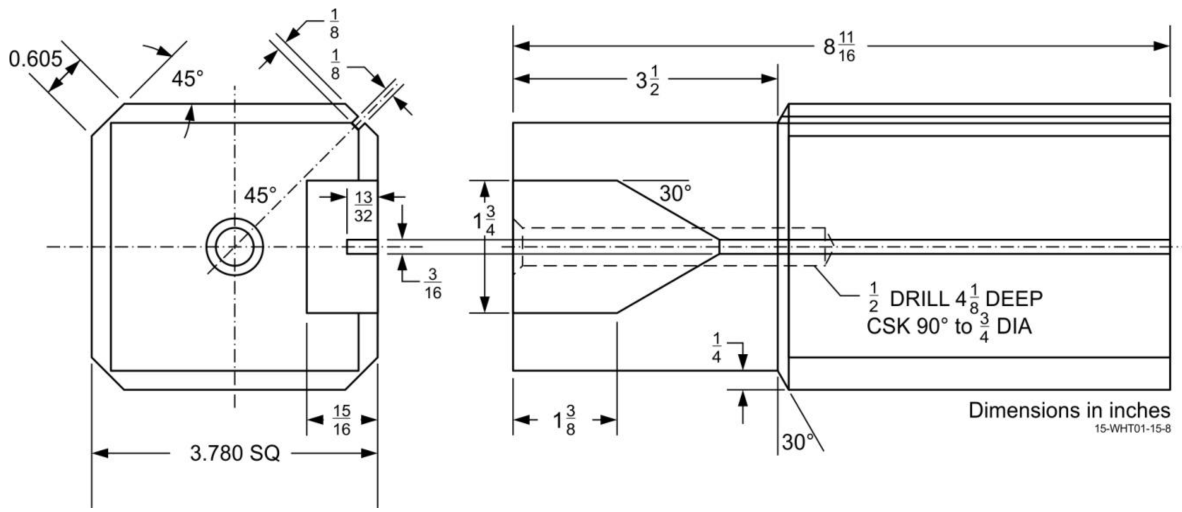


Figure 2.98. Slotted Short Plug (DWG# RE-1-24219).

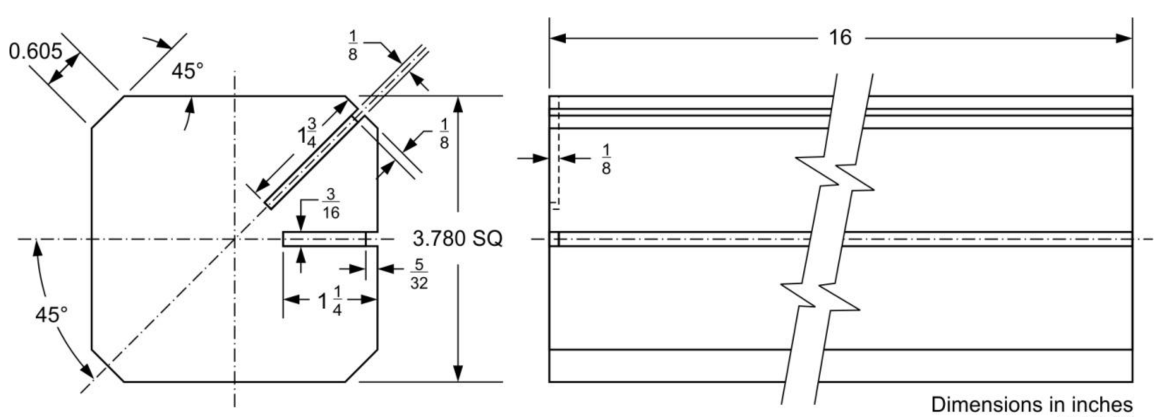


Figure 2.99. Slotted Long Plug (DWG# RE-1-24220).

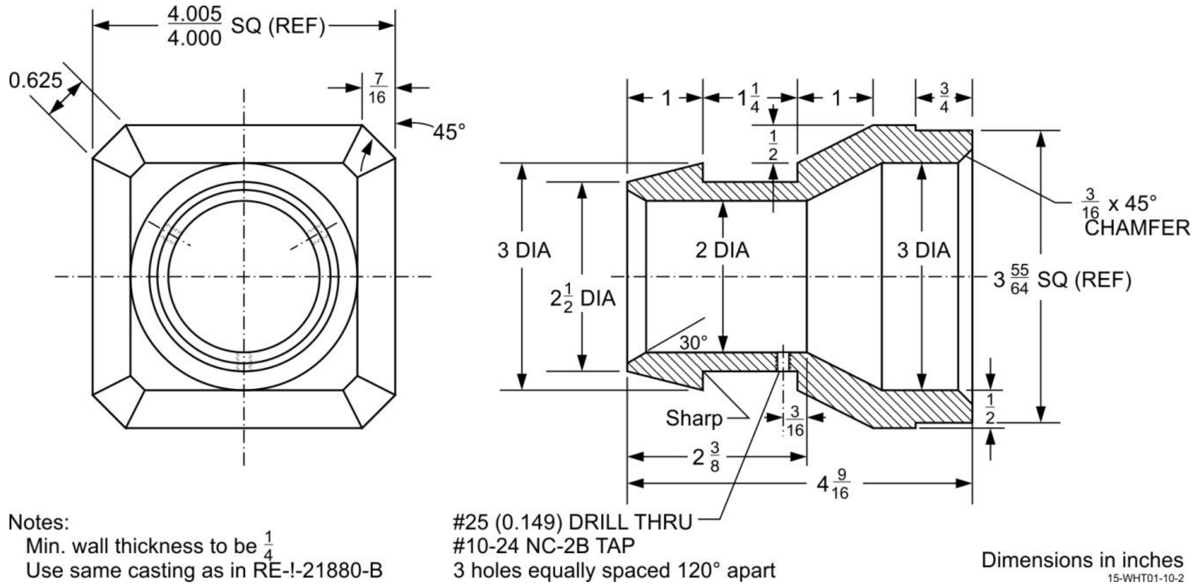


Figure 2.100. Top Fuel Fitting Rework (DWG# RE-1-23255).

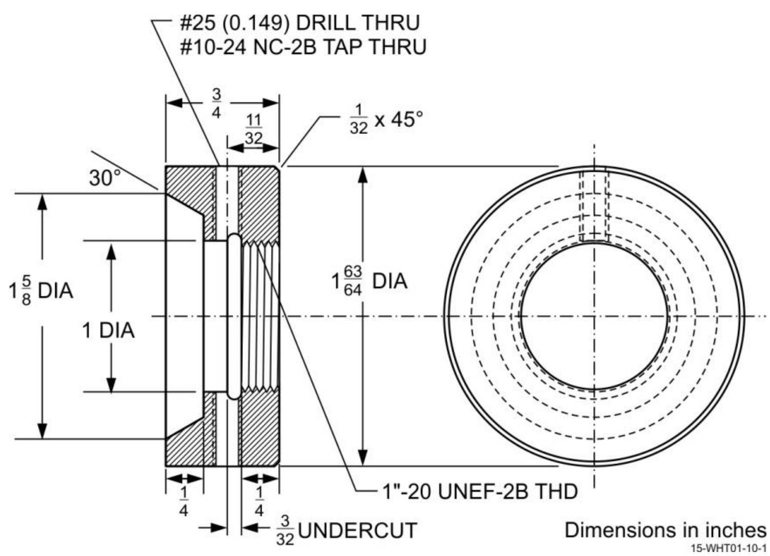


Figure 2.101. Socket Holder (DWG# RE-1-23254).

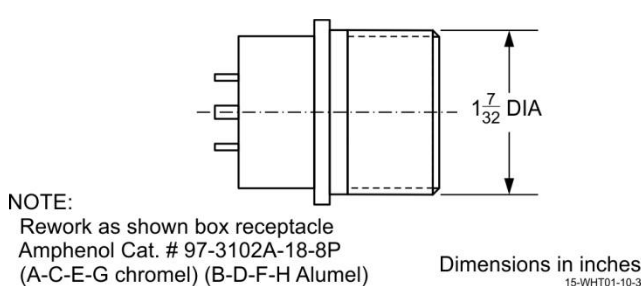


Figure 2.102. Plug Rework Box Receptacle (DWG# RE-1-23257).

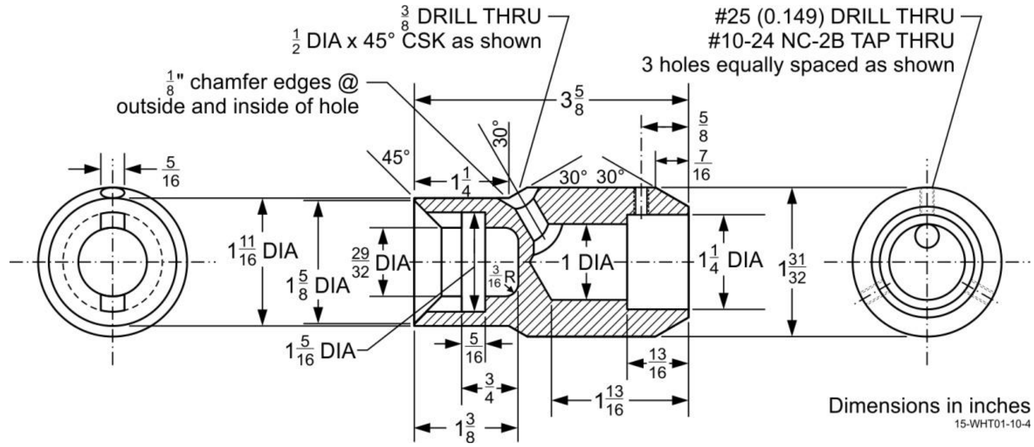


Figure 2.103. Plug Holder (DWG# RE-1-23253).

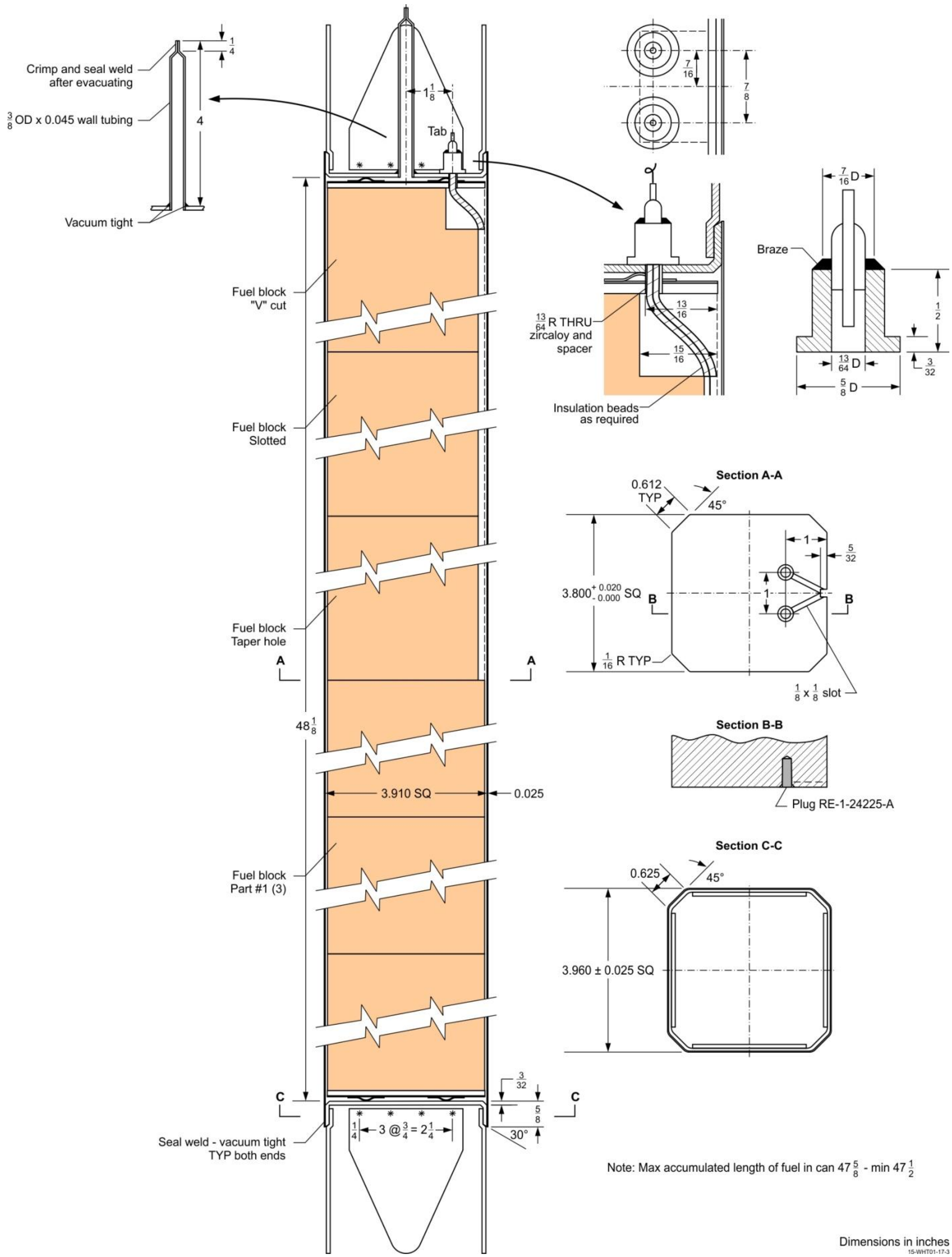


Figure 2.104. Transient Thermocouple Fuel Section (DWG# RE-1-24221).

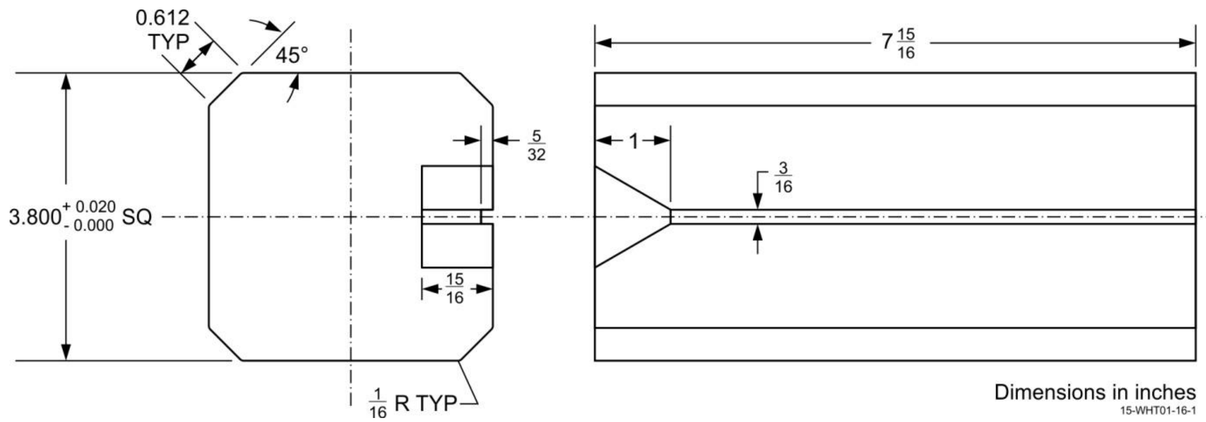


Figure 2.105. Fuel Block "V" Cut (DWG# RE-1-24222).

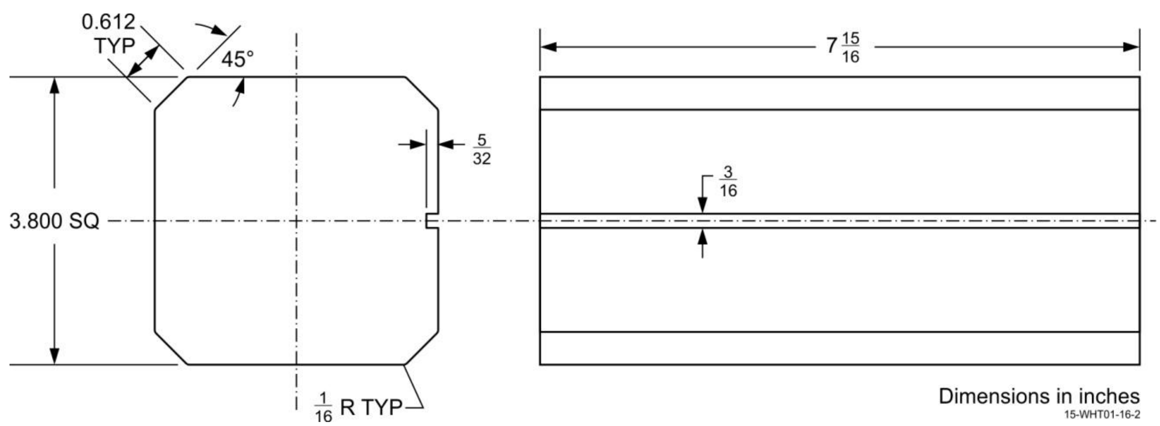


Figure 2.106. Slotted Fuel Block (DWG# RE-1-24223).

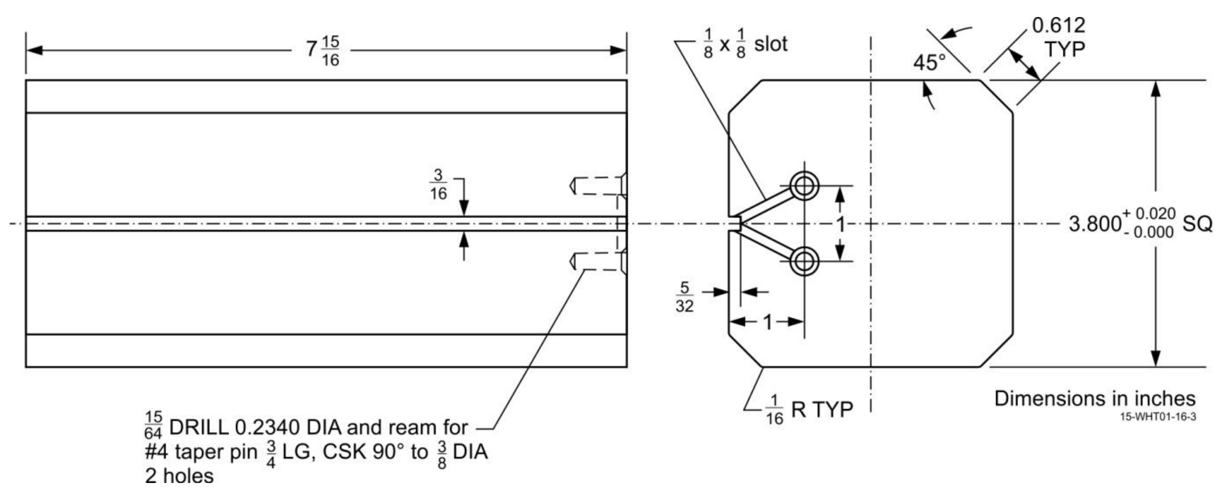


Figure 2.107. Taper Hole Fuel Block (DWG# RE-1-24224).

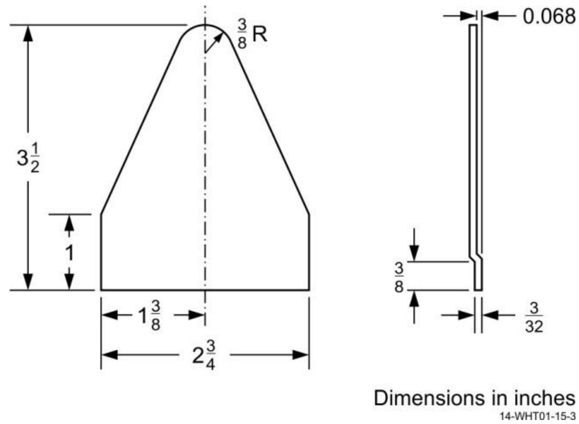


Figure 2.108. Tab (DWG# RE-1-22699).

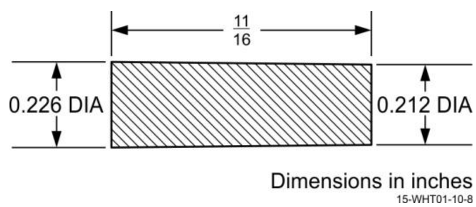


Figure 2.109. Pin (DWG# RE-1-24225).

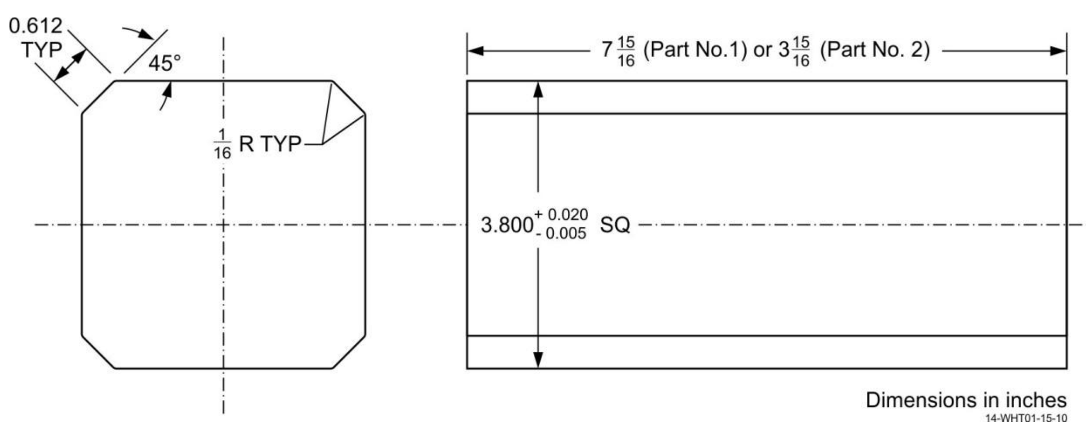


Figure 2.110. Fuel Block (DWG# RE-1-21578).

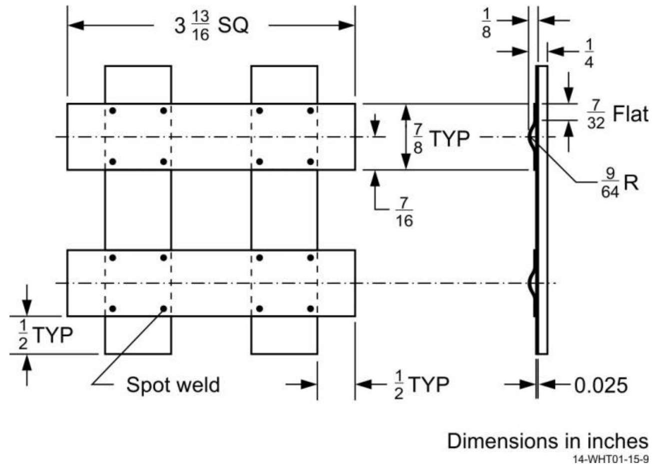


Figure 2.111. Spacer (DWG# RE-1-24160).

2.4.4 Reflector Fuel Temperature Gradient Thermocouple Fuel Assembly

The reflector fuel temperature gradient thermocouple fuel assembly is shown in Figure 2.112 with a list of applicable drawings and materials provided in Table 2.10. Individual component drawings are provided in Figures 2.112 through 2.127.

Table 2.10. Reflector Fuel Temperature Gradient Thermocouple Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.112	RE-1-30263	Reflector Fuel Temperature Gradient Thermocouple Fuel Assembly	--
1	2.112	--	Straight Amphenol Plug	Al-6061
4	2.112	--	Chromel-Alumel Thermocouples	--
1	2.113	RE-1-23253	Plug Holder	Al-6061
1	2.114	RE-1-23254	Socket Holder	Al-6061
1	2.115	RE-1-23255	Top Fuel Fitting Rework	Al-1100
1	2.116	RE-1-30264	Reflector Long Plug	CP-2 Graphite
1	2.117	RE-1-22736	End Tube Part #1	Al-6063
1	2.117	RE-1-22736	End Tube Part #2	Al-6063
1	2.118	RE-1-30265	Reflector Short Plug	CP-2 Graphite
4	2.119	RE-1-24159	Thermocouple Well Part #2	Zr-3
1	2.120	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.121	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.122	RE-1-22739	Plain Short Plug	CP-2 Graphite
1	2.123	RE-1-30266	Reflector Fuel Temperature Gradient Fuel Section	Zr-3
6	2.124	RE-1-21578	Fuel Block Part #1	Graphite Fuel
8	2.125	RE-1-22699	Tab	Zr-3
2	2.126	RE-1-24160	Spacer	Zr-3
1	2.127	RE-1-23257	Plug Rework Box Receptacle	Al-6061

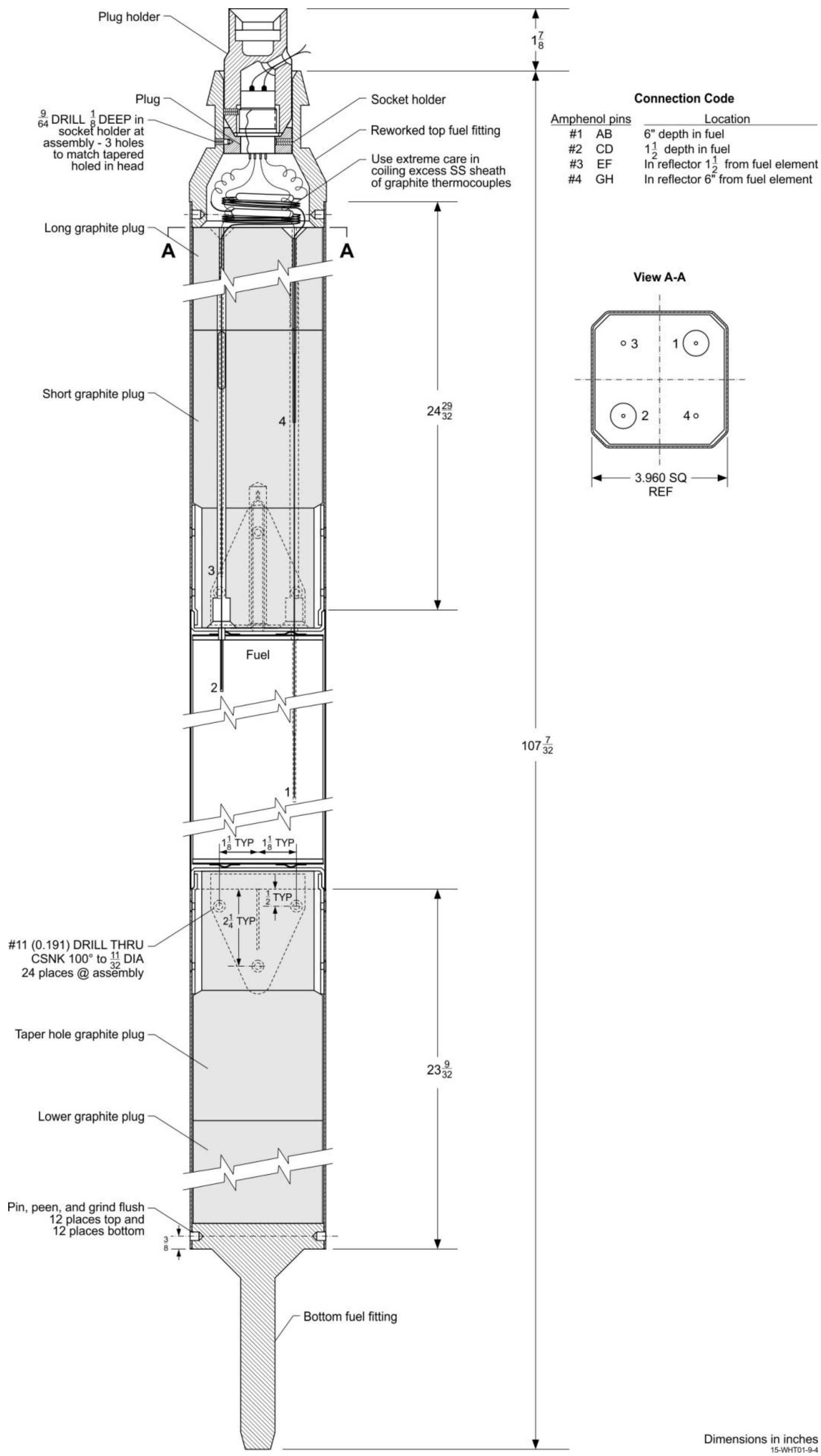


Figure 2.112. Reflector Fuel Temperature Gradient Thermocouple Fuel Assembly (DWG# RE-1-30263).

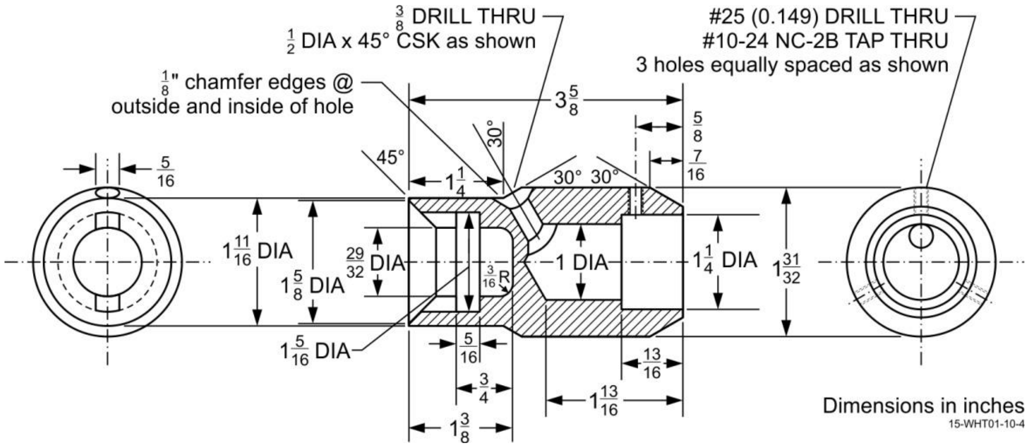


Figure 2.113. Plug Holder (DWG# RE-1-23253).

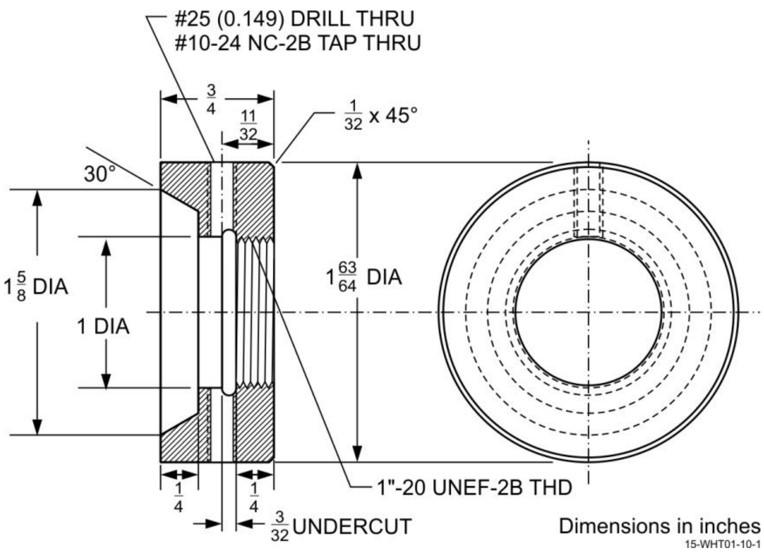


Figure 2.114. Socket Holder (DWG# RE-1-23254).

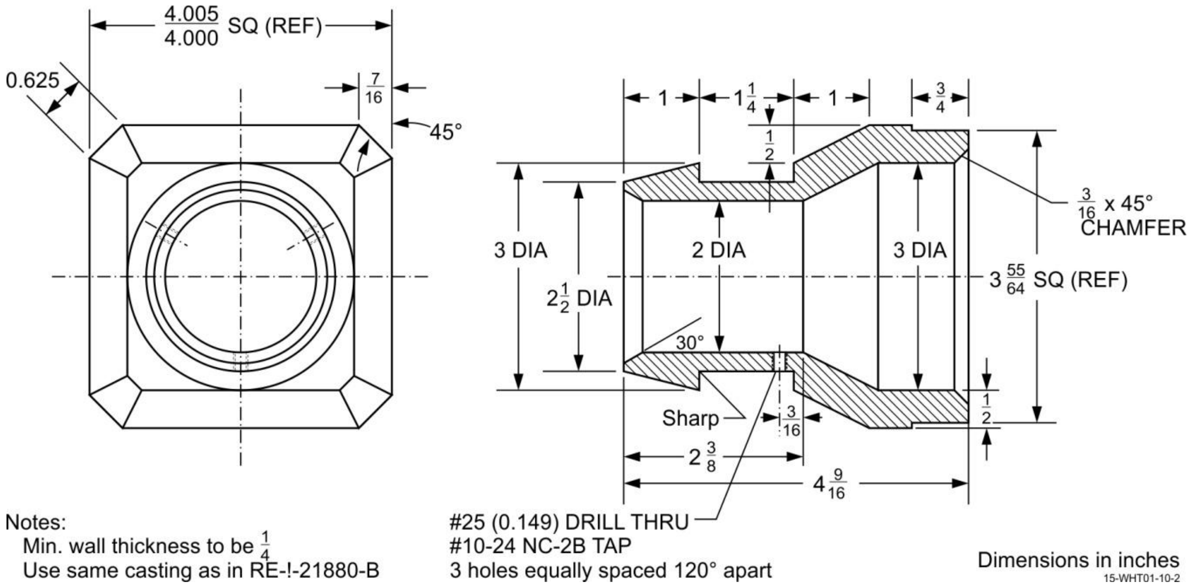


Figure 2.115. Top Fuel Fitting Rework (DWG# RE-1-23255).

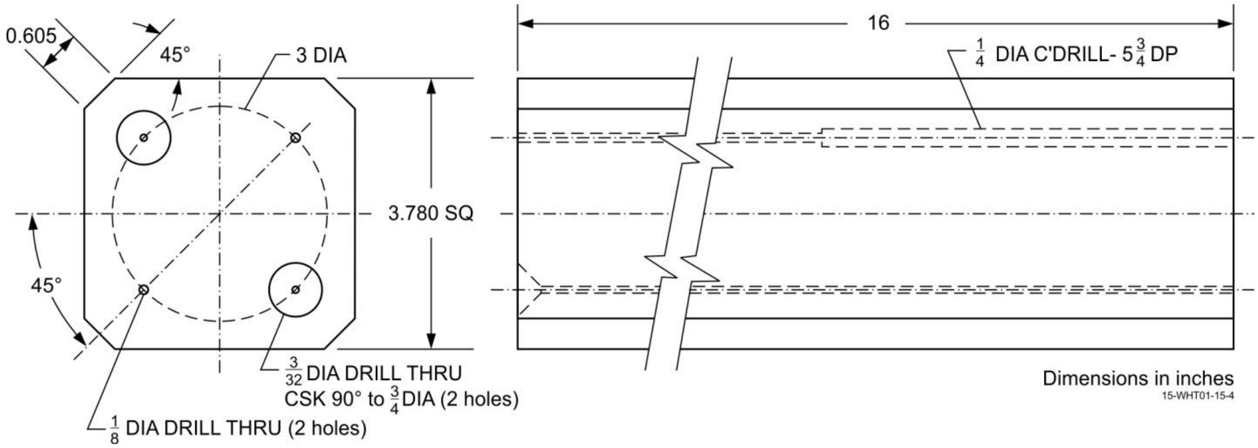


Figure 2.116. Reflector Long Plug (DWG# RE-1-30264).

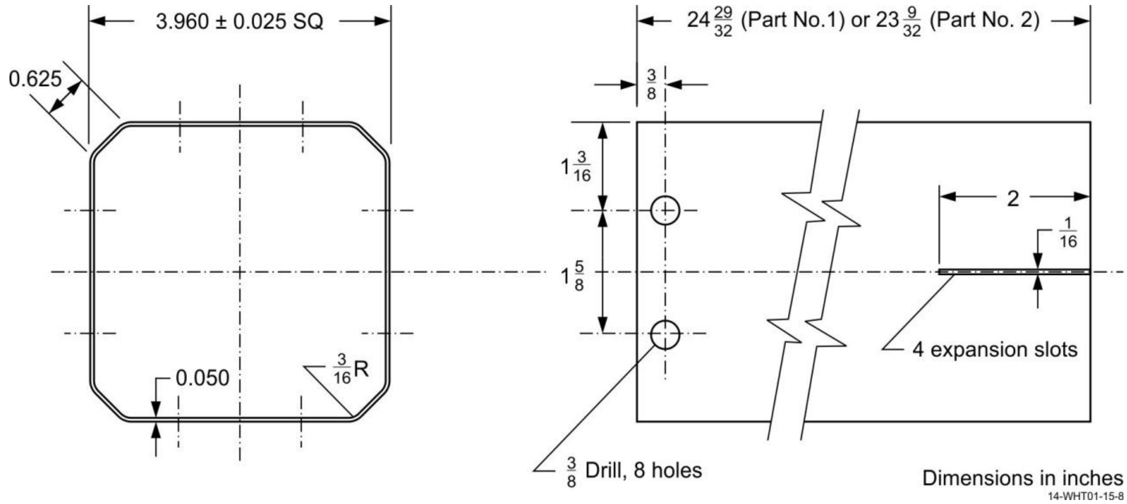


Figure 2.117. End Tube (DWG# RE-1-22736).

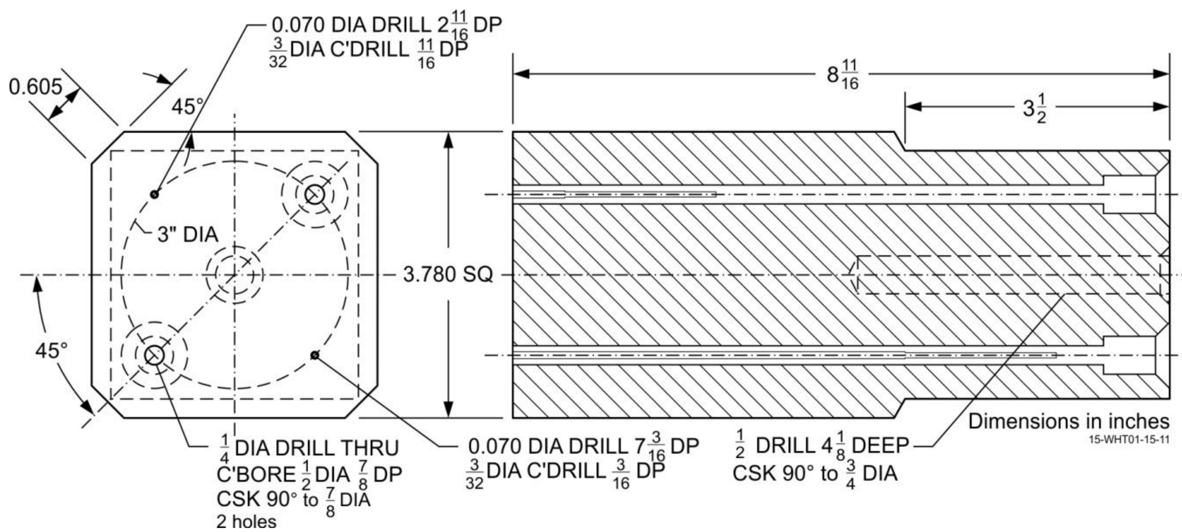


Figure 2.118. Reflector Short Plug (DWG# RE-1-30265).

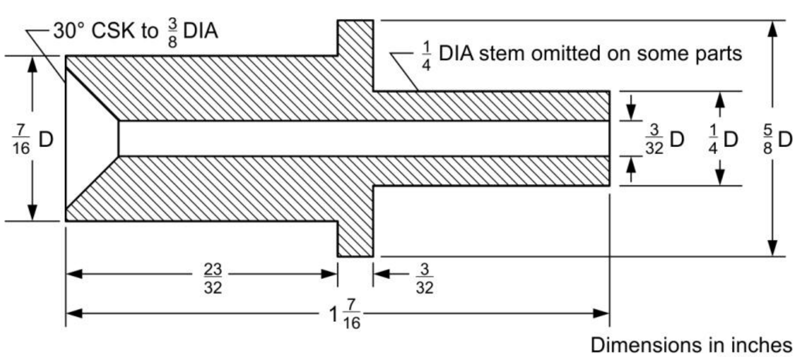


Figure 2.119. Thermocouple Well (DWG# RE-1-24159).

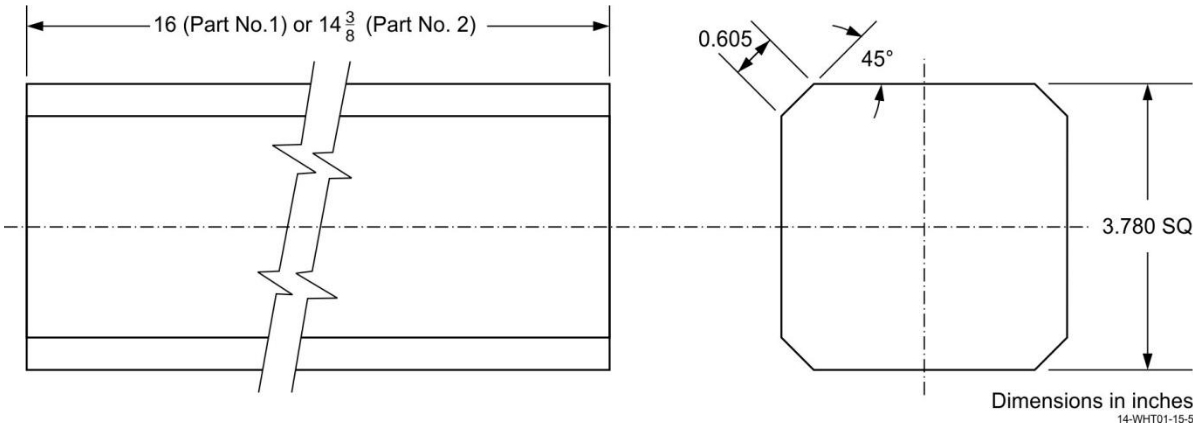


Figure 2.120. Long Plug (DWG# RE-1-21768).

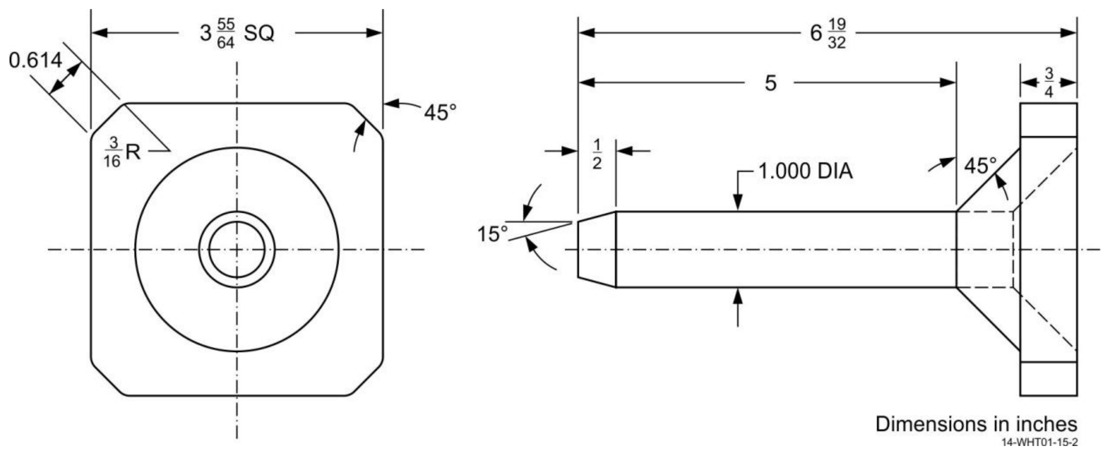


Figure 2.121. Bottom Fuel Fitting (DWG# RE-1-21881).

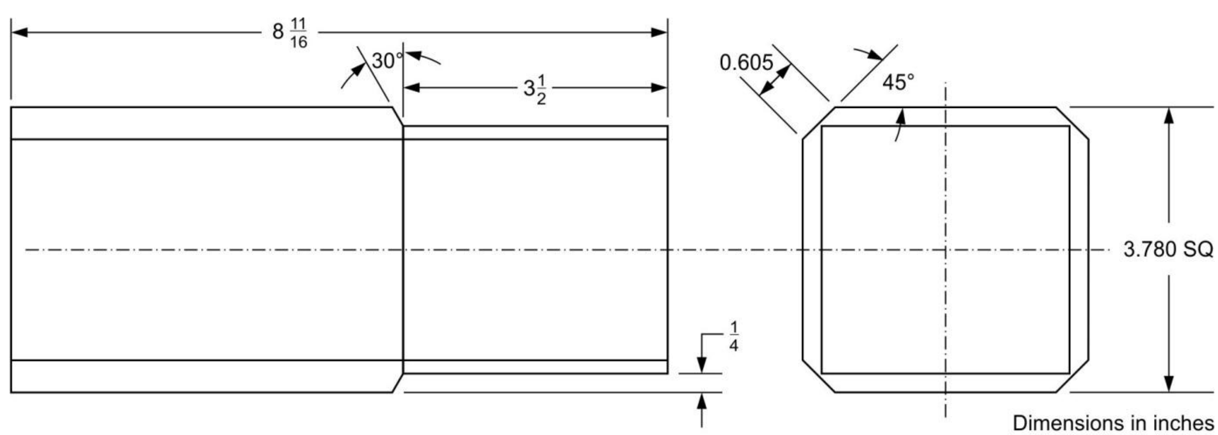


Figure 2.122. Plain Short Plug (DWG# RE-1-22739).

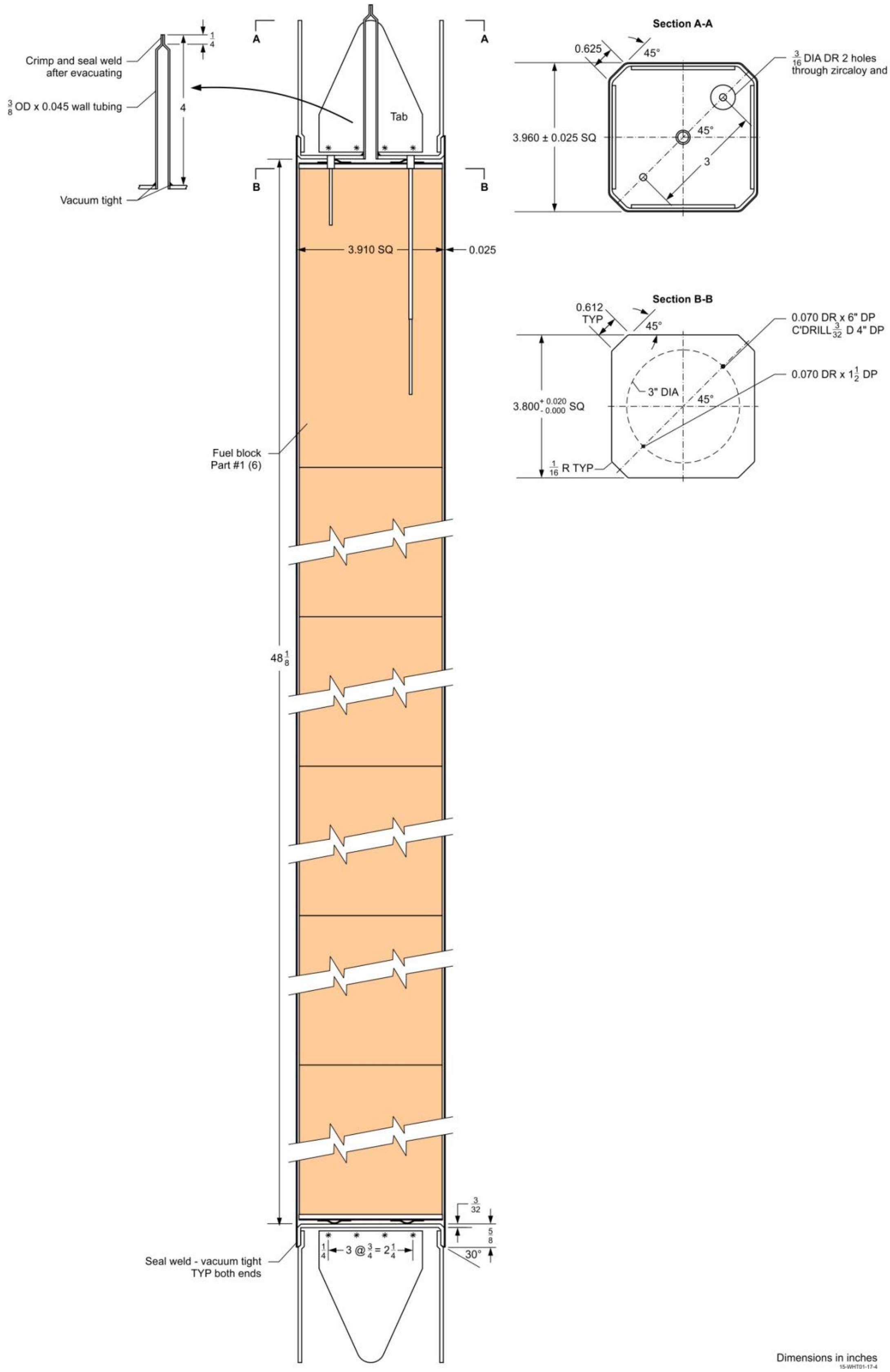


Figure 2.123. Reflector Fuel Temperature Gradient Thermocouple Fuel Section (DWG# RE-1-30266).

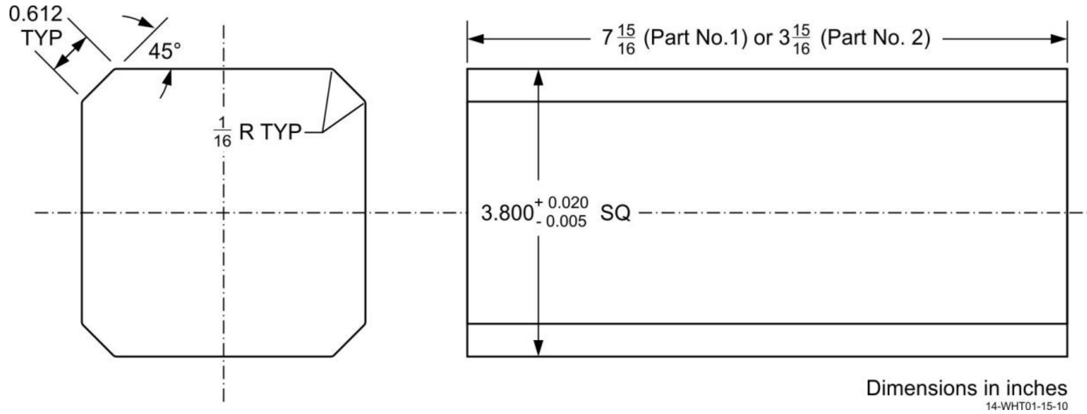


Figure 2.124. Fuel Block (DWG# RE-1-21578).

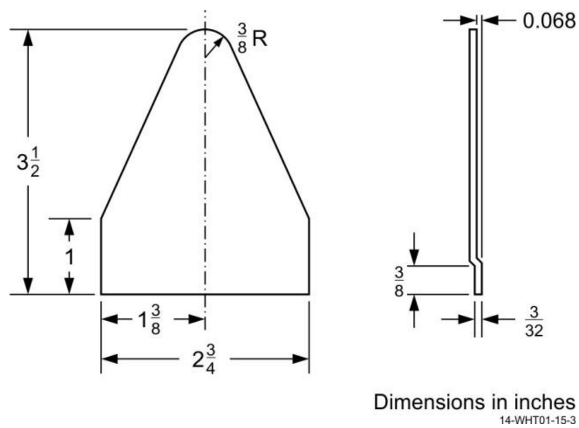


Figure 2.125. Tab (DWG# RE-1-22699).

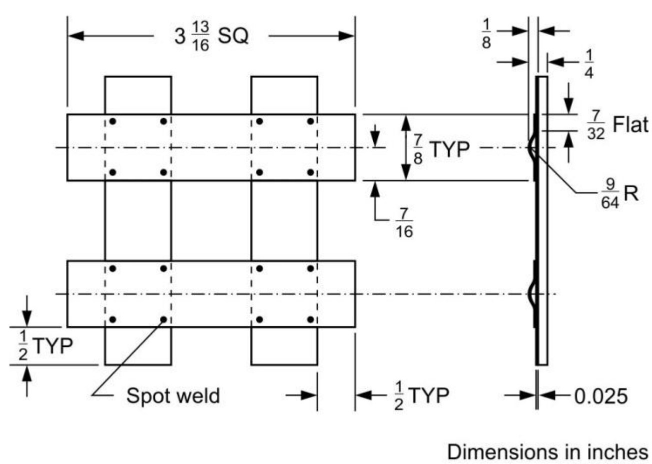


Figure 2.126. Spacer (DWG# RE-1-24160).

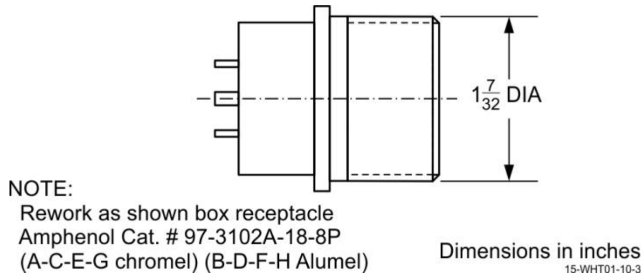


Figure 2.127. Plug Rework Box Receptacle (DWG# RE-1-23257).

2.4.5 Access Hole (24-inch) Thermocouple Fuel Assembly

The access hole (24-inch) thermocouple fuel assembly is shown in Figure 2.128 with a list of applicable drawings and materials provided in Table 2.11. Individual component drawings are provided in Figures 2.128 through 2.148.

Table 2.11. Access Hole (24-inch) Thermocouple Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.128	RE-1-30333	Access Hole Thermocouple Fuel Assembly	--
1	2.128	--	Straight Amphenol Plug	Al-6061
4	2.128	--	Chromel-Alumel Thermocouples	--
1	2.129	RE-1-23253	Plug Holder	Al-6061
1	2.130	RE-1-23254	Socket Holder	Al-6061
1	2.131	RE-1-23255	Top Fuel Fitting Rework	Al-1100
1	2.132	RE-1-30334	Long Plug	CP-2 Graphite
1	2.133	RE-1-30335	Short Plug	CP-2 Graphite
1	2.134	RE-1-30336	Thermocouple Shield	Zr-3
1	2.135	RE-1-22736	End Tube Part #1	Al-6063
1	2.135	RE-1-22736	End Tube Part #2	Al-6063
1	2.136	RE-1-24159	Thermocouple Well Part #1	Zr-3
1	2.136	RE-1-24159	Thermocouple Well Part #2	Zr-3
1	2.137	RE-1-21767	Short Plug	CP-2 Graphite
1	2.138	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.139	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.140	RE-1-30337	Access Hole Thermocouple Fuel Section	Zr-3
8	2.141	RE-1-22699	Tab	Zr-3
2	2.142	RE-1-24160	Spacer	Zr-3
1	2.143	RE-1-30338	Thermocouple Fuel Block	Graphite Fuel
2	2.144	RE-1-21578	Fuel Block Part #2	Graphite Fuel
1	2.144	RE-1-21578	Fuel Block Part #1	Graphite Fuel
4	2.145	RE-1-24660	Anchor Tab	Zr-3
2	2.146	RE-1-24659	Side Frame	Zr-3
2	2.147	RE-1-24661	Guide	Zr-3
1	2.148	RE-1-23257	Plug Rework Box Receptacle	Al-6061

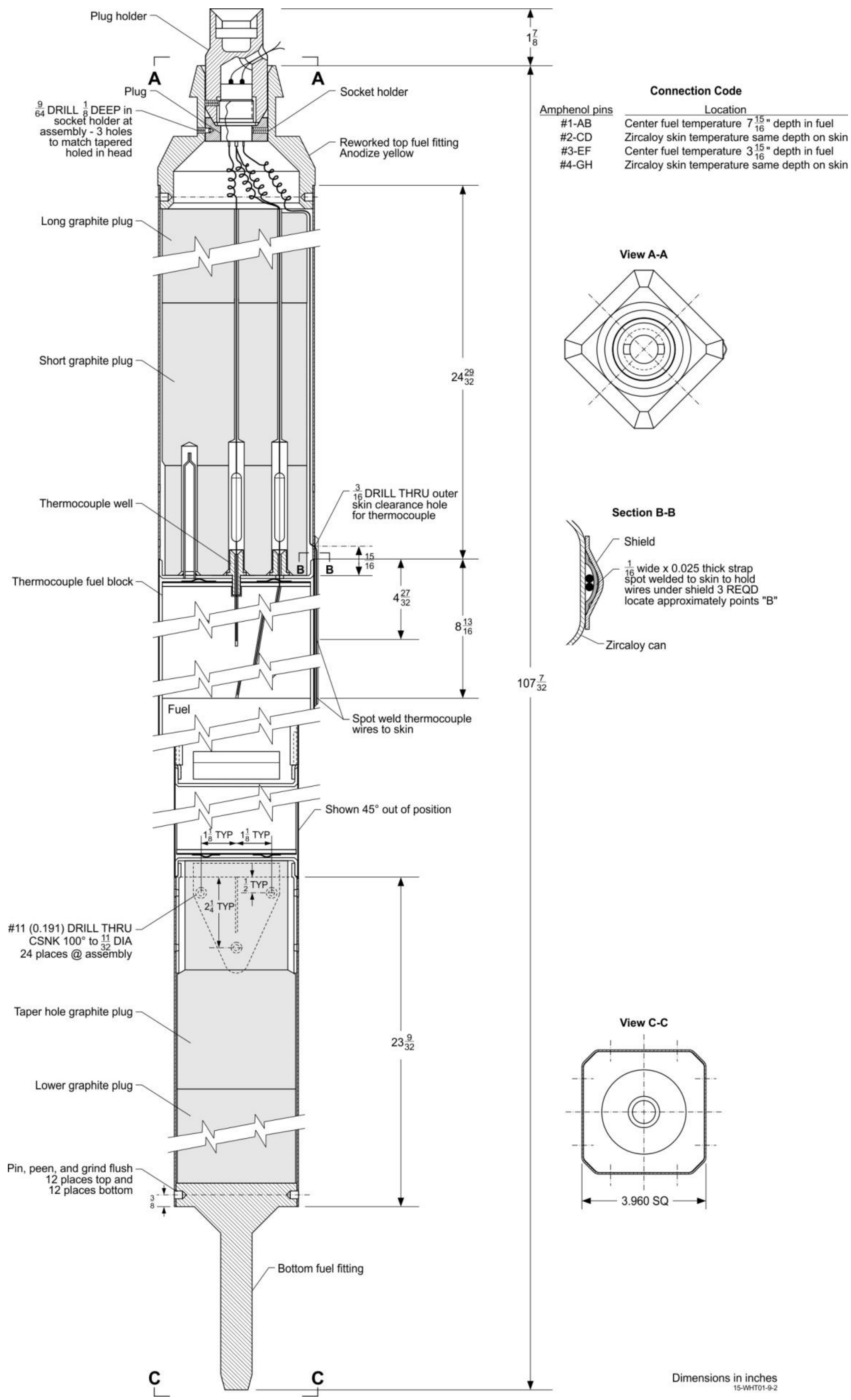


Figure 2.128. Access Hole Thermocouple Fuel Assembly (DWG# RE-1-30333).

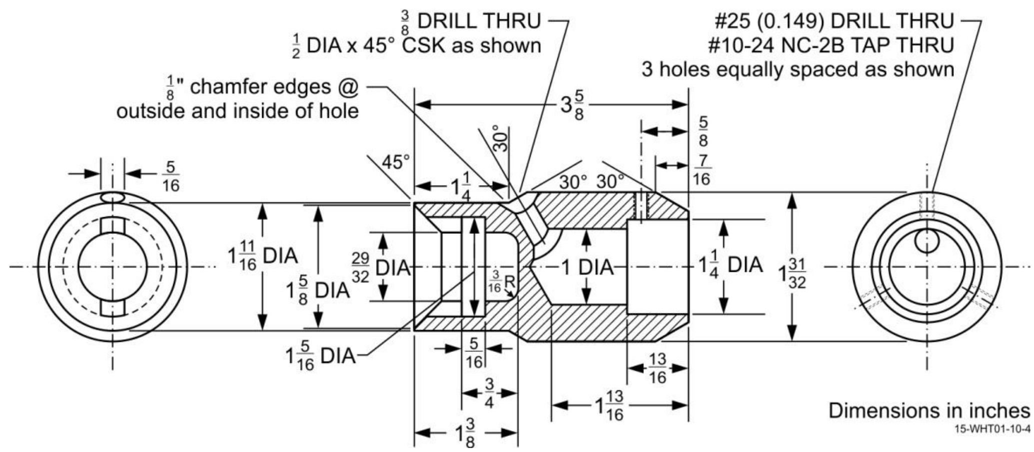


Figure 2.129. Plug Holder (DWG# RE-1-23253).

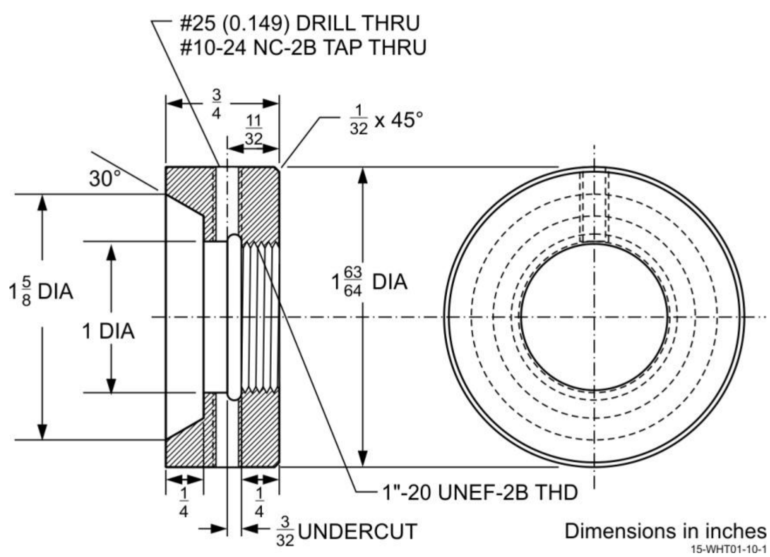


Figure 2.130. Socket Holder (DWG# RE-1-23254).

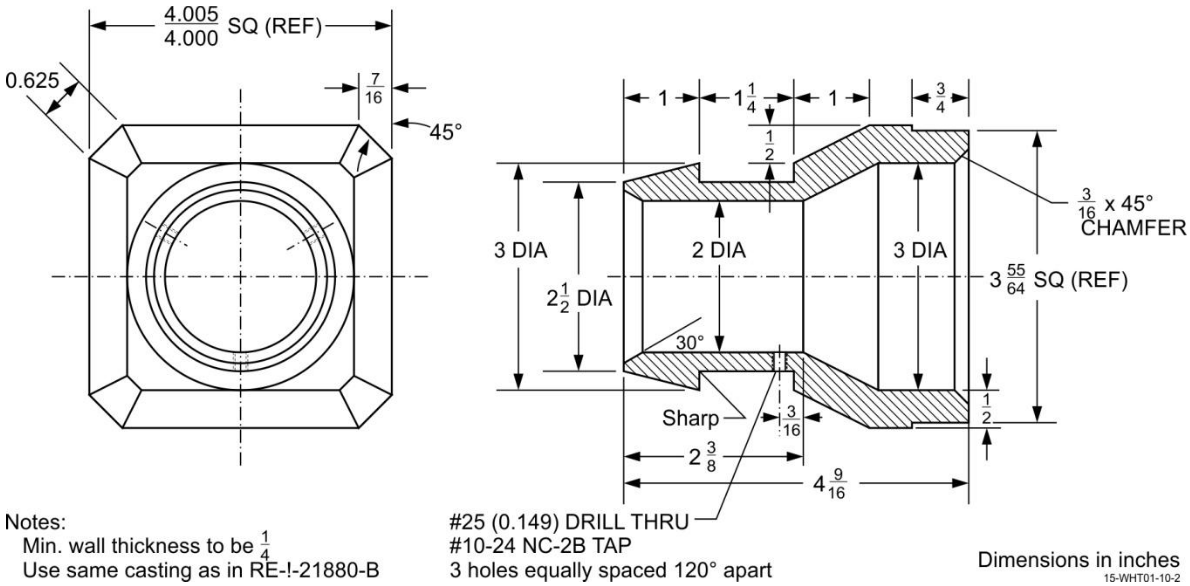


Figure 2.131. Top Fuel Fitting Rework (DWG# RE-1-23255).

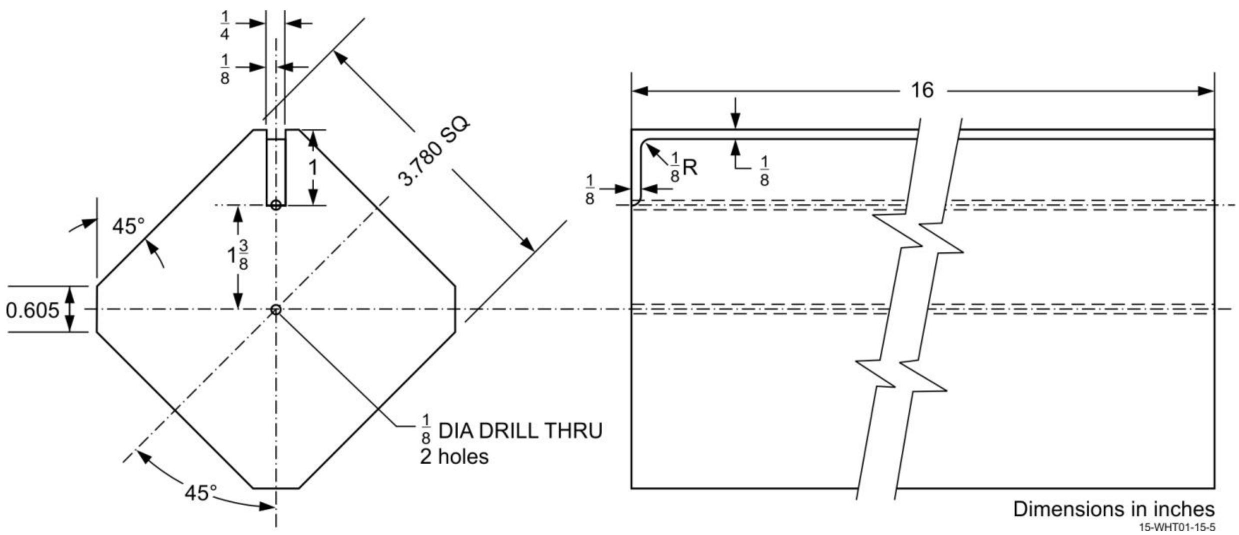


Figure 2.132. Long Plug (DWG# RE-1-30334).

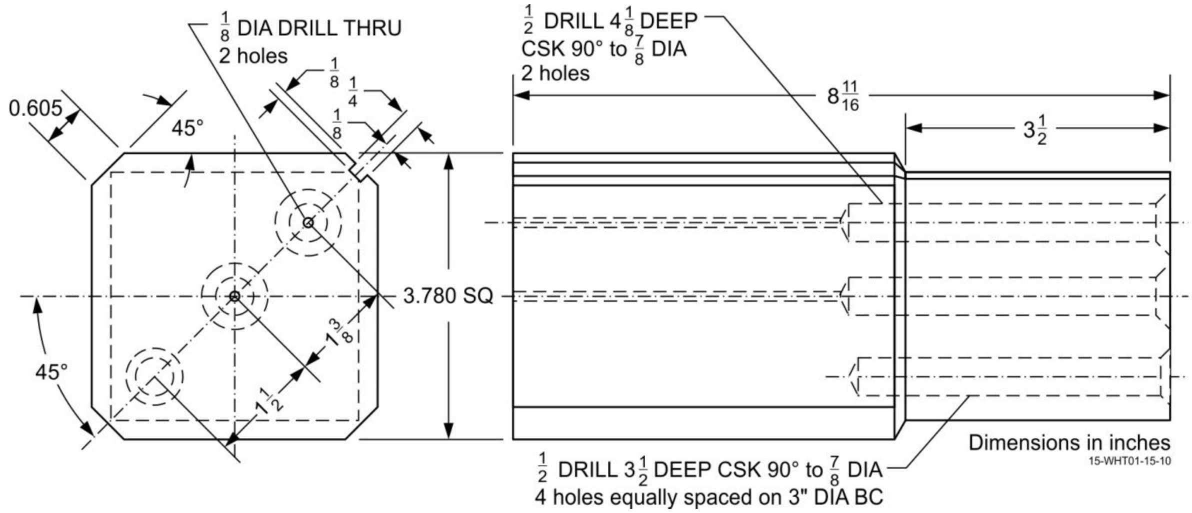


Figure 2.133. Short Plug (DWG# RE-1-30335).

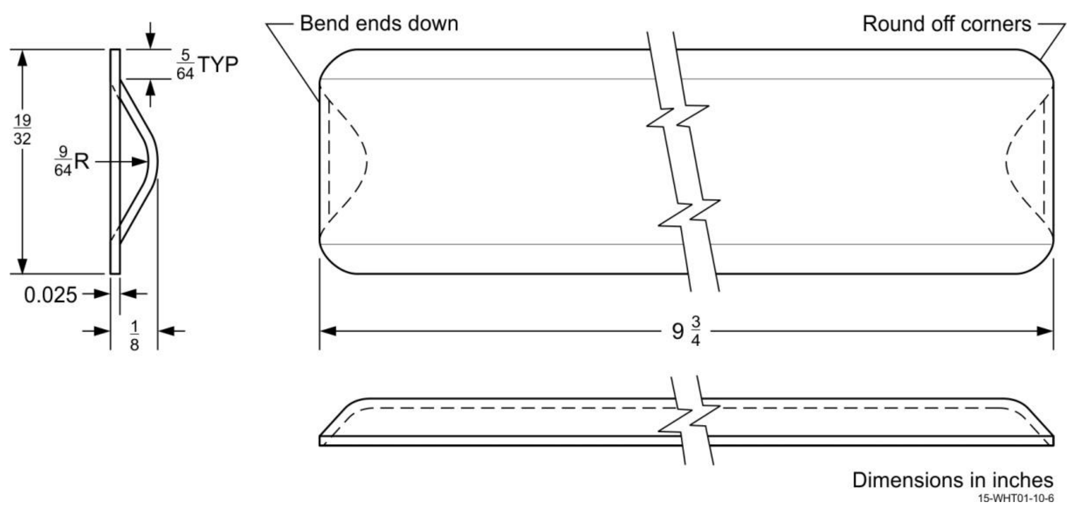


Figure 2.134. Thermocouple Shield (DWG# RE-1-30336).

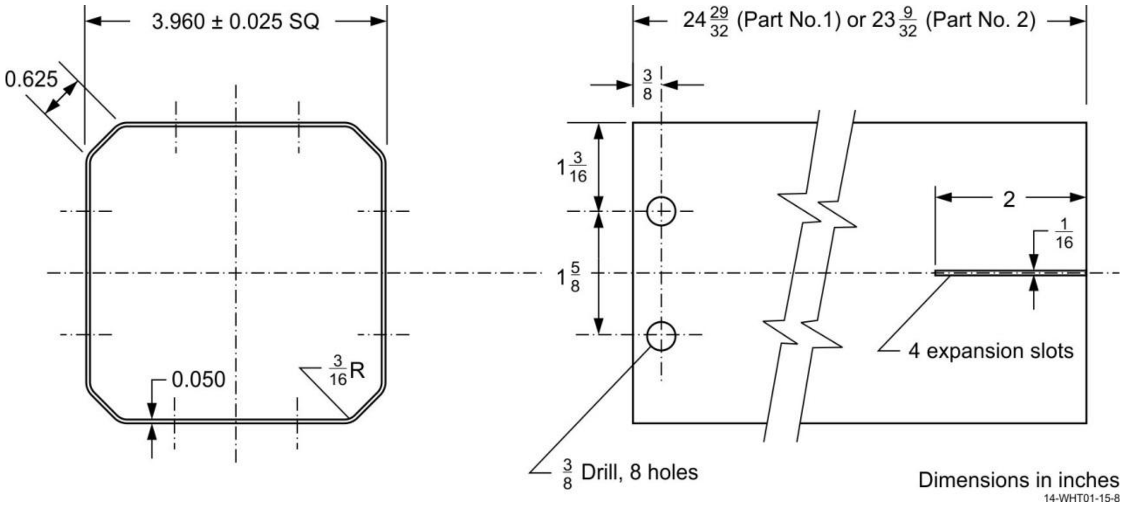


Figure 2.135. End Tube (DWG# RE-1-22736).

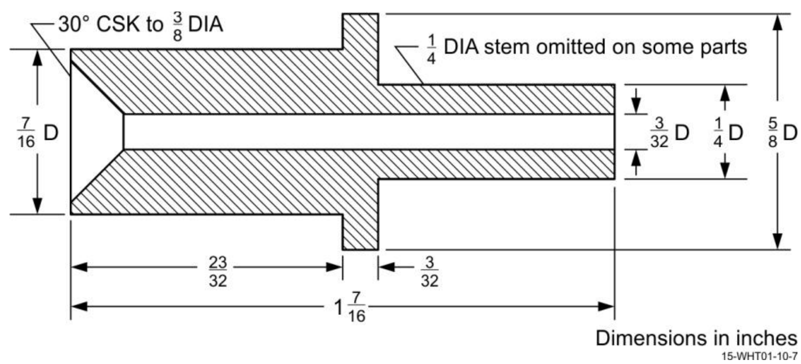


Figure 2.136. Thermocouple Well (DWG# RE-1-24159).

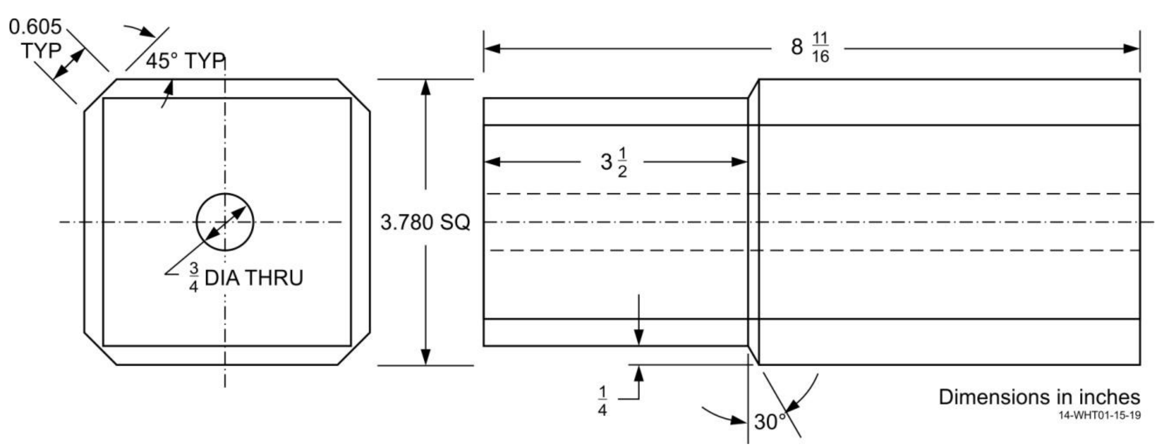


Figure 2.137. Short Plug (DWG# RE-1-21767).

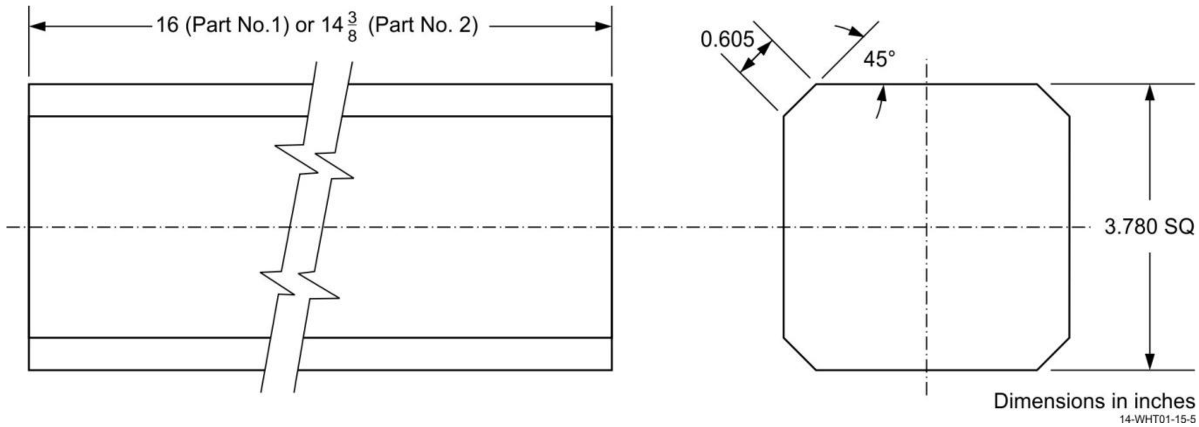


Figure 2.138. Long Plug (DWG# RE-1-21768).

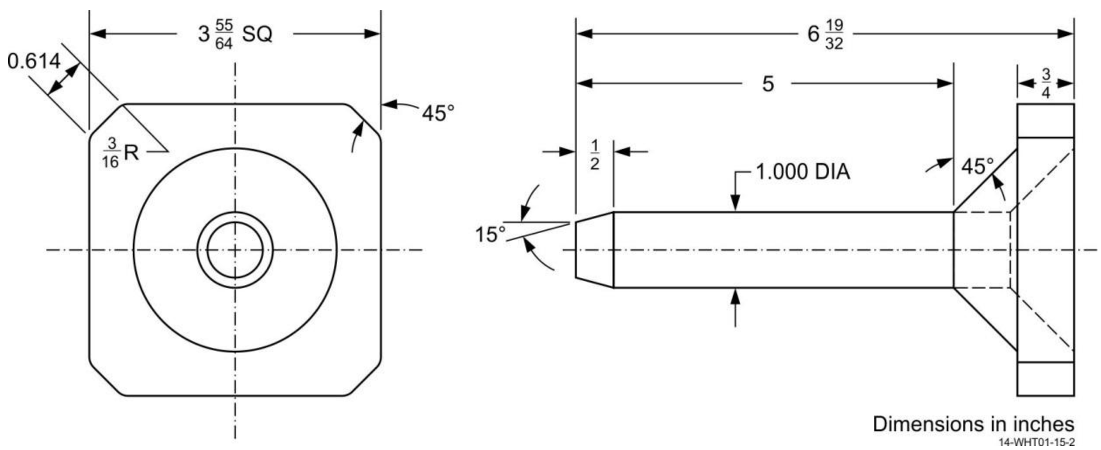


Figure 2.139. Bottom Fuel Fitting (DWG# RE-1-21881).

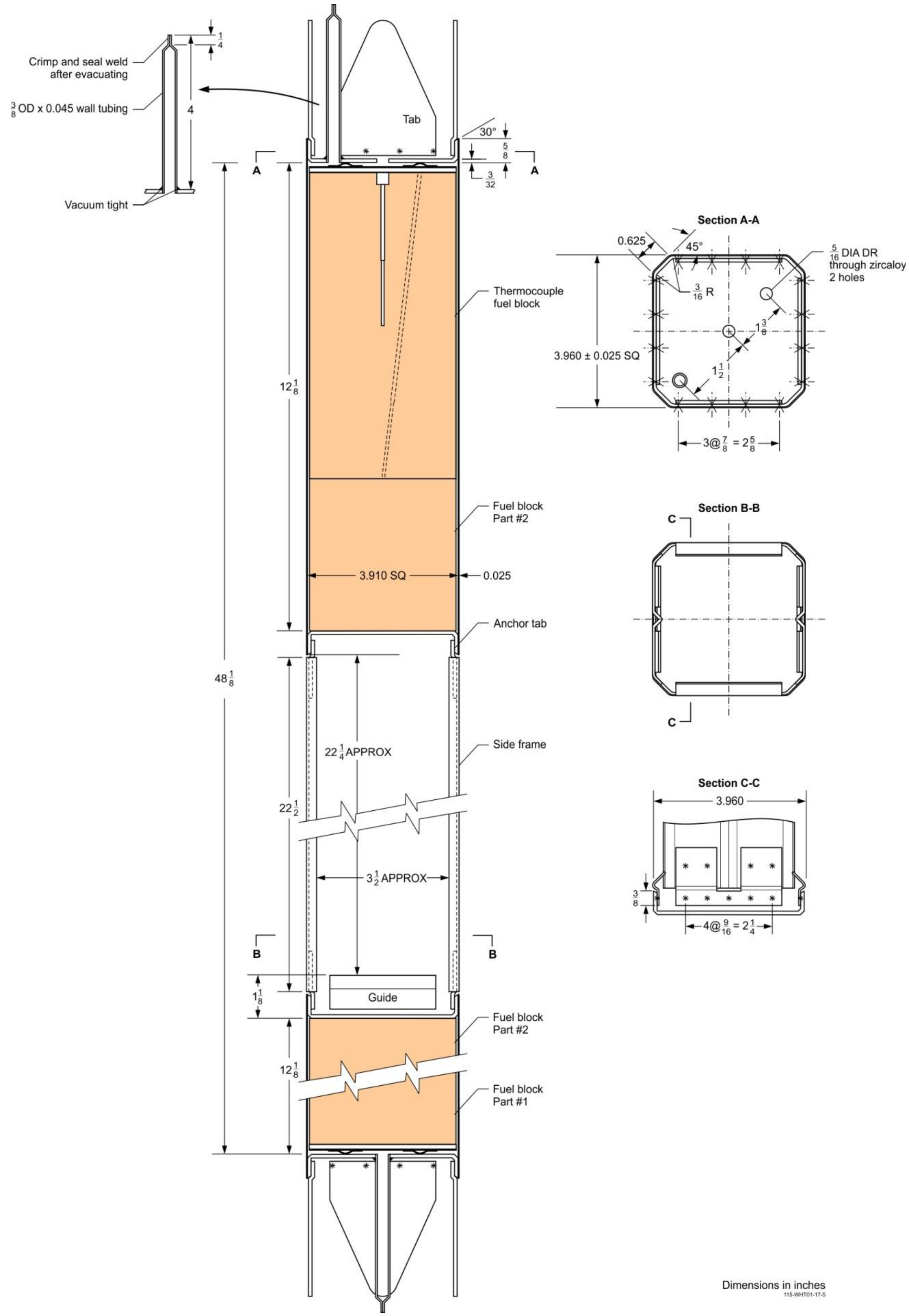


Figure 2.140. Access Hole Fuel Section (DWG# RE-1-30337).

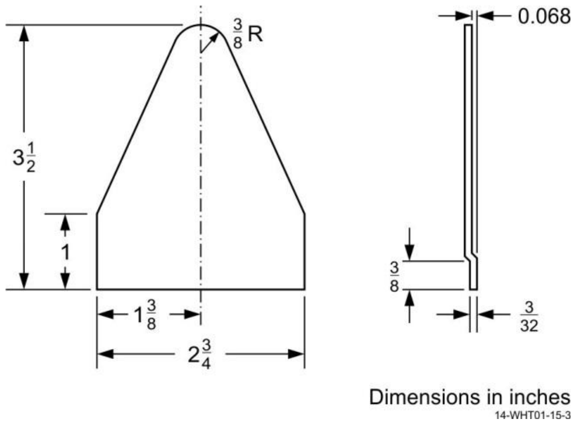


Figure 2.141. Tab (DWG# RE-1-22699).

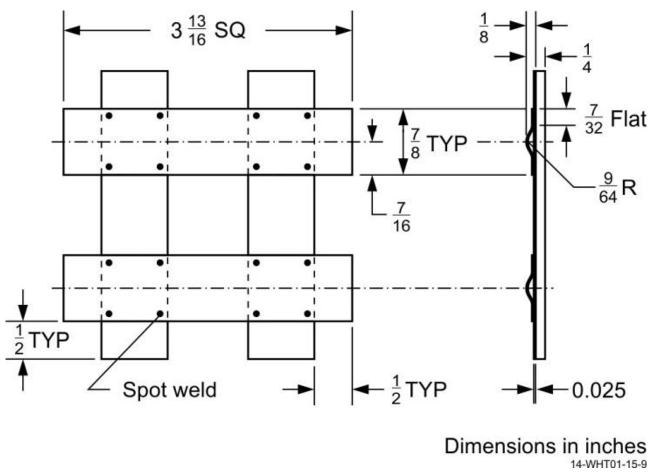


Figure 2.142. Spacer (DWG# RE-1-24160).

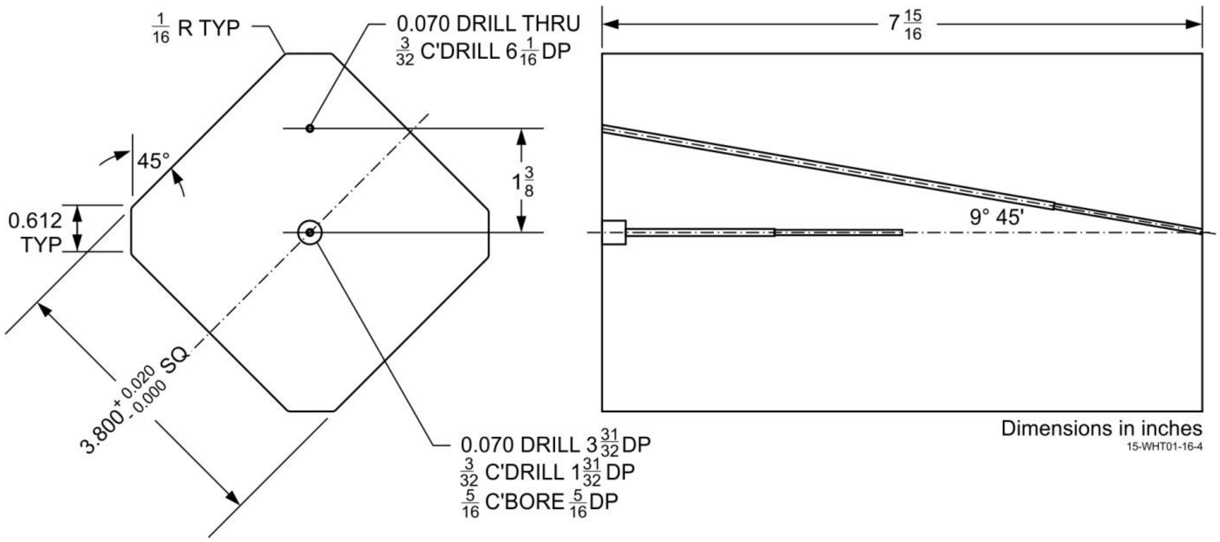


Figure 2.143. Thermocouple Fuel Block (DWG# RE-1-30338).

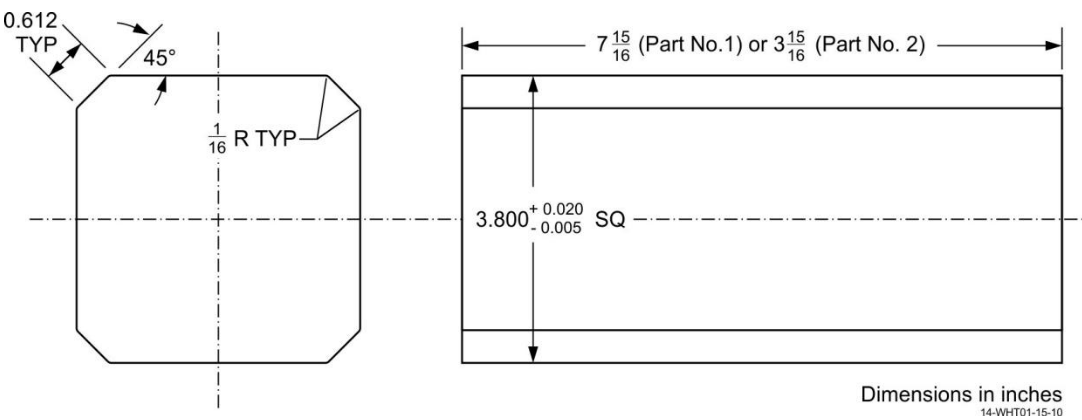


Figure 2.144. Fuel Block (DWG# RE-1-21578).

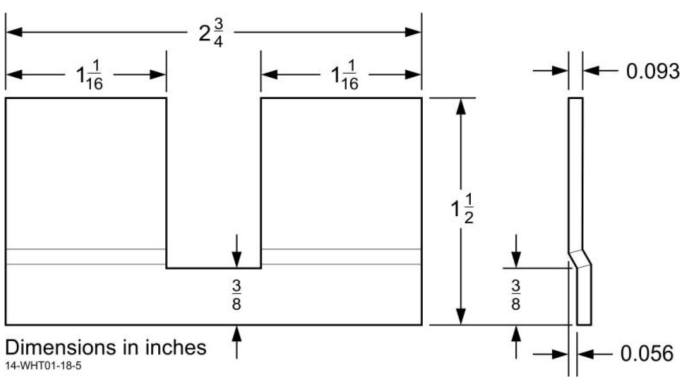


Figure 2.145. Anchor Tab (DWG# RE-1-24660).

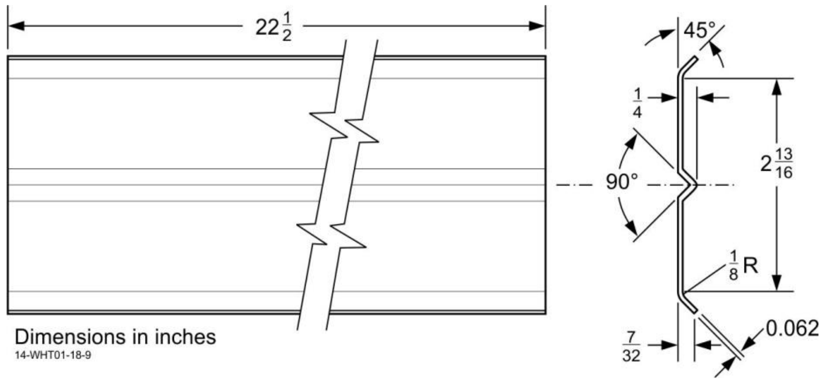


Figure 2.146. Side Frame (DWG# RE-1-24659).

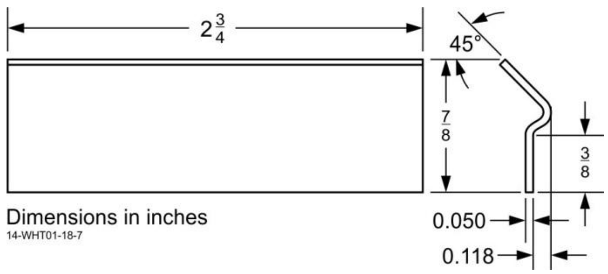


Figure 2.147. Guide (DWG# RE-1-24661).

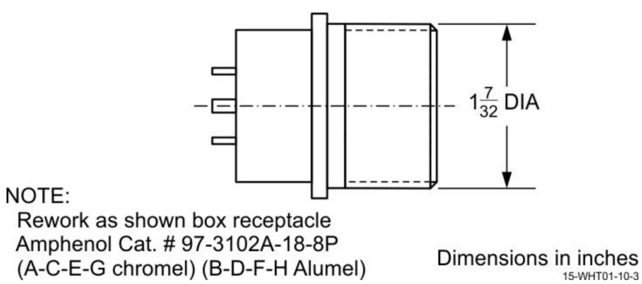


Figure 2.148. Plug Rework Box Receptacle (DWG# RE-1-23257).

2.5 Aluminum-Clad Dummy Fuel Assembly

The aluminum-clad dummy fuel assembly contains no fuel. Essentially this assembly is an aluminum tube filled with graphite blocks that served to provide additional radial core reflection when the core contained smaller quantities of fueled assemblies. These assemblies were never placed in the core directly adjacent to fueled assemblies; the Zircaloy-clad dummy fuel assemblies provided a thermal buffer between fueled and non-fueled regions of the core. The aluminum-clad dummy fuel assembly is shown in Figure 2.149 with a list of applicable drawings and materials provided in Table 2.12. Individual component drawings are provided in Figures 2.149 through 2.154.

Table 2.12. Aluminum-Clad Dummy Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.149	RE-1-21720	Aluminum Clad Dummy Fuel Assembly	--
1	2.150	RE-1-21880	Top Fuel Fitting	Al-1100
5	2.151	RE-1-22762	Dummy Plug #1	CP-2 Graphite
1	2.151	RE-1-22762	Dummy Plug #2	CP-2 Graphite
1	2.152	RE-1-22740	Tube	Al-1100
1	2.153	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.154	Z0012-0314 to -316	Fuel Identification Tag	Al-6061

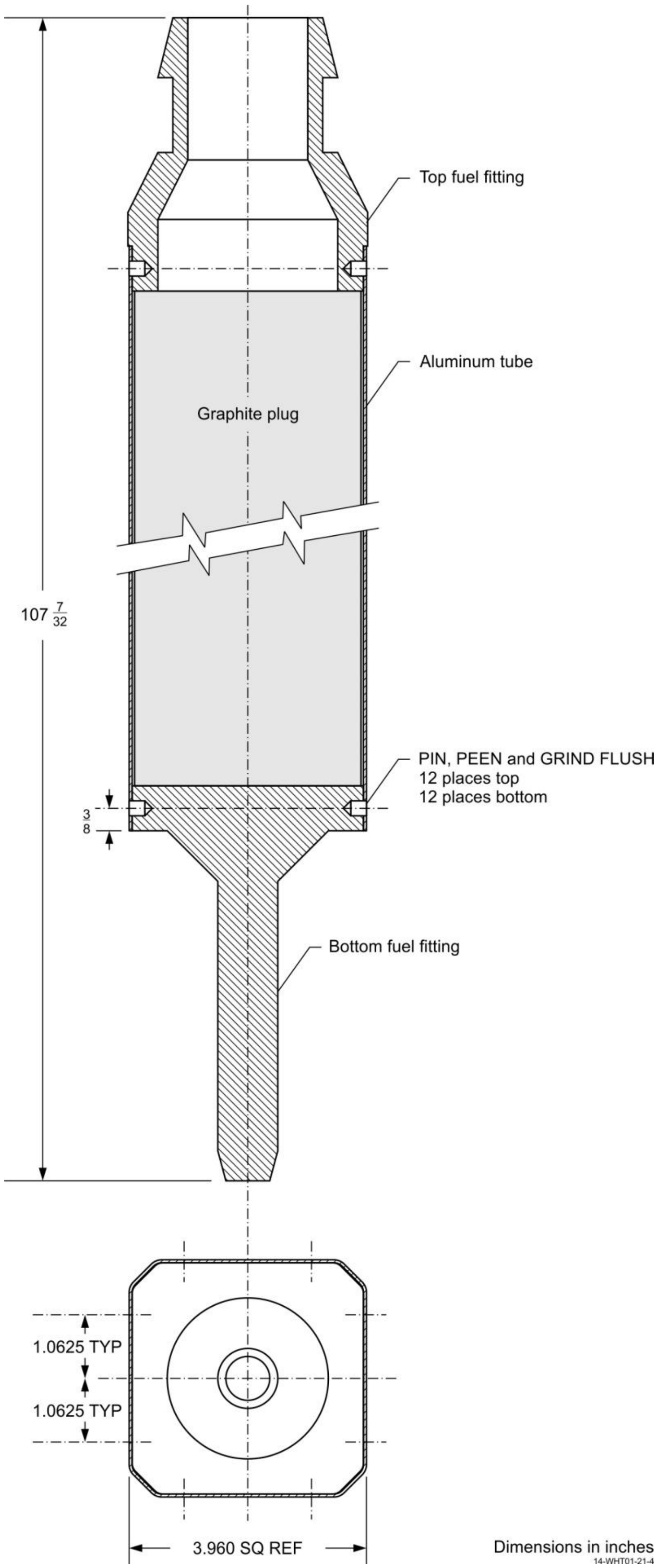


Figure 2.149. Aluminum Clad Dummy Fuel Assembly (DWG# RE-1-21720).

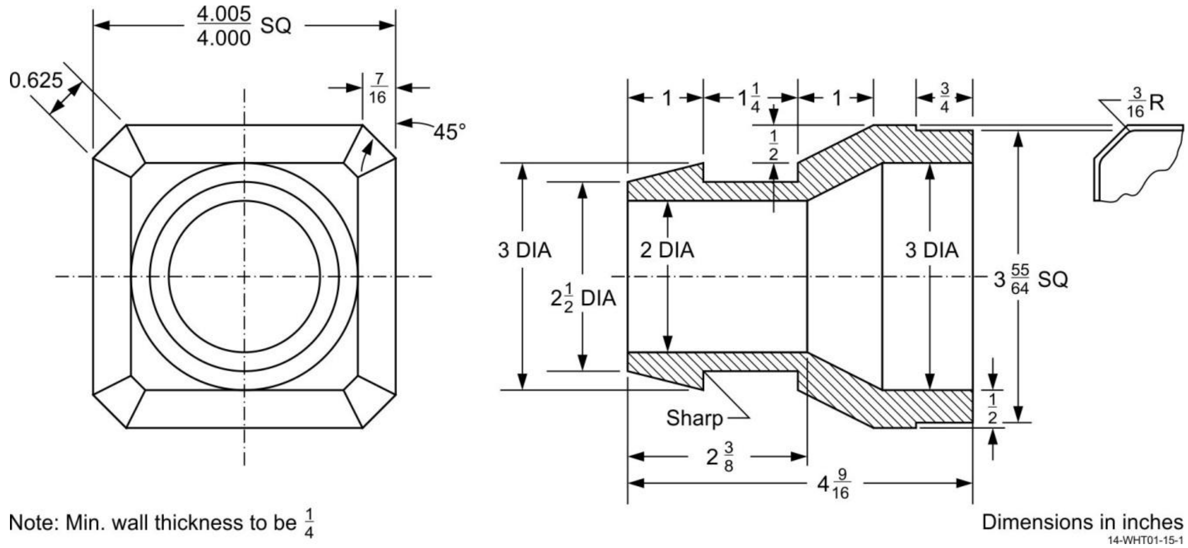


Figure 2.150. Top Fuel Fitting (DWG# RE-1-21880).

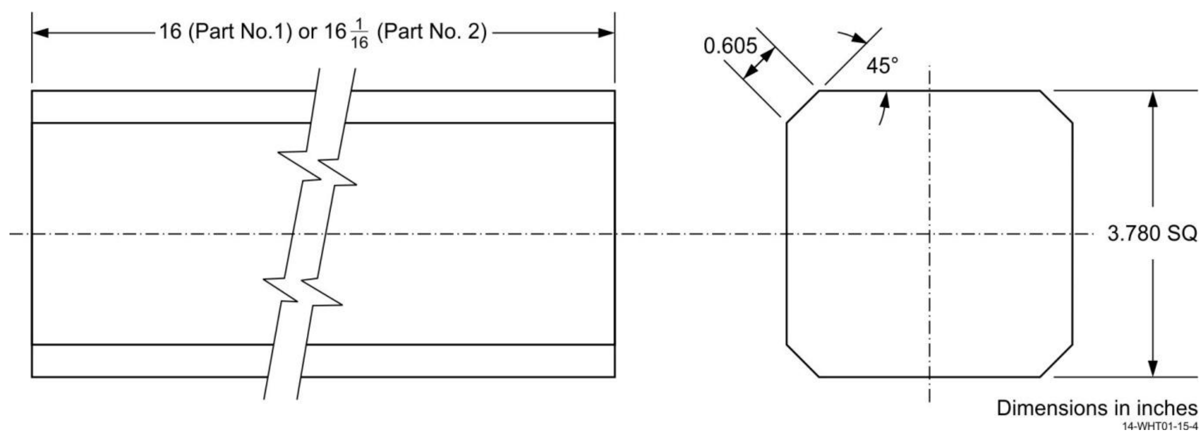


Figure 2.151. Dummy Plug (DWG# RE-1-22762).

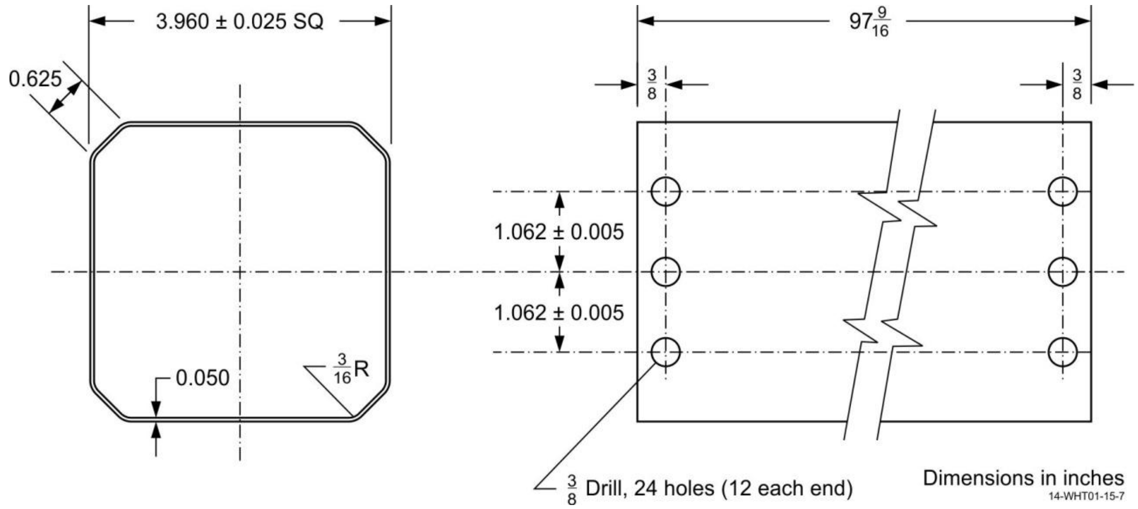


Figure 2.152. Tube (DWG# RE-1-22740).

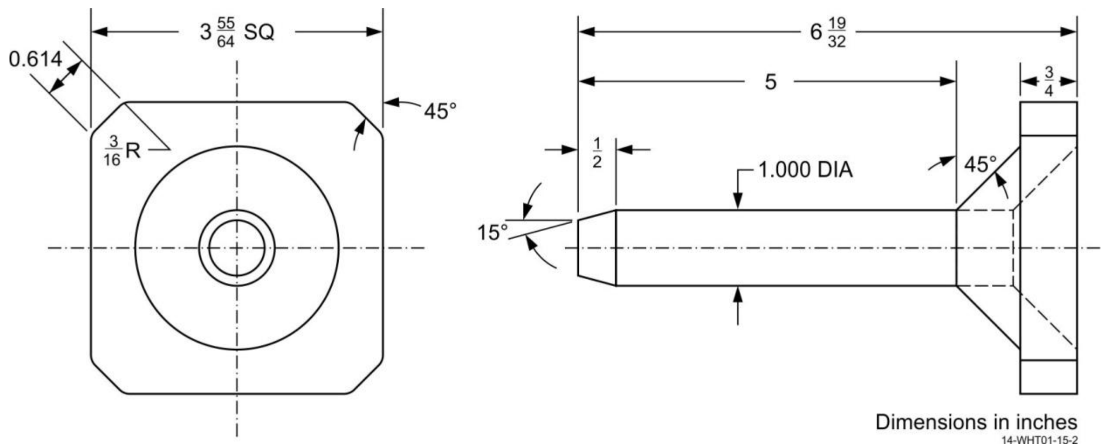


Figure 2.153. Bottom Fuel Fitting (DWG# RE-1-21881).

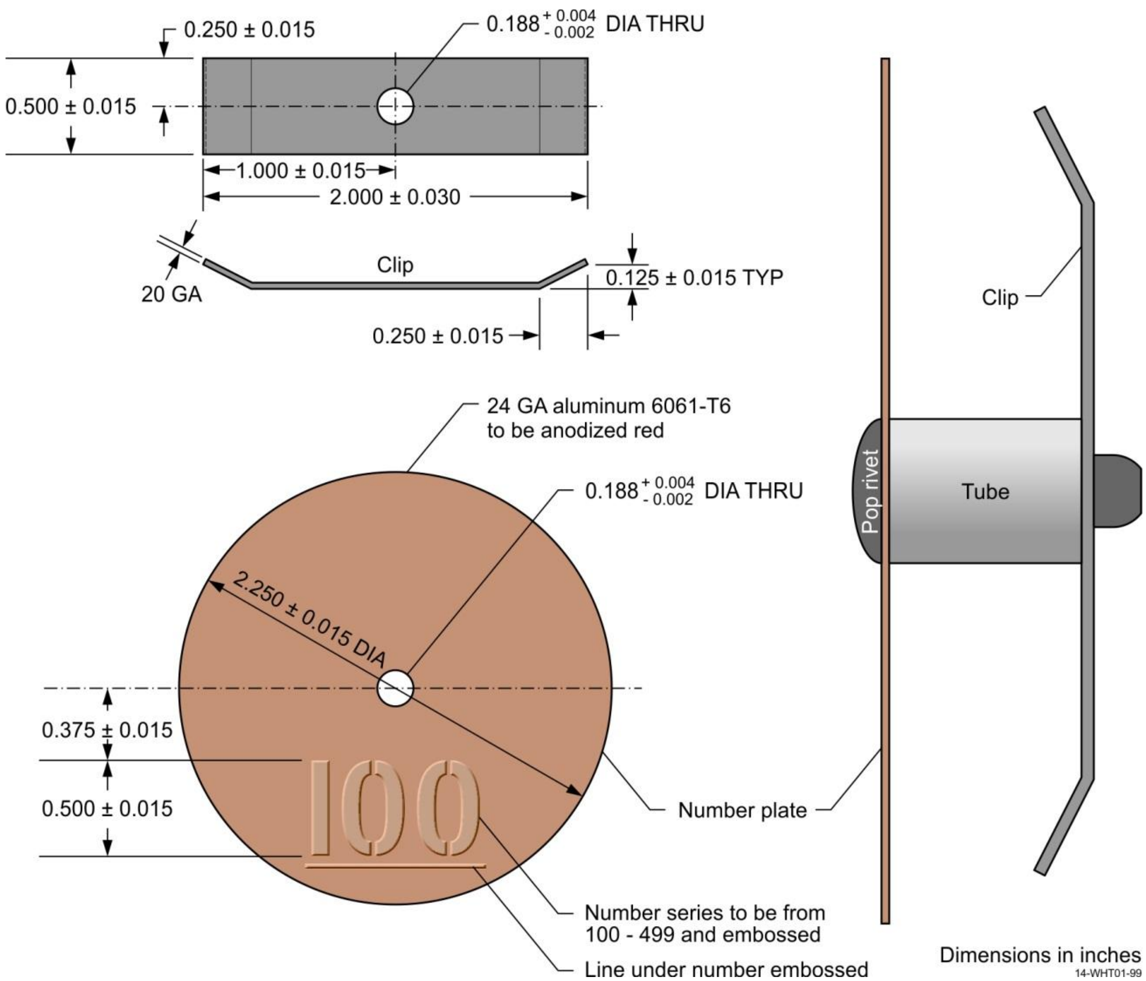


Figure 2.154. Fuel Identification Tag (DWG# Z0012-0314 through -0316).

2.6 Zircaloy-Clad Dummy Fuel Assemblies

The variations in the fueled assemblies are, for the most part, duplicated in dummy-fuel designs. The primary difference is that all the graphite-fuel blocks are replaced with graphite blocks. The other notable feature is that outgas tubes are not needed in non-fueled assemblies, and are also removed.

2.6.1 Standard Dummy Assembly

The standard dummy assembly is a standard fuel assembly without fuel. The assembly is shown in Figure 2.155 with a list of applicable drawings and materials provided in Table 2.13. Individual component drawings are provided in Figures 2.155 through 2.165.

Table 2.13. Standard TREAT Zircaloy-Clad Dummy Fuel Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.155	RE-1-22705	Zircaloy Clad Dummy Fuel Assembly	--
1	2.156	RE-1-21880	Top Fuel Fitting	Al-1100
1	2.157	RE-1-21768	Long Plug Part #1	CP-2 Graphite
1	2.157	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.158	RE-1-22736	End Tube Part #1	Al-6063
1	2.158	RE-1-22736	End Tube Part #2	Al-6063
2	2.159	RE-1-22739	Short Plain Plug	CP-2 Graphite
1	2.160	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.161	RE-1-22710	Dummy Fuel Section	Zr-3
6	2.162	RE-1-22741	Dummy Block Part #1	CP-2 Graphite
8	2.163	RE-1-22699	Tab	Zr-3
2	2.164	RE-1-24160	Spacer	Zr-3
1	2.165	Z0012-0314 to -316	Fuel Identification Tag	Al-6061

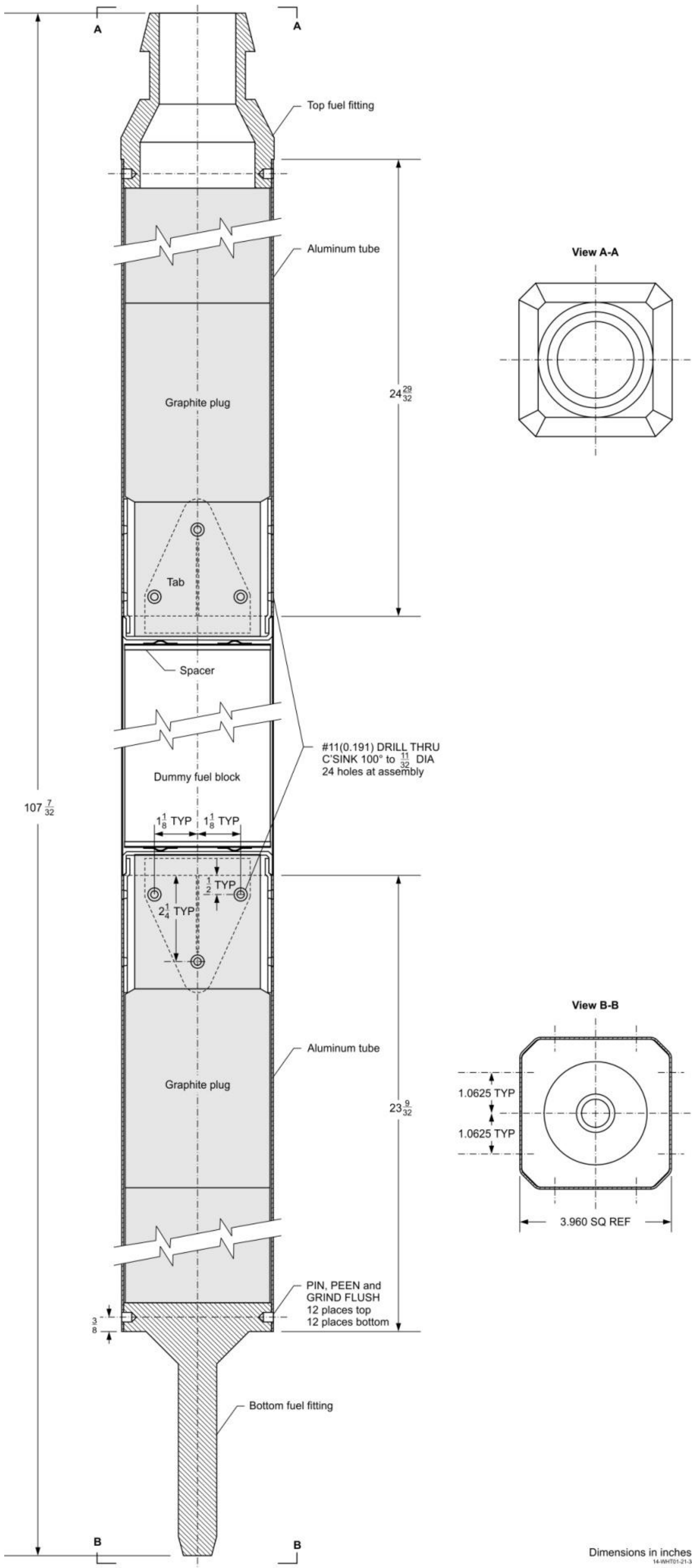


Figure 2.155. Zircaloy Clad Dummy Fuel Assembly (DWG# RE-1-22705).

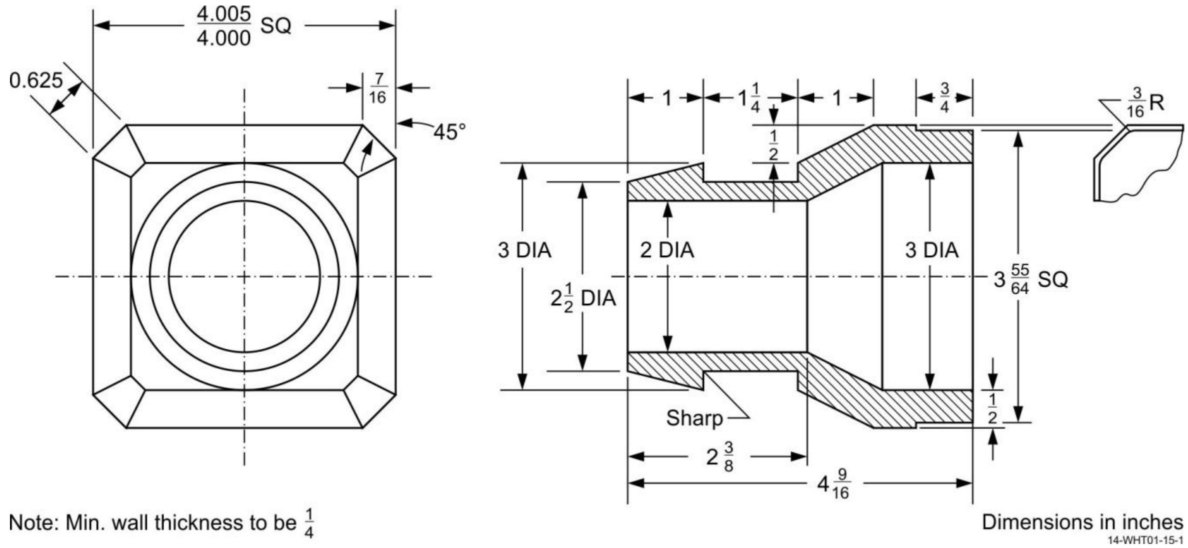


Figure 2.156. Top Fuel Fitting (DWG# RE-1-21880).

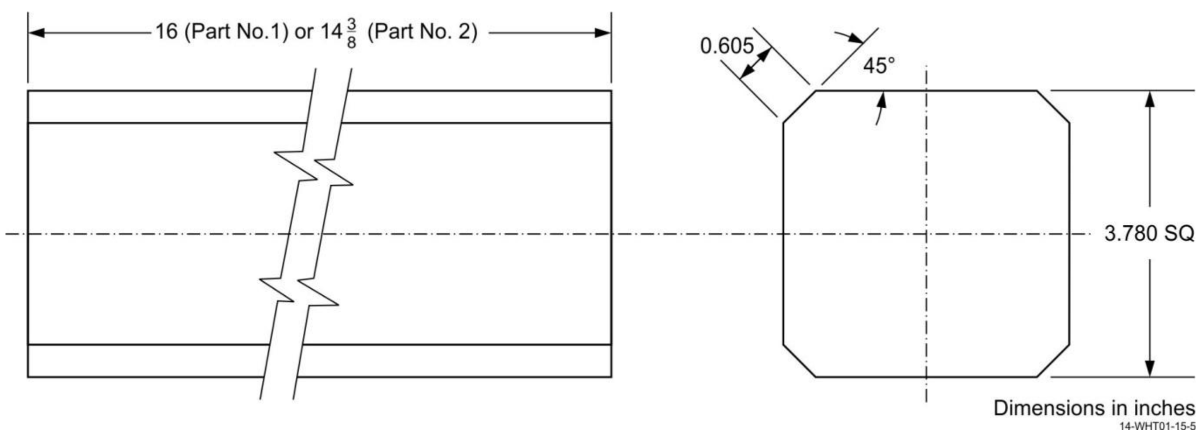


Figure 2.157. Long Plug (DWG# RE-1-21768).

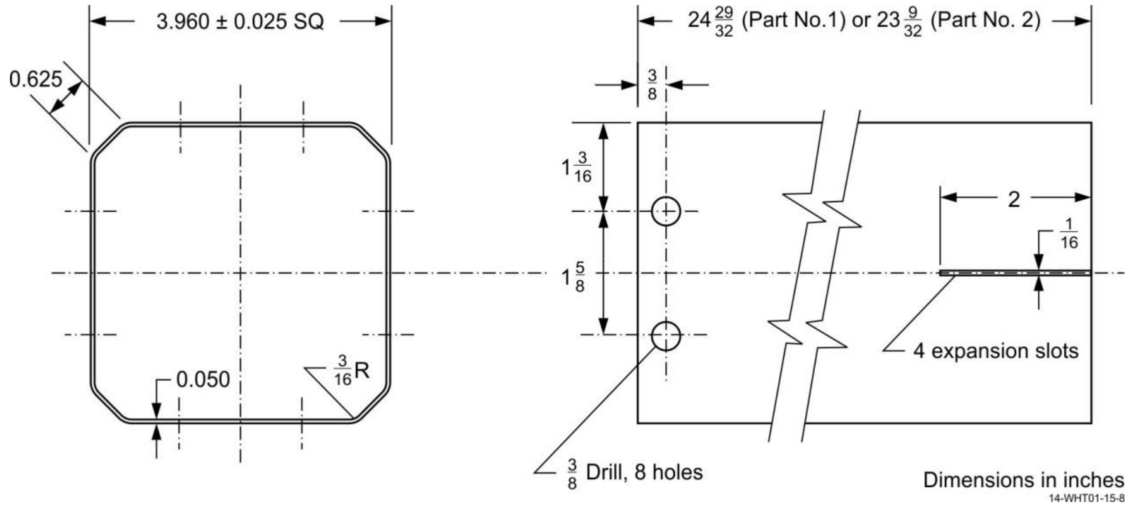


Figure 2.158. End Tube (DWG# RE-1-22736).

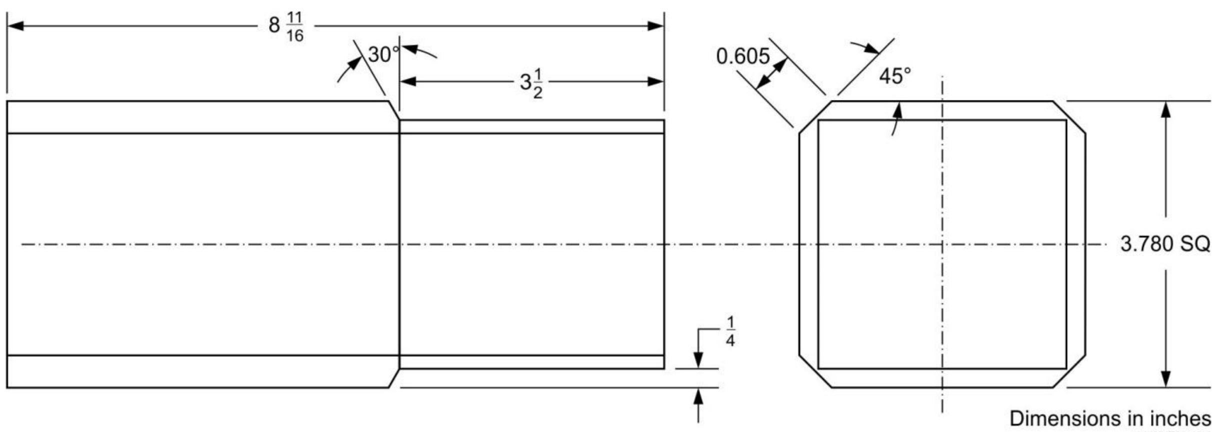


Figure 2.159. Short Plain Plug (DWG# RE-1-22739).

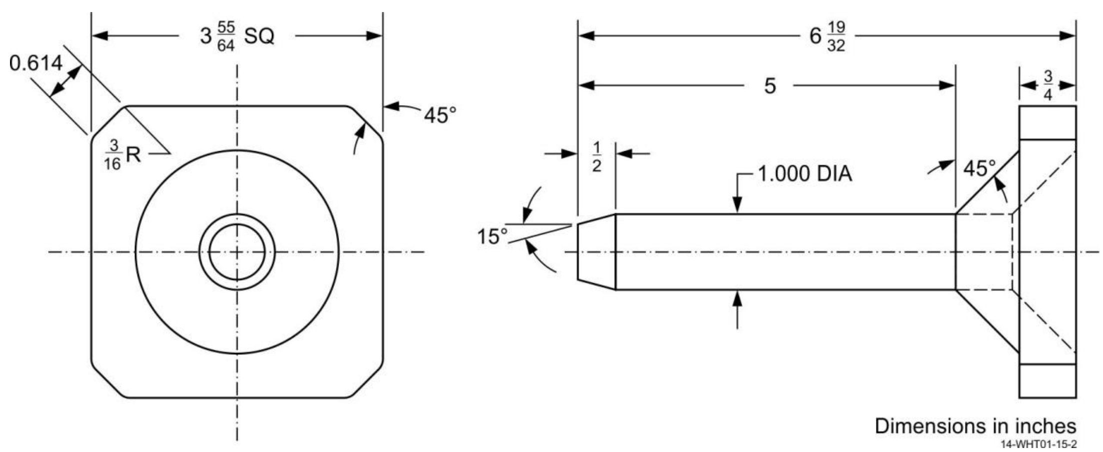


Figure 2.160. Bottom Fuel Fitting (DWG# RE-1-21881).

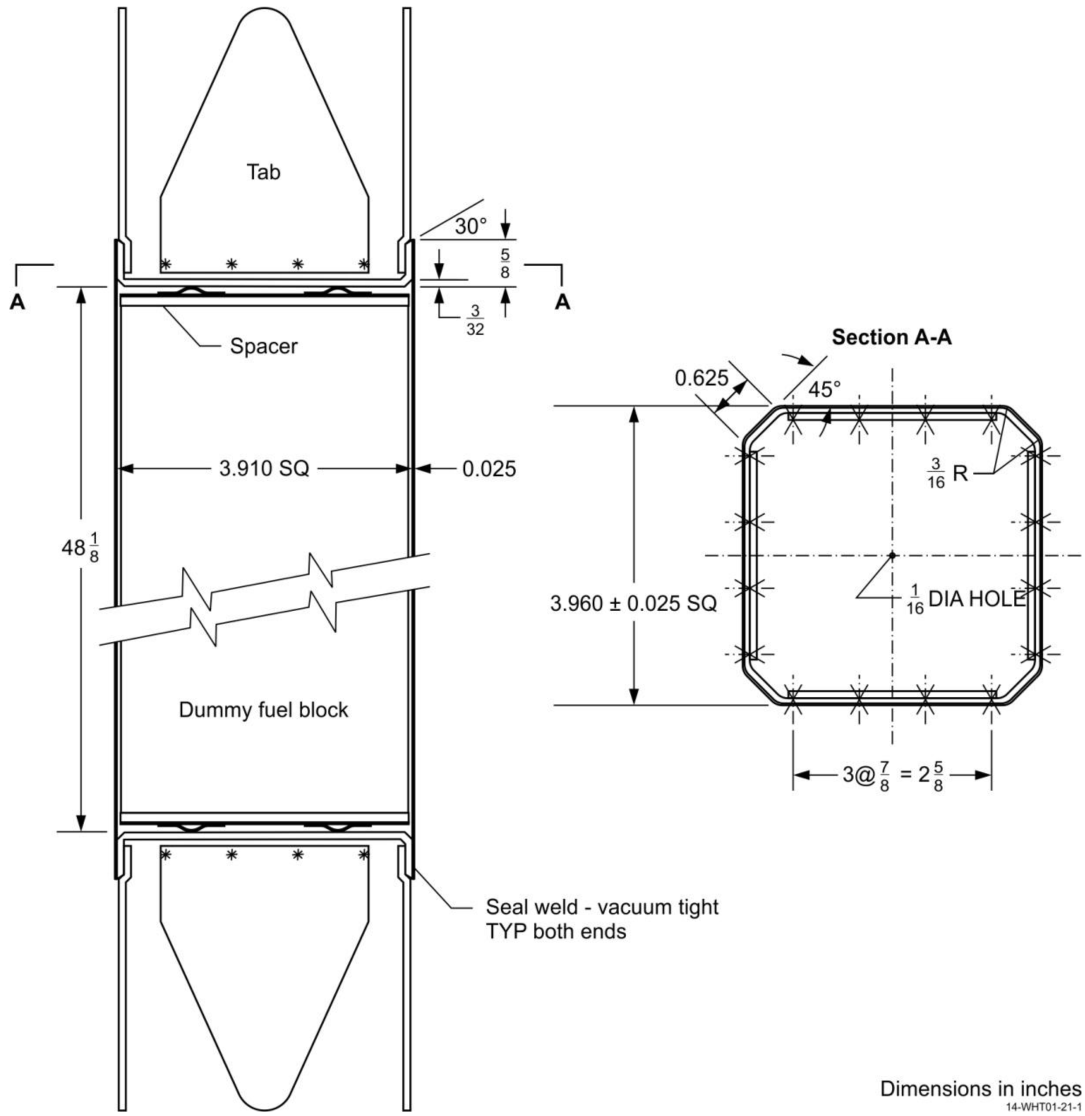


Figure 2.161. Dummy Fuel Section (DWG# RE-1-21710).

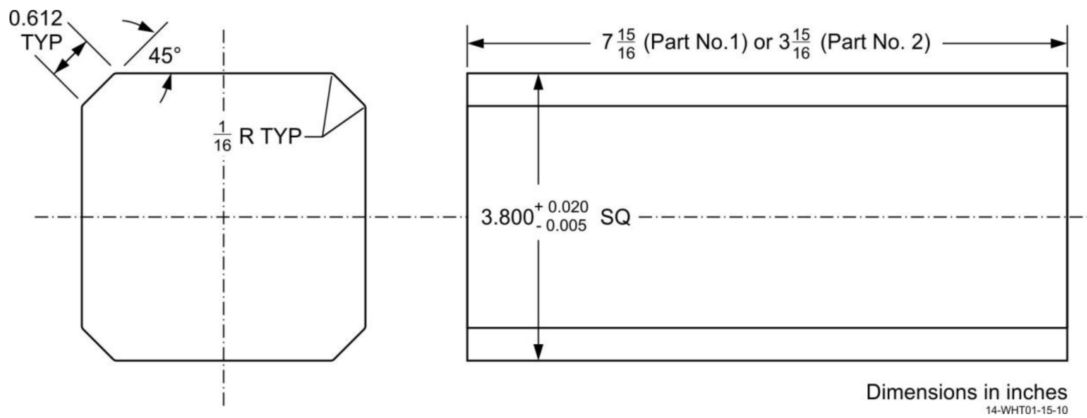


Figure 2.162. Dummy Block (DWG# RE-1-22741).

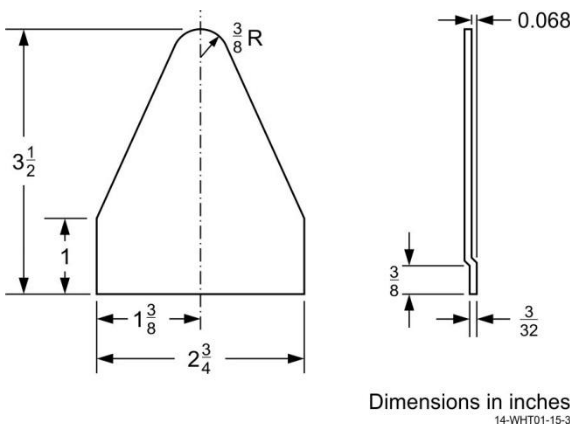


Figure 2.163. Tab (DWG# RE-1-22699).

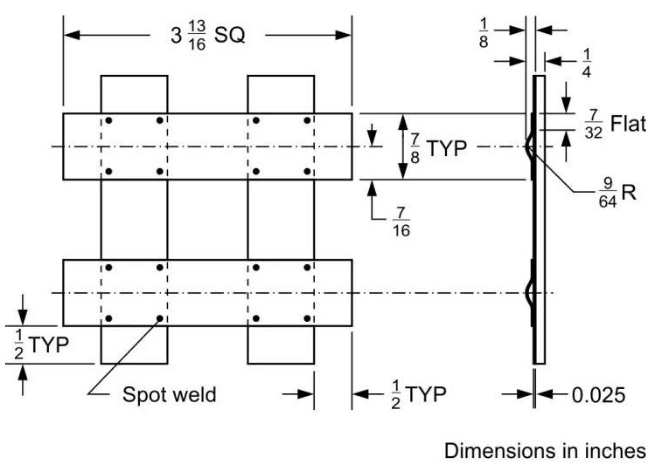


Figure 2.164. Spacer (DWG# RE-1-24160).

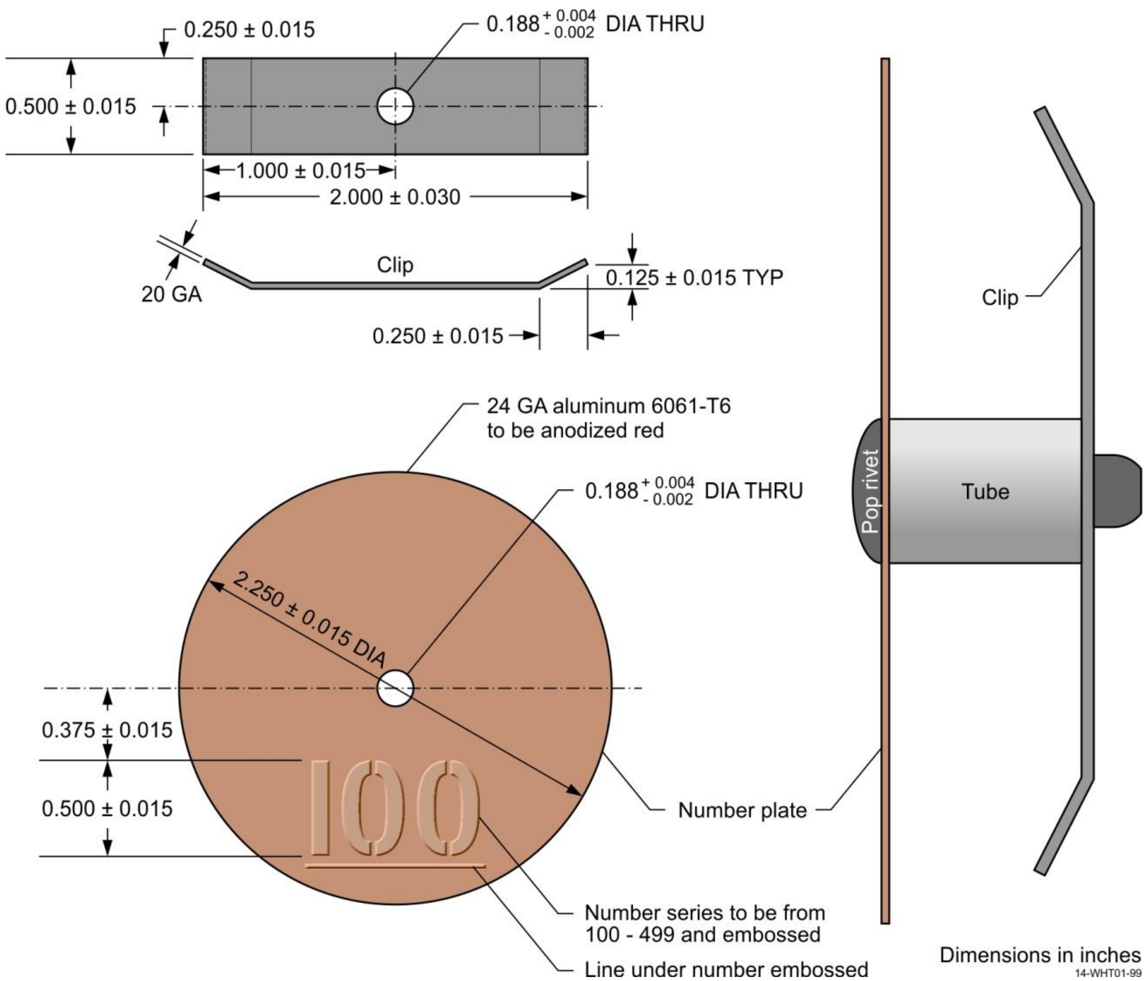


Figure 2.165. Fuel Identification Tag (DWG# Z0012-0314 through -0316).

2.6.2 Half Assembly

The half assembly is an unfueled assembly of graphite blocks that fills roughly half of the footprint of a standard assembly. The purpose of this assembly was to allow for placement of a 4 in. × 8 in. experimental can into the center of the reactor core, for example the various M-series experiments [Robinson 1994]. This assembly reduced neutron leakage from the core, helped maintain the position of the experiment in the center of the core, and also was typically placed behind the experimental assembly in relation to the hodoscope to help reduce background radiation noise in hodoscope measurements of the experiment. The assembly is shown in Figure 2.166 with a list of applicable drawings and materials provided in Table 2.14. Individual component drawings are provided in Figures 2.166 through 2.171.

Table 2.14. Zircaloy-Clad Dummy Half Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.166	Z0012-0172	MK-III Half Element Assembly	--
--	2.166	--	Graphite Blocks	CP-2 Graphite
1	2.167	Z0012-0174	Lifting Adapter	Al-6061
1	2.168	Z0012-0175	P1 Extension	Al-6061
1	2.168	Z0012-0175	P2 Extension	Al-6061
1	2.169	Z0012-0177	Bottom Fitting	Al-6061
1	2.170	Z0012-0181	Can	Zr-3
2	2.171	Z0012-0176	Lead Brick	Pb-B29

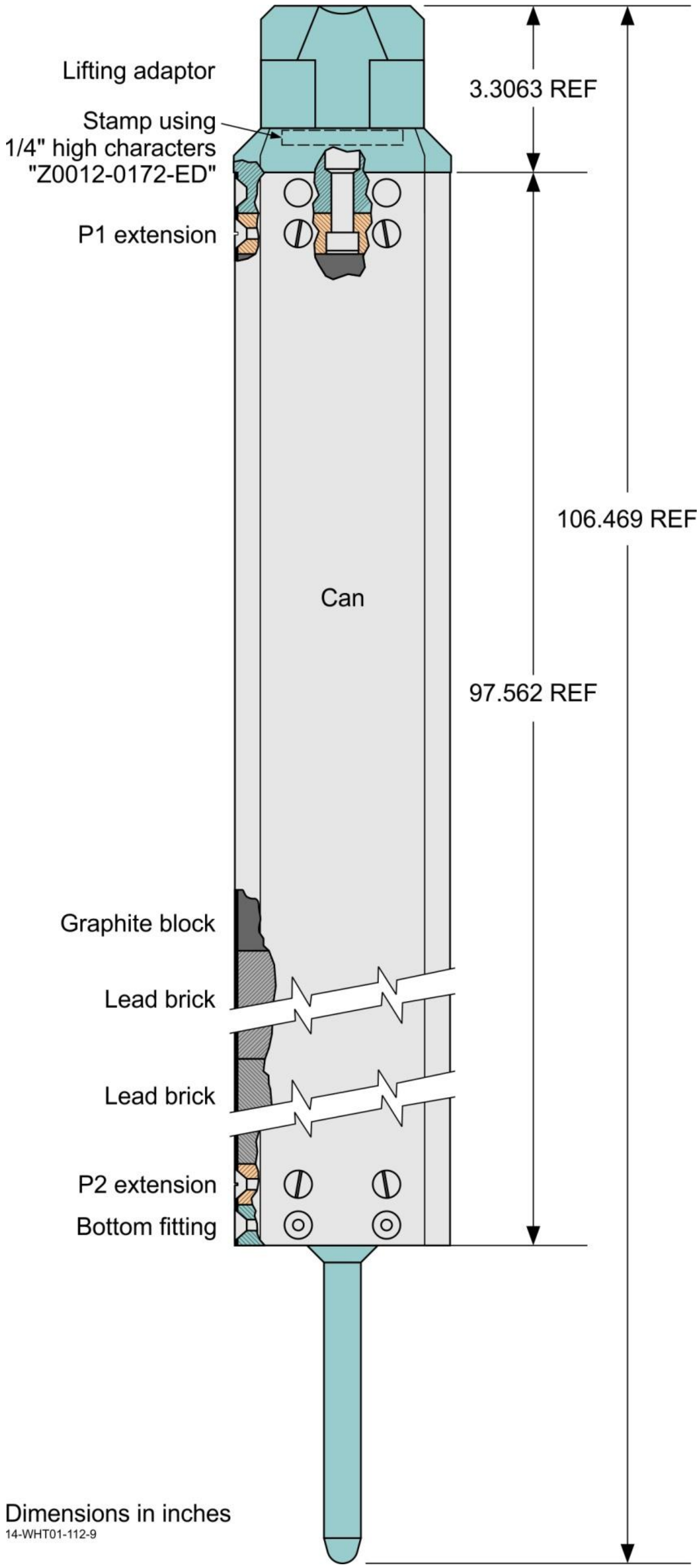


Figure 2.166. MK-III Half Element Assembly (DWG# Z0012-0172).

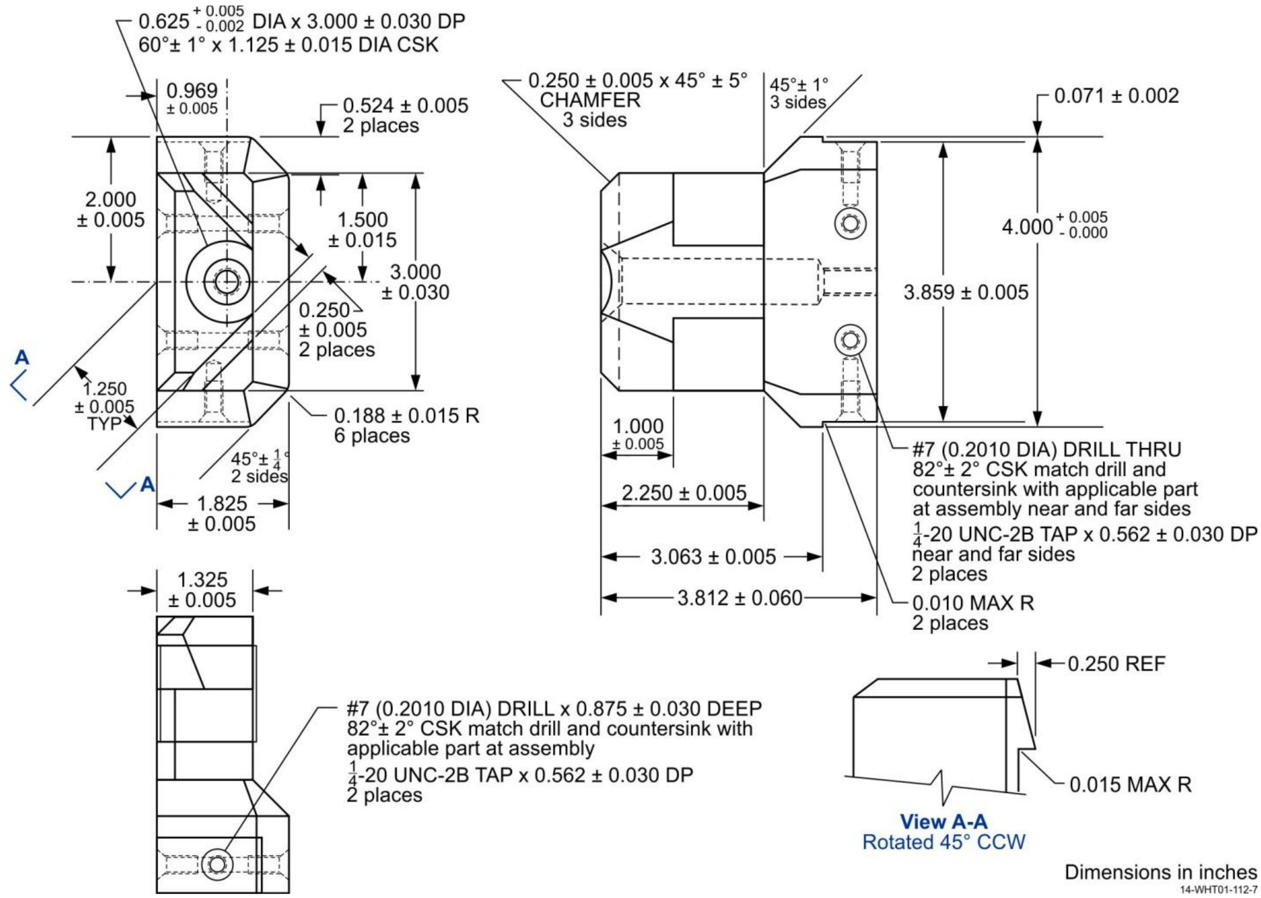


Figure 2.167. Lifting Adapter (DWG# Z0012-0174).

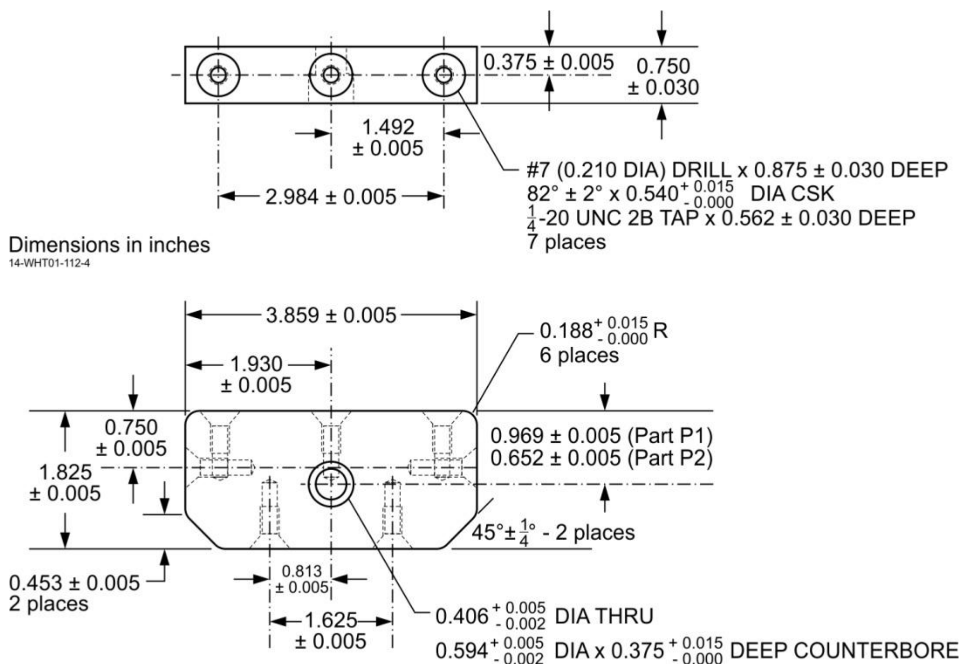


Figure 2.168. P1 & P2 Extension (DWG# Z0012-0175).

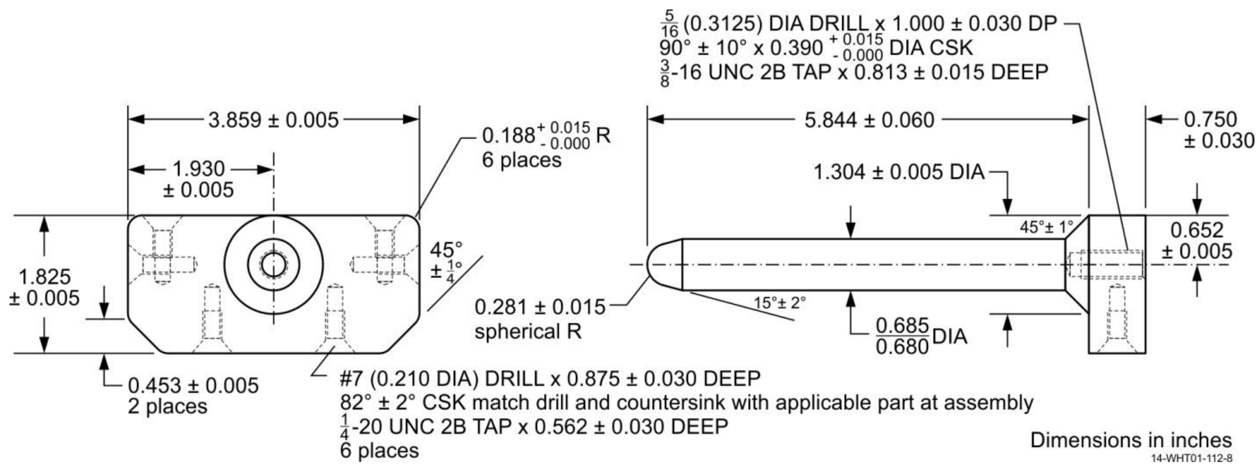


Figure 2.169. Bottom Fitting (DWG# Z0012-0177).

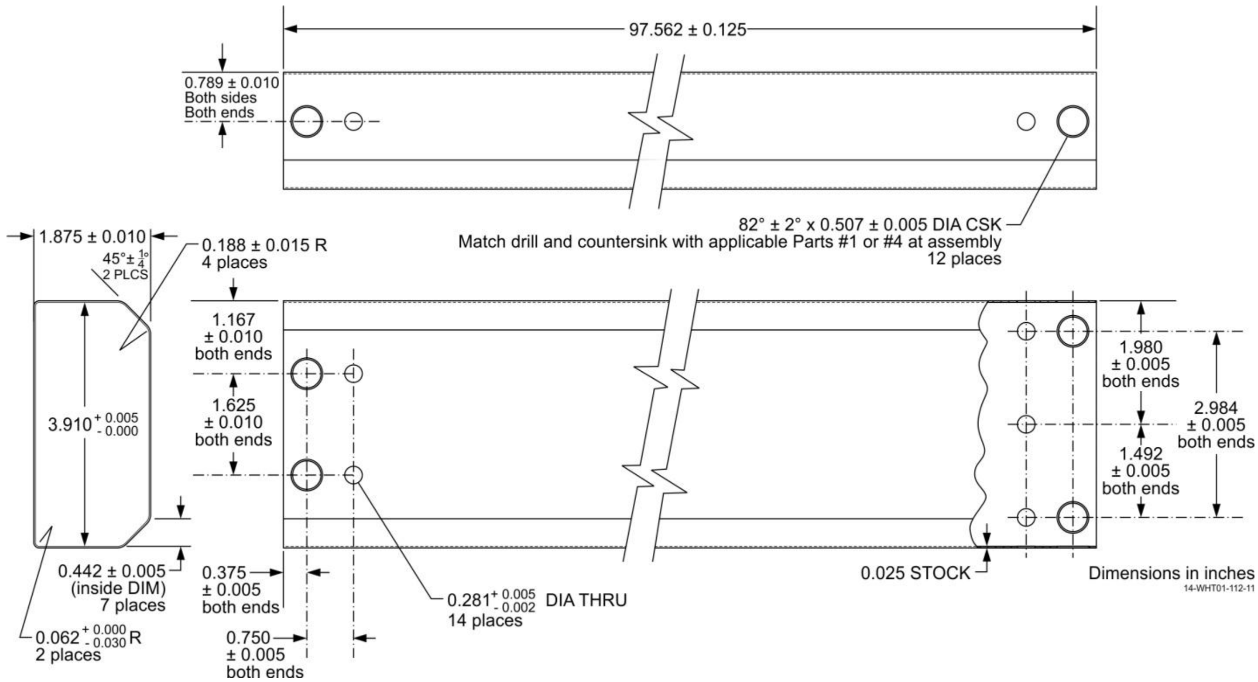


Figure 2.170. Can (DWG# Z0012-0181).

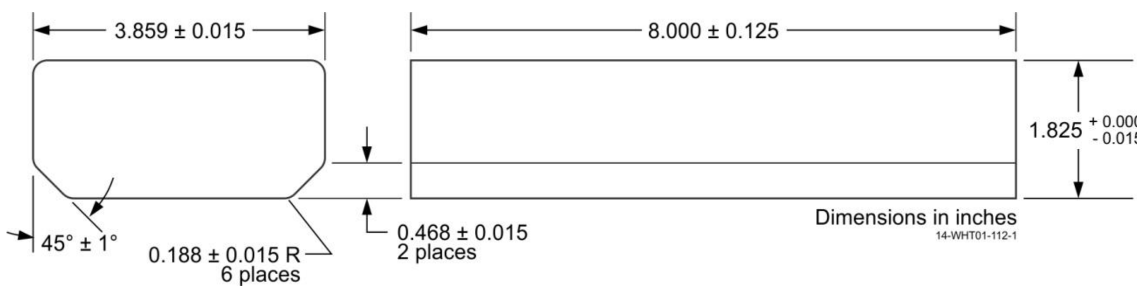


Figure 2.171. Lead Brick (DWG# Z0012-0176).

2.6.3 Control Rod Dummy Assembly

The control rod dummy assembly is a control rod fuel assembly without fuel. The assembly is shown in Figure 2.172 with a list of applicable drawings and materials provided in Table 2.15. Individual component drawings are provided in Figures 2.172 through 2.186.

Table 2.15. Control Rod Dummy Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.172	--	Control Rod Dummy Assembly	--
1	2.173	RE-1-22603	Head	Al-1100
1	2.174	RE-1-22604	Upper Long Plug	CP-2 Graphite
1	2.175	RE-1-22605	Upper Short Plug	CP-2 Graphite
1	2.176	RE-1-22606	Lower Short Plug	CP-2 Graphite
1	2.177	RE-1-22607	Lower Long Plug	CP-2 Graphite
1	2.178	RE-1-22736	End Tube Part #1	Al-6063
1	2.178	RE-1-22736	End Tube Part #2	Al-6063
1	2.179	RE-1-22608	Base	Al-1100
1	2.180	RE-1-22609	Bearing Tube	Al-1100
1	2.181	RE-1-22610	Carbon Graphite Bushing	Graphitar
1	2.182	RE-1-22611	Bushing Retainer	Al-1100
1	2.183	--	Control Rod Element Dummy Section	Zr-3
6	2.184	--	Dummy Block	CP-2 Graphite
8	2.185	RE-1-22699	Tab	Zr-3
2	2.186	RE-1-24150	Spacer	Zr-3

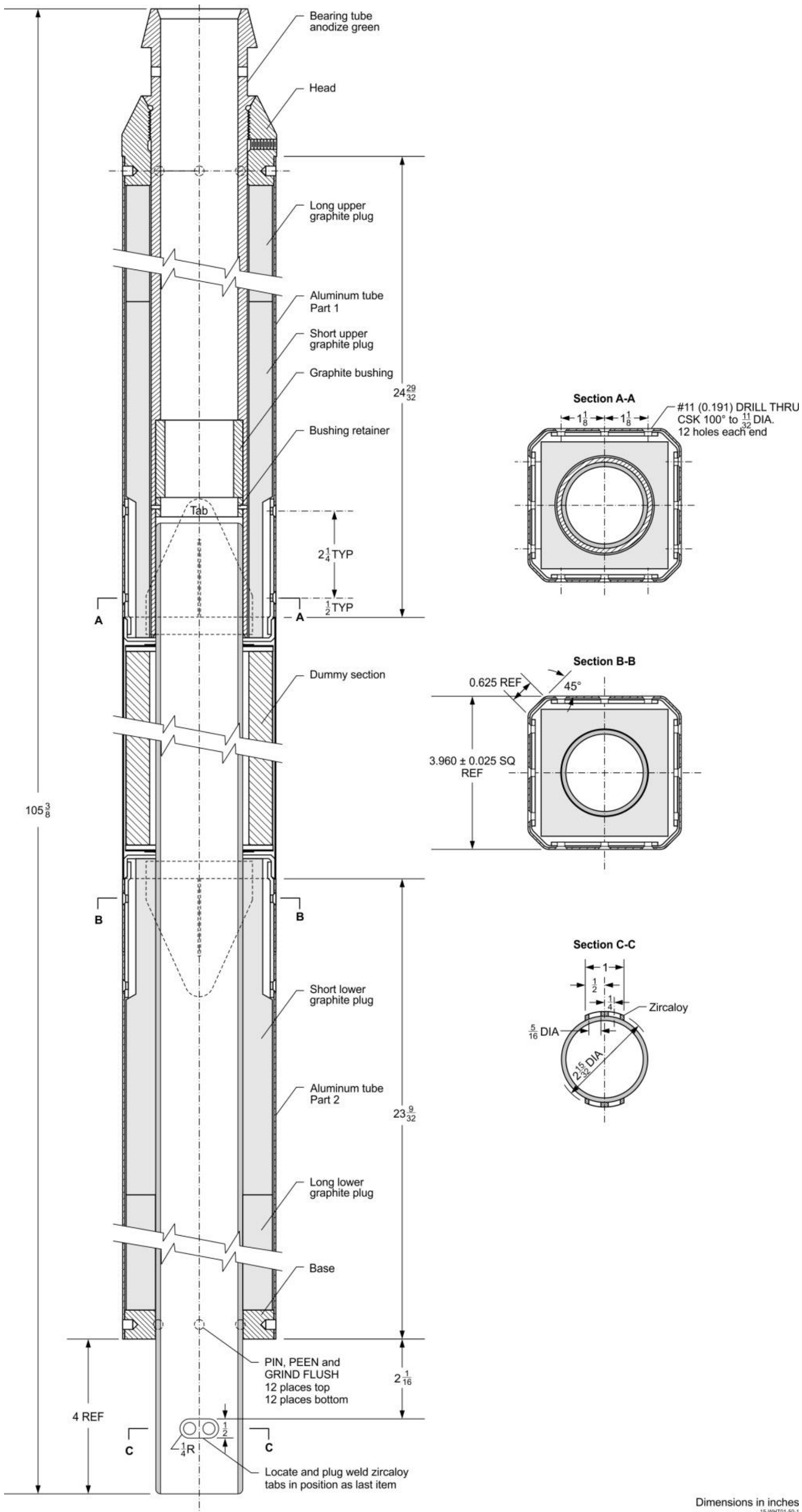


Figure 2.172. Control Rod Fuel Assembly .

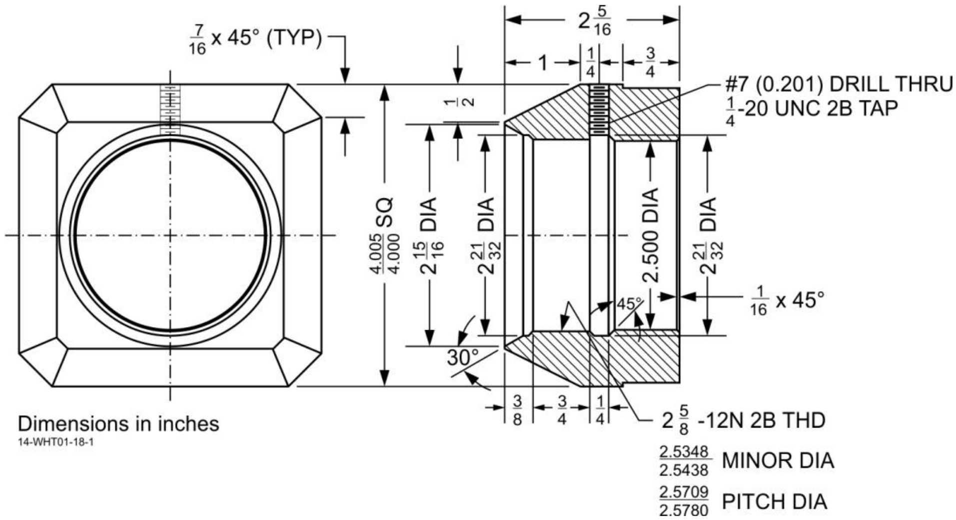


Figure 2.173. Head (DWG# RE-1-22603).

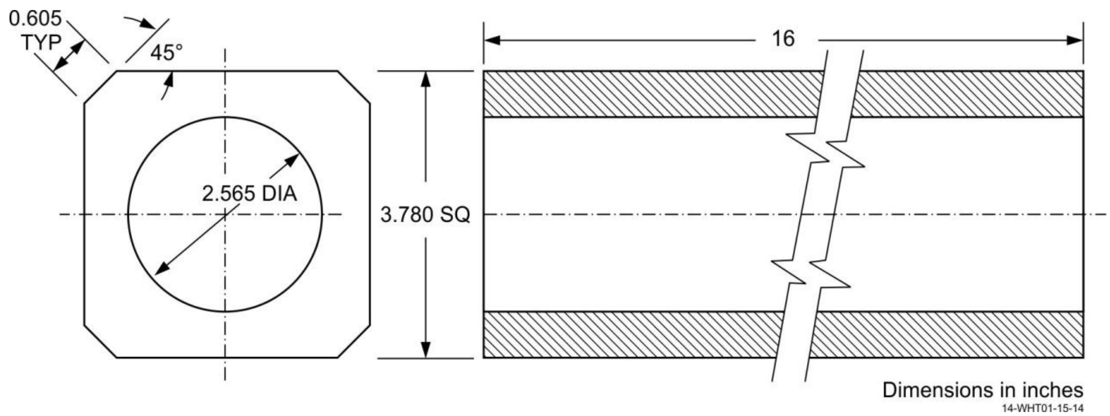


Figure 2.174. Upper Long Plug (DWG# RE-1-22604).

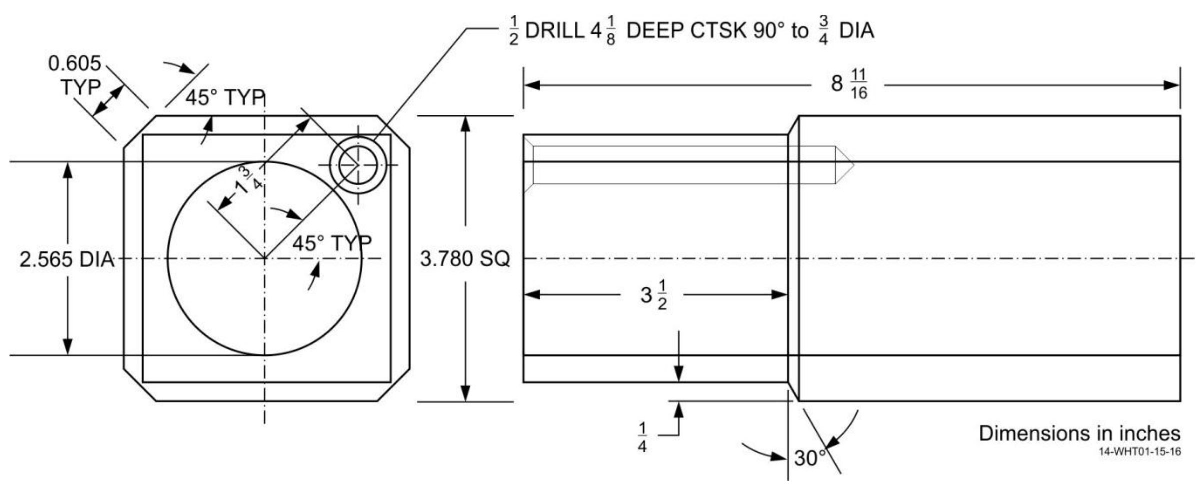


Figure 2.175. Upper Short Plug (DWG# RE-1-22605).

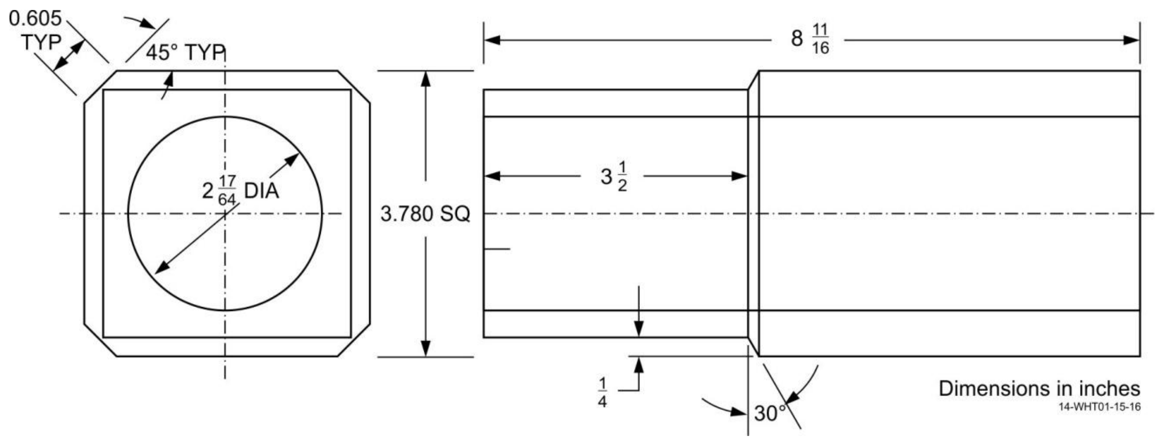


Figure 2.176. Lower Short Plug (DWG# RE-1-22606).

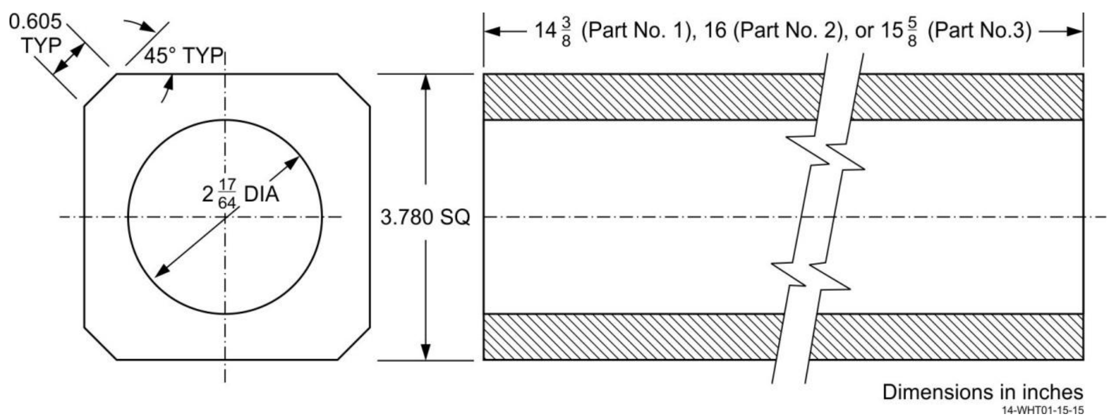


Figure 2.177. Lower Long Plug (DWG# RE-1-22607).

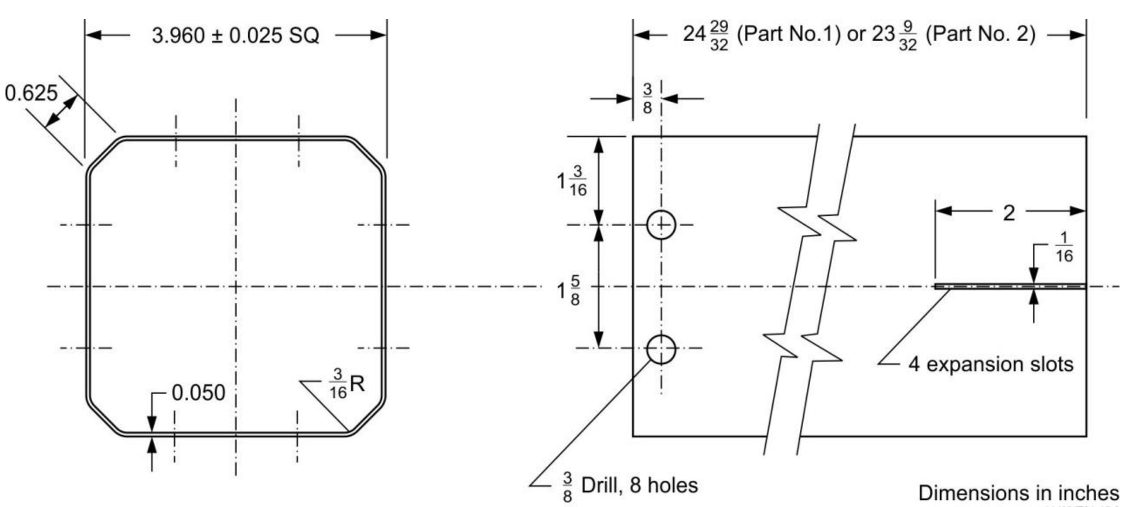


Figure 2.178. End Tube (DWG# RE-1-22736).

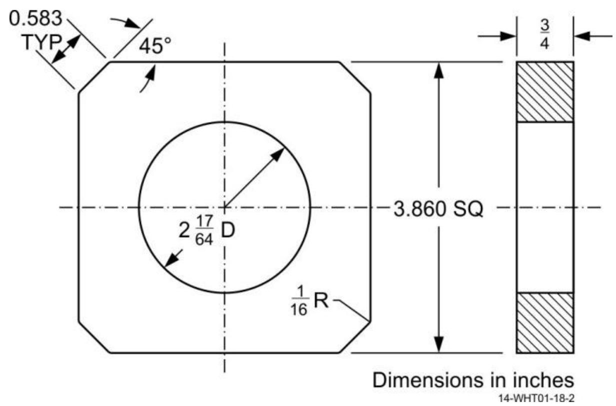


Figure 2.179. Base (DWG# RE-1-22608).

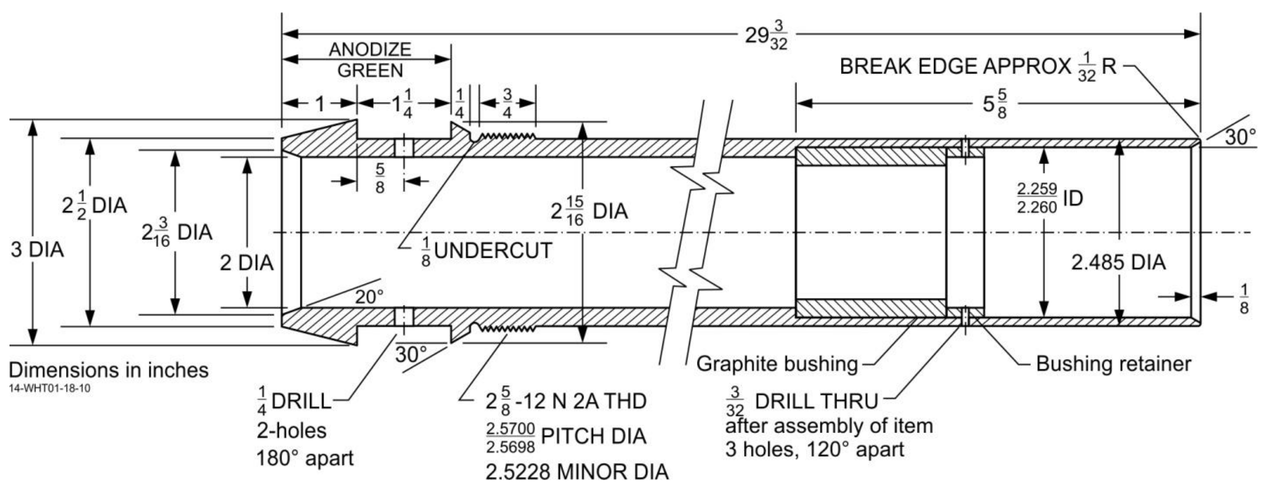


Figure 2.180. Bearing Tube (DWG# RE-1-22609).

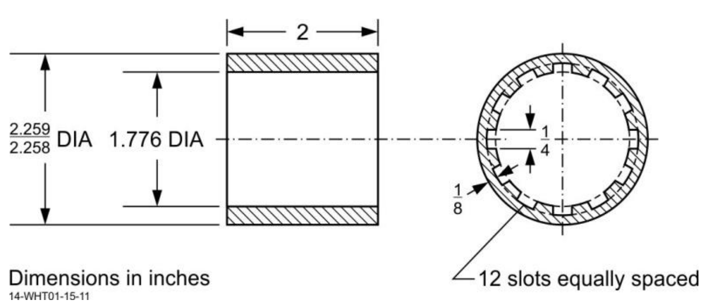


Figure 2.181. Carbon Graphite Bushing (DWG# RE-1-22610).

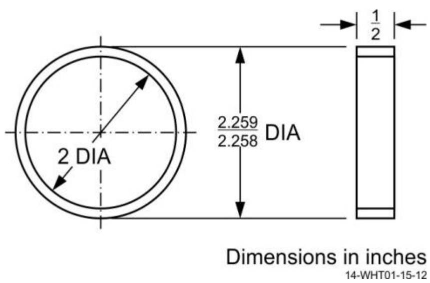


Figure 2.182. Bushing Retainer (DWG# RE-1-22611).

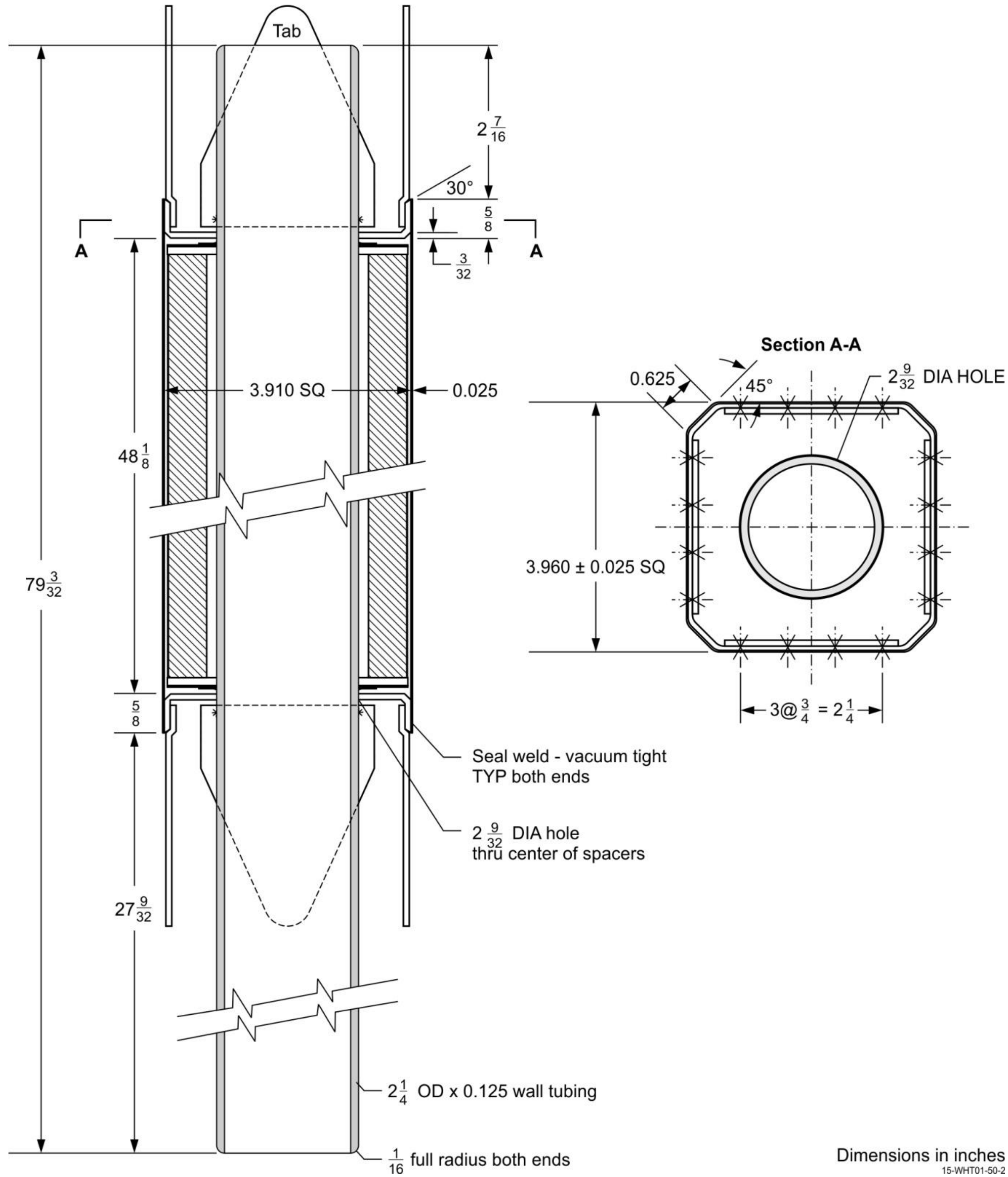


Figure 2.183. Control Rod Element Dummy Section.

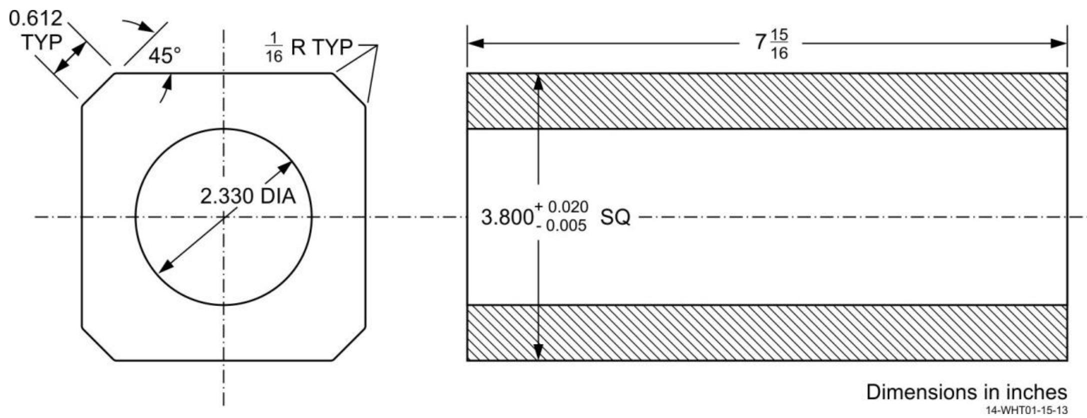


Figure 2.184. Dummy Block.

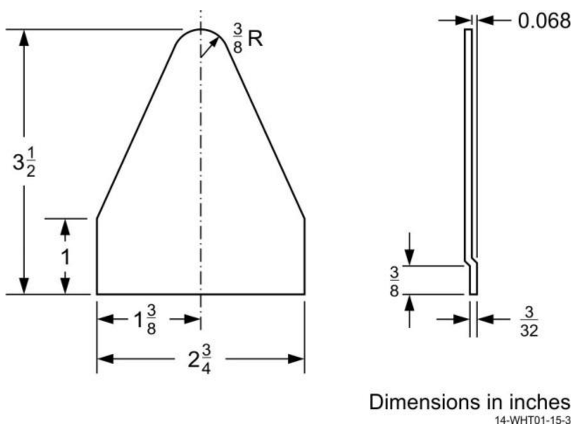


Figure 2.185. Tab (DWG# RE-1-22699).

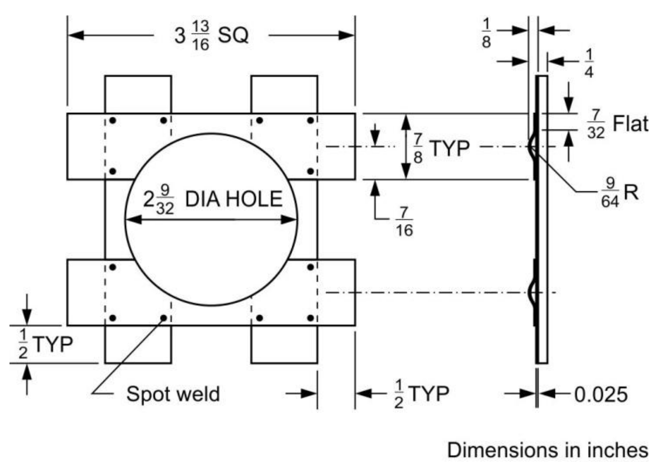


Figure 2.186. Spacer (DWG# RE-1-24150).

2.6.4 Vertical Access Hole Dummy Assembly

The vertical access hole dummy assembly is a vertical access hole fuel assembly without fuel. The assembly is shown in Figure 2.187 with a list of applicable drawings and materials provided in Table 2.16. Individual component drawings are provided in Figures 2.187 through 2.199.

Table 2.16. Vertical Access Hole Dummy Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.187	--	Vertical Access Hole Dummy Assembly	--
1	2.188	RE-1-22603	Head	Al-1100
1	2.189	RE-1-22604	Upper Long Plug	CP-2 Graphite
1	2.190	RE-1-22605	Upper Short Plug	CP-2 Graphite
1	2.191	RE-1-22606	Lower Short Plug	CP-2 Graphite
1	2.192	RE-1-22607	Lower Long Plug	CP-2 Graphite
1	2.193	RE-1-22736	End Tube Part #1	Al-6063
1	2.193	RE-1-22736	End Tube Part #2	Al-6063
1	2.194	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.195	RE-1-22610	Bearing Tube	Al-1100
1	2.196	--	Vertical Access Element Dummy Section	Zr-3
6	2.197	--	Dummy Block	CP-2 Graphite
8	2.198	RE-1-22699	Tab	Zr-3
2	2.199	RE-1-24150	Spacer	Zr-3

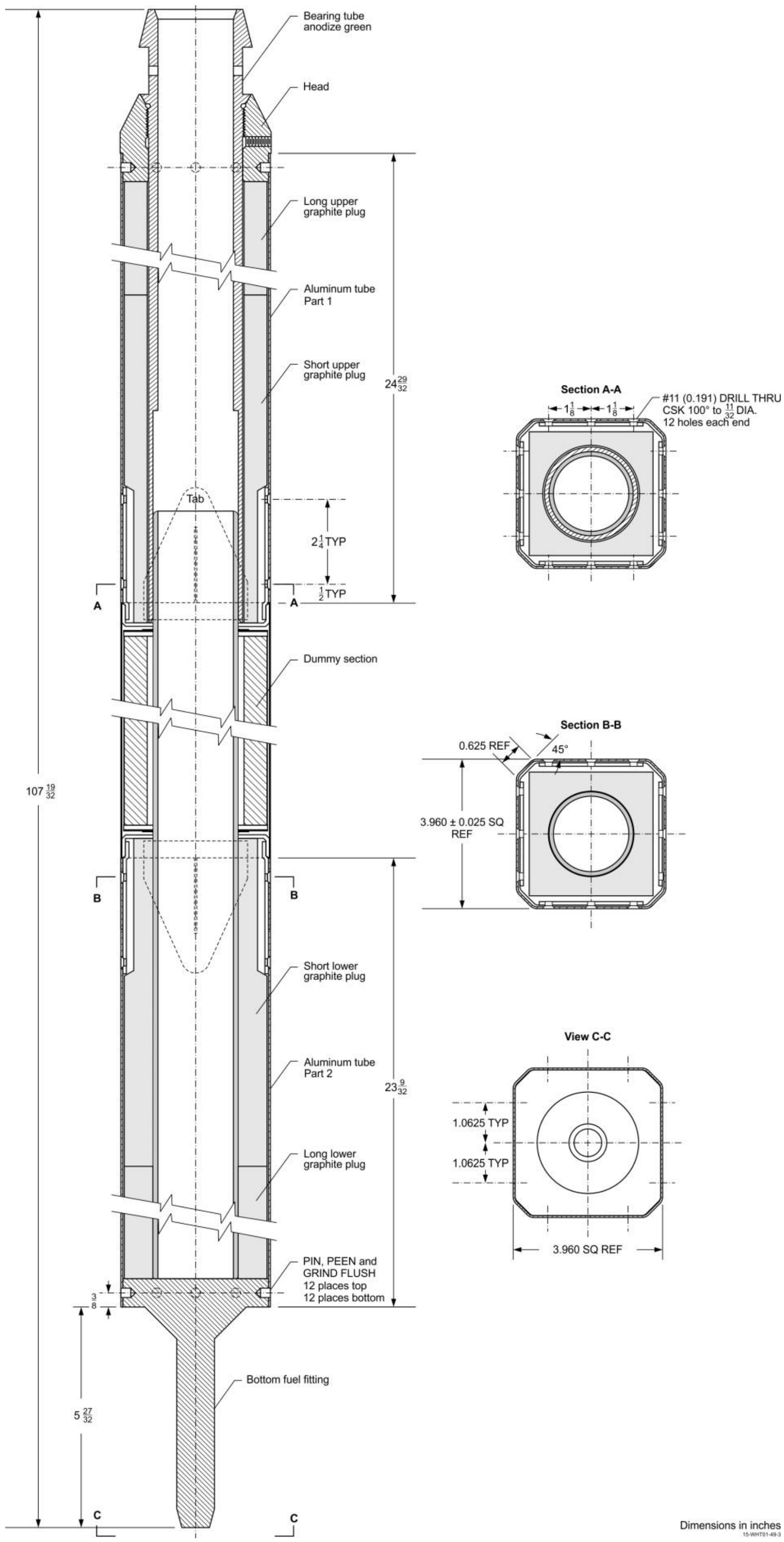


Figure 2.187. Vertical Access Hole Dummy Assembly.

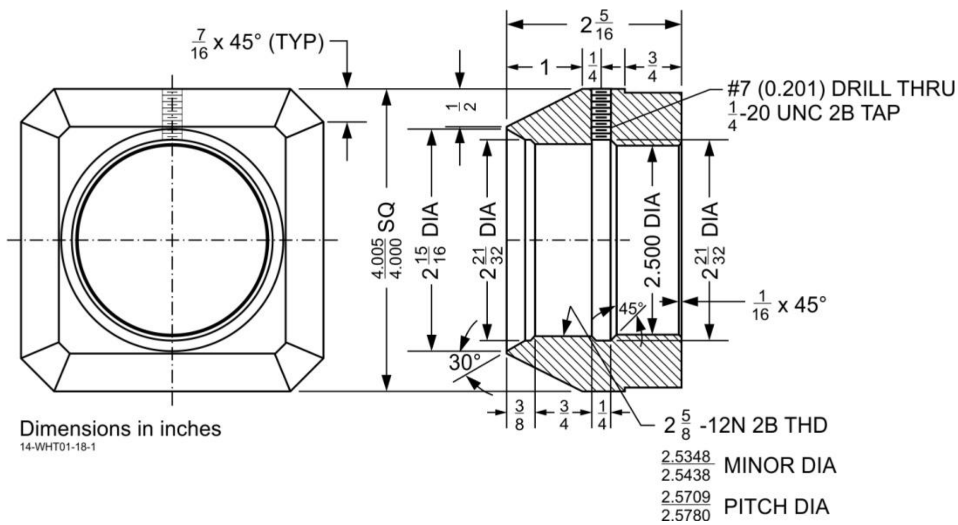


Figure 2.188. Head (DWG# RE-1-22603).

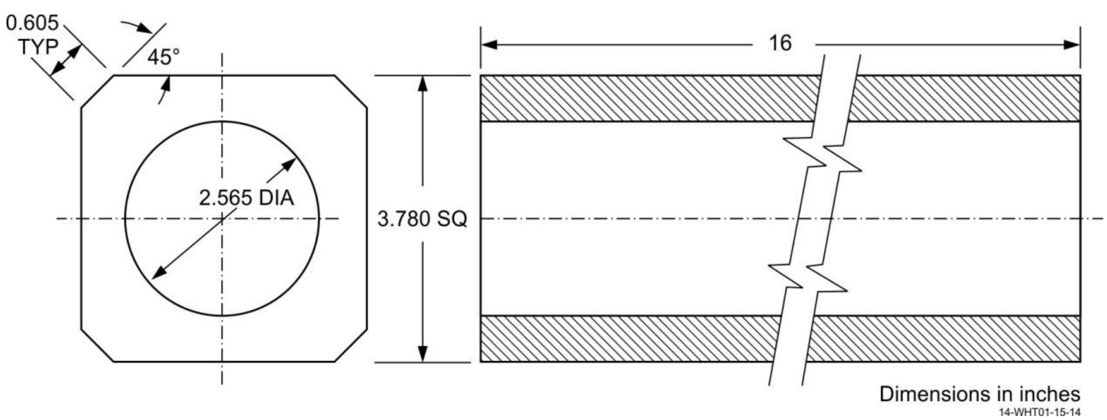


Figure 2.189. Upper Long Plug (DWG# RE-1-22604).

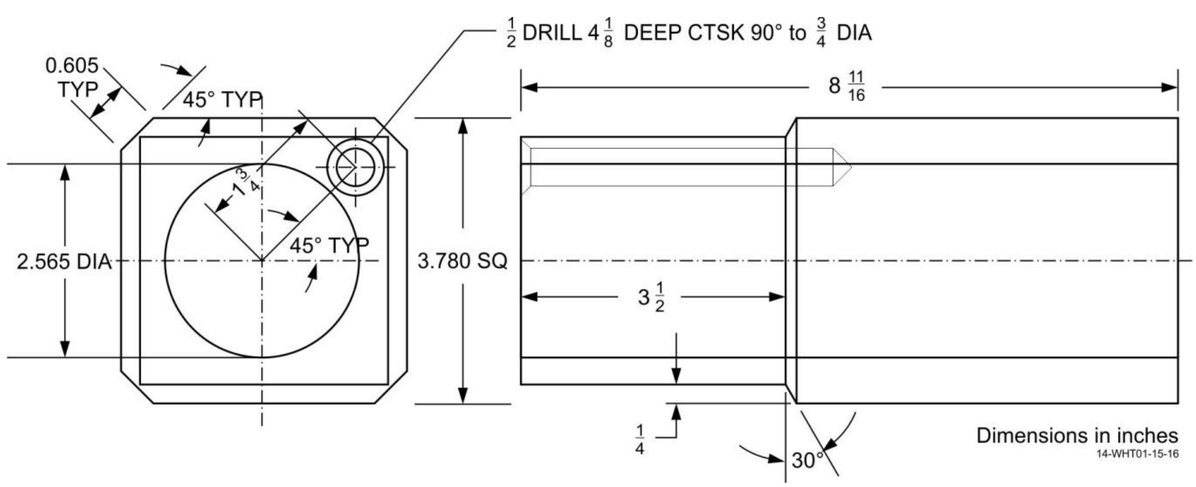


Figure 2.190. Upper Short Plug (DWG# RE-1-22605).

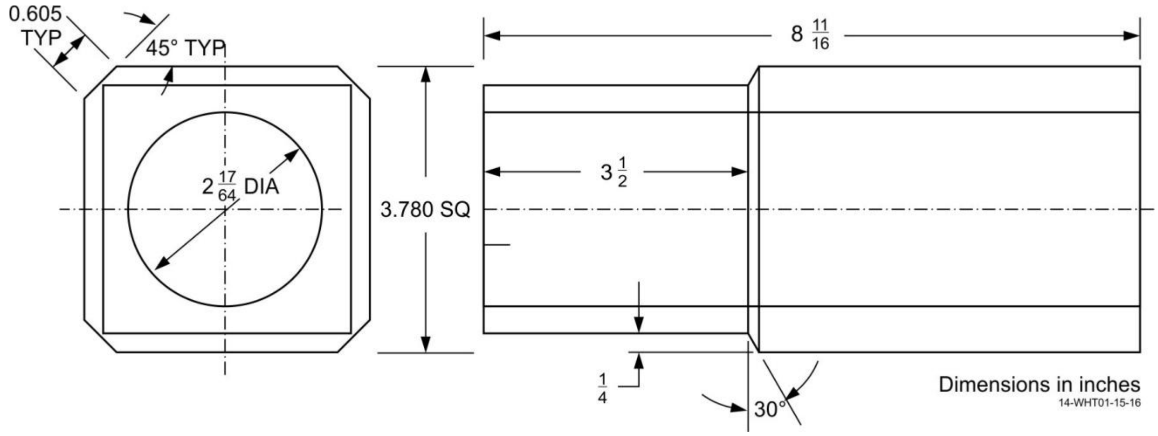


Figure 2.191. Lower Short Plug (DWG# RE-1-22606).

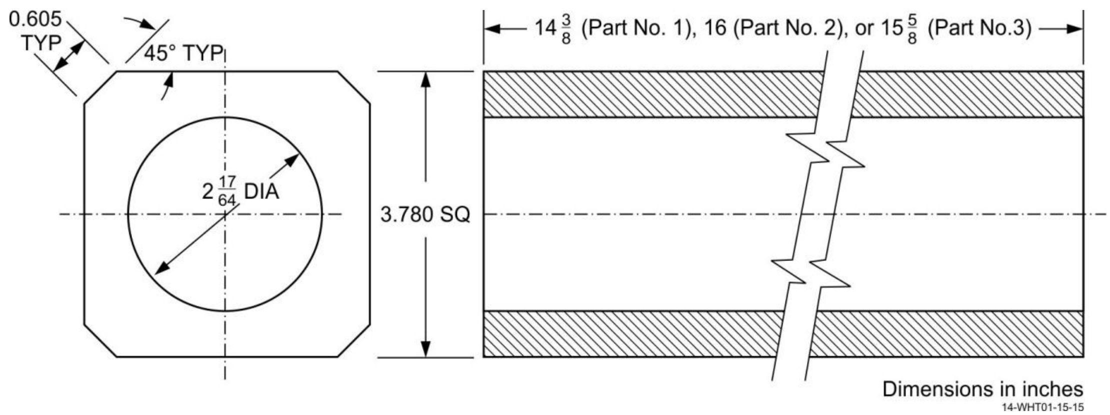


Figure 2.192. Lower Long Plug (DWG# RE-1-22607).

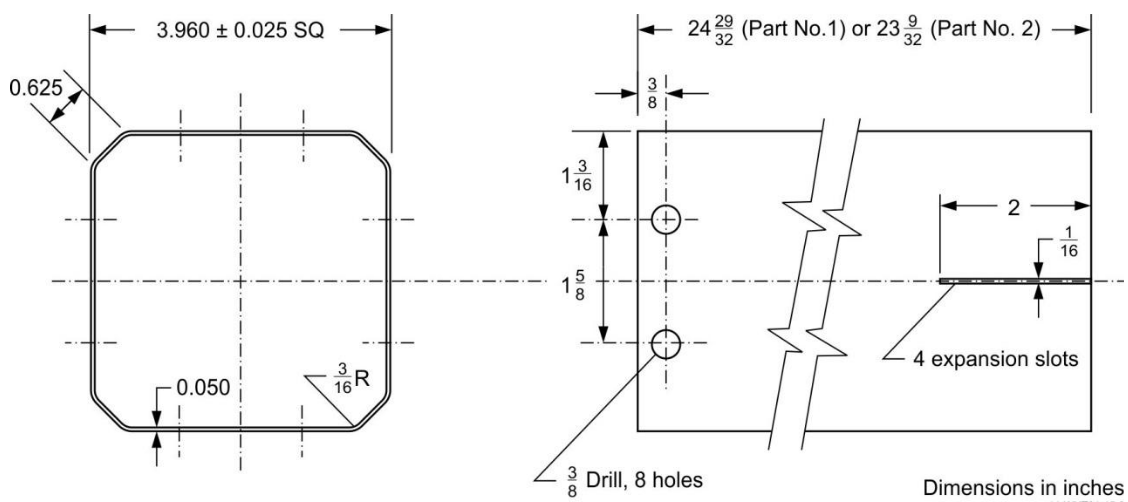


Figure 2.193. End Tube (DWG# RE-1-22736).

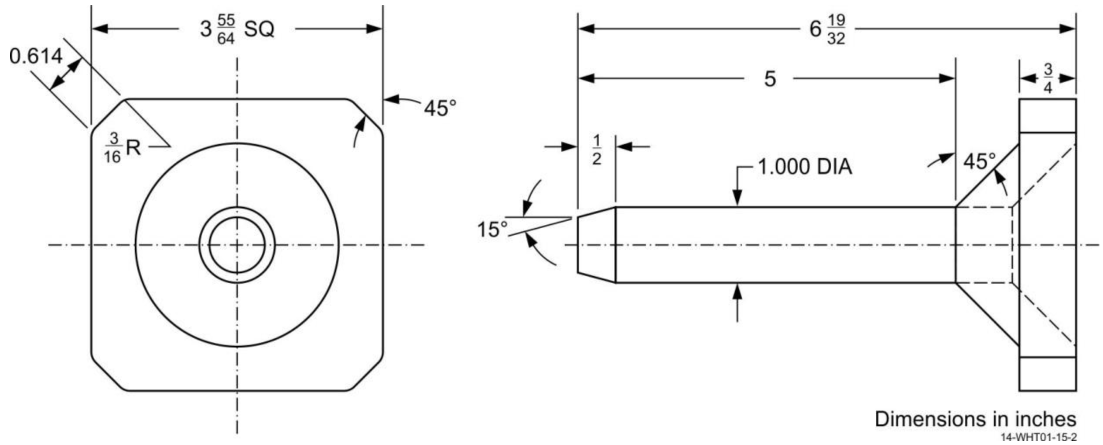


Figure 2.194. Bottom Fuel Fitting (DWG# RE-1-21881).

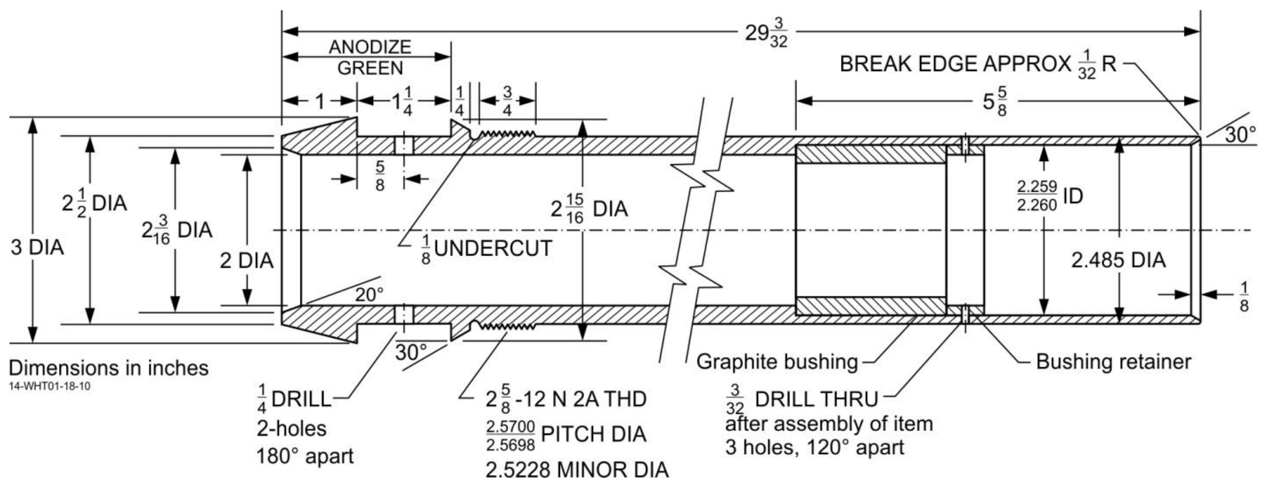


Figure 2.195. Bearing Tube (DWG# RE-1-22609).

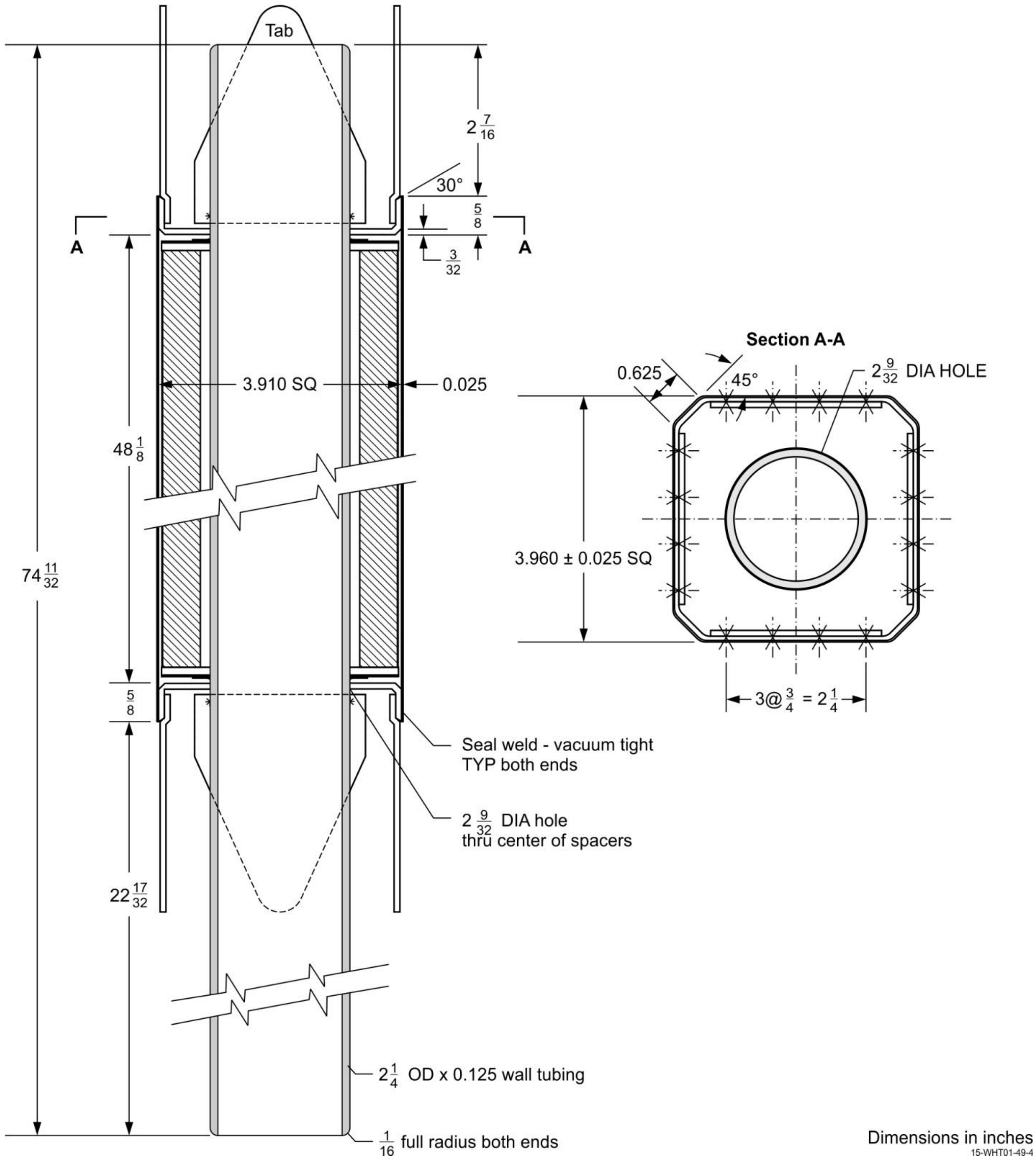


Figure 2.196. Vertical Access Element Dummy Section.

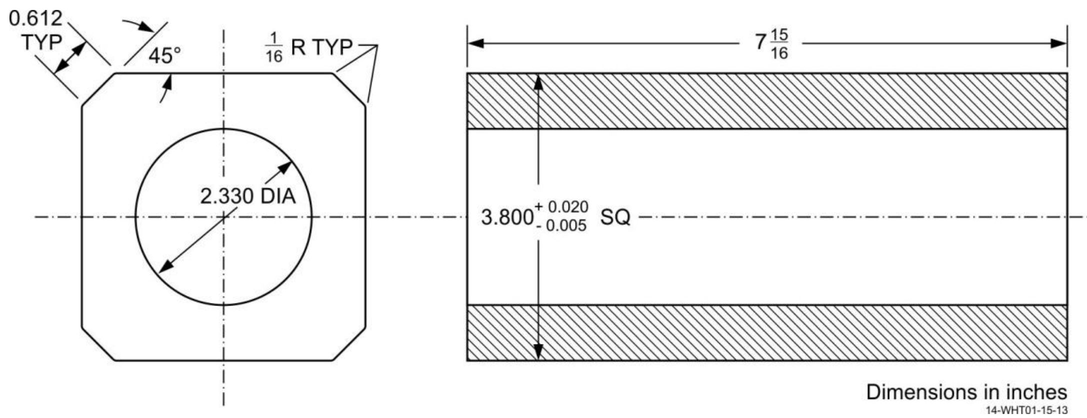


Figure 2.197. Dummy Block.

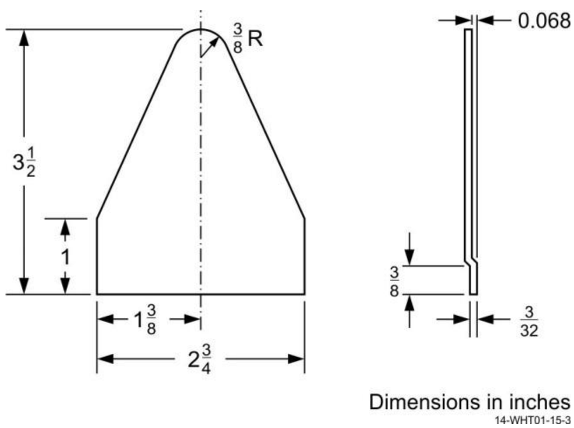


Figure 2.198. Tab (DWG# RE-1-22699).

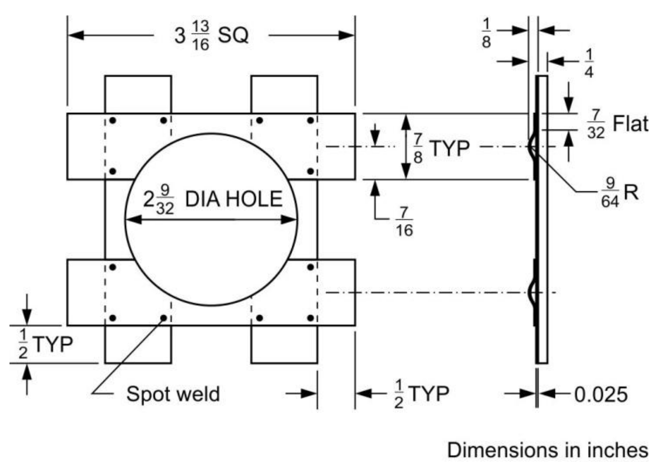


Figure 2.199. Spacer (DWG# RE-1-24150).

2.6.5 Access Hole (24-inch) Dummy Assembly

The access hole (24-inch) dummy assembly is a access hole (24-inch) fuel assembly without fuel. The assembly is shown in Figure 2.200 with a list of applicable drawings and materials provided in Table 2.17. Individual component drawings are provided in Figures 2.200 through 2.215.

Table 2.17. Access Hole (24-inch) Dummy Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.200	RE-1-22706	Access Dummy Hole Fuel Assembly	--
1	2.201	RE-1-21880	Top Fuel Fitting	Al-1100
1	2.202	RE-1-21768	Long Plug Part #1	CP-2 Graphite
1	2.202	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.203	RE-1-22736	End Tube Part #1	Al-6063
1	2.203	RE-1-22736	End Tube Part #2	Al-6063
2	2.204	RE-1-22739	Short Plain Plug	CP-2 Graphite
1	2.205	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.206	RE-1-21709	Access Hole Dummy Fuel Section	Zr-3
2	2.207	RE-1-21741	Dummy Fuel Block Part #1	CP-2 Graphite
2	2.207	RE-1-21741	Dummy Fuel Block Part #2	CP-2 Graphite
8	2.208	RE-1-22699	Tab	Zr-3
2	2.209	RE-1-24160	Spacer	Zr-3
4	2.210	RE-1-24660	Anchor Tab	Zr-3
2	2.211	RE-1-24659	Side Frame	Zr-3
2	2.212	RE-1-24661	Guide	Zr-3
1	2.213	Z0012-0314 to -316	Fuel Identification Tag	Al-6061
--	--	--	Optional Additional Parts	--
1	2.214	RE-1-22706	Access Hole Roller Dummy Assembly	--
1	2.215	ID-IC-13441	Access Hole Roller Assembly	--
1	2.215	ID-IC-13442	Housing	Mild Steel
2	2.215	ID-IC-13443	Roller	Mild Steel
2	2.215	ID-IC-13444	Pin	Brass B16

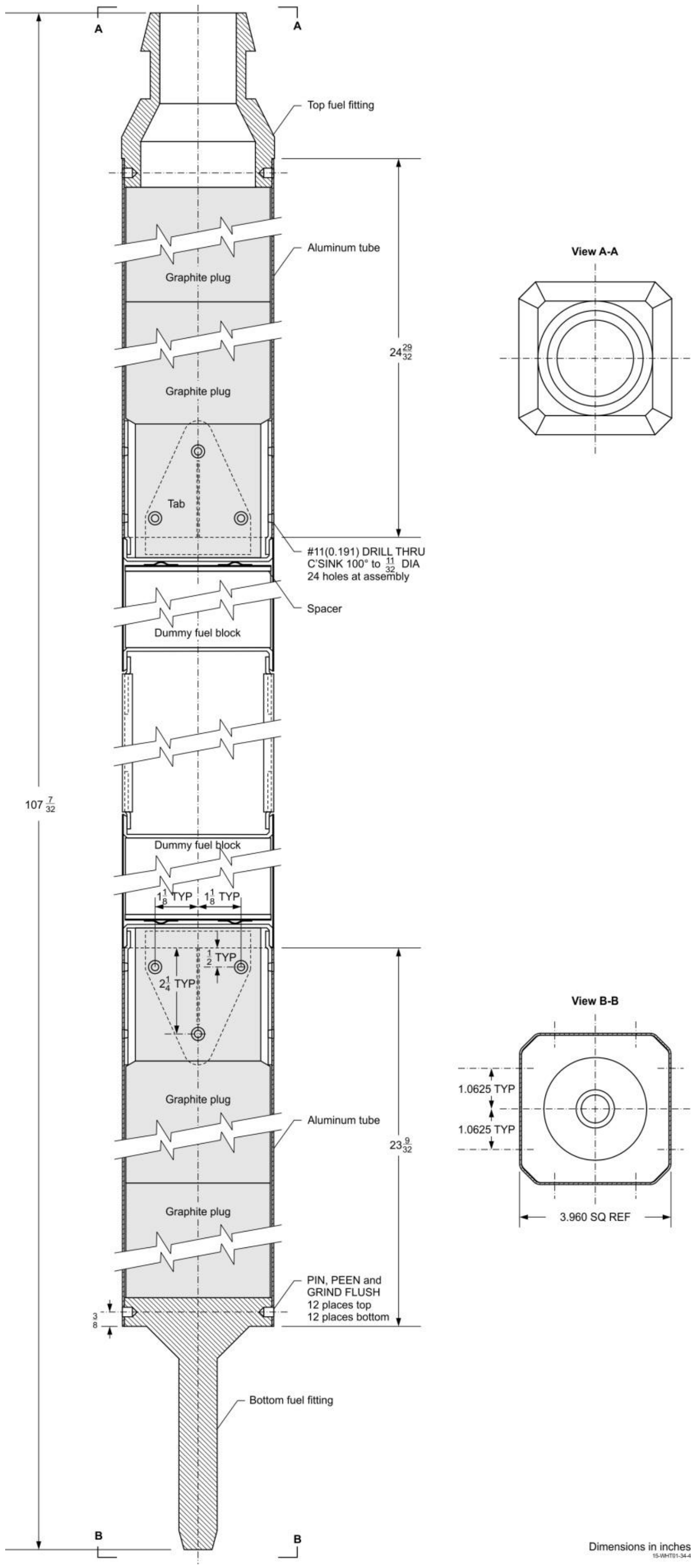


Figure 2.200. Access Hole Dummy Assembly (DWG# RE-1-22706).

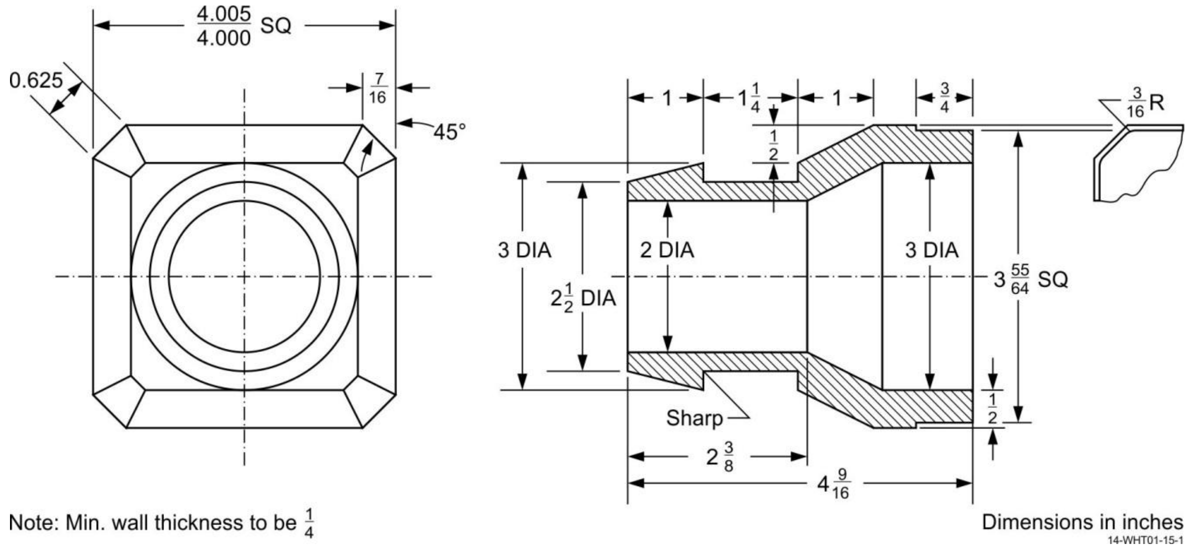


Figure 2.201. Top Fuel Fitting (DWG# RE-1-21880).

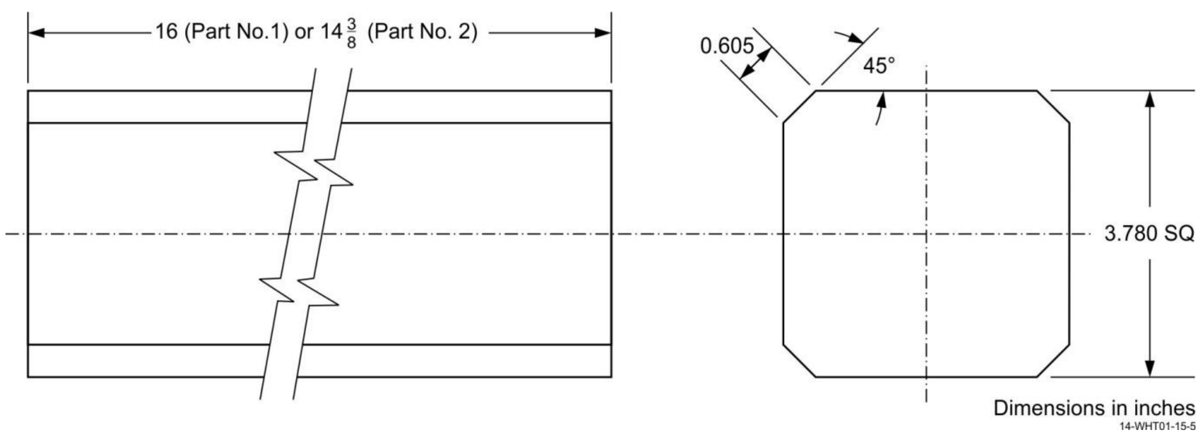


Figure 2.202. Long Plug (DWG# RE-1-21768).

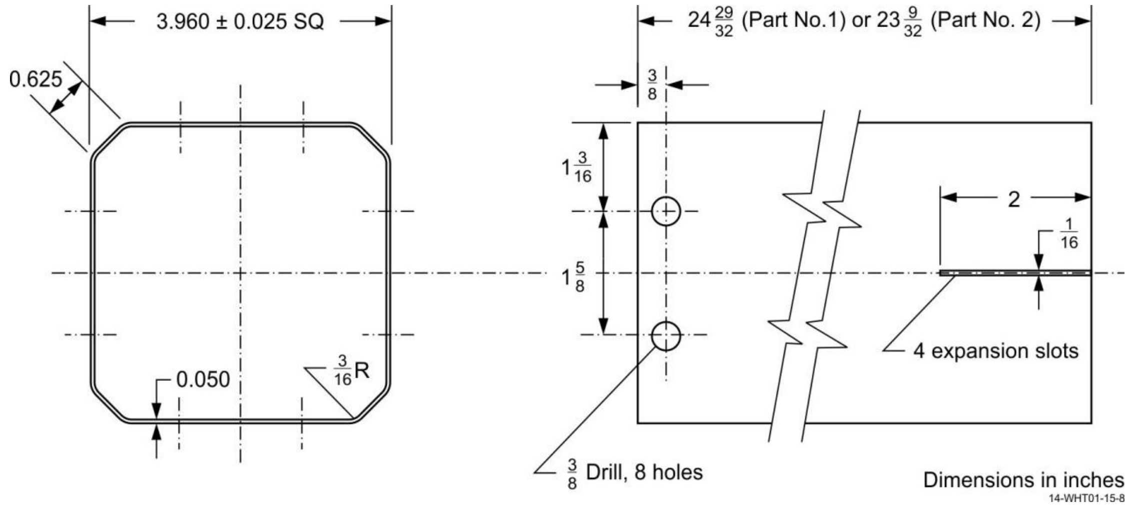


Figure 2.203. End Tube (DWG# RE-1-22736).

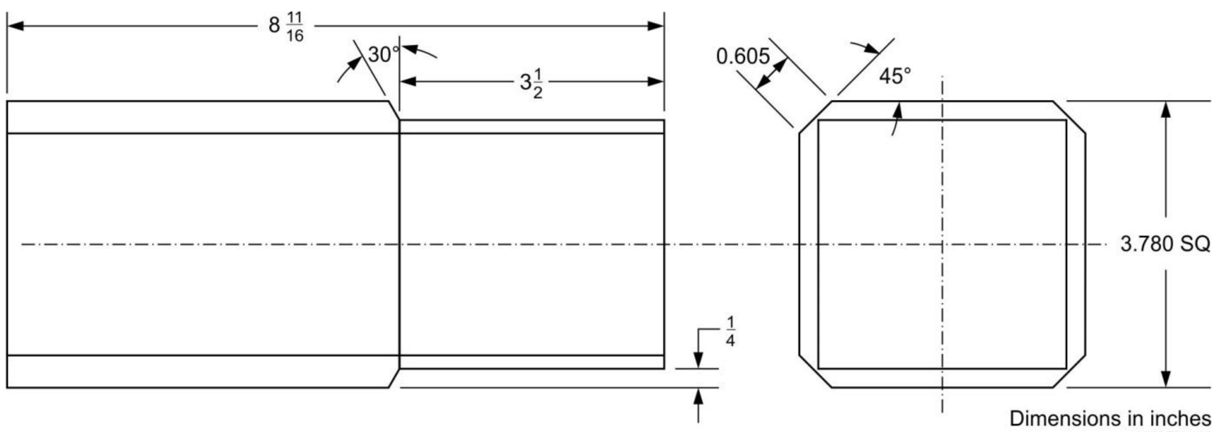


Figure 2.204. Short Plug (DWG# RE-1-21739).

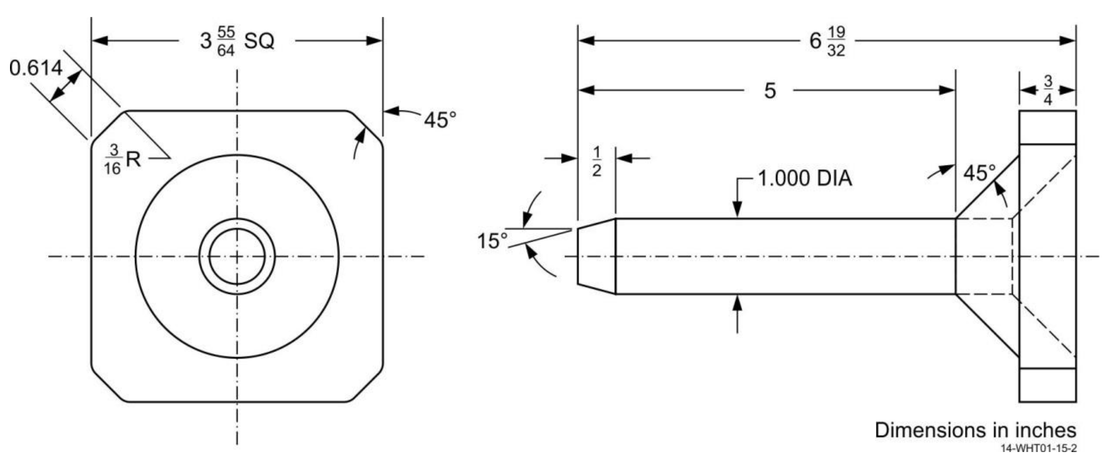


Figure 2.205. Bottom Fuel Fitting (DWG# RE-1-21881).

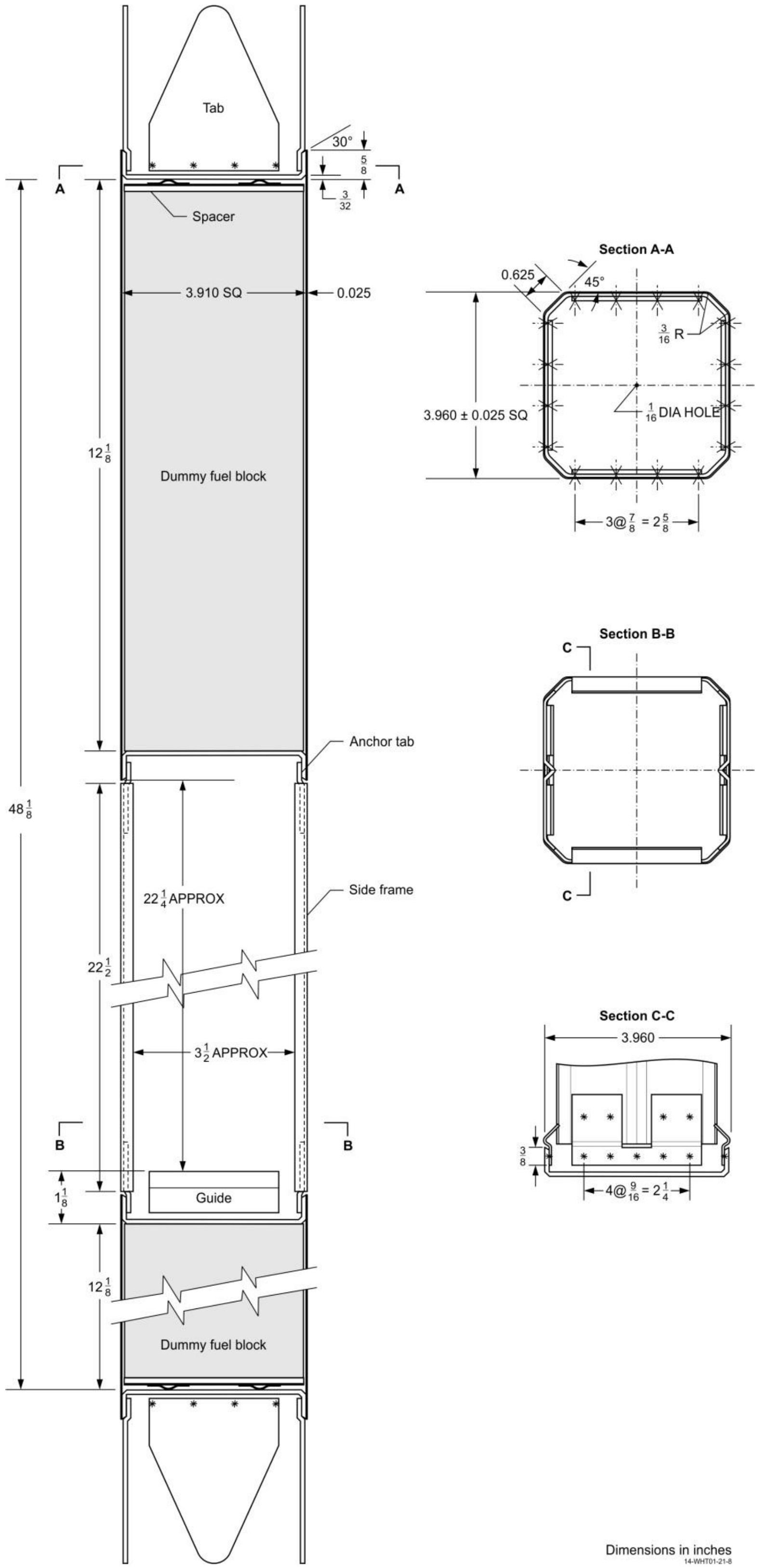


Figure 2.206. Access Hole Dummy Section (DWG# RE-1-21709).

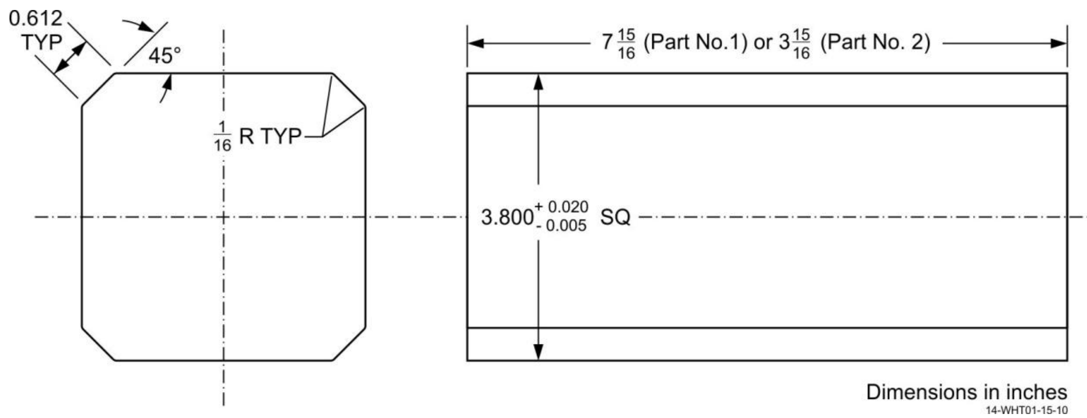


Figure 2.207. Dummy Block (DWG# RE-1-21741).

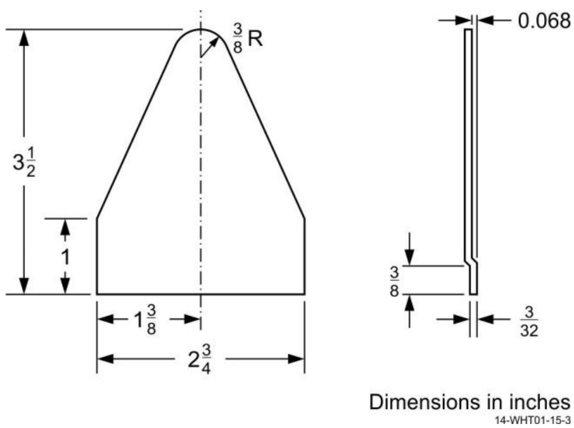


Figure 2.208. Tab (DWG# RE-1-22699).

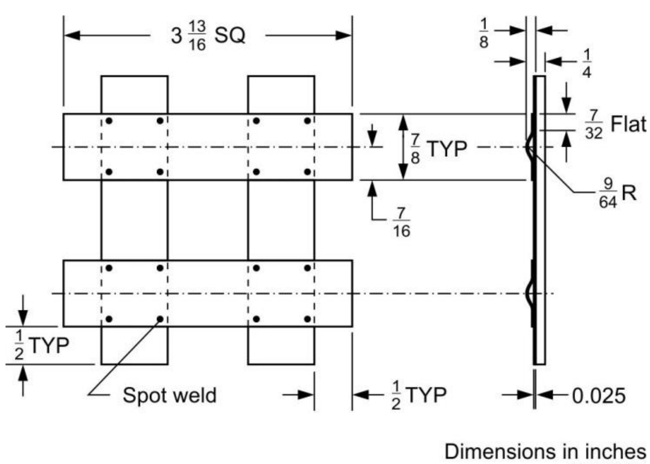


Figure 2.209. Spacer (DWG# RE-1-24160).

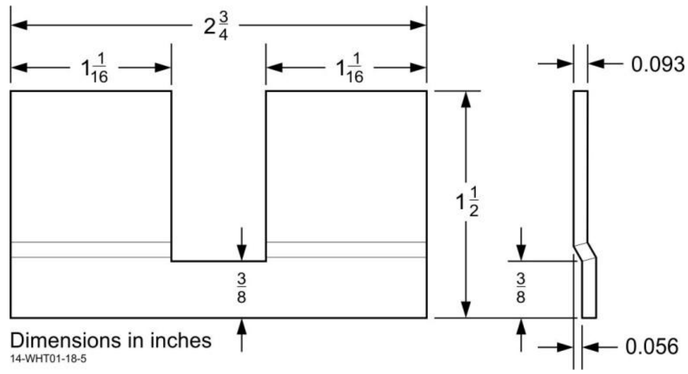


Figure 2.210. Anchor Tab (DWG# RE-1-24660).

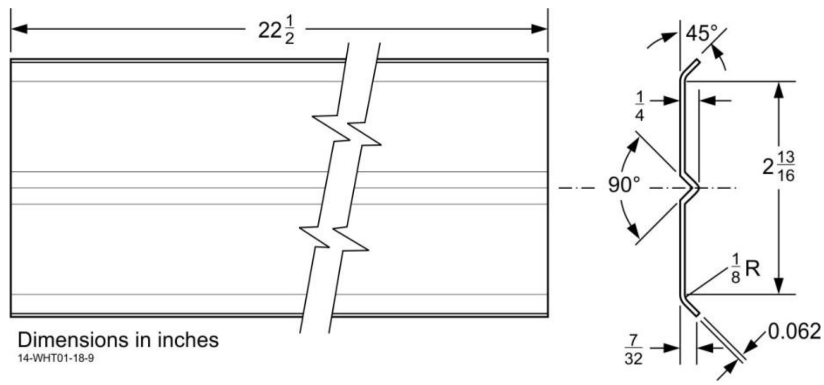


Figure 2.211. Side Frame (DWG# RE-1-24659).

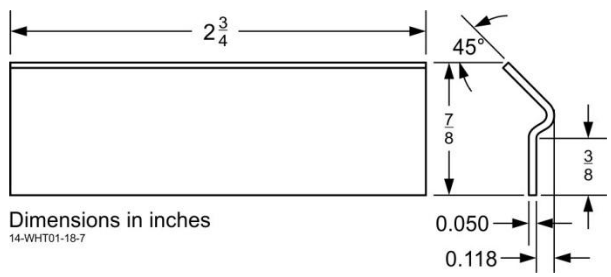


Figure 2.212. Guide (DWG# RE-1-24661).

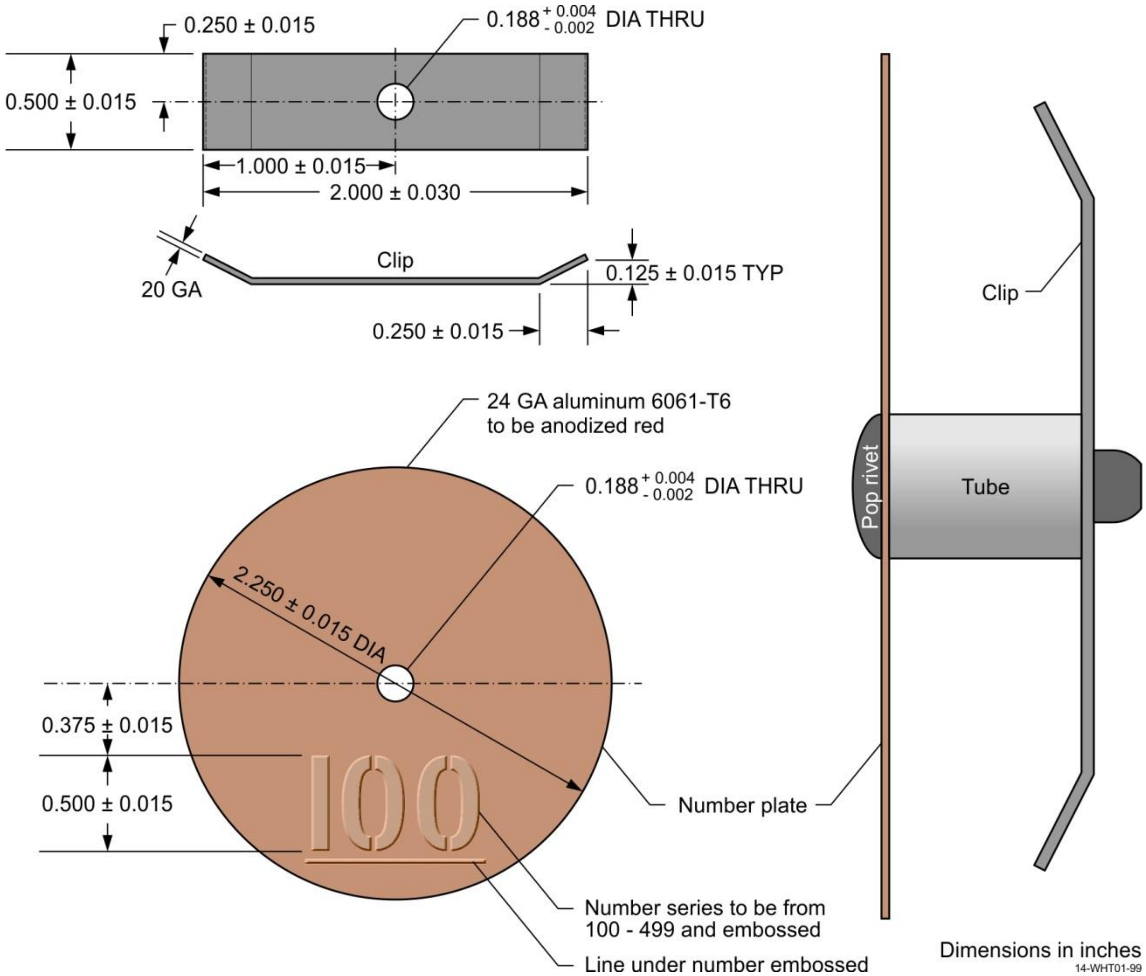


Figure 2.213. Fuel Identification Tag (DWG# Z0012-0314 through -0316).

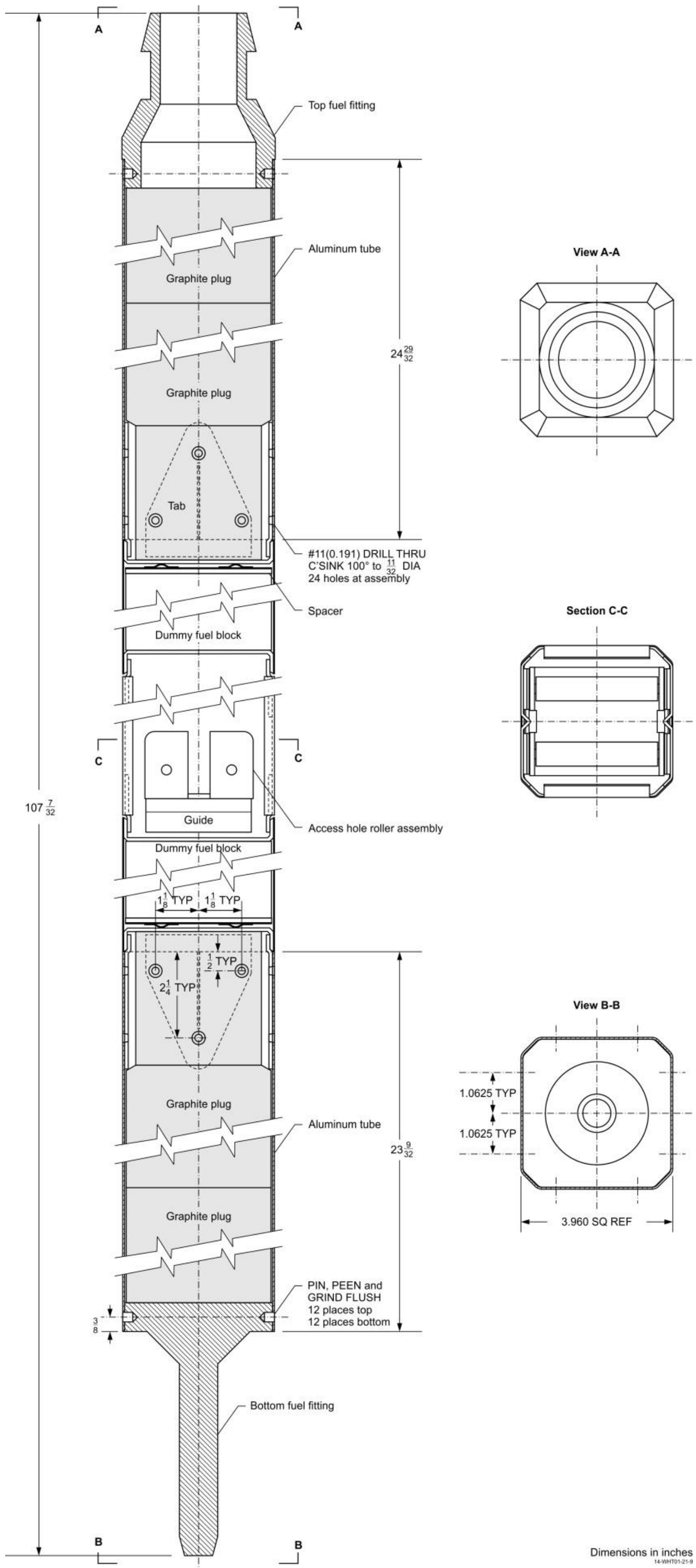


Figure 2.214. Access Hole Roller Dummy Assembly (DWG# RE-1-22706).

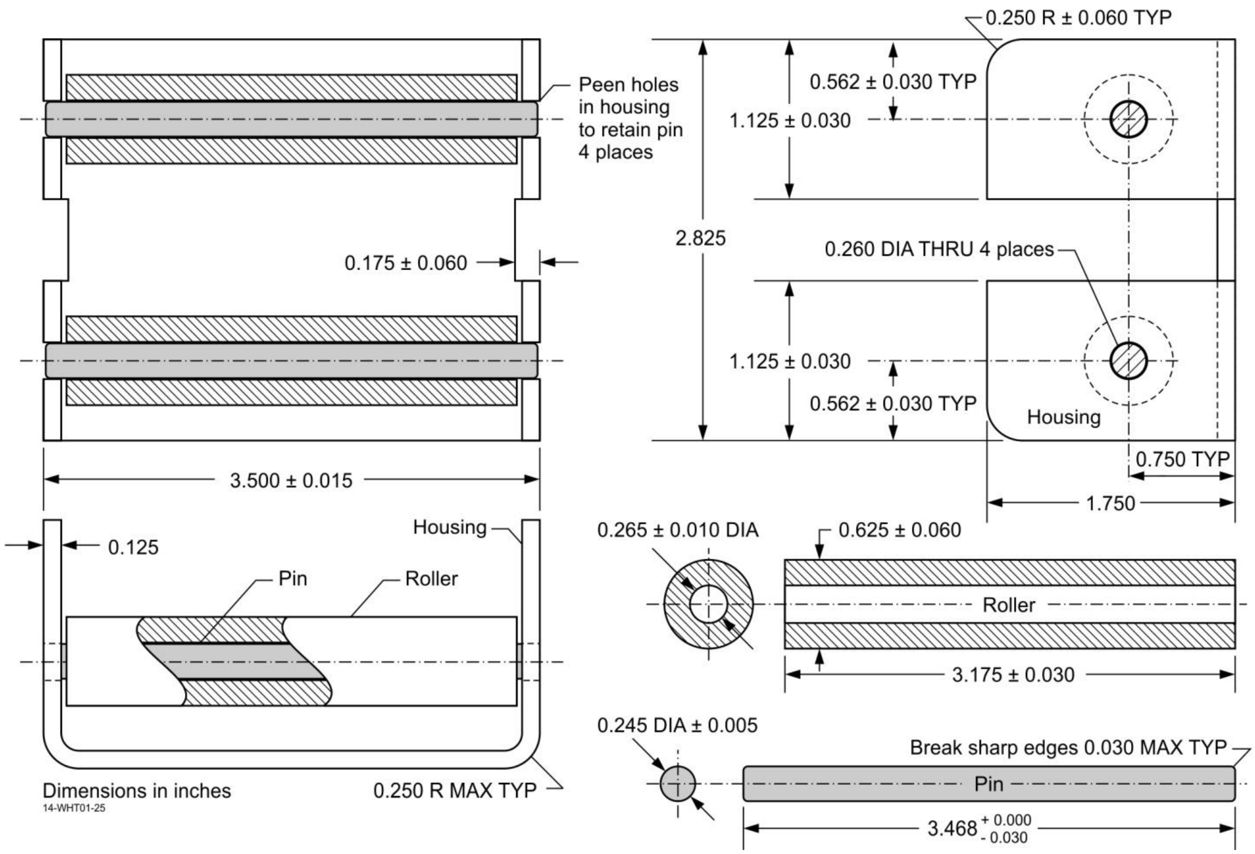


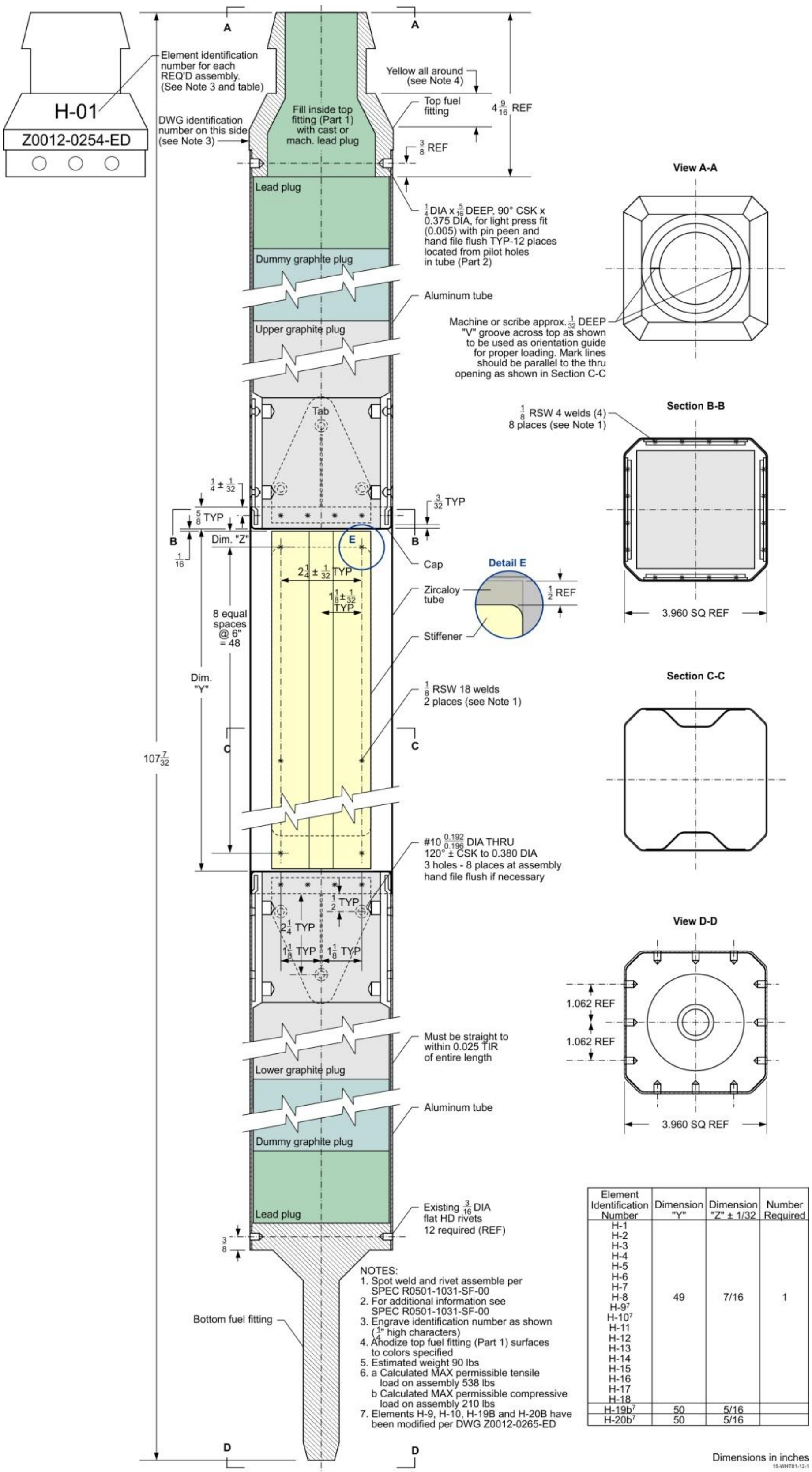
Figure 2.215. Fuel Identification Tag (DWG# ID-IC-13441 through -13444).

2.6.6 Access Hole (48- and 49-inch) Dummy Assemblies

The access hole (28- and 49-inch) dummy assemblies are very similar to their 24-inch counterparts. These assemblies provide a larger access hole, or slot, between the experiment and the hodoscope. The entire 4-foot section of the fueled region found in standard fuel assemblies is absent and only some zircaloy support structure remains to separate the upper and lower graphite reflectors. These assemblies were fabricated later than the original TREAT assemblies although many similarities in construction still exist. The assembly is shown in Figures 2.216 and 2.217 with a list of applicable drawings and materials provided in Table 2.18. Individual component drawings are provided in Figures 2.216 through 2.231.

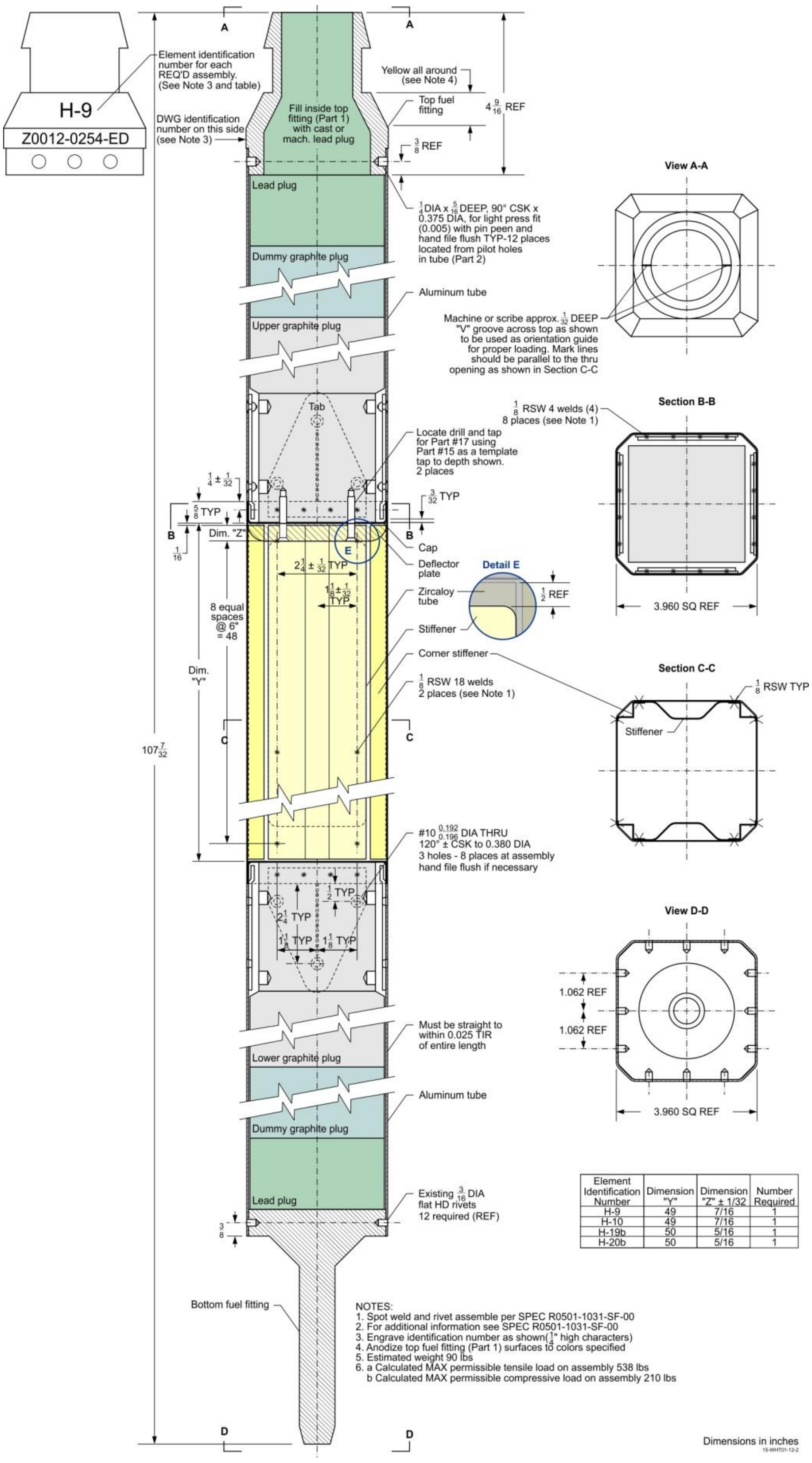
Table 2.18. Access Hole (48- and 49-inch) Dummy Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.216 or 2.217	Z0012-0254, or Z0012-0265	Access Hole Unfueled Assembly, or Access Hole Unfueled Modification Assembly	--
1	2.218	RE-1-21880	Top Fuel Fitting	Al-1100
1	2.219	Z0012-0255	Top End Tube	Al-1100
1	2.220	Z0012-0256	Bottom End Tube	Al-1100
1	2.221	Z0012-0260	Lower Plug	CP-2 Graphite
1	2.222	Z0012-0261	Upper Plug	CP-2 Graphite
2	2.223	Z0012-0263	Dummy Plug	CP-2 Graphite
1	2.224	Z0012-0257	Tube	Zr-3 or Zr-4
2	2.225	Z0012-0258	Cap	Zr-3
8	2.226	Z0012-0262	Tab	Zr-3 or Zr-4
1	2.227	RE-1-21881	Bottom Fuel Fitting	Al-1100
2	2.228	Z0012-0259	Stiffener	Zr-3 or Zr-4
2	2.229	Z0012-0264	Lead Plug	Pb-B29
1	2.230	Z0012-0266	Deflector Plate (Modified Assembly Only)	Al-6061
4	2.231	Z0012-0267	Corner Stiffener (Modified Assembly Only)	Zr-3



Element Identification Number	Dimension "Y"	Dimension "Z" ± 1/32	Number Required
H-1 H-2 H-3 H-4 H-5 H-6 H-7 H-8 H-9[7] H-10[7] H-11 H-12 H-13 H-14 H-15 H-16 H-17 H-18	49	7/16	1
H-19b[7]	50	5/16	
H-20b[7]	50	5/16	

Figure 2.216. Access Hole Unfueled Assembly (DWG# Z0012-0254).



Element Identification Number	Dimension "Y"	Dimension "Z" ± 1/32	Number Required
H-9	49	7/16	1
H-10	49	7/16	1
H-19b	50	5/16	1
H-20b	50	5/16	1

Figure 2.217. Access Hole Unfueled Modification Assembly (DWG# Z0012-0265).

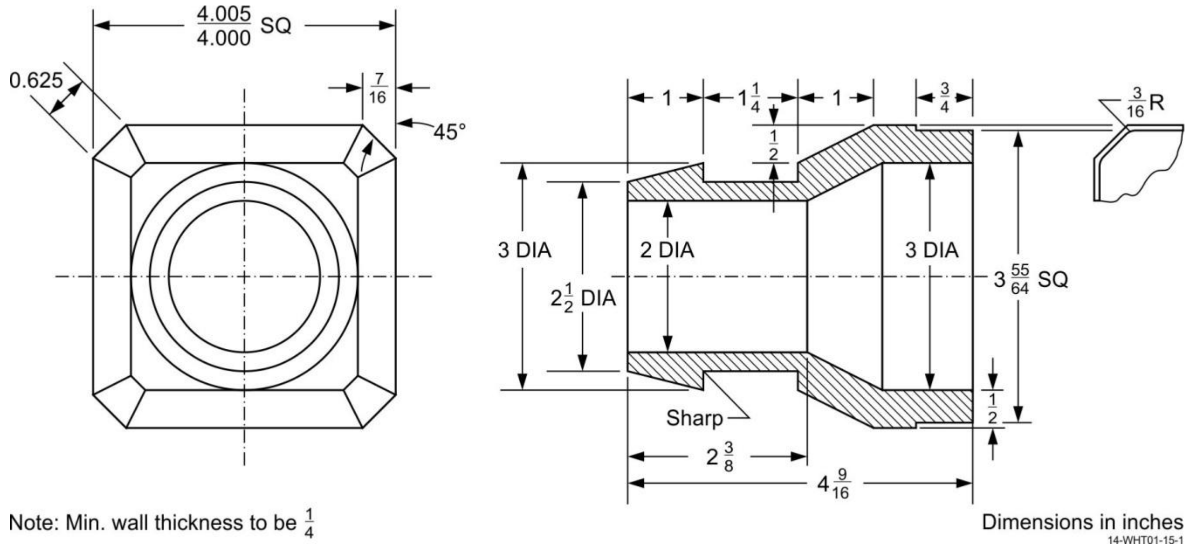


Figure 2.218. Top Fuel Fitting (DWG# RE-1-21880).

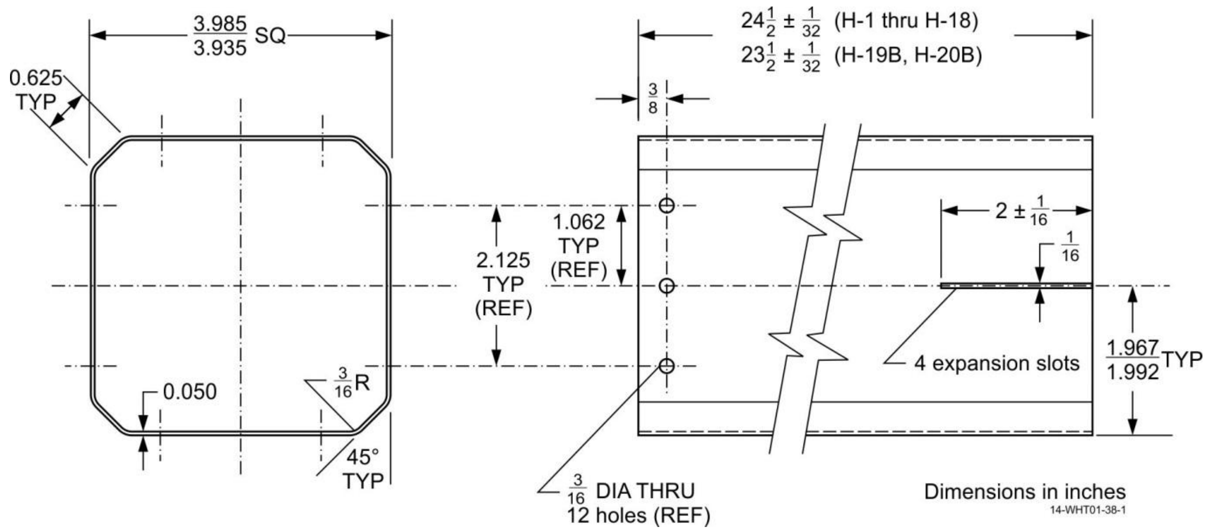


Figure 2.219. Top End Tube (DWG# Z0012-0255).

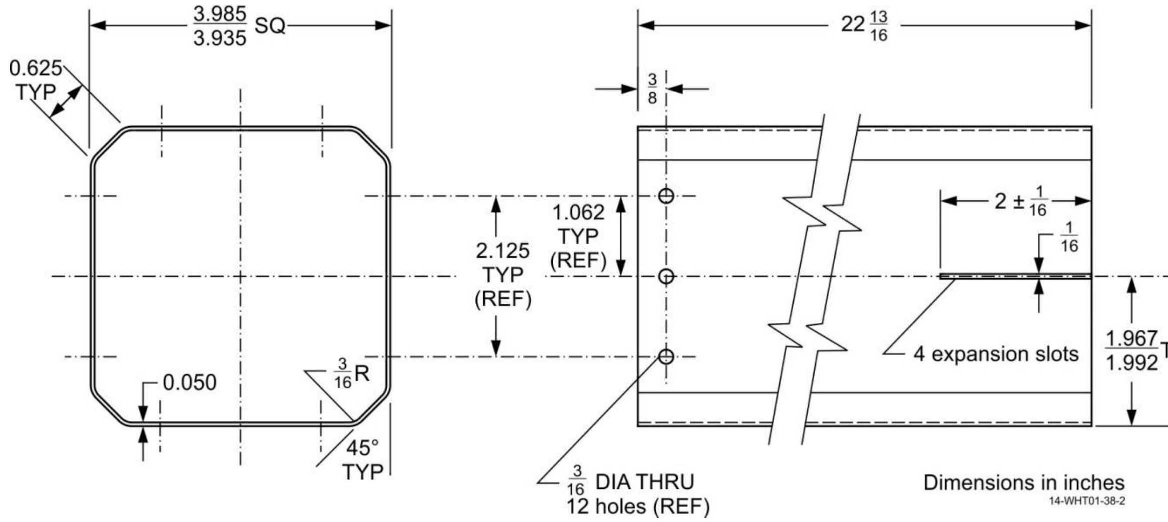


Figure 2.220. Bottom End Tube (DWG# Z0012-0256).

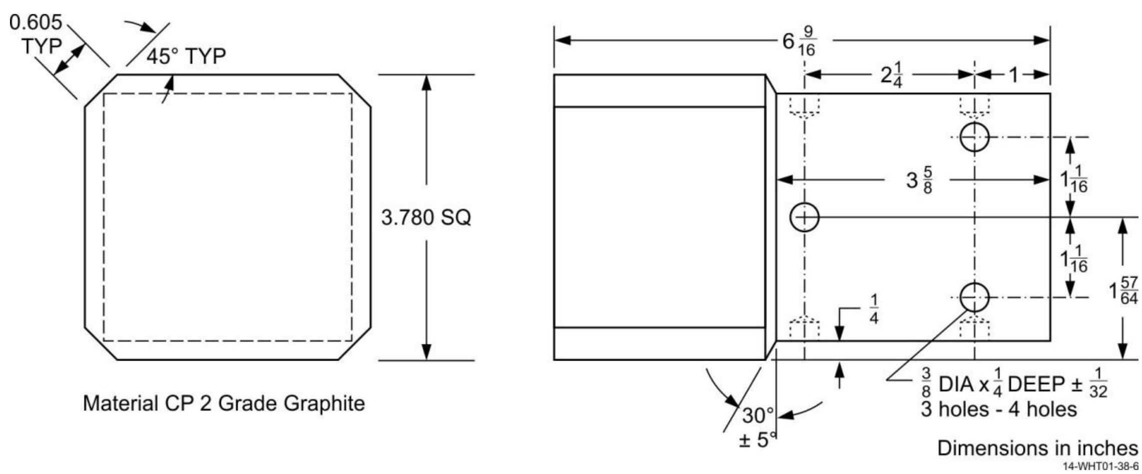


Figure 2.221. Lower Plug (DWG# Z0012-0260).

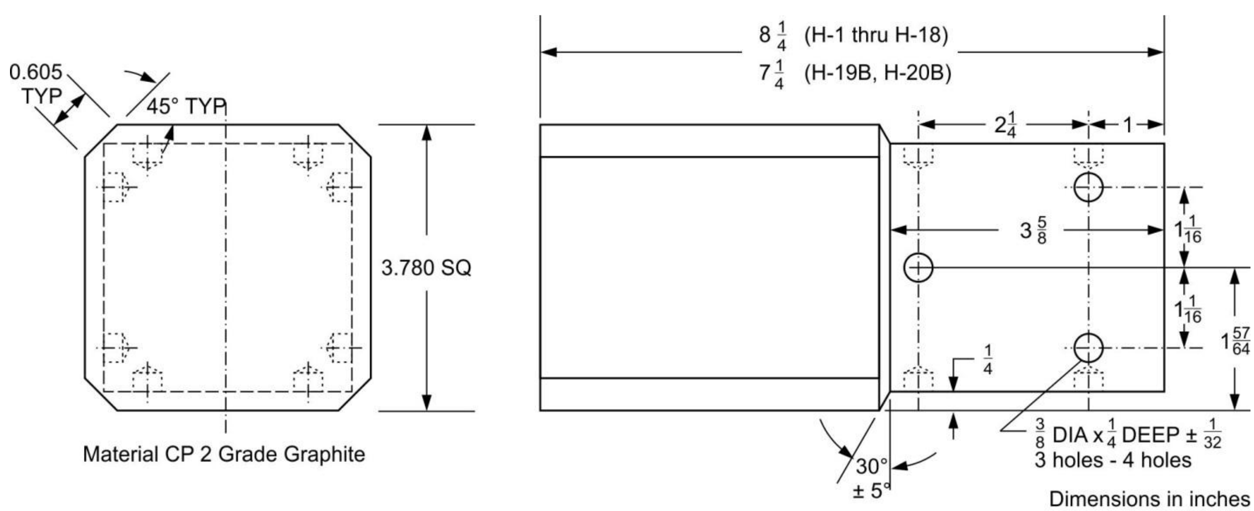


Figure 2.222. Upper Plug (DWG# Z0012-0261).

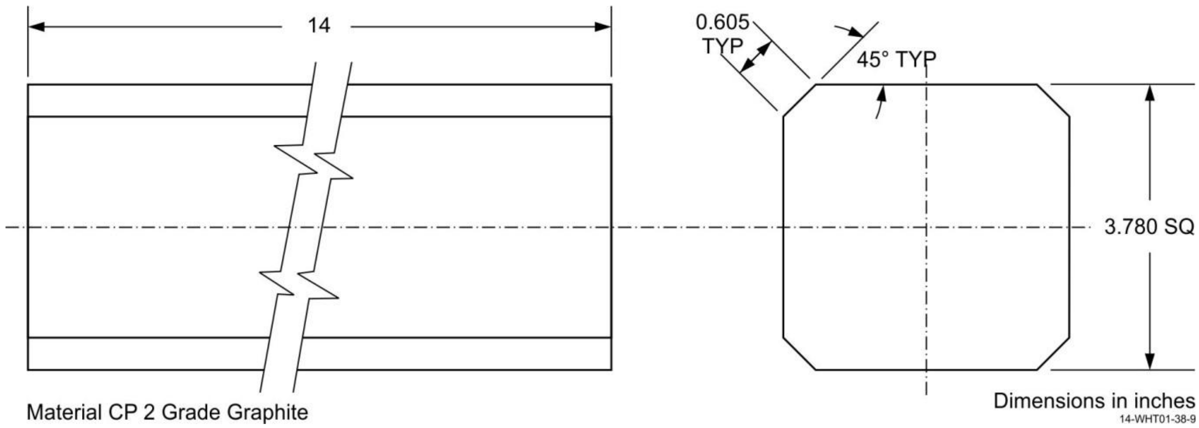


Figure 2.223. Dummy Plug (DWG# Z0012-0263).

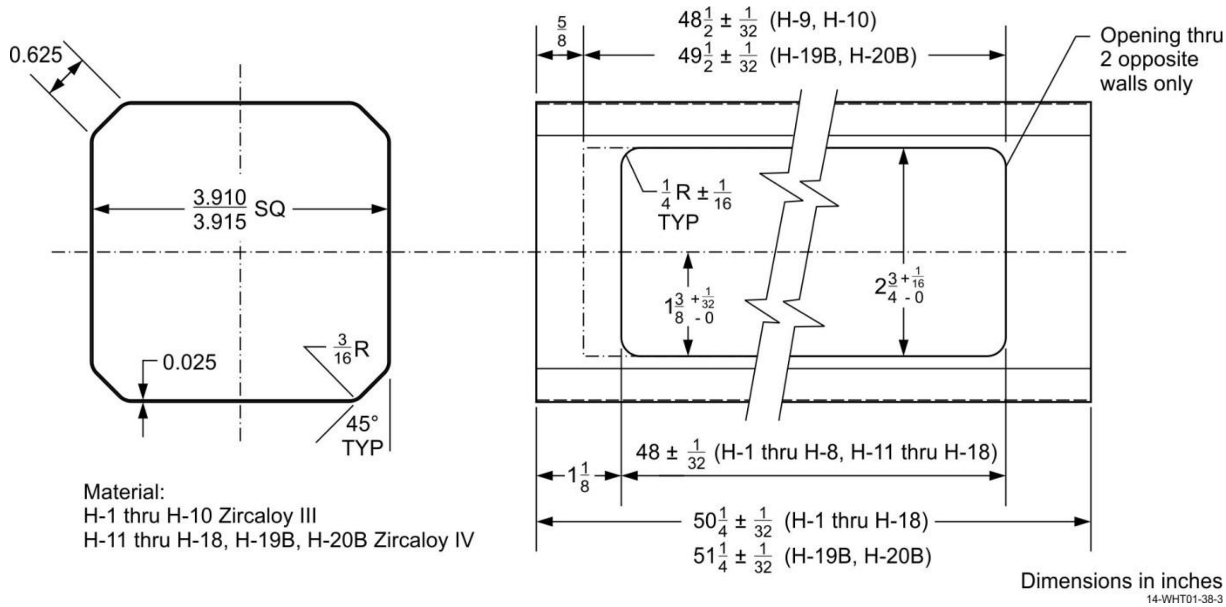


Figure 2.224. Tube (DWG# Z0012-0257).

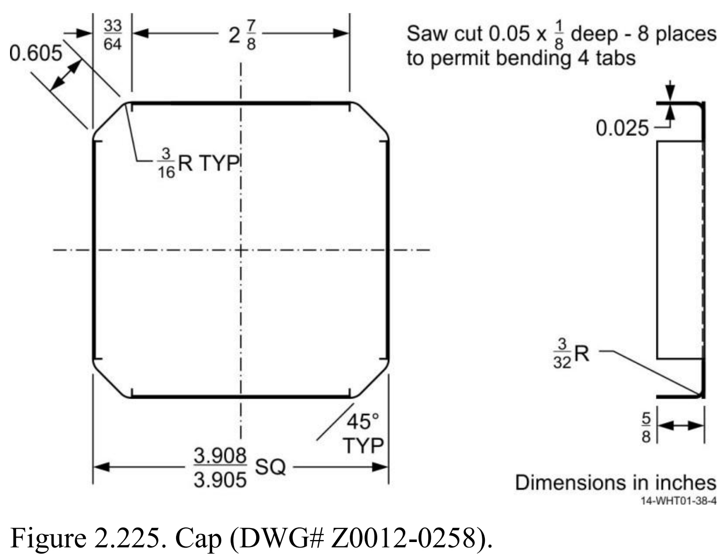


Figure 2.225. Cap (DWG# Z0012-0258).

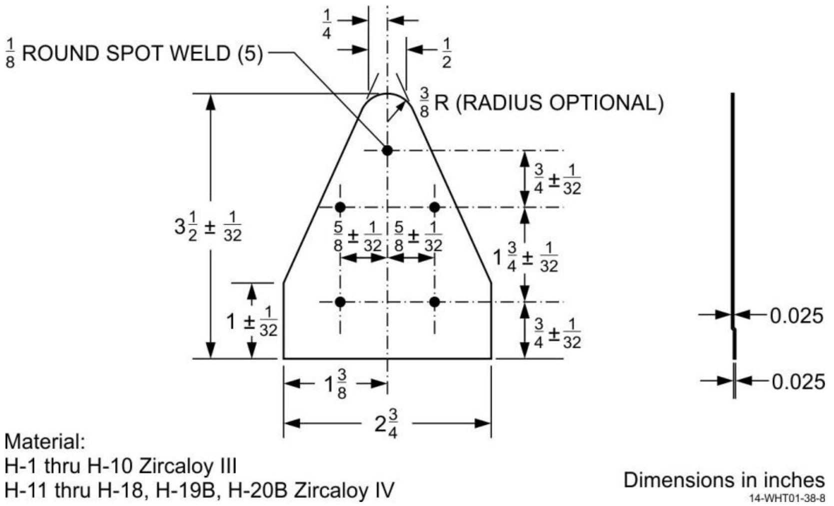


Figure 2.226. Tab (DWG# Z0012-0262).

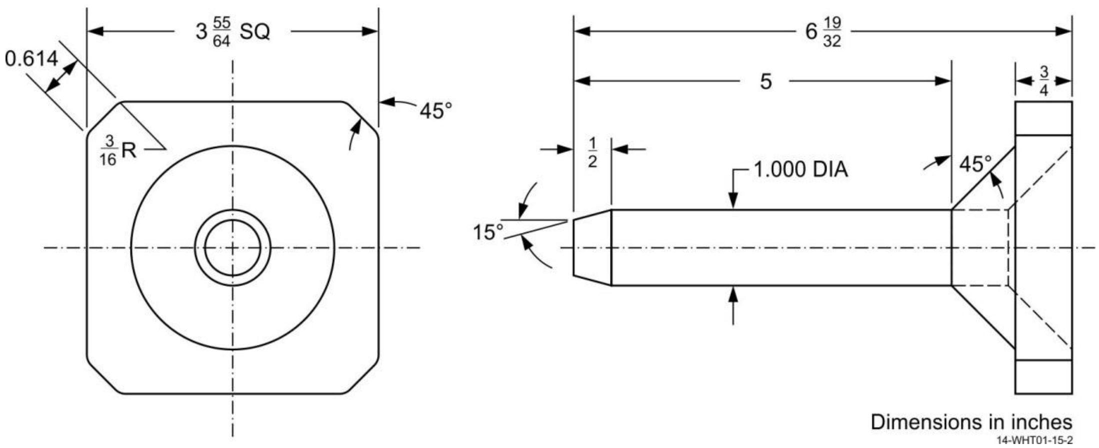


Figure 2.227. Bottom Fuel Fitting (DWG# RE-1-21881).

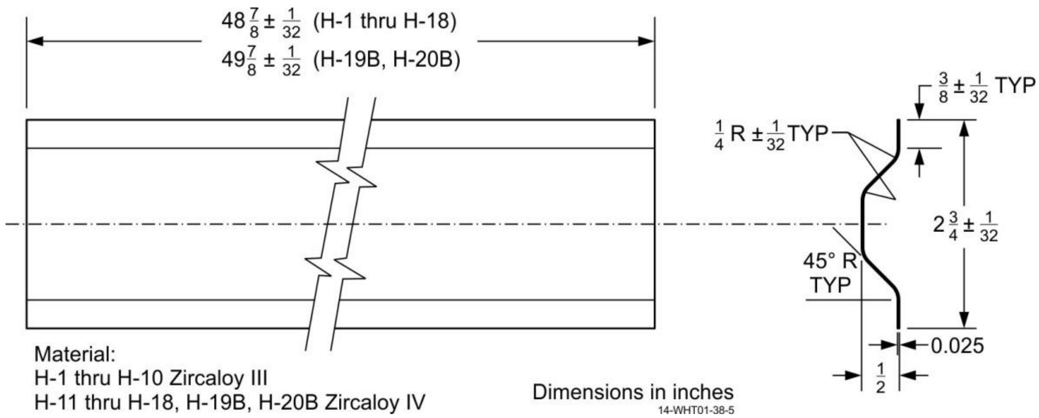


Figure 2.228. Stiffener (DWG# Z0012-0259).

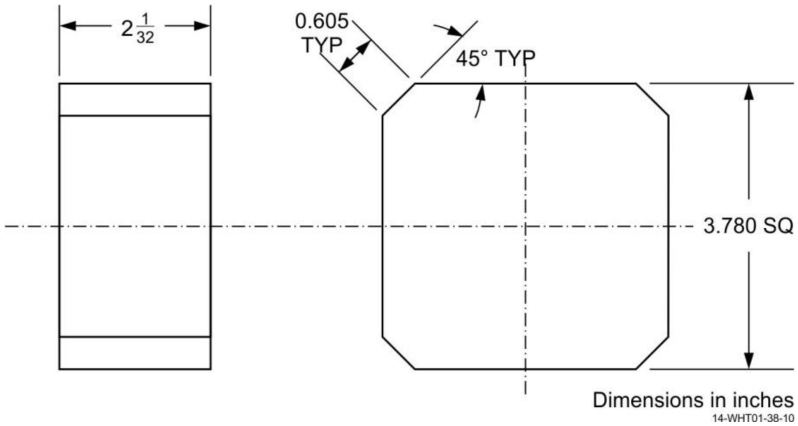


Figure 2.229. Lead Plug (DWG# Z0012-0264).

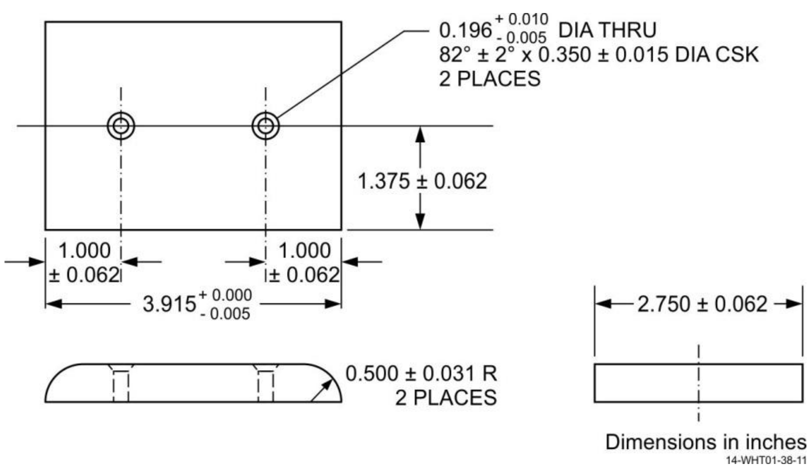


Figure 2.230. Deflector Plate in Modified Assembly Only (DWG# Z0012-0266).

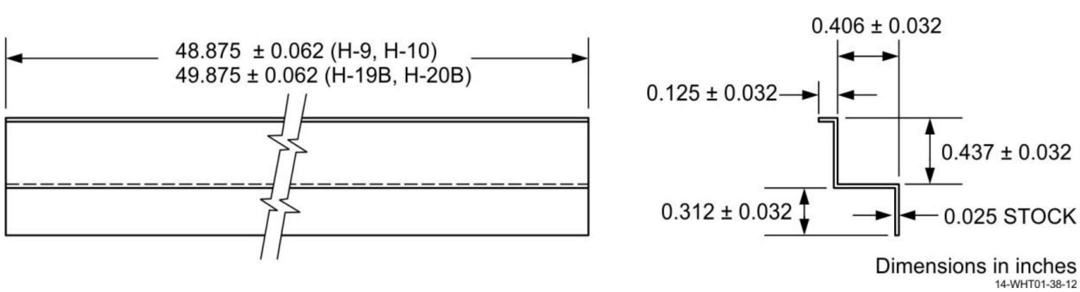


Figure 2.231. Corner Stiffener in Modified Assembly Only (DWG# Z0012-0267).

2.6.7 Access Hole (48-inch) Half Assembly

The access hole (48-inch) half assembly is an unfueled assembly of graphite blocks that fills roughly half of the footprint of a standard assembly and contains no graphite in the region of the 4-foot fueled section typical of the fueled assemblies to accommodate the slot between experiment and hodoscope, reduce axial leakage from the core, and help maintain the position of the experiment in the core center. This assembly was used in experiments implementing a 4 in. × 8 in. experimental can, such as in the various M-series experiments [Robinson 1994]. The assembly is shown in Figure 2.232 with a list of applicable drawings and materials provided in Table 2.19. Individual component drawings are provided in Figures 2.232 through 2.238.

Table 2.19. Access Hole (48-inch) Dummy Half Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.232	Z0012-0173	MK-III Slotted Half Element Assembly	--
--	2.232	--	Graphite Blocks	CP-2 Graphite
1	2.233	Z0012-0174	Lifting Adapter	Al-6061
1	2.234	Z0012-0175	P1 Extension	Al-6061
1	2.234	Z0012-0175	P2 Extension	Al-6061
3	2.235	Z0012-0176	Lead Brick	Pb-B29
1	2.236	Z0012-0177	Bottom Fitting	Al-6061
1	2.237	Z0012-0178	Stiffener & Retainer Weldment	Zr-3
1	2.238	Z0012-0182	Can	Zr-3

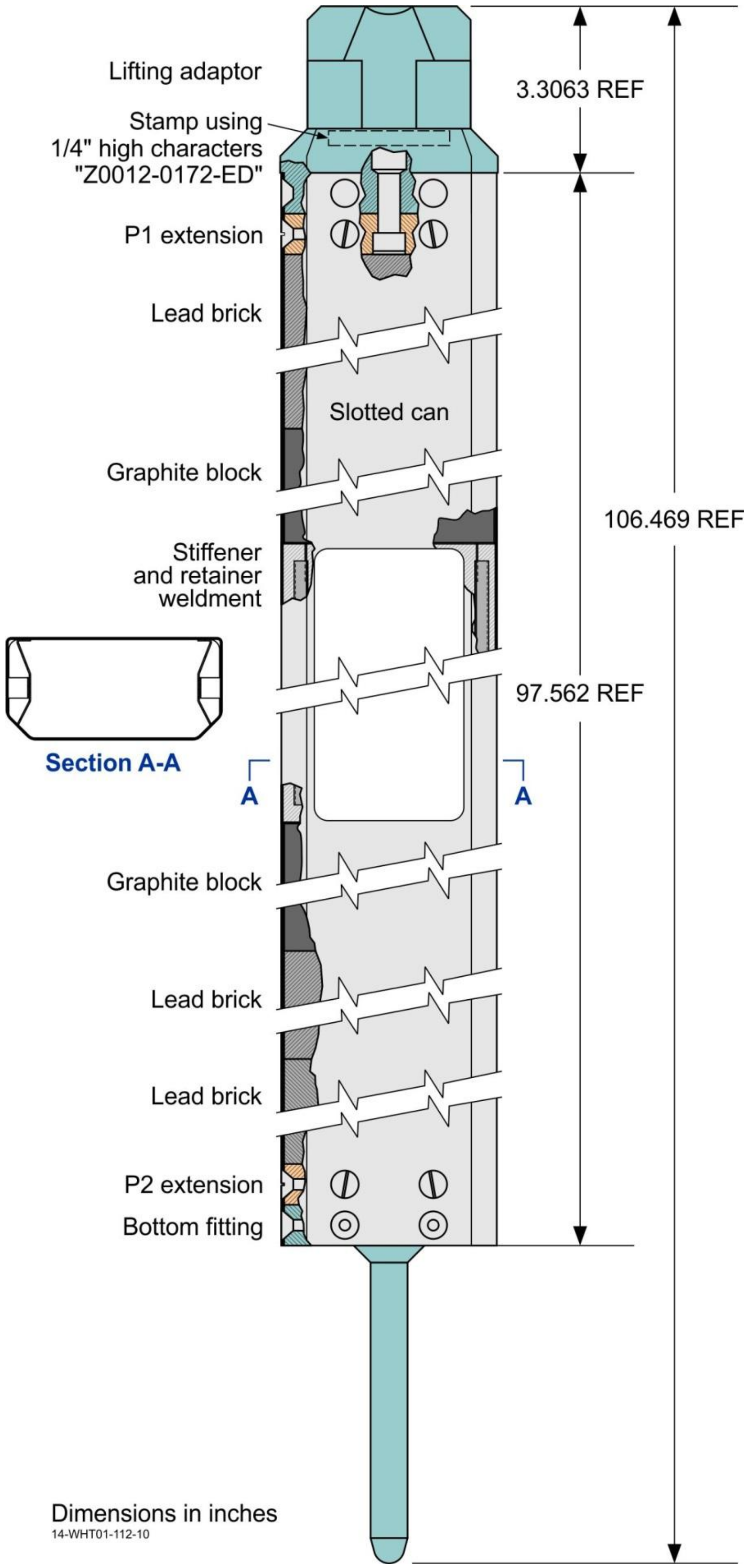


Figure 2.232. MK-III Slotted Half Element Assembly (DWG# Z0012-0173).

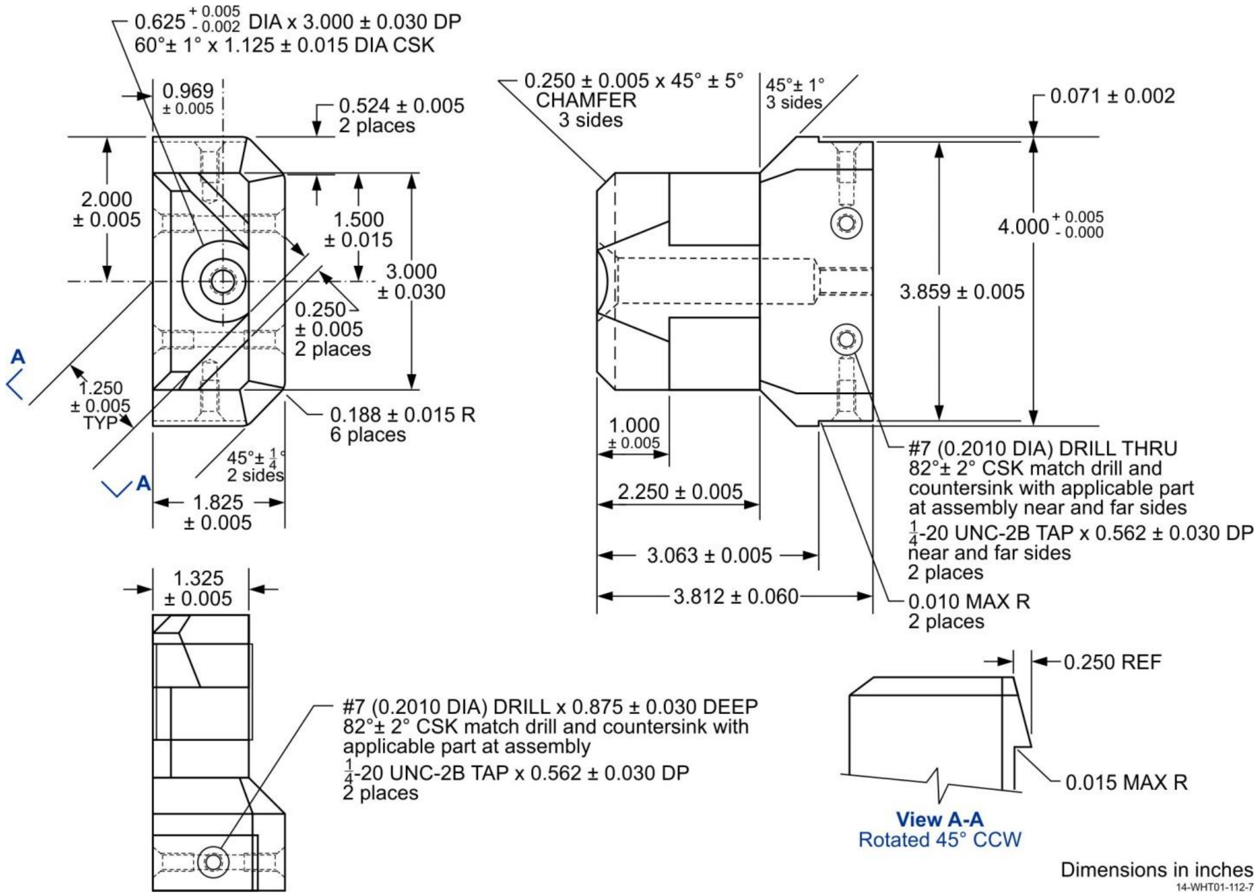


Figure 2.233. Lifting Adapter (DWG# Z0012-0174).

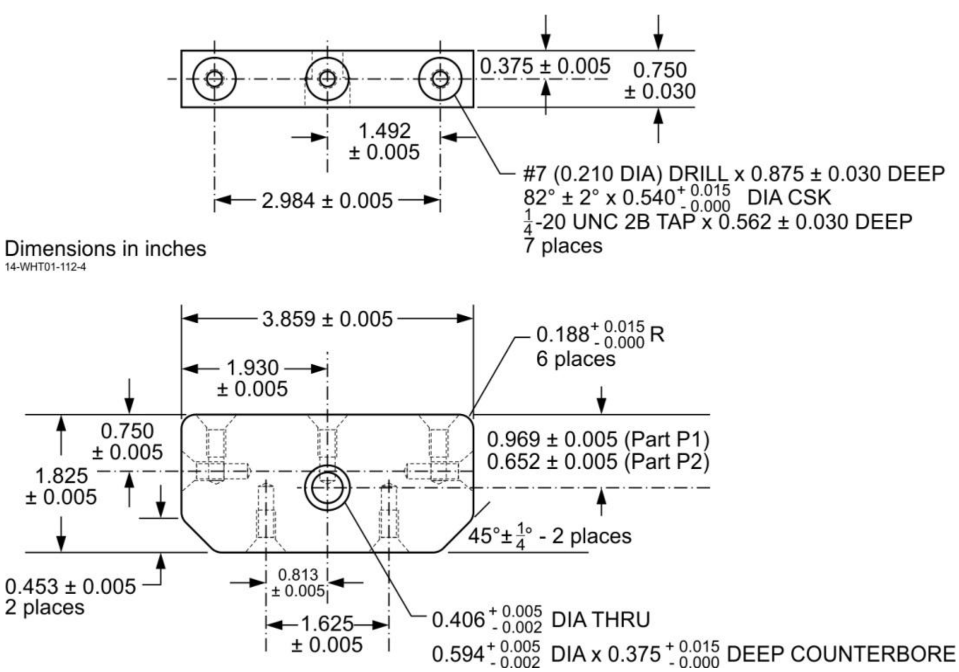


Figure 2.234. P1 & P2 Extensions (DWG# Z0012-0175).

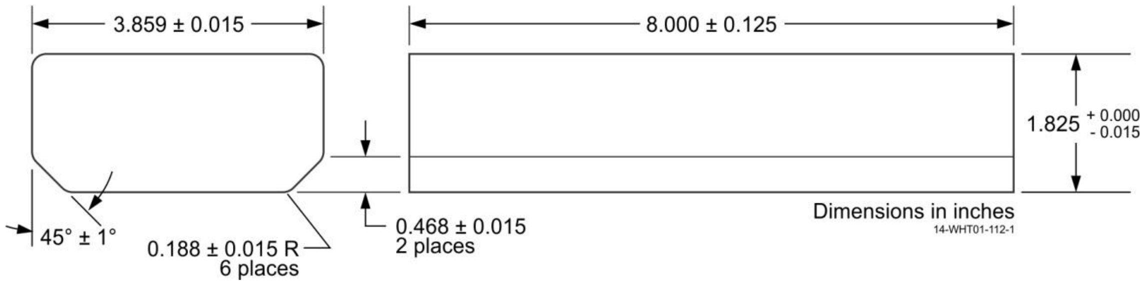


Figure 2.235. Lead Brick (DWG# Z0012-0176).

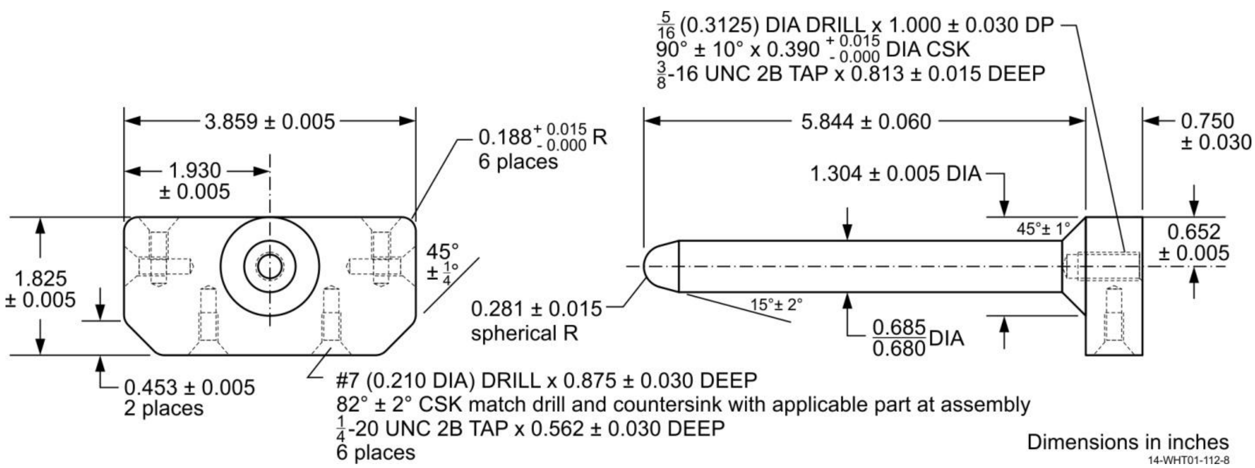


Figure 2.236. Bottom Fitting (DWG# Z0012-0177).

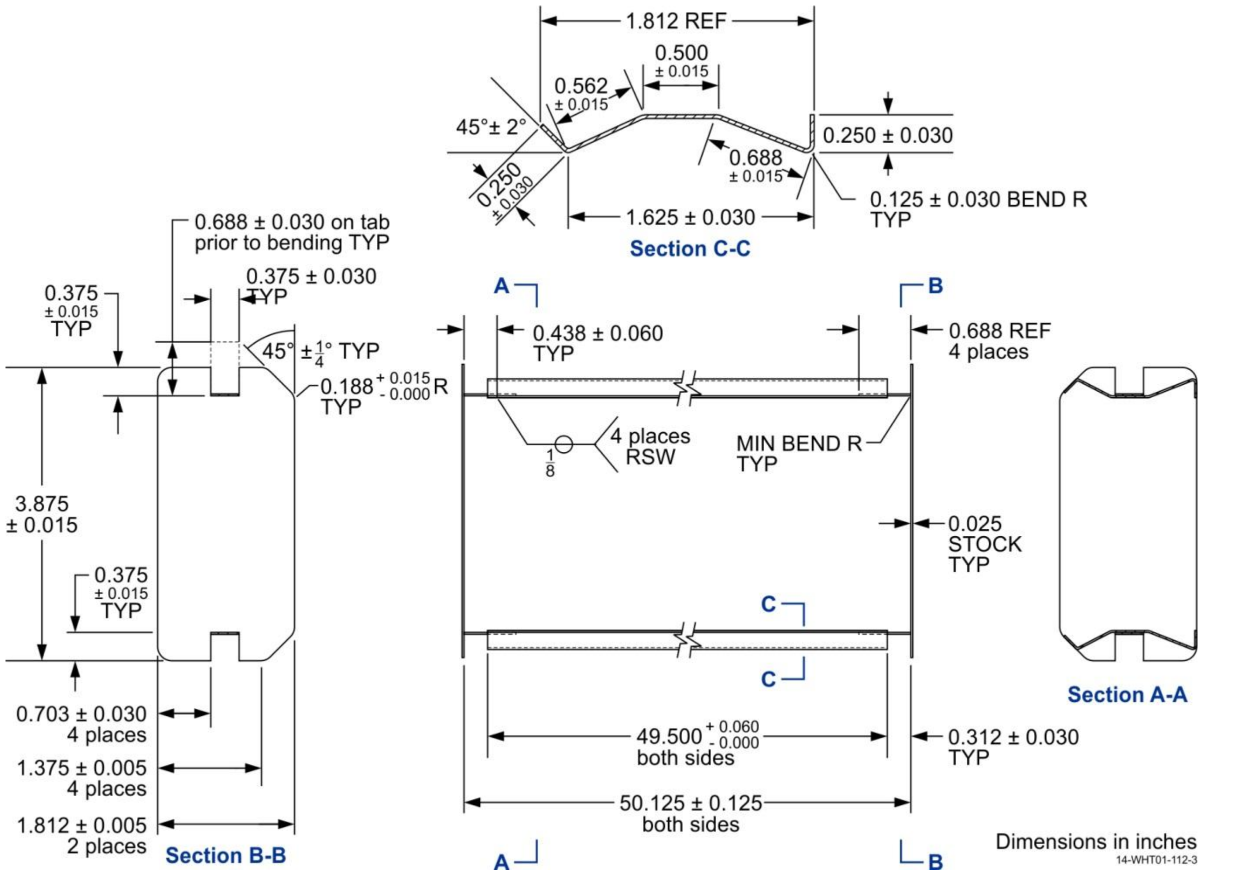


Figure 2.237. Stiffener & Retainer Weldment (DWG# Z0012-0178).

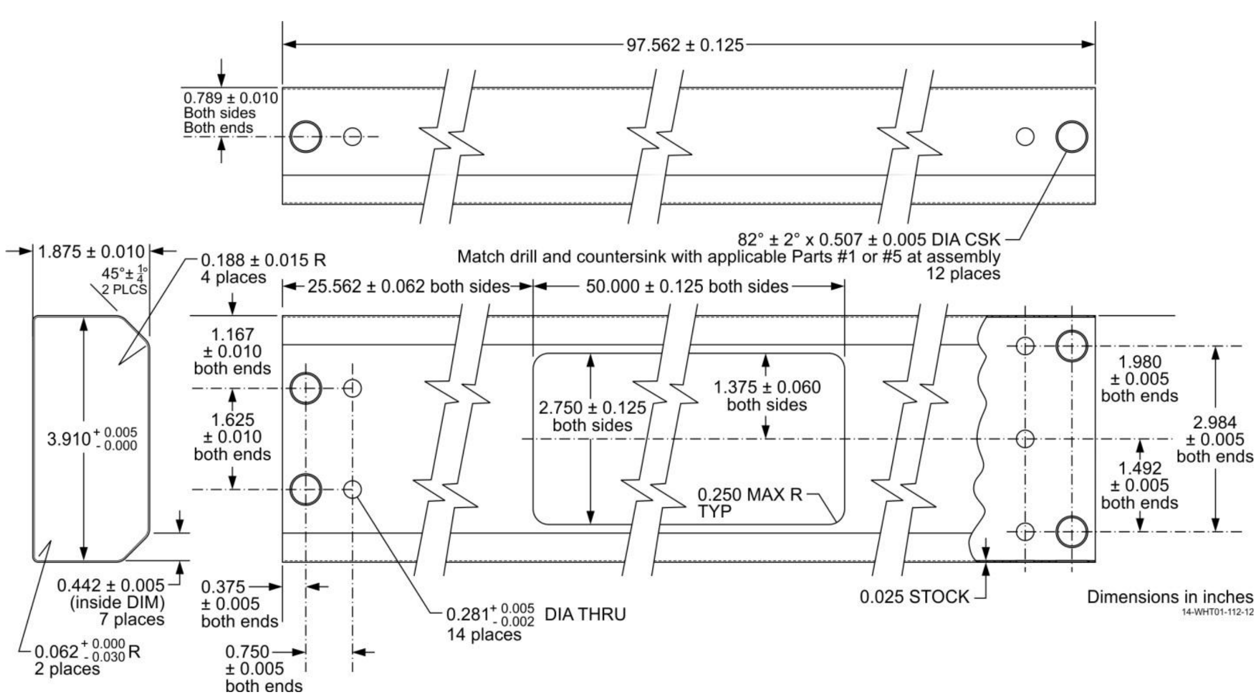


Figure 2.238. Can (DWG# Z0012-0182).

2.6.8 Thermocouple Dummy Assembly

The thermocouple dummy assembly is a four thermocouple fuel assembly without fuel. The assembly is shown in Figure 2.239 with a list of applicable drawings and materials provided in Table 2.20. Individual component drawings are provided in Figures 2.239 through 2.254.

Table 2.20. Four Thermocouple Dummy Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.239	--	4 Thermocouple Dummy Assembly	--
1	2.239	--	Straight Amphenol Plug	Al-6061
4	2.239	--	Chromel-Alumel Thermocouples	--
1	2.240	RE-1-23270	Special Plug	CP-2 Graphite
1	2.241	RE-1-22739	Short Plain Plug	CP-2 Graphite
1	2.242	RE-1-23269	Top Plug	CP-2 Graphite
1	2.243	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.244	RE-1-22736	End Tube Part #1	Al-6063
1	2.244	RE-1-22736	End Tube Part #2	Al-6063
1	2.245	RE-1-22881	Bottom Fuel Fitting	Al-1100
1	2.246	RE-1-23253	Plug Holder	Al-6061
1	2.247	RE-1-23254	Socket Holder	Al-6061
1	2.248	RE-1-23255	Top Fuel Fitting Rework	Al-1100
4	2.249	RE-1-24159	Thermocouple Well Part #1	Zr-3
1	2.250	--	4 Thermocouple Dummy Section	Zr-3
6	2.251	--	Dummy Block Part #1	CP-2 Graphite
8	2.252	RE-1-22699	Tab	Zr-3
2	2.253	RE-1-24160	Spacer	Zr-3
1	2.254	RE-1-23257	Plug Rework Box Receptacle	Al-6061

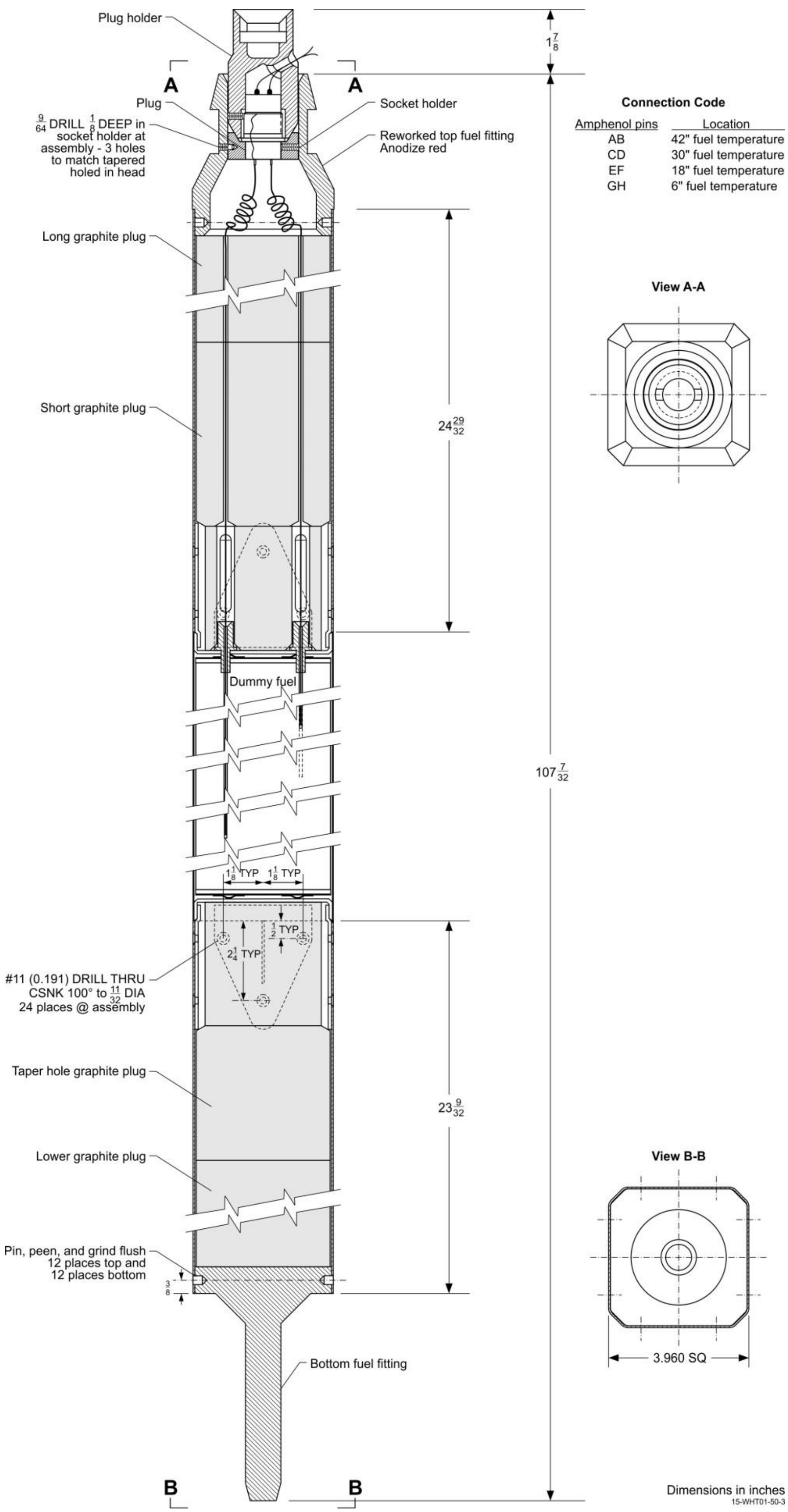


Figure 2.239. 4 Thermocouple Dummy Assembly.

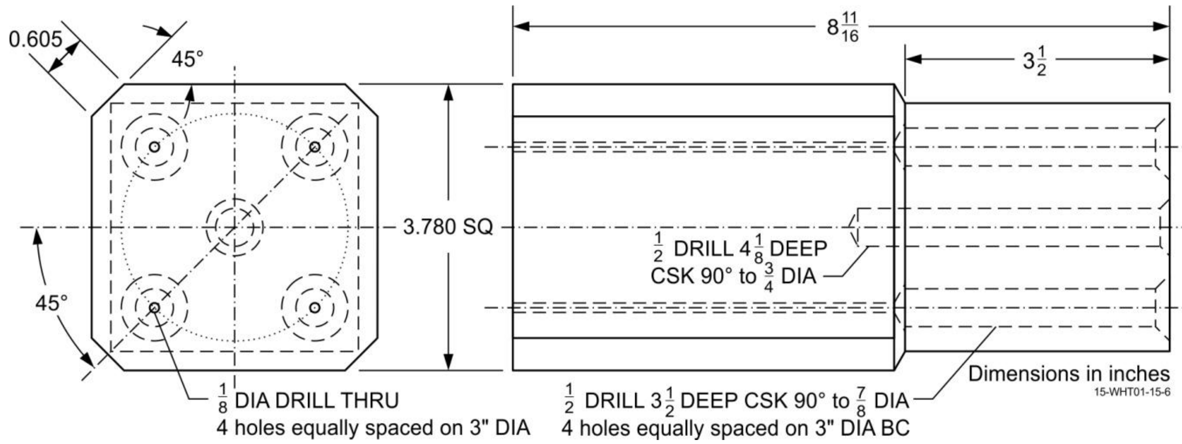


Figure 2.240. Special Plug (DWG# RE-1-23270).

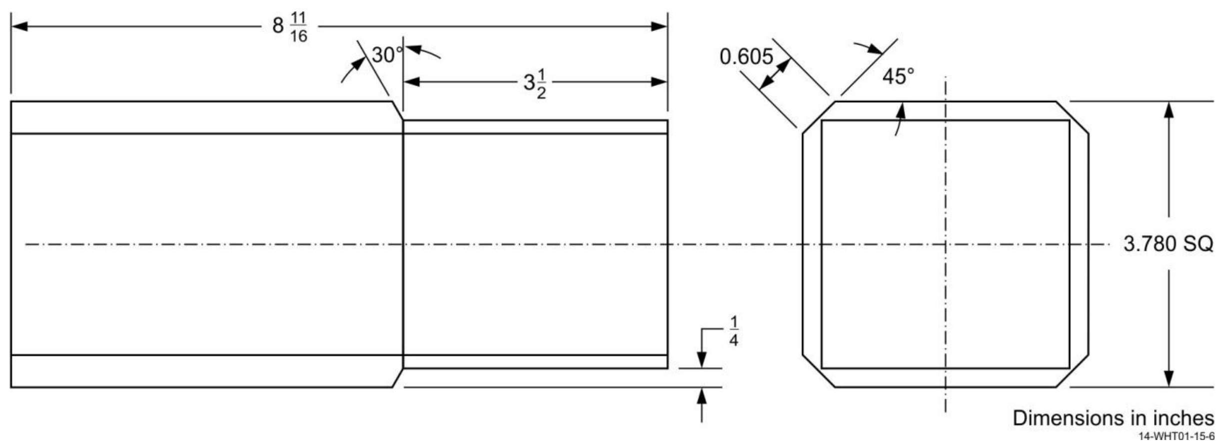


Figure 2.241. Short Plain Plug (DWG# RE-1-22739).

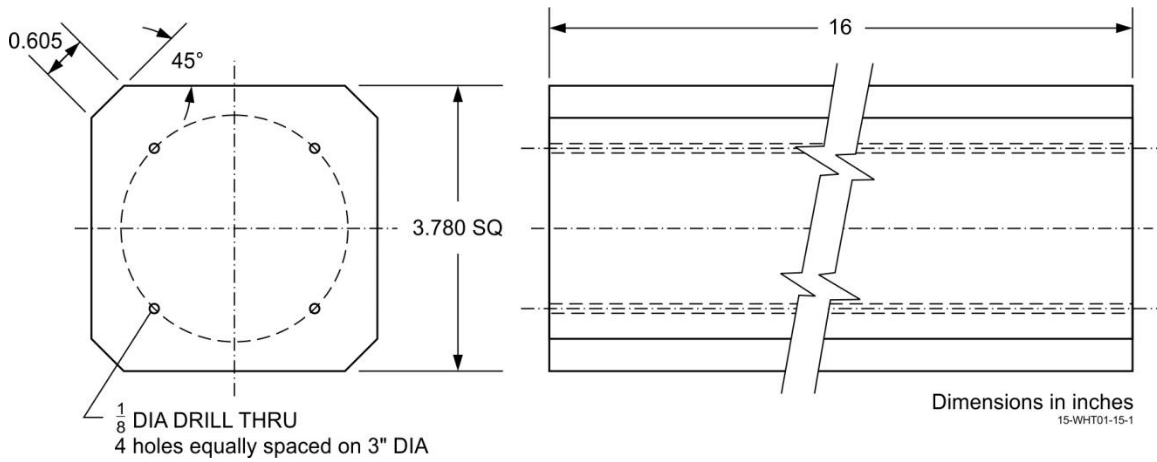


Figure 2.242. Top Plug (DWG# RE-1-23269).

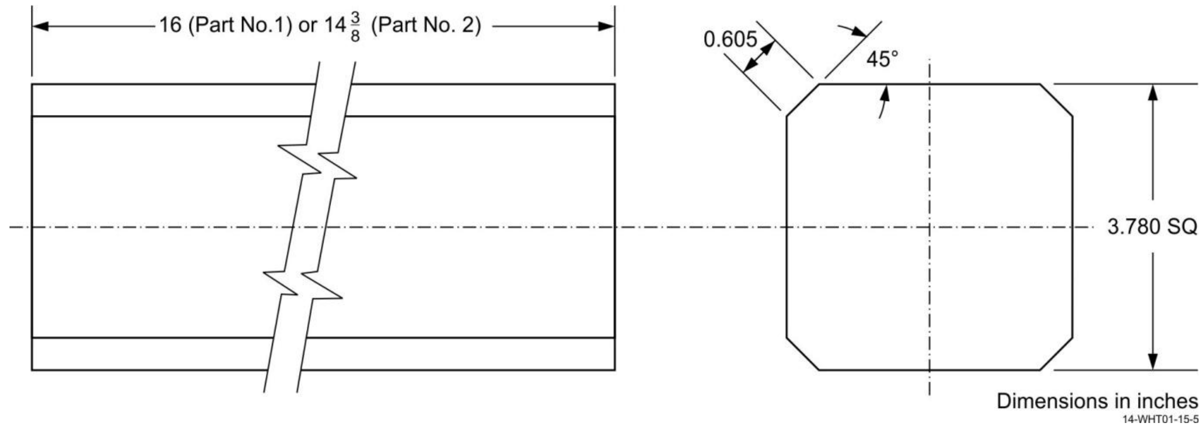


Figure 2.243. Long Plug (DWG# RE-1-21768).

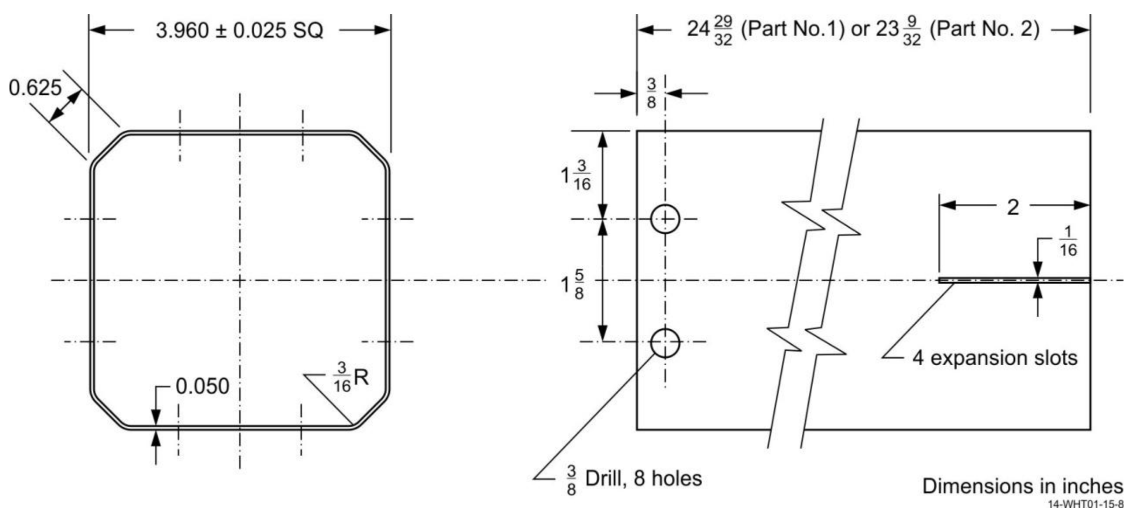


Figure 2.244. End Tube (DWG# RE-1-22736).

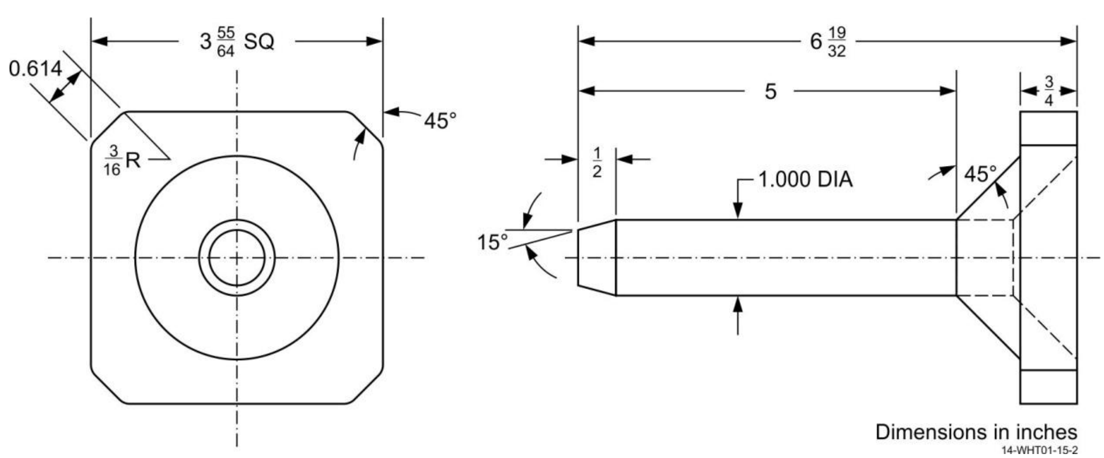


Figure 2.245. Bottom Fuel Fitting (DWG# RE-1-21881).

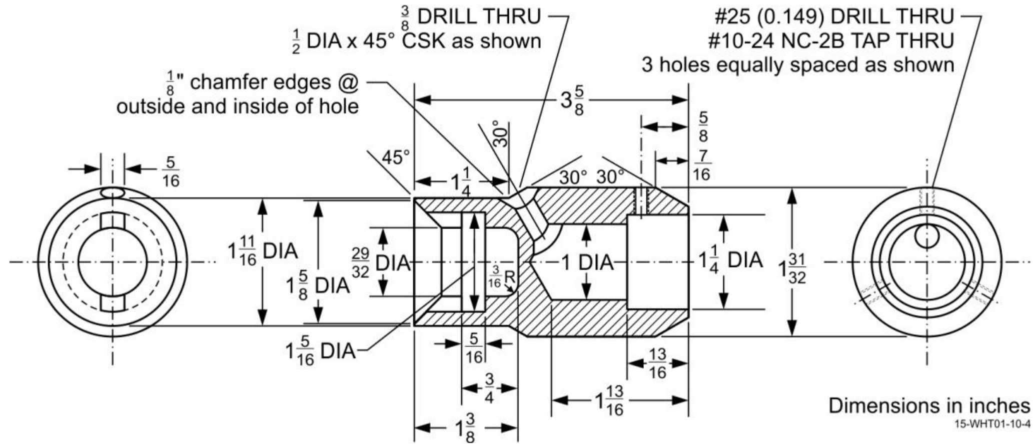


Figure 2.246. Plug Holder (DWG# RE-1-23253).

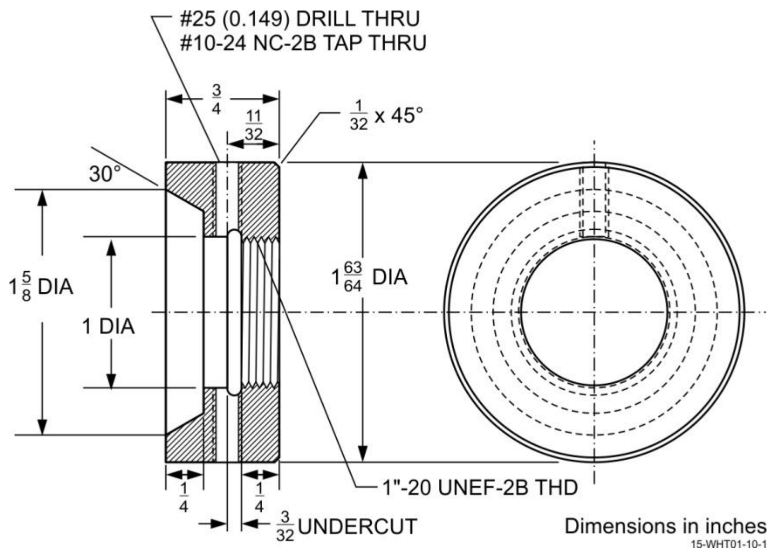


Figure 2.247. Socket Holder (DWG# RE-1-23254).

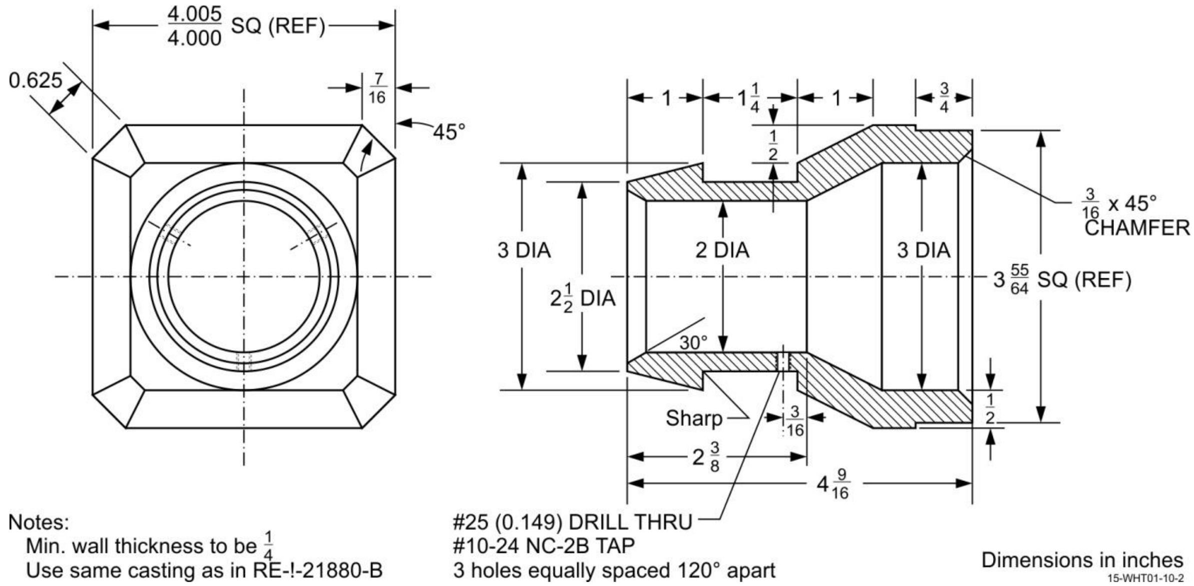


Figure 2.248. Top Fuel Fitting Rework (DWG# RE-1-23255).

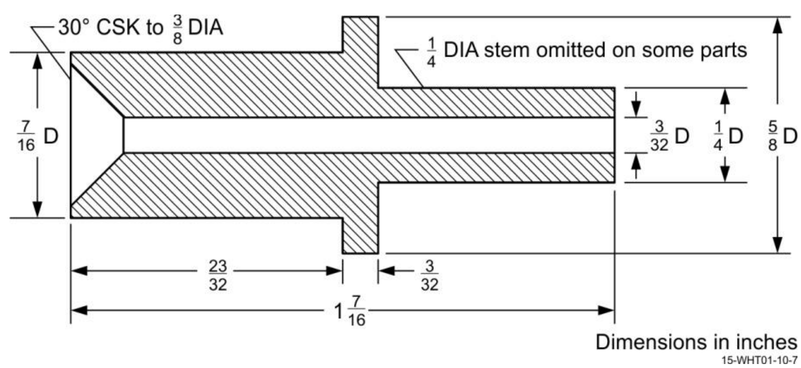


Figure 2.249. Thermocouple Well (DWG# RE-1-24159).

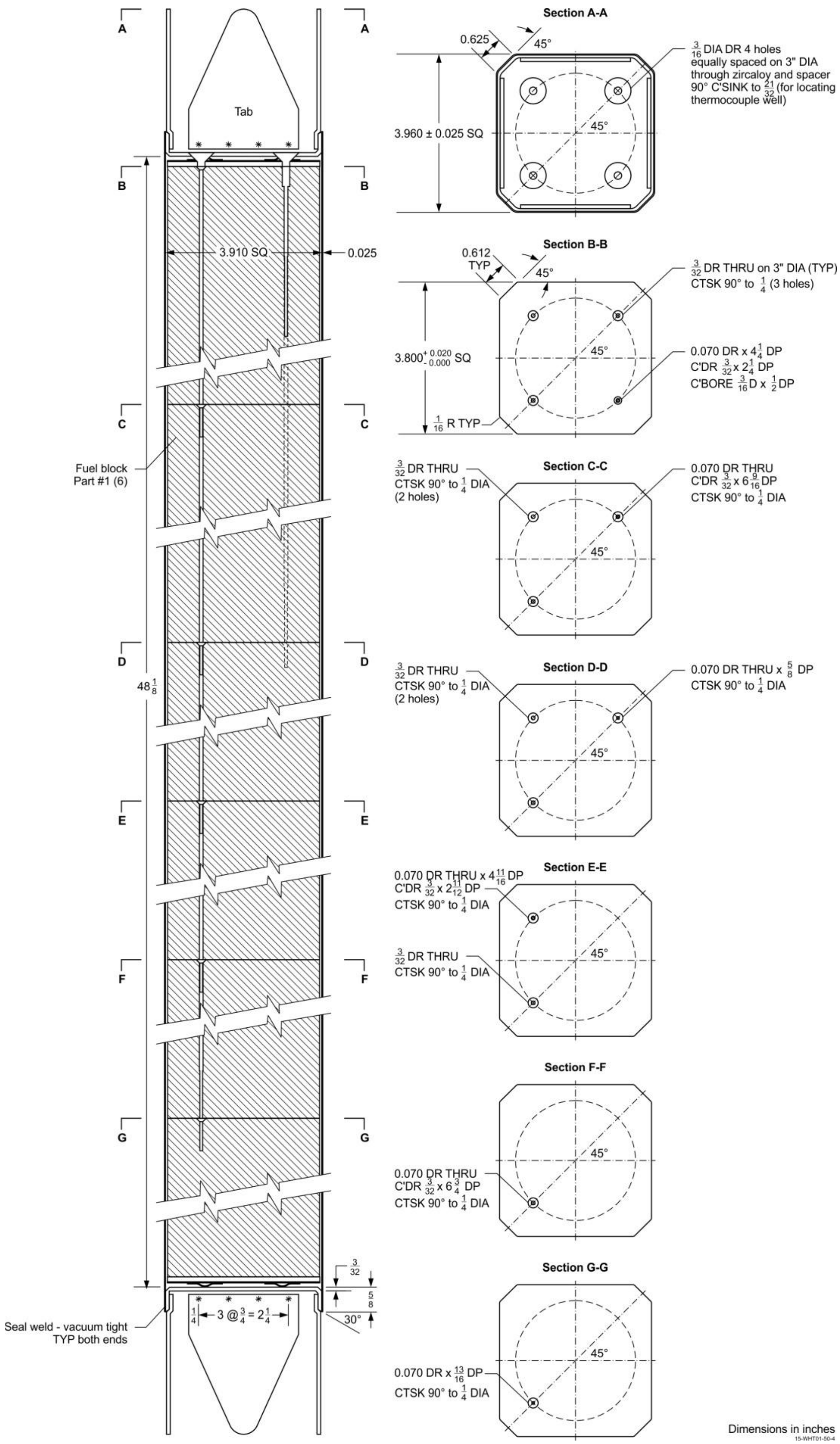


Figure 2.250. 4 Thermocouple Dummy Section.

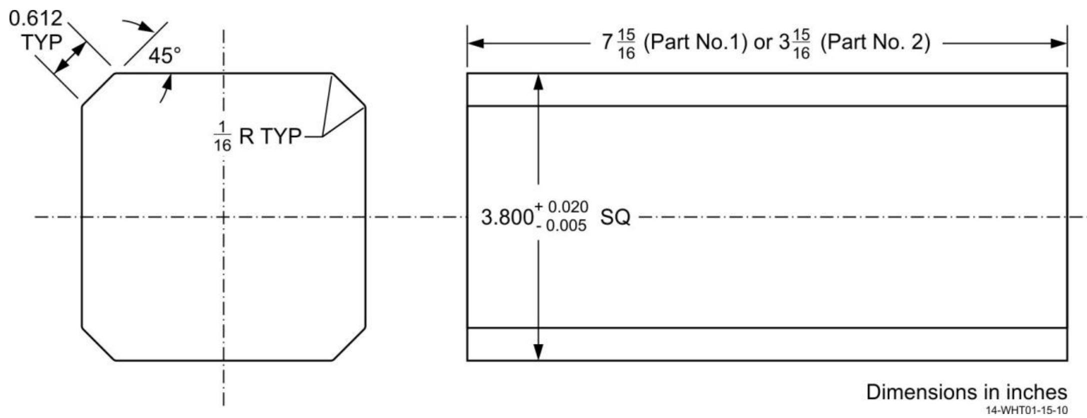


Figure 2.251. Dummy Block.

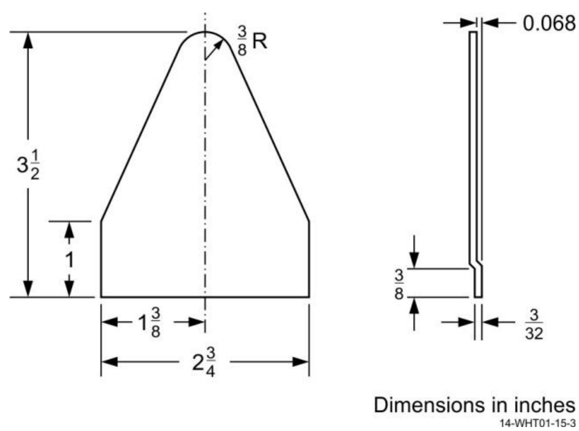


Figure 2.252. Tab (DWG# RE-1-22699).

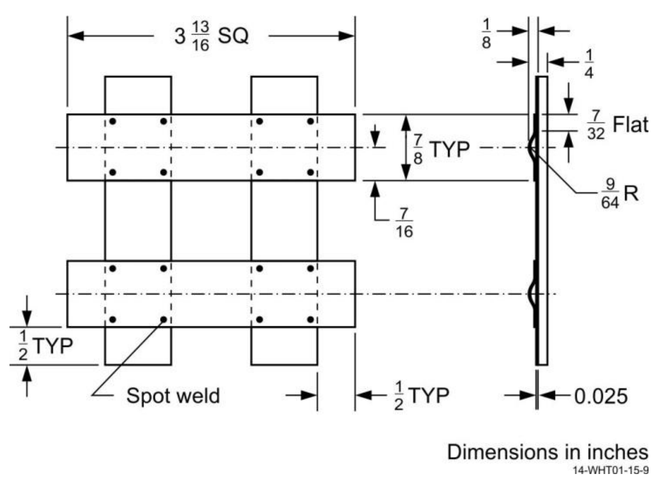


Figure 2.253. Spacer (DWG# RE-1-24160).

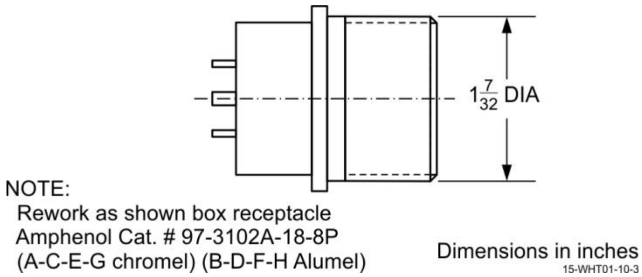


Figure 2.254. Plug Rework Box Receptacle (DWG# RE-1-23257).

2.6.9 Three-Quarter Assemblies

Three-quarter assemblies were developed to surround the circular experimental footprint of the AN-CAL experiments [Robinson 1992]. They consist of a zircaloy can containing graphite, which served to hold the experiment canister in place and reduce axial neutron leakage from the core. The assemblies are shown in Figures 2.255 and 2.256 with a list of applicable drawings and materials provided in Table 2.21. Individual component drawings are provided in Figures 2.255 through 2.262.

Table 2.21. Zircaloy-Clad Dummy Three-Quarter Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.255	R0269-0011	¾ Graphite Element SW/NE Assembly	--
1	2.256	R0269-0012	¾ Graphite Element SE/NW Assembly	--
1	2.257	R0269-0204	¾ Graphite Element Graphite Plug	Arco Graphite
1	2.258	R0269-0205	¾ Graphite Element Zirc Tube	Zr-3
1	2.259	R0269-0206	¾ Graphite Element Top Fitting SW/NE	Al-6061
1	2.260	R0269-0207	¾ Graphite Element Bottom Fitting SW/NE	Al-6061
1	2.261	R0269-0208	¾ Graphite Element Top Fitting NW/SE	Al-6061
1	2.262	R0269-0209	¾ Graphite Element Bottom Fitting NW/SE	Al-6061

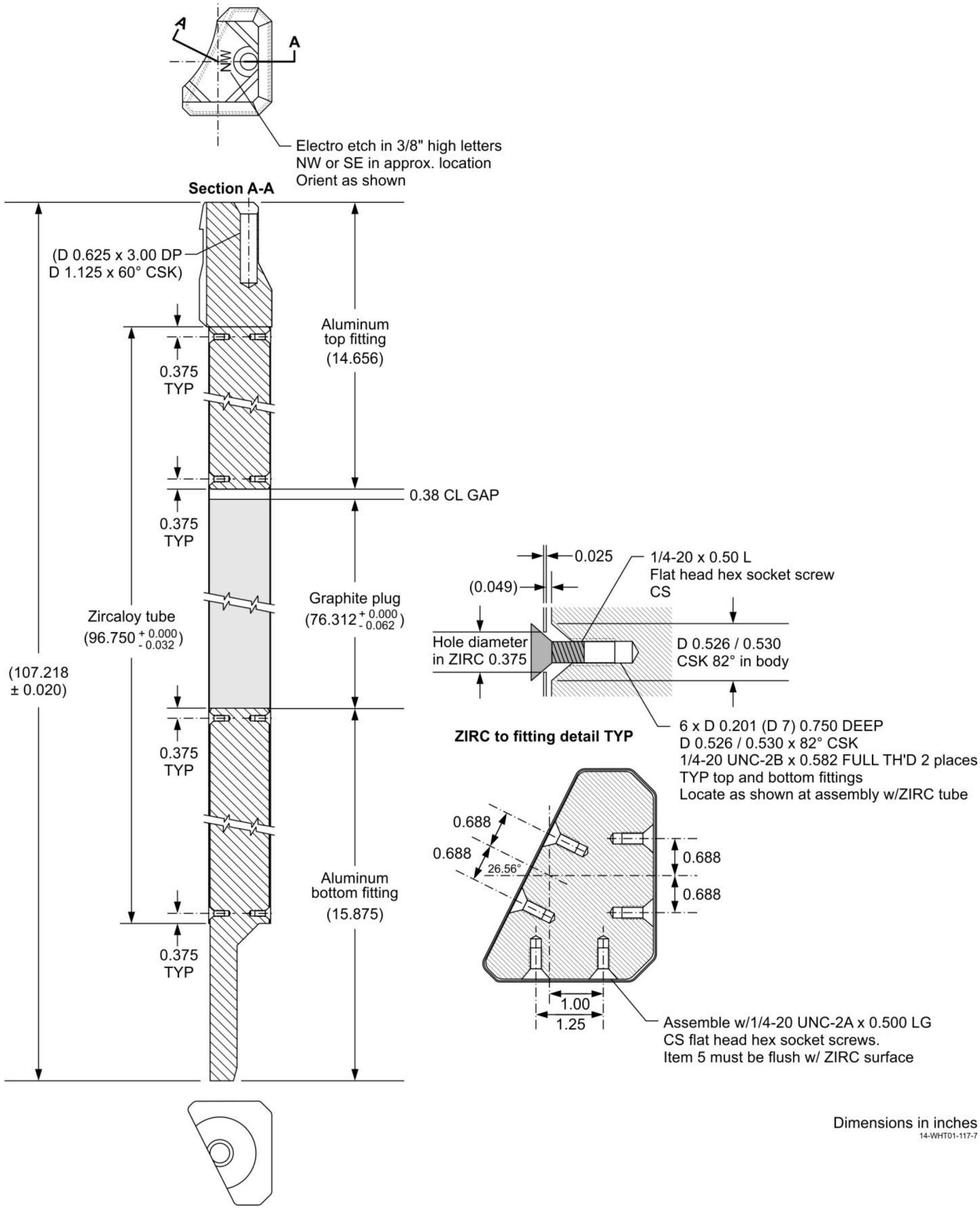


Figure 2.255. ¾ Graphite Element SW/NE Assembly (DWG# R0269-0011).

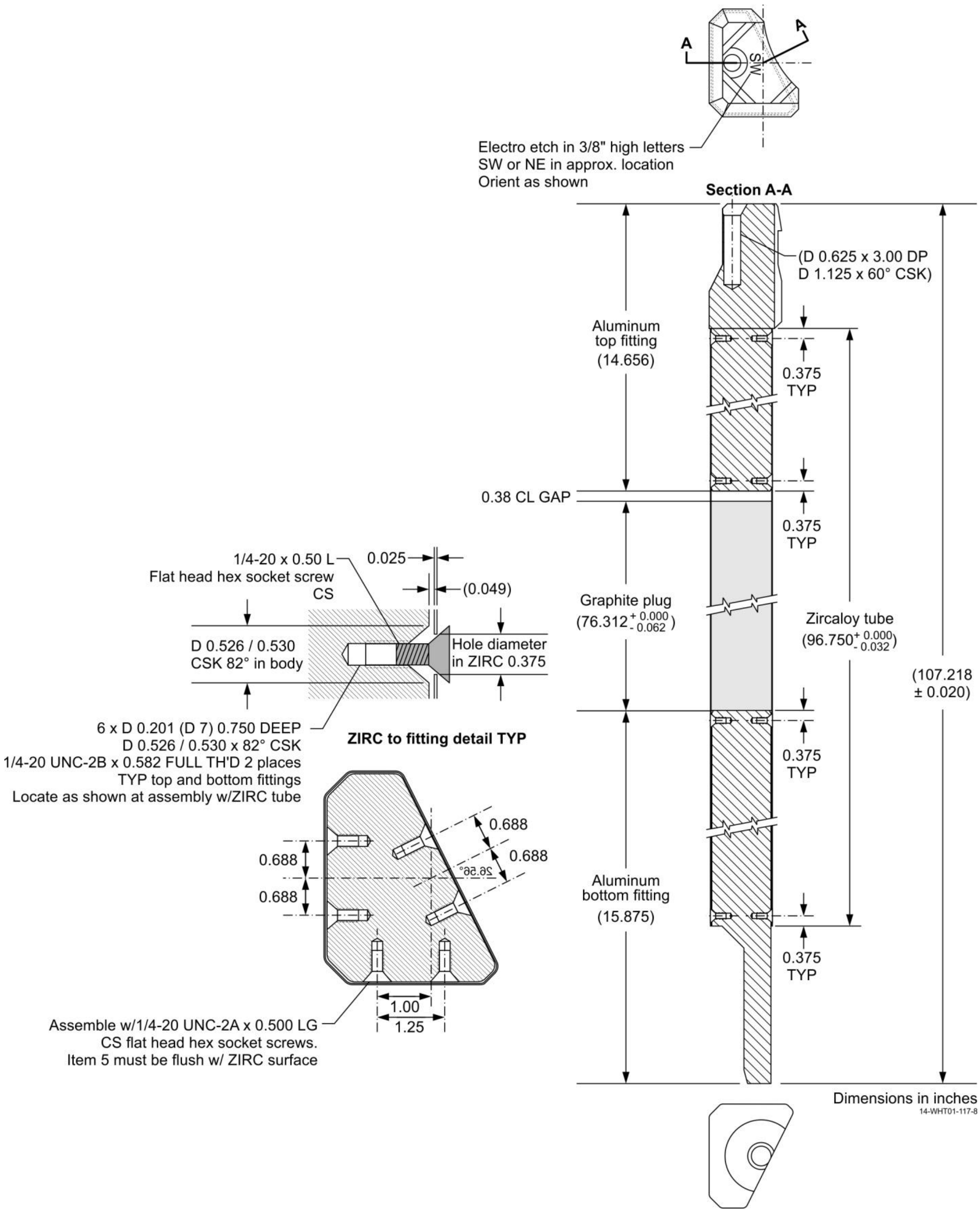


Figure 2.256. ¾ Graphite Element SE/NW Assembly (DWG# R0269-0012).

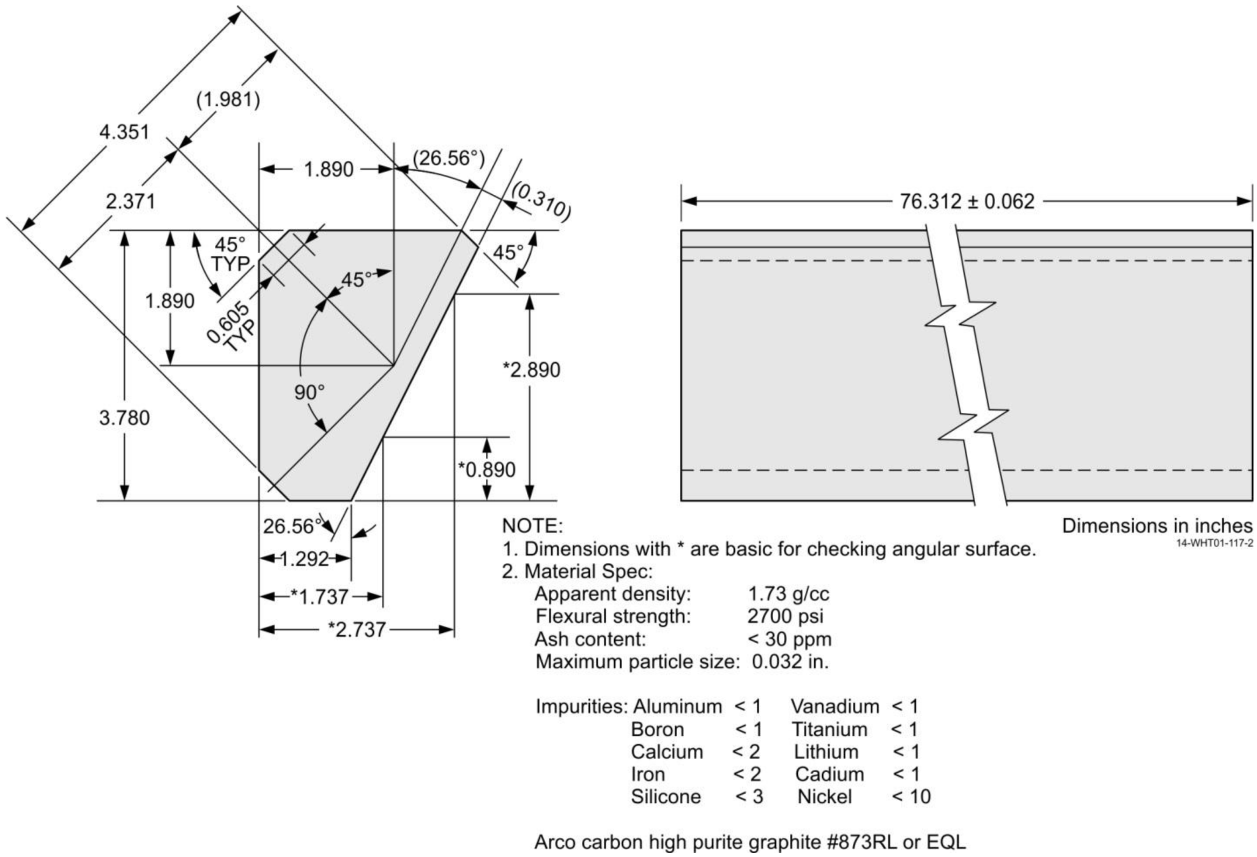


Figure 2.257. ¾ Graphite Element Graphite Plug (DWG# R0269-0204).

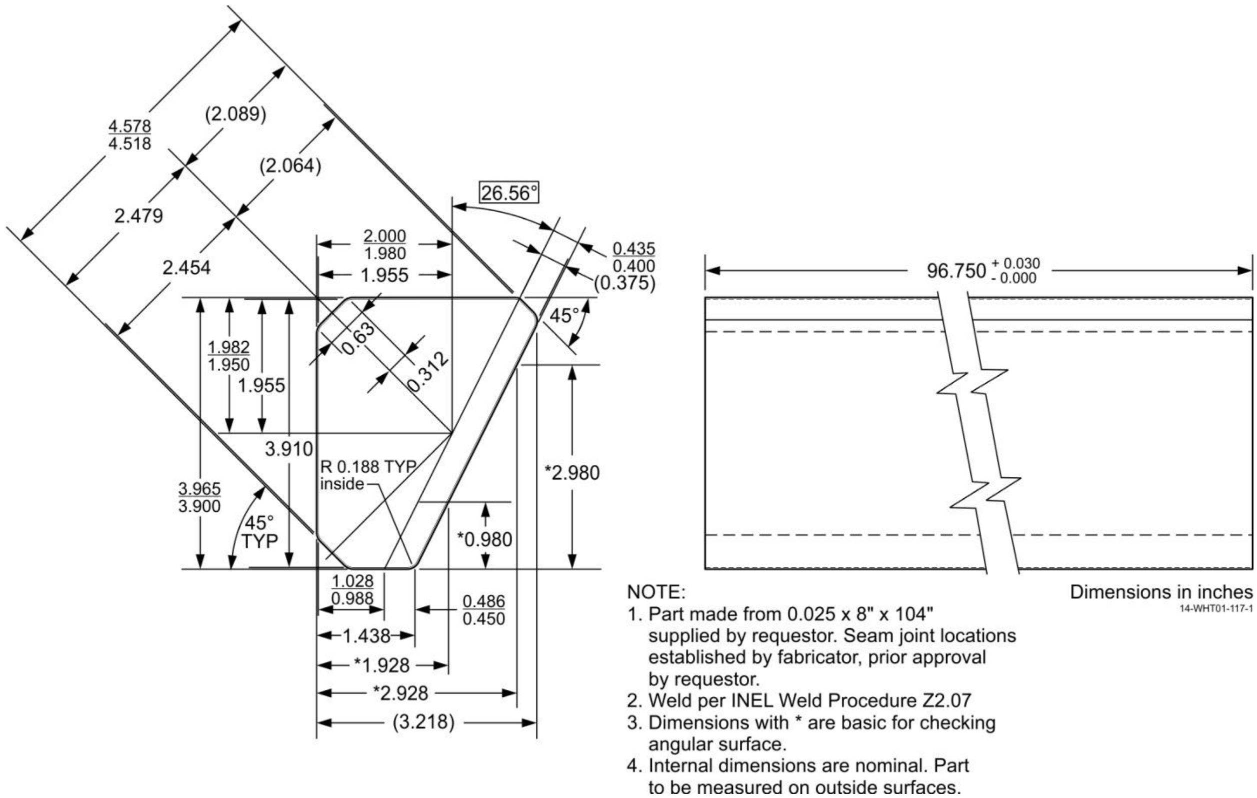


Figure 2.258. ¾ Graphite Element Zirc Tube (DWG# R0269-0205).

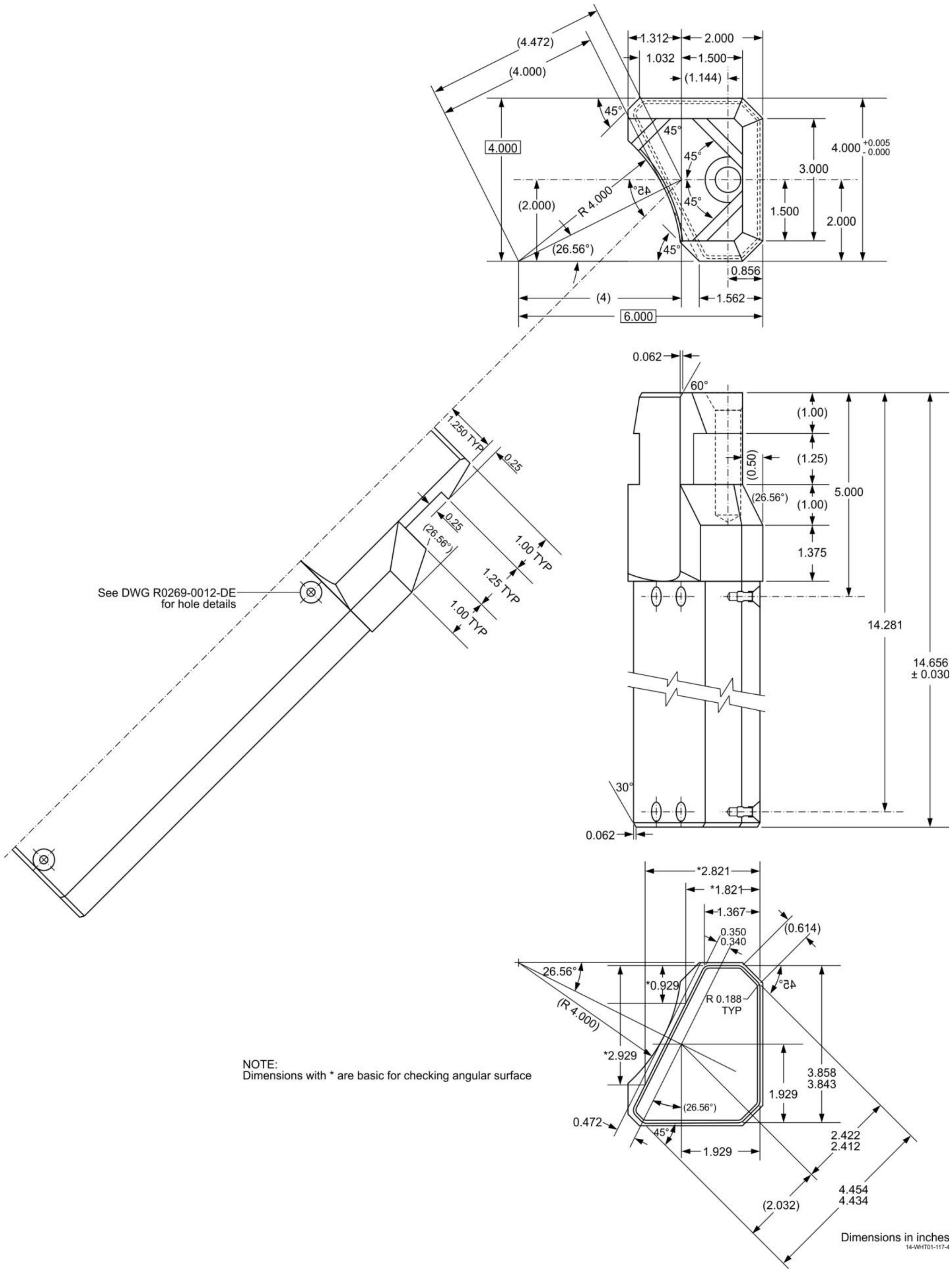


Figure 2.259. ¾ Graphite Element Top Fitting SW/NE (DWG# R0269-0206).

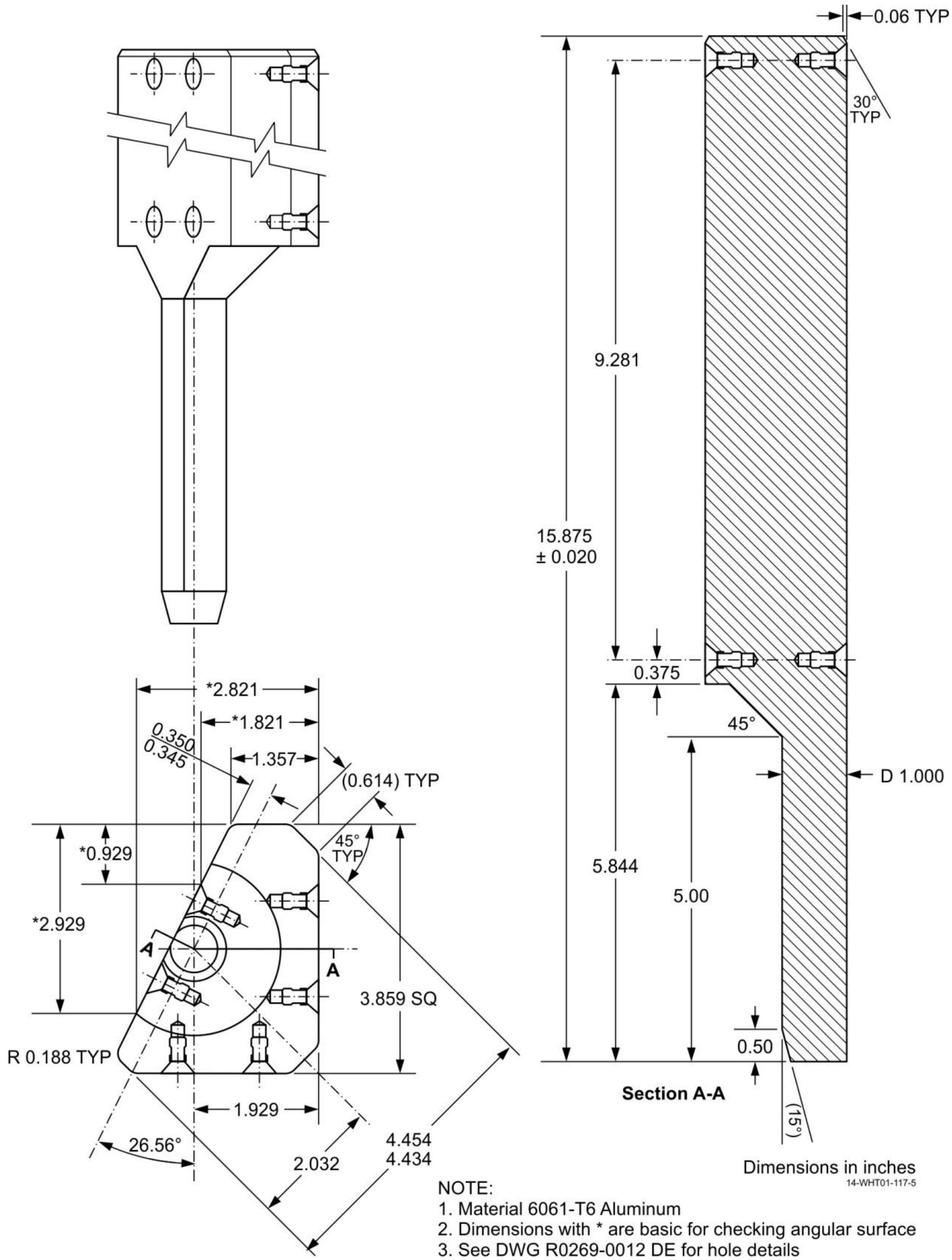


Figure 2.260. ¾ Graphite Element Bottom Fitting SW/NE (DWG# R0269-0207).

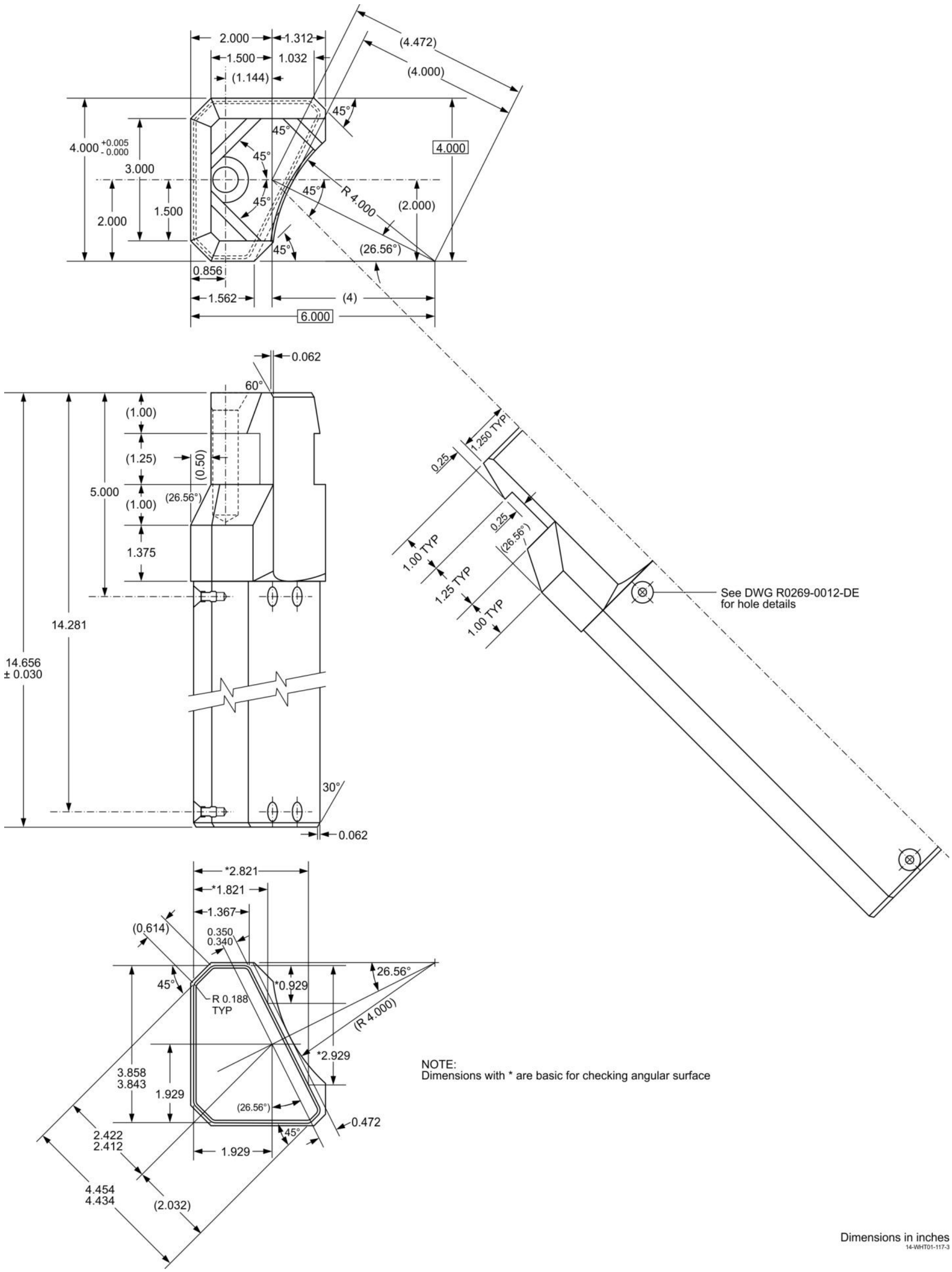


Figure 2.261. ¾ Graphite Element Top Fitting NW/SE (DWG# R0269-0208).

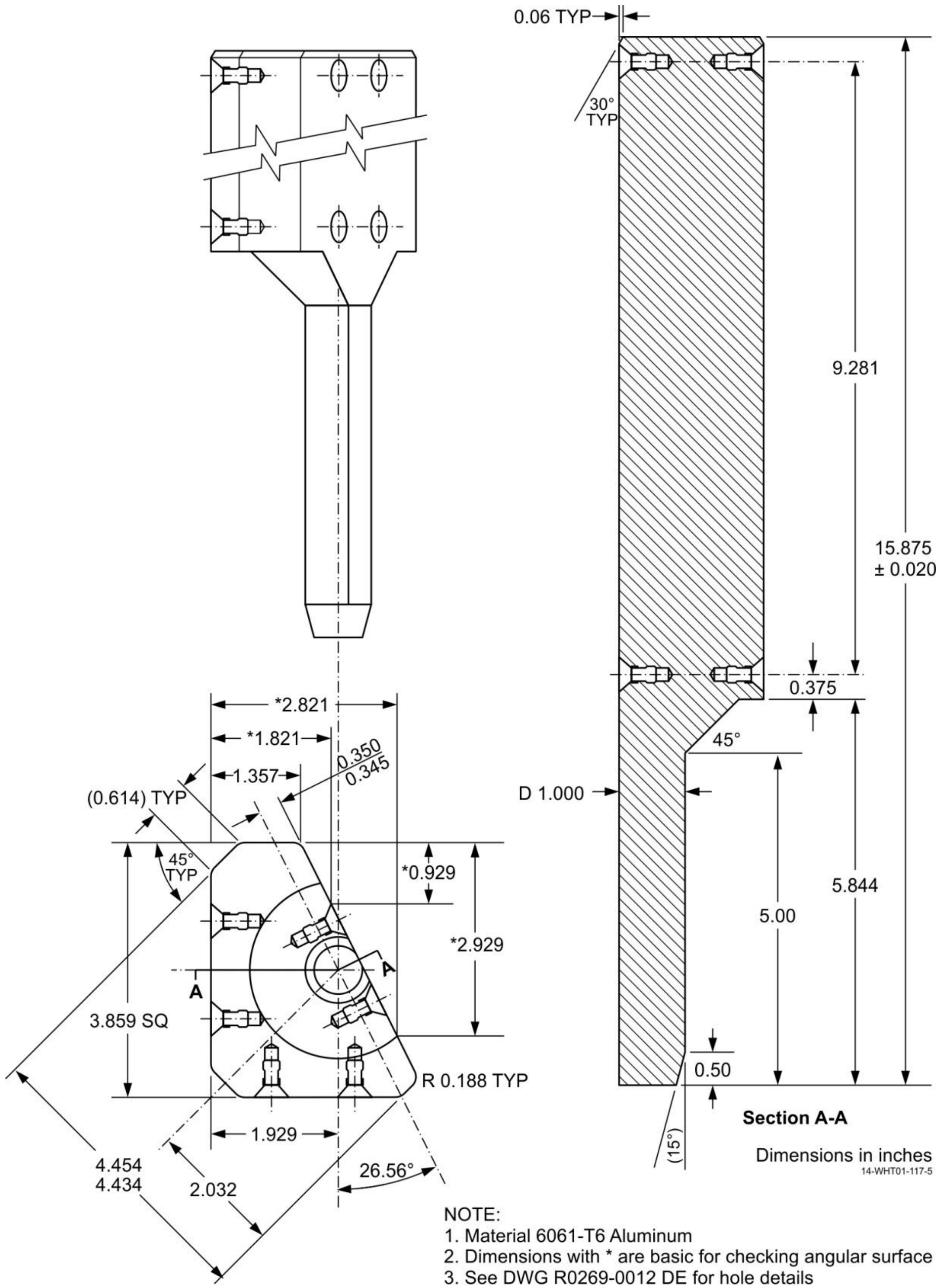


Figure 2.262. ¾ Graphite Element Bottom Fitting NW/SE (DWG# R0269-0209).

2.6.10 Source Assembly

The source assembly is a unique combination of components from a standard dummy assembly and a dummy control rod assembly. The purpose of this assembly is to house a start-up source for the reactor. The assembly is shown in Figure 2.263 with a list of applicable drawings and materials provided in Table 2.22. Individual component drawings are provided in Figures 2.263 through 2.276.

As seen in Figure 2.263, there are two cylindrical graphite plugs: a 2-1/4-in. diameter 23-5/32-in. long plug that sits below the source can, and a 1-15/16-in. diameter 51-5/8-in. long plug that sits inside the source can on top of the source. Original drawings for the source can (RE-1-23167, Fig. 2.264) and the housing top fuel (RE-1-23168, Fig. 2.271) were not available; however, their dimensions were estimated based upon existing drawings and similarity in part design to other typical TREAT assembly components.

A plutonium-beryllium source (10^6 n/sec) was used for initial TREAT startup. After initial criticality, a stronger (1.5×10^7 n/sec) polonium beryllium source was used [Freund 1960]. The Po-Be source was encased in a steel jacket (0.7 in. diameter by 0.7 in. long) [MacFarlane 1958]. Later a commercially available 2.5 Ci americium-beryllium source encased in a steel jacket was used [ANL 1992].

Table 2.22. Source Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.263	RE-1-23166	Source Fuel Assembly	--
1	2.263	--	Plug	CP-2 Graphite
1	2.263	--	Small Plug	CP-2 Graphite
1	2.263	--	Source	--
1	2.264	RE-1-23167	Source Can	Zr-3
1	2.265	RE-1-21881	Bottom Fuel Fitting	Al-1100
1	2.266	RE-1-21768	Long Plug Part #2	CP-2 Graphite
1	2.267	RE-1-22739	Plain Short Plug	CP-2 Graphite
1	2.268	RE-1-22736	End Tube Part #2	Al-6063
1	2.268	RE-1-22736	End Tube Part #2	Al-6063
1	2.269	RE-1-22606	Short Lower Plug	CP-2 Graphite
1	2.270	RE-1-22607	Long Lower Plug Part #2	CP-2 Graphite
1	2.271	RE-1-23168	Housing Top Fuel	Al-1100
1	2.272	RE-1-23169	Cap	Al-1100
1	2.273	RE-1-23171	Source Section	Zr-3
2	2.270	RE-1-22607	Long Lower Plug Part #2	CP-2 Graphite
1	2.270	RE-1-22607	Long Lower Plug Part #3	CP-2 Graphite
8	2.274	RE-1-22699	Tab	Zr-3
1	2.275	RE-1-24150	Spacer	Zr-3
1	2.276	RE-1-24160	Spacer	Zr-3

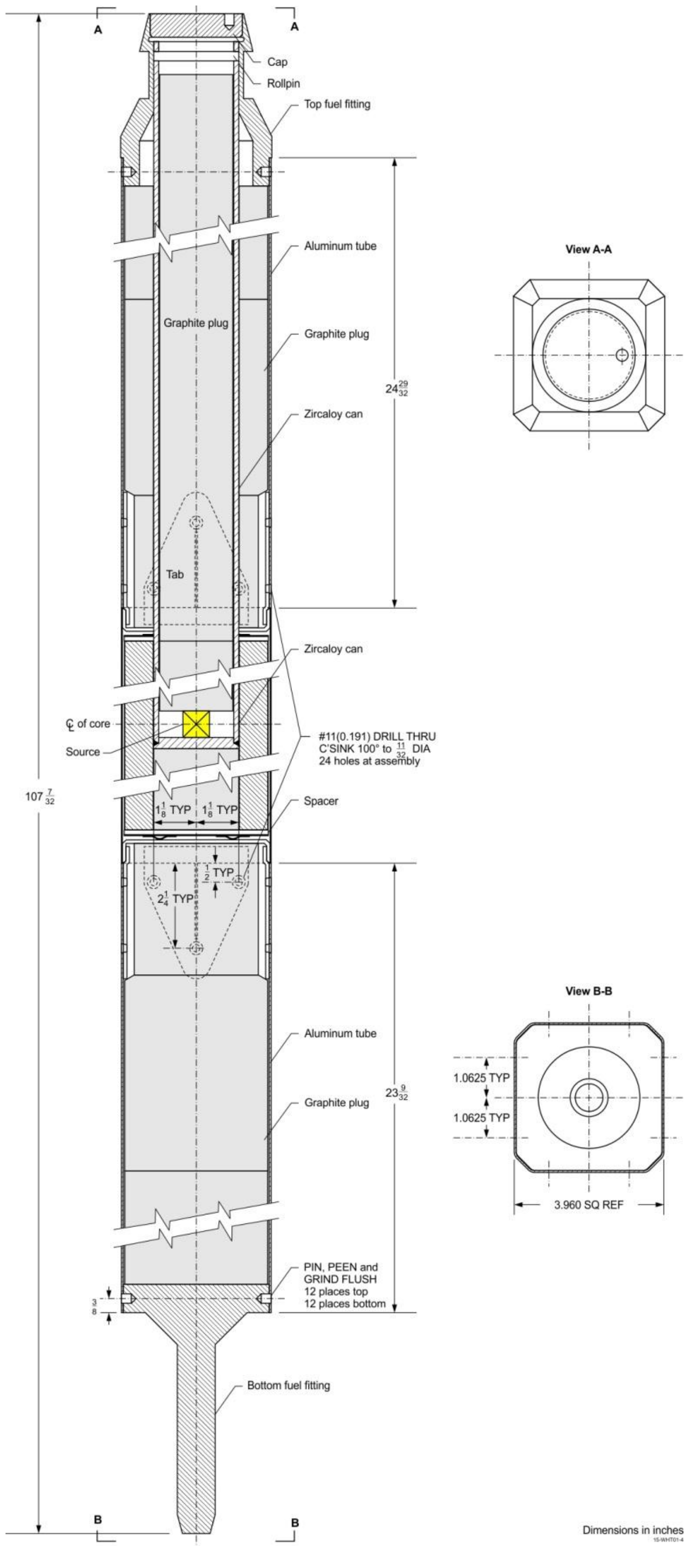


Figure 2.263. Source Assembly (DWG# RE-1-23166).

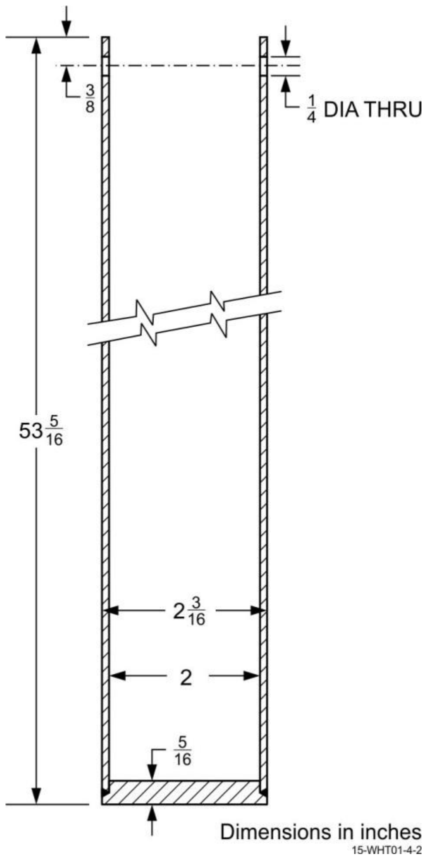


Figure 2.264. Source Can (DWG# RE-1-23167, estimated).

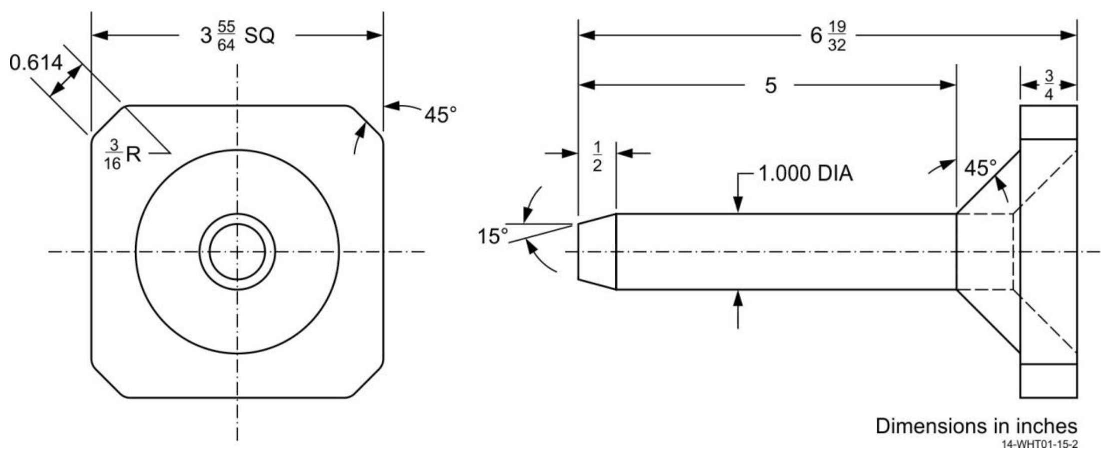


Figure 2.265. Bottom Fuel Fitting (DWG# RE-1-21881).

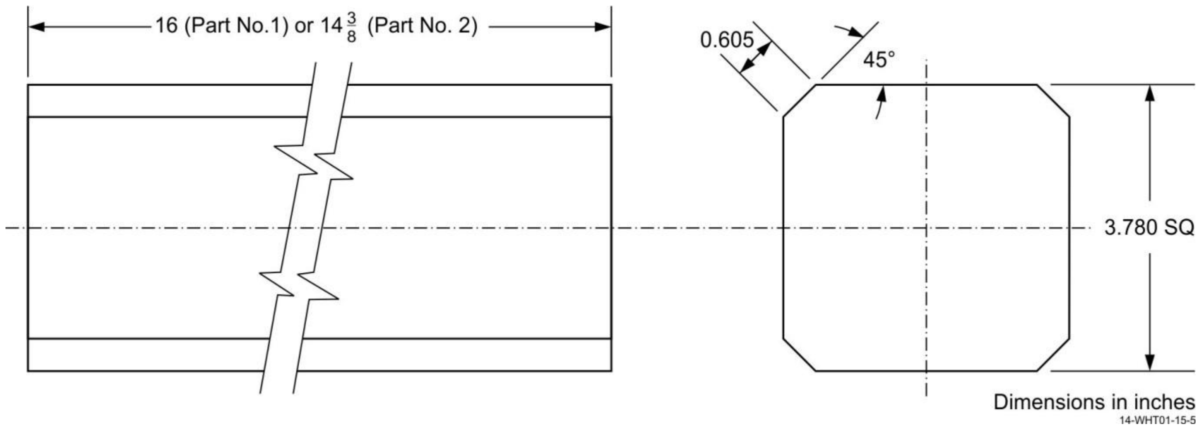


Figure 2.266. Long Plug (DWG# RE-1-21768).

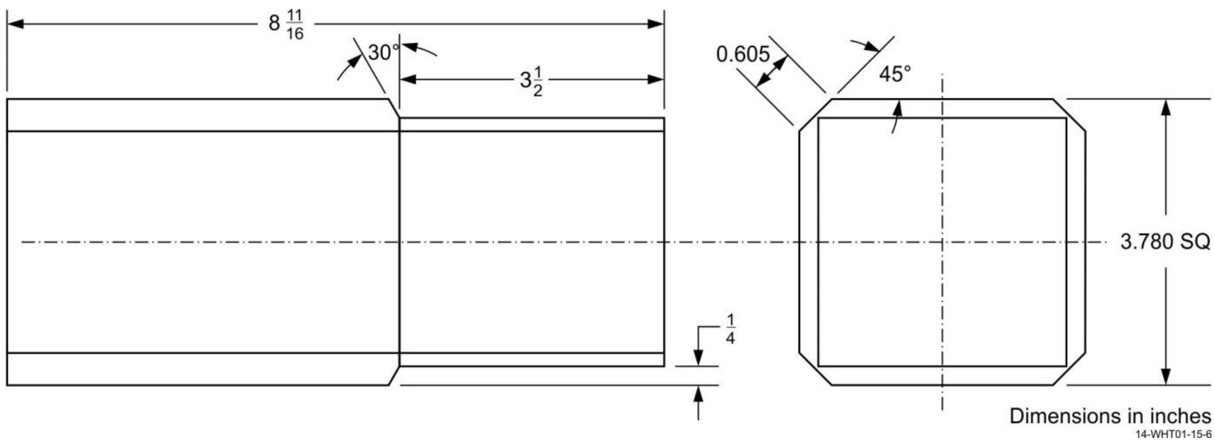


Figure 2.267. Plain Short Plug (DWG# RE-1-22739).

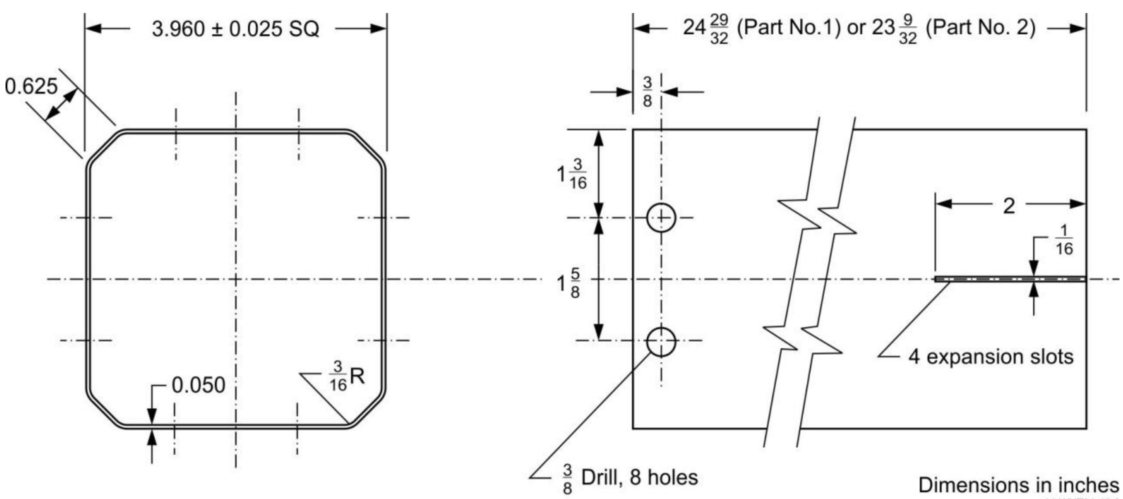


Figure 2.268. End Tube (DWG# RE-1-22736).

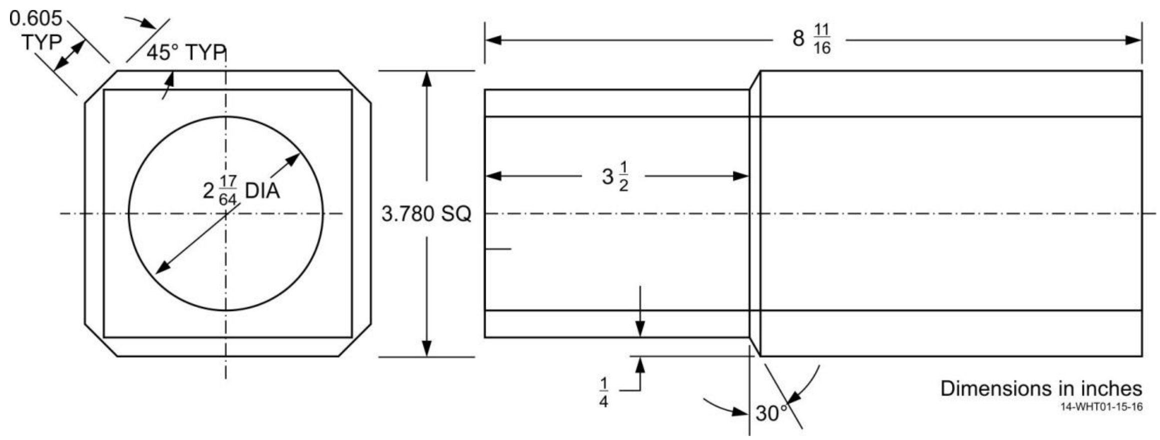


Figure 2.269. Short Lower Plug (DWG# RE-1-22606).

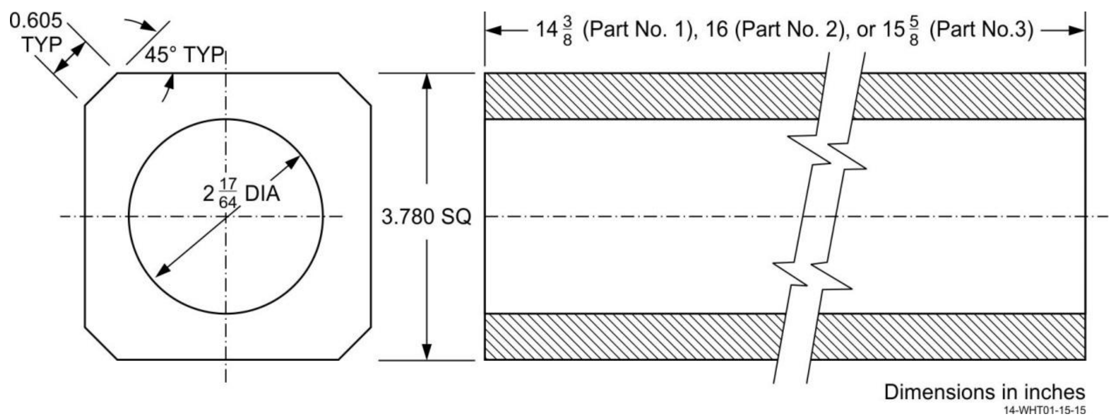


Figure 2.270. Long Lower Plug (DWG# RE-1-22607).

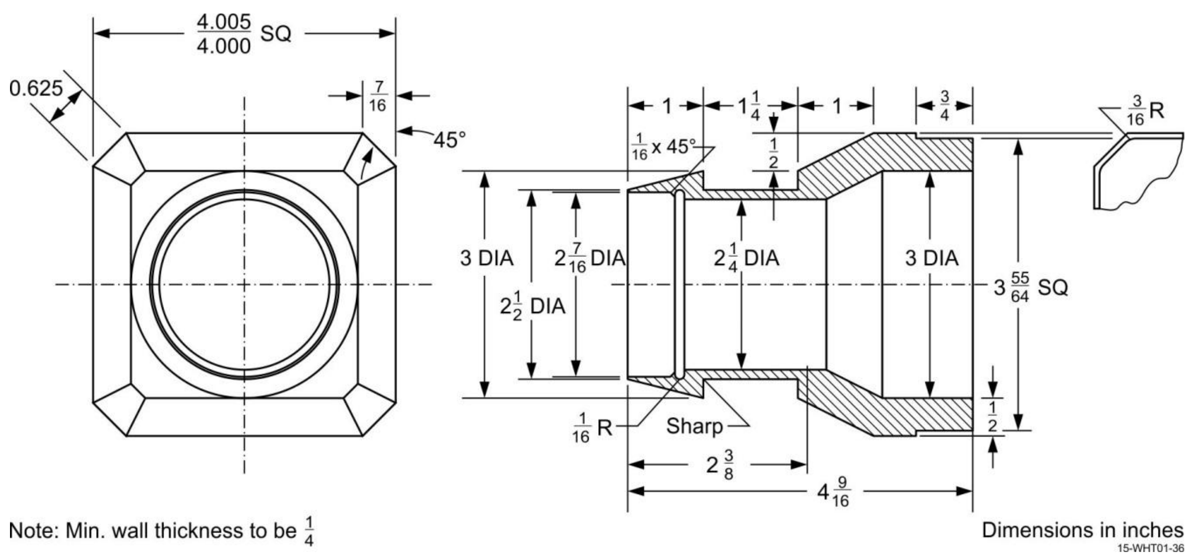


Figure 2.271. Housing Top Fuel (DWG# RE-1-23168, estimate).

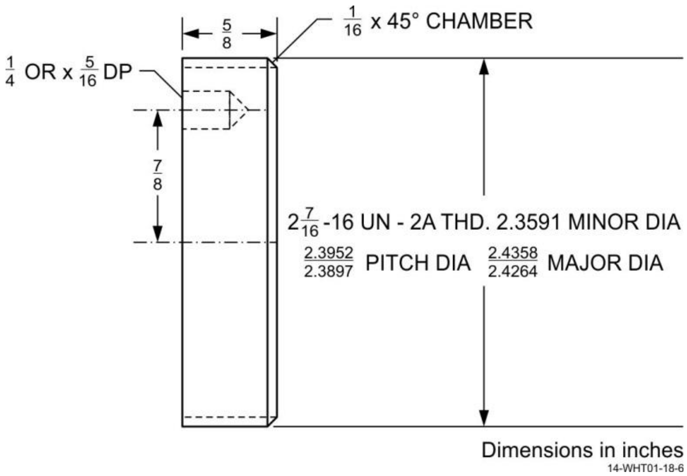


Figure 2.272. Cap (DWG# RE-1-23169).

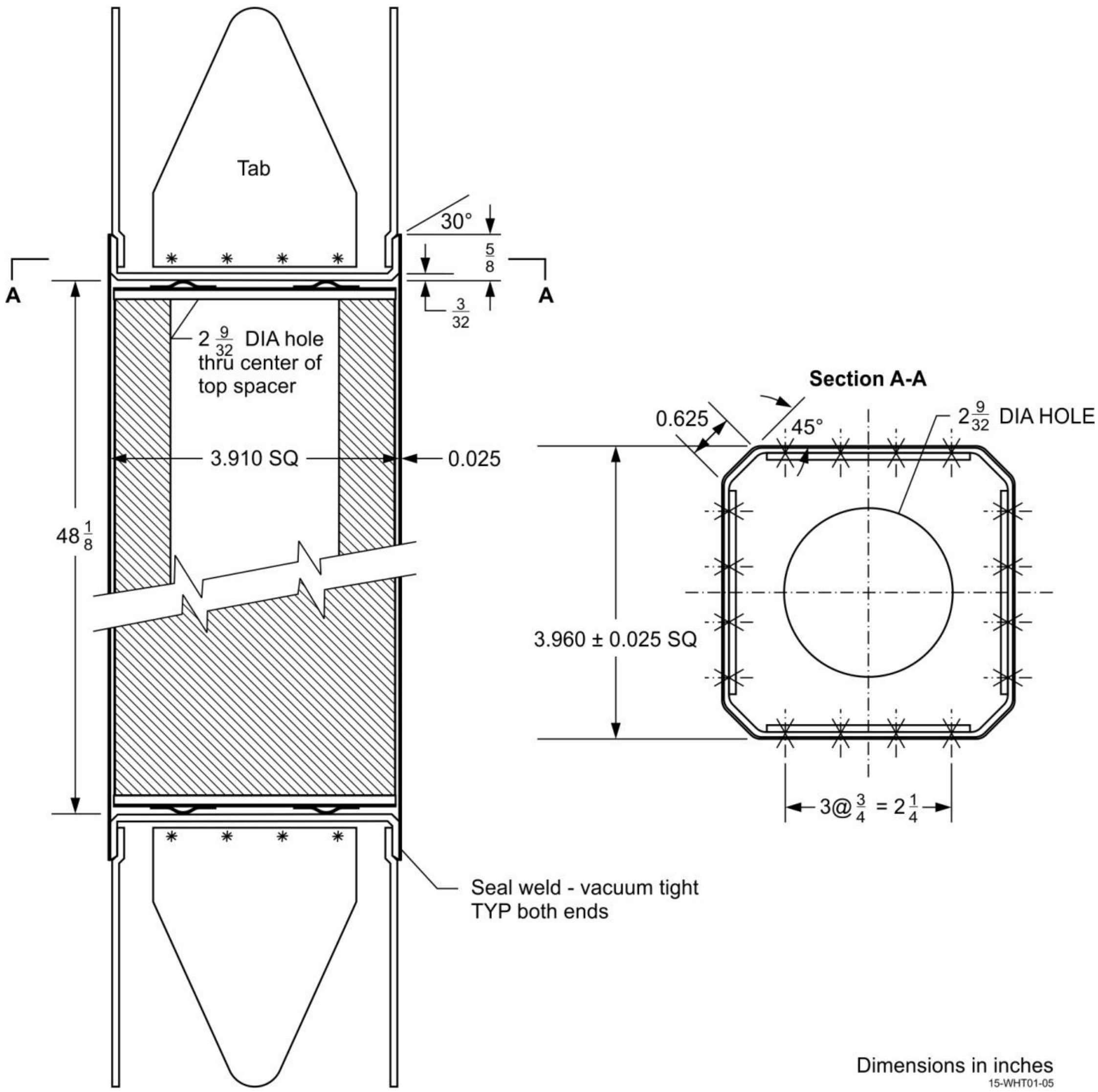


Figure 2.273. Source Section (DWG# RE-1-23171).

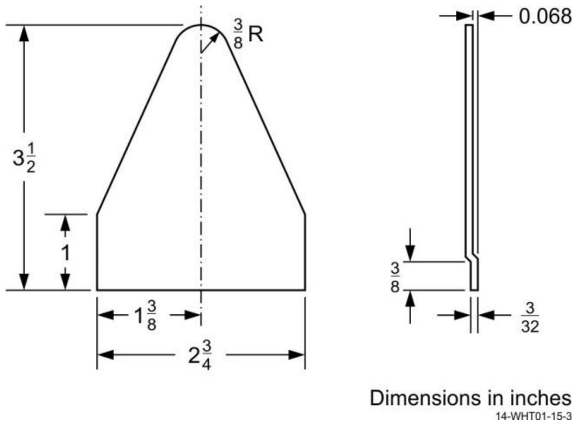


Figure 2.274. Tab (DWG# RE-1-22699).

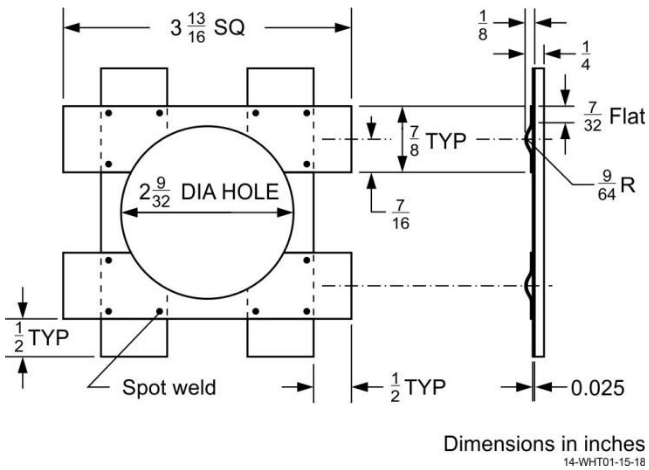


Figure 2.275. Spacer (DWG# RE-1-24150).

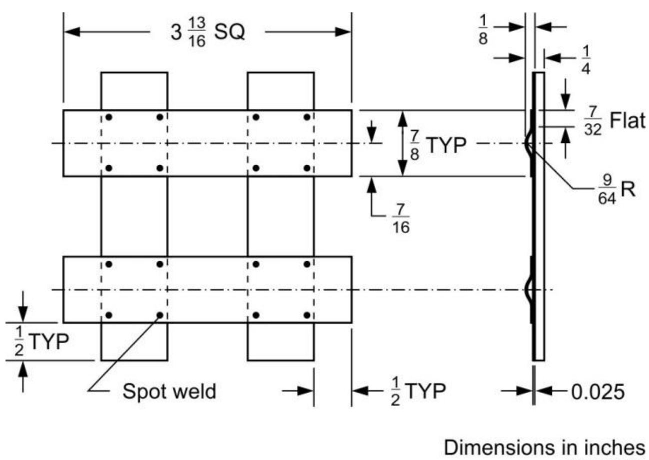


Figure 2.276. Spacer (DWG# RE-1-24160).

2.7 Shielding Assembly

The shielding assembly is not used during normal TREAT reactor operations. It is placed into the core to provide shielding between reactor operations when radiation exposure to personnel during core rearrangement is necessary. The assembly is shown in Figure 2.277. As indicated in Table 2.23, lead shot is contained within the element to serve as radiation shielding.

Table 2.23. Shielding Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.277	RE-1-24966	Shielding Dummy Element	Mild Steel
--	--	--	Lead Shot	Lead Shot

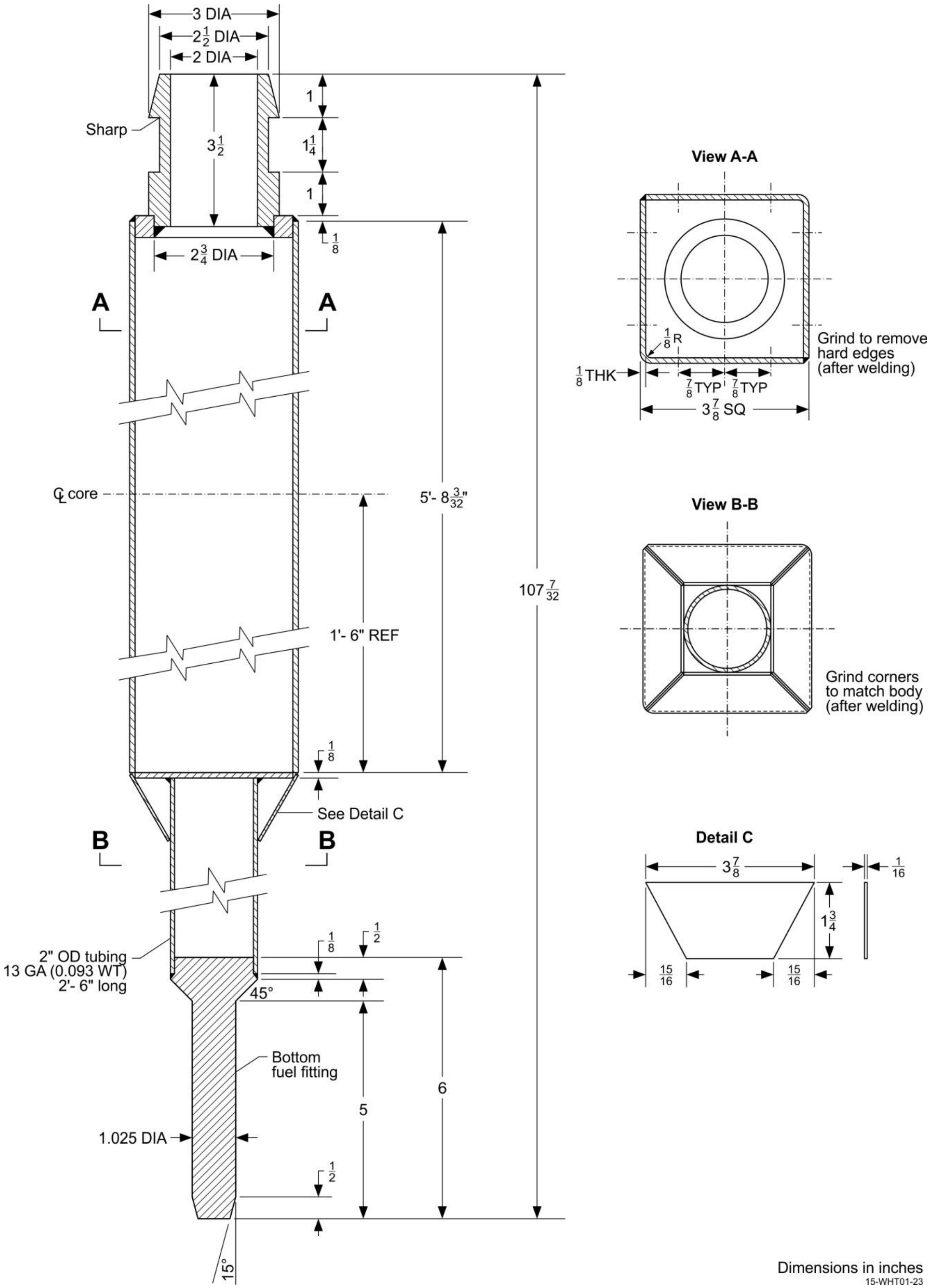


Figure 2.277. Shielding Dummy Element (DWG# RE-1-24966).

2.8 Control Rods

It should be noted that drawing S3332-7141 (not provided in this report) was for the upgrade TREAT core and not actually implemented. The existing control rod assembly is in ID-ID-13461 (Figure 2.278) for the current shutdown/compensation rods and transient rods.

As shown in Figure 2.278, the control rod consists of an upper grappling adapter, followed by a steel-clad poison section, then a Zircaloy-clad graphite section and finally two steel-clad graphite sections before connecting at the base to the control rod drives. Individual control rod components are summarized in Table 2.24 and shown in Figures 2.279 through 2.285.

The poison steel clad poison section and upper follower sections in the initial control rods were clad in 2-mils-thick Kannigen nickel plating. Later control rods were chrome plated (7-mils-thick) instead.

It should also be noted that in the minimum critical mass core and some of the early TREAT measurements, Control Rod Number I was utilized. The difference is that the bottom 18 in. of B4C was replaced with graphite to shorten the poison section length to 42 in. Thus in the fully withdrawn state, the poison section was removed completely out of the upper reflector.

Table 2.24. Control Rod Components.

Quantity	Figure	DWG#	Component	Material
1	2.278	ID-ID-13461	Control Rod Number II	--
3	2.279	RE-1-23187	Screw – Rework	18-8 SST
1	2.280	Z0720-0259	Adapter Control Rod Grapple	STL AISI 1010-1020
1	2.281	RE-1-22250	Poison Section	Mild Steel, B_4C, Plating
1	2.282	RE-1-22088	Zirconium Follower	Zr-3, CP-2 Graphite
1	2.283	RE-1-24962	P1 Upper Follower (Transient Rods)	Mild Steel, CP-2 Graphite, Plating
1	2.283	RE-1-24962	P2 Upper Follower (Other Control Rods)	Mild Steel, CP-2 Graphite, Plating
1	2.284	ID-IC-13463	Follower Control Rod #2	Mild Steel
1	2.285	ID-IB-13435	Adapter – Control Rod	STL AISI 1015

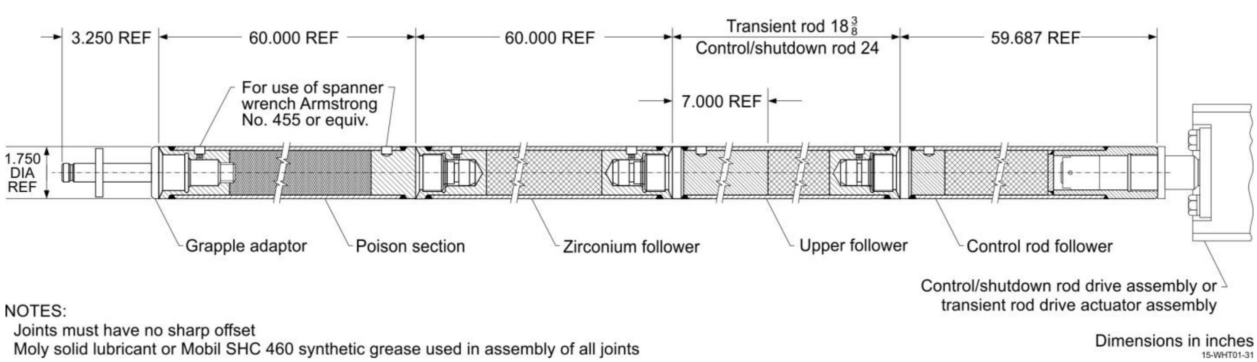


Figure 2.278. Control Rod Number II (DWG# ID-ID-13461).

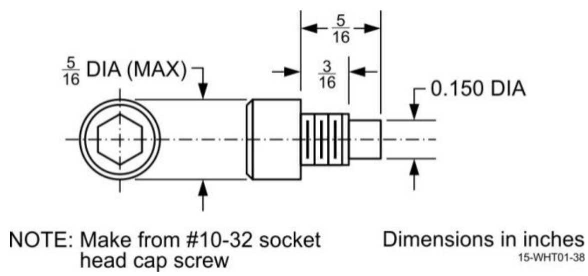


Figure 2.279. Screw Rework (DWG# RE-1-23187).

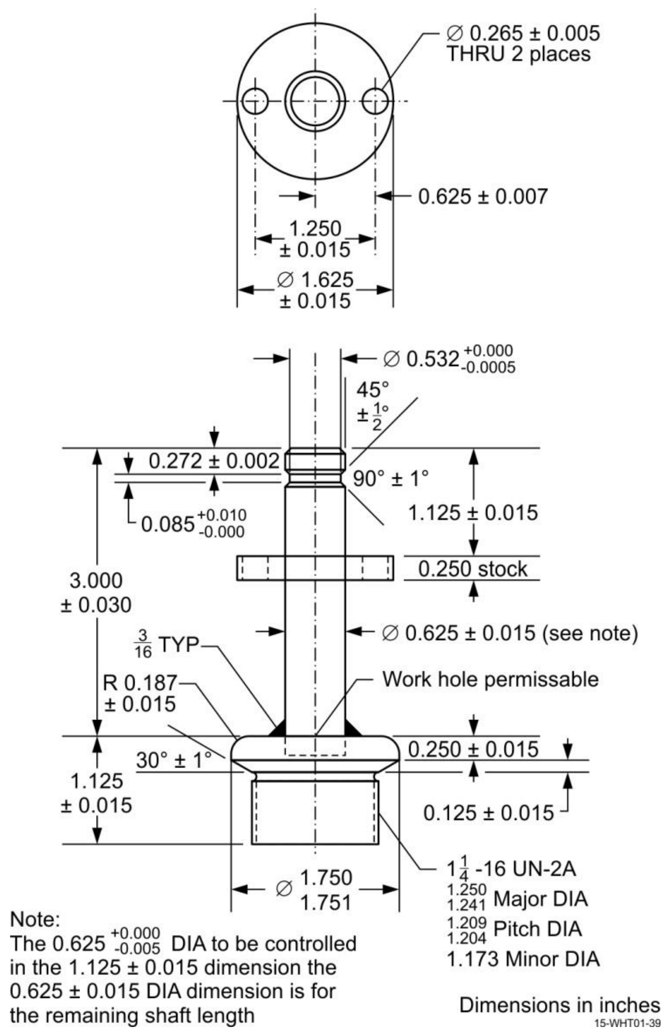
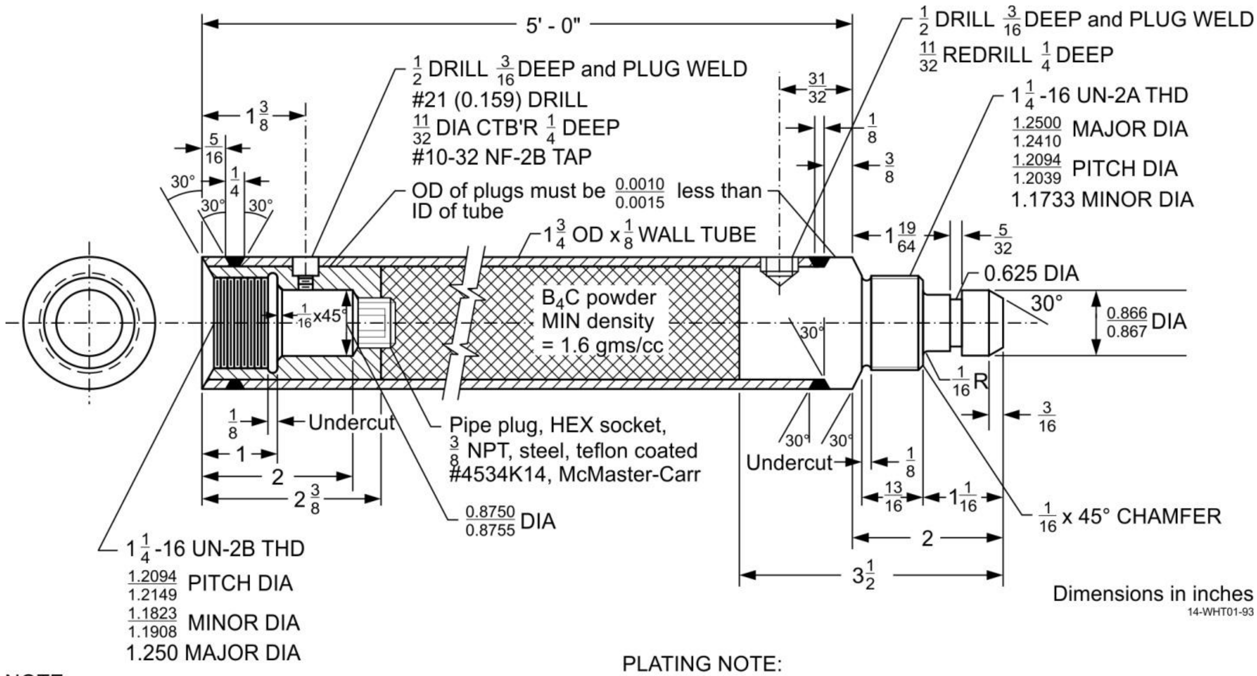


Figure 2.280. Adapter Control Rod Grapple (DWG# Z0720-0259).



NOTE:
1. Compact with B_4C to min density of 1.6 gms/cc, press in top end fitting and clamp down tightly (so that no void between powder and plug exist) and weld. Welds must be gas tight. Leak test. X-ray. Additional fill and compacting if required shall be done through 3/8 NPT tapped hole.
2. Machining to be done after welding.

PLATING NOTE:
0.002 Kannigen plating (for RE-1-21729-D assembly only)
1. Chromium shall be deposited for maximum adherence according to the latest ASTM-B-177 specification.
2. Finished plating must be concentric with the shaft. Thickness of the plating shall be 0.0007 ± 0.002 in.
3. The plated chromium hardness shall be 1000 ± 50 BHN.
4. The chromium plate shall be finished to 5 to 8 micro inches.

Figure 2.281. Poison Section (DWG# RE-1-22250).

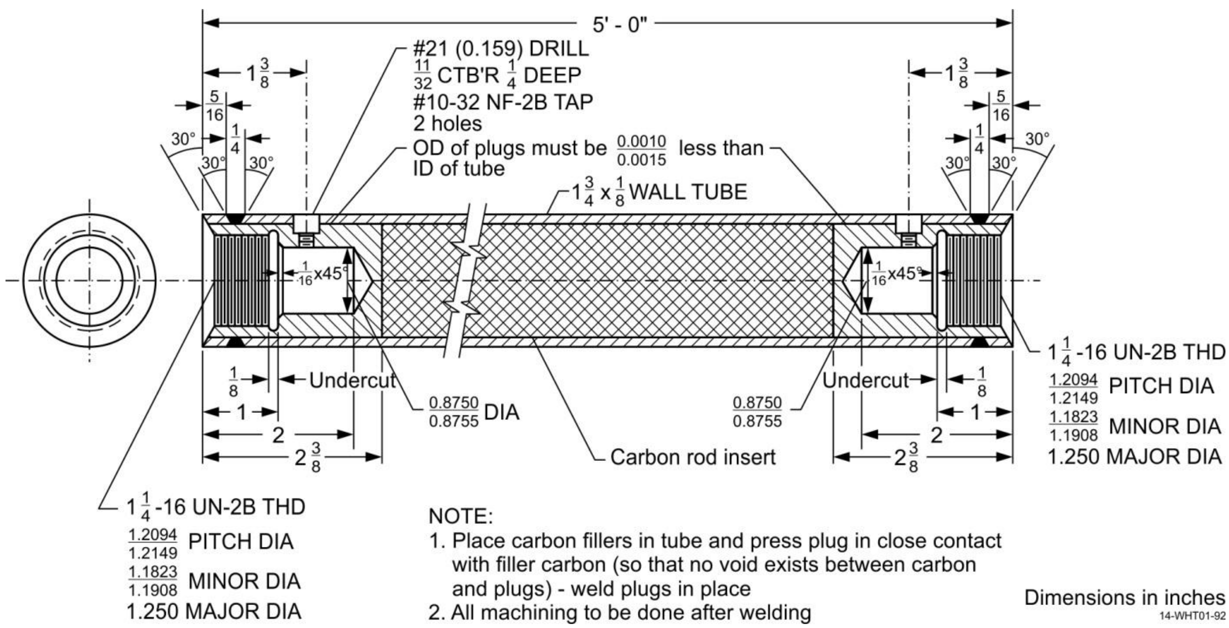


Figure 2.282. Zirconium Follower (DWG# RE-1-22088).

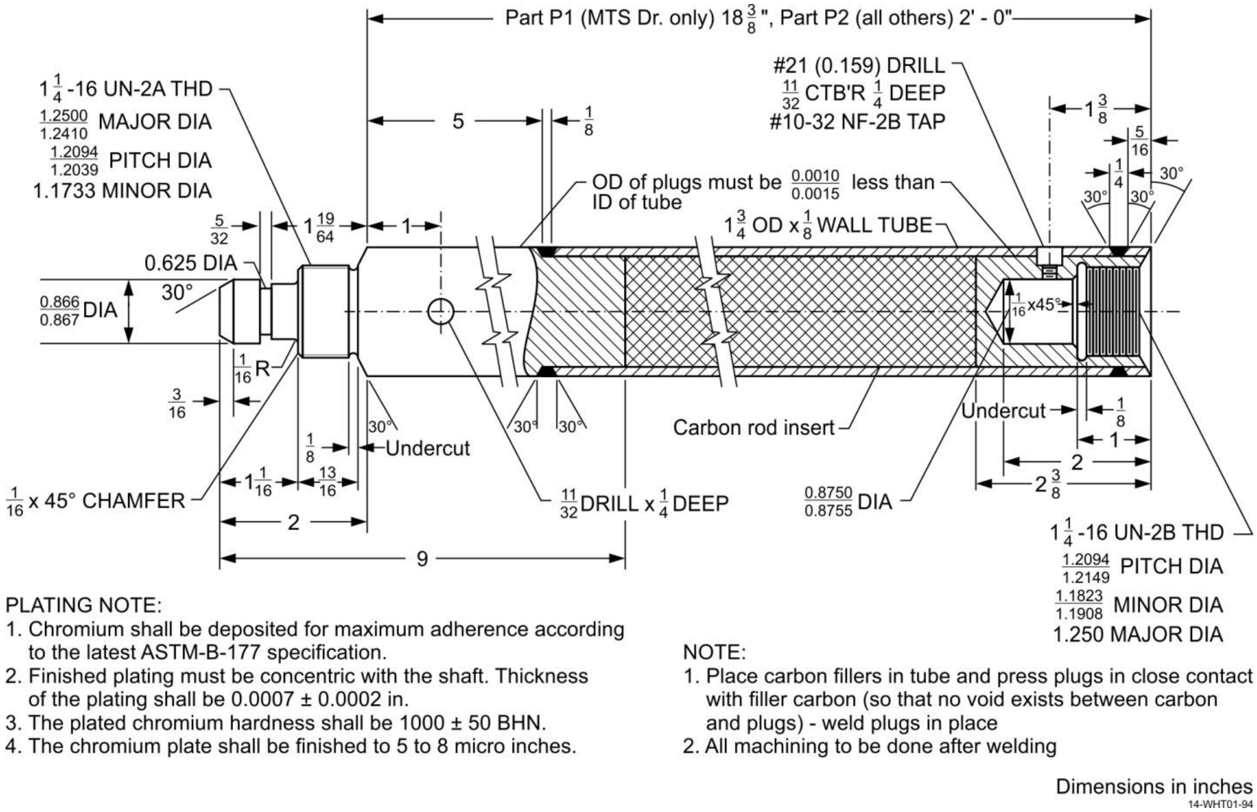


Figure 2.283. P1 (Transient Rods) & P2 (Other Control Rods) Upper Followers (DWG# RE-1-24962).

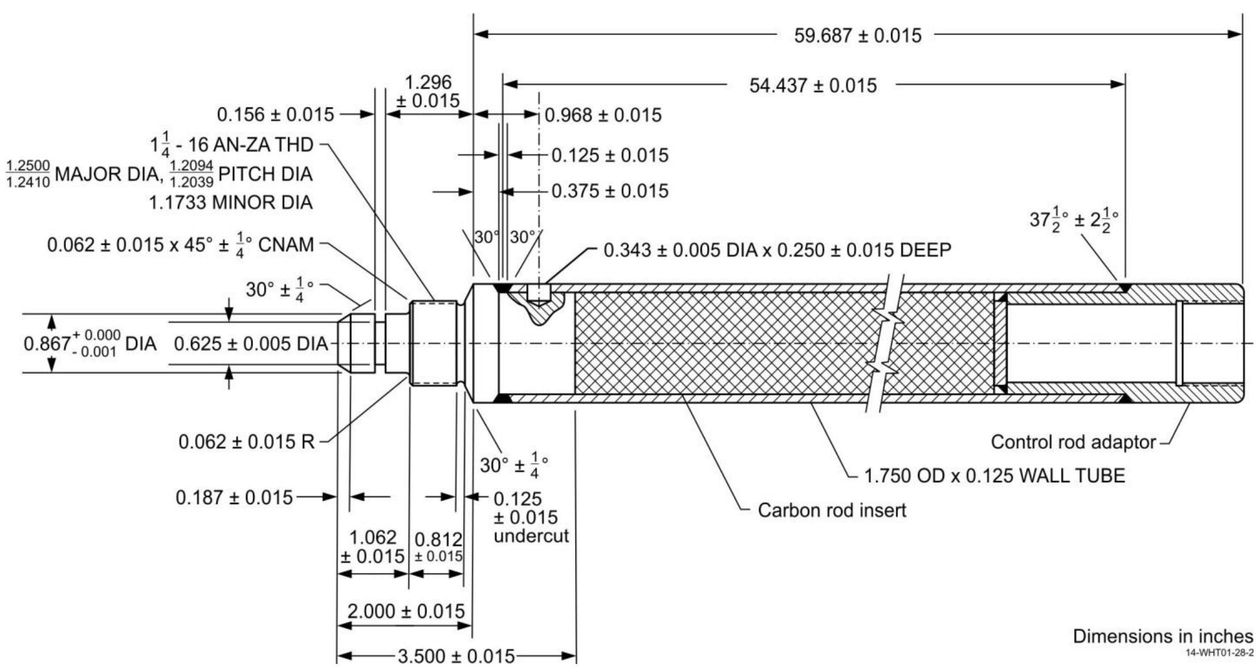


Figure 2.284. Follower Control Rod #2 (DWG# ID-IC-13463).

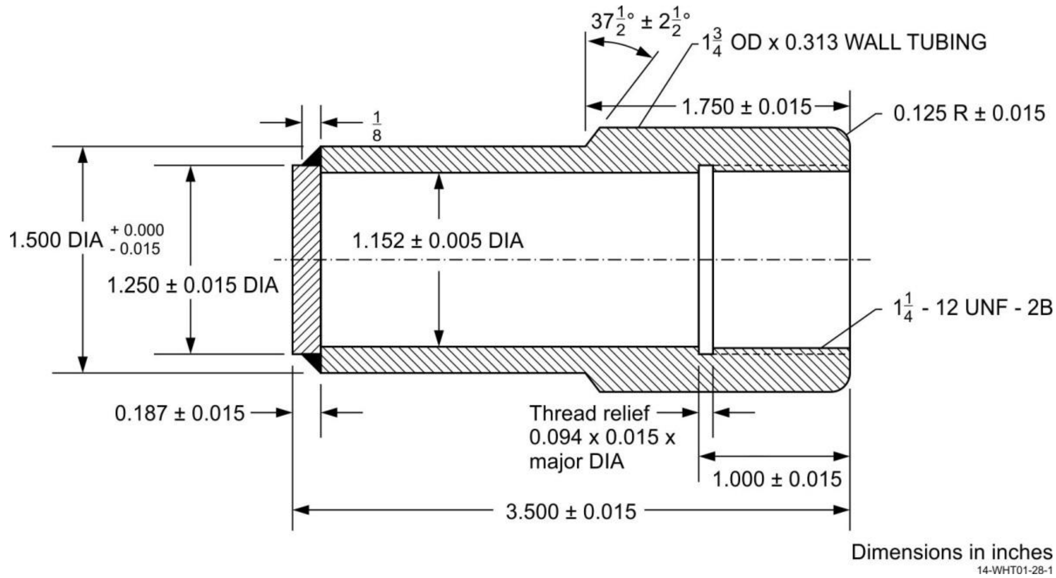


Figure 2.285. Adapter – Control Rod (DWG# ID-IB-13435).

2.9 Permanent Reflector

The permanent graphite reflector provides radial neutron reflection surrounding the reactor core assemblies. The reflector was constructed from graphite blocks allowing for penetrations to the core for instrumentation/detectors and experiments. When the experimental holes extending from the south, west, and north core faces were not in use, they were closed with graphite gates in the permanent reflector. Matching penetrations in the concrete shielding were closed with concrete blocks. The east face of the reactor core was the thermal column, which consisted of additional graphite extending through the reactor concrete shielding. Aluminum and steel sheeting provided structural support for the graphite blocks; steel angle supports provided the rigid framework to support the permanent reflector sheeting.

2.9.1 Graphite Components

The permanent reflector (see Figure 2.286) is formed by stacking 4-in.-square graphite blocks (sometimes called stringers) to a height of 7 ft. 8 in., 2 ft. thick. Special blocks were necessary to accommodate penetrations in the permanent reflector for structural support (see Figure 2.287), instrumentation (see Figure 2.288), and to accommodate access gates for experimentation and measurement (see Figures 2.289 through 2.291).

Table 2.25. Permanent Reflector Graphite Components.

Quantity	Figure	DWG#	Component	Material
1	2.286	RE-1-23095	Permanent Reflector	--
As Needed	--	--	Standard Graphite Block	CP-2 Graphite
46	2.287	RE-1-23102	Special Block Tie Bolt	CP-2 Graphite
24	2.288	RE-1-23105	Special Block Instrument Hole	CP-2 Graphite
As Needed	2.289	RE-1-24212	Special Block Small	CP-2 Graphite
As Needed	2.290	RE-1-24213	Special Block Large	CP-2 Graphite
As Needed	2.291	RE-1-24214	Special Block Notched	CP-2 Graphite

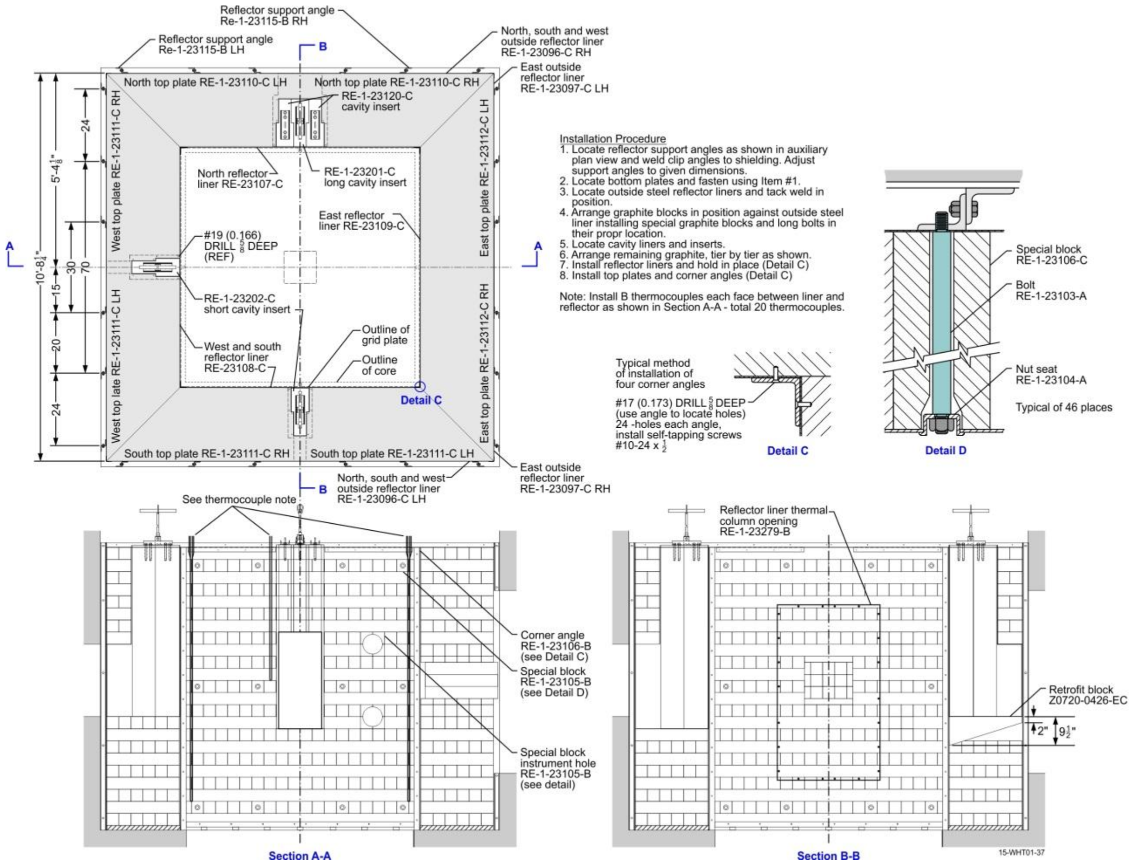


Figure 2.286. Permanent Reflector (DWG# RE-1-23095).

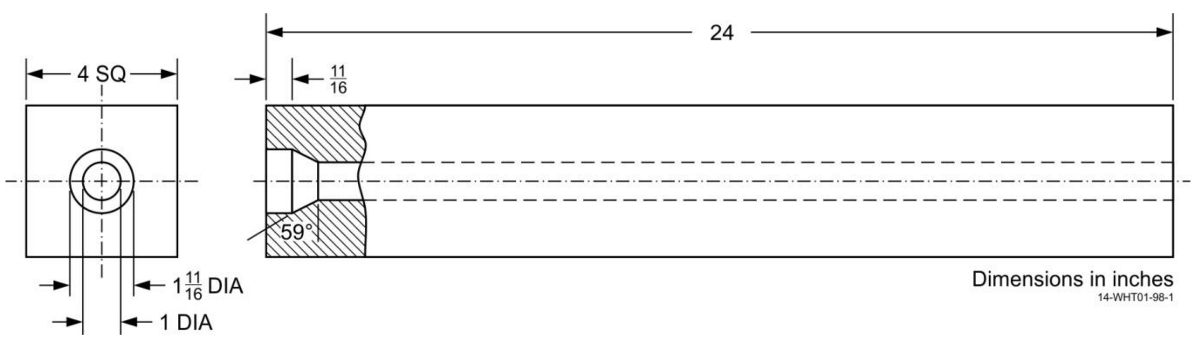


Figure 2.287. Special Block Tie Bolt (DWG# RE-1-23102).

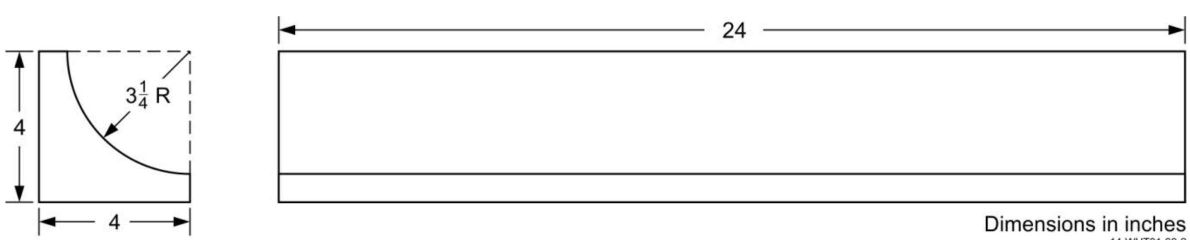


Figure 2.288. Special Block Instrument Hole (DWG# RE-1-23105).

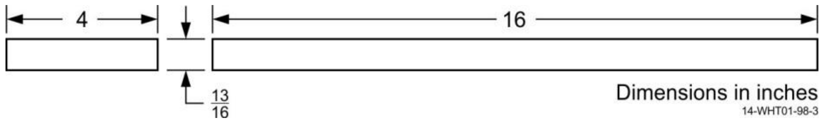


Figure 2.289. Special Block Small (DWG# RE-1-23212).

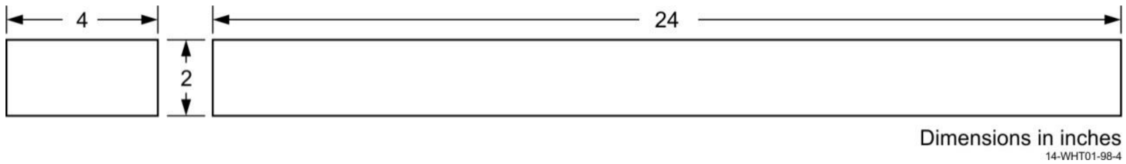


Figure 2.290. Special Block Large (DWG# RE-1-23213).

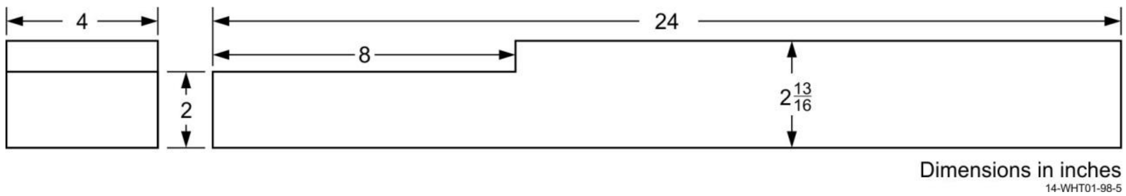


Figure 2.291. Special Block Notched (DWG# RE-1-23214).

2.9.2 Reflector Lining and Support

The permanent reflector is supported by angle iron spacers and sheet metal framework that is anchored to the steel liner of the concrete shield cavity. The permanent reflector is supported by 1/8-in.-thick aluminum support pans and vertical angle iron spacers. The support pans rest on 7/8-in.-thick aluminum bars which are shimmed up from the concrete to level the pans (see Figures 2.306 and 2.307). The angle irons are pinned to clips, which in turn are welded to the steel liner. Steel liner sheets (1/16-in.-thick, see Figures 2.292 through 2.295) are tack-welded to the angle irons to provide vertical support for the graphite blocks. The gap formed by the angle iron spacers and the aluminum bars beneath the support pans provide a passage for coolant to flow between the reflector and concrete shield. A 1/16-in.-thick aluminum cover sheet (see Figures 2.303 through 2.305) is installed on top of the permanent reflector graphite blocks and 1/8-in.-thick aluminum retaining sheets (see Figures 2.300 through 2.302) are placed on the inner (core-side) surface. The retaining sheets are held in place by aluminum tie bolts (see Figure 2.298) that extend through the graphite stringers and are fastened to the vertical angle iron spacers. The retaining sheets are drilled and the graphite stringers are recessed (see Figure 2.287) to accommodate cupped washers for the holddown nuts (see Figure 2.299). The top cover sheets are attached with sheet metal screws. Aluminum sheet guides (1/16-in.-thick) are provided for the moveable graphite blocks (see Figures 2.296 and 2.297). The horizontal instrument holes are formed by machining a quarter-circle from four stringers (see Figure 2.288) and placing them surrounding aluminum tubes (6 in. diameter, 1/8 in. thick) which extend into the concrete shield [Freund 1960].

Drawings of the angle iron spacers and clips are not provided. The location of the angle iron support structure in relation to the TREAT reactor core and permanent reflector can be seen in Figure 2.286.

Table 2.26. Permanent Reflector Lining and Support.

Quantity	Figure	DWG#	Component	Material
6	2.292	RE-1-23096	Steel Reflector Liner N, S & W	Mild Steel
2	2.293	RE-1-23097	Steel Reflector Liner E	Mild Steel
2	2.294	RE-1-23098	Steel Reflector Liner W & S	Mild Steel
1	2.295	RE-1-23099	Steel Reflector Liner N	Mild Steel
1	2.296	RE-1-23100	Al N Cavity Reflector Liner	Al-1100
2	2.297	RE-1-23101	Al S & W Cavity Reflector Liner	Al-1100
46	2.298	RE-1-23103	Tie Bolt	Al-1100
46	2.299	RE-1-23104	Nut Seat	Al-1100
1	2.300	RE-1-23107	Reflector Liner North Face	Al-1100
2	2.301	RE-1-23108	Reflector Liner West & South Face	Al-1100
1 each	2.302	RE-1-23109 and RE-1-24215	Reflector Liner East Face and Face Plate	Al-1100
2	2.303	RE-1-23110	North Top Plate	Al-1100
4	2.304	RE-1-23111	West & South Top Plate	Al-1100
2	2.305	RE-1-23112	East Top Plate	Al-1100
4	2.306	RE-1-23118	RH Bottom Plate	Al-1100
4	2.307	RE-1-23119	LH Bottom Plate	Al-1100

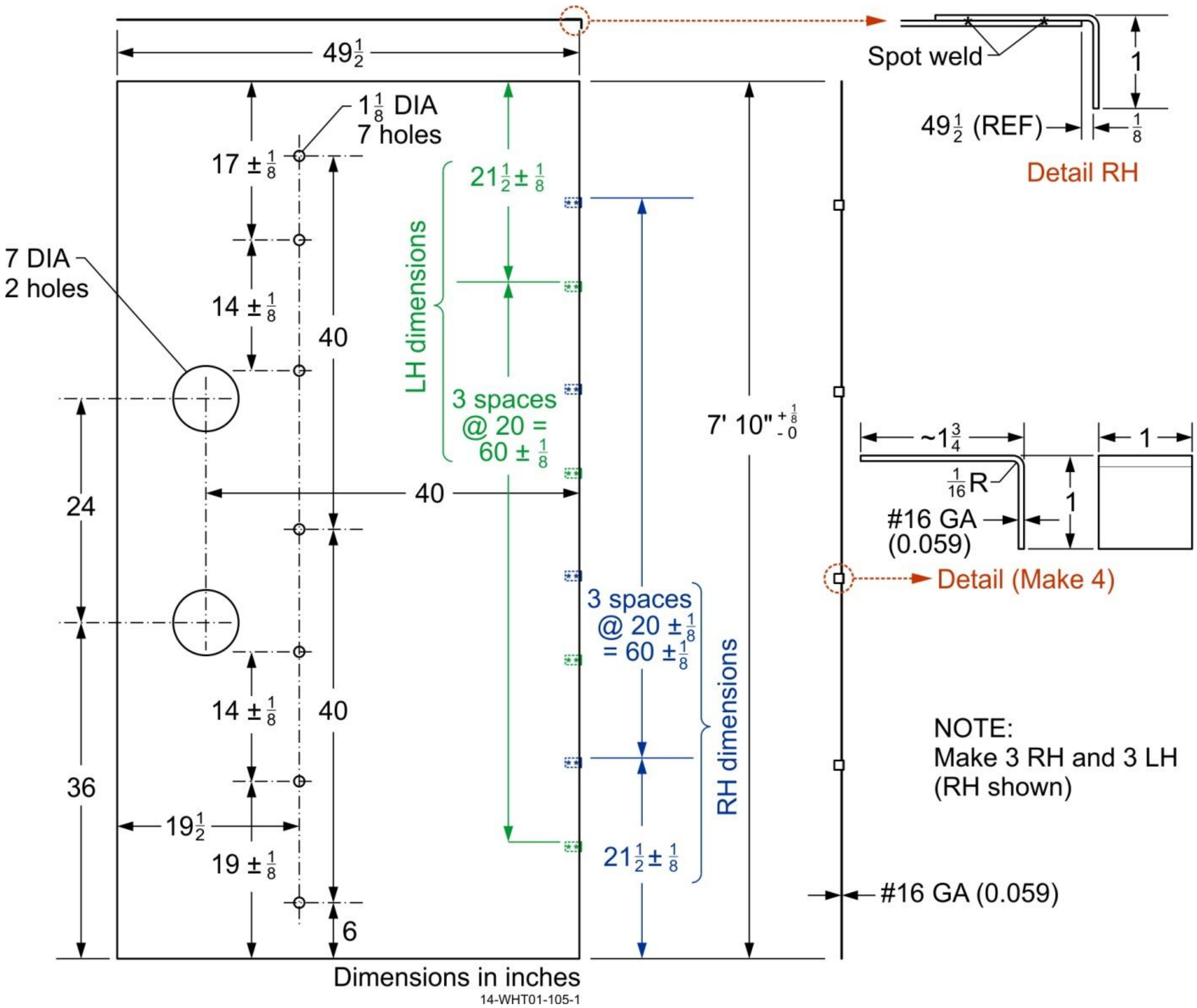


Figure 2.292. Steel Reflector Liner N, S & W (DWG# RE-1-23096).

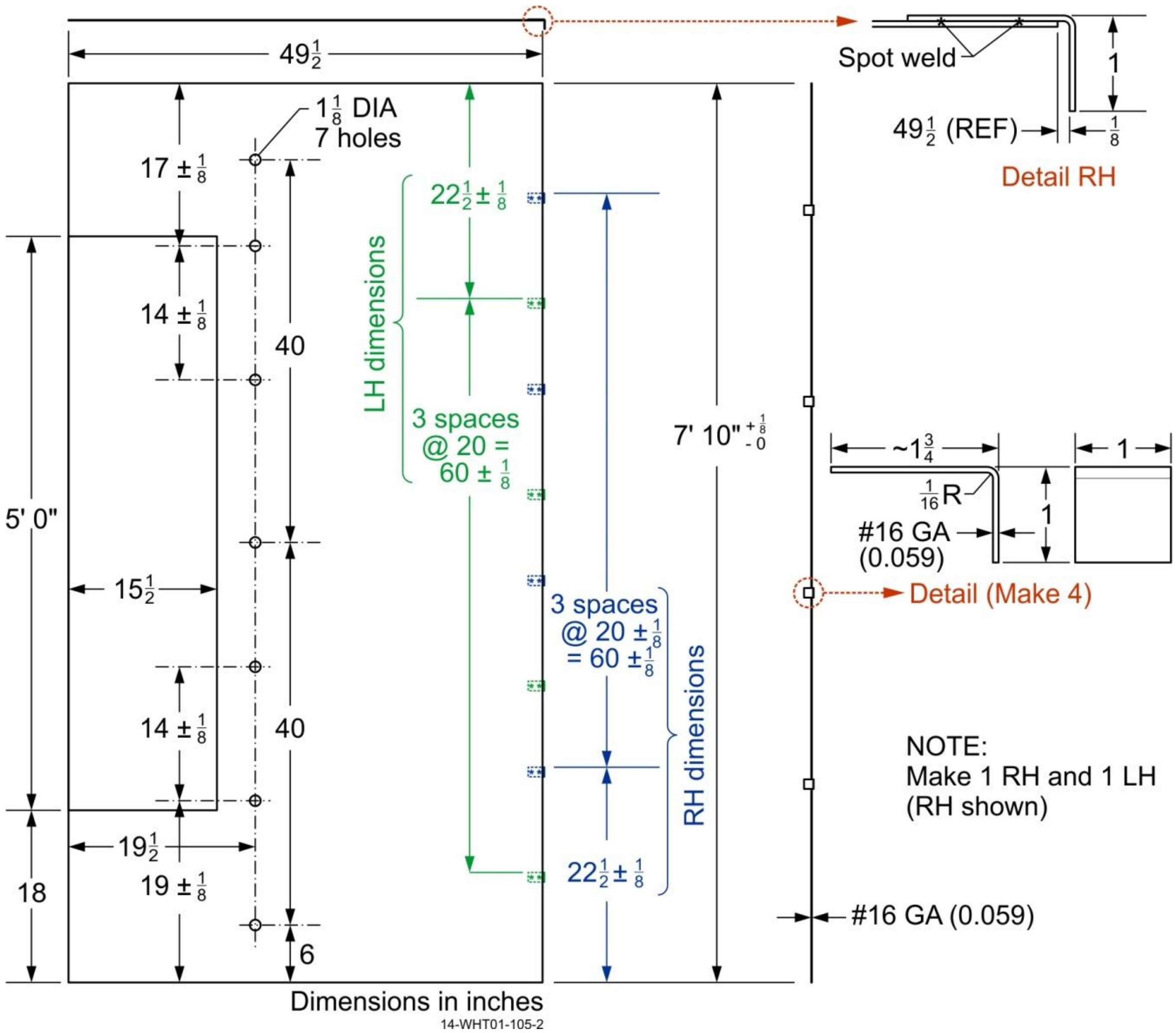


Figure 2.293. Steel Reflector Liner E (DWG# RE-1-23097).

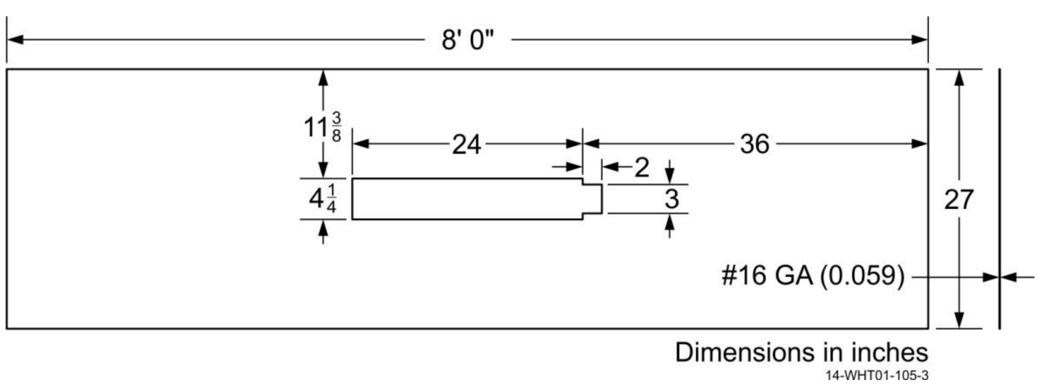


Figure 2.294. Steel Reflector Liner W & S (DWG# RE-1-23098).

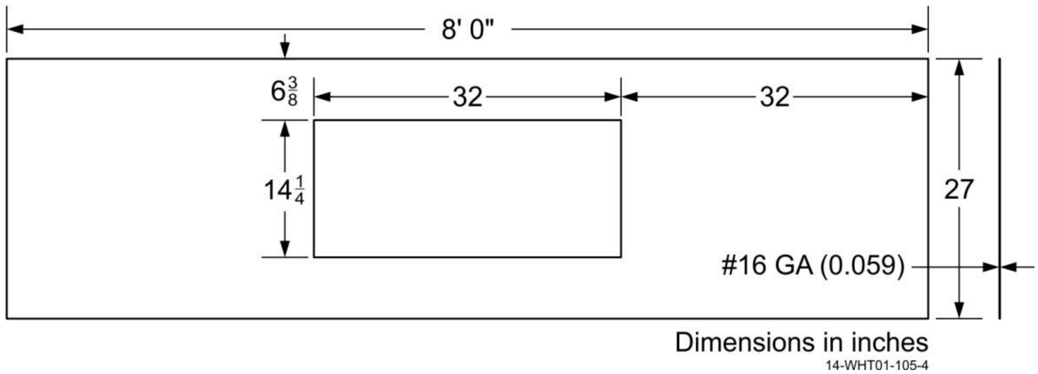


Figure 2.295. Steel Reflector Liner N (DWG# RE-1-23099).

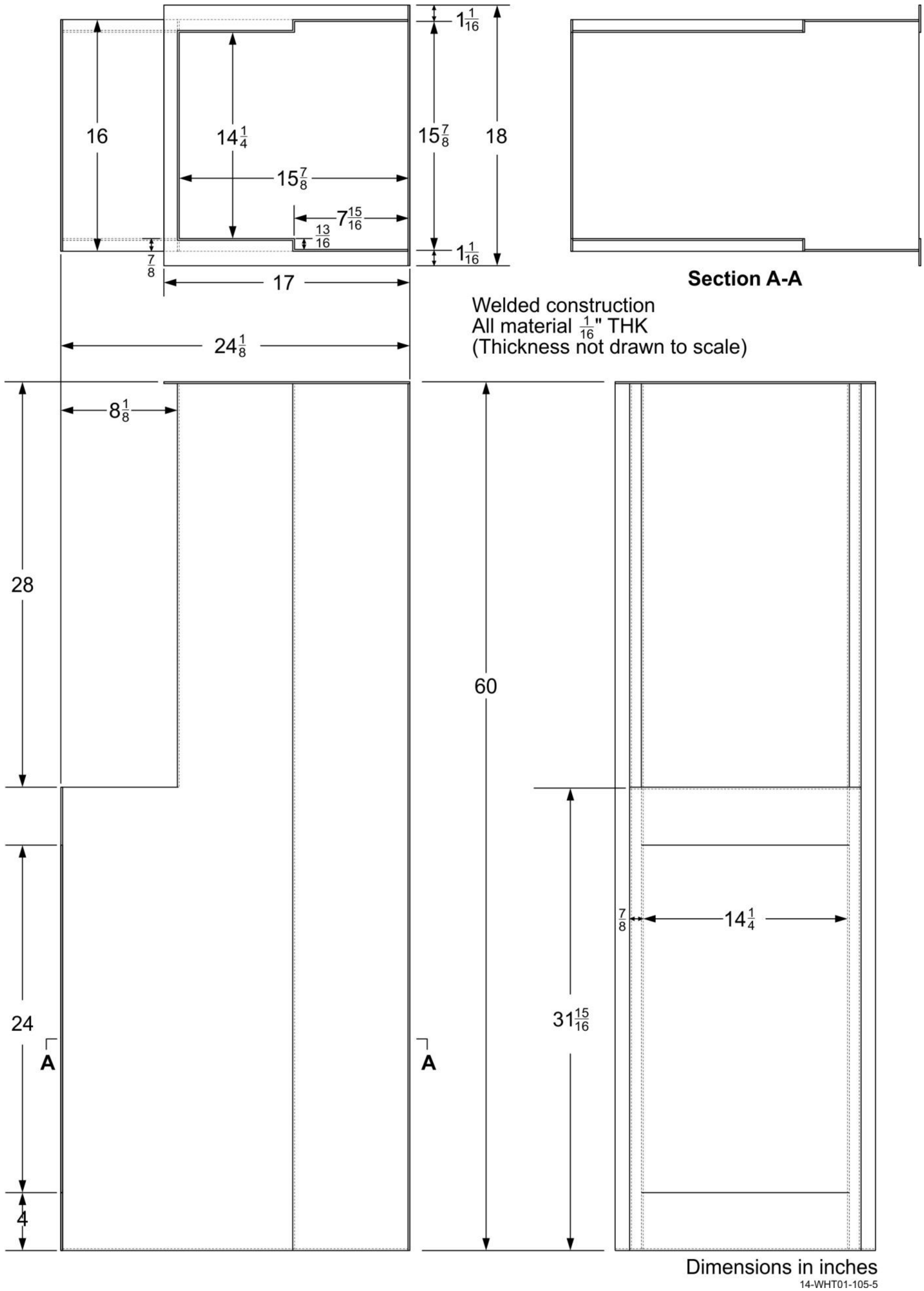

16
14 1/4
15 7/8
15 7/8
18
1 1/16
7 15/16
13/16
1 1/16
7/8
17
Section A-A
Welded construction
All material 1/16" THK
(Thickness not drawn to scale)
24 1/8
8 1/8
28
60
24
A
A
4
7/8
14 1/4
31 15/16
Dimensions in inches
14-WHT01-105-5

Figure 2.296. Al N Cavity Reflector Liner (DWG# RE-1-23100).

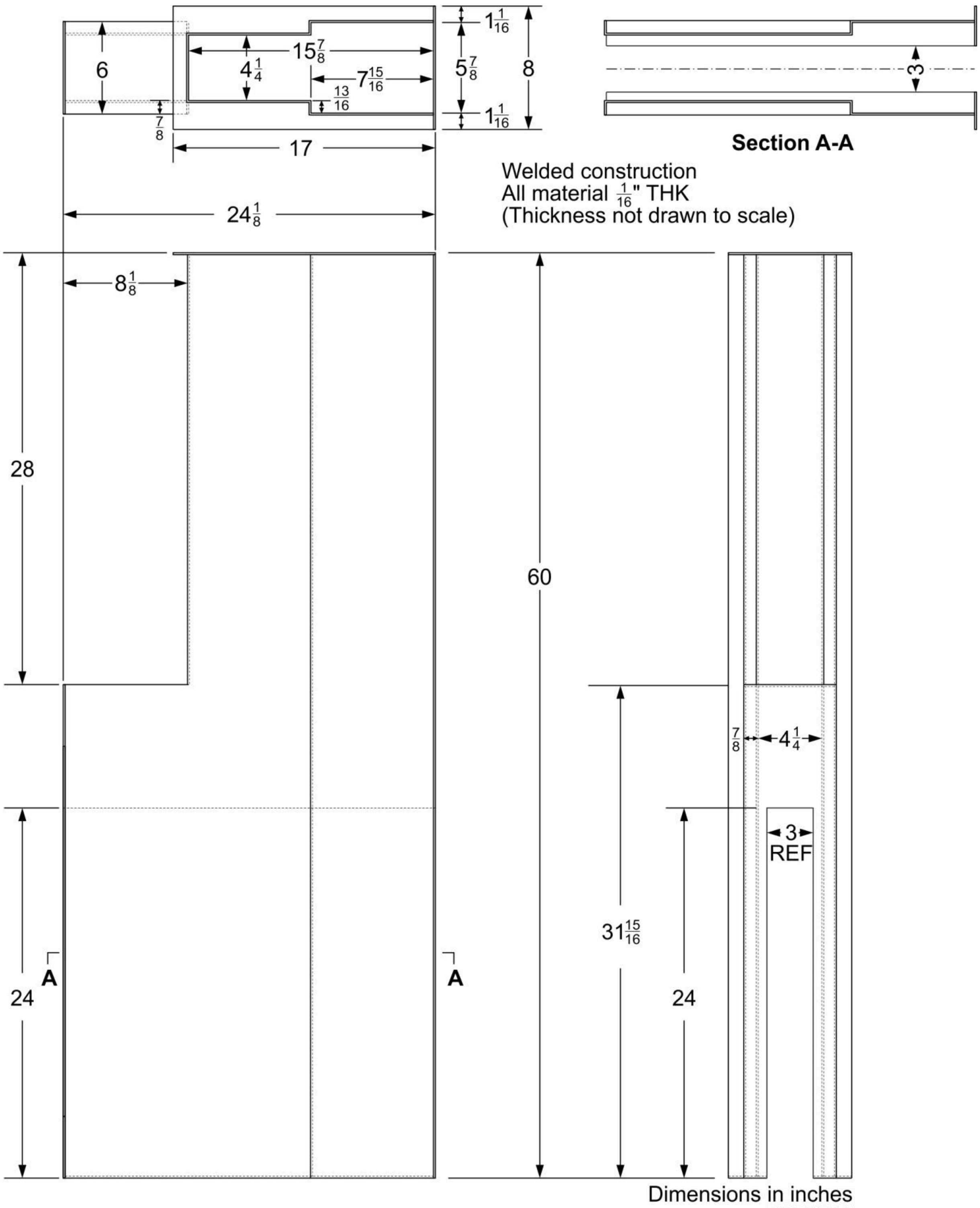


Figure 2.297. Al S & W Cavity Reflector Liner (DWG# RE-1-23101).

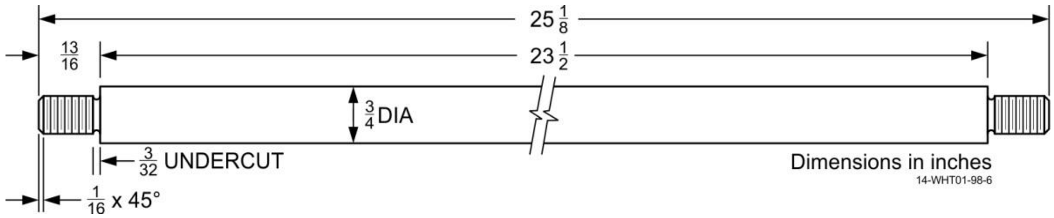


Figure 2.298. Tie Bolt (DWG# RE-1-23103).

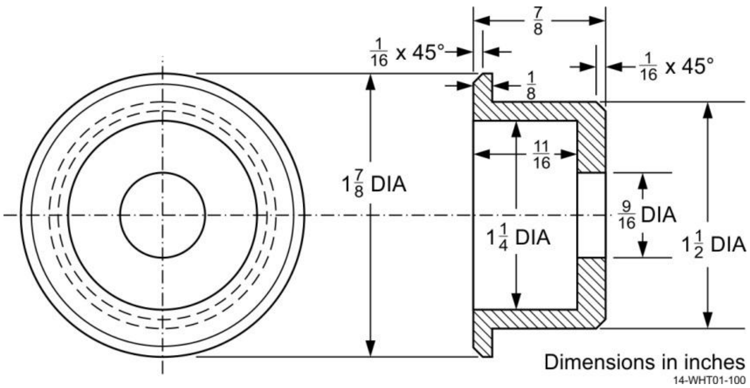


Figure 2.299. Nut Seat (DWG# RE-1-23104).

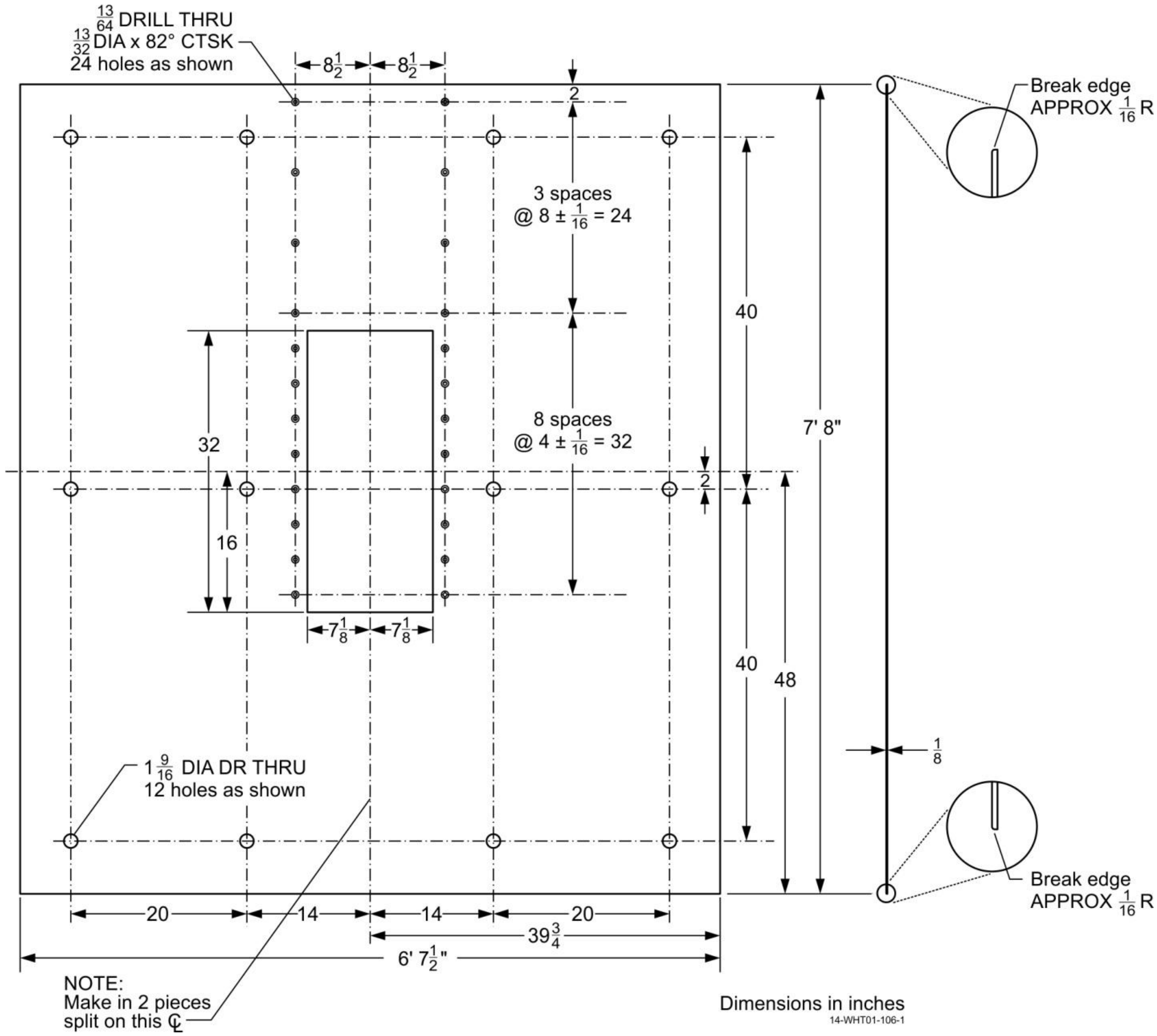


Figure 2.300. Reflector Liner North Face (DWG# RE-1-23107).

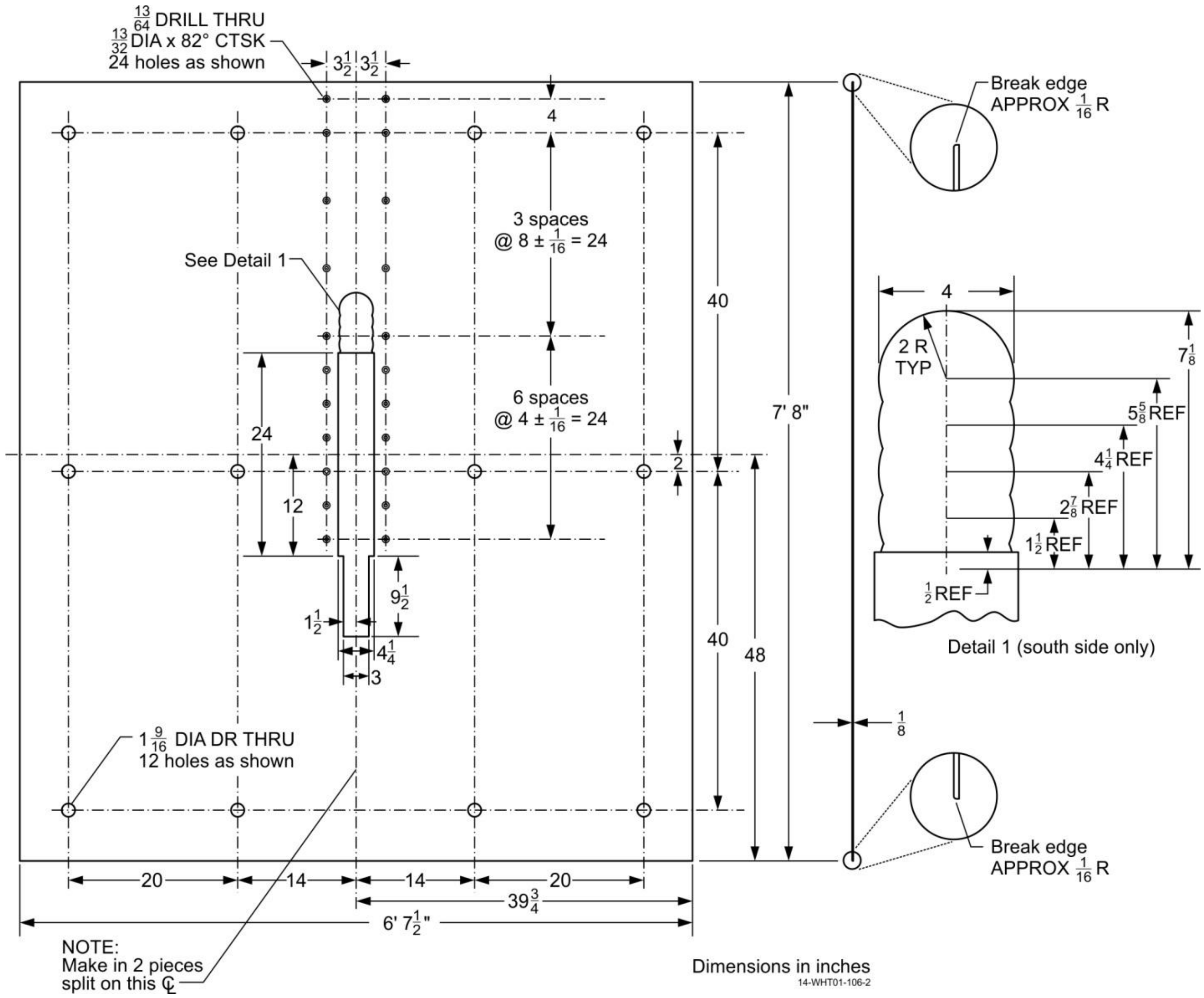


Figure 2.301. Reflector Liner West & South Face (DWG# RE-1-23108).

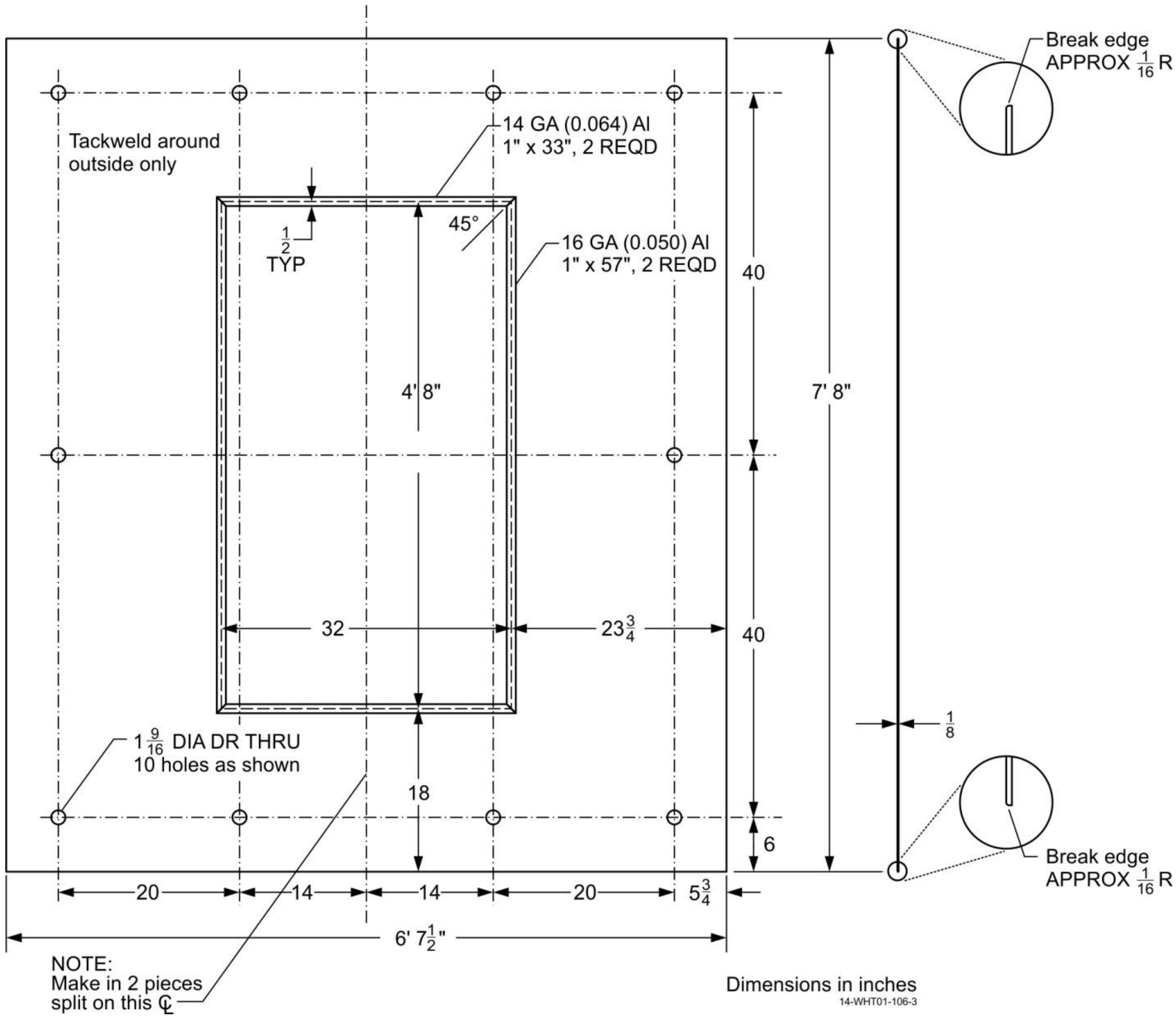


Figure 2.302a. Reflector Liner East Face (DWG# RE-1-23109).

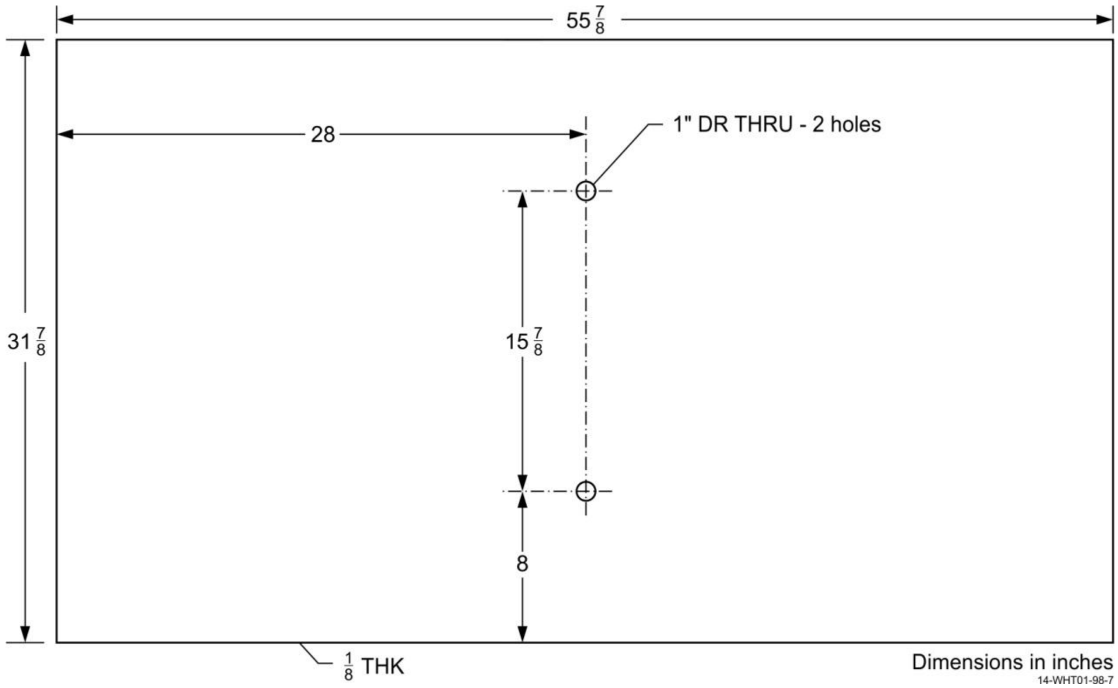


Figure 2.302b. Reflector Liner East Face Plate (DWG# RE-1-24215).

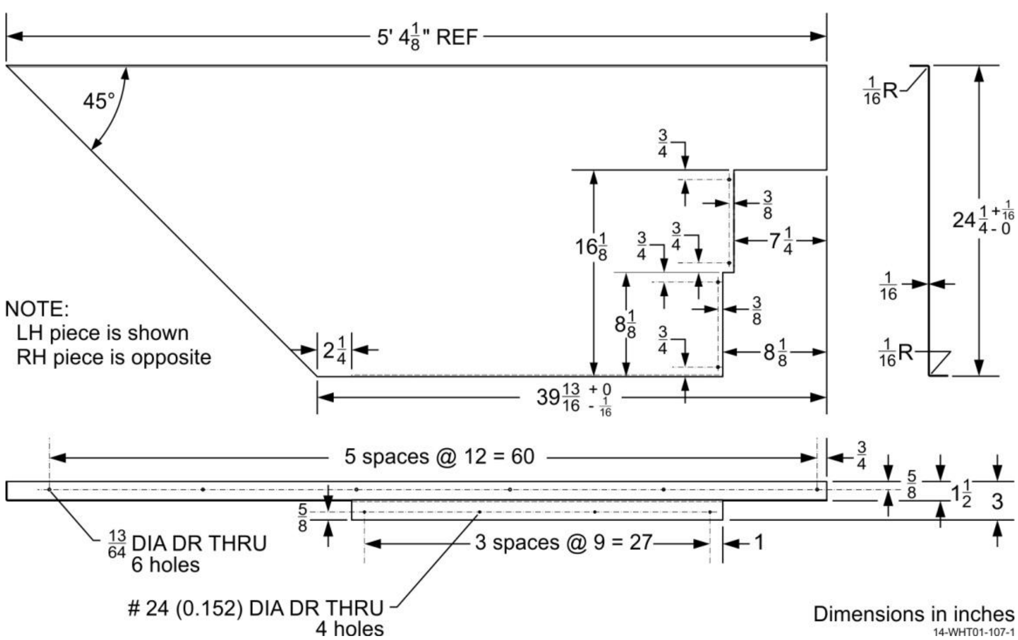


Figure 2.303. North Top Plate (DWG# RE-1-23110).

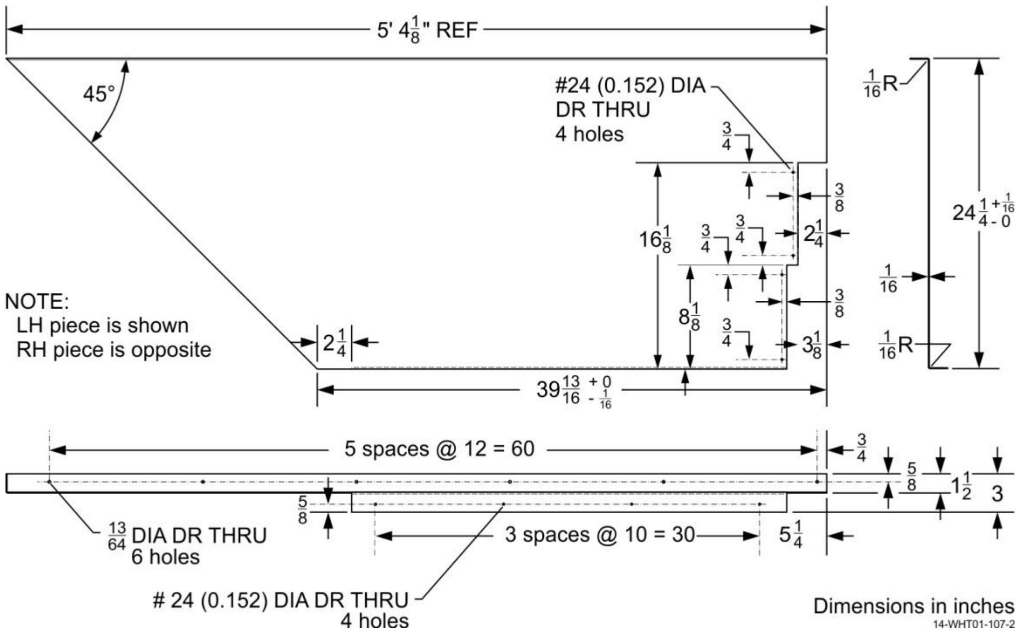


Figure 2.304. West & South Top Plate (DWG# RE-1-23111).

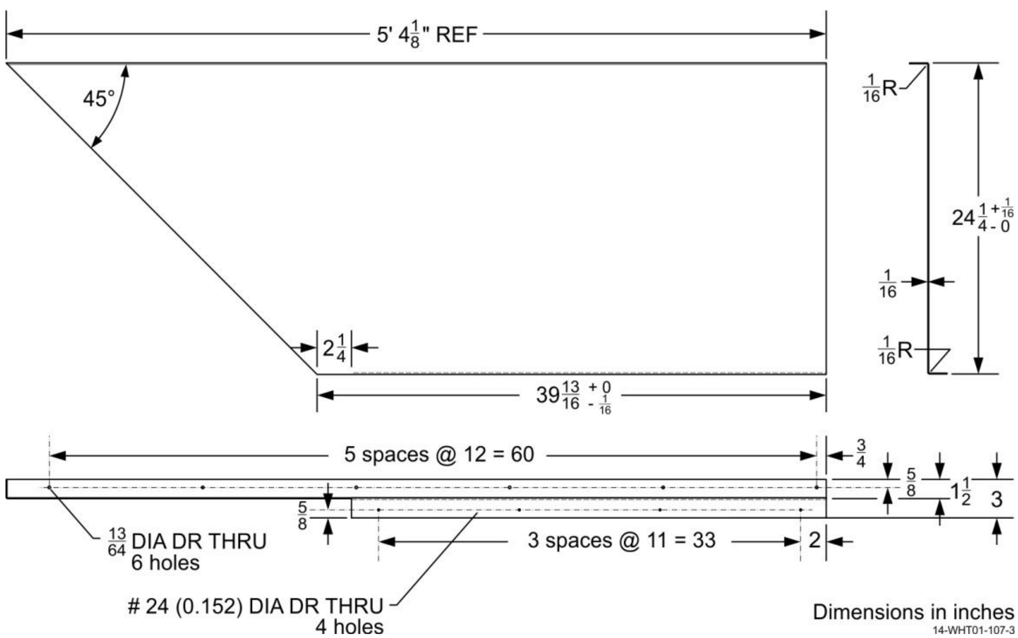


Figure 2.305. East Top Plate (DWG# RE-1-23112).

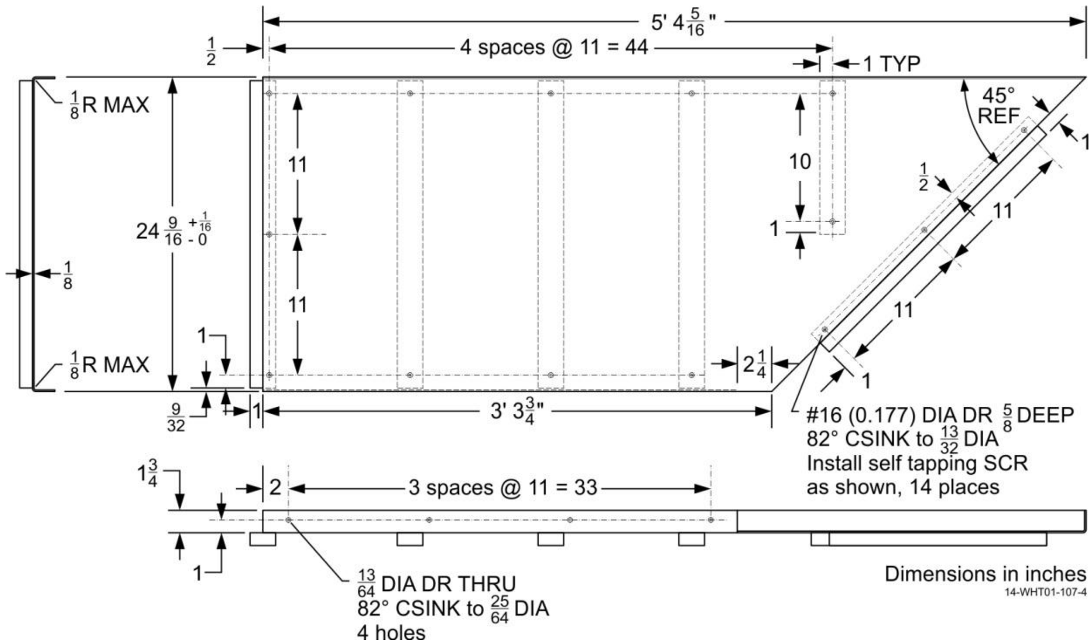


Figure 2.306. RH Bottom Plate (DWG# RE-1-23118).

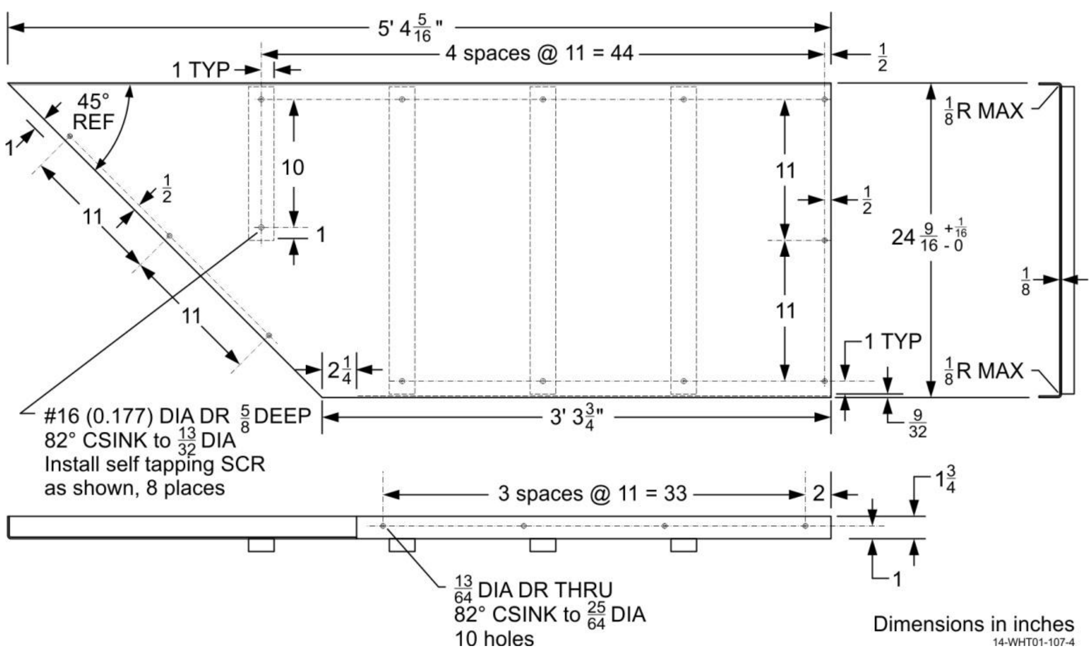


Figure 2.307. LH Bottom Plate (DWG# RE-1-23119).

2.9.3 Gates

Penetrations in the south, west, and north faces of the permanent graphite reflector can be opened by removing graphite cavity inserts used as gates. The south and west gates use the short cavity insert shown in Figure 2.310. The gates can be lifted up and supported above the core by placing a bar through the aluminum adapters fixed to the top of the gates. The north gate uses a single long cavity insert that can similarly be removed and held above the reflector (see Figure 2.309). The north gate can be widened by physically removing reflector cavity inserts (see Figure 2.308) placed to either side of the cavity insert. These inserts cannot be supported above the core and would have to be physically removed from the reflector via the matching north hole in the concrete shielding.

Table 2.28. Permanent Reflector Gates.

Quantity	Figure	DWG#	Component	Material
2	2.308	RE-1-23120	Reflector Cavity Insert	CP-2 Graphite & Al-6061
1	2.309	RE-1-23201	Cavity Insert Long	CP-2 Graphite & Al-6061
2	2.310	RE-1-23202	Cavity Insert Short	CP-2 Graphite & Al-6061

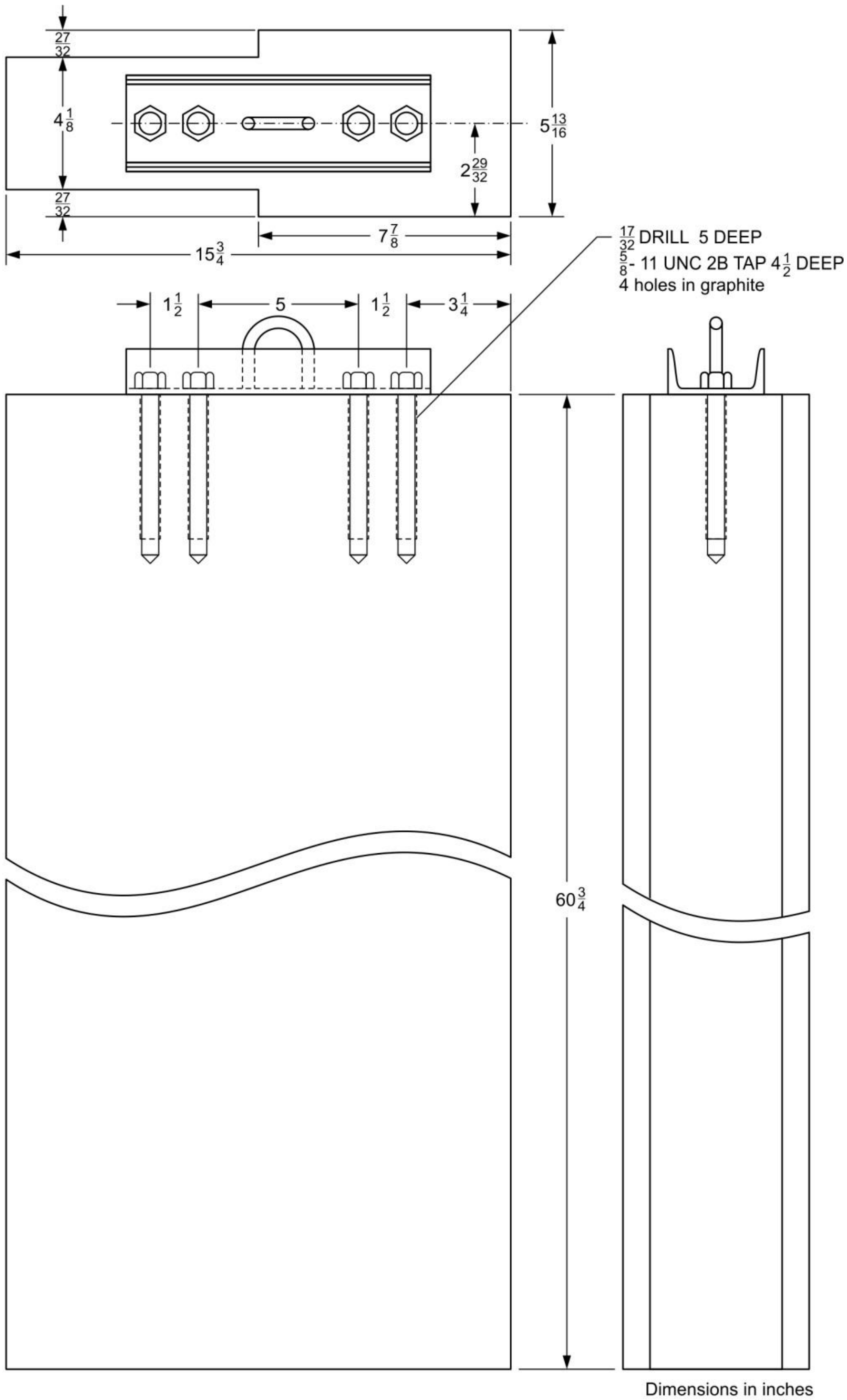


Figure 2.308. Reflector Cavity Insert (DWG# RE-1-23120).

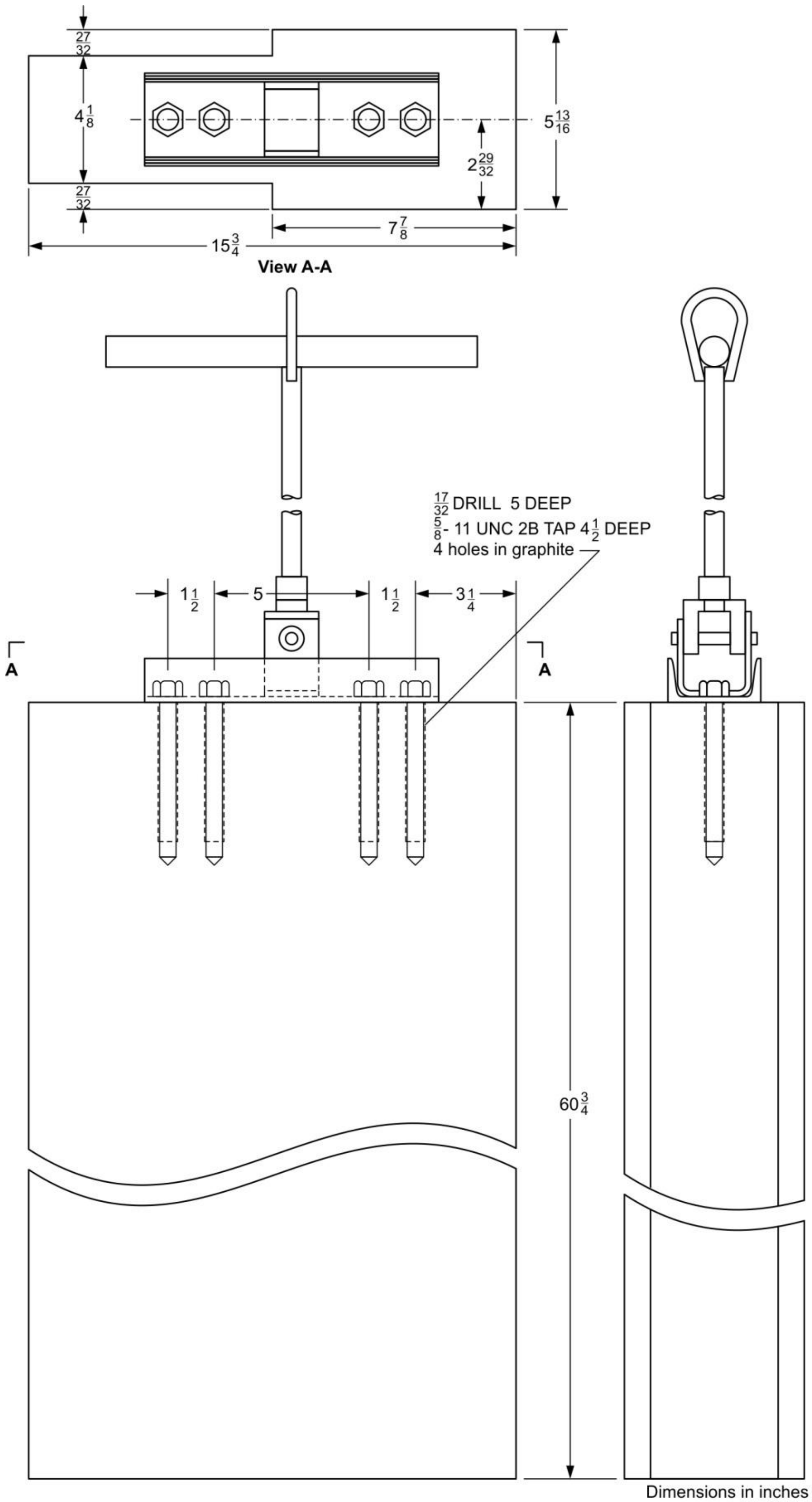


Figure 2.309. Cavity Insert Long (DWG# RE-1-23201).

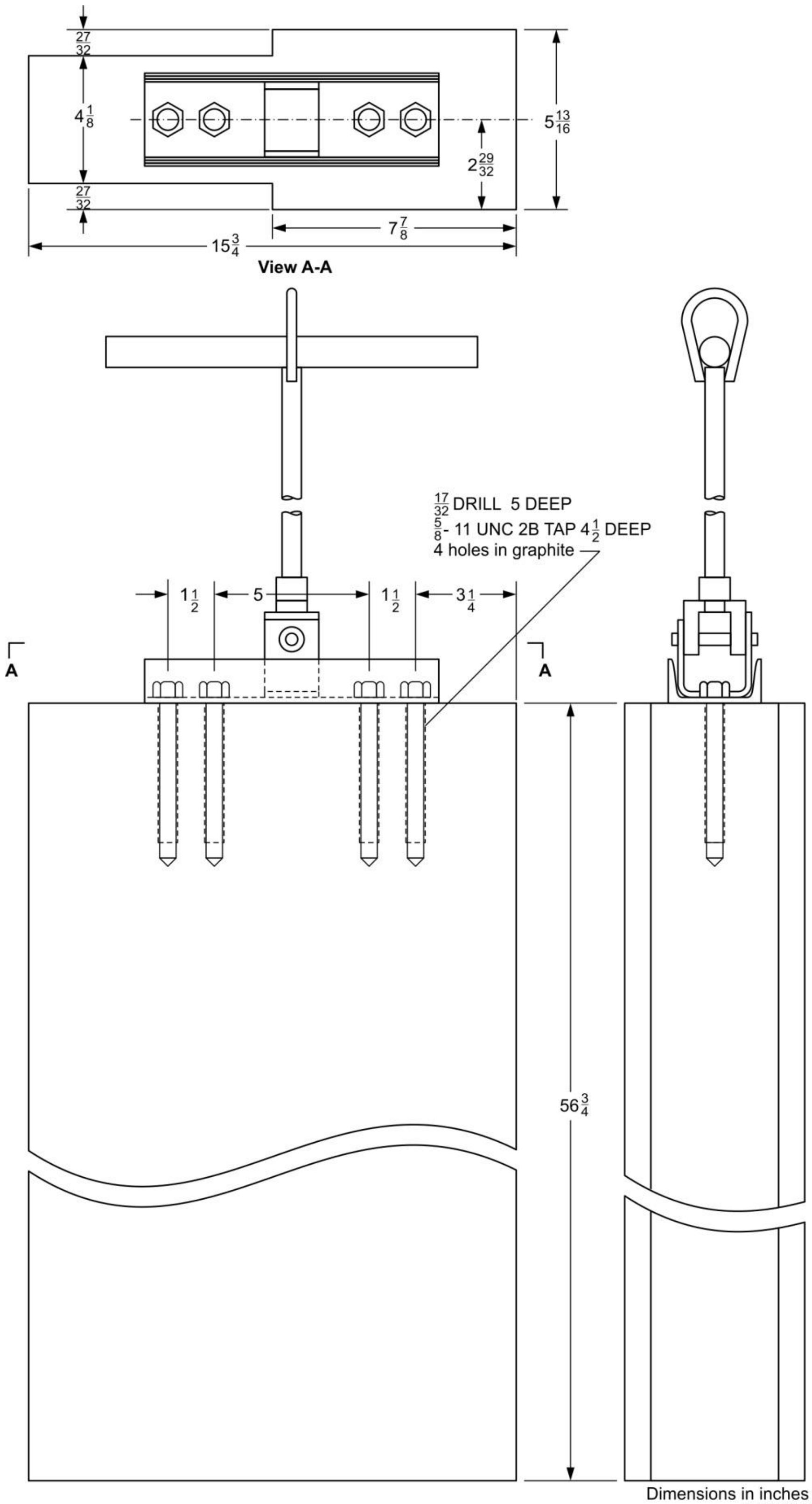


Figure 2.310. Cavity Insert Short (DWG# RE-1-23202).

2.9.4 Front (Inner) Collimator

Iterations of a fast neutron hodoscope were implemented outside the north gate of TREAT. The fast-neutron hodoscope allows for observation of fuel motion during the course of power transient experiments. It generally consists of a series of steel collimators and detectors placed external to the reactor. Fast neutrons emitted from the irradiated test fuel are channeled to the detectors [De Volpi 1976]. The original hodoscope had most of its equipment placed external to the reactor. The later hodoscope design utilized during the M-series experiments [Robinson 1994] had a front (inner) collimator (Figure 2.311) placed within the concrete shielding just outside the north gate of the permanent reflector. A breakdown of the individual components used to construct the front collimator are shown in Figures 2.313 through 2.319.

Table 2.29. Front (Inner) Collimator Components.

Quantity	Figure	DWG#	Component	Material
1	2.311	R0501-2061	Non Occluding Front Collimator Assembly	High Density Concrete
1	2.312	R0501-3005	Upper Focal Shield	Low Carbon Steel
1	2.313	R0501-3006	Lower Focal Shield	Low Carbon Steel
1	2.314	R0501-3000	Base Plate	Low Carbon Steel
2	2.315	R0501-3001	Side Plate	Cold Drawn Flat Steel
1	2.316	R0501-3002	Top Plate	Low Carbon Steel
4	2.317	R0501-3003	Lift Rod	Low Carbon Steel
4	2.318	R0501-3004	Corner Angle	Low Carbon Steel
2	2.319	R0501-0205	Adjustment Screw Block	Low Carbon Steel

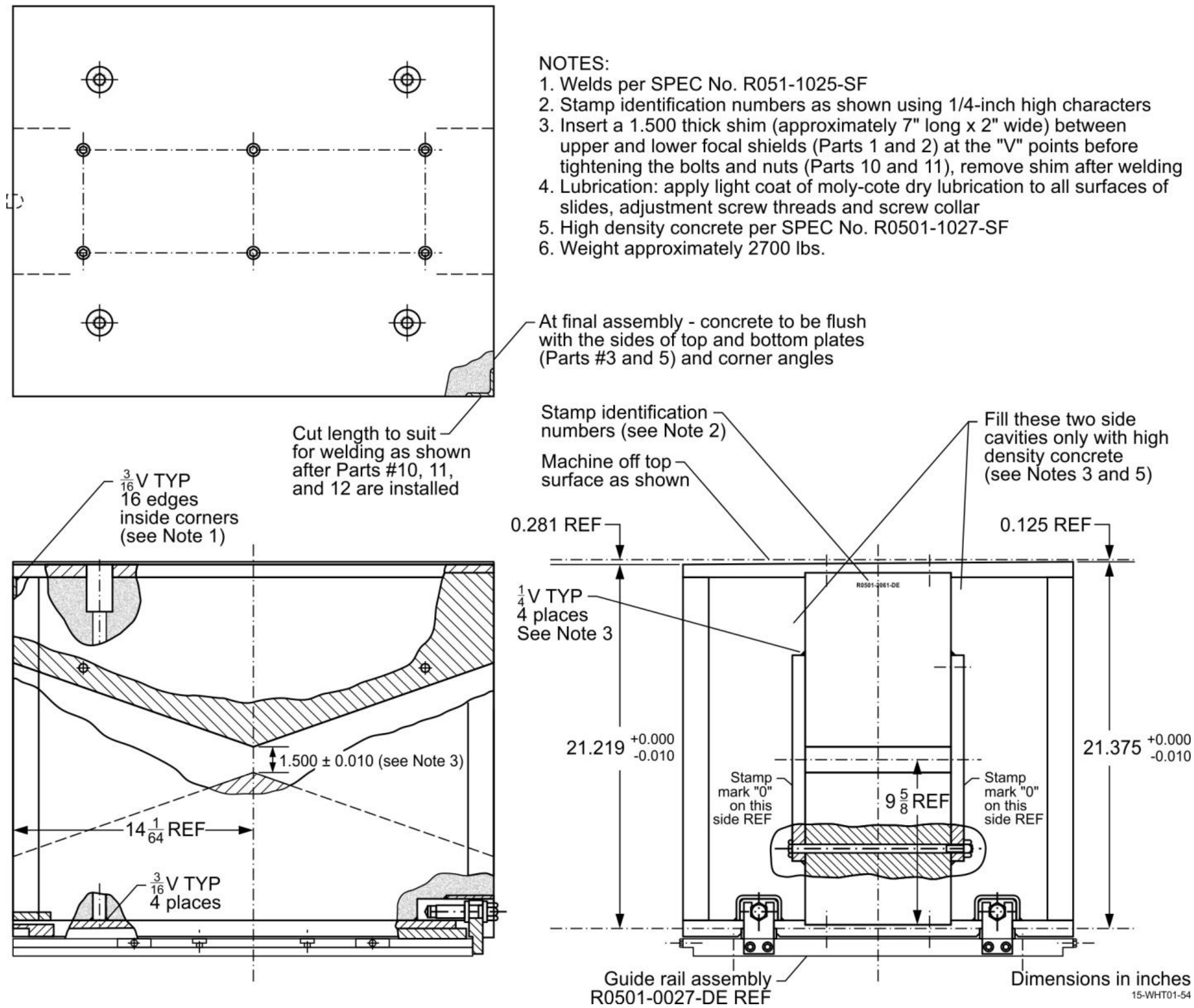


Figure 2.311. Non Occluding Front Collimator Assembly (DWG# R0501-2061).

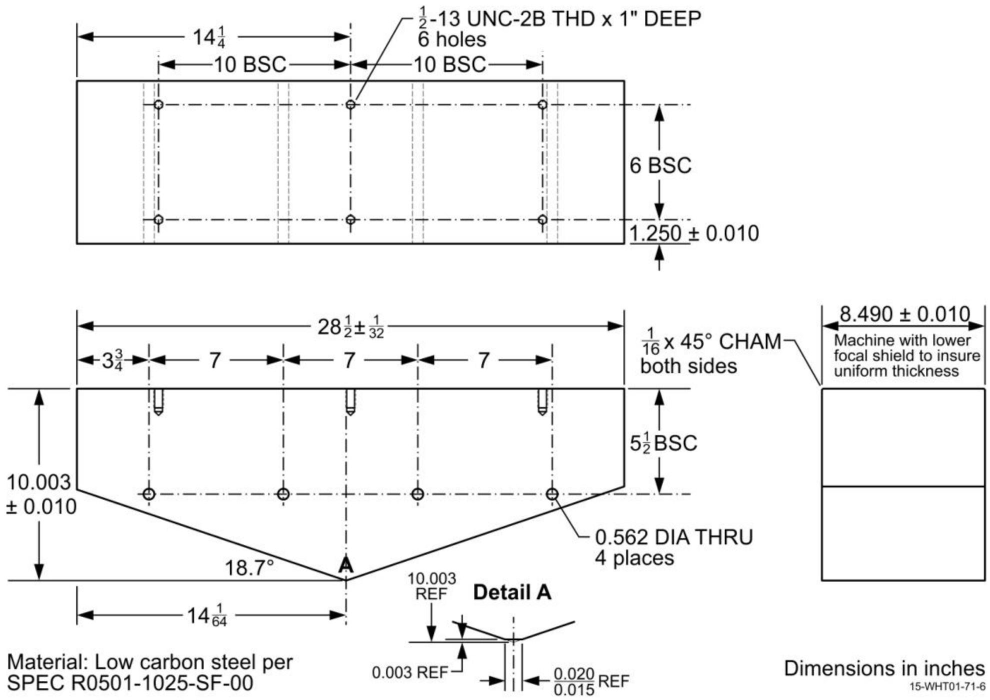


Figure 2.312. Upper Focal Shield (DWG# R0501-3005).

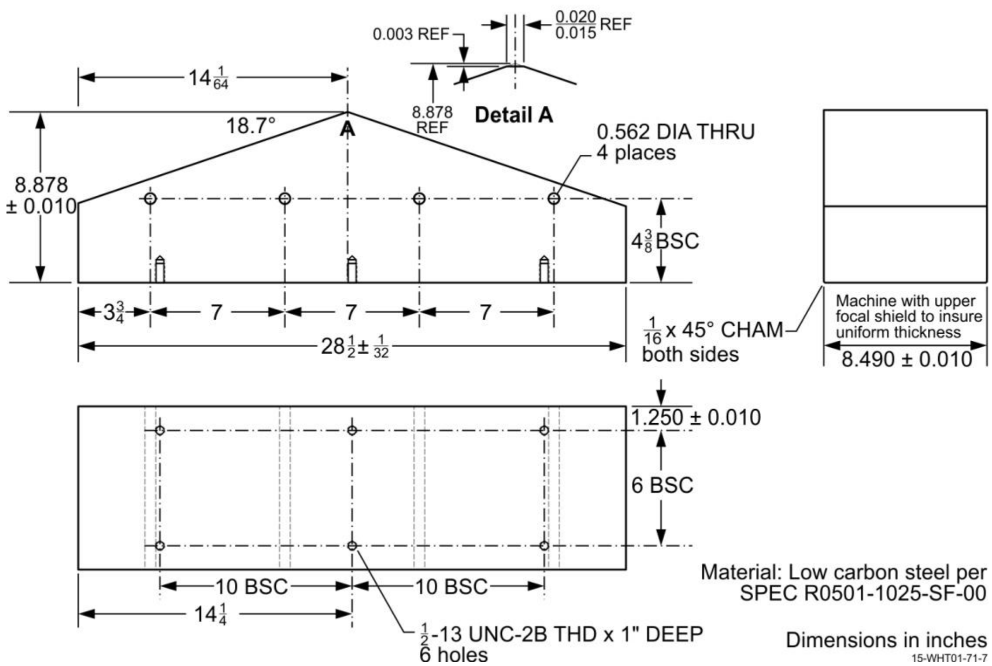


Figure 2.313. Lower Focal Shield (DWG# R0501-3006).

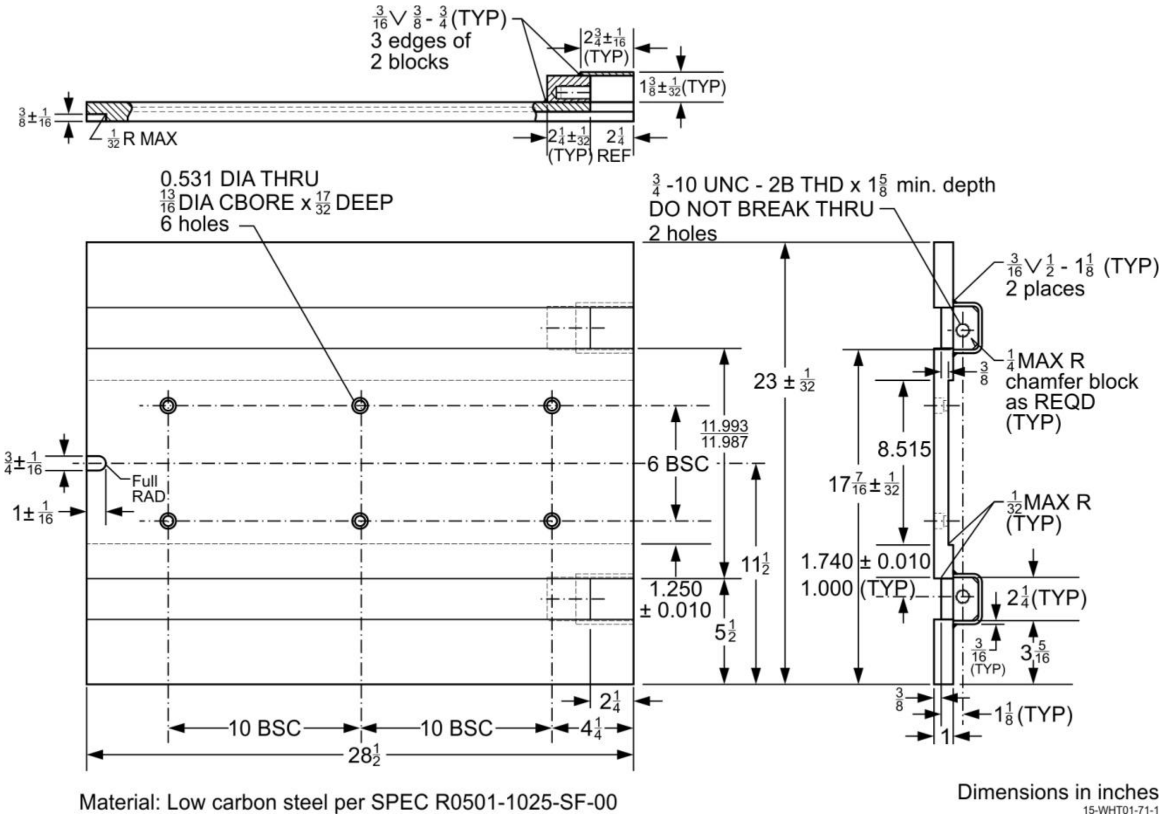


Figure 2.314. Base Plate (DWG# R0501-3000).

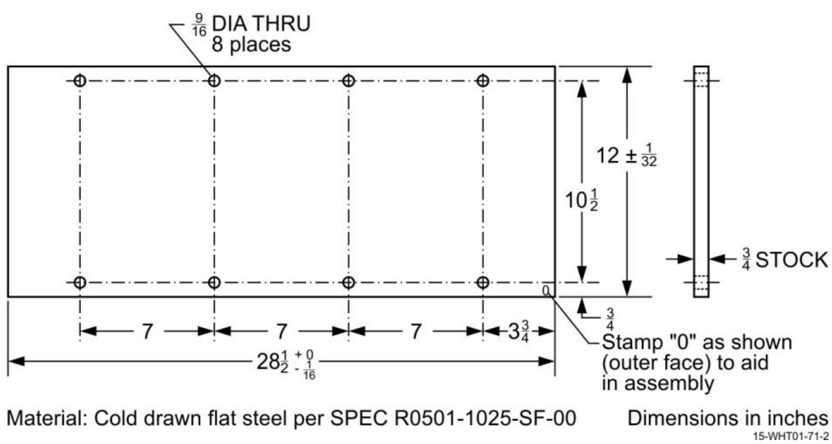


Figure 2.315. Side Plate (DWG# R0501-3001).

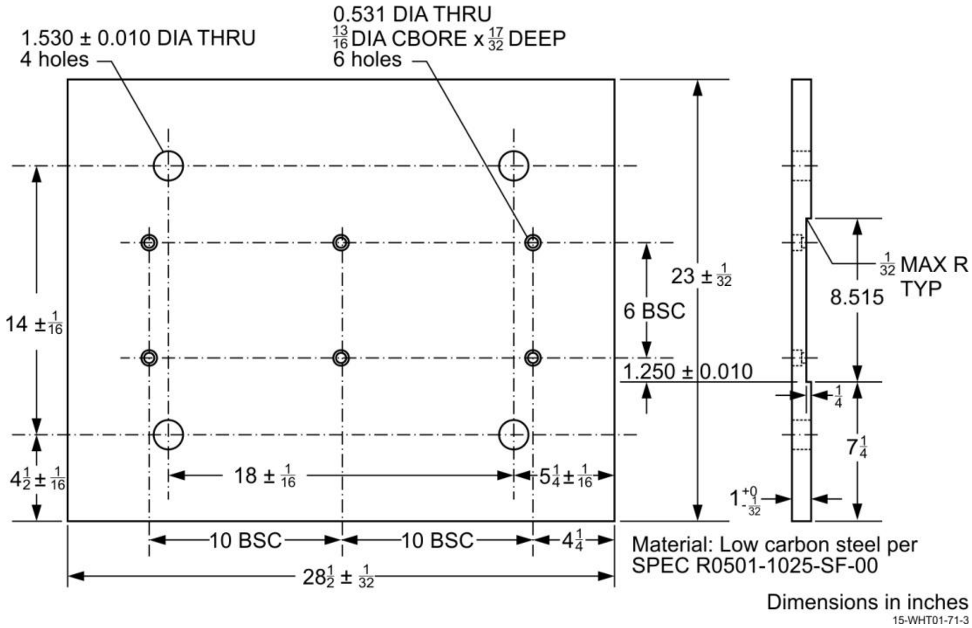


Figure 2.316. Top Plate (DWG# R0501-3002).

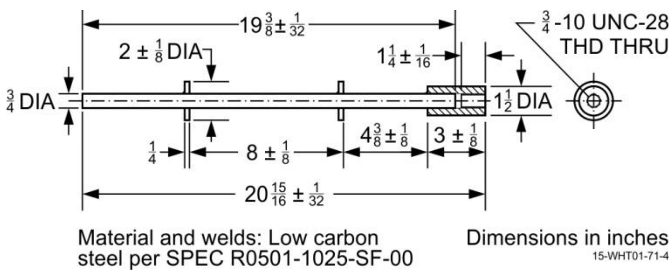


Figure 2.317. Lift Rod (DWG# R0501-3003).

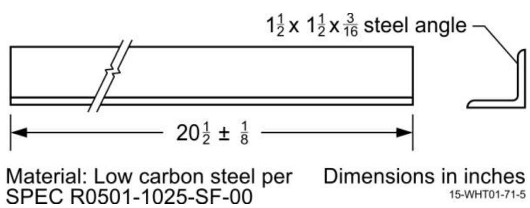


Figure 2.318. Corner Angle (DWG# R0501-3004).

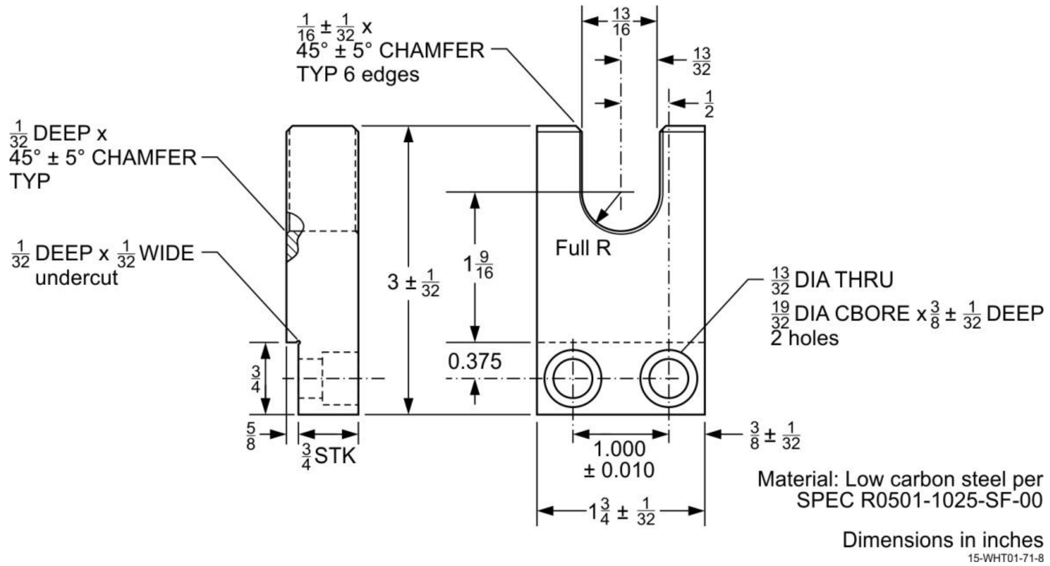


Figure 2.319. Adjustment Screw Block (DWG# R0501-0205).

2.9.5 Thermal Column

A 5-ft.-square graphite thermal column is located on the east face of the radial shield and shielded by a 33-in.-thick high-density concrete door with the inner surface clad in ¼-in.-thick boral. It is constructed from additional 4-in.-square graphite blocks stacked 5 ft. square adjacent to the permanent reflector and stepped out to 5 ft. 8 in. square halfway through the concrete shield. The central nine stringers are machined to a nominal 3.99-in.-square cross section to facilitate ease of their removal so that objects might be placed within the thermal column at 8 in. increments up to the face of the core. A 12-in.-square opening in the concrete door is used to remove the central thermal column graphite blocks. Other openings include three vertical access holes (2-1/2 in. diameter) which extend from the top of the concrete shield and terminate 10 in. above the horizontal center line of the thermal column [Freund 1960].

Table 2.30. Thermal Column Components.

Quantity	Figure	DWG#	Component	Material
1	2.320	--	Thermal Column	--
As Needed	--	--	Standard Graphite Block	CP-2 Graphite
As Needed	--	--	Central 3 × 3 Channel Graphite Block	CP-2 Graphite

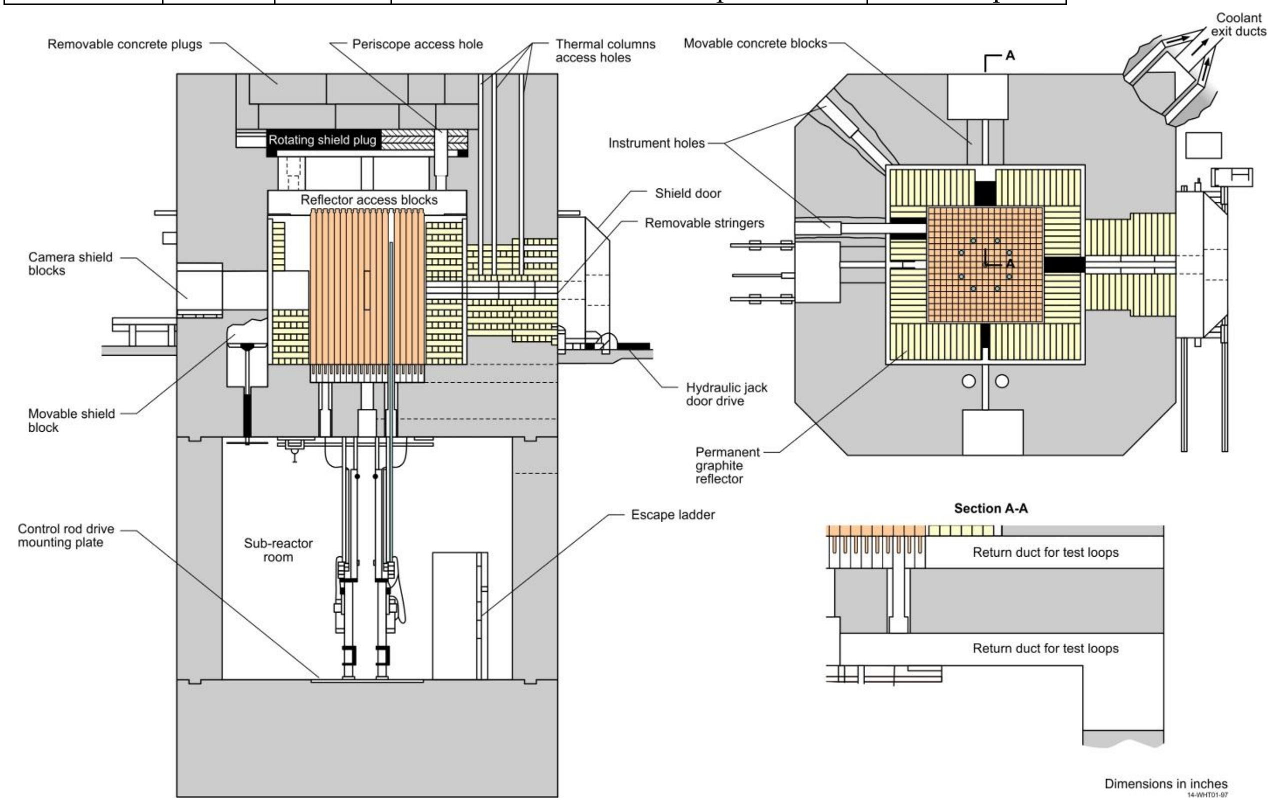


Figure 2.320. TREAT Facility Overview Showing Thermal Column.

2.10 Core Support Structure

2.10.1 Grid Plate and Adapters

The core grid plate (see Figure 2.313) provides the primary support of the reactor assemblies and serves as the lower guide to maintaining the assemblies within the correct pitch. This grid plate is in turn supported along the edges by the concrete shielding and below by the control rod guide assembly. The central portion of the grid plate can contain various inserts allowing for adaptation to experimental needs (see Figures 2.314 and 2.318 through 2.319). The grid plate contains penetrations for standard assembly bottom fittings, control rod assemblies, and an additional experimental location east of core center, near the thermal column. Special adapters are available to make control rod and the additional experimental hole position adaptable to receiving other assemblies (see Figures 2.316 and 2.317, respectively). Fuel element guides (see Figure 2.315) are affixed to the grid plate and adapters to provide additional alignment support to the core assemblies.

Table 2.31. Core Support Structure Grid Plate and Adapters Components.

Quantity	Figure	DWG#	Component	Material
1	2.321	RE-1-21695	Grid Plate	Mild Steel
1	2.322	RE-1-21722	Center Piece Grid Plate	Mild Steel
As Needed	2.323	RE-1-21723	Fuel Element Guide	Mild Steel
As Needed	2.324	RE-1-23147	Control Rod Hole Adapter	Al-1100
As Needed	2.325	RE-1-23419	Special Hole Adapter	Mild Steel
1	2.326	Z0012-0162	Grid Plate Insert Assembly MK-III Configuration	Mild Steel
1	2.327	Z0012-0163	Grid Plate Insert Assembly Normal Configuration	Mild Steel
1	2.328	Z0012-0164	Grid Plate Insert Assembly PFR Configuration	Mild Steel

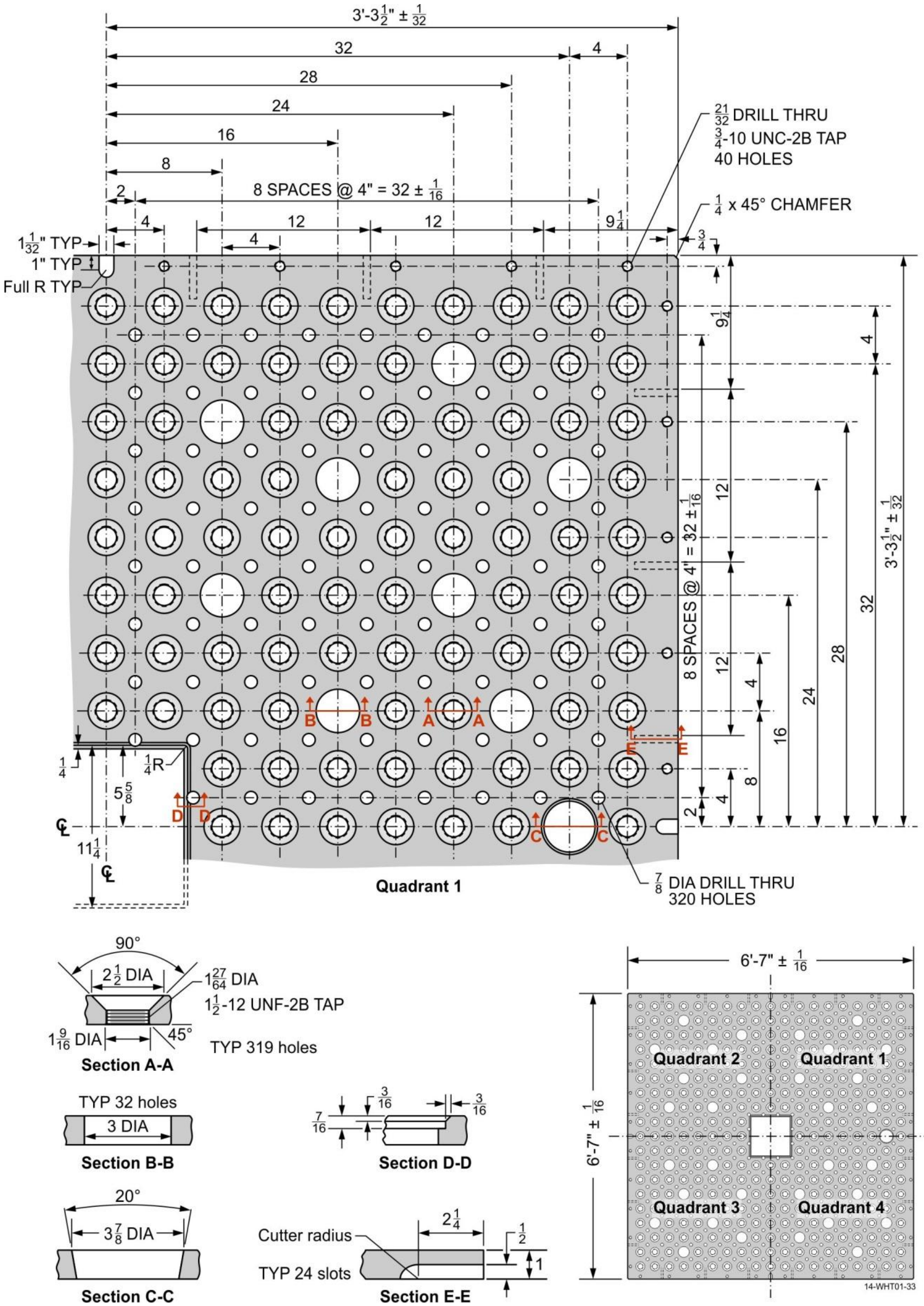


Figure 2.321. Grid Plate (DWG# RE-1-21695).

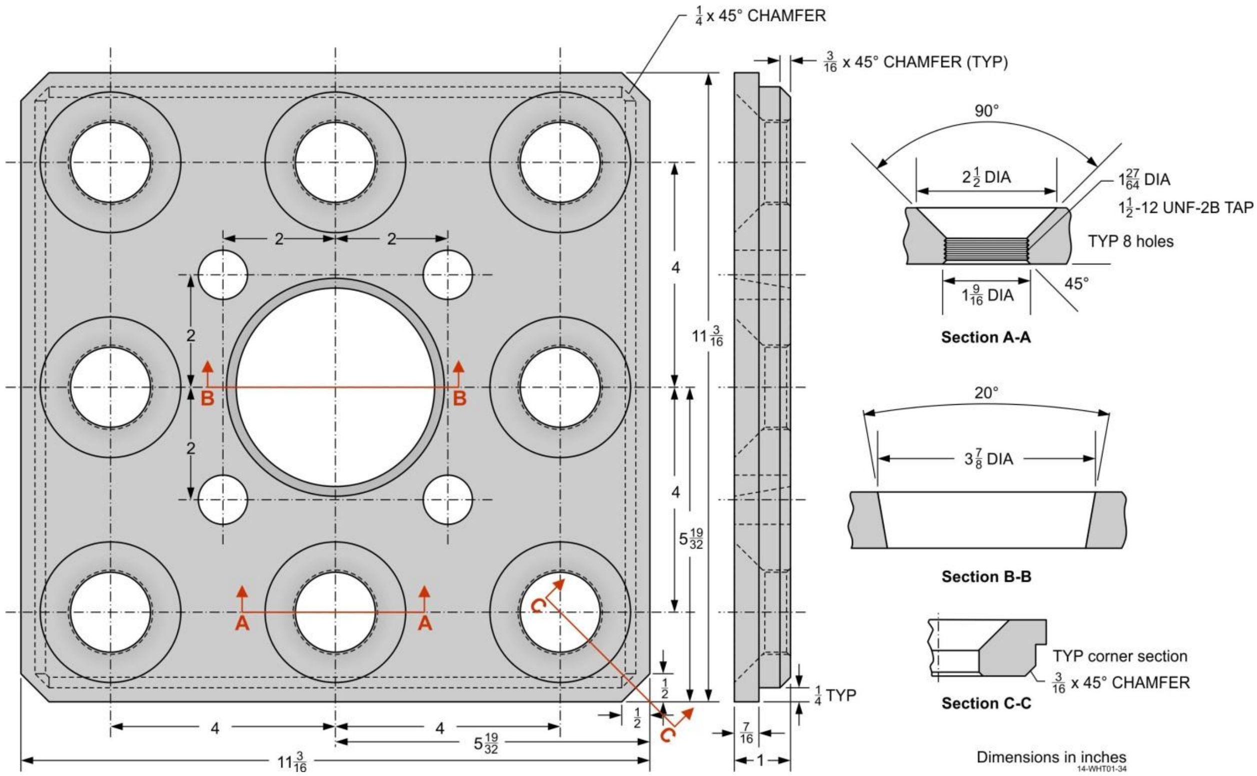


Figure 2.322. Center Piece Grid Plate (DWG# RE-1-21722).

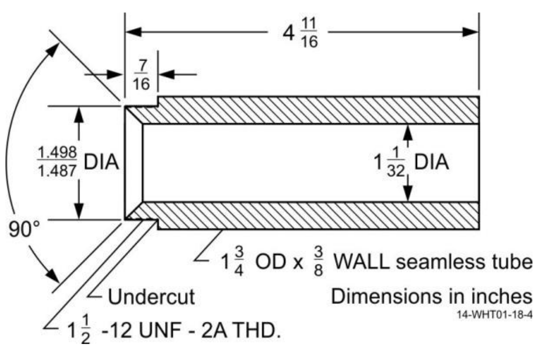


Figure 2.323. Fuel Element Guide (DWG# RE-1-21723).

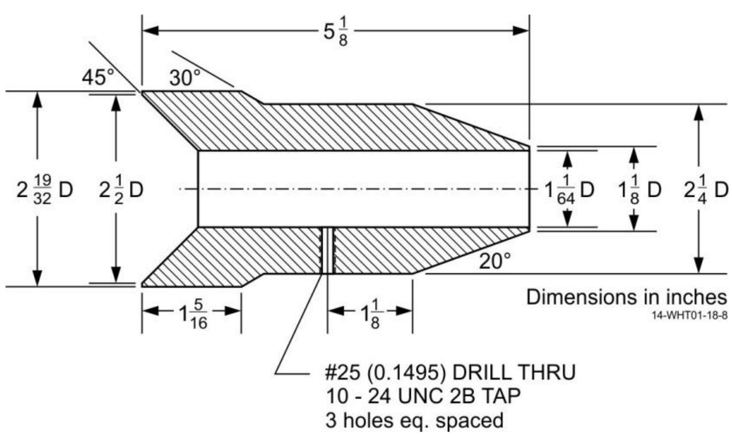


Figure 2.324. Control Rod Hole Adapter (DWG# RE-1-23147).

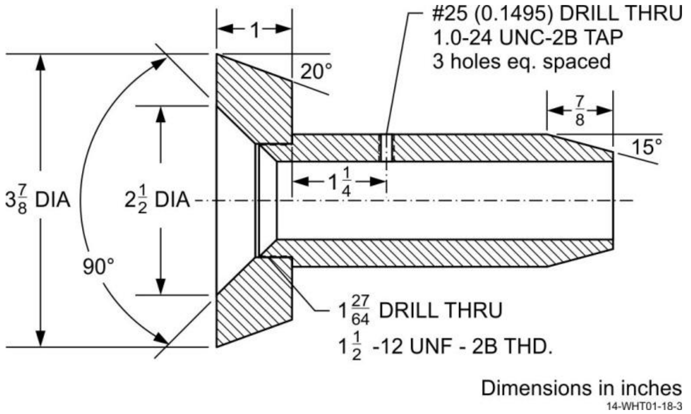


Figure 2.325. Special Hole Adapter (DWG# RE-1-23419).

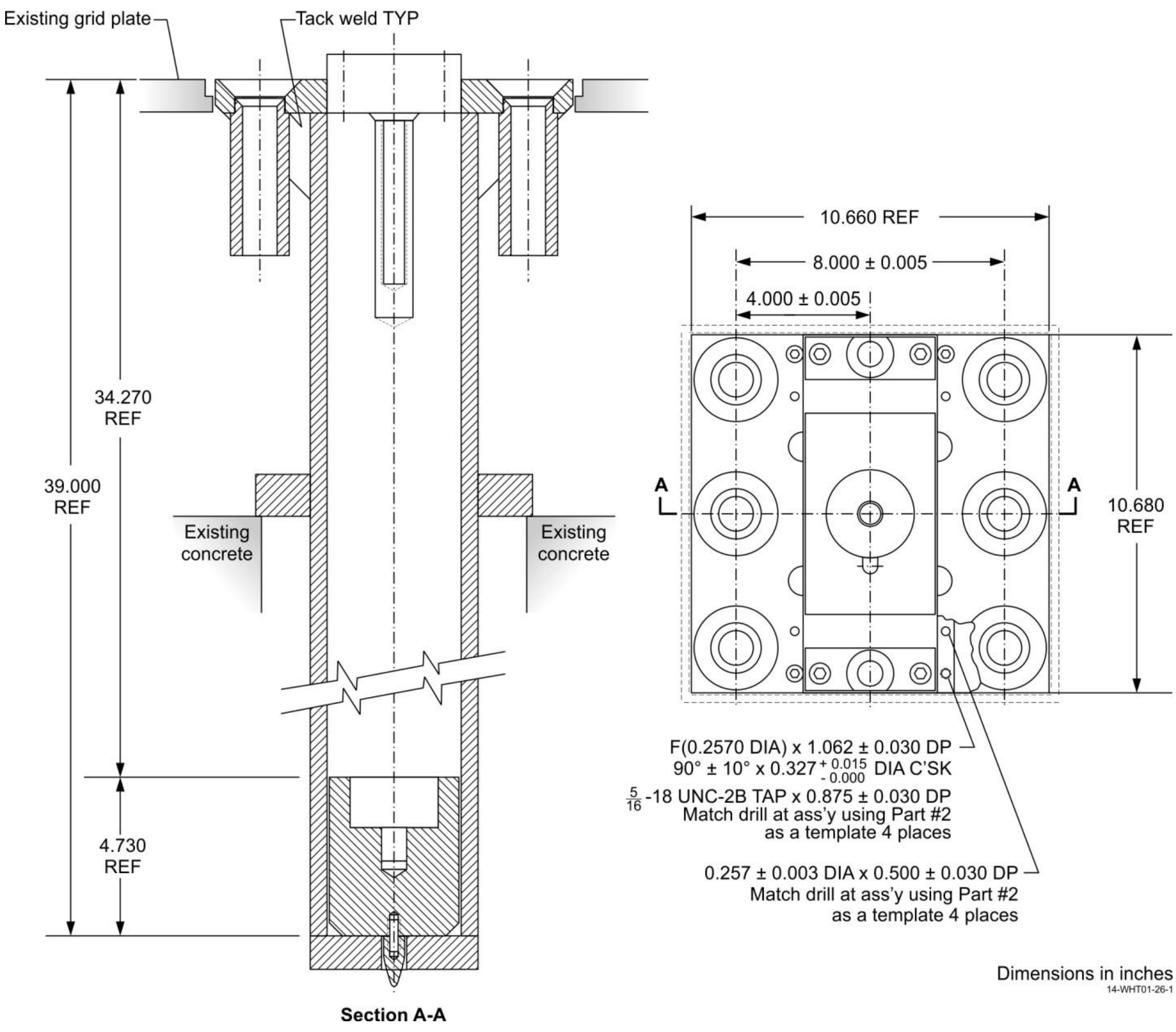


Figure 2.326. Grid Plate Insert Assembly MK-III Configuration (DWG# Z0012-0162).

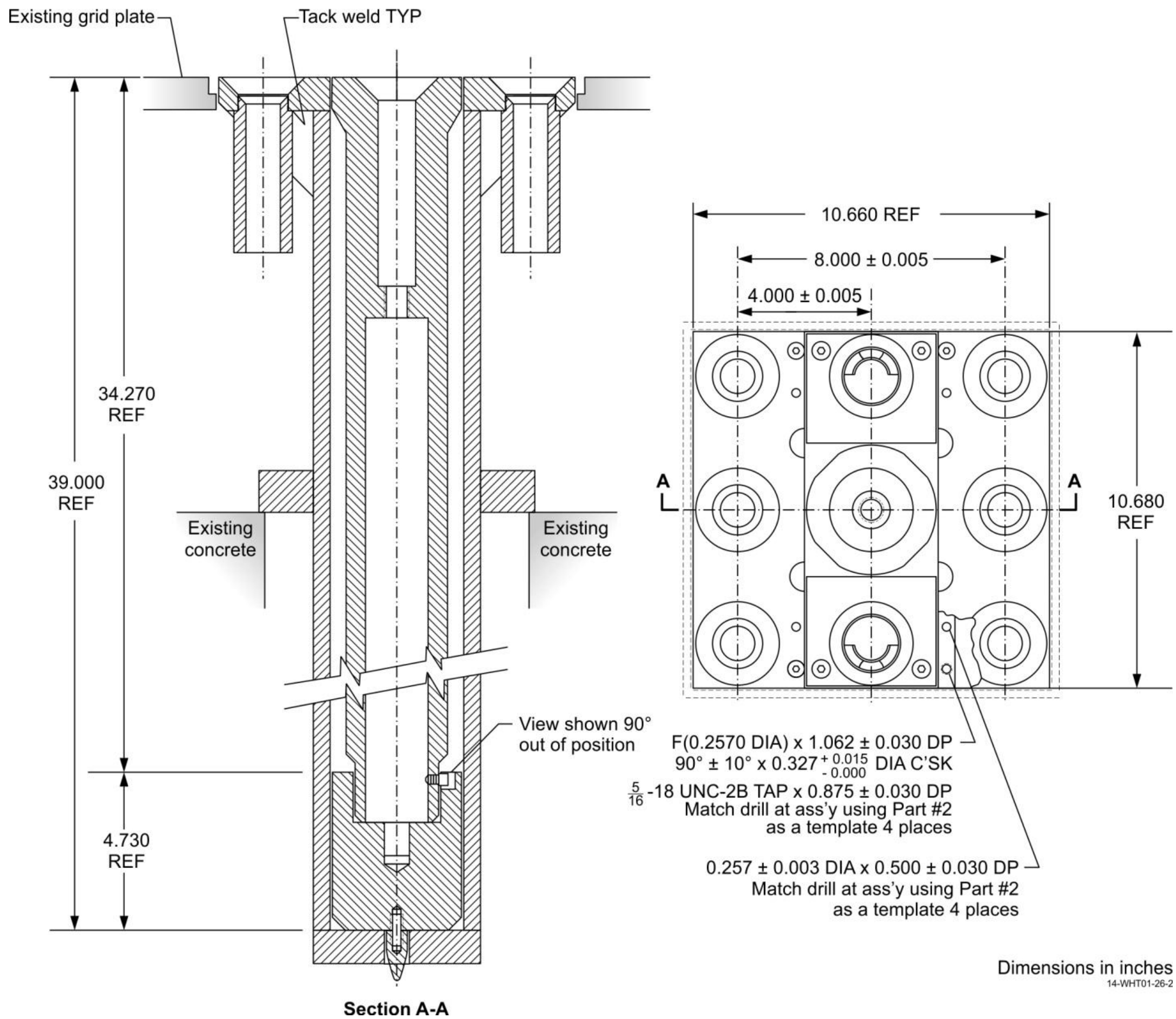


Figure 2.327. Grid Plate Insert Assembly Normal Configuration (DWG# Z0012-0163).

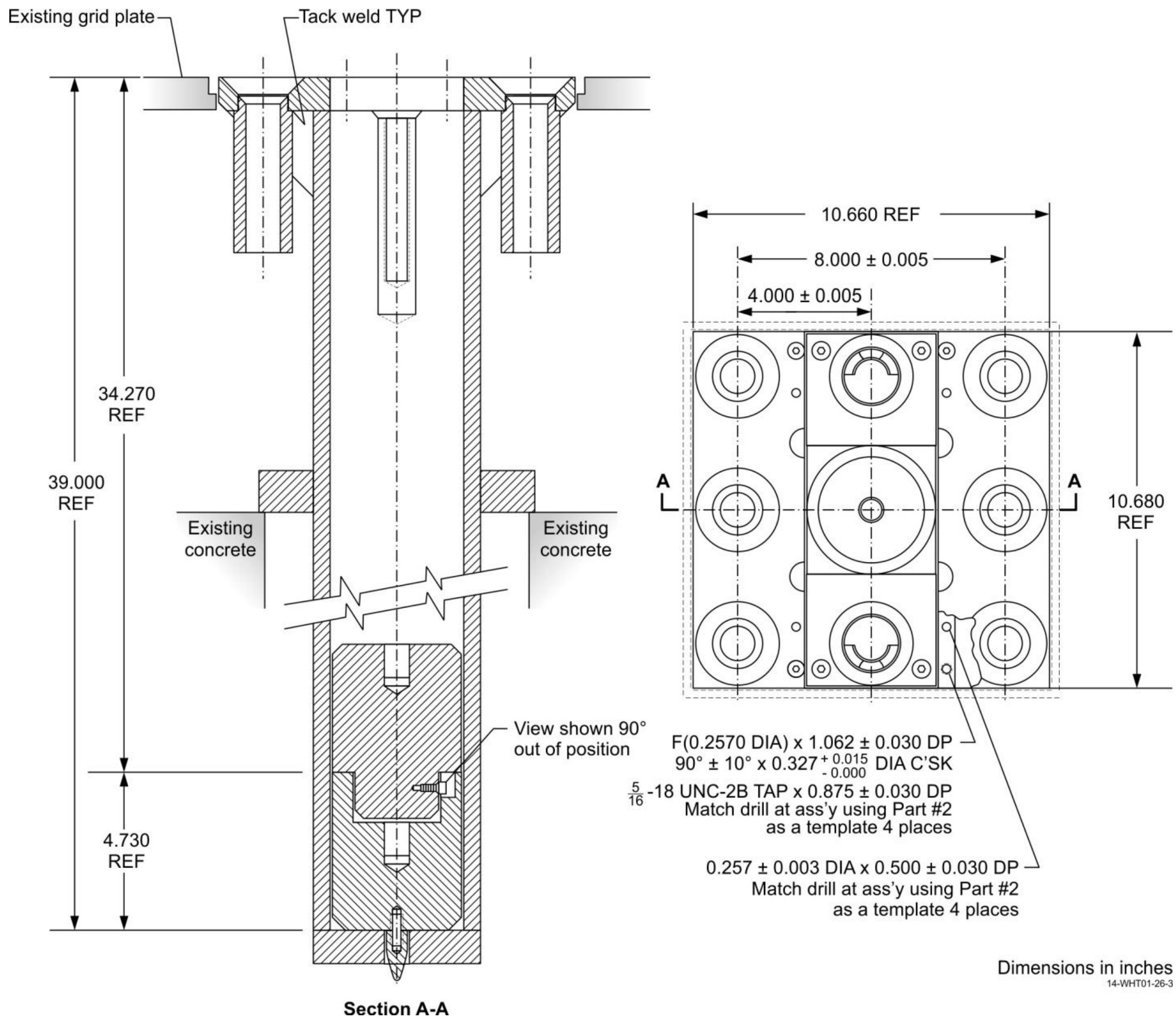


Figure 2.328. Grid Plate Insert Assembly PFR Configuration (DWG# Z0012-0164).

2.10.2 Control Rod Guide Assembly

Thirty-two control rod guide thimbles (Figure 2.329) extend through the bottom concrete shield into the subreactor room. To ensure accurate alignment of the thimbles and steel tubes for the central and offset through-holes with corresponding openings in the grid plate, the entire unit was bolted between two steel plates and case into the concrete shield [Freund 1960]. The mounting plate and tube are shown in Figures 2.331 and 2.332, respectively, with additional assembly structure shown in Figure 2.330. Additional components of the control rod guide thimbles are shown in Figures 2.333 through 2.336. The control rods contact the reactor facility at three graphitar bushing locations: one in the control rod assembly, and two in the guide thimble assembly. Figures 2.337 through 2.342 provide additional views of the reactor substructure and control rod guide assembly.

Table 2.32. Core Support Structure Control Rod Guide Assembly Components.

Quantity	Figure	DWG#	Component	Material
1	2.329	--	Control Rod Guide Thimble	--
1	2.330	RE-1-21689	Control Rod Guide Assembly	Mild Steel
1	2.331	RE-1-21690	Mounting Plate	Mild Steel
32	2.332	RE-1-21691	Mounting Tube	Mild Steel
32	2.333	RE-1-21730	Control Rod Seal Assembly	Mild Steel
32	2.334	RE-1-22566	Control Rod Seal	Mild Steel
64	2.335	RE-1-22568	Bushing	Mild Steel
64	2.336	RE-1-22575	Graphitar Bushing	Graphitar
1	2.337	--	Lower Plenum Liner	--
1	2.338	--	Center Through Hole and Thimble	--
--	2.339-2.342	--	Additional Depictions of Core Support Structure	--

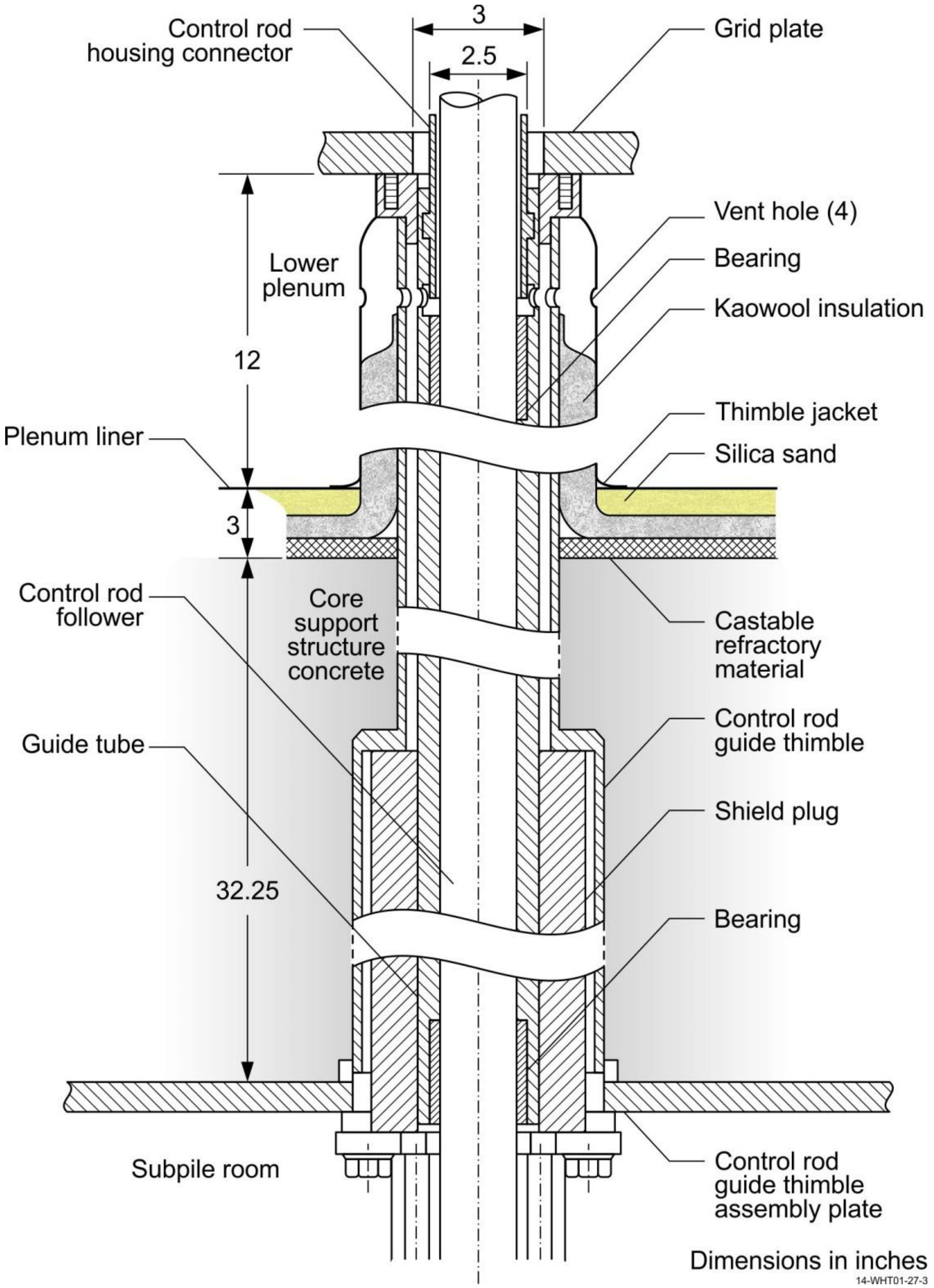


Figure 2.329. Control Rod Guide Thimble.

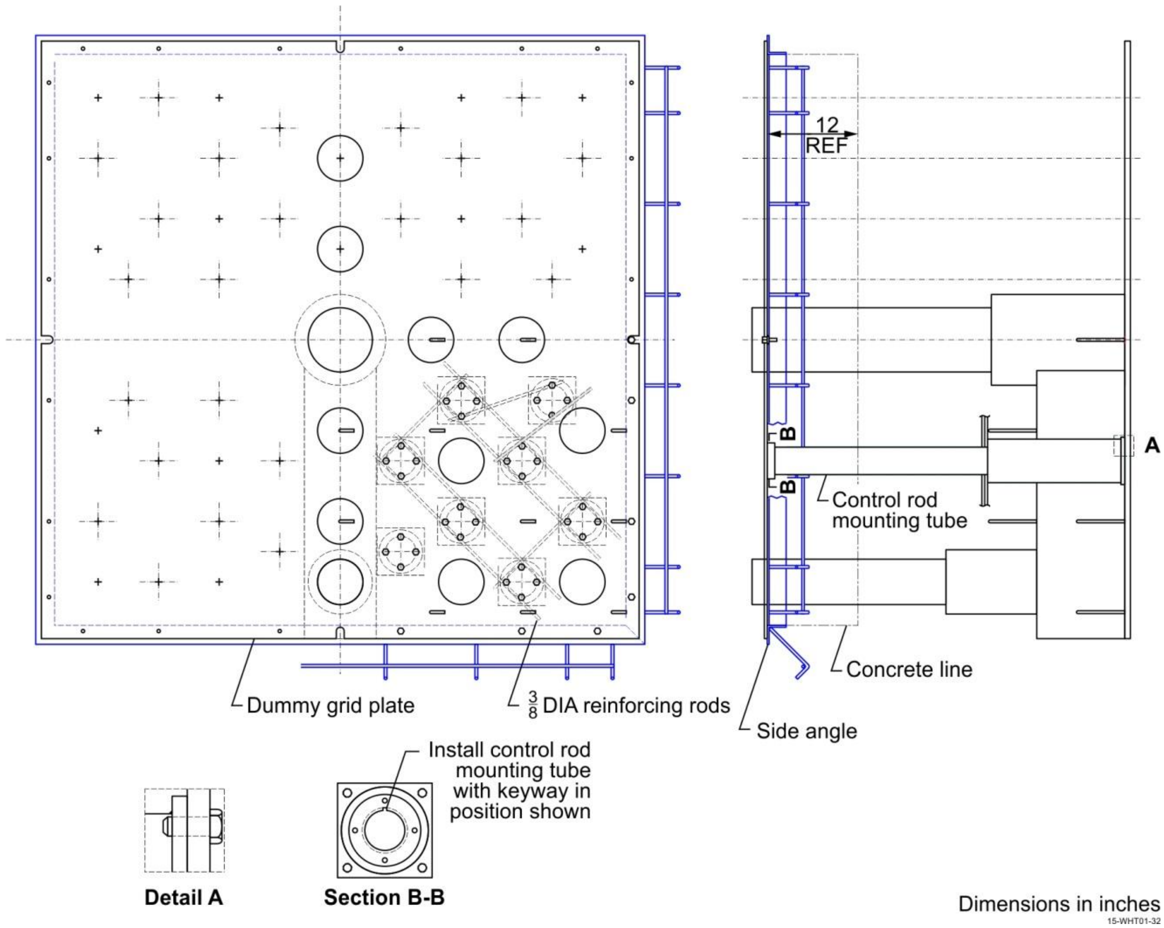


Figure 2.330. Control Rod Guide Assembly (DWG# RE-1-21689).

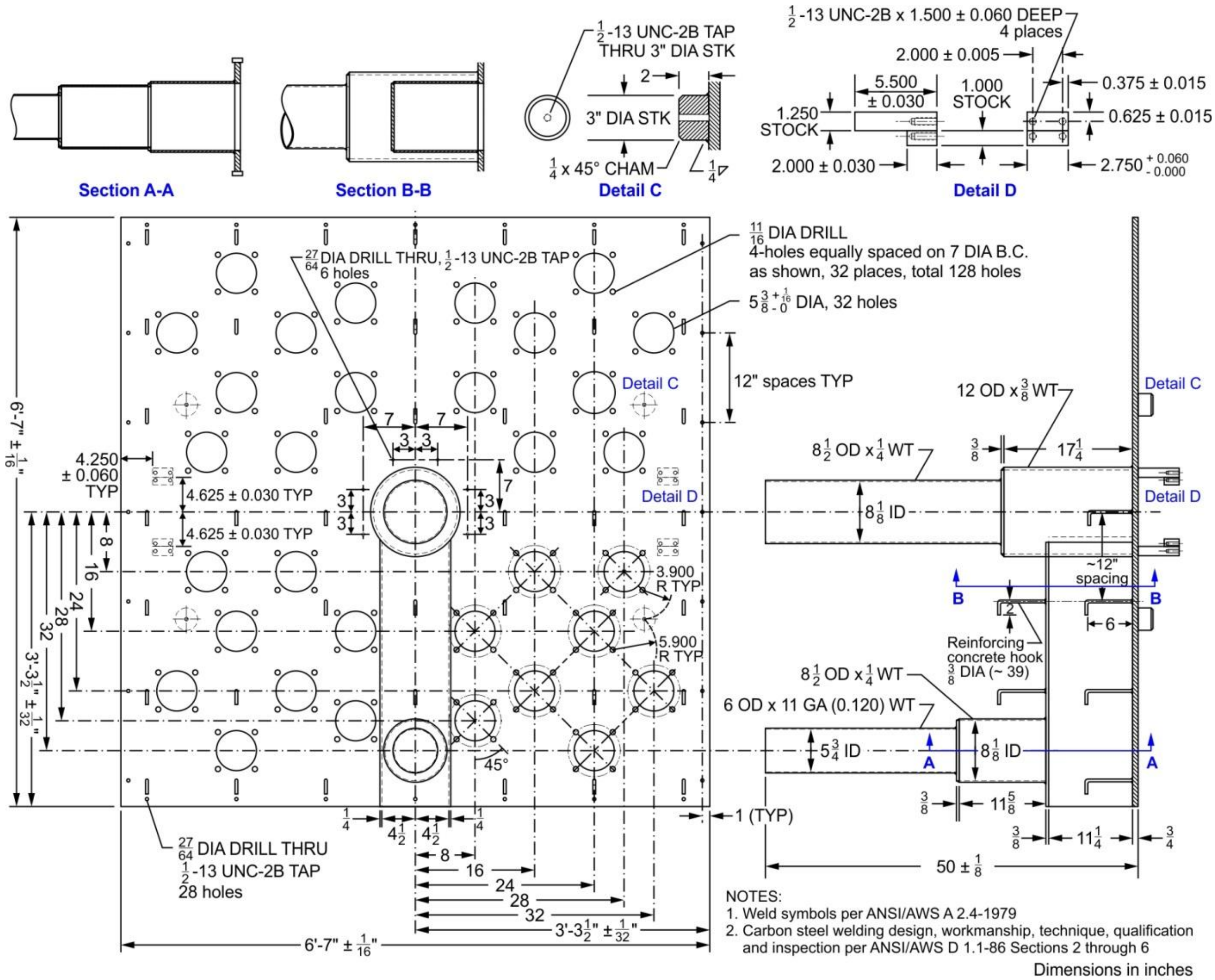


Figure 2.331. Mounting Plate (DWG# RE-1-21690).

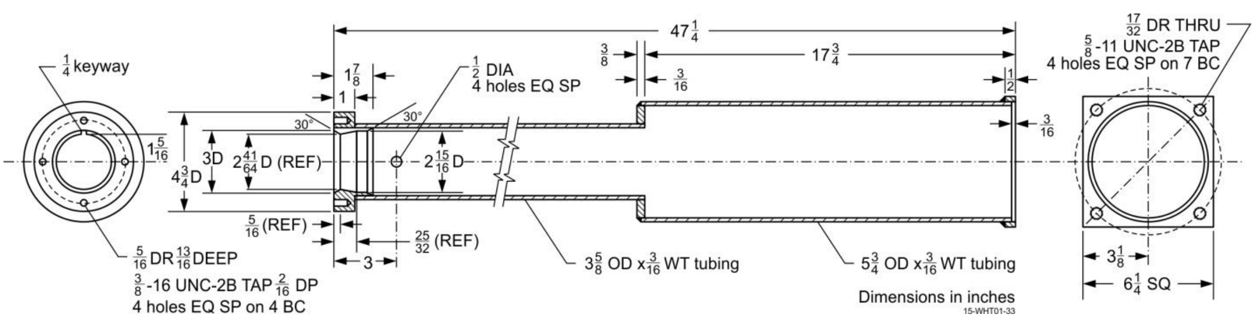


Figure 2.332. Mounting Tube (DWG# RE-1-21691).

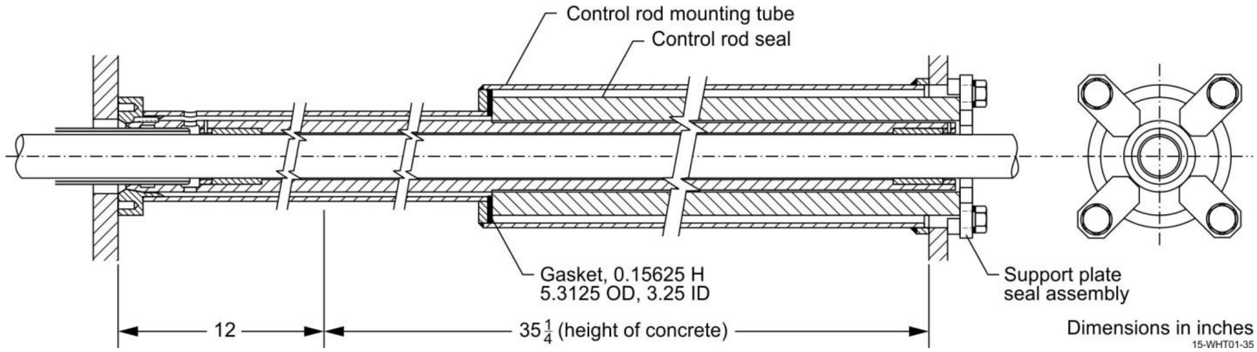


Figure 2.333. Control Rod Seal Assembly (DWG# RE-1-21730).

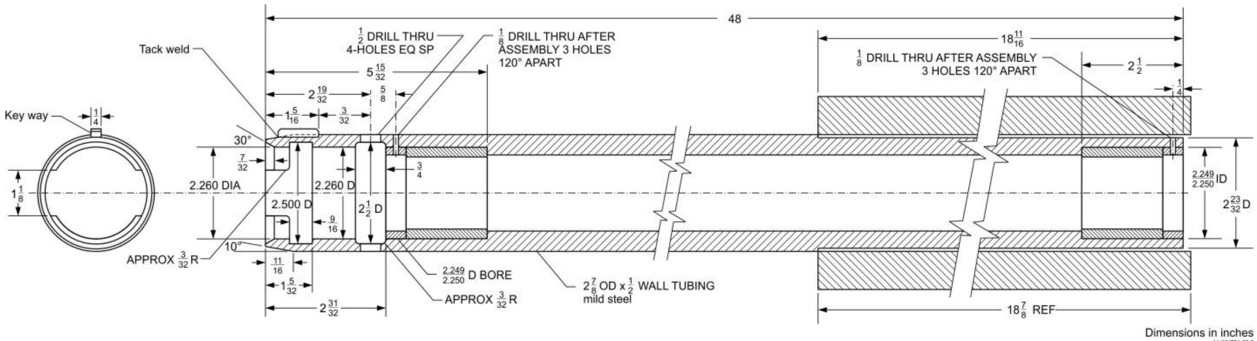


Figure 2.334. Control Rod Seal (DWG# RE-1-22566).

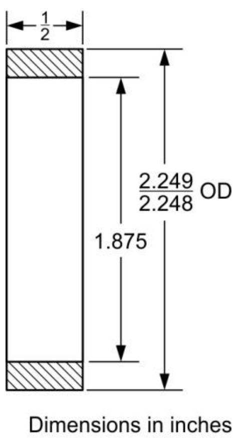


Figure 2.335. Bushing (DWG# RE-1-22568).

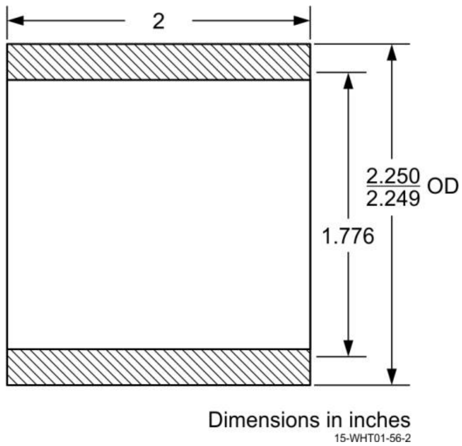


Figure 2.336. Graphitar Bushing (DWG# RE-1-22575).

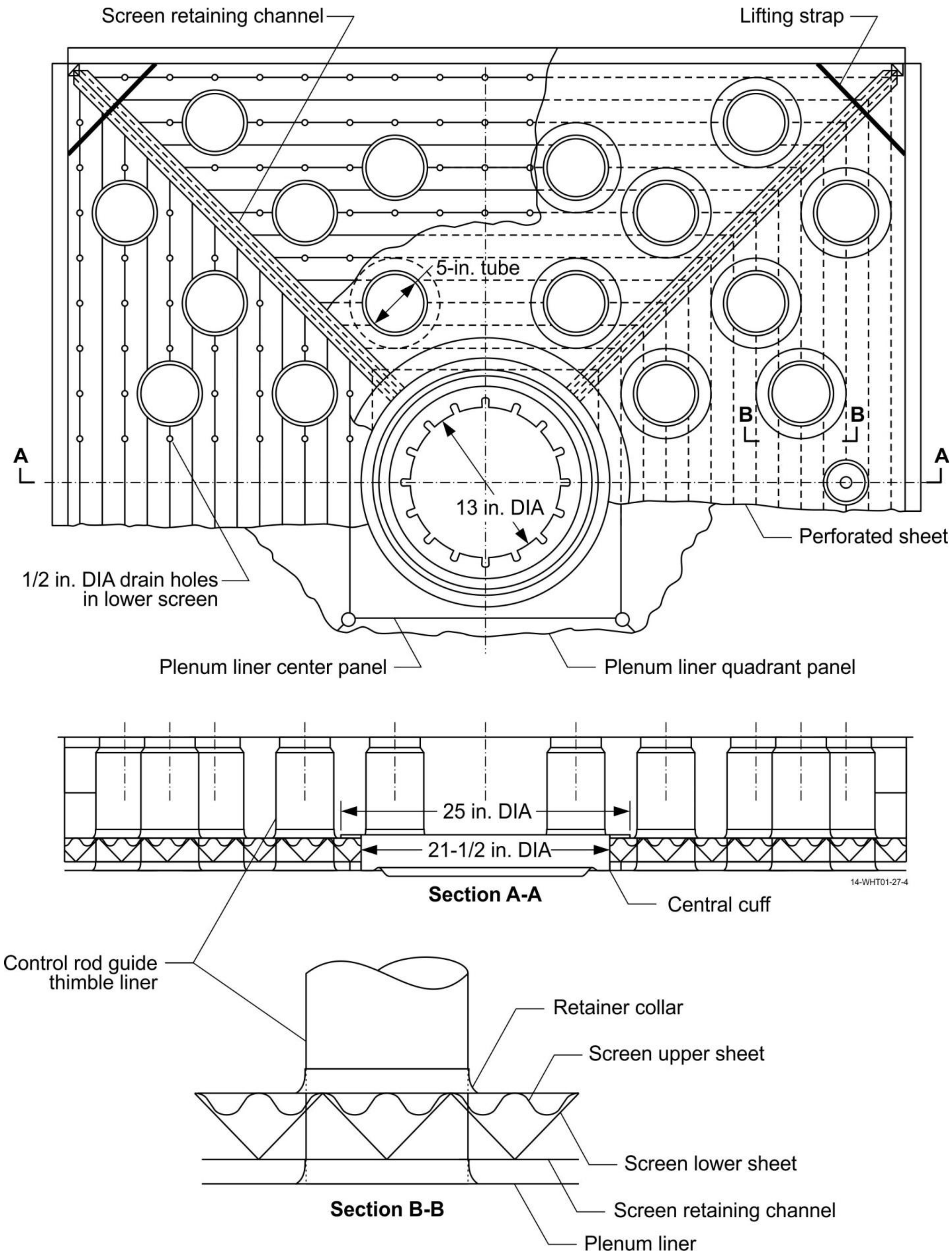


Figure 2.337. Lower Plenum Liner.

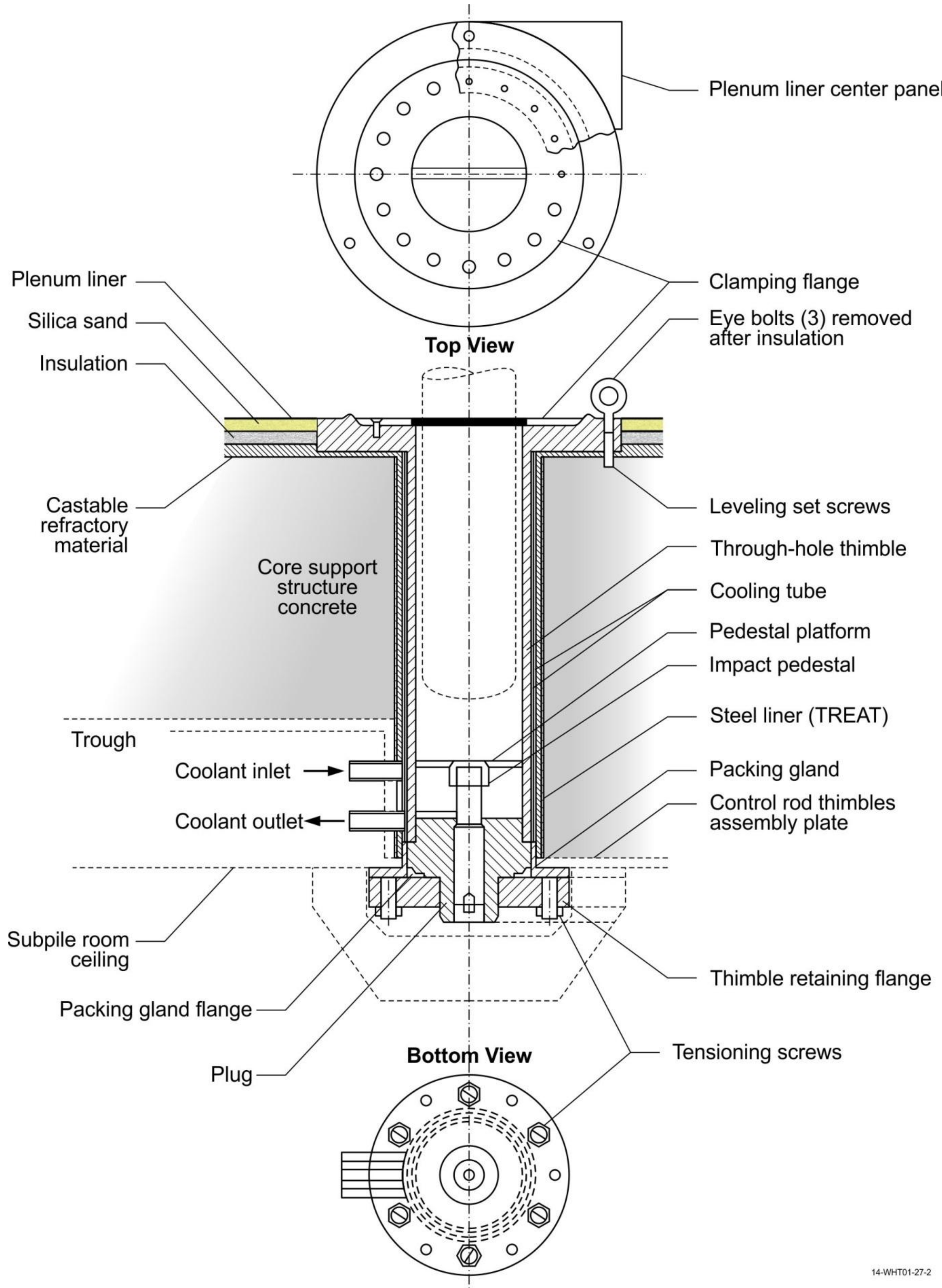


Figure 2.338. Center Through Hole and Thimble.

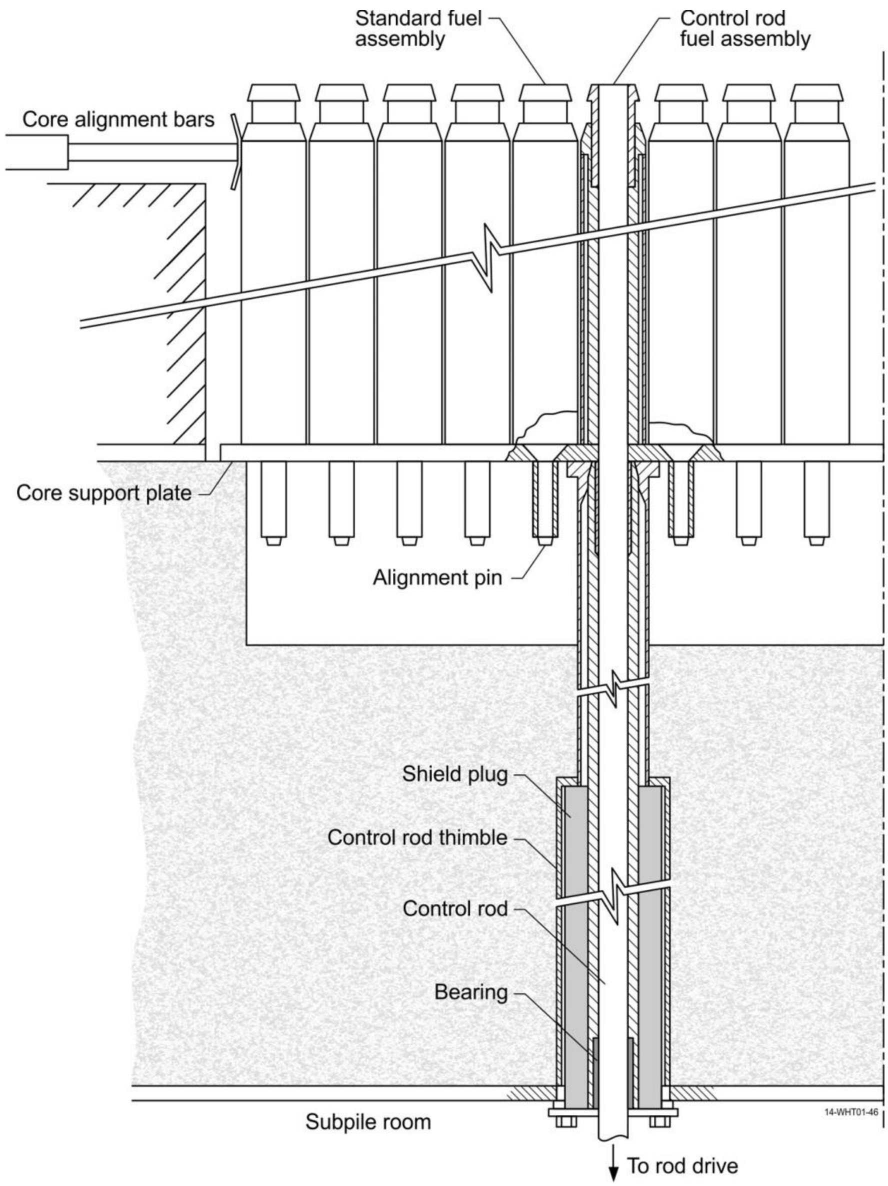


Figure 2.339. Core Support and Alignment.

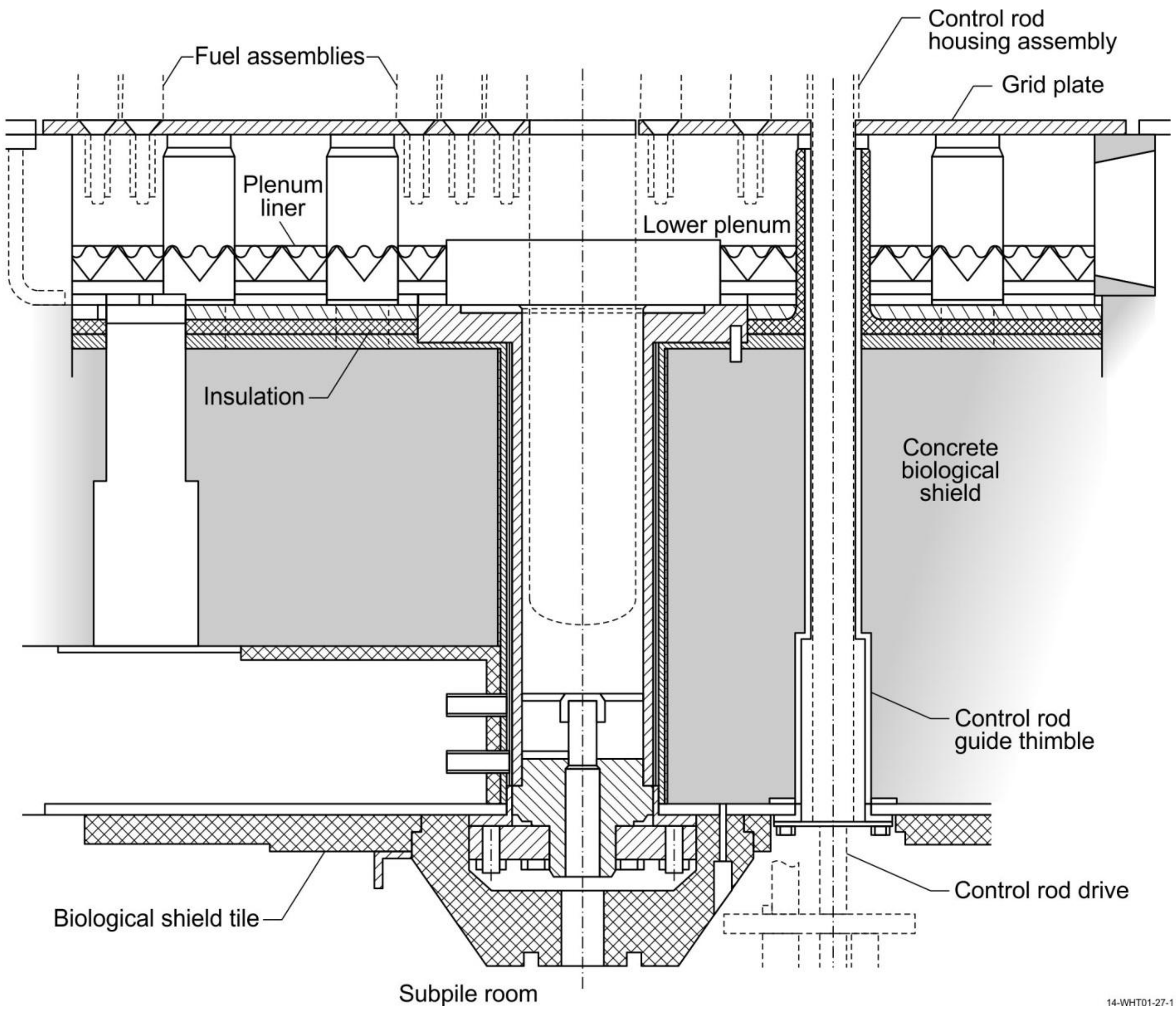


Figure 2.340. Core Support Structure.

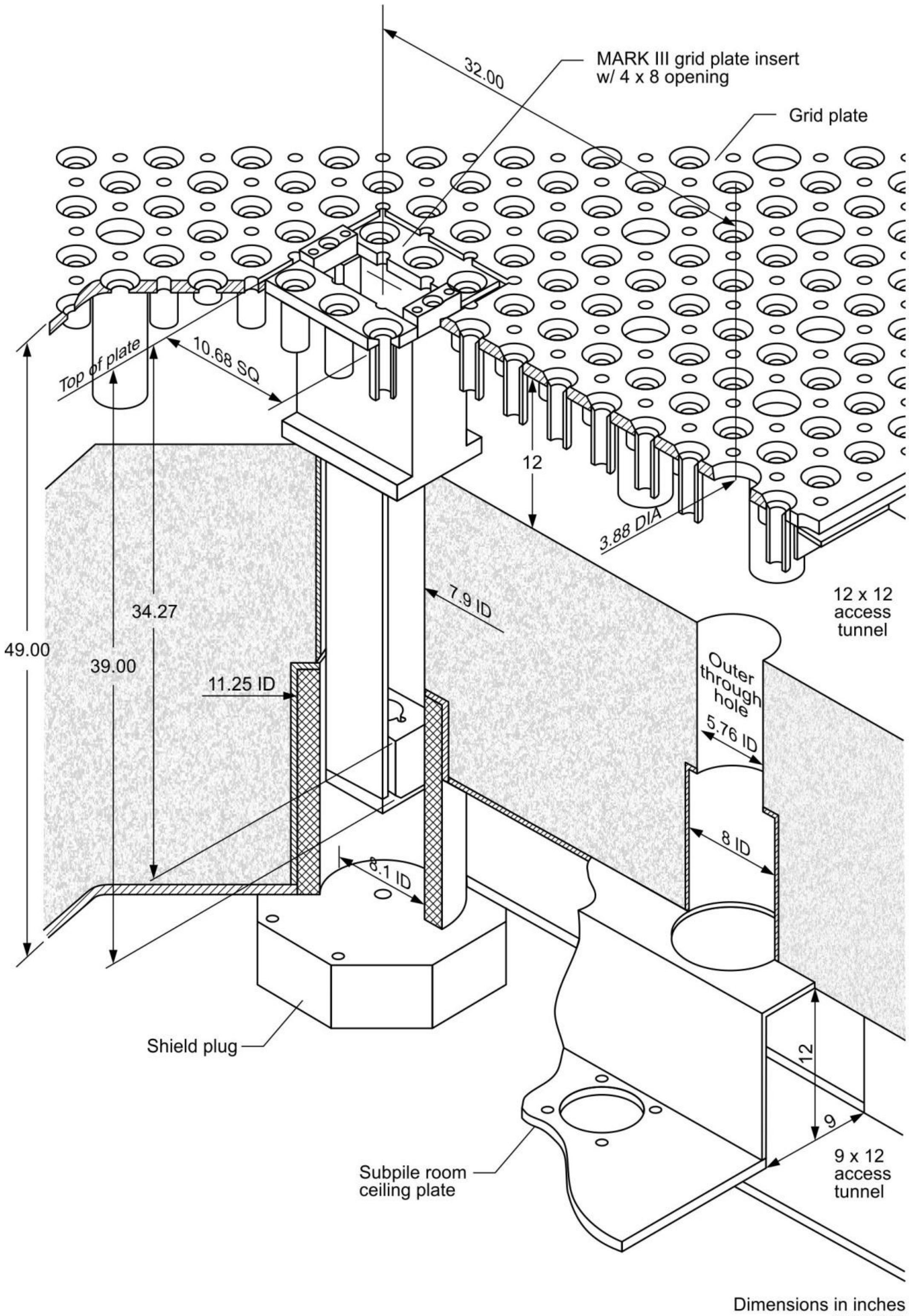


Figure 2.341. Grid Plates and Access Holes.

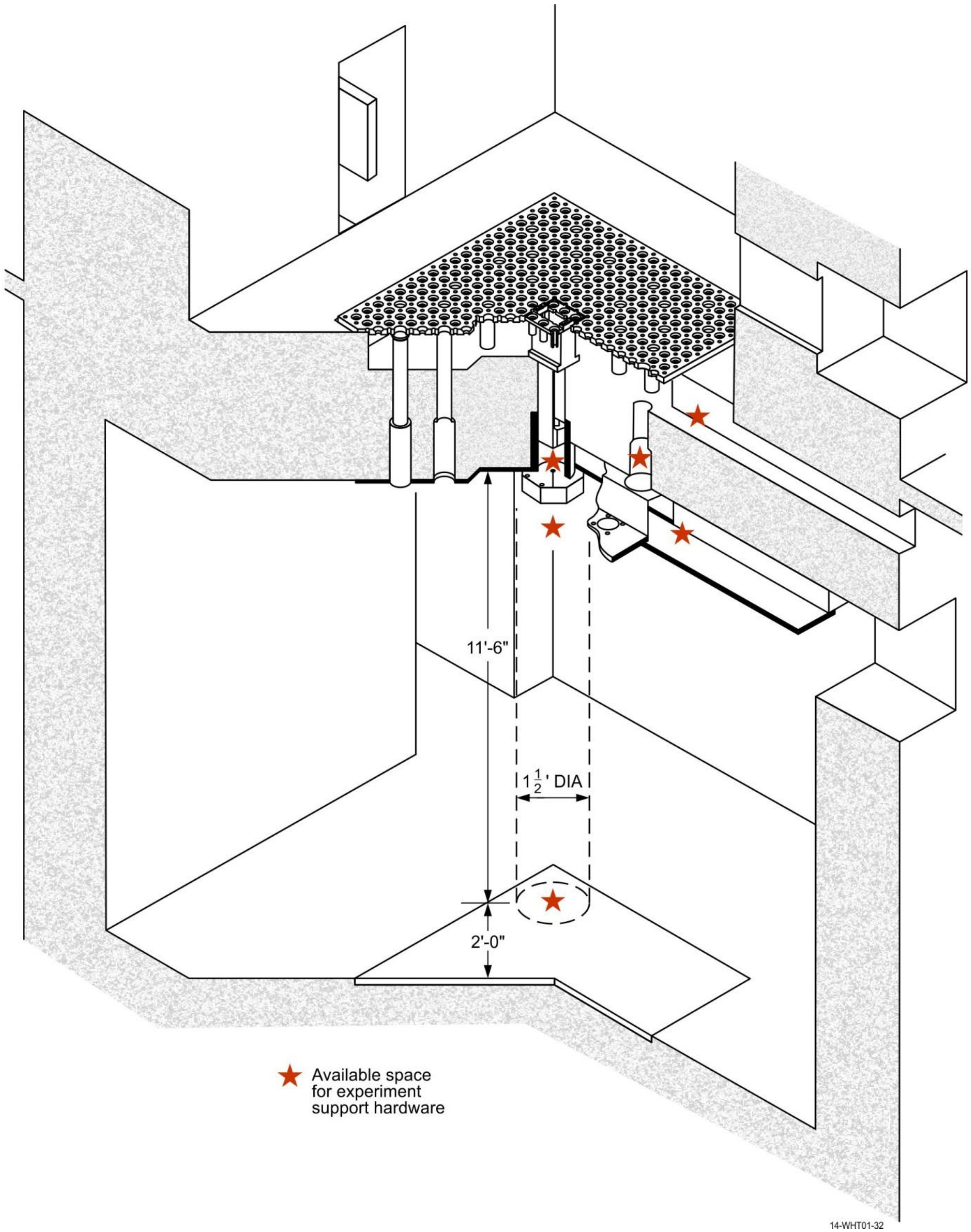


Figure 2.342. Grid Plate and Subpile Room.

2.10.3 Clamping Bars

The top ends of the assemblies are aligned and clamped by four horizontal clamping bars to form a rigid "bundle" by applying pressure to the outermost row of assemblies on each side of the core. Each clamping bar is actuated by two push rods that operate through horizontal penetrations in the concrete shield. The push rods on the north and east sides of the core are flanged and bolted in position, while those on the south and west sides are spring loaded with a total spring force of about 1000 lb per bar. The spring loading ensures a uniform clamping force and permits thermal expansion of the core and the push rods [Freund 1960].

Table 2.33. Core Support Structure Clamping Bars Components.

Quantity	Figure	DWG#	Component	Material
4	2.343	--	Core Clamping Bars	--
4	2.344	RE-1-21725	Core Pusher Assembly	--
8	2.345	RE-1-22458	Bolt Pusher Rod	Mild Steel
8	2.346	RE-1-22459	Flange Pusher (rework)	Mild Steel
8	2.347	RE-1-22460	Rod Pusher	Mild Steel
4	2.348	RE-1-22461	Plate Pusher	Mild Steel
8	2.349	RE-1-22584	Support Bracket Pusher Plate	Mild Steel
8	2.350	RE-1-24386	Flange Pusher #2	Mild Steel

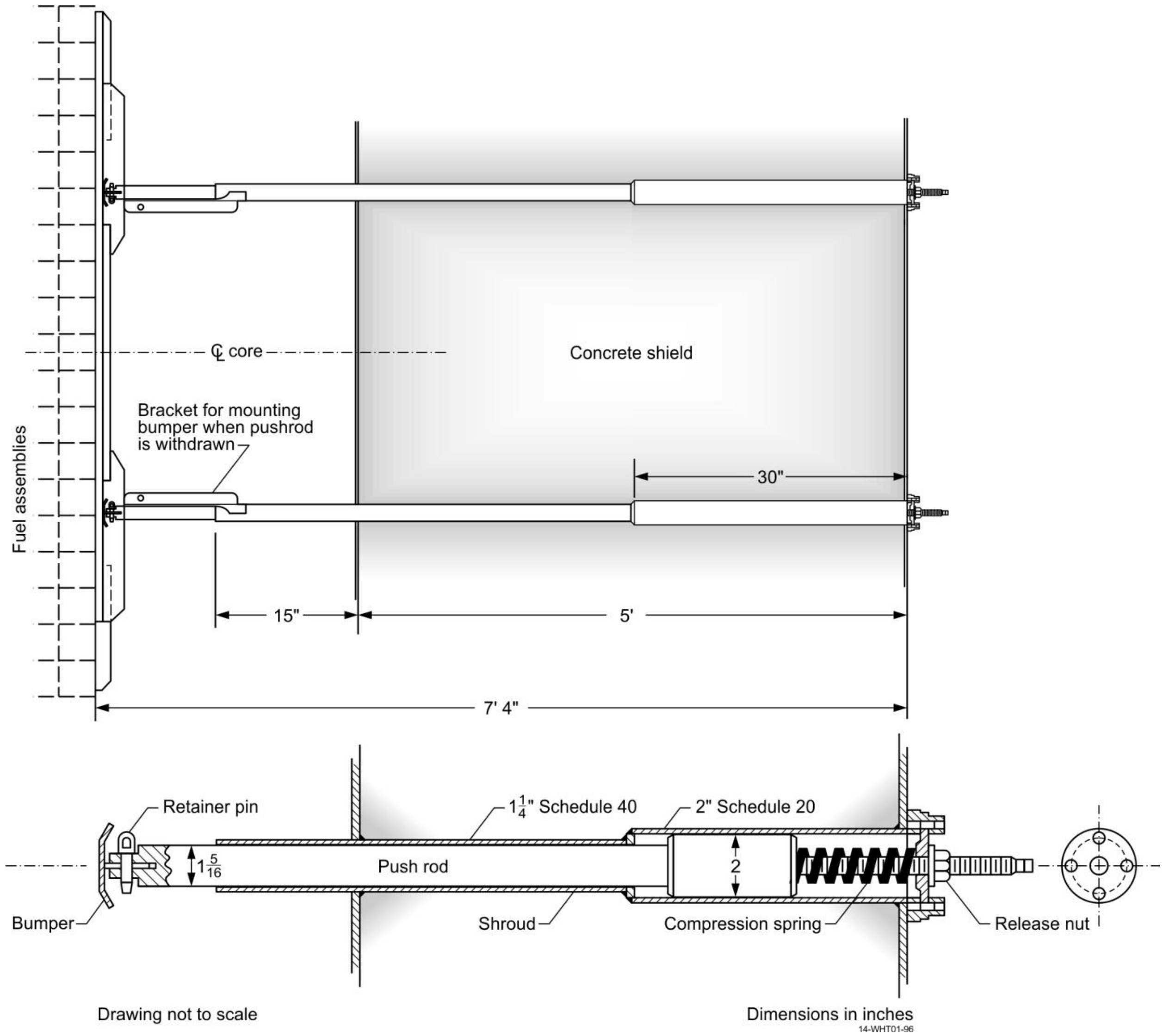


Figure 2.343. Core Clamping Bars.

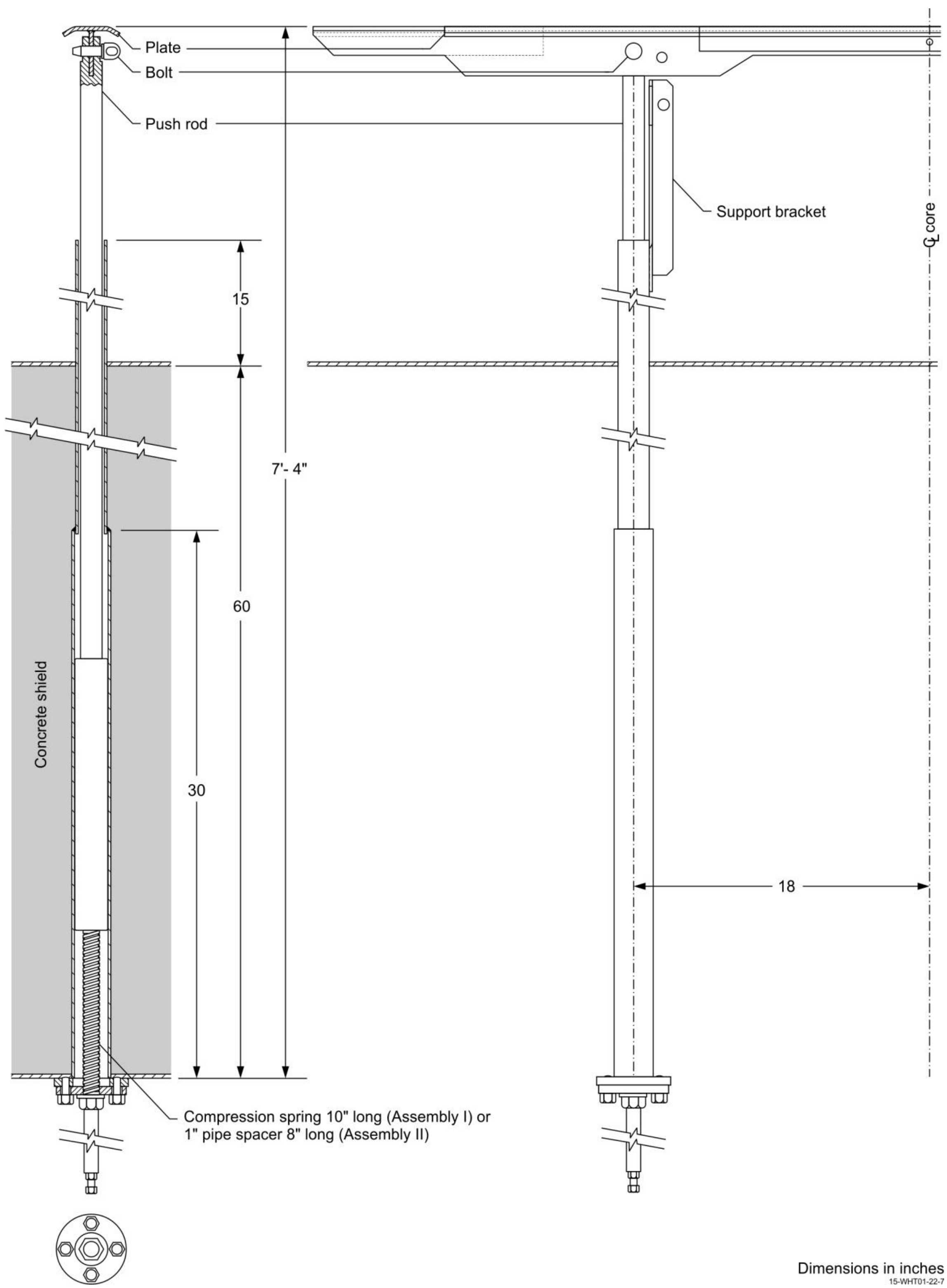


Figure 2.344. Core Pusher Assembly (DWG# RE-1-21725).

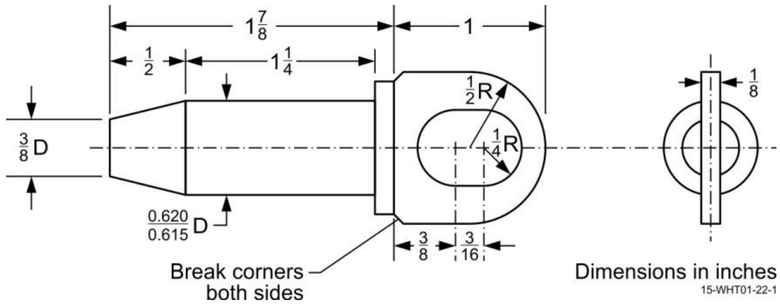


Figure 2.345. Bolt Pusher Rod (DWG# RE-1-22458).

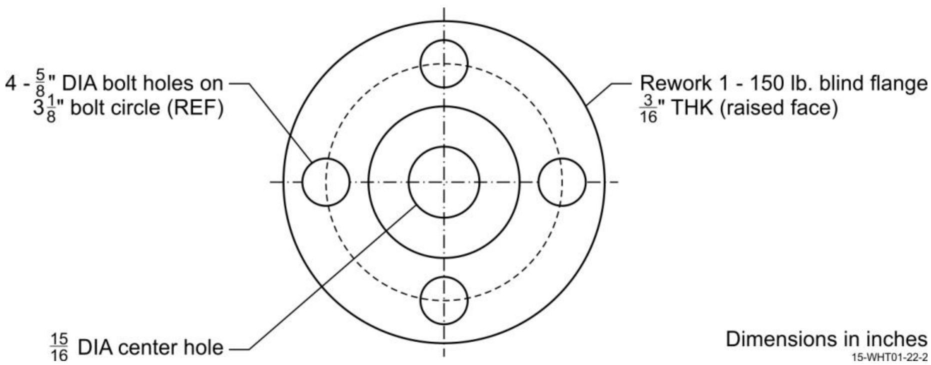


Figure 2.346. Flange Pusher (rework) (DWG# RE-1-22459).

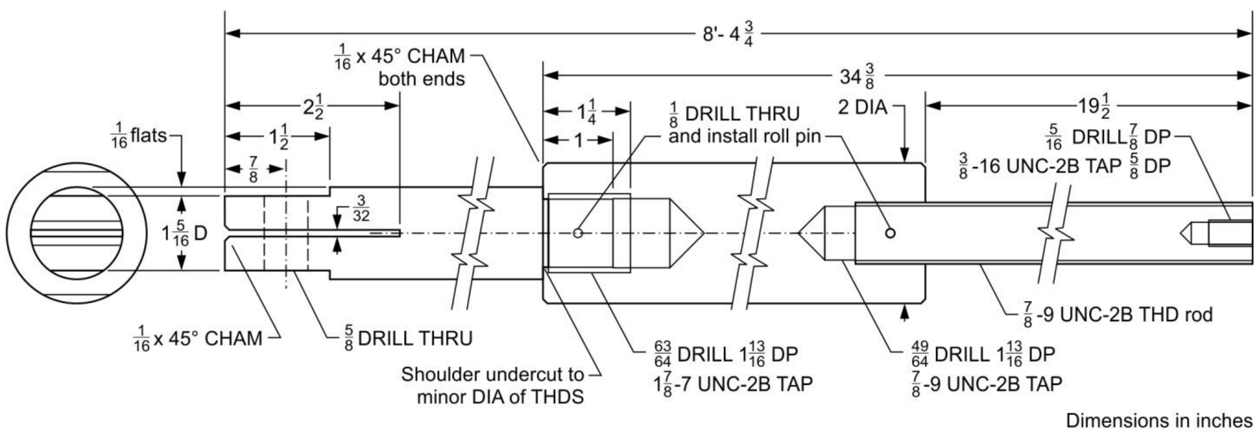


Figure 2.347. Rod Pusher (DWG# RE-1-22460).

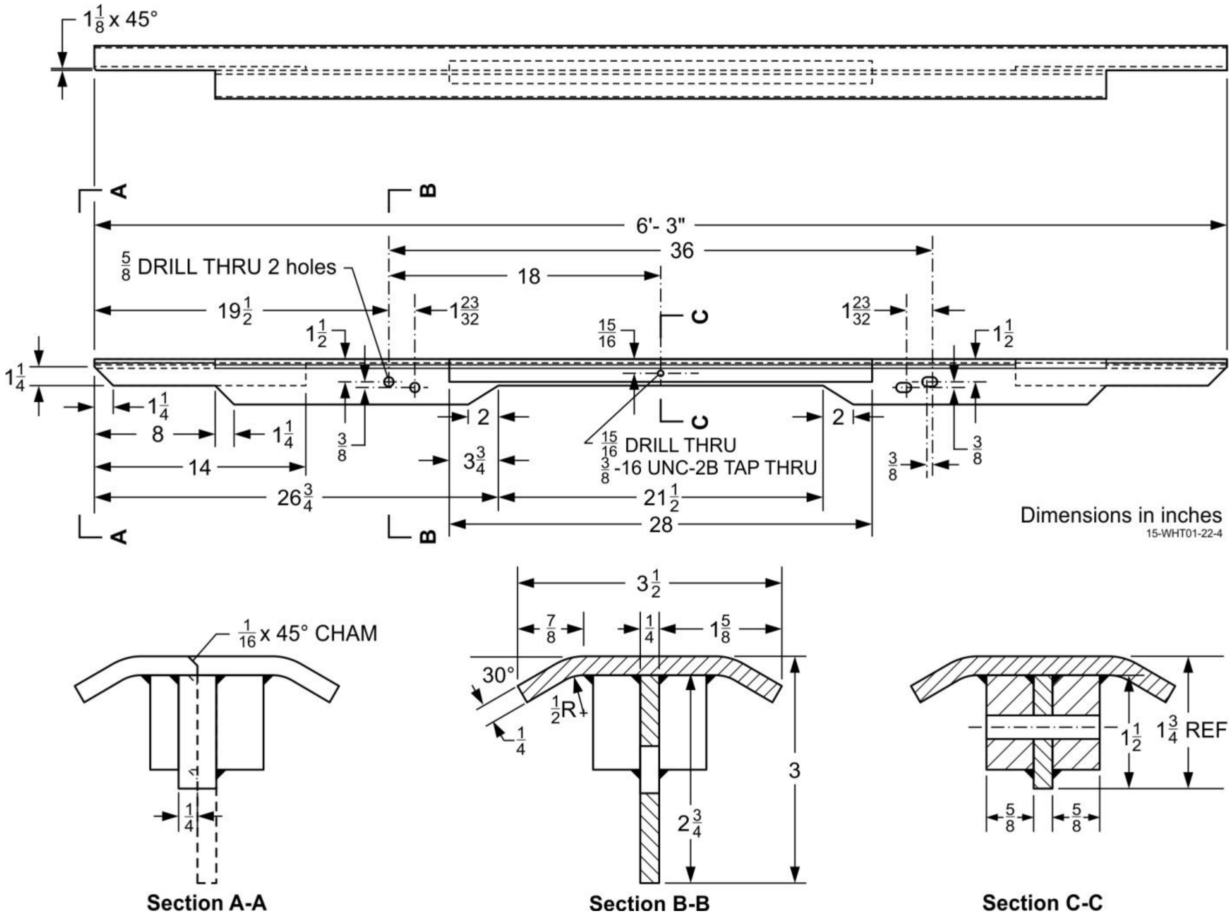


Figure 2.348. Plate Pusher (DWG# RE-1-22461).

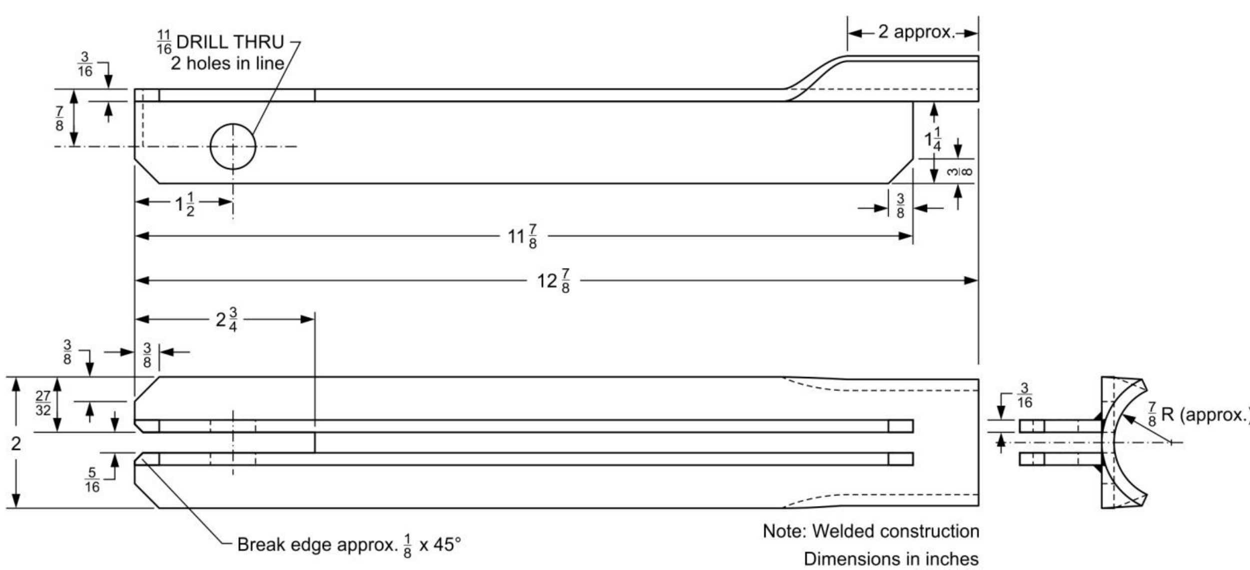


Figure 2.349. Support Bracket Pusher Plate (DWG# RE-1-22584).

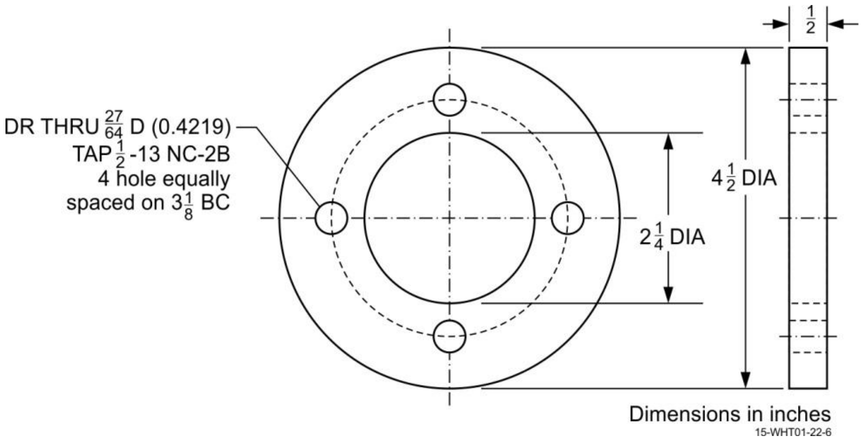


Figure 2.350. Flange Pusher #2 (DWG# RE-1-24386).

2.11 Reactor Shielding and Containment

The reactor is shielded radially by a 15-ft.-high, 5-ft.-thick high-density (200-220 lb/ft^3) heavy magnetite and/or hematite concrete. The shielding below the reactor is 3-ft.-thick reinforced high-density concrete, which forms a portion of the ceiling of the subreactor room. The bottom of this concrete is faced with the ¾-in.-think steel plate used to pre-assembly the control rod thimbles. The concrete below the permanent reflector is 4 ft. thick and surrounds the core support region, providing a 1-ft.-deep core plenum area. The inside surface of the concrete is faced with permanent forms of ¼-in.-thick steel plate installed prior to pouring of the bulk concrete. The outside surface has steel plate extending up 8 ft. from the floor level. [Freund 1960].

The ledge of the concrete structure above the core is called the corbel and provides a load-bearing surface for the rotating shield plug. The bottom and inside ledges of this shelf are lined with ¼-in.-thick carbon steel plate, which is a continuation of the liner from the inside walls of the reactor structure. The top shielding has removable 3-ft.-thick concrete blocks which expose a 10 ft. 10 in. diameter, laminated steel and boral, rotating shield with indexing plug (1 ft. thick). The plug features a radial slot containing boron-steel blocks that can be moved to provide access to assemblies within the core, and a lead glass viewing window [Freund 1960].

The plug consists of three 4-in.-thick slabs of steel with the top and bottom surfaces coated with a layer of ¼-in.-thick boral for thermal neutron attenuation. The top boral layer is covered with ¼-in.-thick steel checker plate. The plug rotates on a ball bearing which is embedded in the bottom of the plug cavity formed in the top of the concrete shield [Freund 1960].

The various shielding penetrations are plugged with smaller shielding components, such as those shown in Figures 2.358 and 2.359.

Table 2.34. Reactor Shielding Components.

Quantity	Figure	DWG#	Component	Material
1	2.351	RE-1-21237	Shielding Side View	Hematite/Magnetite Concrete
1	2.352	RE-1-21365	Shielding Main View	Hematite/Magnetite Concrete
1	2.353	RE-1-21379	Reactor Shielding Blocks	Hematite/Magnetite Concrete
1	2.354	--	Core Access Structure	--
1	2.355	--	Rotating Shield Plug	--
1	2.356	RE-1-22423	Top Plug Assembly	Mild Steel and Boral
1	2.357	S3310-0121	Modified Rotating Plug	Mild Steel and Boral
1	2.358a	IPE-720-4	Reactor Shielding Part I	Hematite/Magnetite Concrete
1	2.358b	IPE-720-4	Reactor Shielding Part II	Hematite/Magnetite Concrete
1	2.358c	IPE-720-4	Reactor Shielding Part III	Hematite/Magnetite Concrete
As Needed	2.358d & e	IPE-720-4	Reactor Shielding Part IV	Hematite/Magnetite Concrete
As Needed	2.358f	IPE-720-4	Reactor Shielding Part V	Hematite/Magnetite Concrete
4	2.359	RE-1-22737	Periscope Hole Liner	Mild Steel
1	2.360	RE-1-22222	Reactor Facility Plan Section	--

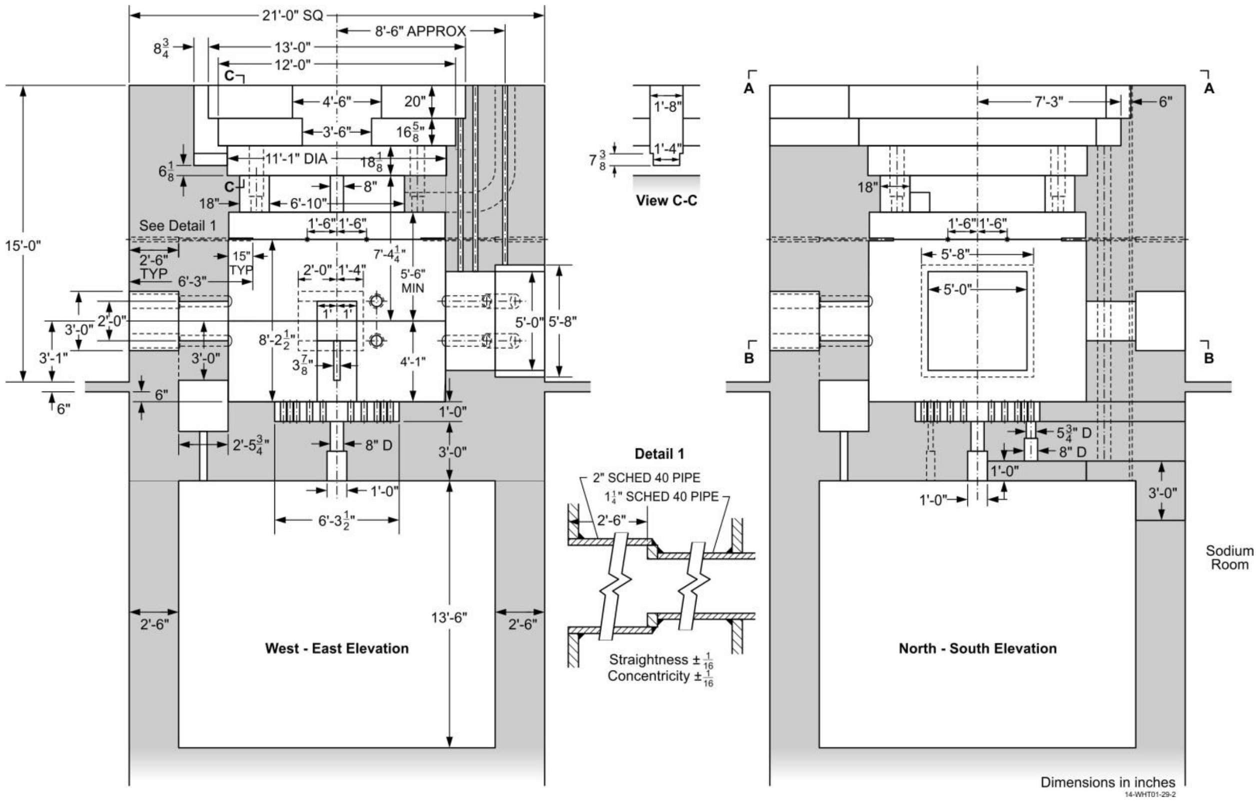


Figure 2.351. Shielding Side View (DWG# RE-1-21237).

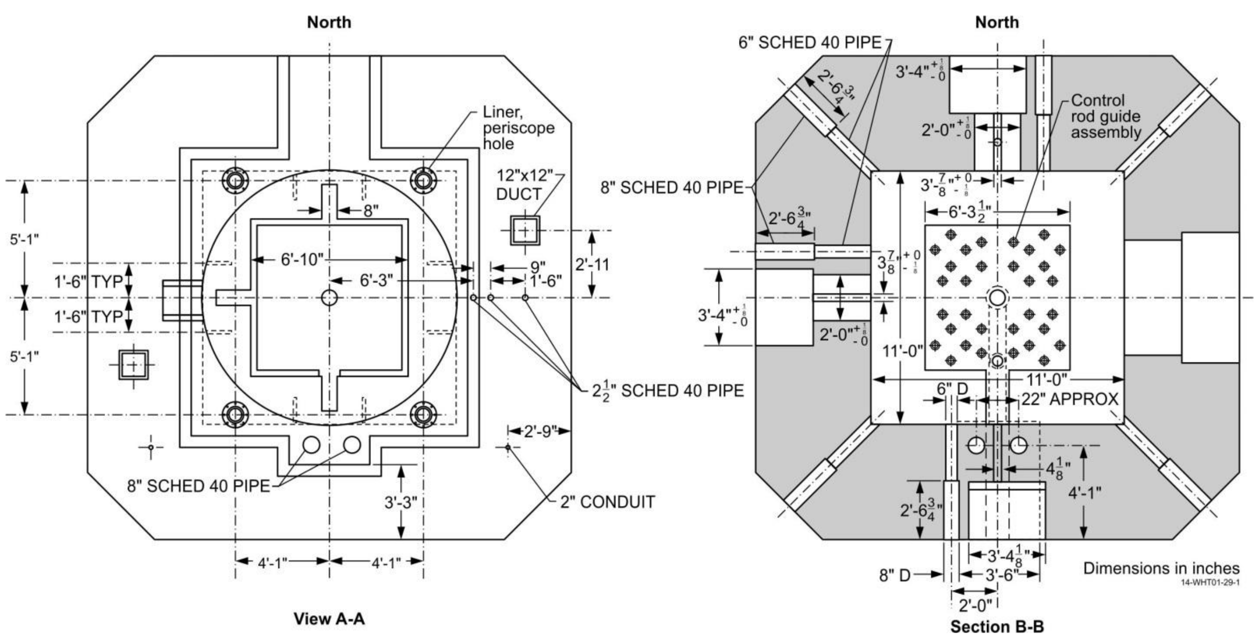


Figure 2.352. Shielding Main View (DWG# RE-1-21365).

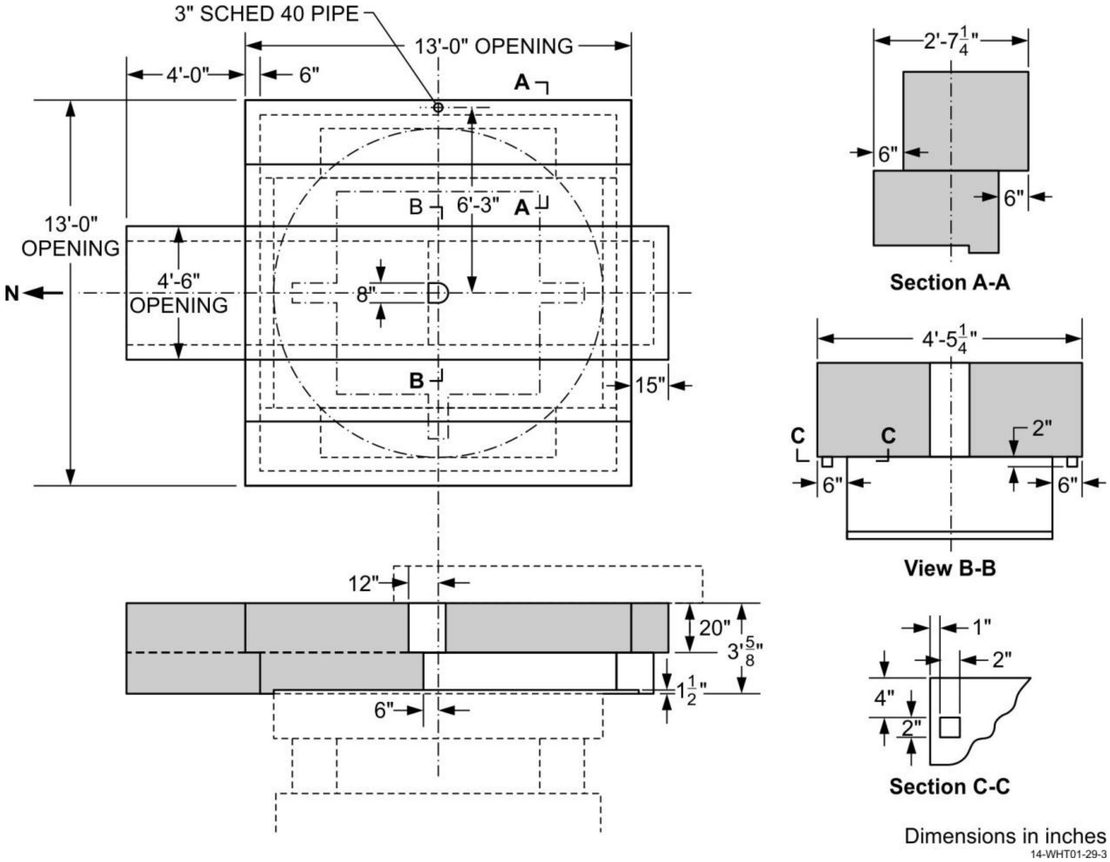


Figure 2.353. Reactor Shielding Blocks (DWG# RE-1-21379).

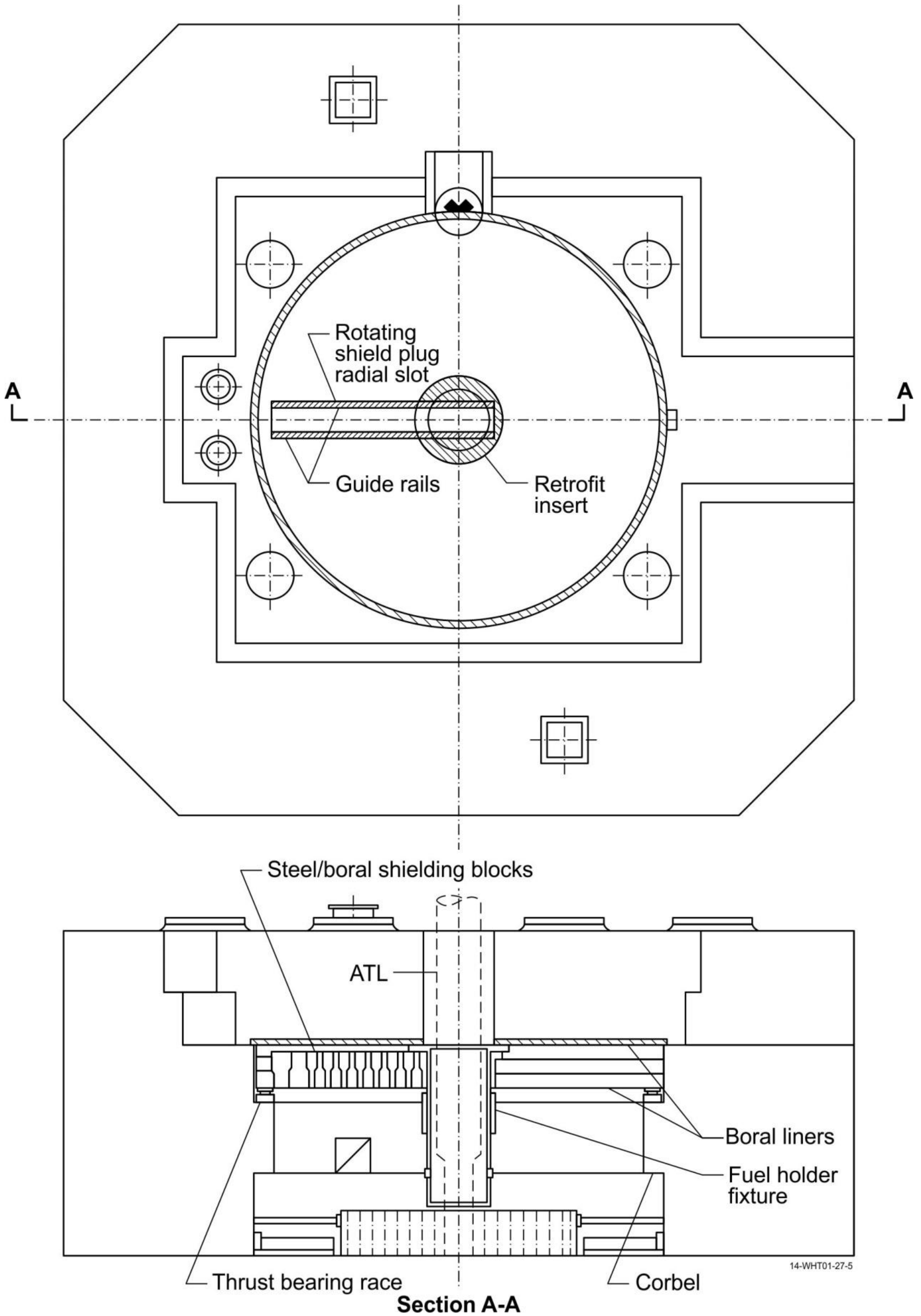


Figure 2.354. Core Access Structure.

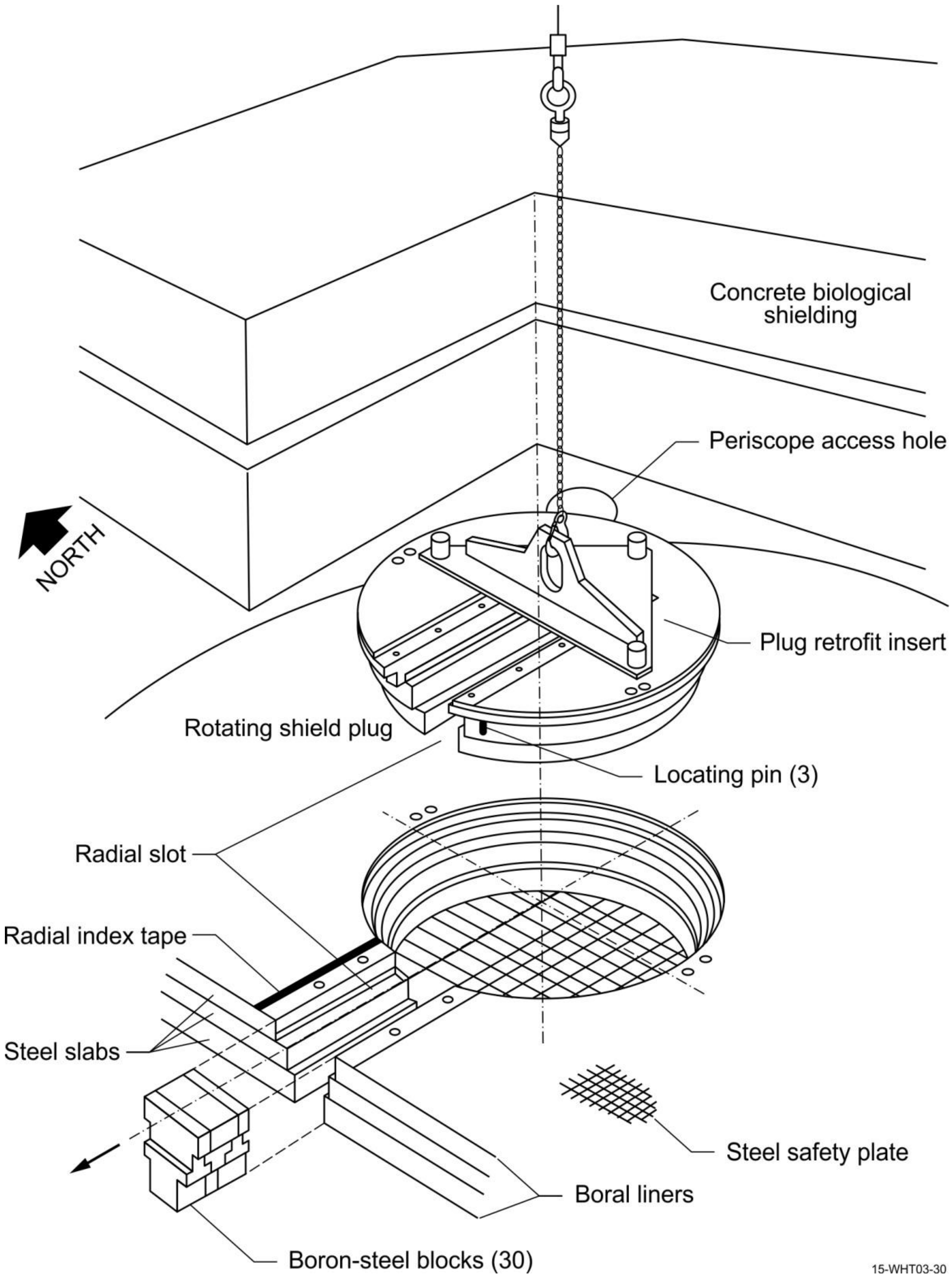


Figure 2.355. Rotating Shield Plug.

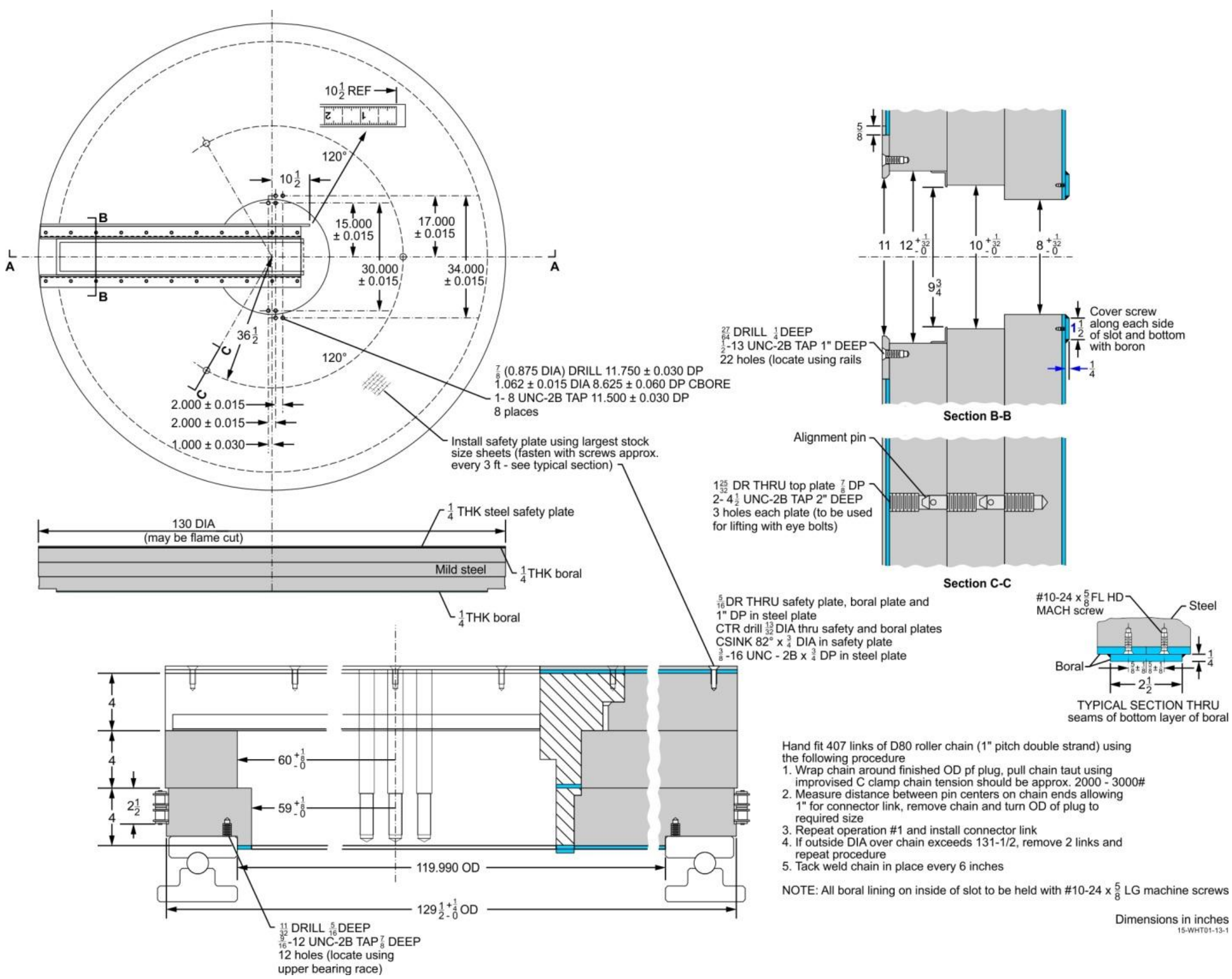


Figure 2.356. Top Plug Assembly (DWG# RE-1-22423).

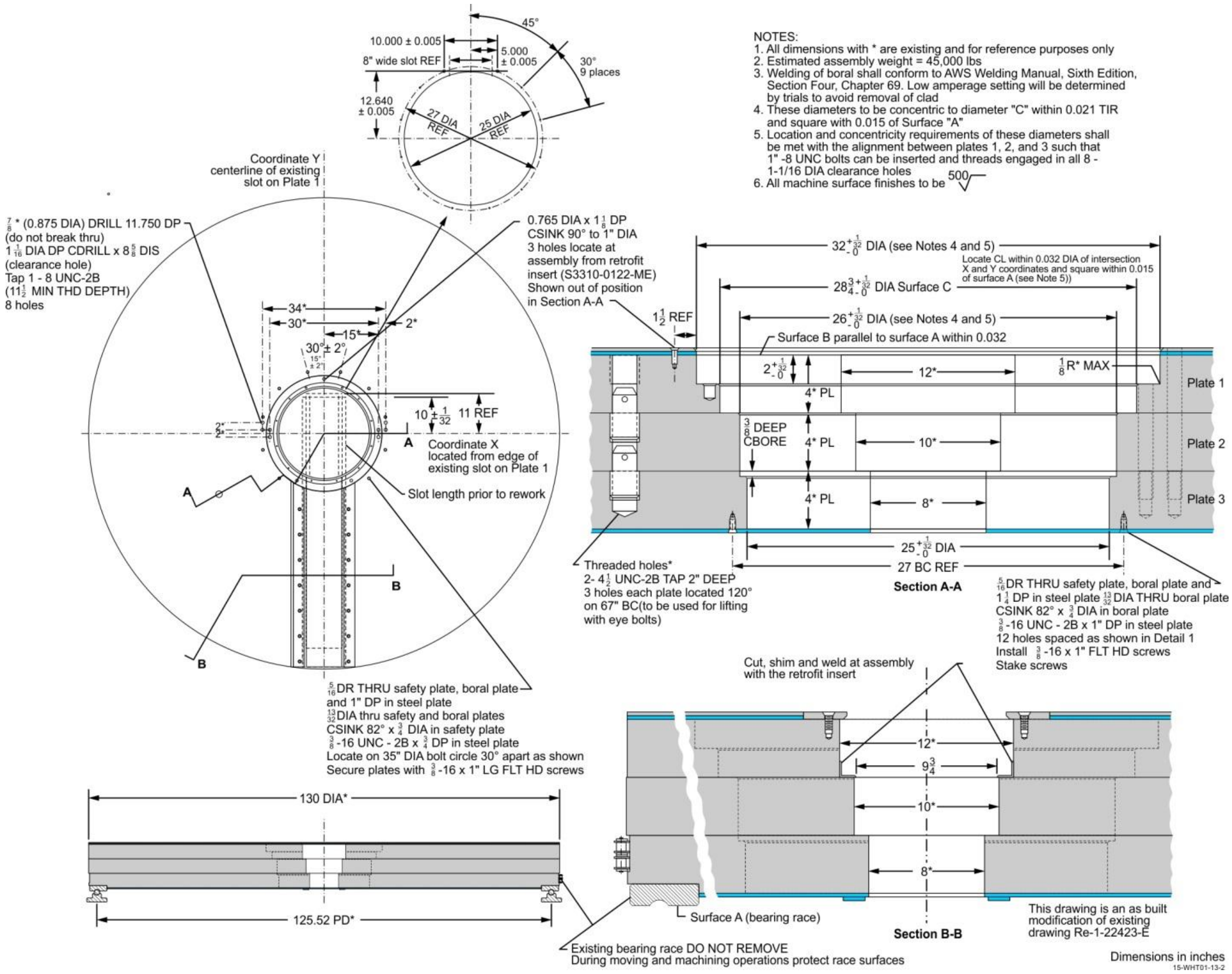


Figure 2.357. Modified Rotating Plug (DWG# S3310-0121).

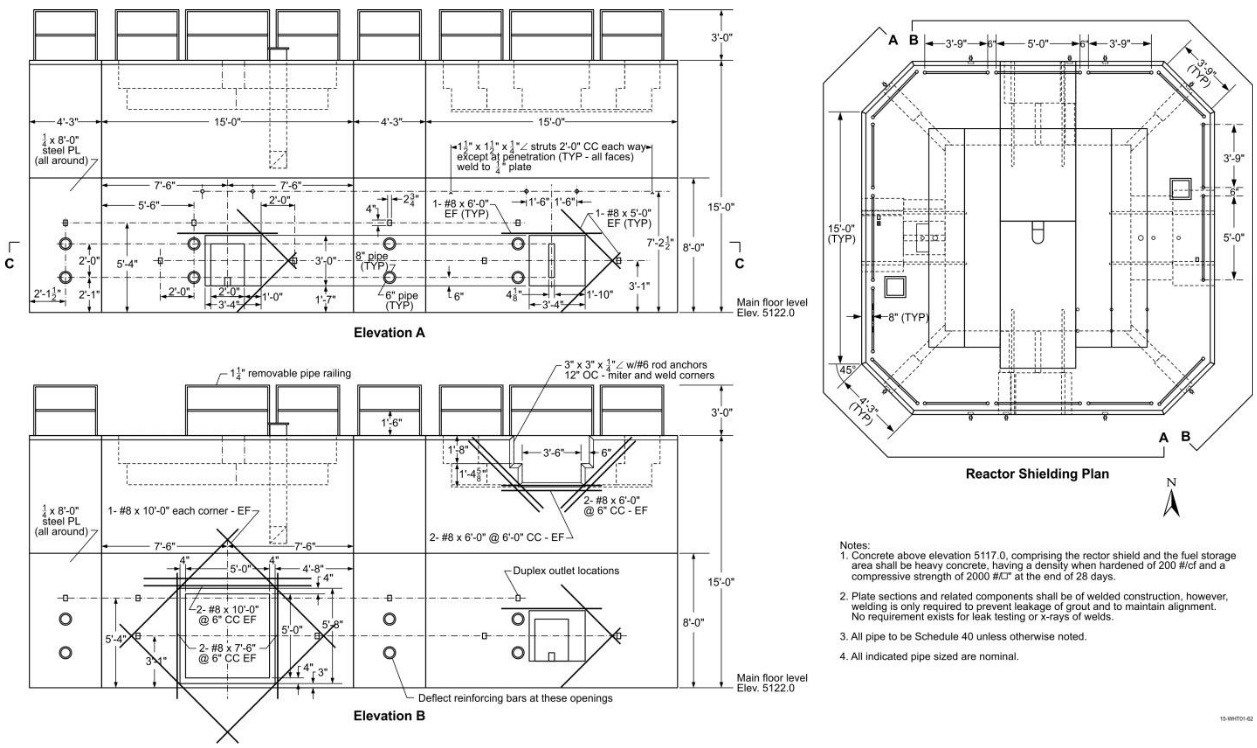


Figure 2.358a. Reactor Shielding Part I (DWG# IPE-720-4).

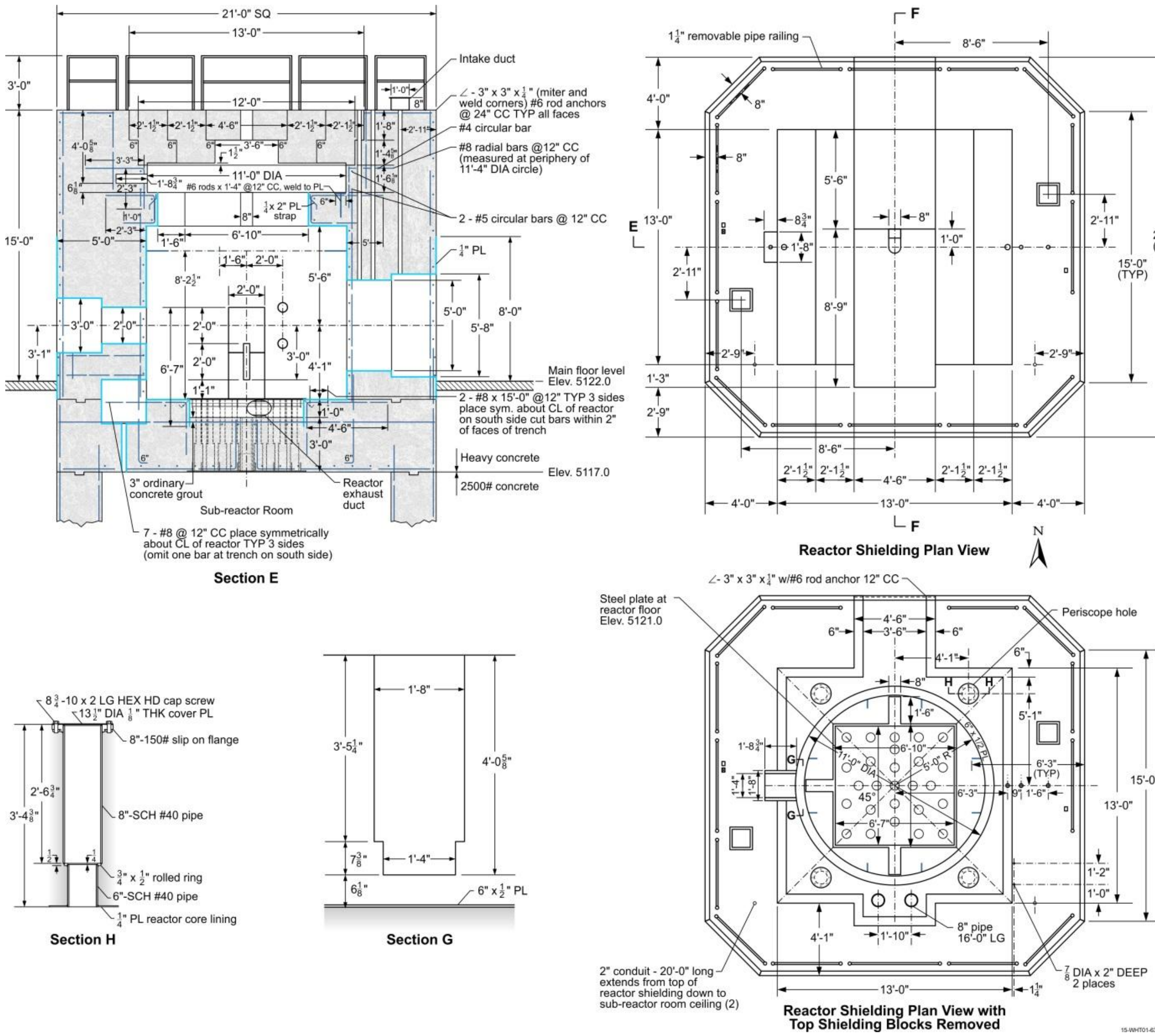


Figure 2.358b. Reactor Shielding Part II (DWG# IPE-720-4).

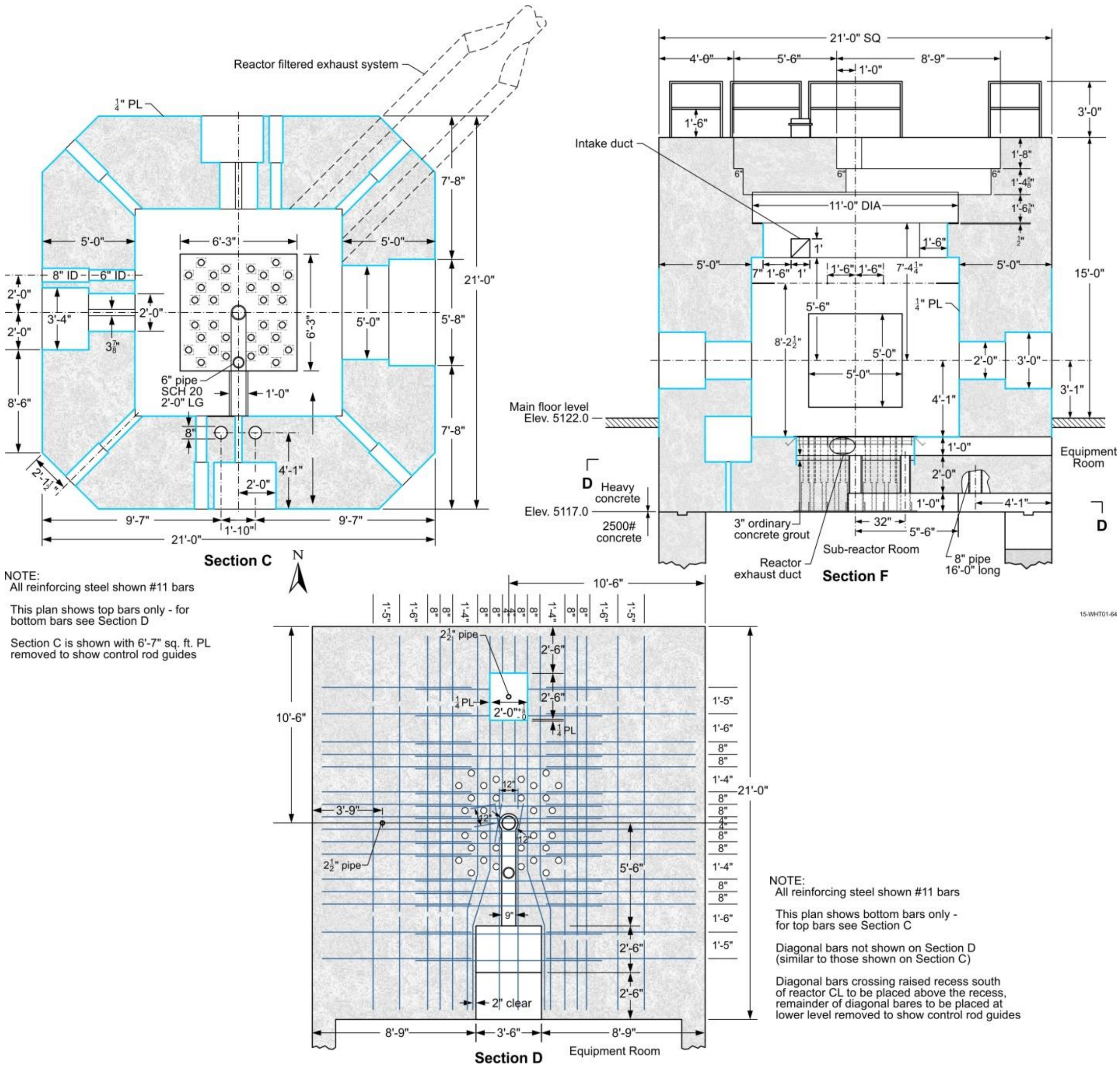


Figure 2.358c. Reactor Shielding Part III (DWG# IPE-720-4).

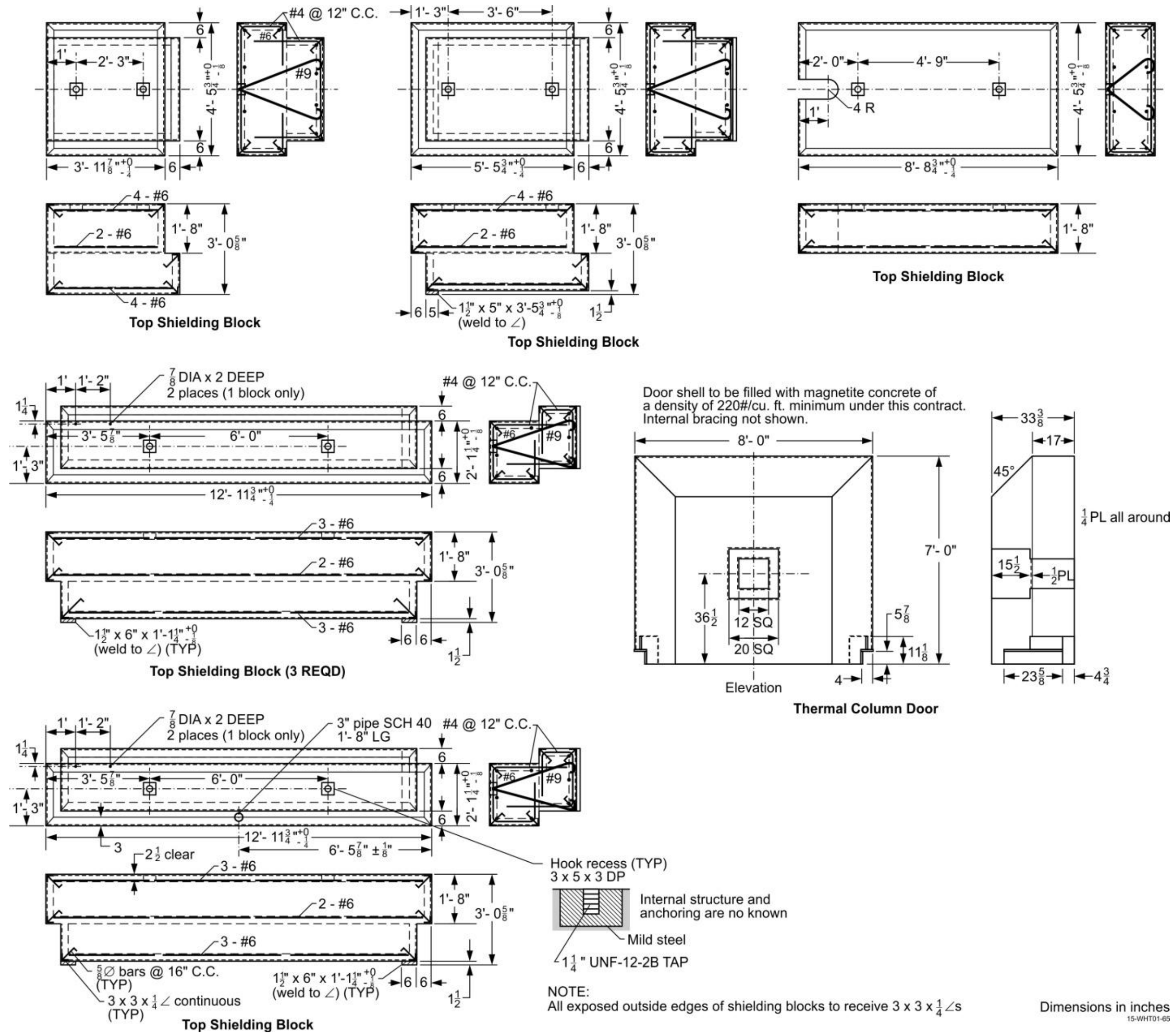


Figure 2.358d. Reactor Shielding Part IV (DWG# IPE-720-4).

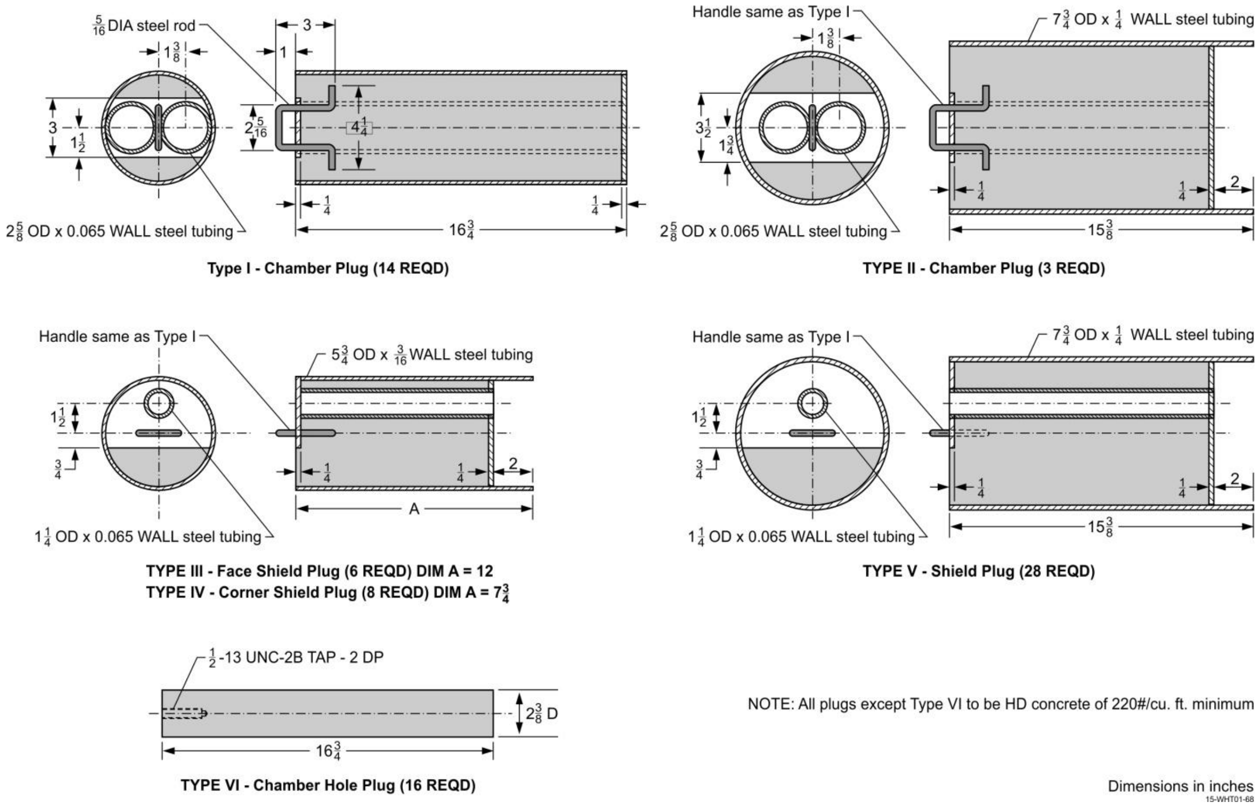


Figure 2.358e. Reactor Shielding Part IV (DWG# IPE-720-4).

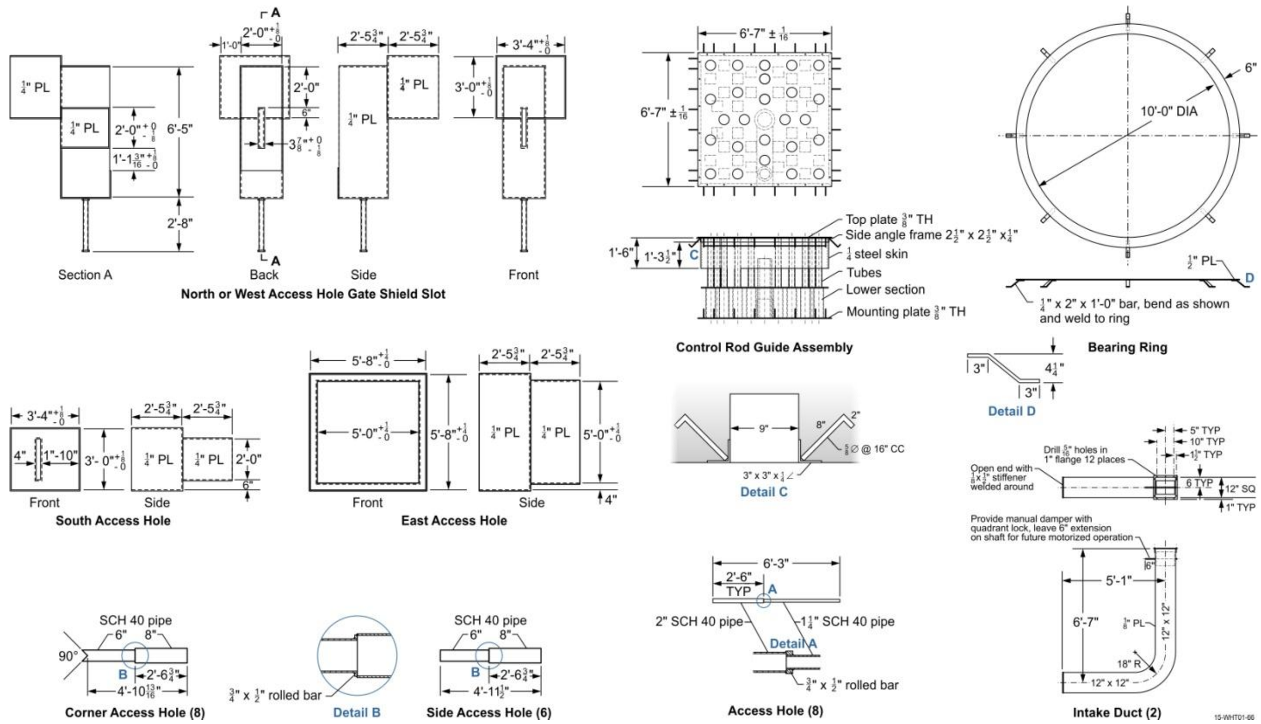


Figure 2.358f. Reactor Shielding Part V (DWG# IPE-720-4).

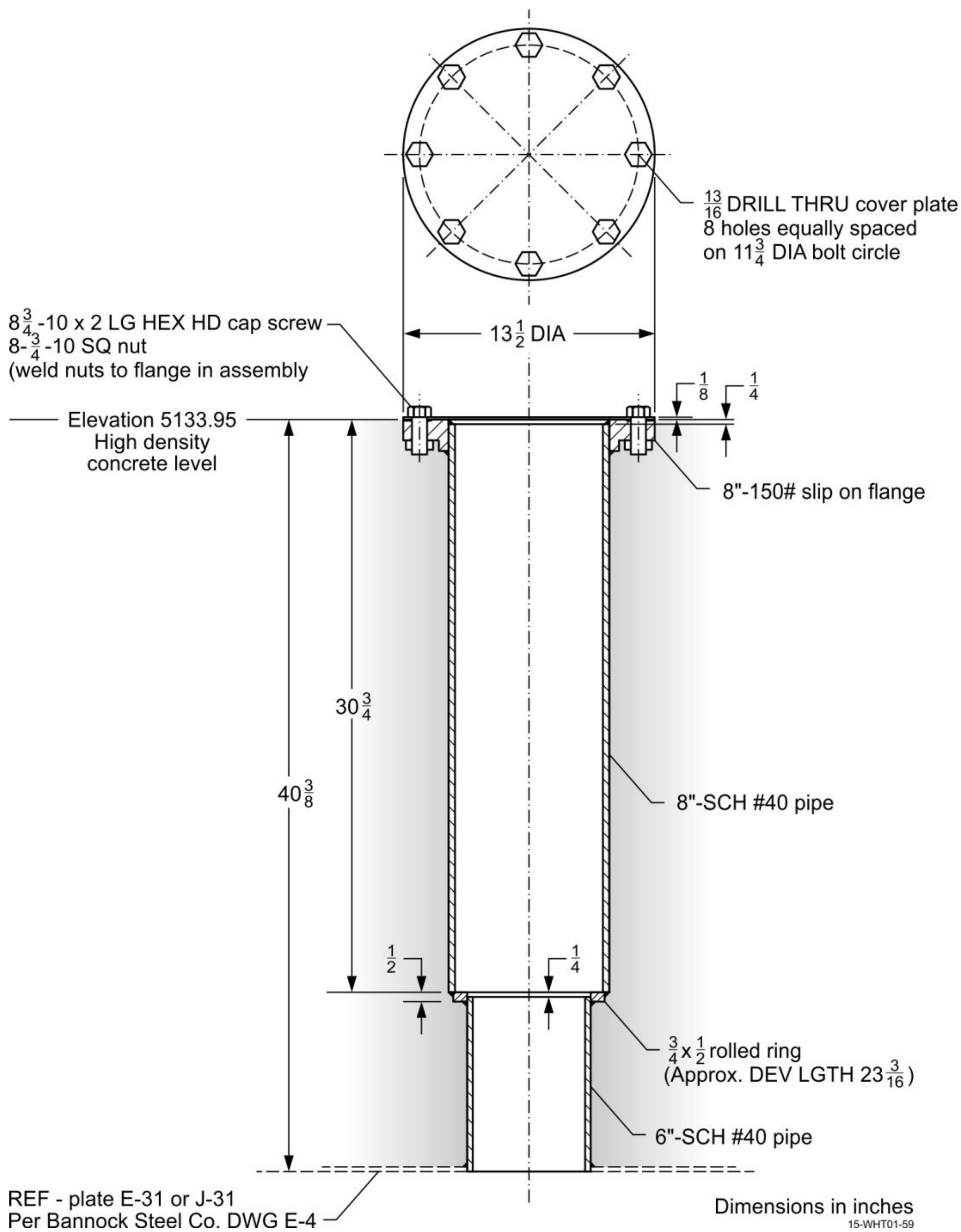


Figure 2.359. Periscope Hole Liner (DWG# RE-1-22737).

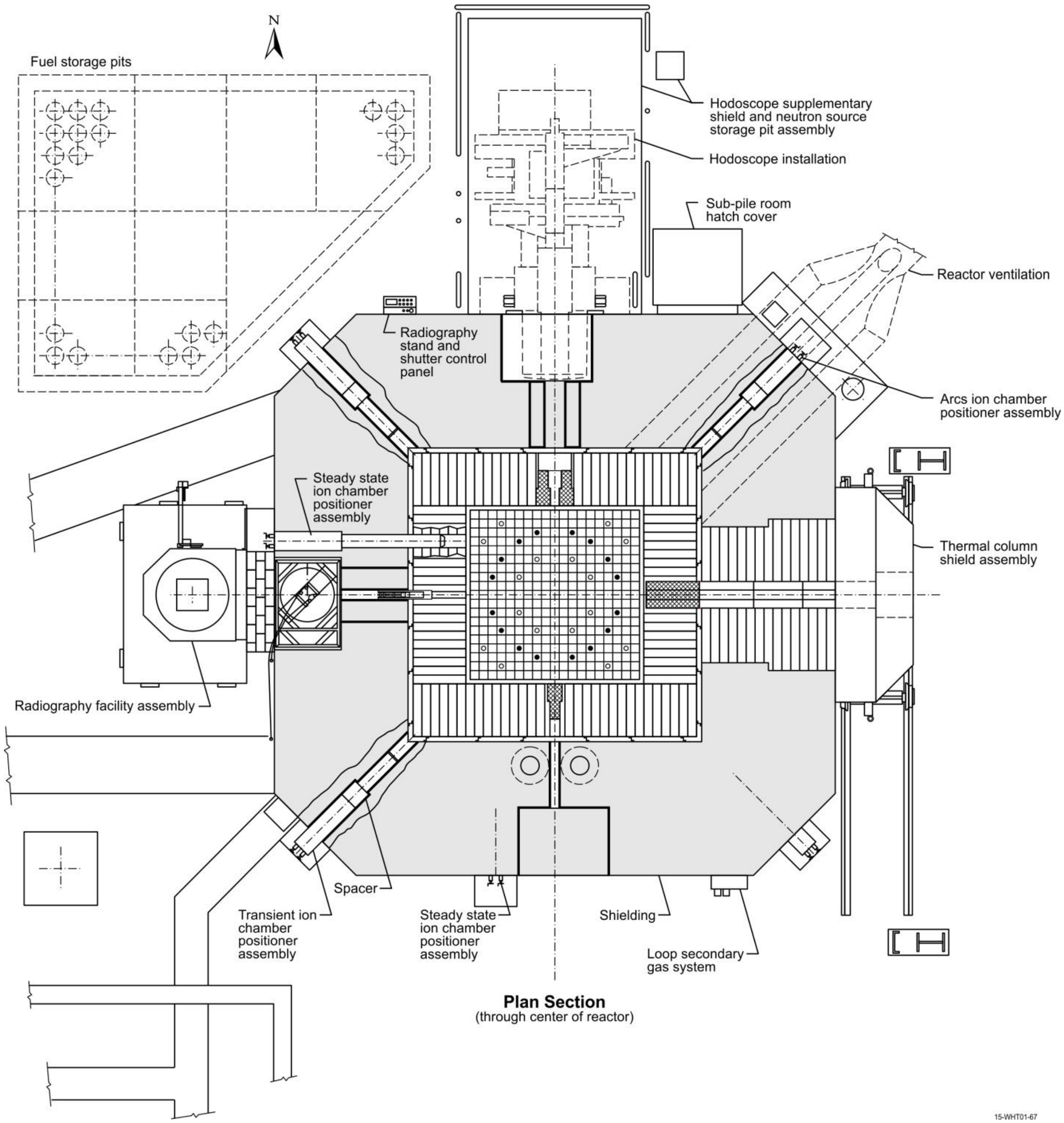


Figure 2.360. Reactor Facility Plan Section (DWG# RE-1-22222).

2.12 Coolant

The core is cooled by a once-through, induced-draft, air-cooling system. Two turbocompressors draw 6,000 cfm (max) of air through the reactor. The air is filtered as it enters at the top of the reactor shield. The flow continues downward through square coolant passages formed by the chamfered corners of adjacent assemblies and around the permanent reflector into the lower plenum. Then the coolant is drawn from the plenum by blowers, passed through another set of filters, and discharged up a 60 ft. stack to the atmosphere. The cooling system permits steady-state operation at 100 kW and can completely cool the reactor within several hours after a transient experiment [Freund 1960].

2.13 Example Experimental Components

The principal experimental test facilities are two vertical through-holes. One hole extends through the geometric center of the core, and the other is offset 32 in. Most experiments were performed in the central position due to its alignment with the gates containing radiography and hodoscope facilities. Numerous types of experiments have been performed over the years. Various examples of containment, assemblies, and their respective components are listed in Table 2.36 and shown in Figures 2.361 through 2.380. As these experimental components are solely provided as examples, further detailed explanation of their assembly, dimensions, and materials will not be included in this report.

Overviews of the numerous TREAT experimental campaigns are summarized elsewhere [Crawford 1998, Deitrich 1998, Wright 2010, and Wright 2015]

Table 2.36. Example Experimental Components.

Figure	DWG#	Component	Material
2.361	R0230-0188	Mark III Can	SS304 – ASTM A-240
2.362	--	M8CAL Cross Section	As Shown
2.363	--	Reference Metal Alloy Pin	As Shown
2.364	R0225-0143	Clamp (top expansion tank tube)	Inconel X-750
2.365	R0275-0010	Monitor Wire	As Shown
2.366	R0258-0152	M2+3 MKIIIC Loop	As Shown
2.367	R0288-0006	M2+3CAL Test Train	As Shown
2.368	R0288-0004	M2+3CAL Assembly (Bottom)	As Shown
2.369	R0288-0004	M2+3CAL Assembly (Middle)	As Shown
2.370	R0288-0004	M2+3CAL Assembly (Top)	As Shown
2.371	R0288-0017	Upper M2M3 Shaping Collar	As Shown
2.372	R0288-0018	Lower M2M3 Shaping Collar	As Shown
2.373	R0288-0019	M2M3 Conversion Collar	As Shown
2.374	R0288-0100	Al-6061 Shims	Al-6061
2.375	R0288-0101	SS304 Shims	SS304
2.376	--	Dysprosium Shaping Collar	Dysprosium
2.377	R0253-0130	Pump Leg Flow Meter Magnet	ALNICO-V
2.378	R0288-0002	Spool Piece Assembly M2CAL	SS304 and/or SS316
2.379	R0288-0004	M2+3CAL w/ M7CAL Outfitting	As Shown
2.380	R0289-0007	Fueled M7CAL Test Train	As Shown

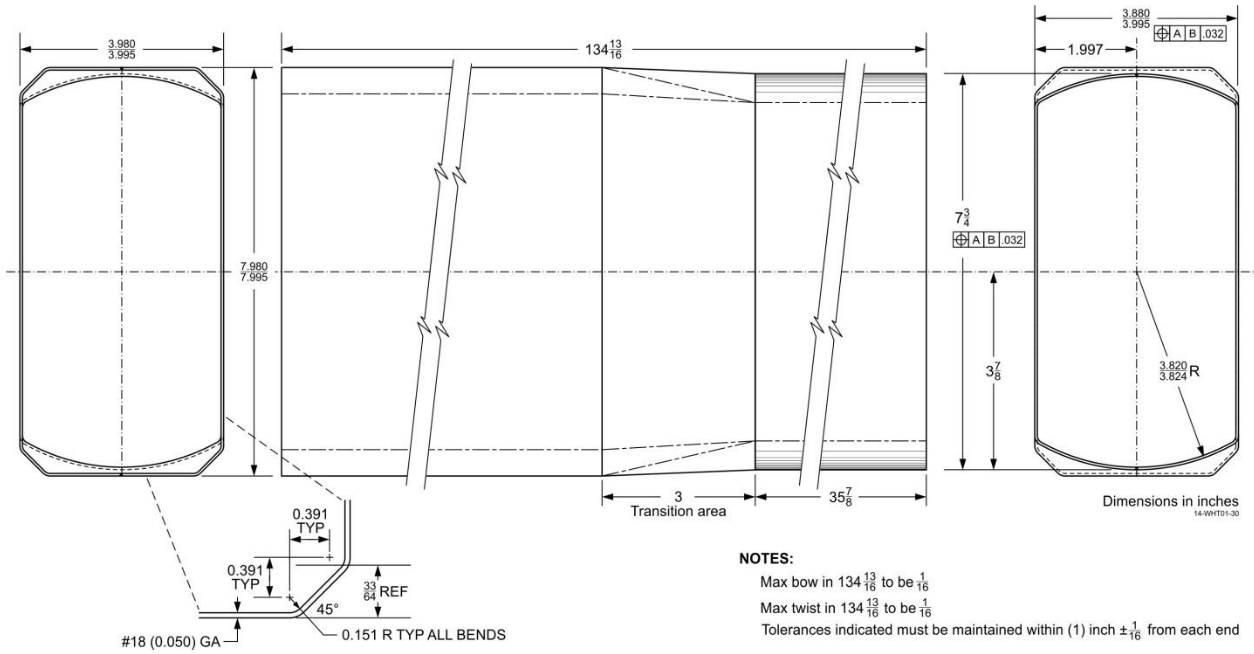


Figure 2.361. Mark III Can (DWG# R0230-0188).

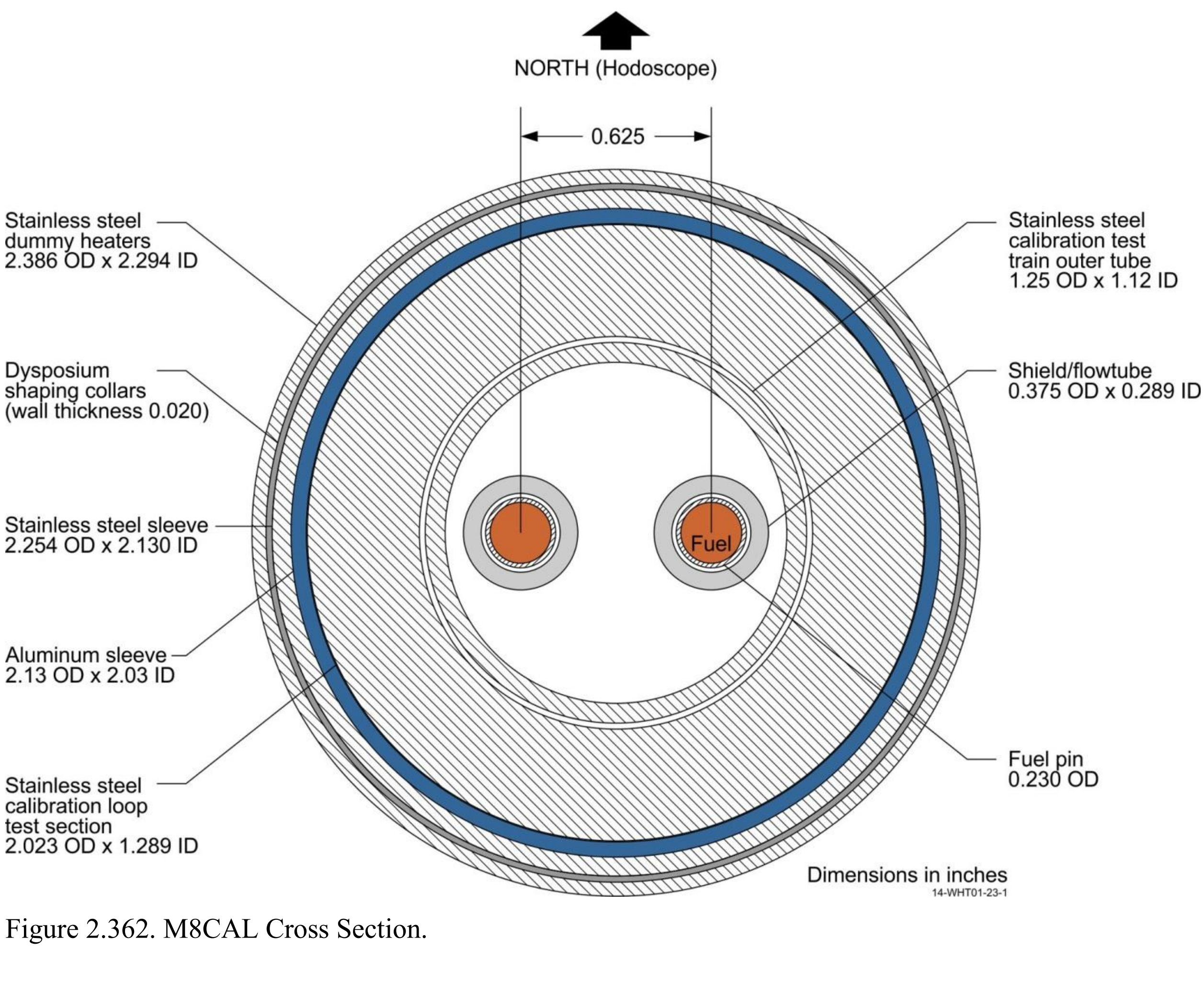


Figure 2.362. M8CAL Cross Section.

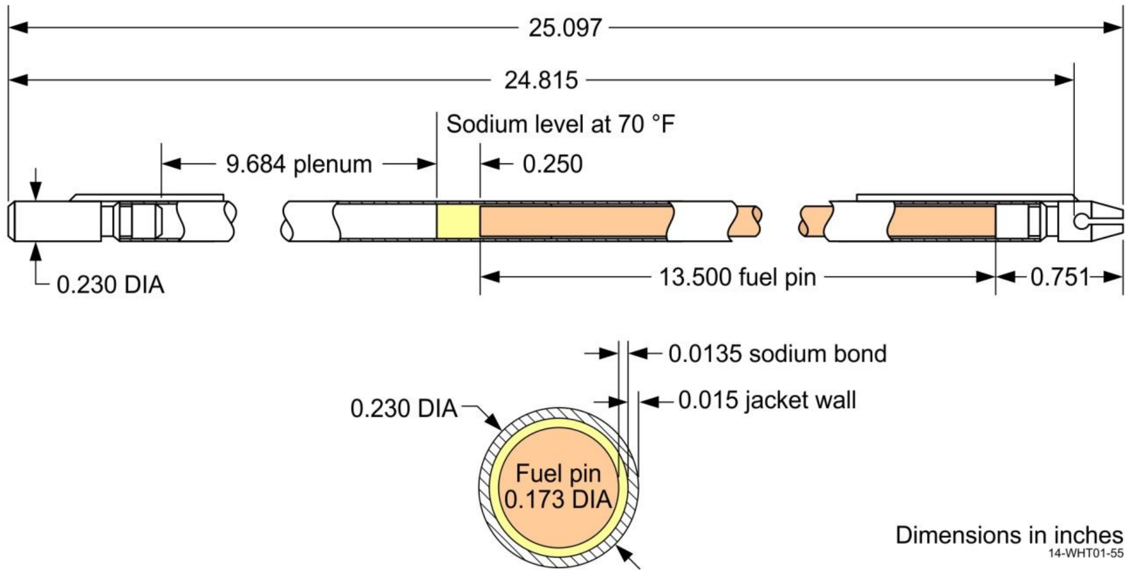


Figure 2.363.Reference Metal Alloy Pin.

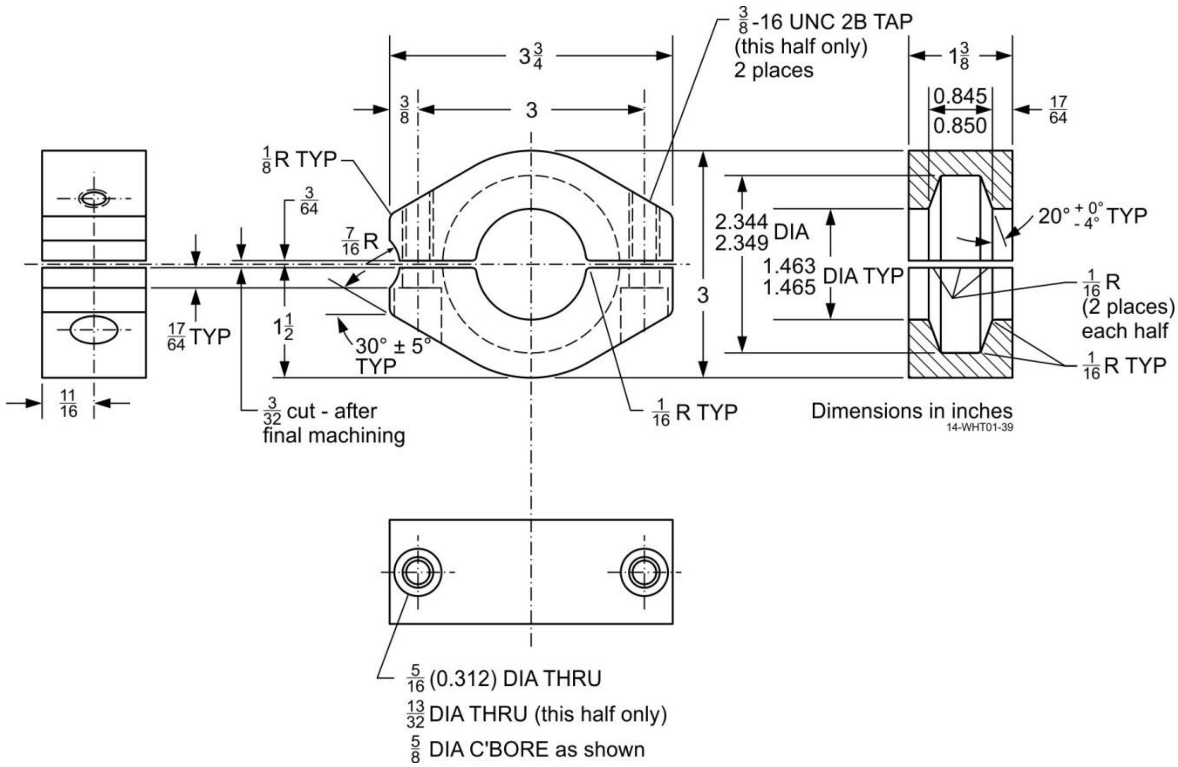


Figure 2.364. Clamp (top expansion tank tube) (DWG# R0225-0143).

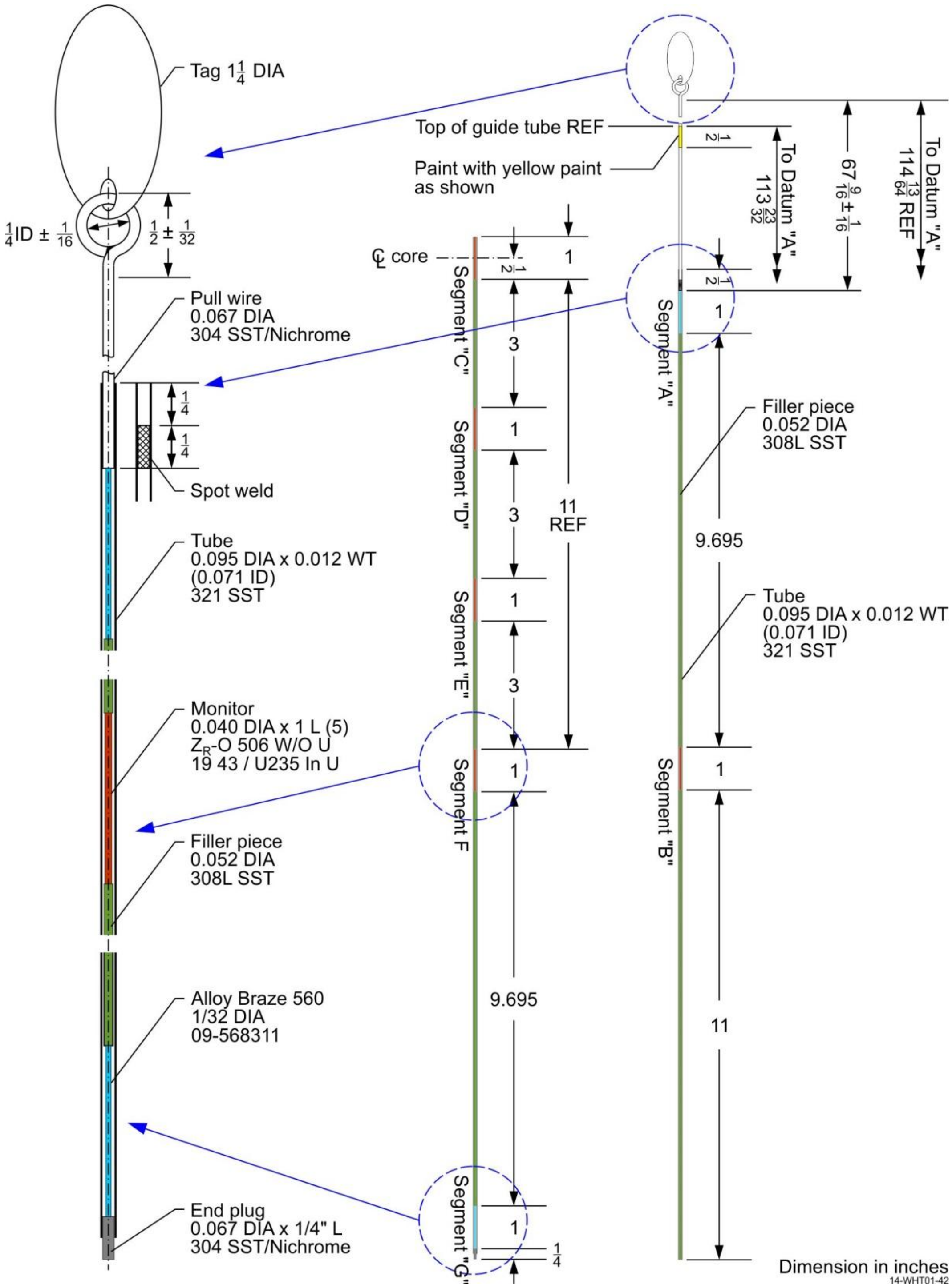


Figure 2.365. Monitor Wire (DWG# R0275-9910).

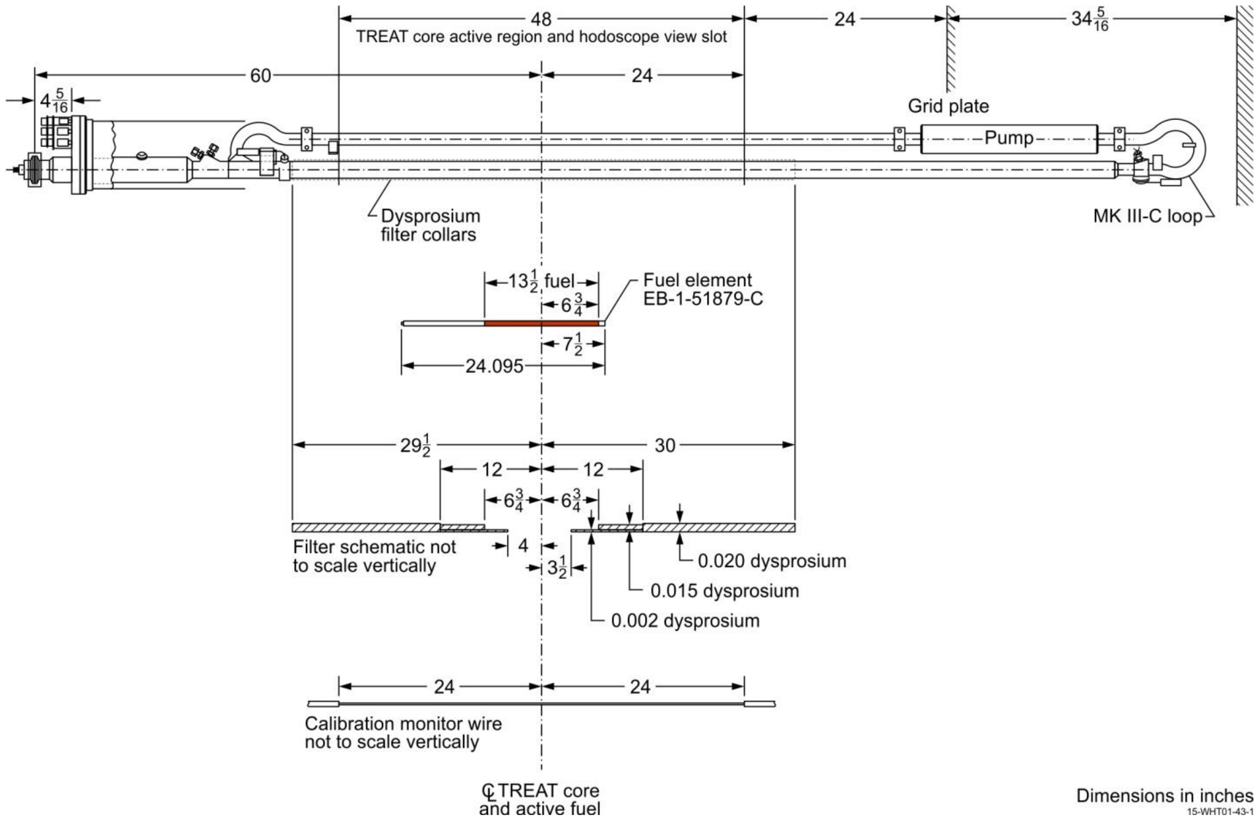


Figure 2.366. M2+3 MKIIIC Loop (DWG# R0258-0152).

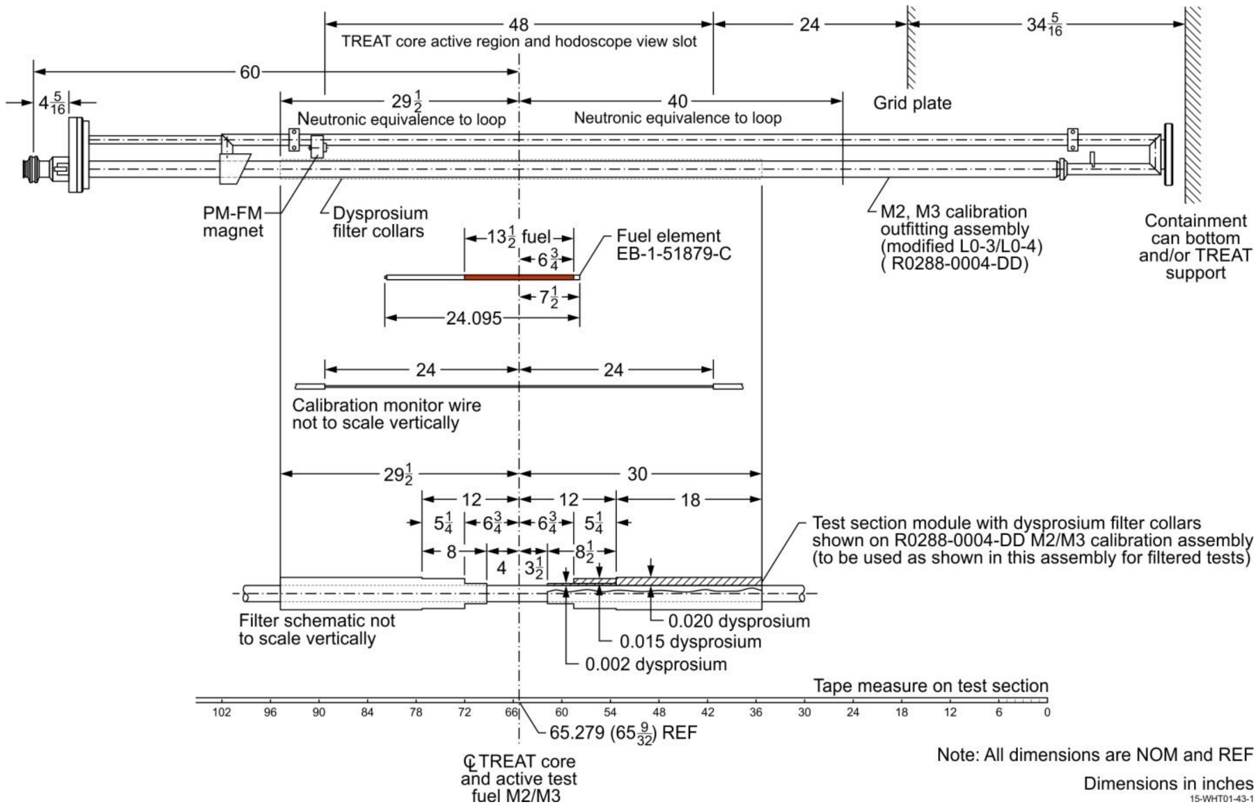


Figure 2.367. M2+3CAL Test Train (DWG# R0288-0006).

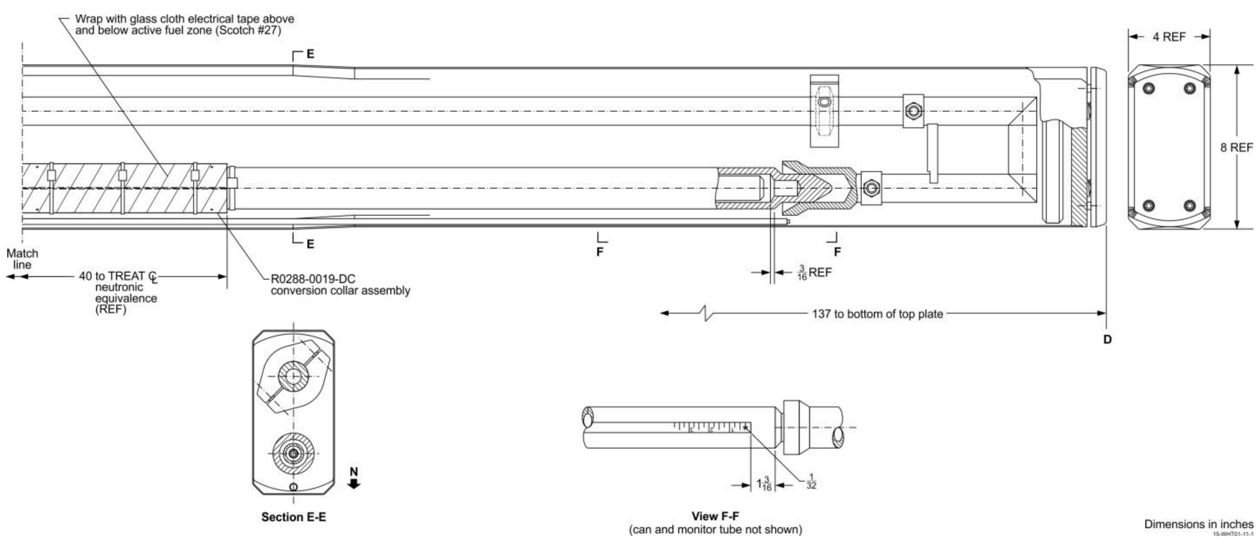


Figure 2.368. M2+3CAL Assembly (Bottom) (DWG# R0288-0004).

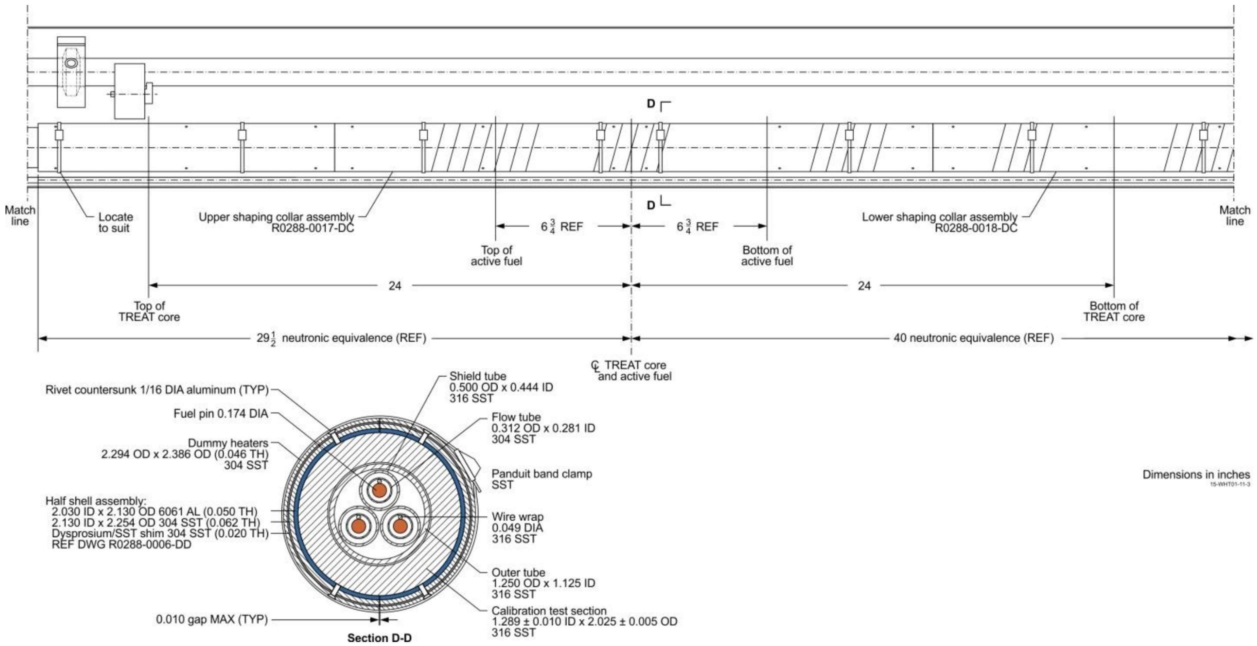


Figure 2.369. M2+3CAL Assembly (Middle) (DWG# R0288-0004).

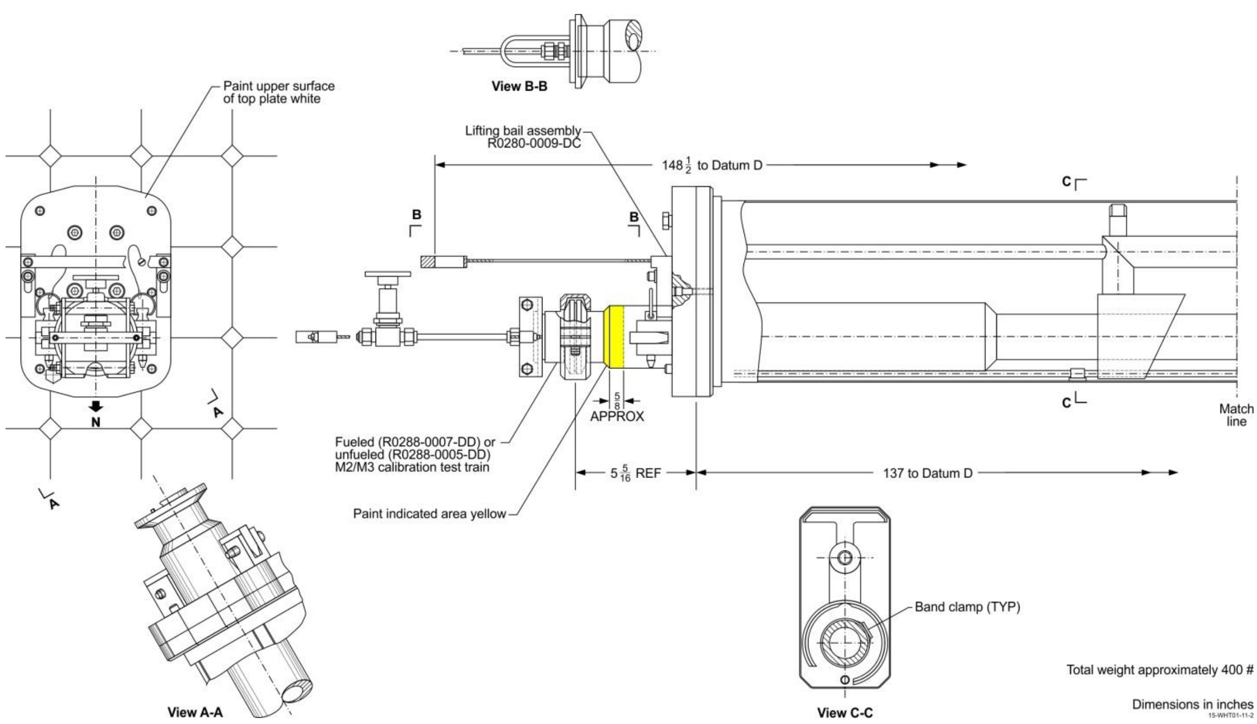


Figure 2.370. M2+3CAL Assembly (Top) (DWG# R0288-0004).

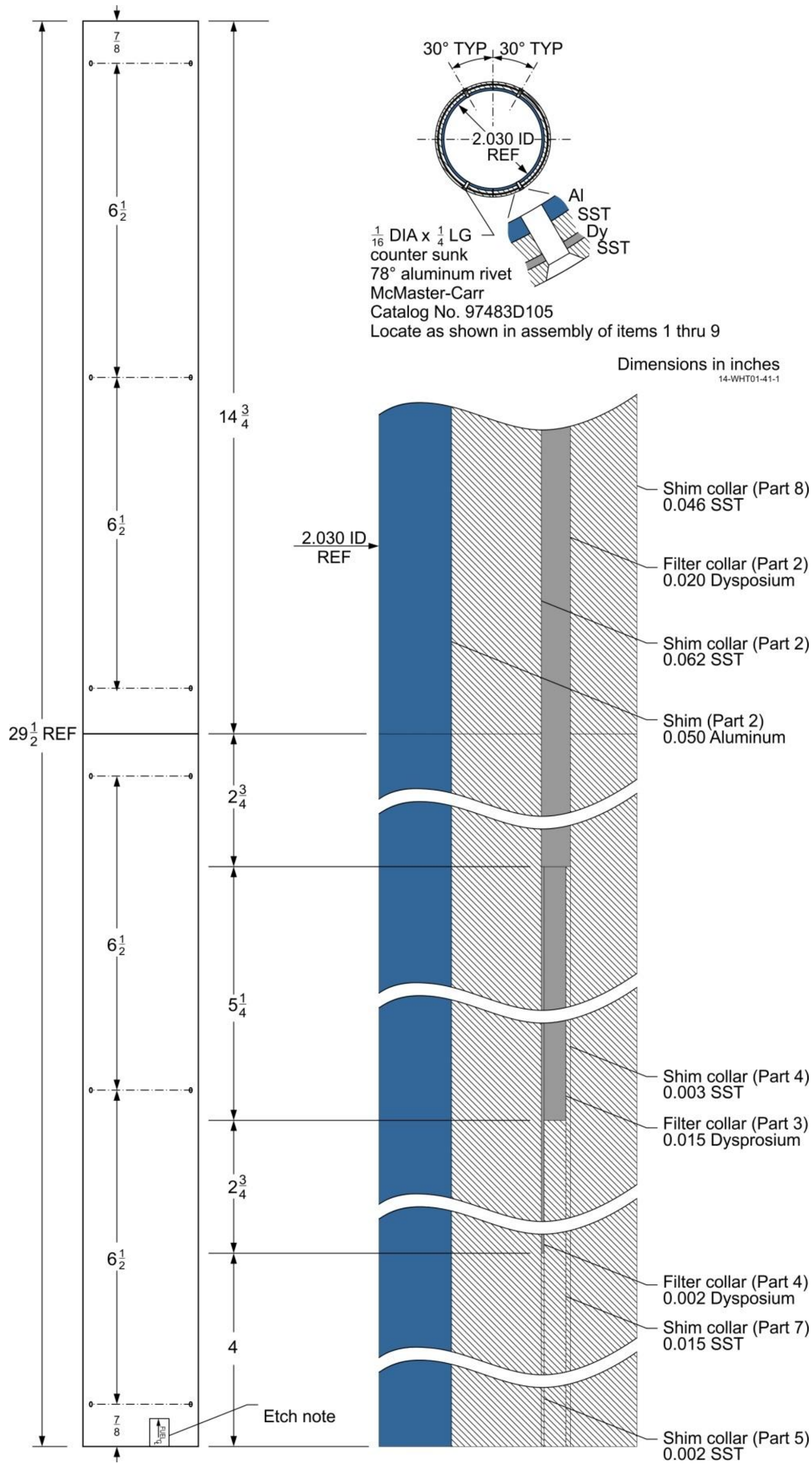


Figure 2.371. Upper M2M3 Shaping Collar (DWG# R0288-0017).

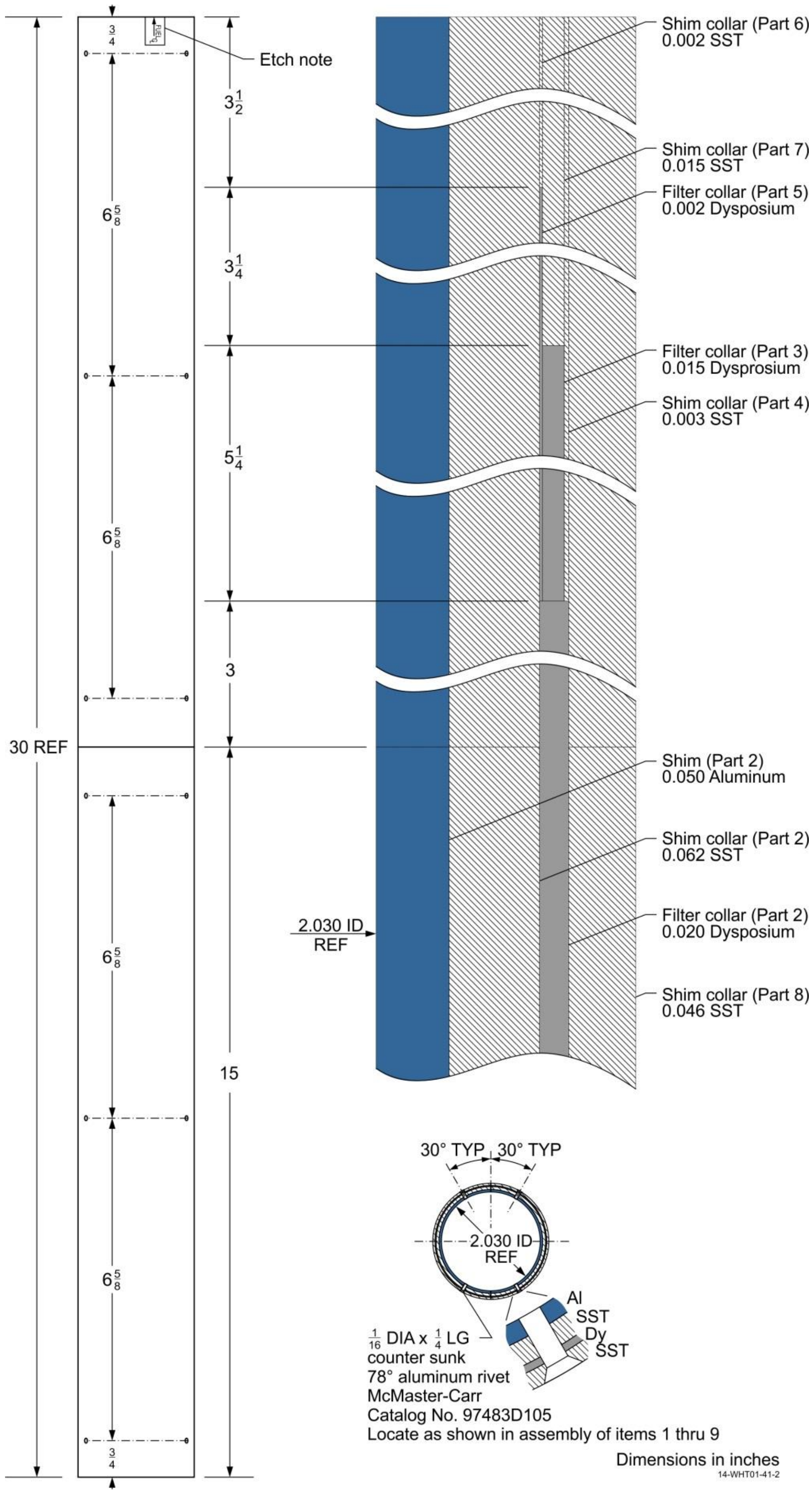


Figure 2.372. Lower M2M3 Shaping Collar (DWG# R0-288-0018).

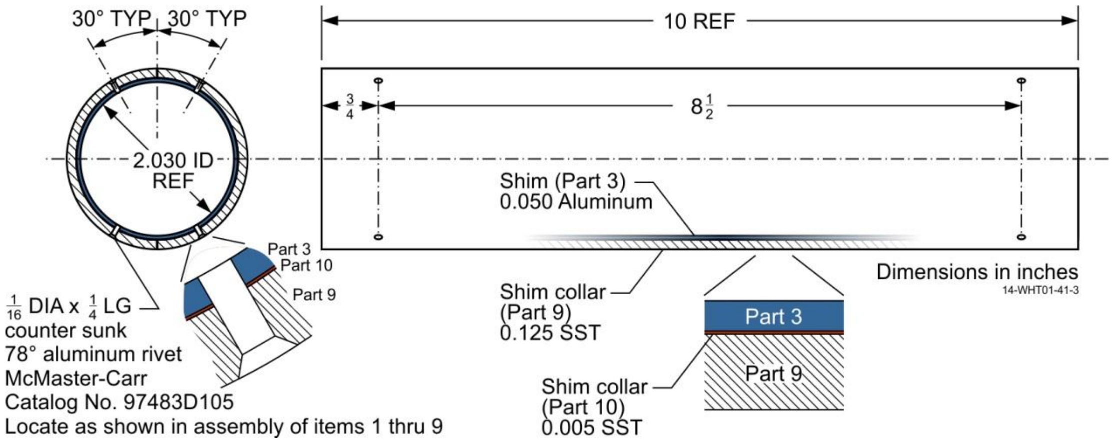
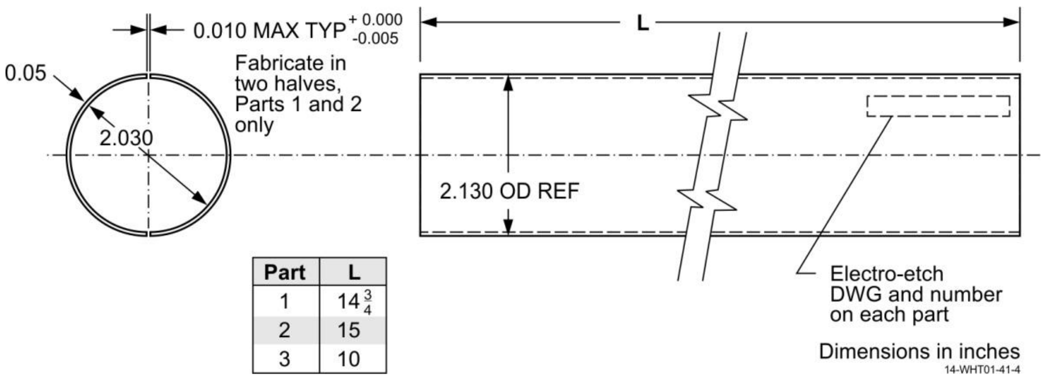
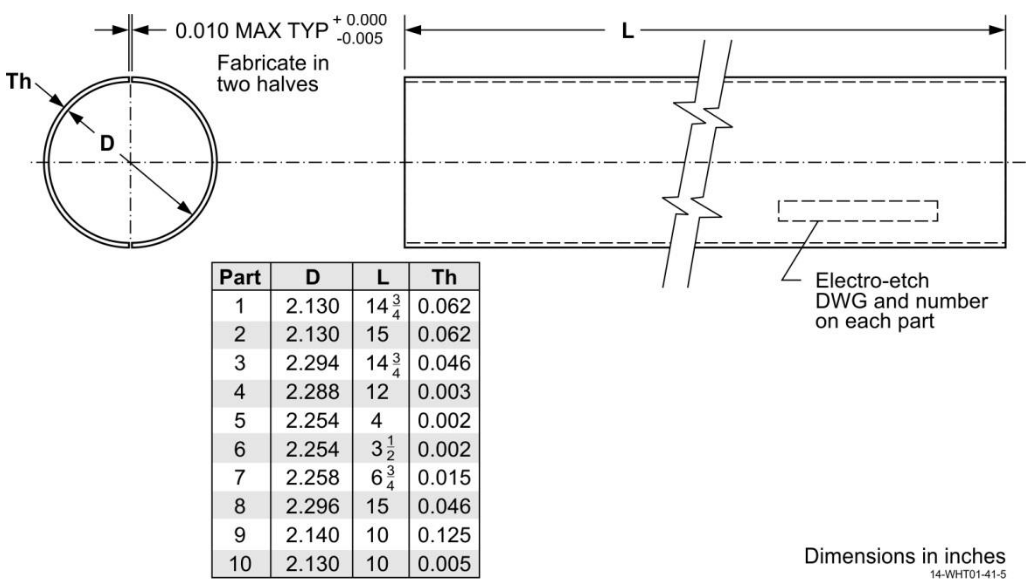


Figure 2.373. M2M3 Conversion Collar (DWG# R0288-0019).



Part	L
1	$14\frac{3}{4}$
2	15
3	10

Figure 2.374. Al-6061 Shims (DWG# R0288-0100).



Part	D	L	Th
1	2.130	$14\frac{3}{4}$	0.062
2	2.130	15	0.062
3	2.294	$14\frac{3}{4}$	0.046
4	2.288	12	0.003
5	2.254	4	0.002
6	2.254	$3\frac{1}{2}$	0.002
7	2.258	$6\frac{3}{4}$	0.015
8	2.296	15	0.046
9	2.140	10	0.125
10	2.130	10	0.005

Figure 2.375. SS304 Shims (DWG# R0288-0101).

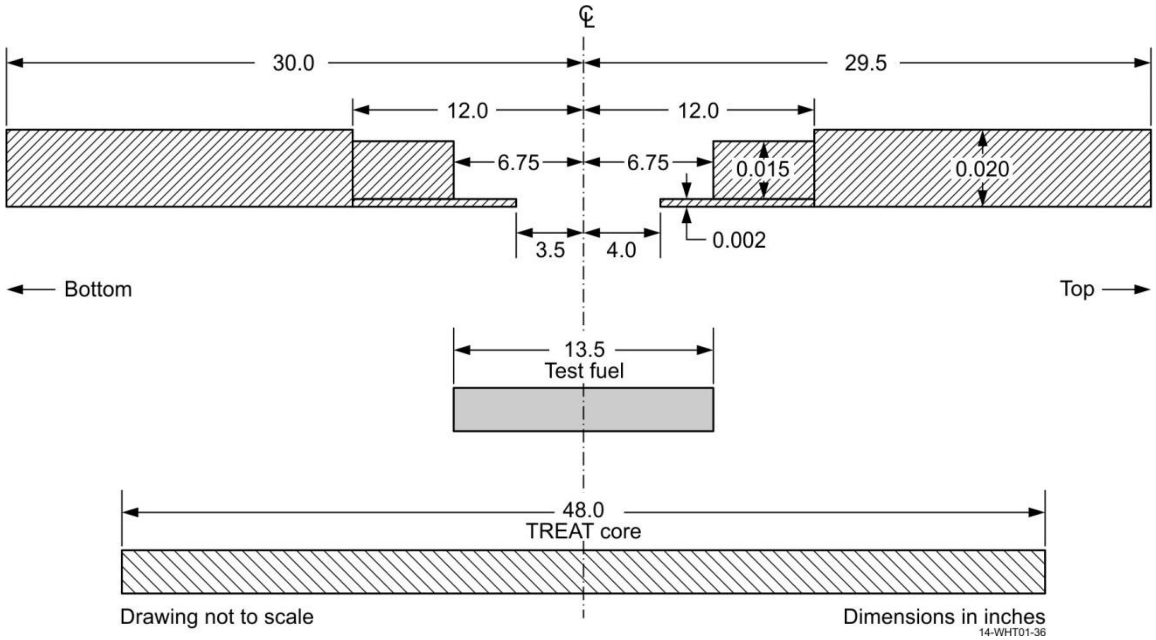


Figure 2.376. Dysprosium Shaping Collars.

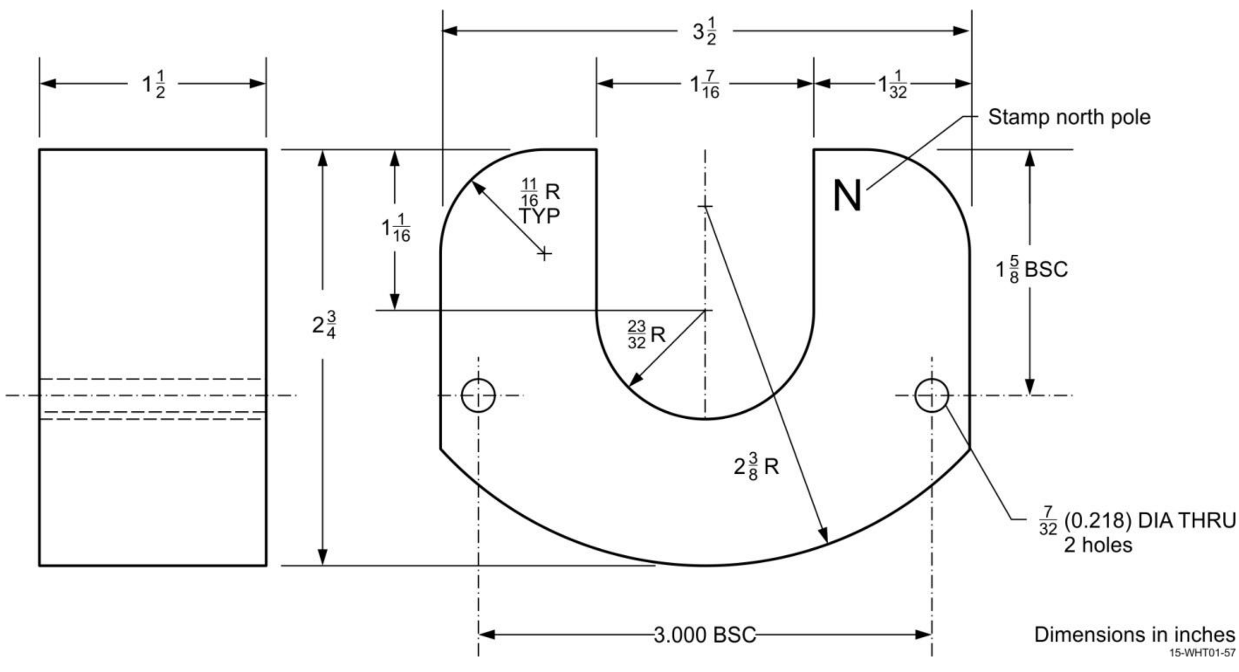


Figure 2.377. Pump Leg Flow Meter Magnet (DWG# R0253-0130).

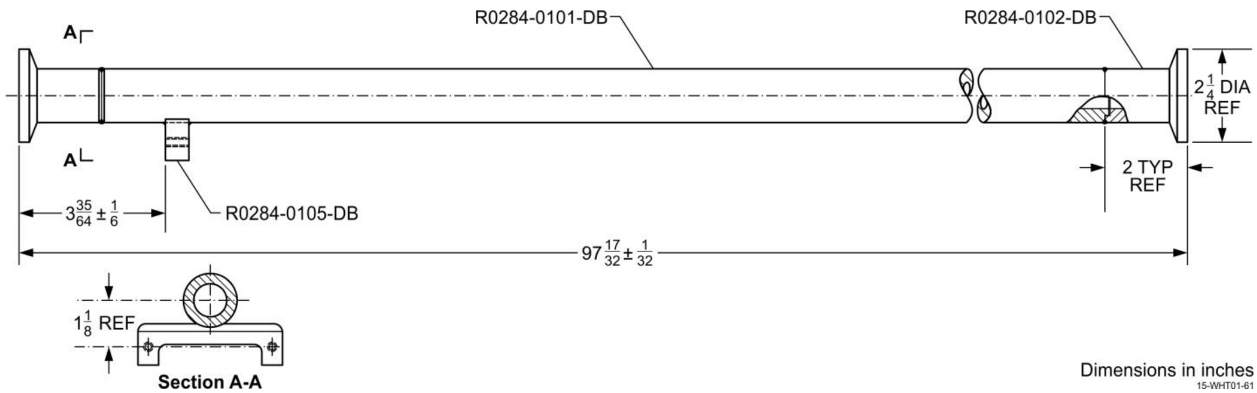


Figure 2.378. Spool Piece Assembly M2CAL (DWG# R0288-0002).

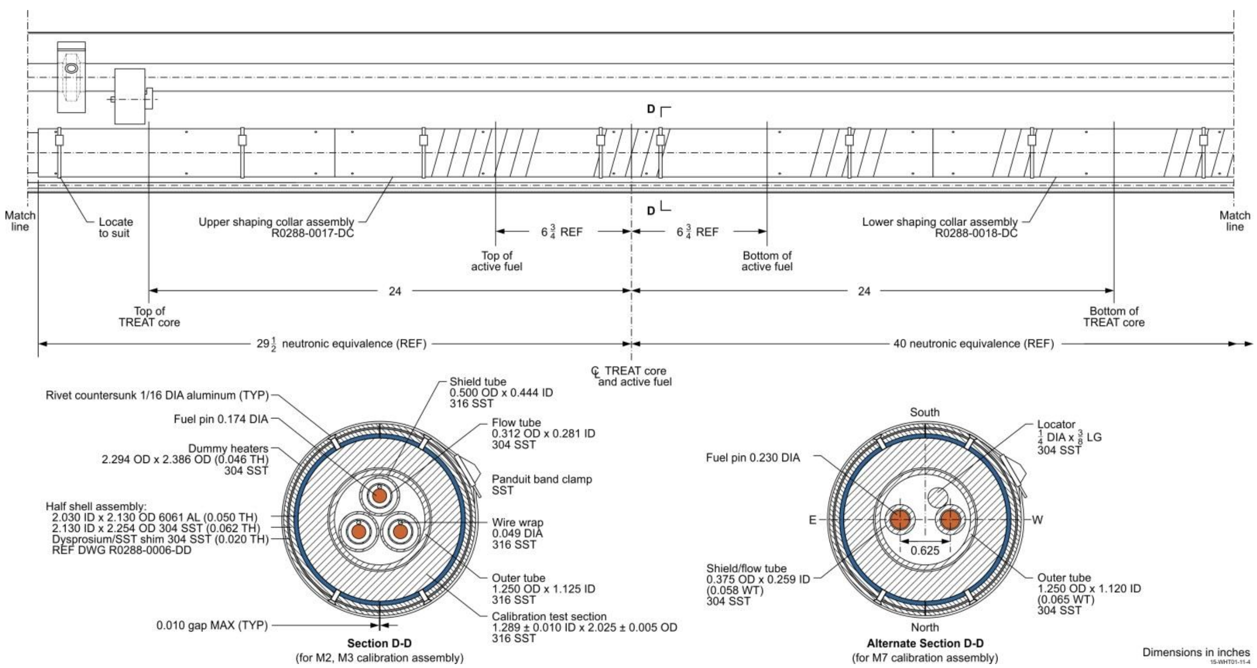


Figure 2.379. M2+3CAL w/ M7CAL Outfitting (DWG# R0288-0004).

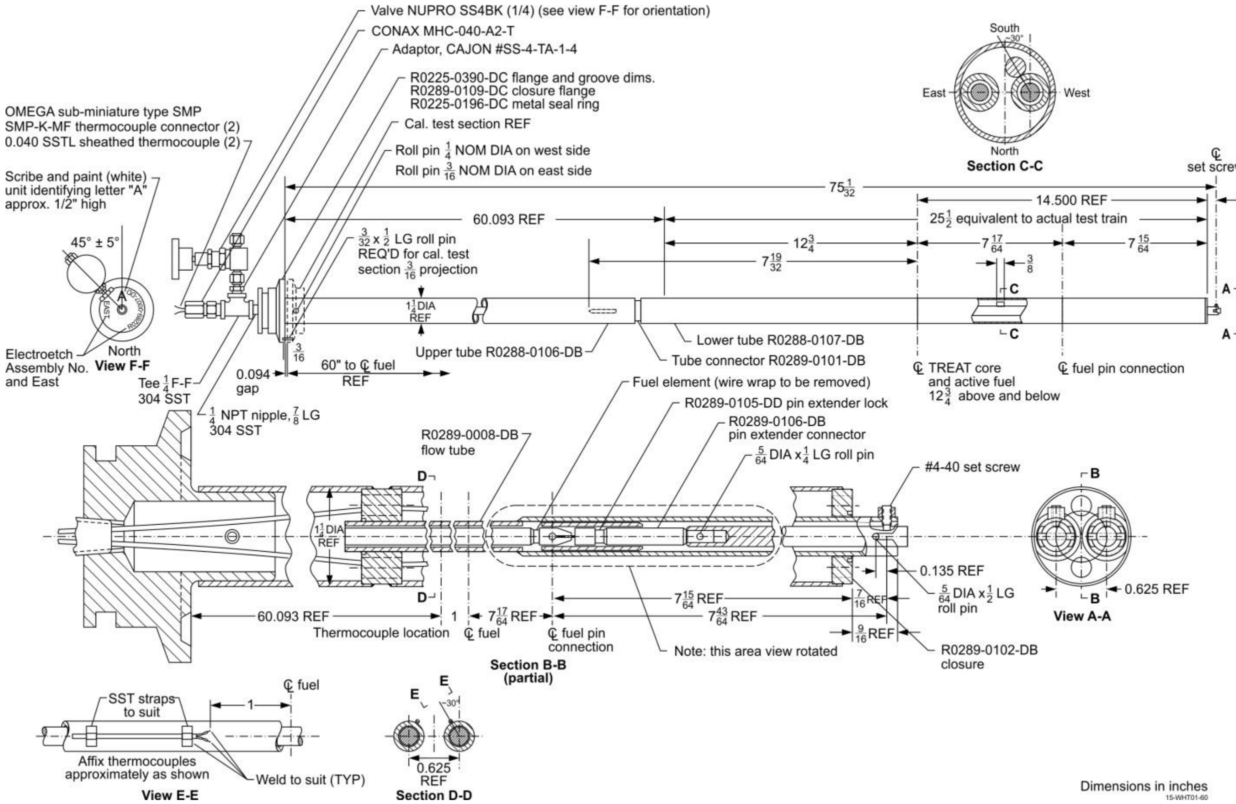


Figure 2.380. Fueled M7CAL Test Train (DWG# R0289-0007).

2.14 Example Core Loadings

Figure 2.381 through 2.385 demonstrate example TREAT core loadings. The smallest core loading is shown in Figure 2.381, which has the least number of fuel assemblies and the poison section of the control rods completely withdrawn from the core. Additional fuel assemblies were added to the core to allow for the initial core physics measurements [Kirn 1960]. Later core loadings with the largest quantity of fuel assemblies loaded into the core are for the M-series experiments such as M7CAL, M8CAL, and AN-CAL.

Organization of the core assemblies was performed in a grid pattern by letter (west to east skipping 'I' and 'Q') and by number (north to south).

Table 2.37. Example Core Loadings.

Core Loading	Figure	Reference
Minimum Critical Mass	2.381	Kirn 1960
Original Loading 7-7-1959	2.382	--
M7CAL	2.383	Robinson 1987
M8CAL	2.384	Robinson 1994
AN-CAL	2.385	Robinson 1992

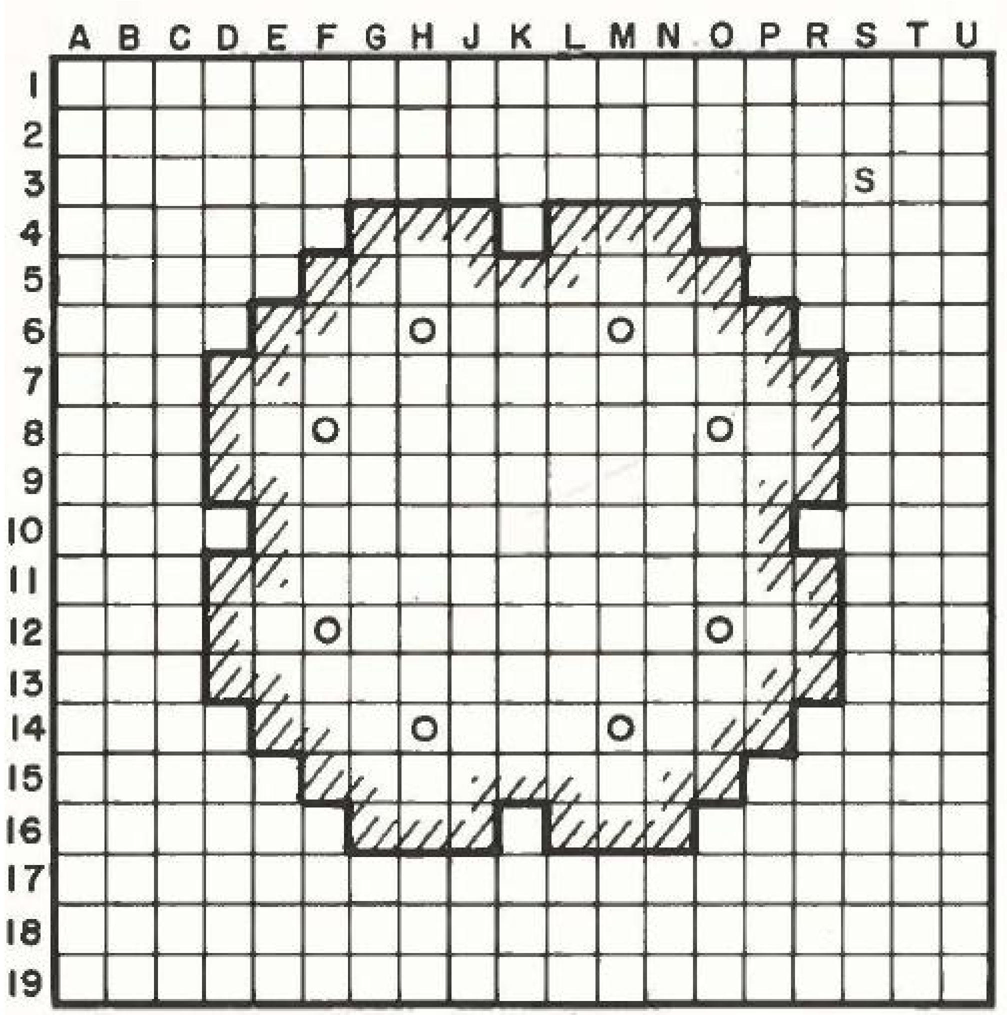


Figure 2.381. Minimum Critical Mass Core Loading.

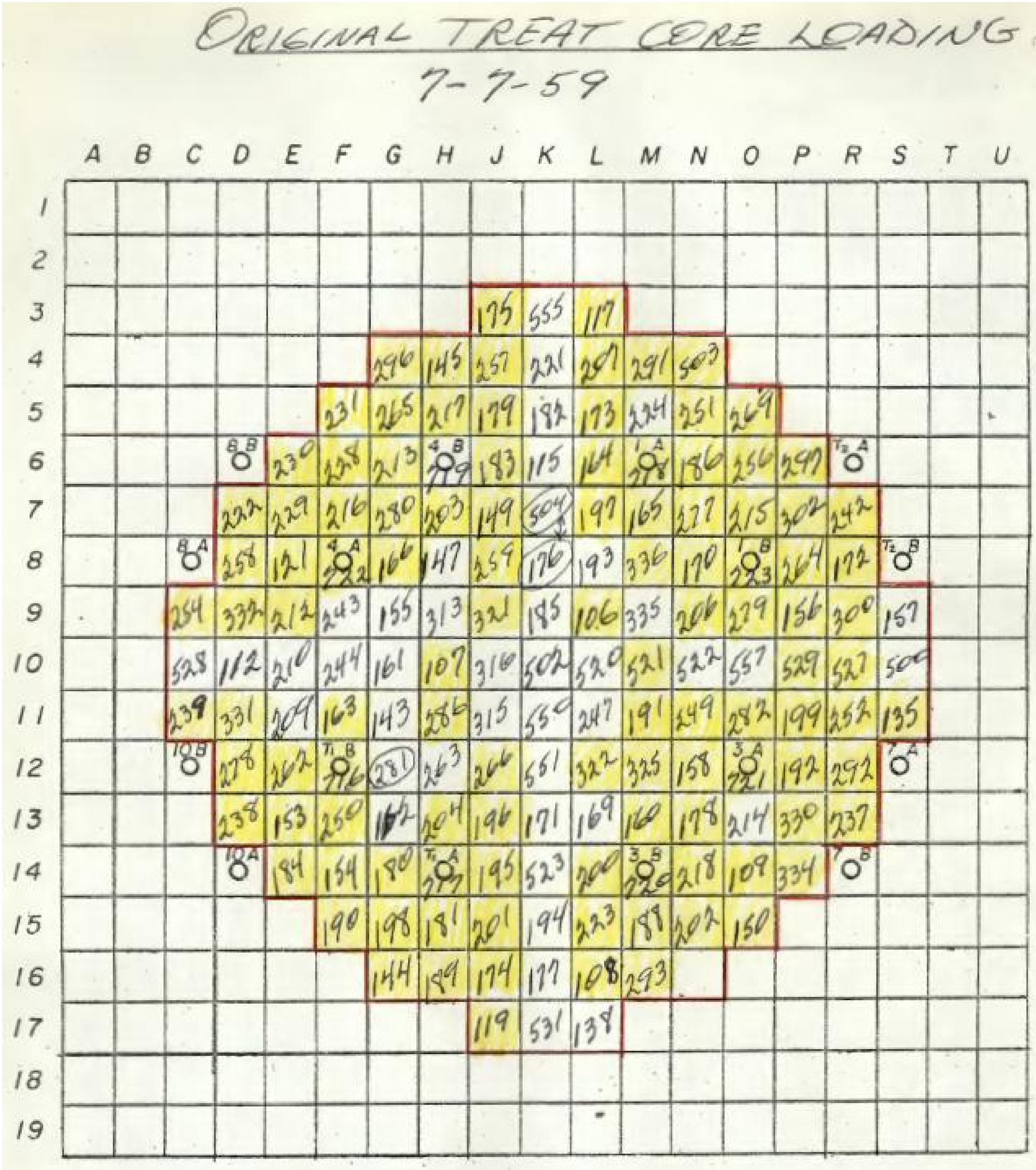


Figure 2.382. Original TREAT Core Loading (7-7-1959).

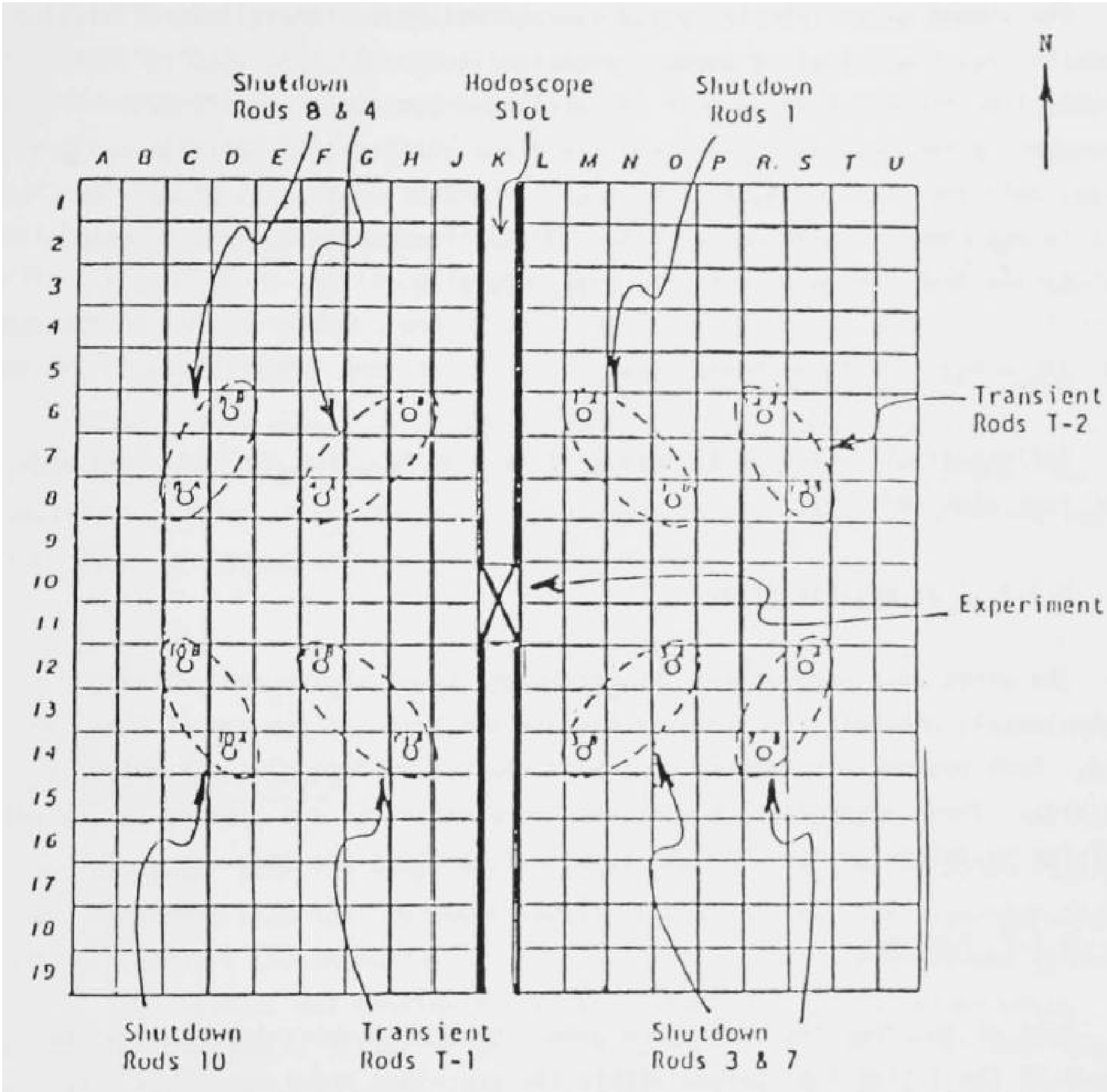


Figure 2.383. Example M7CAL Core Loading.

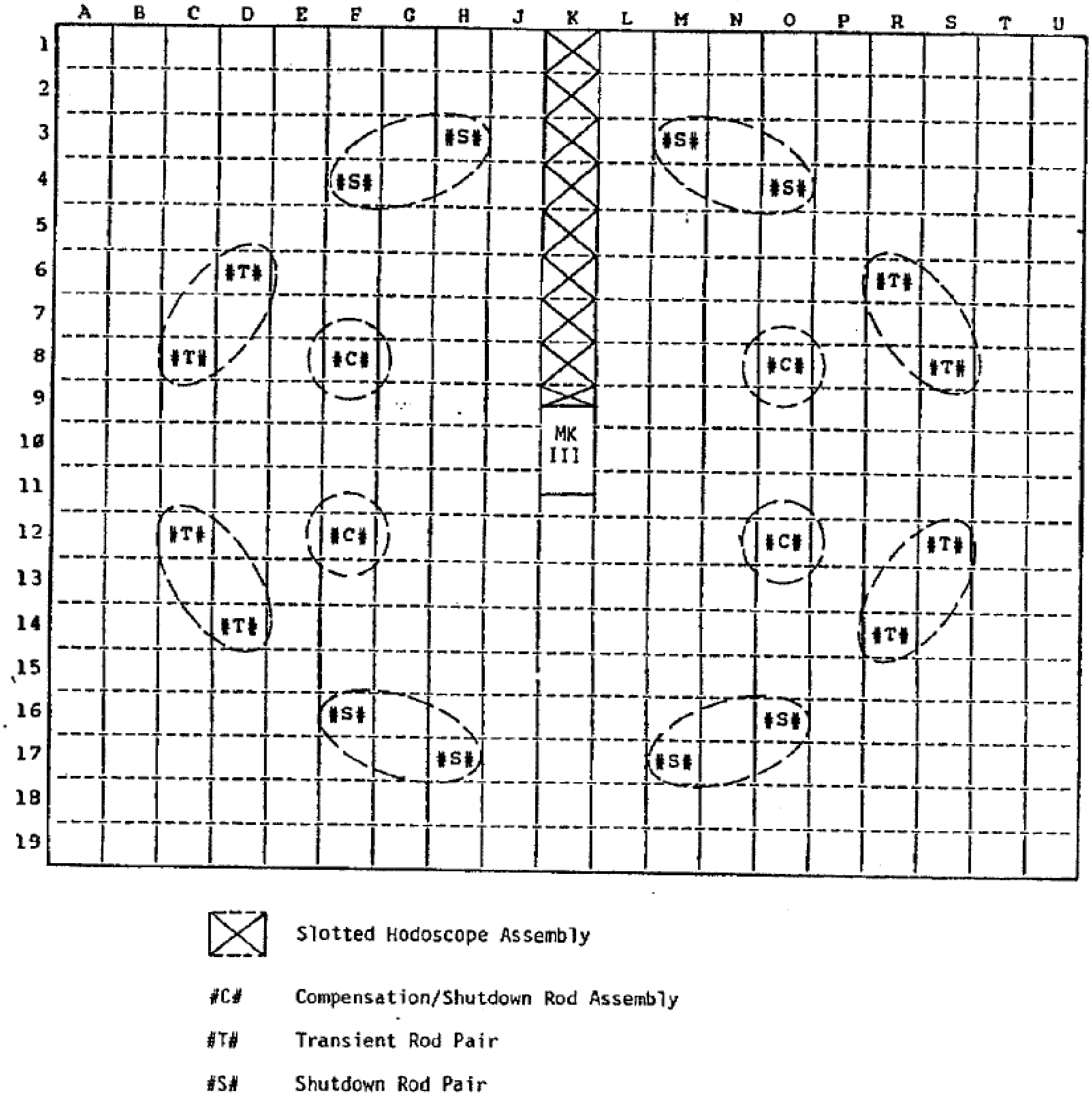


Figure 2.384. Example M8CAL Core Loading.

ZRD: Graphite-filled, zirconium-alloy-clad dummy TREAT element
SLT: Hodoscope slot (typical element orientation)
ROT: Hodoscope slot (element rotated 90 degrees)
#S#: Shutdown/Control rods
#T#: Transient rods
#C#: Compensation rods

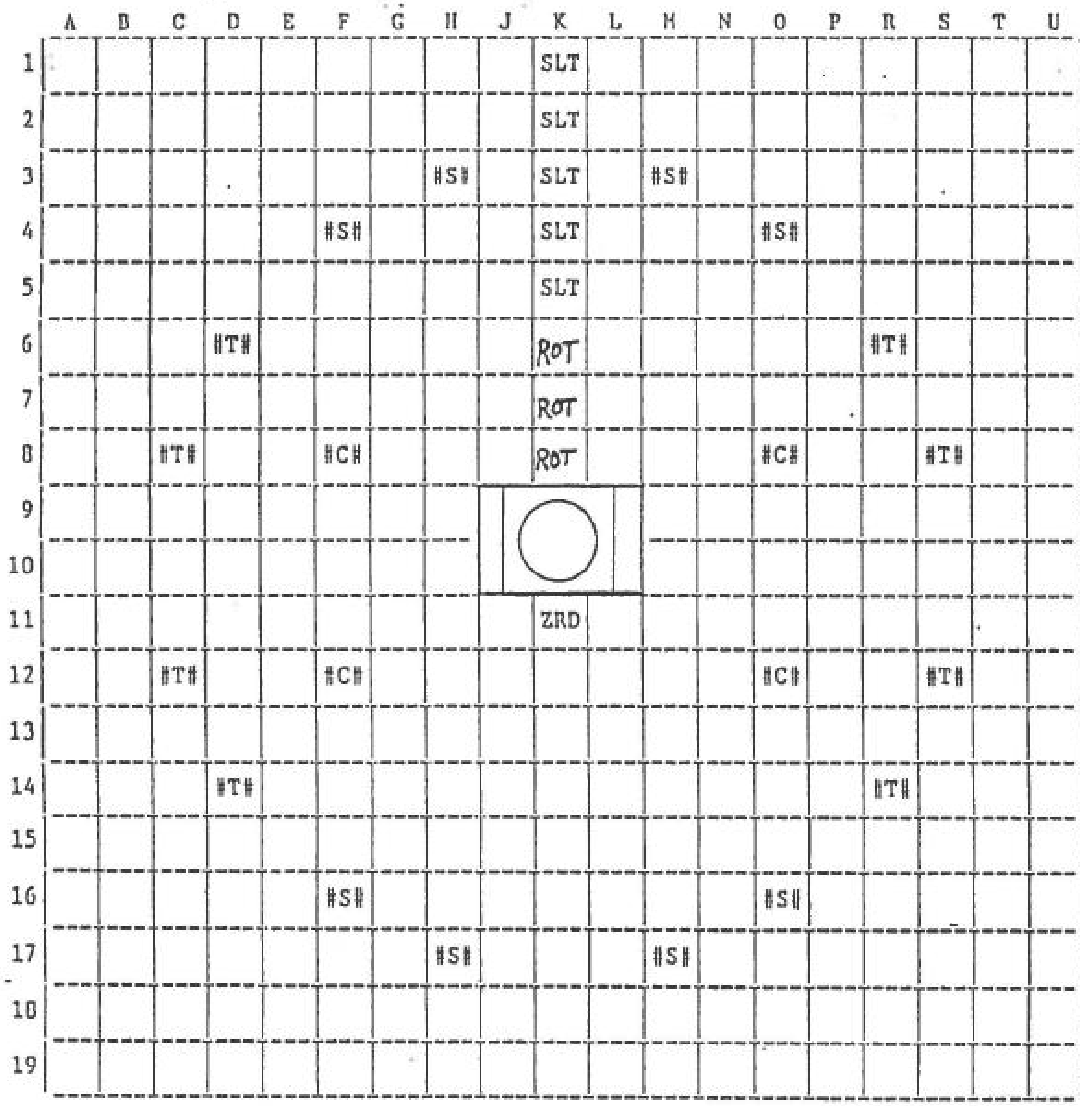


Figure 2.385. Example AN-CAL Core Loading.

2.15 Control Rod Positioning

The TREAT reactor core structure can facilitate installation of up to 32 control rods (see Figure 2.386). Each control rod comprises a poison section of compacted boron carbide powder, a Zircaloy-clad follower, a two-piece steel follower, and a handling attachment. Threaded connections are installed at the ends of each section allowing for the interchanging of the top poison section and Zircaloy follower to convert the function of the control rod from a normal shutdown rod to a transient rod [Freund 1960]. The first transients were performed by scramming selected rod drives on which the poison and follower sections had been reversed; this provided the capability to perform temperature-limited transients. As more advanced hydraulic transient rod drives with computer control were introduced to TREAT (i.e. current control rod operations), the swapping of poison and follower sections was no longer necessary [Swanson 2000].

In the fully-inserted position, the poison section overlaps the top and bottom of the active core region. There is negligible change in reactivity for the 6 in. of rod travel directly above and below the core; reactivity of the core changes during the 4 ft. of control rod travel within the fueled region of the core. In the "up" position, the B_4C poison section is driven up out of the core and replaced by the graphite-filled Zircaloy-clad section [Freund 1960].

Fine reactivity control on some of the control rod drives is accurate to ±0.002 in. using selsyn position indicators; the remaining drives are accurate to ±0.02 in. using potentiometer position indicators [Freund 1960].

TREAT specifications vary for control rod positioning in-core. For example some specifications indicate that when the control/shutdown and compensation rod is fully inserted, the poison section extends approximately 4.25 in. above the top and 4.25 in. below the bottom of the fuel region of the core. When the transient rod is fully inserted, the bottom of the poison section is 13.5 in. above the bottom of the poison section of the shutdown rod (see Figure 2.386) [ANL 1992].

However, to match the specifications provided above for TREAT, the bottom of the B4C poison section would need to be roughly 3.875 in. below the bottom of the active fuel region when the shutdown and compensation control rods are fully inserted into the core. The transient control rods would then be 9.625 in. above the bottom of the active fuel region when fully inserted into the core.

Table 2.37. Control Rod Positioning.

Quantity	Figure	DWG#	Component	Reference
As Needed	2.386	--	Vertical Control Rod Placement	Robinson 1994
1	2.387	--	Control Rod In-Core Placement	Freund 1960

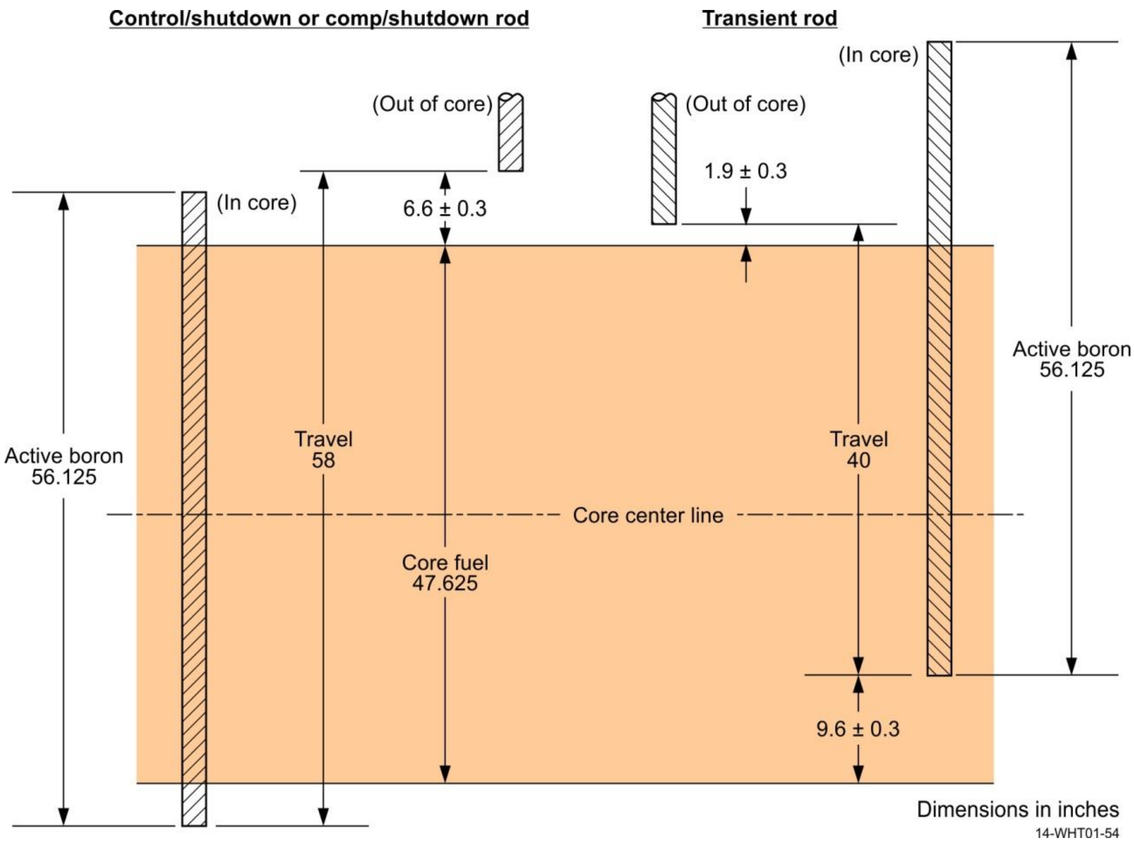


Figure 2.386. Vertical Control Rod Placement.

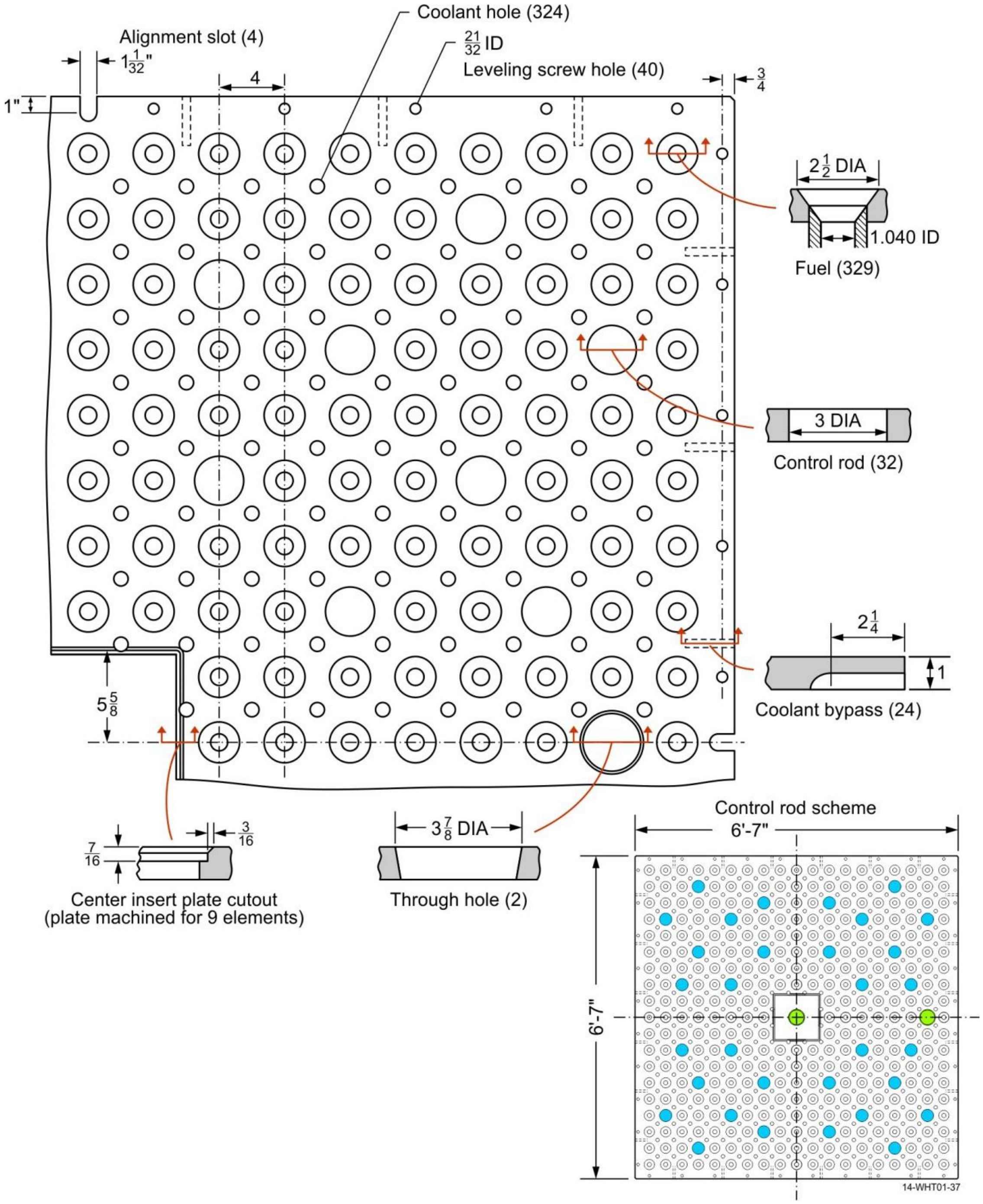


Figure 2.387. Control Rod In-Core Placement.

3. MATERIAL PROPERTIES

The primary materials have been identified and characterized, as best as possible, to be summarized in this section. Throughout the previous section, materials were identified, where known, for the various reactor facility components. Conflicting information for some materials was found in the reference literature. The competing information is provided and discussed herein, with a final value selected that is believed to be the most accurate. It can be noticed that quite a bit of similarity exists between the different types of assemblies, which is useful when developing models of TREAT.

3.1 Graphite Fuel

At the time of construction of the TREAT reactor, existing technology supported the feasible use of uranium dispersed in graphite. The graphite serves as both a moderator and a means to disperse the heat generated by the micron-size uranium particles during operation. Heating of the graphite increases the neutron leakage probability in the core, creating a sizable negative temperature coefficient. Initial fuel development activities identified the best method for fabrication of the TREAT fuel from graphite flour, U_3O_8 and thermosetting resin binder to create a bonded carbon matrix [Lied 1960]. Details regarding the fabrication of the graphite fuel assemblies are provided elsewhere [Bean 1959].

The graphite flour was likely #1008 graphite flour from Great Lakes Carbon Company. The Thermax Brand Carbon Black was from Termatomic Carbon Corporation and the thermosetting resin, plaspreg, which was used as the binder, from Furane Plastics and Chemical Company [Pavone 1957]. Plaspreg is approximately 95 % furfuryl alcohol and 5 % furfuraldehyde, and then catalyzed with approximately 10 wt.% maleic anhydride [Schell 1960]. Alternatively, Varcum, a partially polymerized furfuryl alcohol prepared by Varcum Chemical Company, was used as the thermosetting resin and catalyzed with approximately 5 wt.% maleic anhydride [Schell 1961]

Density

The average density of the fuel blocks was 1.73 g/cc with a range of 1.71 to 1.76 g/cc [Handwerk 1960]. Another reference indicated a density of 1.72 g/cc [Okrent 1960].

Graphitization

A considerable amount of the carbon in the TREAT fuel was not in the form of graphite, which is not just important for considering the evaluation of stored energy in the fuel, but also for neutronics analysis. In neutronics analysis, the scattering behavior of the carbon is treated differently whether it is graphite or not. The fabrication process used the following formulation: 75 parts graphite flour, 25 parts thermax (a thermatomic carbon produced by "cracking" natural gas), and 29.4 parts koppers coal tar, by weight. The weight fraction of 0.913 was reported for the carbon content in coal tar. During the baking portion of the fabrication process the coal tar dissociated into carbon. The temperature maintained during the baking process was only 950 °C, which was insufficient to graphitize the dissociated coal tar carbon or the carbon from the thermax. The recommended graphite to total carbon ratio of 0.59 was specified for the graphite fuel while the graphite reflectors would still be considered 100 % graphite [Swanson 1988].

Recalculation of the graphitization estimate for the graphite fuel confirms the value of 59 %, with a bounding uncertainty of ± 1 %.

Uranium Content

The uranium-to-carbon atom ratio was approximately 1 to 10,000 based on the batch mixture of 0.248 wt.% U_3O_8. The measured uranium content was measured to be 0.211 ± 0.004 wt.% with a range between 0.205 and 0.222 wt.% [Handwerk 1960]. Another reference indicated a mean uranium content of 0.2109 wt.% uranium [Okrent 1960], which isn't significantly different from the aforementioned mean value. The baking temperature of 950 °C served to convert to U_3O_8 to UO_2 [Swanson 1988]. Typically the U_3O_8 reduces to $UO_{2.06}$; while most of the uranium was in the form of UO_2, some remained with a ratio of $UO_{2.3}$ [Pavone 1957].

Uranium Enrichment

The uranium for TREAT fuel was reported to have an ^{235}U enrichment of 93.1 wt.% in early references [Okrent 1960 and Freund 1960] and 93.24 wt.% in latter references [ANL 1972 and ANL 1992] with no mention of the ^{234}U and ^{236}U content.

To assess the complete uranium vector, contemporary ANL experimental data was investigated for the ZPR-3 critical assembly benchmark evaluation found in the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* (ICSBEP Handbook) [ICSBEP 2015] and the *International Handbook of Evaluated Reactor Physics Benchmark Experiments* (IRPhEP Handbook) [IRPhEP 2015]. Results are provided in Table 3.1 and match the ^{235}U content reported in the latter TREAT reports. The uranium vector is expected to be nearly identical between ZPR-3 and TREAT as the material would have been obtained from the same facility.

Table 3.1. Uranium Isotopic Vector for ZPR-3 and TREAT.

Isotope	**Content (wt.%)**	**Uncertainty among ZPR-3 Fuel Plates**	**Uncertainty Typically Applied**
^{234}U	0.910	± 0.008	± 0.01
^{235}U	93.239	± 0.026	± 0.05
^{236}U	0.428	± 0.008	± 0.01
^{238}U	5.413	± 0.016	--

Impurity Content

The raw materials had been analyzed for boron content; the manufactured blocks had a boron content very close to 1 ppm. Later analyses of the fuel blocks contained varying quantities of boron with an average of about 6 ppm. The increase in boron content was contributed to unexpected diffusion of boron from the borated steel divider plates used in the baking crucibles [Handwerk 1960, Freund 1960].

Some example impurity measurements are provided in Tables 3.2 and 3.3, with a summary of the calculated average boron content provided in Table 3.4 [Iskenderian 1960].

Table 3.2. Typical Spectrochemical Analysis of Core Graphite (wppm) [Iskenderian 1960].

Sample No.	B	Fe	V	Gd	Eu	Sm	Cd
1	13	300	30	< 0.2	< 0.2	< 1	--
2	4	400	30	< 0.2	< 0.2	< 1	--
3	10	400	30	< 0.2	< 0.2	< 1	--
4	5	500	30	< 0.2	< 0.2	< 1	--
5	7	1000	--	--	--	--	--
6	4	1000	--	--	--	--	15

Table 3.3. Comparison of Impurities (wppm) [Iskenderian 1960].

Sample No.	Chemical Analysis		Spectrochemical Analysis	
	B	Cd[(a)]	B	Cd[(a)]
1	14	--	13	--
2	8.9	--	10	--
3	8.9	10-20	--	10-20

(a) Chemical analysis indicated that Cd was very much localized in the graphite sample and had a very low averaged value.

Table 3.4. Summary of Boron Impurity Measurements in Core Graphite (wppm) [Iskenderian 1960].

Group No.	Number of Samples in Group	Average for Group	Average Deviation for Group	Average Deviation
1	8	6.4	2.7	0.95
2	10	5.1	1.3	0.4[(a)]
3	20	10.0	4.7	1.0
4	12	7.4	6.4	1.8
Total Number of Samples				50
Average Impurity for Four Groups				7.6
Average Deviation for Four Groups				1.4

(a) Reported incorrectly as 0.2 in original reference.

Reanalysis of the values provided in Table 3.4 does not produce the average impurity content of 7.6 ± 1.4 ppm. The variance-weighted mean boron impurity content is computed to be 5.90 ± 0.35 ppm, which is similar to the 6 ppm value reported in the other TREAT references.

The average iron content of the fuel was measured to be 0.0267 wt.% [Handwerk 1960].

Based on Table 3.2, the vanadium content is 30 ppm and other measured contents are negligible compared against the boron content.

The cadmium content is believed to be negligible and a localized phenomenon encountered in some of the sample measurements [Iskenderian 1960].

The graphite fuel for TREAT contained approximately 1 wt.% hydrogen content prior to baking. The fuel blocks were then baked up to 950 ºC to initiate graphitization and release volatile gases. To achieve complete graphitization and completely release most non-graphite materials, a baking temperature of approximately 3000 ºC is necessary. At that point, the hydrogen content is < 50 ppm [Nightingale 1962]. The TREAT fuel fabrication process was simulated by B&W but only baked to 900 ºC in February 2015 and then tested by NSL Analytical in April 2015 for impurity content. The measured hydrogen content was 0.097 wt.% (970 ppm).

Water Content and Void Fraction

The graphite fuel blocks were baked as part of the fabrication process to release volatiles and water via outgassing. Assembly of the fuel assemblies included evacuation of the fueled portion of the assembly; therefore, water, gases, and air were not present in the graphite fuel blocks.

3.2 Graphite

3.2.1 CP-2 Graphite

The graphite used in the reflectors of the TREAT reactor was formerly used in Chicago Pile (CP-2), which initially came from the 385.5 tons of graphite used to construct CP-1. A total of 35 tons of CP-1/-2 graphite was later used in the TREAT reflector [Nightingale 1962].

Density

The density of CP-2 graphite was reported as 1.67 g/cc [Okrent 1960]. Original CP-1 graphite had a range of densities between 1.58 and 1.70 g/cc. A mean density of 1.67 g/cc was calculated based on data regarding the grade and quantity of graphite utilized in CP-1 [Nightingale 1962], which matches the reported density value.

Impurity Content

The average boron content for CP-2 graphite was reported to be about 1.0 ppm, based on a spectrochemical analysis of reflector graphite impurities (see Table 3.5) [Isekenderian 1960]. A sample of CP-2 graphite was sent to Evans Analytical Group (EAG) for analysis in September 2012. The results from GDMS measurements are provided in Table 3.6; as stated in the table, the equivalent boron content (EBC) is roughly 1.0 ppm.

Table 3.5. Reflector Graphite Impurities (ppm), Spectrochemical Analyses [Iskenderian 1960].

Sample No.	B	Fe	V	Gd	Eu	Sm	Cd	H_2O (%)
1	0.1	--	--	--	--	--	--	--
2	0.2	--	--	--	--	--	--	--
3	2	15	300	< 0.2	< 0.01	< 0.2	< 0.1	--
4	2	10	400	< 0.2	< 0.01	< 0.2	< 0.1	--
5	1.5	2000	150	--	--	--	--	0.12

Table 3.6. GDMS Measurement of CP-2 Graphite.[(a)]

Element	Concentration [ppm wt]	Element	Concentration [ppm wt]
Li	0.67	Pd	< 0.05
Be	< 0.05	Ag	< 0.05
B	0.35	Cd	< 0.05
C	Matrix	In	< 0.05
N	--	Sn	< 0.05
O	--	Sb	< 0.05
F	< 0.1	Te	< 0.05
Na	< 0.05	I	< 0.01
Mg	0.06	Cs	< 0.05
Al	2.2	Ba	< 0.05
Si	70	La	< 0.05
P	0.65	Ce	< 0.05
S	45	Pr	< 0.05
Cl	0.45	Nd	< 0.05
K	< 0.1	Sm	< 0.01
Ca	160	Eu	< 0.01
Sc	< 0.01	Gd	< 0.01
Ti	12	Tb	< 0.01
V	120	Dy	< 0.01
Cr	< 0.5	Ho	< 0.01
Mn	0.02	Er	< 0.01
Fe	6.2	Tm	< 0.01
Co	< 0.01	Yb	< 0.01
Ni	1.4	Lu	< 0.01
Cu	0.15	Hf	< 0.01
Zn	< 0.05	Ta	< 100
Ga	< 0.01	W	< 0.05
Ge	< 0.05	Re	< 0.01
As	< 0.05	Os	< 0.01
Se	< 0.05	Ir	< 0.01
Br	< 0.1	Pt	< 0.01
Rb	< 0.05	Au	< 0.1
Sr	1.2	Hg	< 0.1
Y	0.05	Tl	< 0.05
Zr	0.34	Pb	< 0.05
Nb	< 0.05	Bi	< 0.05
Mo	< 0.05	Th	< 0.05
Ru	< 0.05	U	< 0.05
Rh	< 0.01	EBC	0.9176

(a) Precision and bias typical of GDMS measurements are discussed under ASTM F1593.

Water Content

The graphite utilized in TREAT assemblies had been assembled in an enclosed building and covered by plastic material during storage. There had been no indication of appreciable moisture in this graphite [Iskenderian 1960].

Some of the graphite stacks in the permanent radial reflector had been exposed to the atmosphere for an appreciable length of time and not always protected against moisture. Depending on the moisture content of circulating air around the graphite, the graphite could retain considerable amounts of moisture, but probably less than 1 % [Iskenderian 1960].

Results from the various tests are provided in a memo [Boland 1959]. It was concluded that the water content results were different between tests performed in Idaho and Chicago. The former content roughly 0.02 wt.% and the latter approximately 1 wt.%. Accurate estimation of the water content cannot be achieved without good knowledge of exposure history. Long-term exposure to hot dry air would be needed to remove any remaining water content.

Because the TREAT reactor is located and operated in Idaho, it is estimated that a water content of 0.02 ± 0.01 wt.% based on moisture content measurements reported in the aforementioned memo [Boland 1959] is appropriate to represent the water content of CP-2 graphite, especially following years of transient test experimentation.

Void Fraction

The void fraction of CP-2 graphite is approximately 0.26, which is assumed to contain ambient air.

3.2.2 Arco Graphite

Graphite manufactured for the three-quarter assemblies used in the AN-CAL experimental series [Robinson 1992] were reported to have been Arco carbon high purite graphite #873RL or equivalent. Further detailed aside from what is provided in Figure 2.257 is not available.

Density

The apparent density reported for Arco graphite is 1.73 g/cc.

Impurity Content

The impurity limits for Arco graphite are reported in Table 3.7.

Table 3.7. Impurity Content of Arco Graphite.

Element	ppm
Aluminum	< 1
Boron	< 1
Calcium	< 2
Iron	< 3
Silicon	< 3
Vanadium	< 1
Titanium	< 1
Lithium	< 1
Cadmium	< 1
Nickel	< 10

Water Content

The water content is not recorded for Arco graphite. It could be assumed that the content would be equal to or less than the water content of CP-2 graphite in Idaho.

Void Fraction

The void fraction of Arco graphite is approximately 0.23, which is assumed to contain ambient air.

3.3 Zircaloy Alloys

3.3.1 Zircaloy-2

Density

The density of Zr-2 is 6.55 g/cc.

Composition and Impurity Content

Direct measurement of the impurity content of Zr-2 alloy from TREAT was not available. Contemporary Zr-2 material used during that time period to study the reactor between zirconium and water at high temperatures were reported to have the contents provided in Table 3.8 and 3.9 [Lemmon 1957 and Kendall 1955, respectively]. The standard composition of Zr-2 is provided in Table 3.10 [ASTM B351 2013].

Table 3.8. Analysis of Zircaloy-2 [Lemmon 1957].

Element	**Amount Present (wt.%)**
Tin	1.5
Iron	0.20
Chromium	0.05
Nickel	0.03
Silicon	0.007
Aluminum	0.006
Manganese	0.002
Magnesium	0.002
Lead	0.002
Oxygen	0.089
Nitrogen	0.003
Hydrogen	0.002
Zirconium	Balance

Table 3.9. Analysis of Zircaloy-2 [Kendall 1955].

Element	ppm	Element	ppm
Al	30	Mo	< 10
B	< 0.5	N_2	44
Cd	< 0.5	Ni	569
Co	< 10	Pb	30
Cr	1032	Si	25
Cu	30	Sn	1.52 %
Fe	1660	Ti	< 50
Hf	85	V	< 20
Mg	50	Zn	< 50
Mn	< 10	Zr	Balance

Table 3.10. Standard Composition of Zircaloy-2 [ASTM B351 2013].

Element	Min wt.%	Max wt.%
Sn	1.2	1.7
Fe	0.07	0.2
Cr	0.05	0.15
Ni	0.03	0.08
Al	--	0.0075
B	--	0.00005
Cd	--	0.00005
Ca	--	0.003
C	--	0.027
Co	--	0.002
Cu	--	0.005
Hf	--	0.01
H	--	0.0025
Mg	--	0.002
Mn	--	0.005
Mo	--	0.005
Nb	--	0.01
N	--	0.008
Si	--	0.012
W	--	0.01
Ti	--	0.005
U (total)	--	0.00035
Zr	--	Balance

3.3.2 Zircaloy-3

Density

The density of Zr-3 is 6.53 g/cc.

Composition and Impurity Content

A sample of Zr-3 was sent to Evans Analytical Group (EAG) for analysis in September 2012. The results from ICP-MS and other measurements are provided in Tables 3.11 and 3.12. The standard composition of Zr-3 is provided in Table 3.13 [ASM Zr-5 1969].

Table 3.11. ICP-MS Measurement of Zircaloy-3 Composition.[(a)]

Element	Concentration [ppm wt]	Element	Concentration [ppm wt]
Li	< 1	Pd	< 1
Be	< 1	Ag	150
B	< 1	Cd	< 1
C	--	In	7
N	--	Sn	3000
O	--	Sb	< 1
F	--	Te	< 1
Na	< 10	I	--
Mg	< 1	Cs	< 1
Al	5	Ba	< 1
Si	< 10	La	< 1
P	< 10	Ce	< 1
S	--	Pr	< 1
Cl	--	Nd	< 1
K	< 10	Sm	< 1
Ca	< 10	Eu	< 1
Sc	< 100[(b)]	Gd	< 1
Ti	8	Tb	< 1
V	< 1	Dy	< 1
Cr	< 1	Ho	< 1
Mn	1	Er	< 1
Fe	2600	Tm	< 1
Co	< 1	Yb	< 1
Ni	< 1	Lu	< 1
Cu	< 1	Hf	79
Zn	< 1	Ta	< 1
Ga	< 1	W	< 1
Ge	< 1	Re	< 1
As	< 1	Os	< 1
Se	< 1	Ir	< 1
Br	--	Pt	< 1
Rb	< 1	Au	< 1
Sr	< 1	Hg	< 1
Y	10	Tl	< 1
Zr	Matrix	Pb	6
Nb	10	Bi	< 1
Mo	< 1	Th	< 1
Ru	< 1	U	< 1
Rh	< 1		

(a) Concentration measurements of major elements done by ICP have an uncertainty typically in the range from 3 to 5 % (at the 95% confidence level). The uncertainty in the concentrations of trace elements might be significantly higher.

(b) Elevated limit due to polyatomic interference from zirconium.

Table 3.12.Other Measurements of Zircaloy-3 Composition.[a]

Element	Concentration [ppm wt]
C[b]	120
N[c]	51
O[d]	920
S[b]	--
H[c]	22

(a) Precision and bias typical of IGA measurements are discussed under ASTM E1019 and E1447.
(b) Determined by Combustion-IR.
(c) Determined by IGF-TC.
(d) Determined by IGF-NDIR.

Table 3.13. Standard Composition of Zircaloy-3 [ASM Zr-5 1969].

Element	Min wt.%	Max wt.%
C	--	0.05
Sn	0.2	0.3
Fe	0.2	0.3
Cr	--	0.5
Ni	--	0.5
N	--	0.1
Hf	--	0.2
Si	--	0.1
Pb	--	0.013
Al	--	0.0075
Ti	--	0.005
W	--	0.01
V	--	0.005
Mo	--	0.005
Co	--	0.002
Zr	--	Balance

3.3.3 Zircaloy-4

Density

The density of Zr-4 is 6.56 g/cc.

Composition and Impurity Content

Direct measurement of the impurity content of Zr-4 alloy from TREAT was not available. The standard composition of Zr-4 is provided in Table 3.14 [ASTM B350 2011 and ASTM B351 2013].

Table 3.14. Standard Composition of Zircaloy-4 [ASTM B350 2011 and ASTM B351 2013].

Element	Min wt.%	Max wt.%
Sn	1.2	1.7
Fe	0.18	0.24
Cr	0.07	0.13
Ni	--	0.007
Al	--	0.0075
B	--	0.00005
Cd	--	0.00005
Ca	--	0.003
C	--	0.027
Co	--	0.002
Cu	--	0.005
Hf	--	0.01
H	--	0.0025
Mg	--	0.002
Mn	--	0.005
Mo	--	0.005
Nb	--	0.01
N	--	0.008
Si	--	0.012
W	--	0.01
Ti	--	0.005
U (total)	--	0.00035
Zr	--	Balance

3.4 Aluminum Alloys

3.4.1 Al-1100

Density

The density of Al-1100 is 2.71 g/cc.

Composition and Impurity Content

Direct measurement of the impurity content of Al-1100 alloy from TREAT was not available. The standard composition of Al-1100 is provided in Table 3.15 [ASTM B209 2010 and ASTM B247 2009].

Table 3.15. Standard Composition of Al-1100 [ASTM B209 2010 and ASTM B247 2009].

Element	Min wt.%	Max wt.%
Si+Fe	--	0.95
Cu	0.05	0.2
Mn	--	0.05
Mg	--	--
Cr	--	--
Zn	--	0.1
Ti	--	--
Others Each[(a)]	--	0.05
Others Total	--	0.15
Al	99	Balance

(a) Typical "other" impurities might include Co, Ni, and Sn.

3.4.2 Al-6061

Density

The density of Al-6061 is 2.70 g/cc.

Composition and Impurity Content

Direct measurement of the impurity content of Al-6061 alloy from TREAT was not available. The standard composition of Al-6061 is provided in Table 3.16 [ASTM B209 2010].

Table 3.16. Standard Composition of Al-6061 [ASTM B209 2010].

Element	Min wt.%	Max wt.%
Si	0.4	0.8
Fe	--	0.7
Cu	0.15	0.4
Mn	--	0.15
Mg	0.8	1.2
Cr	0.04	0.35
Zn	--	0.25
Ti	--	0.15
Others Each[(a)]	--	0.05
Others Total	--	0.15
Al	--	Balance

(a) Typical "other" impurities might include Co, Ni, and Sn.

3.4.3 Al-6063

Density

The density of Al-6063 is 0.097 lb/in.^{3} (2.685 g/cc) [Alcoa 2002] or elsewhere reported as 0.097 lb/in.^{3} or 2.7 g/cc (Metal 2015).

Composition and Impurity Content

Direct measurement of the impurity content of Al-6063 alloy from TREAT was not available. The standard composition of Al-6063 is provided in Table 3.17 [Alcoa 2002 and Metal 2015].

Table 3.17. Standard Composition of Al-6063 [Alcoa 2002 and Metal 2015].

Element	Min wt.%	Max wt.%
Si	0.2	0.6
Fe	--	0.35
Cu	--	0.1
Mn	--	0.1
Mg	0.45	0.9
Cr	--	0.1
Zn	--	0.1
Ti	--	0.1
Others Each[(a)]	--	0.05
Others Total	--	0.15
Al	--	Balance

(a) Typical "other" impurities might include Co, Ni, and Sn.

3.5 Steels

3.5.1 Mild, Low-Carbon, Steel

Density

The density of type 1018 mild low-carbon steel is 7.87 g/cc and the density of 7.8 g/cc for type A36 low-carbon steel. The mean density of 7.835 g/cc can be selected to represent all mild, low-carbon steels.

Composition and Impurity Content

Mild, low-carbon steels are reported as AISI 1010-1020 steel or type ASTM A36. The composition of mild, low-carbon steel in TREAT is expected to be fairly similar to type 1018 or A36, as shown in Table 3.18 [ASTM 1018 2010 and ASTM A36 2012, respectively]. Direct measurement of the impurity content of steel alloys from TREAT was not available.

Table 3.18. Standard Composition of Mild, Low-Carbon Steels 1018 and A36 [ASTM 1018 2010 and ASTM A36 2012, respectively].

Element	1018		A36	
	Min wt.%	Max wt.%	Min wt.%	Max wt.%
C	0.15	0.2	--	0.29
Mn	0.6	0.9	0.8	1.2
P	--	0.03	--	0.04
S	--	0.035	--	0.05
Cu	--	0.2	--	--
Ni	--	0.2	--	--
Cr	--	0.15	--	--
Mo	--	0.06	--	--
V	--	0.008	--	--
Nb	--	0.008	--	--
Ti	--	0.0025	--	--
Si	--	--	0.15	0.4
Fe	--	Balance	--	Balance

3.5.2 SS-304 (also SS-18-8)

Density

The density of SS-304 is 8 g/cc.

Composition and Impurity Content

The grade of SS-304 is not specified; the composition range for SS-304, -304L, and -304H are compiled in Table 3.19 [ASTM A240 2015 and ASTM A276 2015]. Steel SS-18-8 has a composition practically identical to SS-304. Direct measurement of the impurity content of steel alloys from TREAT was not available.

Table 3.19. Standard Composition of SS-304 [ASTM A240 2015 and ASTM A276 2015].

Element	Min wt.%	Max wt.%
C	--	0.1
Cr	18	20
Ni	8	12
Mn	--	2
Si	--	0.75
P	--	0.045
S	--	0.03
N	--	0.1
Fe	--	Balance

3.6 Lead Bricks

Density

The density of Pb is 11.34 g/cc.

Composition and Impurity Content

Direct measurement of the impurity content of Pb from TREAT was not available. The standard composition of Pb is provided in Table 3.20 [ASTM B29 2009].

Table 3.20. Standard Composition of Pb [ASTM B29 2009].

Element	Min wt.%	Max wt.%
Sb	--	0.001
As	--	0.001
Sn	--	0.001
Sb, As, & Sn	--	0.002
Cu	--	0.0015
Ag	--	0.01
Bi	--	0.05
Zn	--	0.001
Te	--	--
Ni	--	0.0005
Fe	--	0.001
Pb	99.94	Balance

3.7 Additional Control Rod Materials

3.7.1 Boron Carbide

Density

The density of the initial control rod poison section B_4C powder was 1.6 g/cc. The second generation (replaced in 1960 due to densification and voiding issues) of control rods used epoxy resin with the powder packed to a density of 1.8 g/cc. These were later replaced again (after January 1967 due to resin decomposition issues) with the current control rods packed to 1.8 g/cc without use of an epoxy resin. With exception of the density of the boron carbide powder, there are no other differences between the replacement and original control rods [Boland 1967].

Composition and Impurity Content

The basic composition of boron carbide is four boron atoms per carbon atom, or approximately 78.264 wt.% natural boron. Direct measurement of the impurity content of boron carbide from TREAT was not available. However, possible impurities might include those shown in Table 3.21 [Fujii 2003], which are quite negligible.

Table 3.21. Example Impurities in Sintered B_4C Pellets [Fujii 2003].

Impurity	Quantity (ppm by weight)
Na	~10
Al	~1000
Si	~1000
Ca	~100
Ti	~1000
Mn	~10

3.7.2 Kanigen Nickel Plating

Density

The density of Kanigen nickel plating is between 7.8 and 8.1 g/cc [Verbrugge 2015b].

Composition and Impurity Content

Kanigen nickel plating is a nickel-phosphor alloy containing between 9 and 12 wt.% phosphorous in nickel [Kanigen 2011]. The impurity content, if any, is unknown, and assumed to be negligible.

3.7.3 Chrome Plating

Density

Chrome plating has a density of 7.2 g/cc [Verbrugge 2015a].

Composition and Impurity Content

Chrome plating is assumed to be 100 % pure. The impurity content, if any, is unknown, and assumed to be negligible.

3.8 Shielding Materials

3.8.1 Hematite/Magnetite Concrete

Density

Throughout the various TREAT reports, the shielding is referred to as high-density heavy magnetite and/or hematite concrete with a density between 200 and 220 lb/ft^3 (3.204 and 3.524 g/cc) [Freund 1960, MacFarlane 1958, ANL 1972, and ANL 1992]

Composition and Impurity Content

No details regarding the fabrication of the concrete or measured composition is available in TREAT documentation. A probable composition for the concrete can be derived from compositions of Portland cement [ASTM C150 2014 and Czernin 1962], hematite concrete [Dubrovskii 1970], magnetite concrete [Lewis 1970], and water, as summarized in Table 3.22.

Table 3.22. Possible Composition (wt.%) of High-Density Hematite/Magnetite Concrete.

Material	Hematite	Magnetite	Portland Cement	Water	High-Density Concrete
Hematite	40	--	--	--	40
Magnetite	--	40	--	--	40
Portland Cement	--	--	10	--	10
Water	--	--	--	10	10
CaO	2.6	0.1594	63	--	7.40
SiO_2	7.09	0.0648	20	--	4.90
Al_2O_3	--	5.9594	6	--	3.00
Fe_2O_3	88.2	49.858	3	--	55.52
MgO	1.35	4.1557	1.5	--	2.40
SO_3	--	--	2	--	0.20
K_2O	--	--	0.5	--	0.05
Na_2O	--	--	0.5	--	0.05
FeO	--	32.169	--	--	12.90
MnO	--	0.2192	--	--	0.10
V_2O_3	--	0.1495	--	--	0.06
Cr_2O_3	--	0.0249	--	--	0.01
TiO_2	--	7.24	--	--	2.90
LOI (assume H_2O)	0.76	--	2	100	10.51
Other (ignore)	--	--	1.5	--	--
Total	100	99.9999	100	100	100

3.8.2 Boral (50:50)

Density

Data regarding the Boral utilized at TREAT is not available. However, description of the Boral is very similar to descriptive data available for the early development of Boral at ORNL. The density of Boral is 2.53 g/cc [McKinney 1949].

Composition and Impurity Content

The basic composition of Boral is provided in Table 3.23 with a list of the aluminum powder impurities provided in Table 3.24 [McKinney 1949].

Table 3.23. Basic Composition of Boral [McKinney 1949].

Component	Concentration
B_4C	50 vol.%
Al	50 vol.%
B	36 wt.%
Al	55.1 wt.%
C	8.9 wt.%

Table 3.24. Impurities in Aluminum Powder Used in Boral Fabrication [McKinney 1949].

Element	wt.%
Ag	< 0.04
Al	> 0.10
B	< 0.015
Be	< 0.004
Ca	< 0.08
Cd	< 0.15
Co	< 0.08
Cr	< 0.15
Cu	0.08
Fe	0.15
In	< 0.08
Mg	0.04
Mn	0.04
Mo	< 0.15
Ni	< 0.08
Pb	0.08
Pt	0.08
Si	0.2
Sn	< 0.08
Ti	< 0.04
V	< 0.08
Zn	< 0.31
Zr	< 0.15

3.9 Air

Density

The density of air at INL is approximately 0.0012 g/cc.

Composition and Impurity Content

The basic composition of air is provided in Table 3.25 [NASA 2013]. During operation, trace quantities of fission product gases could be detected [Swanson 1994 and Powell 1994], such as those reported in Table 3.26.

Table 3.25. Basic Composition of Air [NASA 2013].

Component	Volume (ppm)
Nitrogen (N_2)	780840
Oxygen (O_2)	209460
Argon (Ar)	9340
Carbon Dioxide (CO_2)	380
Neon (Ne)	18.18
Helium (He)	5.24
Methane (CH_4)	1.7
Krypton (Kr)	1.14
Hydrogen (H_2)	0.55
Water (H_2O)	10000

Table 3.26. TREAT Gaseous Fission Product Average Effluence at the Top of the Stack.

Isotope	Measurement 1 pCi/cc	Measurement 2 pCi/cc
^{41}Ar	81.9 ± 1.5	66.4 ± 6.0
^{85m}Kr	3.5 ± 0.8	1.40 ± 0.15
^{87}Kr	10.5 ± 0.5	7.36 ± 0.80
^{88}Kr	8.7 ± 0.4	6.71 ± 0.75
^{135}Xe	0.66 ± 0.12	0.34 ± 0.15
^{135m}Xe	2.4 ± 0.7	0.41 ± 0.15
^{138}Xe	30.2 ± 3.9	10.7 ± 1.5

3.10 Thermocouple Materials

3.10.1 Chromel

Density

The density of various Chromel materials ranges between 7.94 and 8.73 g/cc with a mean value of approximately 8.5 g/cc. A density of 8.710 g/cc is reported for the composition provided below [Evek 2015b].

Composition and Impurity Content

The composition of Chromel is provided in Table 3.27 [Evek 2015b].

Table 3.27. Chromel Thermocouple Alloy Chemical Composition [Evek 2015b].

Element	wt.%
Ni + Co	87.4 – 90.4
Fe	≤ 0.3
C	≤ 0.2
Si	≤ 0.4
Mn	≤ 0.4
S	≤ 0.01
P	≤ 0.003
Cr	9 – 10
Co	0.6 – 1.2
Al	≤ 0.15
Cu	≤ 0.25
As	≤ 0.002
Pb	≤ 0.002
Mg	≤ 0.05
Sb	≤ 0.002
Bi	≤ 0.002
Other	Total 1.4

3.10.2 Alumel

Density

The density of various Alumel materials is generally approximately between 8.50 and 8.60 g/cc. A density of 8.480 g/cc is reported for the composition provided below [Evek 2015a].

Composition and Impurity Content

The composition of Alumel is provided in Table 3.28 [Evek 2015a].

Table 3.28. Alumel Thermocouple Alloy Chemical Composition [Evek 2015a].

Element	wt.%
Ni + Co	91.5 – 95.15
Fe	≤ 0.3
C	≤ 0.1
Si	0.85 – 1.5
Mn	1.8 – 2.7
S	≤ 0.01
P	≤ 0.005
Co	0.6 – 1.2
Al	1.6 – 2.4
Cu	≤ 0.25
As	≤ 0.002
Pb	≤ 0.002
Mg	≤ 0.05
Sb	≤ 0.002
Bi	≤ 0.002
Other	Total 0.7

3.10.3 MgO Insulation

Density

The density of MgO insulation is typical about 75 % of the theoretical density, 3.58 g/cc.

Composition and Impurity Content

Example impurities in a 99.5 to 99.95 % pure sample of MgO is shown in Table 3.29 [Leipold 1966].

Table 3.29. Mass-Spectrographic Analyses of MgO Powders (ppm atomic) [Liepold 1966].

Species	M-300(a)	JPL 8(b)
B	3	2
N	100	50
F	110	40
Na	100	< 1
Al	75	35
Si	2400	75
P	130	< 1
S	510	115
Cl	285	75
K	< 1	< 1
Ca	150	30
Ti	10	< 1
Cr	5	3
Mn	2	< 1
Fe	85	15
Ni	10	< 1
Co	10	< 1
Zn	5	2
Cu	--	10

(a) Average of 4 specimens.
(b) Average of 5 specimens.

3.10.4 Glass Insulation

Density

Glass insulation, typically known as fiberglass or E-glass, has a density of between 2.54 and 2.55 g/cc for boron containing E-glass, and 2.62 g/cc for boron-free E-glass [Wallenberger 2001].

Composition and Impurity Content

The composition of E-glass is provided in Table 3.30 [Wallenberger 2001].

Table 3.30. Compositions (wt.%) of Commercial E-Glass Fibers [Wallenberger 2001].

Component	Boron-containing E-glass	Boron-free E-glass
SiO_2	52 – 56	59.0 / 60.1
B_2O_3	4 – 6	-- / --
Al_2O_3	12 – 15	12.1 / 13.2
CaO	21 – 23	22.6 / 22.1
MgO	0.4 – 4	3.4 / 3.1
ZnO	--	--
TiO_2	0.2 – 0.5	1.5 / 0.5
Zr_2O_3	--	--
Na_2O	0 – 1	0.9 / 0.6
K_2O	Trace	-- / 0.2
Li_2O	--	--
Fe_2O_3	0.2 – 0.4	0.2 / 0.2
F_2	0.2 – 0.7	-- / 0.1

3.10.5 Asbestos Insulation

Density

The most typical form of asbestos utilized in the United States was Chrysotile: $Mg_3(Si_2O_5)(OH)_4$ or $3MgO\text{-}2SiO_2\text{-}2H_2O$. Chrysotile has a density of 2.55 ± 0.02 g/cc [Pundsack 1956].

Composition and Impurity Content

Example chemical composition of Chrysotile is provided in Table 3.31 [Pundsack 1955].

Table 3.31. Analysis of Chrysotile from Danville Area, Quebec, Canada [Pundsack 1955].

Component	wt.%
MgO	42.50
SiO_2	41.97
$H_2O^{(a)}$	13.56
FeO	1.57
Fe_2O_3	0.38
Al_2O_3	~0.10
K_2O	0.08
Others[(b)]	~0.10

(a) Ignition loss between 175 – 1100 º.
(b) E.g. Cr_2O_3, TiO_2, CaO, NiO, Mn_2O_3; determined by spectrographic analysis.

3.11 Other Materials

3.11.1 Brass

Density

The density of brass ranges between 8.4 and 8.7 g/cc, with a nominal density of 8.52 g/cc.

Composition and Impurity Content

The standard composition of brass is provided in Table 3.32 [ASTM B16 2010].

Table 3.32. Standard Composition of Brass [ASTM B16 2010].

Element	Min wt.%	Max wt.%
Cu	60.0	63.0
Pb	2.5	3.7
Fe	--	0.35
Zn	--	Balance

3.11.2 Graphitar

Density

No information is available regarding the graphitar bearing material properties for TREAT. Graphitar is made from blending powder allotrops of carbon (natural and artificial), carbon blacks, petroleum cokes, etc. with a hydrocarbon binder. Then the mixture is pressed into the desired shape and bakes in a furnace. The exact composition and process is modified depending on the proposed used for the graphitar. There are various grades of graphitar; typical bearing grades are 14, 18, 39, 67, 80, and 86. It is most likely that grades 67 or 86 were utilized in TREAT. Grade 67 is for light duty, non-lubricated applications such as guides and slides, or conventional sleeve bearings. Grade 86 is utilized in a wide range of bearing applications which require good strength and hardness for high speed operations, and can handle heavy loads under dry or lubricated conditions. Grade 67 has a density of 1.72 g/cc, and grade 86 has a density of 1.90 g/cc [Graphite 2003].

Composition and Impurity Content

The exact composition of graphitar, including impurity content, is unknown. Grade 67 contains carbon and graphite only. Grade 86 also includes resin impregnation [Graphite 2003].

3.11.3 Start-Up Sources

A plutonium-beryllium source (10^6 n/sec) was used for startup. After initial criticality, a stronger (1.5×10^7 n/sec, 5 curie) polonium-beryllium source was used [Freund 1960]. The Po-Be source was encased in a steel jacket (0.7 in. dia. by 0.7 in. long) [MacFarlane 1958]. Additional information regarding these early sources is unavailable.

Later a commercially available 2.5-curie americium-beryllium source encased in a steel jacket was used [ANL 1972 and ANL 1992]. Shipping documentation for the Am-Be source indicate that it was produced by the Monsanto Research Corporation in Dayton, Ohio and had the source number of MRC-N-SS-W-AmBe-539. The isotope is ^{241}Am in the chemical form of AmO_2 with beryllium target material. The mass of the isotope is 0.710 g; the mass of the target is 2.3 g. The emission rate was recorded as 4.89×10^6 n/sec; a date for this emission measurement was not reported, but date the source was shipped from Monsanto was April 10, 1967. The source container is described to be stainless steel type 304 with an outer diameter of 0.7 in. and a length of 1.26 in. The thickness of the steel, and mass of steel or total mass of the source, were not reported.

The exact chemical composition of the AmBe source is unknown. A different 5 Ci source of unspecified origin (purchased in 1986) was dismantled, sampled (sub-sampled), and analyzed using inductively coupled plasma mass spectrometry (ICP-MS) at the Idaho National Laboratory. The source was comprised of three separate pellets of varying thickness and mass. Each pellet was sub-sampled to provide 10 samples ranging in size from 6 to 15 mg. Results from the analyses are provided in Table 3.33 [Sommers 2009]. Another 5 Ci source purchased from Monsanto in 1968 for use with the Neutron Radiography (NRAD) Reactor also located at Idaho National Laboratory [Bess 2014].

Table 3.33. Example AmBe Source Properties at Idaho National Laboratory [Sommers 2009].

Be:Am Ratio	6.30 ± 52 % (1σ)
% Pu in ^{241}Am	0.157
% ^{239}Pu	72.7 ± 0.4 %
% ^{240}Pu	27.3 ± 2 %
U:Pu Ratio	0.177 ± 120 %
^{238}U Isotopic Content[(a)]	90 ± 1 %
Impurities[(b)]	**ng/mg ^{241}Am (or ppm) ± 10 % (2σ)**
Sc	1470
Sr	1590
Y	1480
Zr	1610
Mo	1830
Ba	1830
W	313

(a) This value represents a variance weighted average of the original data: 98 ± 2 %, 84 ± 3 %, and 88 ± 1 %.

(b) Only the impurities of significant measurable content were reported.

4. INFINITE FUEL LATTICE STUDIES

Benchmark data is needed to support validation of advanced models and simulations of TREAT in support of reactor restart, core operations, experimentation, and also LEU conversion. Prior to development of this report, ongoing activities included the recovery and evaluation of prior design and experiment data for use in benchmark model development and identification of missing information. A summary of this effort to capture available data for the original TREAT HEU fuel assemblies current utilized in the TREAT reactor core was previously presented [Bess 2015]. Key analyses and results from this study are summarized in this section, and document activities to develop models of the TREAT HEU fuel assemblies to address uncertainties and sensitivities in an infinite lattice model as a pre-assessment of possible impacts when developing full-core benchmark experiment evaluations.

4.1 Model Description and Analysis Methodology

An infinite lattice model was developed using the TREAT fuel assemblies with simulated shielding located above and below the assemblies. The drawings provided in Section 2 of this report and material properties described in Section 3 were instrumental in preparing models of the standard fuel assemblies for subsequent analyses. The actual TREAT reactor is limited to a finite maximum array size surrounded by a permanent reflector and concrete shielding, and also contains a variety of additional fueled and unfueled assemblies. The purpose of the infinite lattice model was to test uncertainties and sensitivities relevant to model development typical of benchmark evaluation exercises. The magnitude of the sensitivities will vary in a finite-reactor configuration but the dominant biases and uncertainties identified in this exercise would still be of similar relative importance.

The constructed standard fuel assembly used in this study is shown in Figure 4.1. It should be noted that some minor modifications were applied to the upper aluminum adapter, beveled edges of the axial reflectors, and zircaloy tabs; the impact upon neutronic simulation was negligible and further detailed evaluation of assembly simplifications would be necessary when processing a comprehensive benchmark evaluation. It should be noted that even some of the basic assembly geometries do not match those described as a standard baseline model for computational analyses in the 1970s [Brittan 1970] that is still utilized for TREAT modeling and analysis in some applications today.

Calculations were performed using Monte Carlo N-Particle, MCNP-6.1, [Goorley 2013] with ENDF/B-VII.1 nuclear data libraries [Chadwick 2011]. Sufficient neutron histories were utilized to reduce the Monte Carlo statistical uncertainty to 0.00002 Δk (2 pcm). Additional uncertainty parameter scaling was used to reduce the uncertainty in the calculated reactivities, $\rho(\Delta k/k)$, to $\leq$ 1 pcm. A sample input deck is provided, as an example, in Appendix A. The input deck is not recommended, nor has it been thoroughly vetted, for use in TREAT sample calculations, validation, or core neutronics analyses.

It should be noted, to address the partial graphitization aspect of the graphite-urania fuel, the carbon nuclear data library, 6000.80c, was duplicated to create a second carbon cross section file, 6002.80c. The graphite thermal scattering data was only applied to the original carbon nuclear data file, which represented 59 % of the carbon atoms in the graphite-urania.

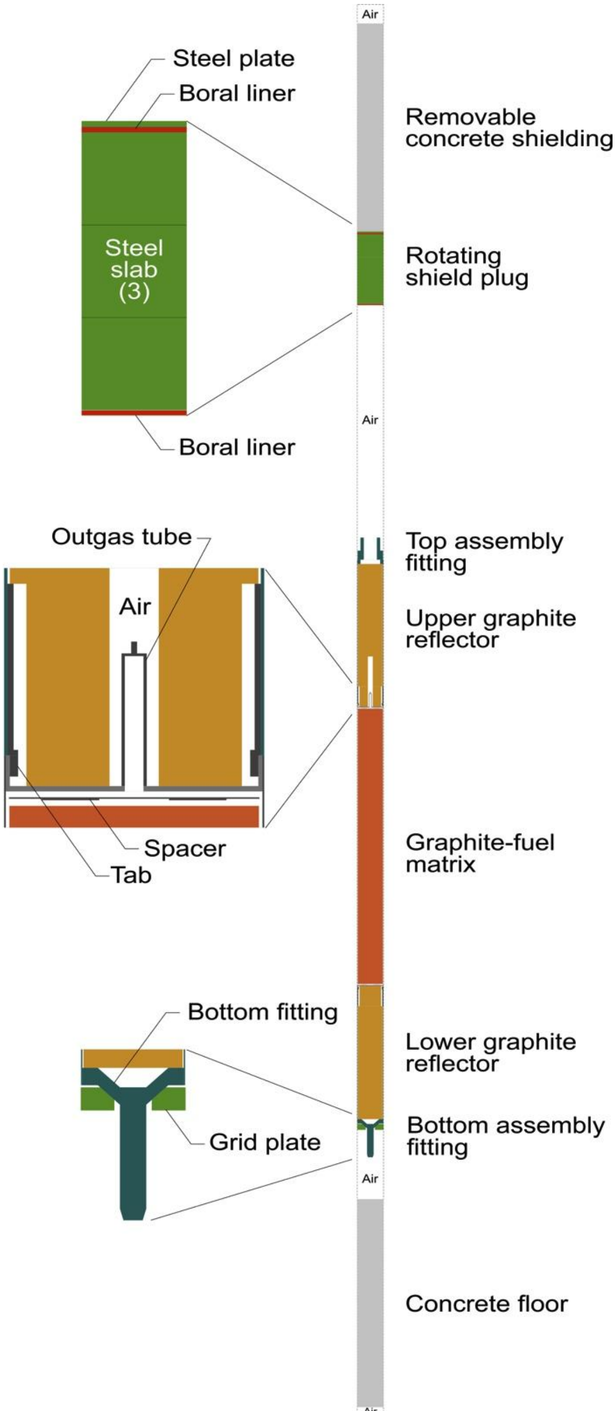


Figure 4.1. Diagram of TREAT Fuel, Support Structure, and Shielding as Implemented in Infinite Lattice Calculations.

4.2 Example Bias Assessment

The k_∞ value for the infinite lattice calculation is 1.44057 ± 0.00002. As expected, the typical neutronic leakage exhibited in the finite TREAT core configuration is neglected in an infinite lattice assessment. Table 4.1 provides a summary of the calculated reactivity worth for various simplifications applied to the infinite lattice configuration. Components of the fuel assembly lattice of most worth include metal structures of significant mass, such as aluminum reflector cans and Zr-3 materials. Because of the very thermal spectrum of the TREAT core, even the removal of trace impurities found in various components and the presence of air can impact computational analyses.

Removal of components beyond the axial graphite reflectors demonstrated very little reactivity impact on the lattice calculations. It is expected that removal of assembly adapters, core support structure, and shielding from eigenvalue calculations would similarly be negligible. However, calculation of other reactor physics parameters, such as neutron detection response of the ion chambers used for measuring core power (found in the concrete shielding surrounding the core), would not be possible without inclusion of the concrete superstructure.

The impact of the boron content in the graphite fuel is of the most significance and should be further investigated. Initial discrepancies between fabrication, design, and reactor physics analysis for the initial criticality measurements indicated accidental introduction of boron into the graphite fuel during the baking process, typically reported as 7.6 ppm [Iskenderian 1960]. Reevaluation of the initial impurity measurements results in a mean average content of 5.90 ± 0.35 ppm, which is similar to another previously reported value of 6 ppm for TREAT fuel [Freund 1960]. Additional test experiments demonstrated that the boron impurity ingress was not uniform through the fuel block [Iskenderian 1960]. Modern-day measurements of various layers from a cored HEU fuel block would be extremely valuable in characterization of the impurity content and distribution within the existing TREAT fuel.

Table 4.1. Effective Bias for Changes to the Infinite Lattice Fuel Assemblies.

Simulated Bias	**ρ(Δk/k) [pcm]**
Remove Air (i.e. replace with void)	53
Remove Al-6063 Reflector Cans	1,260
Remove Al-1100 Top Adapter	-12
Remove Al-1100 Bottom Adapter	-2
Remove Mild Steel Grid Plate	30
Remove Zr-3 Cans	3,339
Remove Zr-3 End Caps	287
Remove Zr-3 Spacers	46
Remove Zr-3 Assembly Tabs	296
Remove Zr-3 Outgas Tube	8
Remove CP-2 Outgas Tube Hole	16
Remove CP-2 Trace Impurities	26
Remove CP-2 All Impurities	98
Remove CP-2 Adsorbed Air	28
Remove Graphite-Fuel Fe Impurity	280
Remove Graphite-Fuel V Impurity	30
Increase Graphite-Fuel B Content to 7.6 ppm	-1,200
Remove Concrete Floor	-7
Remove Rotating Shield	33
Remove Removable Concrete Shielding	0
Remove All Shielding	-8

4.3 Example Uncertainty Evaluation

Uncertainties were evaluated via direct perturbation for many of the standard fuel assembly components to demonstrate sensitivities to various component geometric and compositional factors. Whereas the removal of some components, such as the core support grid plate and shielding materials, demonstrated a small computational bias, perturbation uncertainties for these components were not performed. It would be expected that any uncertainties and sensitivities in these components would be of the same order of magnitude or smaller than their respective evaluated biases. A summary of the uncertainty analysis is provided in Table 4.2.

Many of the uncertainties were available as either a tolerance or range and treated as either a normal distribution or bounding distribution with uniform probability (i.e. divided by 3 or $\sqrt{3}$, respectively). Uncertainties for many of the geometries were obtained from drawings in Section 2. Uncertainties in the material properties were obtained when evaluating the baseline properties provided in Section 3. It is believed that uncertainties due to air properties would be relatively small, as a direct perturbation of 10 % in the air density produced an almost negligible result.

The total uncertainty in the infinite lattice model of standard HEU TREAT fuel assemblies is ~500 pcm. All uncertainties were treated as 100 % systematic with no reduction for perturbation of the number of assemblies or assembly components. The calculated results are more qualitative than quantitative when comparing the infinite lattice study versus a benchmark evaluation of an actual TREAT core loading. While the computed values will definitely be different, the primary uncertainty factors demonstrated in this study would be expected to similarly dominate fuel assembly uncertainties in an evaluation of an actual TREAT core.

Table 4.2. Evaluated Uncertainties for TREAT HEU Standard Fuel Assemblies in Infinite Lattices.

Parameter	Nominal Value	±1σ Uncertainty	ρ(Δk/k) [pcm]
U-234 Content in Graphite Fuel (wt.%)	0.910	0.01	-1
U-235 Content in Graphite Fuel (wt.%)	93.239	0.05	8
U-236 Content in Graphite Fuel (wt.%)	0.438	0.01	-1
O:U Ratio in Graphite Fuel	2.00	0.05 ÷ √3	1
Graphite Fuel Fe Content (wt.%)	0.0267	0.01335 ÷ 3	-22
Graphite Fuel V Content (wt.%)	0.003	0.0015 ÷ 3	-5
Graphite Fuel B Content (ppm)	5.9	0.35	-243
U Mass Content in Fuel (wt.%)	0.211	(0.205 to 0.222) ÷ √3	308
Density of Graphite Fuel (g/cm^3)	1.73	(1.71 to 1.76) ÷ √3	153
Graphite Fuel Graphitization (%)	59	1 ÷ √3	-4
Height of Graphite Fuel (in.)	48-1/8	1/64 ÷ 3	2
Flat-to-Flat Distance of Graphite Fuel (in.)	3.800	(-0.00, +0.02) ÷ 3	7
Al 6063 Composition (wt.% Al)	98.425	(97.5 to 99.35) ÷ √3	-51
Al 6063 Density (g/cm^3)	2.685	0.01	-4
Al 6063 Can Thickness (in.)	0.050	1/64 ÷ 3	-56
Al 6063 Flat-to-Flat Can Distance (in.)	3.960	0.025 ÷ 3	-11
Al 1100 Composition (wt.% Al)	99.25	(98.55 to 99.95) ÷ √3	-15
Al 1100 Density (g/cm^3)	2.71	0.01	0
Al 1100 Component Dimensions	--	Assumed Negligible	0
Zr-3 Composition (wt.% Zr)	99.291	(99.242 to 99.340) ÷ 2	-16
Zr-3 Density (g/cm^3)	6.53	0.01	-6
Zr-3 Can Thickness (in.)	0.025	1/64 ÷ 3	-242
Zr-3 End Cap Thickness (in.)	3/32	1/64 ÷ 3	-11
Zr-3 Assembly Tab Thickness (in.)	3/32	1/64 ÷ 3	-15
Zr-3 Spacers Thickness (in.)	0.025	1/64 ÷ 3	-3
Zr-3 Flat-to-Flat Can Distance (in.)	3.960	0.025 ÷ 3	-7
Zr-3 Outgas Tube Dimensions (in.)	--	Assumed Negligible	0
CP-2 Composition (wt.% C)	99.933	(99.941 to 99.925) ÷ 2	-6
CP-2 Water Content (wt.%)	0.02	0.01	-7
CP-2 Density (g/cm^3)	1.67	0.02	24
CP-2 Height (in.)	24-11/16 Top 23-5/32 Bottom	1/64 ÷ 3	1
CP-2 Flat-to-Flat Distance (in.)	3.780	1/64 ÷ 3	12
CP-2 Outgas Tube Hole Dimensions (in.)	--	Assumed Negligible	0
Air Density (g/cm^3)	0.0012	Assumed 10 %	-3
Air Composition/Temperature/Humidity	--	Assumed Negligible	0
Concrete Parameters	--	Assumed Negligible	0
Rotating Shield Parameters	--	Assumed Negligible	0
Core Support Grid Plate Parameters	--	Assumed Negligible	0
Total	**--**	**--**	**495**

4.4 Conclusions Drawn from Analysis

An infinite lattice model of standard HEU TREAT fuel assemblies was developed to perform a preliminary assessment of bias and uncertainty sensitivities of various components prior to development of formal benchmark evaluations of TREAT experimental data. A summary of key results are provided in this section to indicate materials with the most importance when investigating biases and uncertainties in actual TREAT core models.

As data recovery from historical TREAT reports continues, the parameters and uncertainties governing simulation of TREAT reactor components will be refined. Additional measurements of TREAT components using modern methods can significantly improve the quality of our understanding of current TREAT design for use in modeling and simulation methods to support restart, operation, experimentation design, and conversion activities.

5. FUTURE WORK

This report is a first attempt to collect various drawings, reports and design information into a single document to serve as a reference for future work. With respect to TREAT, much future work remains. The following subsections briefly describe future work that is anticipated to build on top of the data that has been provided here. These applications are somewhat inter-related but all are expected to rely heavily on the information provided herein.

5.1 Benchmark Evaluation Development

The U.S. Department of Energy Office of Nuclear Energy is currently funding the development of a number of university-based benchmark evaluations under the Nuclear Energy University Program. These evaluations will focus on specific core configurations and measurements, and will rely on information provided for each of those configurations (core configuration, rod locations, and both steady state and transient data). Information of that nature is not provided in this report; however, those benchmarks will certainly rely on the contents of this report, including references, in development of appropriate benchmarks.

In addition, the Nuclear Energy Agency (NEA) of the Organization for Economic Cooperation and Development (OECD) has formed an Expert Group on Multi-Physics Experimental Data, Benchmarks and Validation (EGMPEBV) to begin the process (among other tasks) of identifying data appropriate for true multi-physics benchmarking. Much of that effort will be based on past and future measurement at both TREAT and the CABRI facility in France [OECD-NEA 2015]. This document will be an invaluable resource in the evaluation of the suitability of TREAT for development of such benchmarks.

5.2 Core Restart Data

This document is based entirely on historical data. The information provided here will no doubt be of value in the current efforts to prepare the core for low power startup testing and ultimately for transient testing and operations. However, it is anticipated that these selfsame tests will be accompanied by detailed core measurements. The nature of these data is not yet known, but it is hoped that detailed flux, spectrum and temperature data will be provided. Such data is beyond the scope of this report, but will be of significant value in benchmarking efforts.

5.3 LEU Conversion

Because TREAT's core currently contains HEU, the Reduced Enrichment for Research and Test Reactors (RERTR), in anticipation of restart of TREAT, is funding research and development efforts to determine the feasibility and design modifications for converting the core to use fuel containing only LEU, enriched to <20% ^{235}U. Staff at ANL are responsible for design of an LEU-fueled alternative design for TREAT. ANL has led efforts to update the core analysis approach and validate these methods against documented experiments, and ultimately will use the new approach for evaluation of proposed LEU core designs. INL is modeling TREAT neutronics using an independent approach, in collaboration with ANL. In general, independent analyses have been in reasonable agreement; however, differences in models have been found to be due to differences in assumptions (for lack of data), selection of inconsistent data between different reports, or in different interpretations of descriptions. This document will provide a common reference that can be used in independent modeling efforts and for development of a subset of benchmarks needed to verify that codes being used for HEU fuel could also be reasonably expected to represent LEU physics in potential low-enrichment designs.

5.4 Experiment Design and Simulation

While transient testing is not expected to resume until the 2018-2020 timeframe, experiment vessels and experiments themselves are currently being designed so that they are ready to go when the reactor is ready to accept them. Because these designs are based on the static and dynamic performance of TREAT during a transient pulse, design calculations rely on accurate core models. Development of such models to date has seen the same issues as noted previously – difficulty in finding data over a broad set of historical documents, incomplete data and inconsistent specifications, resulting in the need to make assumptions that are not necessarily consistent with other work. This report provides what is hoped to be a complete, consistent and accurate representation of TREAT physical data.

6. CONCLUSIONS

This report provides the most comprehensive collection of compositions, drawings and descriptions available for a detailed description of TREAT. Early design documents provided enough information to understand the base TREAT design, and subsequent reports provided information about changes to the core in support of different missions. But no document has been assembled to date that provides data on the level needed for benchmark modeling. It is a best estimate physical description of TREAT and the various element types that are present in the core, have been used in the core previously, and that are presently available for potential future configurations. It provides drawings and tables pulled from various sources with all references listed. However, in the case of conflicting information, an assessment of conflicting information was made, as described in the report, and engineering judgment was used to assist in the resolution of such contradictory information.

This report is not a benchmark specification. It is not an attempt to specify a specific core configuration and perform as assessment of the ability to model that core with sensitivity and uncertainty evaluations. It does not make recommendations on approximations that may be made in modeling a given core configuration. This is left to the developer of a specific benchmark or for the preparation of a model of TREAT for other analysis needs. This report provides physical data to be used in the development of benchmarks and evaluation of benchmark sensitivities and uncertainties. An example evaluation of sensitivities and uncertainties in a fuel model is also supplied, but this is furnished for illustrative purposes only. Such parameters are always dependent on a number of factors, not the least of which are the core model and control rod locations, neither of which is provided in those examples.

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APPENDIX A:

Sample MCNP Input Deck for Infinite Fuel Lattice

This is a sample input deck and is provided as an example. This input deck is not recommended, nor has it been thoroughly vetted, for use in TREAT sample calculations, validation, or core neutronics analyses. Geometries and material properties are similar to, but not identical to, those provided in Sections 2 and 3 of this baseline report summary.

```
Infinite TREAT Fuel Lattice
c
c John Darrell Bess - Idaho National Laboratory
c Last Updated: November 24, 2014
c
c Notes ***********************************************************************
c
c
c
c
c ****************************************************************************
c
c Cell Cards ******************************************************************
c
c --- Control Rod Vertical Positions -------------------------------------------
c
c * Control Rods are fully inserted when the values in parenthesis are (0 0 0) *
c * Control Rods are fully withdrawn when the values are (0 0 38.1), which     *
c * corresponds to 1000 units withdrawn                                        *
c
c --- Assemblies ---------------------------------------------------------------
c ------ Empty Position ------                                            ------
c 1
c 2
c
c ------ Lead Shielding Assembly ------                                   ------
c 10000
c
c ------ Standard Fuel Assembly ------                                    ------
c 11000 1 5.0820E-05    -1108 -1109 1000 -70011  u=1 imp:n=1 $ Upper Air Space
c 11001 1 5.0820E-05    (1513 -1108 -1109 1001 -1000):
c                       (1002 -1001 -1108 -1109 1511)  u=1 imp:n=1  $ Air Gap
c 11002 1 5.0820E-05    (-1513 1005 -1004):(1004 -1000 -1512):
c                       (1512 -1515 -1513 1004 -1002)  u=1 imp:n=1  $ Air Gap
91002 1 5.0820E-05    1005 -1004 -1513  u=1 imp:n=1  $ Air Gap
11003 100 6.0308E-02  (1513 -1106 -1107 1005 -1004)  u=1 imp:n=1  $ Upper Fitting
91003 100 6.0308E-02  (1004 -1000 1512 -1513)  u=1 imp:n=1  $ Upper Fitting
92003 100 6.0308E-02  (1513 -1116 -1117 -1002 1004)  u=1 imp:n=1  $ Upper Fitting
11004 101 5.9803E-02  (1106:1107) -1108 -1109 1013 -1004  u=1 imp:n=1 $ Upper Al Can
11005 1 5.0820E-05    (((1101:1102) -1106 -1107 -1005 1007):
                      (-1106 -1107 1103 -1007 1013):
                      (-1114 -1115 1103 1015 -1013))
                      #11010 #11011 #11012 #11013  u=1 imp:n=1  $ Air Gap
11006 500 8.3734E-02  ((1015 -1007 -1103):
                      (-1101 -1102 1007 -1005))
                      (1502:1006)  u=1 imp:n=1 $ Upper Graphite Reflector
11007 1 5.0820E-05  (-1502 1015 -1006 1501):(1099 -1006 -1501 (-1212:1213)):
                    (1212 -1213 -1501 1010 -1006)  u=1 imp:n=1 $ Outgas Tube Hole
11008 0  -1500 1016 -1011  u=1 imp:n=1  $ Inside Outgas Tube
11009 201 4.3469E-02  (1500 -1501 1015 -1011):(1011 -1099 -1501):
                      (-1501 1099 -1010 1212 -1213)  u=1 imp:n=1 $ Outgas Tube
11010 201 4.3469E-02  (-1114 -1215 1216 -1217 1014 -1013):
```

```
                      (-1106 -1215 1216 -1217 1013 -1098):
                      (-1106 -1214 1216 -1217 1098 -1012):
                      (-1106 -1214 -1218 -1219 1012 -1008):
                      (-1106 -1214 1008 -1503) -1007  u=1 imp:n=1 $ Upper Tab 1
11011 201 4.3469E-02  (-1114  1221 1216 -1217 1014 -1013):
                      (-1106  1221 1216 -1217 1013 -1098):
                      (-1106  1220 1216 -1217 1098 -1012):
                      (-1106  1220 -1218 -1219 1012 -1008):
                      (-1106  1220 1008 -1503) -1007  u=1 imp:n=1 $ Upper Tab 2
11012 201 4.3469E-02  (-1114 -1225 1226 -1227 1014 -1013):
                      (-1106 -1225 1226 -1227 1013 -1098):
                      (-1106 -1224 1226 -1227 1098 -1012):
                      (-1106 -1224 -1222 -1223 1012 -1008):
                      (-1106 -1224 1008 -1504) -1007  u=1 imp:n=1 $ Upper Tab 3
11013 201 4.3469E-02  (-1114  1229 1226 -1227 1014 -1013):
                      (-1106  1229 1226 -1227 1013 -1098):
                      (-1106  1228 1226 -1227 1098 -1012):
                      (-1106  1228 -1222 -1223 1012 -1008):
                      (-1106  1228 1008 -1504) -1007  u=1 imp:n=1 $ Upper Tab 4
11014 201 4.3469E-02  1500 (1016 -1015 -1110 -1111):
                      ((1114:1115) -1110 -1111 1016 -1013)  u=1 imp:n=1 $ Upper Endcap
11015 0  1018 -1016 (1017:-1200:1201:-1202:1203) -1110 -1111
                    (1017:-1200:1201:-1204:1205)  u=1 imp:n=1 $ Top Void of Upper Spacer Region
11016 201 4.3469E-02  1018 -1017 1200 -1201 1202 -1203  u=1 imp:n=1 $ Top of Upper Spacer #1
11017 201 4.3469E-02  1018 -1017 1200 -1201 1204 -1205  u=1 imp:n=1 $ Top of Upper Spacer #2
11018 201 4.3469E-02  1019 -1018 1206 -1207 1208 -1209  u=1 imp:n=1 $ Bottom of Upper Spacer #1
11019 201 4.3469E-02  1019 -1018 1206 -1207 1210 -1211  u=1 imp:n=1 $ Bottom of Upper Spacer #2
11020 0  1020 -1018 (-1019:-1206:1207:-1208:1209) -1110 -1111
                    (-1019:-1206:1207:-1210:1211)  u=1 imp:n=1 $ Bottom Void of Upper Spacer
Region
11021 501 8.6541E-02  -1020 1021 -1104 -1105  u=1 imp:n=1  $ Graphite Fuel
11022 0  -1020 1021 (1104:1105) -1110 -1111  u=1 imp:n=1   $ Void (Fuel/Clad Gap)
11023 0  1023 -1021 (1022:-1200:1201:-1202:1203) -1110 -1111
                    (1022:-1200:1201:-1204:1205)  u=1 imp:n=1 $ Top Void of Lower Spacer Region
11024 201 4.3469E-02  1023 -1022 1200 -1201 1202 -1203  u=1 imp:n=1 $ Top of Lower Spacer #1
11025 201 4.3469E-02  1023 -1022 1200 -1201 1204 -1205  u=1 imp:n=1 $ Top of Lower Spacer #2
11026 201 4.3469E-02  1024 -1023 1206 -1207 1208 -1209  u=1 imp:n=1 $ Bottom of Lower Spacer #1
11027 201 4.3469E-02  1024 -1023 1206 -1207 1210 -1211  u=1 imp:n=1 $ Bottom of Lower Spacer #2
11028 0  1025 -1023 (-1024:-1206:1207:-1208:1209) -1110 -1111
                    (-1024:-1206:1207:-1210:1211)  u=1 imp:n=1 $ Bottom Void of Lower Spacer
Region
11029 201 4.3469E-02  (1110:1111) -1112 -1113 1028 -1013 u=1 imp:n=1  $ Zr-3 Can
11030 201 4.3469E-02  (1026 -1025 -1110 -1111):
                      ((1114:1115) -1110 -1111 1028 -1026)  u=1 imp:n=1 $ Lower Endcap
11031 201 4.3469E-02  (-1114 -1215 1216 -1217 -1027 1028):
                      (-1106 -1215 1216 -1217 -1028 1097):
                      (-1106 -1214 1216 -1217 -1097 1029):
                      (-1106 -1214 -1238 -1239 -1029 1031):
                      (-1106 -1214 -1031 -1505) 1032  u=1 imp:n=1 $ Lower Tab 1
11032 201 4.3469E-02  (-1114  1221 1216 -1217 -1027 1028):
                      (-1106  1221 1216 -1217 -1028 1097):
                      (-1106  1220 1216 -1217 -1097 1029):
                      (-1106  1220 -1238 -1239 -1029 1031):
                      (-1106  1220 -1031 -1505) 1032  u=1 imp:n=1 $ Lower Tab 2
11033 201 4.3469E-02  (-1114 -1225 1226 -1227 -1027 1028):
                      (-1106 -1225 1226 -1227 -1028 1097):
                      (-1106 -1224 1226 -1227 -1097 1029):
                      (-1106 -1224 -1240 -1241 -1029 1031):
                      (-1106 -1224 -1031 -1506) 1032  u=1 imp:n=1 $ Lower Tab 3
11034 201 4.3469E-02  (-1114  1229 1226 -1227 -1027 1028):
                      (-1106  1229 1226 -1227 -1028 1097):
                      (-1106  1228 1226 -1227 -1097 1029):
                      (-1106  1228 -1240 -1241 -1029 1031):
                      (-1106  1228 -1031 -1506) 1032  u=1 imp:n=1 $ Lower Tab 4
11035 500 8.3734E-02  ((1032 -1026 -1103):
                      (-1101 -1102 1033 -1032))  u=1 imp:n=1 $ Lower Graphite Reflector
11036 1 5.0820E-05    (((1101:1102) -1106 -1107 1033 -1032):
                      (-1106 -1107 1103 1032 -1028):
                      (-1114 -1115 1103 1028 -1026))
                      #11031 #11032 #11033 #11034  u=1 imp:n=1  $ Air Gap
11037 101 5.9803E-02  (1106:1107) -1108 -1109 1034 -1028  u=1 imp:n=1 $ Lower Al Can
```

```
11038 100 6.0308E-02  (1034 -1033 -1106 -1107 1507):(1036 -1034 -1508 1507):
                      (1037 -1035 -1509):(1038 -1037 -1510)  u=1 imp:n=1 $ Bottom Fitting
11039 1 5.0820E-05    1035 -1033 -1507  u=1 imp:n=1  $ Air Gap
c
11100 301 8.5418E-02  (56500:56002) (-56000 56001
                       56501 56502 56503 56504 56505)  u=1 imp:n=1 $ Grid Plate (Standard
Assembly)
11101 1 5.0820E-05    -56000 56001 -56501  u=1 imp:n=1 $ Coolant Hole
11102 1 5.0820E-05    -56000 56001 -56502  u=1 imp:n=1 $ Coolant Hole
11103 1 5.0820E-05    -56000 56001 -56503  u=1 imp:n=1 $ Coolant Hole
11104 1 5.0820E-05    -56000 56001 -56504  u=1 imp:n=1 $ Coolant Hole
11105 1 5.0820E-05    56000 -1034 1508  u=1 imp:n=1 $ Assembly/Grid Air Gap
11106 1 5.0820E-05    56001 -56500 56505 1509  u=1 imp:n=1 $ Air Gap
c
11998 1 5.0820E-05  ((1112:1113) -1013 1028)  u=1 imp:n=1 $ Air Around Assembly
91998 1 5.0820E-05  ((1108:1109) -1028) 1034  u=1 imp:n=1 $ Air Around Assembly
92998 1 5.0820E-05  ((1108:1109) 1013) -1004  u=1 imp:n=1 $ Air Around Assembly
93998 1 5.0820E-05  1004 -70011 #91003 #92003   u=1 imp:n=1 $ Air Around Assembly
11999 1 5.0820E-05  -56001 (1509:1510:-1038) 75000 u=1 imp:n=1  $ Air Below Assembly
c
c ------ Fuel Thermocouple Assembly ------                              ------
c 12000
c
c ------ Mid Fuel, Reflector and Skin Thermocouple Assembly ------        ------
c 13000
c
c ------ Transient Thermocouple Assembly ------                          ------
c 14000
c
c ------ 24" Access Hole Fuel Assembly ------                            ------
c 15000
c
c ------ 24" Access Hole Thermocouple Fuel Assembly ------               ------
c 16000
c
c ------ Control Rod Fuel Assembly ------                                ------
c 21000
c
c ------ Vertical Access Hole Fuel Assembly ------                       ------
c 22000
c
c ------ Zr-Clad Dummy Fuel Assembly ------                              ------
c 31000
c
c ------ 24" Access Hole Dummy Fuel Assembly ------                      ------
c 32000
c
c ------ 48" Access Hole Dummy Assembly ------                           ------
c 33000
c
c ------ Al-Clad Dummy Assembly ------                                   ------
c 34000
c
c ------ Control Rod Dummy Fuel Assembly ------                          ------
c 35000
c
c ------ Source Dummy Fuel Assembly ------                               ------
c 36000
c
c ------ Vertical Access Hole Dummy Assembly ------                      ------
c 37000
c
c ------ 48" Access Hole Dummy Half-Assembly ------                      ------
c 41000
c
c ------ Zr-Clad Dummy Half-Assembly ------                              ------
c 42000
c
c ------ Zr-Clad Dummy 3/4-Assembly ------                               ------
c 43000
c
```

```
c --- TREAT Reactor Core ------------------------------------------------------
c ------ Core Map ------
c 50000
c
c ------ Core Map Legend ------
c
c ------ Core Map Positions ------
c
c    Note: Visual Core Map is Mirrored Vertically Compared to Actual Positions
c
c --- Permanent Reflector -----------------------------------------------------
c 53000
c
c --- Support Structure -------------------------------------------------------
c 56000
c
c --- Experimental Facilities -------------------------------------------------
c 60000
c
c --- Reactor Shielding -------------------------------------------------------
c ------ Rotating Shield Plug ------                                   ------
70000 1 5.0820E-05     70000        u=1 imp:n=1 $ Air Above Removable Shielding
70001 900 9.6208E-02  -70000 70001  u=1 imp:n=1 $ Removable Concrete Shielding Blocks
70002 301 8.5418E-02  -70001 70002  u=1 imp:n=1 $ Steel Plate
70003 100 6.0308E-02  -70002 70003  u=1 imp:n=1 $ Aluminum Sheet
70004 901 9.2783E-02  -70003 70004  u=1 imp:n=1 $ Boral
70005 100 6.0308E-02  -70004 70005  u=1 imp:n=1 $ Aluminum Sheet
70006 301 8.5418E-02  -70005 70008  u=1 imp:n=1 $ Steel Sheets
70007 100 6.0308E-02  -70008 70009  u=1 imp:n=1 $ Aluminum Sheet
70008 901 9.2783E-02  -70009 70010  u=1 imp:n=1 $ Boral
70009 100 6.0308E-02  -70010 70011  u=1 imp:n=1 $ Aluminum Sheet
c
75000 900 9.6208E-02  -75000 75001  u=1 imp:n=1 $ Concrete Shielding
75001 1 5.0820E-05    -75001        u=1 imp:n=1 $ Air Below Concrete Shielding
c
c --- Model Boundary ----------------------------------------------------------
c 99999
90000 1 5.0820E-05 -1100  imp:n=1 u=2 lat=1  fill=-2:2 -2:2 0:0
      1 1 1 1 1
      1 1 1 1 1
      1 1 1 1 1
      1 1 1 1 1
      1 1 1 1 1
90001 1 5.0820E-05 6 -5 7 -8 9 -10 imp:n=1 fill=2
90002 0 -6:5:-7:8:-9:10 imp:n=0
c
c ****************************************************************************
c Surface Cards **************************************************************
c
c --- Basics ------------------------------------------------------------------
1     px 0.0
2     py 0.0
3     pz 0.0  $ Fuel/Core Midplane
c
5     pz 370
6     pz -250
*7     px -15.24
*8     px 15.24
*9     py -15.24
*10    py 15.24
c
c --- Primary Assembly Dimensions ---------------------------------------------
c ------ Horizontal Planes --------
1000  pz   135.651875  $ Top of Assembly
1001  pz   133.111875  $ Top Fitting Plane #1
1002  pz   129.936875  $ Top Fitting Plane #2
1003  pz   127.396875  $ Top Fitting Plane #3
1004  pz   125.968125  $ Top of Aluminum Can / Top Fitting Plane #4
1005  pz   124.063125  $ Top of Graphite Reflector / Top Fitting Plane #5
1006  pz    83.423125  $ Top of Outgas Tube Hole
```

```
1007  pz    70.4301825  $ Transition to/from Graphite Square
1008  pz    70.1675    $ Near Tip of Tab
1009  pz    67.78625   $ Tip of Expansion Slot
1010  pz    67.706875  $ Tip of Pinched Tube
1099  pz    67.186175  $ Model Simplification for Pinched Outgas Tube
1011  pz    67.071875  $ Top of Outgas Tube
1012  pz    64.29375   $ Square of Tab
1098  pz    62.944375  $ Model Simplification for Bend in Tabs
1013  pz    62.70625   $ Top of Zircaloy Can / Bottom of Aluminum Can
1014  pz    61.75375   $ Base of Tab
1015  pz    61.356875  $ Outside of Upper Endcap / Bottom of Graphite Reflector
1016  pz    61.11875   $ Top of Upper Spacer Region / Inside of Upper Endcap
1017  pz    60.86475   $ Top Surface of Upper Spacer
1018  pz    60.80125   $ Middle of Upper Spacer
1019  pz    60.73775   $ Bottom Surface of Upper Spacer
1020  pz    60.48375   $ Top of Fuel / Bottom of Upper Spacer Region
1021  pz   -60.48375   $ Bottom of Fuel / Top of Lower Spacer Region
1022  pz   -60.73775   $ Top Surface of Lower Spacer
1023  pz   -60.80125   $ Middle of Lower Spacer
1024  pz   -60.86475   $ Bottom Surface of Lower Spacer
1025  pz   -61.11875   $ Bottom of Lower Spacer Region / Inside of Lower Endcap
1026  pz   -61.356875  $ Outside of Lower Endcap / Top of Graphite Reflector
1027  pz   -61.75375   $ Base of Tab
1028  pz   -62.70625   $ Bottom of Zircaloy Can / Top of Aluminum Can
1097  pz   -62.944375  $ Model Simplification for Bend in Tabs
1029  pz   -64.29375   $ Square of Tab
1030  pz   -67.78625   $ Tip of Expansion Slot
1031  pz   -70.1675    $ Near Tip of Tab
1032  pz   -70.4301825  $ Transition to/from Graphite Square
1033  pz  -119.935625  $ Bottom of Graphite Reflector / Top of Bottom Fitting
1034  pz  -121.840625  $ Bottom of Aluminum Can / Bottom Fitting Plane #1
1035  pz  -122.07875   $ Bottom Fitting Plane #2
1036  pz  -123.98375   $ Bottom Fitting Plane #3
1037  pz  -135.41375   $ Bottom Fitting Plane #4
1038  pz  -136.68375   $ Bottom of Assembly
c
c ------ Vertical Planes ------
1100  rpp    -5.08 5.08 -5.08 5.08 -300 400  $ Core Assembly Pitch
c
1101  rpp    -4.8006 4.8006 -4.8006 4.8006 -300 400  $ Graphite Reflectors
1102  1 rpp  -6.020723628 6.020723628 -6.020723628 6.020723628 -300 400  $ Graphite Reflectors
Chamfer
1103  rpp    -4.1656 4.1656 -4.1656 4.1656 -300 400  $ Graphite Reflectors Square
1104  rpp    -4.826 4.826 -4.826 4.826 -300 400  $ Graphite Fuel
1105  1 rpp  -6.047754652 6.047754652 -6.047754652 6.047754652 -300 400  $ Graphite Fuel Chamfers
1106  rpp    -4.9022 4.9022 -4.9022 4.9022 -300 400  $ Aluminum Cans Inside
1107  1 rpp  -6.191612848 6.191612848 -6.191612848 6.191612848 -300 400  $ Aluminum Cans Inside
Chamfer
1108  rpp    -5.0292 5.0292 -5.0292 5.0292 -300 400  $ Aluminum Cans Outside
1109  1 rpp  -6.318612848 6.318612848 -6.318612848 6.318612848 -300 400  $ Aluminum Cans Outside
Chamfer
1110  rpp    -4.9657 4.9657 -4.9657 4.9657 -300 400  $ Zirconium Cans Inside
1111  1 rpp  -6.255112848 6.255112848 -6.255112848 6.255112848 -300 400  $ Zirconium Cans Inside
Chamfer
1112  rpp    -5.0292 5.0292 -5.0292 5.0292 -300 400  $ Zirconium Cans Outside
1113  1 rpp  -6.318612848 6.318612848 -6.318612848 6.318612848 -300 400  $ Zirconium Cans Outside
Chamfer
1114  rpp    -4.727575 4.727575 -4.727575 4.727575 -300 400  $ Zirconium Endcaps Inside
1115  1 rpp  -6.016987848 6.016987848 -6.016987848 6.016987848 -300 400  $ Zirconium Endcaps
Inside Chamfer
1116  rpp    -5.08 5.08 -5.08 5.08 -300 400  $ Top Fitting Outside
1117  1 rpp  -6.390454897 6.390454897 -6.390454897 6.390454897 -300 400  $ Top Fitting Outside
Chamfer
1118  rpp    -4.445 4.445 -4.445 4.445 -300 400  $ Top Fitting Inside
1119  1 rpp  -5.120454897 5.120454897 -5.120454897 5.120454897 -300 400  $ Top Fitting Inside
Chamfer
c
1200  px    -4.841875  $ Spacer Length
1201  px     4.841875  $ Spacer Length
1202  py    -3.571875  $ Spacer Outer Edge
1203  py    -1.349375  $ Spacer Inner Edge
```

```
1204  py     1.349375  $ Spacer Inner Edge
1205  py     3.571875  $ Spacer Outer Edge
1206  py    -4.841875  $ Spacer Length
1207  py     4.841875  $ Spacer Length
1208  px    -3.571875  $ Spacer Outer Edge
1209  px    -1.349375  $ Spacer Inner Edge
1210  px     1.349375  $ Spacer Inner Edge
1211  px     3.571875  $ Spacer Outer Edge
1212  px    -0.1143    $ Pinched Outgas Tube
1213  px     0.1143    $ Pinches Outgas Tube
1214  px    -4.664075  $ Inner Surface Tab Against Zr Clad
1215  px    -4.48945   $ Inner Surface Tab Against Zr Endcap
1216  py    -3.4925    $ Tab Base Width
1217  py     3.4925    $ Tab Base Width
1218  p      -4.48945 -3.4925 64.29375  -4.664075 -3.4925 64.29375
             -4.664075 -0.7235 69.9135  $ Side Angle of Tab
1219  p      -4.48945 3.4925 64.29375  -4.664075 3.4925 64.29375
             -4.664075 0.7235 69.9135  $ Side Angle of Tab
1220  px     4.664075  $ Inner Surface Tab Against Zr Clad
1221  px     4.48945   $ Inner Surface Tab Against Zr Endcap
1222  p      -3.4925 -4.48945 64.29375  -3.4925 -4.664075 64.29375
             -0.7235 -4.664075 69.9135  $ Side Angle of Tab
1223  p      3.4925 -4.48945 64.29375  3.4925 -4.664075 64.29375
             0.7235 -4.664075 69.9135  $ Side Angle of Tab
1224  py    -4.664075  $ Inner Surface Tab Against Zr Clad
1225  py    -4.48945   $ Inner Surface Tab Against Zr Endcap
1226  px    -3.4925    $ Tab Base Width
1227  px     3.4925    $ Tab Base Width
1228  py     4.664075  $ Inner Surface Tab Against Zr Clad
1229  py     4.48945   $ Inner Surface Tab Against Zr Endcap
c
c Note: MCNP runs into errors when using the undercut planes.  While retained
c       for reference, they are not currently used in the models.  Because
c       of the large quantity of particles run, some particles get "lost"
c       during simulated transport.  Cause of error is currently unknown.
c
1230  p      -4.8006 -4.8006 70.61349  -4.8006 4.8006 70.61349
             -4.1656 -4.1656 70.24688  $ Upper Graphite Undercut
1231  p      -4.8006 -4.8006 70.61349  4.8006 -4.8006 70.61349
             -4.1656 -4.1656 70.24688  $ Upper Graphite Undercut
1232  p      4.8006 4.8006 70.61349  -4.8006 4.8006 70.61349
             4.1656 4.1656 70.24688  $ Upper Graphite Undercut
1233  p      4.8006 4.8006 70.61349  4.8006 -4.8006 70.61349
             4.1656 4.1656 70.24688  $ Upper Graphite Undercut
1234  p      -4.8006 -4.8006 -70.61349  -4.8006 4.8006 -70.61349
             -4.1656 -4.1656 -70.24688  $ Lower Graphite Undercut
1235  p      -4.8006 -4.8006 -70.61349  4.8006 -4.8006 -70.61349
             -4.1656 -4.1656 -70.24688  $ Lower Graphite Undercut
1236  p      4.8006 4.8006 -70.61349  -4.8006 4.8006 -70.61349
             4.1656 4.1656 -70.24688  $ Lower Graphite Undercut
1237  p      4.8006 4.8006 -70.61349  4.8006 -4.8006 -70.61349
             4.1656 4.1656 -70.24688  $ Lower Graphite Undercut
1238  p      -4.48945 -3.4925 -64.29375  -4.664075 -3.4925 -64.29375
             -4.664075 -0.7235 -69.9135  $ Side Angle of Tab
1239  p      -4.48945 3.4925 -64.29375  -4.664075 3.4925 -64.29375
             -4.664075 0.7235 -69.9135  $ Side Angle of Tab
1240  p      -3.4925 -4.48945 -64.29375  -3.4925 -4.664075 -64.29375
             -0.7235 -4.664075 -69.9135  $ Side Angle of Tab
1241  p      3.4925 -4.48945 -64.29375  3.4925 -4.664075 -64.29375
             0.7235 -4.664075 -69.9135  $ Side Angle of Tab
c
c Note: MCNP runs into errors when using the octa-edge planes.  While retained
c       for reference, they are not currently used in the models.  Because
c       of the large quantity of particles run, some particles get "lost"
c       during simulated transport.  Cause of error is currently unknown.
c
1242  p      -5.08 -1 127.396875 -5.08 1 127.396875 -3.81 -1 129.936875  $ Top Fitting Octa-edge
1243  p       5.08 -1 127.396875  5.08 1 127.396875  3.81 -1 129.936875  $ Top Fitting Octa-edge
1244  p      -1 -5.08 127.396875 1 -5.08 127.396875 -1 -3.81 129.936875  $ Top Fitting Octa-edge
1245  p       -1 5.08 127.396875  1 5.08 127.396875  -1 3.81 129.936875  $ Top Fitting Octa-edge
1246  p      -5.08 3.96875 127.396875 -3.96875 5.08 127.396875
```

```
             -3.62070938 3.62070938 129.936875  $ Top Fitting Octa-edge
1247  p      -5.08 -3.96875 127.396875 -3.96875 -5.08 127.396875
             -3.62070938 -3.62070938 129.936875  $ Top Fitting Octa-edge
1248  p      5.08 -3.96875 127.396875 3.96875 -5.08 127.396875
             3.62070938 -3.62070938 129.936875  $ Top Fitting Octa-edge
1249  p      5.08 3.96875 127.396875 3.96875 5.08 127.396875
             3.62070938 3.62070938 129.936875  $ Top Fitting Octa-edge
c
c ------ Radii ------
1500  cz     0.36195  $ Outgas Tube Inner Radius
1501  cz     0.47625  $ Outgas Tube Outer Radius
1502  cz     0.9525   $ Outgas Tube Hole
1503  c/x    0.0  69.43725 0.9525  $ Tab Tops
1504  c/y    0.0  69.43725 0.9525  $ Tab Tops
1505  c/x    0.0 -69.43725 0.9525  $ Tab Tops
1506  c/y    0.0 -69.43725 0.9525  $ Tab Tops
1507  kz  -123.34875 1 1  $ Inside Bottom Fitting Cone
1508  kz  -125.25375 1 1  $ Outside Bottom Fitting Cone
1509  cz     1.27    $ Rod of Bottom Fitting
1510  kz  -140.1534545 0.07179677 1  $ Tip of Bottom Fitting
1511  cz     3.175   $ Top Fitting Radius #1
1512  cz     2.54    $ Top Fitting Radius #2
1513  cz     3.81    $ Top Fitting Radius #3
c
c Note: MCNP was having difficulties with the conics of the top fitting.
c       Swapped with basic annulli.
c
1514  kz   148.351875 0.0625 -1  $ Tip of Top Fitting
1515  kz   134.699375 0.25 -1  $ Top Fitting Inner Conic Transition
c
c --- Shielding Assembly Dimensions -------------------------------------------
c
c --- Thermocouple Assembly Dimensions ----------------------------------------
c
c --- Access Hole Assembly Dimensions -----------------------------------------
c
c --- Control Rod Assembly Dimensions -----------------------------------------
c
c --- Dummy Assembly Dimensions -----------------------------------------------
c
c --- TREAT Reactor Core ------------------------------------------------------
c
c --- Permanent Reflector -----------------------------------------------------
c
c --- Support Structure -------------------------------------------------------
c ------ Horizontal Planes --------
56000 pz  -122.07875    $ Top Grid Plate
56001 pz  -124.61875    $ Bottom Grid Plate
56002 pz  -123.4479688  $ Mid Grid Plane for Standard Assembly
c
c ------ Vertical Planes ------
c
c ------ Radii ------
56500 cz    1.80578125  $ Radius of Grid Plate Hole for Standard Assembly
56501 c/z   5.08 5.08 1.11125  $ Coolant Hole
56502 c/z   -5.08 5.08 1.11125  $ Coolant Hole
56503 c/z   5.08 -5.08 1.11125  $ Coolant Hole
56504 c/z   -5.08 -5.08 1.11125  $ Coolant Hole
56505 kz  -125.25375 1 1  $ Grid Plate Fitting for Standard Assembly
c
c --- Experimental Facilities -------------------------------------------------
c
c --- Reactor Shielding -------------------------------------------------------
c ------ Horizontal Planes --------
70000 pz   361.6325  $ Top of Removable Concrete Blocks
70001 pz   270.1925  $ Top Checkered Steel Plate (Top Rotating Plug)
70002 pz   269.5575  $ Bottom Checkered Steel Plate/Top Aluminum Sheet
70003 pz   269.5067  $ Bottom Aluminum Sheet/Top Boral
70004 pz   268.9733  $ Bottom Boral/Top Aluminum Sheet
70005 pz   268.9225  $ Bottom Aluminum Sheet/Top First Steel Section
70006 pz   258.7625  $ First/Second Steel Section
```

```
70007 pz   248.6025  $ Second/Third Steel Section
70008 pz   238.4425  $ Bottom Third Steel Section/Top Aluminum Sheet
70009 pz   238.3917  $ Bottom Aluminum Sheet/Top Boral
70010 pz   237.8583  $ Bottom Boral/Top Aluminum Sheet
70011 pz   237.8075  $ Bottom Aluminum Sheet (Bottom Rotating Plug)
c
75000 pz -155.09875  $ Below Core Plenum Top of Concrete Shielding
75001 pz -246.53875  $ Bottom Concrete Shielding
c
c ------ Vertical Planes ------
c
c ------ Radii ------
c
c ***************************************************************************

c Data Cards ****************************************************************
c
c *** Material Cards ********************************************************
c
c --- Basics ----------------------------------------------------------------
c ------ Air ------
m1     1001.80c  5.0303E-07   1002.80c  5.7856E-11   7014.80c  3.9125E-05
       7015.80c  1.4294E-07   8016.80c  1.0800E-05   8017.80c  4.1056E-09
      18036.80c  7.9027E-10  18038.80c  1.4843E-10  18040.80c  2.3391E-07
       6000.80c  9.5977E-09   2003.80c  1.7656E-16   2004.80c  1.3176E-10
      36078.80c  1.0176E-13  36080.80c  6.5528E-13  36082.80c  3.3231E-12
      36083.80c  3.2965E-12  36084.80c  1.6335E-11  36086.80c  4.9530E-12
c         Total  5.0820E-05
mt1    lwtr.20t hwtr.20t
c
c ------ Water ------
c m2
c mt2
c
c --- Metals ----------------------------------------------------------------
c ------ Aluminum 1100 ------
m100  14028.80c  1.2727E-04  14029.80c  6.4656E-06  14030.80c  4.2672E-06
      26054.80c  4.0568E-06  26056.80c  6.3683E-05  26057.80c  1.4707E-06
      26058.80c  1.9572E-07  29063.80c  2.2199E-05  29065.80c  9.9036E-06
      25055.80c  7.4265E-06  30064.80c  6.0216E-06  30066.80c  3.4900E-06
      30067.80c  5.1174E-07  30068.80c  2.3733E-06  30070.80c  7.8719E-08
      27059.80c  6.9230E-06  28058.80c  4.7323E-06  28060.80c  1.8229E-06
      28061.80c  7.9238E-08  28062.80c  2.5265E-07  28064.80c  6.4342E-08
      50112.80c  3.3338E-08  50114.80c  2.2684E-08  50115.80c  1.1686E-08
      50116.80c  4.9973E-07  50117.80c  2.6396E-07  50118.80c  8.3242E-07
      50119.80c  2.9523E-07  50120.80c  1.1197E-06  50122.80c  1.5913E-07
      50124.80c  1.9900E-07  13027.80c  6.0032E-02
c         Total  6.0308E-02
mt100 al27.22t fe56.22t
c
c ------ Aluminum 6063 ------
m101  14028.80c  2.1238E-04  14029.80c  1.0789E-05  14030.80c  7.1205E-06
      26054.80c  2.9616E-06  26056.80c  4.6491E-05  26057.80c  1.0737E-06
      26058.80c  1.4289E-07  29063.80c  8.7976E-06  29065.80c  3.9249E-06
      25055.80c  1.4716E-05  12024.80c  3.5471E-04  12025.80c  4.4906E-05
      12026.80c  4.9441E-05  24050.80c  6.7559E-07  24052.80c  1.3028E-05
      24053.80c  1.4773E-06  24054.80c  3.6772E-07  30064.80c  5.9660E-06
      30066.80c  3.4578E-06  30067.80c  5.0701E-07  30068.80c  2.3514E-06
      30070.80c  7.7993E-08  22046.80c  1.3649E-06  22047.80c  1.2309E-06
      22048.80c  1.2196E-05  22049.80c  8.9504E-07  22050.80c  8.5699E-07
      27059.80c  6.8592E-06  28058.80c  4.6886E-06  28060.80c  1.8060E-06
      28061.80c  7.8507E-08  28062.80c  2.5032E-07  28064.80c  6.3748E-08
      50112.80c  3.3031E-08  50114.80c  2.2474E-08  50115.80c  1.1578E-08
      50116.80c  4.9512E-07  50117.80c  2.6152E-07  50118.80c  8.2474E-07
      50119.80c  2.9251E-07  50120.80c  1.1094E-06  50122.80c  1.5766E-07
      50124.80c  1.9716E-07  13027.80c  5.8984E-02
c         Total  5.9803E-02
mt101 al27.22t fe56.22t
c
c ------ Zircaloy-2 ------
m200  50112.80c  4.6735E-06  50114.80c  3.1799E-06  50115.80c  1.6381E-06
```

```
       50116.80c  7.0054E-05  50117.80c  3.7003E-05  50118.80c  1.1669E-04
       50119.80c  4.1387E-05  50120.80c  1.5697E-04  50122.80c  2.2308E-05
       50124.80c  2.7896E-05  26054.80c  5.5734E-06  26056.80c  8.7491E-05
       26057.80c  2.0206E-06  26058.80c  2.6890E-07  24050.80c  3.2962E-06
       24052.80c  6.3563E-05  24053.80c  7.2076E-06  24054.80c  1.7941E-06
       28058.80c  2.5163E-05  28060.80c  9.6927E-06  28061.80c  4.2134E-07
       28062.80c  1.3434E-06  28064.80c  3.4213E-07  13027.80c  5.4822E-06
        5010.80c  1.8152E-08   5011.80c  7.3063E-08  48106.80c  1.0966E-10
       48108.80c  7.8075E-11  48110.80c  1.0957E-09  48111.80c  1.1229E-09
       48112.80c  2.1168E-09  48113.80c  1.0720E-09  48114.80c  2.5203E-09
       48116.80c  6.5706E-10  20040.80c  1.4311E-06  20042.80c  9.5517E-09
       20043.80c  1.9930E-09  20044.80c  3.0796E-08  20046.80c  5.9052E-11
       20048.80c  2.7607E-09   6000.80c  4.4336E-05  27059.80c  6.6931E-07
       29063.80c  1.0731E-06  29065.80c  4.7874E-07  72174.80c  1.7679E-09
       72176.80c  5.8121E-08  72177.80c  2.0552E-07  72178.80c  3.0143E-07
       72179.80c  1.5050E-07  72180.80c  3.8762E-07   1001.80c  4.8912E-05
        1002.80c  5.6255E-09  12024.80c  1.2819E-06  12025.80c  1.6229E-07
       12026.80c  1.7868E-07  25055.80c  1.7950E-06  42092.80c  1.5181E-07
       42094.80c  9.4871E-08  42095.80c  1.6343E-07  42096.80c  1.7145E-07
       42097.80c  9.8262E-08  42098.80c  2.4864E-07  42100.80c  9.9393E-08
       41093.80c  2.1228E-06   7014.80c  1.1224E-05   7015.80c  4.1003E-08
       14028.80c  7.7714E-06  14029.80c  3.9479E-07  14030.80c  2.6055E-07
       74180.80c  1.2874E-09  74182.80c  2.8429E-07  74183.80c  1.5352E-07
       74184.80c  3.2871E-07  74186.80c  3.0500E-07  22046.80c  1.6648E-07
       22047.80c  1.5014E-07  22048.80c  1.4876E-06  22049.80c  1.0917E-07
       22050.80c  1.0453E-07  92234.80c  1.5660E-12  92235.80c  2.0892E-10
       92238.80c  2.8789E-08  40090.80c  2.1847E-02  40091.80c  4.7643E-03
       40092.80c  7.2823E-03  40094.80c  7.3800E-03  40096.80c  1.1889E-03
c          Total  4.3285E-02
mt200 al27.22t fe56.22t
c
c ------ Zircaloy-3 ------
m201    1001.80c  8.5822E-05   1002.80c  9.8707E-09   3006.80c  2.1501E-08
        3007.80c  2.6177E-07   4009.80c  2.1817E-07   5010.80c  3.6192E-08
        5011.80c  1.4568E-07   6000.80c  3.9289E-05   7014.80c  1.4266E-05
        7015.80c  5.2119E-08   8016.80c  2.2604E-04   8017.80c  8.5927E-08
       11023.80c  8.5526E-07  12024.80c  6.3901E-08  12025.80c  8.0898E-09
       12026.80c  8.9068E-09  13027.80c  7.2873E-07  14028.80c  6.4564E-07
       14029.80c  3.2799E-08  14030.80c  2.1647E-08  15031.80c  6.3480E-07
       19039.80c  4.6899E-07  19040.80c  5.8838E-11  19041.80c  3.3846E-08
       20040.80c  4.7559E-07  20042.80c  3.1742E-09  20043.80c  6.6231E-10
       20044.80c  1.0234E-08  20046.80c  1.9624E-11  20048.80c  9.1742E-10
       21045.80c  4.3737E-06  22046.80c  5.4221E-08  22047.80c  4.8898E-08
       22048.80c  4.8451E-07  22049.80c  3.5556E-08  22050.80c  3.4044E-08
       23050.80c  9.6494E-11  23051.80c  3.8501E-08  24050.80c  1.6430E-09
       24052.80c  3.1685E-08  24053.80c  3.5928E-09  24054.80c  8.9432E-10
       25055.80c  7.1579E-08  26054.80c  1.0701E-05  26056.80c  1.6799E-04
       26057.80c  3.8795E-06  26058.80c  5.1630E-07  27059.80c  3.3363E-08
       28058.80c  2.2806E-08  28060.80c  8.7847E-09  28061.80c  3.8186E-10
       28062.80c  1.2175E-09  28064.80c  3.1007E-10  29063.80c  2.1396E-08
       29065.80c  9.5455E-09  30064.80c  1.4510E-08  30066.80c  8.4094E-09
       30067.80c  1.2331E-09  30068.80c  5.7187E-09  30070.80c  1.8968E-10
       31069.80c  1.6951E-08  31071.80c  1.1250E-08  32070.80c  5.5164E-09
       32072.80c  7.3923E-09  32073.80c  2.1005E-09  32074.80c  9.9394E-09
       32076.80c  2.1194E-09  33075.80c  2.6244E-08  34074.80c  2.2162E-10
       34076.80c  2.3333E-09  34077.80c  1.9000E-09  34078.80c  5.9191E-09
       34080.80c  1.2354E-08  34082.80c  2.1739E-09  37085.80c  1.6603E-08
       37087.80c  6.4024E-09  38084.80c  1.2567E-10  38086.80c  2.2126E-09
       38087.80c  1.5708E-09  38088.80c  1.8531E-08  39089.80c  4.4231E-07
       41093.80c  4.2327E-07  42092.80c  3.0270E-09  42094.80c  1.8916E-09
       42095.80c  3.2586E-09  42096.80c  3.4184E-09  42097.80c  1.9592E-09
       42098.80c  4.9576E-09  42100.80c  1.9818E-09  44096.80c  1.0778E-09
       44098.80c  3.6379E-10  44099.80c  2.4823E-09  44100.80c  2.4512E-09
       44101.80c  3.3189E-09  44102.80c  6.1377E-09  44104.80c  3.6223E-09
       45103.80c  1.9107E-08  46102.80c  1.8846E-10  46104.80c  2.0582E-09
       46105.80c  4.1257E-09  46106.80c  5.0495E-09  46108.80c  4.8887E-09
       46110.80c  2.1654E-09  47107.80c  2.8348E-06  47109.80c  2.6336E-06
       48106.80c  2.1864E-10  48108.80c  1.5567E-10  48110.80c  2.1847E-09
       48111.80c  2.2389E-09  48112.80c  4.2207E-09  48113.80c  2.1374E-09
       48114.80c  5.0253E-09  48116.80c  1.3101E-09  49113.80c  1.0285E-08
       49115.80c  2.2946E-07  50112.80c  9.6398E-07  50114.80c  6.5590E-07
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      50115.80c  3.3789E-07  50116.80c  1.4450E-05  50117.80c  7.6323E-06
      50118.80c  2.4070E-05  50119.80c  8.5367E-06  50120.80c  3.2378E-05
      50122.80c  4.6013E-06  50124.80c  5.7541E-06  51121.80c  9.2384E-09
      51123.80c  6.9099E-09  52120.80c  1.3868E-11  52122.80c  3.9293E-10
      52123.80c  1.3714E-10  52124.80c  7.3040E-10  52125.80c  1.0894E-09
      52126.80c  2.9031E-09  52128.80c  4.8909E-09  52130.80c  5.2515E-09
      55133.80c  1.4794E-08  56130.80c  1.5177E-11  56132.80c  1.4461E-11
      56134.80c  3.4606E-10  56135.80c  9.4383E-10  56136.80c  1.1245E-09
      56137.80c  1.6082E-09  56138.80c  1.0266E-08  57138.80c  1.2740E-11
      57139.80c  1.4142E-08  58136.80c  2.5961E-11  58138.80c  3.5222E-11
      58140.80c  1.2412E-08  58142.80c  1.5596E-09  59141.80c  1.3954E-08
      60142.80c  3.7077E-09  60143.80c  1.6630E-09  60144.80c  3.2443E-09
      60145.80c  1.1314E-09  60146.80c  2.3446E-09  60148.80c  7.7699E-10
      60150.80c  7.6336E-10  62144.80c  4.0146E-10  62147.80c  1.9602E-09
      62148.80c  1.4698E-09  62149.80c  1.8072E-09  62150.80c  9.6506E-10
      62152.80c  3.4980E-09  62154.80c  2.9750E-09  63151.80c  6.1860E-09
      63153.80c  6.7527E-09  64152.80c  2.5008E-11  64154.80c  2.7258E-10
      64155.80c  1.8506E-09  64156.80c  2.5595E-09  64157.80c  1.9568E-09
      64158.80c  3.1059E-09  64160.80c  2.7333E-09  65159.80c  1.2372E-08
      66156.80c  6.7759E-12  66158.80c  1.1495E-11  66160.80c  2.8180E-10
      66161.80c  2.2855E-09  66162.80c  3.0824E-09  66163.80c  3.0124E-09
      66164.80c  3.4194E-09  67165.80c  1.1921E-08  68162.80c  1.6340E-11
      68164.80c  1.8821E-10  68166.80c  3.9385E-09  68167.80c  2.6884E-09
      68168.80c  3.1714E-09  68170.80c  1.7527E-09  69169.80c  1.1639E-08
      71175.80c  1.0947E-08  71176.80c  2.9105E-10  72174.80c  2.7848E-09
      72176.80c  9.1550E-08  72177.80c  3.2373E-07  72178.80c  4.7481E-07
      72179.80c  2.3706E-07  72180.80c  6.1057E-07  73180.80c  1.3039E-12
      73181.80c  1.0865E-08  74180.80c  1.2834E-11  74182.80c  2.8342E-09
      74183.80c  1.5305E-09  74184.80c  3.2770E-09  74186.80c  3.0407E-09
      75185.80c  3.9492E-09  75187.80c  6.6101E-09  77191.80c  3.8155E-09
      77193.80c  6.4137E-09  79197.80c  9.9825E-09  80196.80c  1.4703E-11
      80198.80c  9.7728E-10  80199.80c  1.6536E-09  80200.80c  2.2643E-09
      80201.80c  1.2919E-09  80202.80c  2.9269E-09  80204.80c  6.7341E-10
      81203.80c  2.8399E-09  81205.80c  6.7803E-09  82204.80c  1.5942E-09
      82206.80c  2.7444E-08  82207.80c  2.5166E-08  82208.80c  5.9670E-08
      83209.80c  9.4086E-09  90232.80c  8.4737E-09  92234.80c  4.4606E-13
      92235.80c  5.9508E-11  92238.80c  8.2005E-09  40090.80c  2.2022E-02
      40091.80c  4.8024E-03  40092.80c  7.3405E-03  40094.80c  7.4390E-03
      40096.80c  1.1985E-03
c         Total  4.3469E-02
mt201 al27.22t fe56.22t
c
c ------ Mild Low Carbon Steel (A38/1018) ------
m301   6000.80c  8.6425E-04  25055.80c  7.7296E-04  15031.80c  3.0467E-05
      16032.80c  3.4944E-05  16033.80c  2.7590E-07  16034.80c  1.5635E-06
      16036.80c  3.6787E-09  29063.80c  5.1344E-05  29065.80c  2.2906E-05
      28058.80c  5.4726E-05  28060.80c  2.1081E-05  28061.80c  9.1636E-07
      28062.80c  2.9217E-06  28064.80c  7.4408E-07  24050.80c  2.9571E-06
      24052.80c  5.7025E-05  24053.80c  6.4662E-06  24054.80c  1.6096E-06
      42092.80c  2.1792E-06  42094.80c  1.3618E-06  42095.80c  2.3459E-06
      42096.80c  2.4610E-06  42097.80c  1.4105E-06  42098.80c  3.5690E-06
      42100.80c  1.4267E-06  23050.80c  9.2622E-09  23051.80c  3.6956E-06
      41093.80c  2.0314E-06  22046.80c  1.0165E-07  22047.80c  9.1671E-08
      22048.80c  9.0834E-07  22049.80c  6.6659E-08  22050.80c  6.3825E-08
      14028.80c  4.2607E-04  14029.80c  2.1644E-05  14030.80c  1.4285E-05
      26054.80c  4.8518E-03  26056.80c  7.6163E-02  26057.80c  1.7589E-03
      26058.80c  2.3408E-04
c         Total  8.5418E-02
mt301 fe56.22t
c
c ------ Kanigen Nickel Plating ------
m401  15031.80c  1.6230E-02  28058.80c  4.9699E-02  28060.80c  1.9144E-02
      28061.80c  8.3218E-04  28062.80c  2.6533E-03  28064.80c  6.7573E-04
c         Total  8.9234E-02
c
c ------ Chrome Plating ------
m402  24050.80c  3.6233E-03  24052.80c  6.9871E-02  24053.80c  7.9228E-03
      24054.80c  1.9722E-03
c         Total  8.3389E-02
c
c --- Carbides ---------------------------------------------------------------
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c ------ CP-2 Graphite ------
m500   3006.80c  7.3682E-09   3007.80c  8.9709E-08   4009.80c  2.7898E-09
        5010.80c  6.4792E-09   5011.80c  2.6079E-08   9019.80c  2.6468E-09
       11023.80c  1.0936E-09  12024.80c  1.9611E-09  12025.80c  2.4827E-10
       12026.80c  2.7334E-10  13027.80c  8.2001E-08  14028.80c  2.3116E-06
       14029.80c  1.1743E-07  14030.80c  7.7503E-08  15031.80c  2.1105E-08
       16032.80c  1.3407E-06  16033.80c  1.0585E-08  16034.80c  5.9984E-08
       16036.80c  1.4114E-10  17035.80c  9.6708E-09  17037.80c  3.0943E-09
       19039.80c  1.1994E-09  19040.80c  1.5047E-13  19041.80c  8.6557E-11
       20040.80c  3.8921E-06  20042.80c  2.5977E-08  20043.80c  5.4202E-09
       20044.80c  8.3752E-08  20046.80c  1.6060E-10  20048.80c  7.5079E-09
       21045.80c  1.1185E-10  22046.80c  2.0800E-08  22047.80c  1.8758E-08
       22048.80c  1.8586E-07  22049.80c  1.3640E-08  22050.80c  1.3060E-08
       23050.80c  5.9226E-09  23051.80c  2.3631E-06  24050.80c  2.1010E-10
       24052.80c  4.0515E-09  24053.80c  4.5941E-10  24054.80c  1.1436E-10
       25055.80c  3.6612E-10  26054.80c  6.5261E-09  26056.80c  1.0245E-07
       26057.80c  2.3659E-09  26058.80c  3.1486E-10  27059.80c  8.5325E-11
       28058.80c  1.6331E-08  28060.80c  6.2905E-09  28061.80c  2.7344E-10
       28062.80c  8.7186E-10  28064.80c  2.2204E-10  29063.80c  1.6416E-09
       29065.80c  7.3236E-10  30064.80c  1.8554E-10  30066.80c  1.0753E-10
       30067.80c  1.5767E-11  30068.80c  7.3125E-11  30070.80c  2.4255E-12
       31069.80c  4.3350E-11  31071.80c  2.8770E-11  32070.80c  7.0540E-11
       32072.80c  9.4526E-11  32073.80c  2.6859E-11  32074.80c  1.2710E-10
       32076.80c  2.7101E-11  33075.80c  3.3558E-10  34074.80c  2.8339E-12
       34076.80c  2.9836E-11  34077.80c  2.4295E-11  34078.80c  7.5688E-11
       34080.80c  1.5797E-10  34082.80c  2.7798E-11  35079.80c  3.1900E-10
       35081.80c  3.1031E-10  37085.80c  2.1230E-10  37087.80c  8.1868E-11
       38084.80c  7.7131E-11  38086.80c  1.3581E-09  38087.80c  9.6414E-10
       38088.80c  1.1374E-08  39089.80c  5.6559E-10  40090.80c  1.9285E-09
       40091.80c  4.2056E-10  40092.80c  6.4283E-10  40094.80c  6.5145E-10
       40096.80c  1.0495E-10  41093.80c  2.7062E-10  42092.80c  3.8707E-11
       42094.80c  2.4188E-11  42095.80c  4.1668E-11  42096.80c  4.3712E-11
       42097.80c  2.5053E-11  42098.80c  6.3393E-11  42100.80c  2.5341E-11
       44096.80c  1.3781E-11  44098.80c  4.6518E-12  44099.80c  3.1742E-11
       44100.80c  3.1344E-11  44101.80c  4.2439E-11  44102.80c  7.8484E-11
       44104.80c  4.6319E-11  45103.80c  4.8865E-11  46102.80c  2.4098E-12
       46104.80c  2.6319E-11  46105.80c  5.2756E-11  46106.80c  6.4569E-11
       46108.80c  6.2513E-11  46110.80c  2.7689E-11  47107.80c  1.2083E-10
       47109.80c  1.1226E-10  48106.80c  2.7958E-12  48108.80c  1.9906E-12
       48110.80c  2.7936E-11  48111.80c  2.8629E-11  48112.80c  5.3970E-11
       48113.80c  2.7332E-11  48114.80c  6.4259E-11  48116.80c  1.6752E-11
       49113.80c  9.3940E-12  49115.80c  2.0958E-10  50112.80c  2.0544E-12
       50114.80c  1.3979E-12  50115.80c  7.2011E-13  50116.80c  3.0795E-11
       50117.80c  1.6266E-11  50118.80c  5.1297E-11  50119.80c  1.8193E-11
       50120.80c  6.9003E-11  50122.80c  9.8061E-12  50124.80c  1.2263E-11
       51121.80c  1.1813E-10  51123.80c  8.8357E-11  52120.80c  1.7734E-13
       52122.80c  5.0245E-12  52123.80c  1.7537E-12  52124.80c  9.3397E-12
       52125.80c  1.3931E-11  52126.80c  3.7122E-11  52128.80c  6.2540E-11
       52130.80c  6.7151E-11  53127.80c  3.9624E-11  55133.80c  1.8917E-10
       56130.80c  1.9407E-13  56132.80c  1.8491E-13  56134.80c  4.4251E-12
       56135.80c  1.2069E-11  56136.80c  1.4379E-11  56137.80c  2.0564E-11
       56138.80c  1.3127E-10  57138.80c  1.6290E-13  57139.80c  1.8084E-10
       58136.80c  3.3196E-13  58138.80c  4.5039E-13  58140.80c  1.5871E-10
       58142.80c  1.9943E-11  59141.80c  1.7843E-10  60142.80c  4.7411E-11
       60143.80c  2.1265E-11  60144.80c  4.1485E-11  60145.80c  1.4467E-11
       60146.80c  2.9981E-11  60148.80c  9.9355E-12  60150.80c  9.7611E-12
       62144.80c  1.0267E-12  62147.80c  5.0131E-12  62148.80c  3.7590E-12
       62149.80c  4.6218E-12  62150.80c  2.4681E-12  62152.80c  8.9459E-12
       62154.80c  7.6082E-12  63151.80c  1.5820E-11  63153.80c  1.7270E-11
       64152.80c  6.3955E-14  64154.80c  6.9711E-13  64155.80c  4.7327E-12
       64156.80c  6.5458E-12  64157.80c  5.0045E-12  64158.80c  7.9432E-12
       64160.80c  6.9903E-12  65159.80c  3.1640E-11  66156.80c  1.7329E-14
       66158.80c  2.9397E-14  66160.80c  7.2069E-13  66161.80c  5.8451E-12
       66162.80c  7.8831E-12  66163.80c  7.7039E-12  66164.80c  8.7449E-12
       67165.80c  3.0488E-11  68162.80c  4.1789E-14  68164.80c  4.8132E-13
       68166.80c  1.0072E-11  68167.80c  6.8753E-12  68168.80c  8.1106E-12
       68170.80c  4.4825E-12  69169.80c  2.9766E-11  71175.80c  2.7995E-11
       71176.80c  7.4435E-13  72174.80c  4.5075E-14  72176.80c  1.4819E-12
       72177.80c  5.2400E-12  72178.80c  7.6854E-12  72179.80c  3.8371E-12
       72180.80c  9.8828E-12  73180.80c  3.3347E-11  73181.80c  2.7786E-07
       74180.80c  1.6411E-13  74182.80c  3.6242E-11  74183.80c  1.9571E-11
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      74184.80c  4.1904E-11  74186.80c  3.8881E-11  75185.80c  1.0100E-11
      75187.80c  1.6905E-11  77191.80c  9.7578E-12  77193.80c  1.6403E-11
      79197.80c  2.5529E-10  80196.80c  3.7602E-13  80198.80c  2.4993E-11
      80199.80c  4.2290E-11  80200.80c  5.7908E-11  80201.80c  3.3040E-11
      80202.80c  7.4854E-11  80204.80c  1.7222E-11  81203.80c  3.6314E-11
      81205.80c  8.6701E-11  82204.80c  1.6988E-12  82206.80c  2.9244E-11
      82207.80c  2.6817E-11  82208.80c  6.3584E-11  83209.80c  1.2031E-10
      90232.80c  1.0835E-10  92234.80c  5.7039E-15  92235.80c  7.6094E-13
      92238.80c  1.0486E-10   1001.80c  2.2327E-05   1002.80c  2.5679E-09
       8016.80c  1.1161E-05   8017.80c  4.2426E-09   6000.80c  8.3677E-02
       1001.80c  1.2576E-07   1002.80c  1.4464E-11   7014.80c  9.7812E-06
       7015.80c  3.5734E-08   8016.80c  2.7000E-06   8017.80c  1.0264E-09
      18036.80c  1.9757E-10  18038.80c  3.7106E-11  18040.80c  5.8478E-08
       6000.80c  2.3994E-09   2003.80c  4.4139E-17   2004.80c  3.2939E-11
      36078.80c  2.5440E-14  36080.80c  1.6382E-13  36082.80c  8.3078E-13
      36083.80c  8.2412E-13  36084.80c  4.0838E-12  36086.80c  1.2383E-12
c         Total  8.3734E-02
mt500 grph.20t al27.22t fe56.22t lwtr.20t hwtr.20t
c
c ------ Graphite-HEUO2 Fuel ------
m501   6000.80c  5.1039E-02   6002.80c  3.5468E-02   5010.80c  1.1314E-07
       5011.80c  4.5542E-07  26054.80c  2.9114E-07  26056.80c  4.5703E-06
      26057.80c  1.0555E-07  26058.80c  1.4047E-08  23050.80c  1.5339E-09
      23051.80c  6.1201E-07   8016.80c  1.8685E-05   8017.80c  7.1031E-09
      92234.80c  8.5472E-08  92235.80c  8.7202E-06  92236.80c  4.0790E-08
      92238.80c  4.9986E-07
c         Total  8.6541E-02
mt501 grph.20t o2-u.20t u-o2.30t fe56.22t
c
c ------ Boron Carbide Powder (1.6 g/cc) ------
m502   5010.80c  1.3838E-02   5011.80c  5.5698E-02   6000.80c  1.7384E-02
      11023.80c  4.1781E-07  13027.80c  3.5600E-05  14028.80c  3.1541E-05
      14029.80c  1.6023E-06  14030.80c  1.0575E-06  20040.80c  2.3234E-06
      20042.80c  1.5506E-08  20043.80c  3.2355E-09  20044.80c  4.9995E-08
      20046.80c  9.5867E-11  20048.80c  4.4818E-09  22046.80c  1.6555E-06
      22047.80c  1.4930E-06  22048.80c  1.4793E-05  22049.80c  1.0856E-06
      22050.80c  1.0395E-06  25055.80c  1.7484E-07
c         Total  8.7012E-02
mt502 grph.20t al27.22t
c
c --- Experimental ---------------------------------------------------------------
c m600
c
c --- Shielding ------------------------------------------------------------------
c ------ Hematite/Magnetite Concrete ------
m900  20040.80c  2.5914E-03  20042.80c  1.7296E-05  20043.80c  3.6088E-06
      20044.80c  5.5763E-05  20046.80c  1.0693E-07  20048.80c  4.9989E-06
      14028.80c  1.5236E-03  14029.80c  7.7399E-05  14030.80c  5.1082E-05
      13027.80c  1.1921E-03  26054.80c  1.0360E-03  26056.80c  1.6262E-02
      26057.80c  3.7557E-04  26058.80c  4.9981E-05  12024.80c  9.5284E-04
      12025.80c  1.2063E-04  12026.80c  1.3281E-04  16032.80c  4.8069E-05
      16033.80c  3.7953E-07  16034.80c  2.1507E-06  16036.80c  5.0604E-09
      19039.80c  2.0056E-05  19040.80c  2.5162E-09  19041.80c  1.4474E-06
      11023.80c  3.2685E-05  25055.80c  2.8557E-05  23050.80c  4.0548E-08
      23051.80c  1.6178E-05  24050.80c  1.1582E-07  24052.80c  2.2335E-06
      24053.80c  2.5326E-07  24054.80c  6.3043E-08  22046.80c  5.9935E-05
      22047.80c  5.4050E-05  22048.80c  5.3556E-04  22049.80c  3.9303E-05
      22050.80c  3.7632E-05   8016.80c  4.7228E-02   8017.80c  1.7953E-05
       1001.80c  2.3634E-02   1002.80c  2.7182E-06
c         Total  9.6208E-02
mt900 lwtr.20t hwtr.20t
c
c ------ Boral (50:50) ------
m901   5010.80c  1.0066E-02   5011.80c  4.0516E-02   6000.80c  1.1255E-02
      13027.80c  3.0699E-02  47107.80c  8.0689E-07  47109.80c  7.4964E-07
       4009.80c  1.8630E-06  20040.80c  9.7770E-06  20042.80c  6.5254E-08
      20043.80c  1.3615E-08  20044.80c  2.1038E-07  20046.80c  4.0342E-10
      20048.80c  1.8860E-08  48106.80c  7.0014E-08  48108.80c  4.9850E-08
      48110.80c  6.9958E-07  48111.80c  7.1694E-07  48112.80c  1.3515E-06
      48113.80c  6.8445E-07  48114.80c  1.6092E-06  48116.80c  4.1952E-07
      27059.80c  5.6980E-06  24050.80c  5.2614E-07  24052.80c  1.0146E-05
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      24053.80c  1.1505E-06  24054.80c  2.8638E-07  29063.80c  7.3083E-06
      29065.80c  3.2604E-06  26054.80c  1.3180E-06  26056.80c  2.0690E-05
      26057.80c  4.7781E-07  26058.80c  6.3588E-08  49113.80c  1.2547E-07
      49115.80c  2.7992E-06  12024.80c  1.0913E-05  12025.80c  1.3816E-06
      12026.80c  1.5211E-06  25055.80c  6.2369E-06  42092.80c  9.6931E-07
      42094.80c  6.0574E-07  42095.80c  1.0435E-06  42096.80c  1.0947E-06
      42097.80c  6.2739E-07  42098.80c  1.5875E-06  42100.80c  6.3461E-07
      11023.80c  2.9756E-07  28058.80c  3.8948E-06  28060.80c  1.5003E-06
      28061.80c  6.5217E-08  28062.80c  2.0794E-07  28064.80c  5.2956E-08
      82204.80c  4.5378E-08  82206.80c  7.8116E-07  82207.80c  7.1633E-07
      82208.80c  1.6984E-06  14028.80c  7.7596E-05  14029.80c  3.9419E-06
      14030.80c  2.6016E-06  50112.80c  2.7439E-08  50114.80c  1.8670E-08
      50115.80c  9.6177E-09  50116.80c  4.1130E-07  50117.80c  2.1725E-07
      50118.80c  6.8512E-07  50119.80c  2.4299E-07  50120.80c  9.2160E-07
      50122.80c  1.3097E-07  50124.80c  1.6378E-07  22046.80c  1.4384E-06
      22047.80c  1.2972E-06  22048.80c  1.2853E-05  22049.80c  9.4323E-07
      22050.80c  9.0313E-07  23050.80c  1.6480E-08  23051.80c  6.5754E-06
      30064.80c  9.6023E-06  30066.80c  5.5652E-06  30067.80c  8.1604E-07
      30068.80c  3.7846E-06  30070.80c  1.2553E-07  40090.80c  3.5511E-06
      40091.80c  7.7440E-07  40092.80c  1.1837E-06  40094.80c  1.1996E-06
      40096.80c  1.9325E-07
c          Total  9.2783E-02
mt901 grph.20t al27.22t fe56.22t
c
c *** Control Cards ***********************************************************
c
mode  n
kcode 1000000 1 50 1550
ksrc  0.0 0.0 0.0
c print
c kopts  blocksize=10 kinetics=yes precursor=yes
c
c *** Translation Cards *******************************************************
c
*tr1   0.0 0.0 0.0  45 -45 90  135 45 90  90 90 0  1
c
c *** Tally Cards *************************************************************
c
c
c *****************************************************************************
```