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Transmutation Fuel Fabrication-Fiscal Year '16

Fuel Cycle Research & Development Advanced Fuels Campaign

Randall Fielding
Blair Grover

Prepared for
U. S. Department of Energy
Office of Nuclear Energy

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Idaho National Laboratory
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http://www.inl.gov

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ABSTRACT

Nearly all of the metallic fuel that has been irradiated and characterized by the Advanced Fuel Campaign, and its earlier predecessors, has been arc cast. Arc casting is a very flexible method of casting lab scale quantities of materials. Although the method offers flexibility, it is an operator dependent process. Small changes in parameter space or alloy composition may affect how the material is cast. This report provides a historical insight in how the casting process has been modified over the history of the advanced fuels campaign as well as the physical parameters of the fuels cast in fiscal year 2016.

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1. INTRODUCTION

Metallic transmutation fuels are currently being developed under the Fuel Cycle Research and Develop program by the Advanced Fuels Campaign. Metallic fuels have been shown to be a feasible fuel type via long term use in reactors and numerous irradiation tests. One of the advantages of metallic fuels is ease of fabrication by casting. During the EBR-II fuel fabrication campaigns, thousands of fuel pins or slugs were cast. However, during those fabrication campaigns fuel was cast on the kilograms scale in lengths of approximately 38 cm. This scale is much too large for laboratory scale irradiation testing such as is used for the AFC series of irradiation tests. In early 2001 the metal fuel fabrication team chose arc casting as the method of casting transmutation test and characterization fuels. Arc melting is the process of melting a charge of material, usually on either a actively cooled or passively cooled copper hearth, through means of an electric arc. It is often used in the materials industry to produce small batches of specialty materials in gram to a few kilograms quantities. Arc casting is essentially the same as arc melting although after the material is molten it is cast into a specific shape, in the case of the AFC tests, a rod. Arc melting was chosen based on its applicability to lab scale quantities of a tens of grams, very fast heating rates (necessary for americium retention), and its ability to produce homogenously mixed alloys or mixtures.

During early technique development stainless steel was used as a surrogate fuel material in casting studies. Stainless steel is non-radioactive and has a similar, though somewhat higher melting point than the U-10Zr and U-TRU-Zr alloys. Using stainless steel, rods of over 30 cm could be cast which is, much longer than necessary for AFCI testing. However, when the arc melter was transferred into a glovebox and used for melting/casting of radiological material casting did not progress as well. Several problems were encountered such as alloying the fuel with the copper hearth, molten material not flowing into the quartz mold, or flowing into the mold but resulting in fuel slugs that were hollow (tube), or had excessive exposed and unexposed porosity. Since this original development effort many different techniques and configurations have been attempted, although much of the development has not been adequately documented. This report will serve as an initial attempt to capture some of this history and development of arc casting and to document the technique which is currently used for casting of transmutation fuels. It will also summarize the transmutation alloys cast in the fiscal year 2016. Because many of the descriptions of previous work were at best qualitative, a number of the descriptions herein will be approximate, but they will still provide valuable information.

2. ARC MELTINGING

A Centorr 5SA arc melter has been used for most of the AFC irradiation and characterization fuel specimen fabrication. Typically this type of arc melter uses a non-consumable tungsten electrode and a water cooled housing and copper hearth. However, because of the added complications caused by using water cooling in a transuranic glovebox environment, the water cooling was not installed in the arc melters used for this work. In the typical arc melting process the materials to be melted are loaded onto a copper hearth with a slightly rounded depression machined into the surface. This depression serves to both contain the molten alloy and to shape the molten pool. Fuel alloys are generally made up of materials with widely varying melting points and densities, such as uranium, zirconium, and plutonium. In this example melting points vary from 1855°C for Zr to 639°C for plutonium while densities vary from 6.5 g/cm^3 for zirconium to 19.8 g/cm^3 for plutonium. The materials to be melted are placed on the hearth melted in the electric arc forming a “button”. After the initial melt is done and the solid materials are melted together the button is flipped over and melted again. This process is repeated for at least two flips and three melting cycles. Figure 1 shows a typical example of the arc melter, along with a buttoning and casting hearth. The casting hearth is similar to the buttoning hearth except that a quartz mold is inserted up through the bottom of the hearth and brought to just below the upper surface. An opening into the quartz mold is machined into the surface of the hearth. The quartz mold is generally held in place by means of a stainless steel or copper tube or chamber.

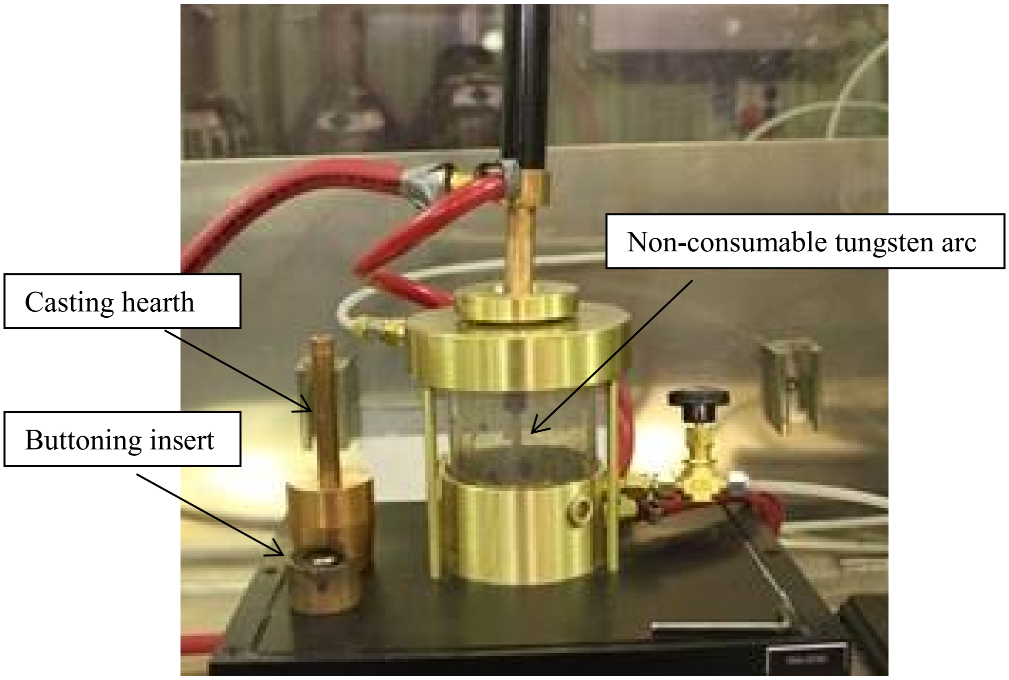


Figure 1- Typical arc melter and buttoning insert and casting hearth. Note the casting hearth is inverted to highlight the quartz mold chamber.

2.1 Casting Laboratory Fuel Casting

The initial transmutation fuels were cast in the Casting Laboratory glovebox, which is a purified argon atmosphere glovebox, where the Integral Fast Reactor program transuranic bearing fuel was also cast on a larger scale. The first castings were done using the basic setup similar to Figure 1, although a buttoning hearth was used instead of an insert. The first issue encountered with the transmutation fuel was fuel material not flowing into the quartz mold. While the fuel could be melted and buttoned with no issue, after it melted it would not flow into the quartz tube. It was reasoned that this lack of flow was due to excessive gas pressure in the mold. A stainless steel plug was placed in the end of the quartz to prevent the molten alloy from flowing too far. The initial endplugs were generally approximately 25 µm smaller in diameter than the inside diameter of the quartz. It was reasoned that if the endplug fit too tightly the gas present in the mold could not be displaced fast enough by the molten alloy. This led to a slight gas pressure which prevented the material from flowing into the mold. In order to mitigate this issue a number of plugs of different diameters and with various gas flow paths were used in the quartz molds. If an alloy would not flow into the mold a smaller diameter plug was used. If an alloy flowed into the quartz but produced a hollow tube or several large voids, a tighter plug was used to slow down the gas flow slightly.

The simplicity of the arc casting equipment makes it well suited for use inside a glovebox. However, the simplicity of the design also means there is no pressure, time, or temperature feedback to the operator. The chamber of the arc melter is not sealed; therefore, the pressure is only controlled by the ambient glovebox pressure, although a gas purge can be applied to the chamber if necessary. Temperature in an arc melter is controlled by the amount of amperage applied to the arc. Although the operator can control the amperage, the correlation between applied amperage and heat built up in the material is complicated and therefore temperature cannot be directly controlled. As with temperature, time is controlled by how long an operator applies an electric current. If too much is heat is applied it is possible to alloy the fuel material with the copper hearth, and if not enough heat is applied the melt may not be fully molten or will cool before it has flowed into the mold. In general, once the material is fully molten and flows slightly, for example towards the mold opening, if it doesn't fully flow into the mold it will freeze off too soon. The amount of heat is further complicated because the material to be melted is sitting on a large copper hearth, which must be maintained at a substantially lower temperature than molten fuel material to prevent alloying with the fuel.

During the early casting campaigns it was reasoned that additional superheat was needed in the melt to allow it to fully flow into the mold. In order to achieve this greater heat input an additional copper plate, or insert, was placed on top of the normal hearth. The gap between the hearth and this copper insert provided a thermal barrier allowing the insert and alloy to build up slightly more heat, although it was necessary to be careful to not alloy the melt with this additional copper plate. Initially the insert was quite thin with an approximate mass of 55 grams. When casting results were still inconsistent, the thickness was increased to approximately 4 mm, which essentially doubled the total mass of the copper insert. The original insert had a mold opening slightly larger than the quartz inside diameter, however, the quartz was mostly covered by the insert. This opening was increased to 5.9 mm which was just less than the outside diameter of the quartz, in hopes this would allow more material to flow into the mold. Despite these changes casting was still inconsistent. The next variable changed was the angle of the hearth. Initially, the quartz was placed in the center of the hearth. A new hearth was fabricated in which the mold was off to one side and the surface of the hearth was machined such that it tapered towards the mold opening. The taper angle was further increased by setting the arc melter on an angle during melting, and at times even slightly shaking the arc melter frame in order to overcome the material surface tension. All of these changes resulted in melts that were only sometimes successful. This variability remained constant throughout the casting campaigns.

The next change made to the process attempted to deal with the pressure variable. The changes made were reminiscent of the traditional injection casting used during the EBR-II fuel campaigns. Suction casting was developed in order to better control the amount of super heat put into the system , the total time the charge was molten and to overcome any possible surface tension issues. This technique employed a hearth similar to the buttoning hearth, although the depression was slightly deeper and the upper support of the arc melter was modified to include an opening which would accommodate insertion of a quartz mold. After the charge was melted and buttoned three times following the standard process the button was melted in the slightly deeper hearth. Once the button was fully molten the quartz tube was inserted from above though the upper support plate into the molten pool and a slight vacuum applied by means of small syringe connected to the quartz with a flexible hose. As the reduced pressure was applied, molten material was drawn into the quartz mold. Figure 2 shows a photo of the arc melter and the quartz mold being inserted into the molten pool. Efforts to cast using this suction method were met with moderate success, although inconsistent results still plagued many of the attempts. Some of the variability may be explained by the simplicity of the design. Because reduced pressure was applied by pulling the plunger on a simple syringe a consistent amount of draw was difficult to obtain. If pressure was reduced too much a gas bubble could be drawn into the mold, resulting in significant voids throughout the rod. If the plunger was pulled back too quickly material would flow too quickly and not remain in a "slug form" due to the fact some of the molten charge would be pulled further up into the quartz, where it would solidify and possibly block off further flow before the bulk of the liquid was drawn into the mold. This could be thought of as a turbulent flow as opposed to a more controlled laminar flow where the whole of the liquid front moved consistently. Also of concern with this process was the large amount of heel left in the hearth. The heel was necessary because if the open end of the quartz is exposed gas is sucked into the casting, resulting in voids. However, this means that the charge size had to be increased, and often pieces of quartz remained remains in the heel. Although, every attempt was made to remove the quartz before recycling the material, it is possible some quartz remained which would add further SiO_2 contamination to the recycled final fuel composition. In many of the fuel samples cast under the AFC program silicon contamination was observed throughout the sample. Although much of this was likely from the quartz mold, a small amount of quartz entrained into the recycled heel may have had a significant contribution as well. Because the suction casting method appeared to be the most consistent method of casting it was used for several casting campaigns, including the FUTURIX tests as well as the associated characterization alloys. Despite this improvement, consistent casting behavior was still an issue and therefore some casting was done using the more traditional gravity casting using the casting insert.

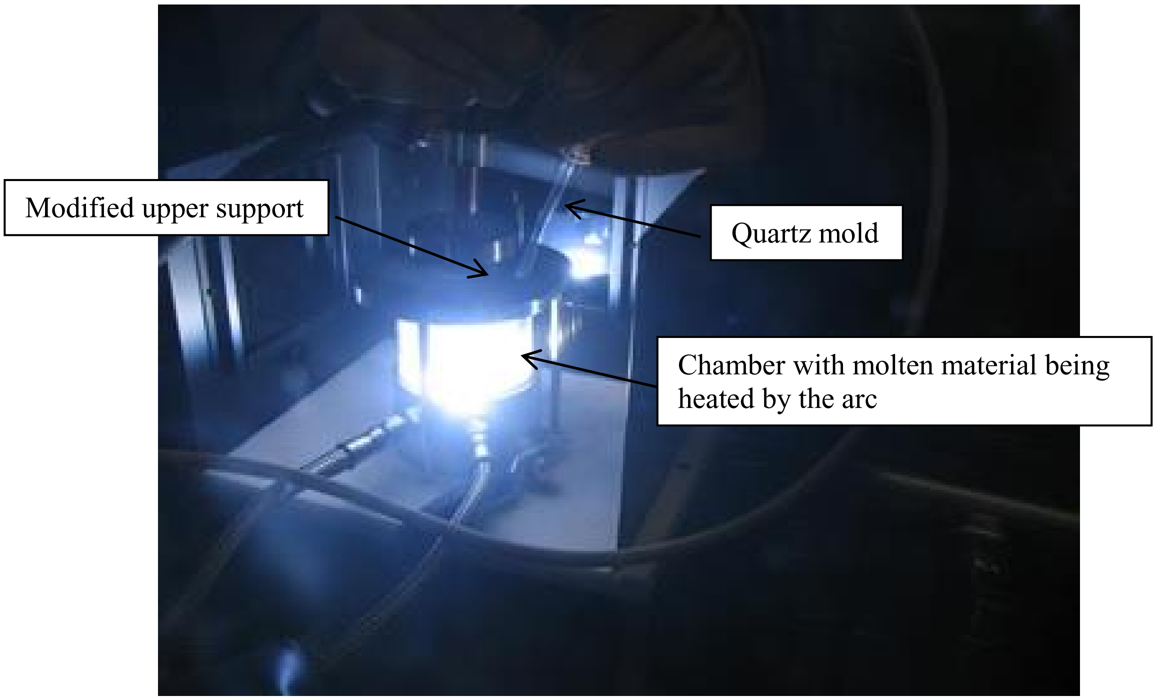


Figure 2- Arc melter set up to perform suction arc casting. Not pictured is the flexible hose and syringe connected to the quartz.

In an attempt to further improve the casting technique additional modifications were made. The next change was to move to a pseudo-continuous casting technique. In continuous casting the material is withdrawn directly from the crucible through a die, which is usually water chilled, and then it is cooled. This method of casting is very common in the aluminum industry as well as other industries where it is done on a very large scale. To employ this method using the arc melting system a plug was placed into the quartz mold and extended all the way to the surface of the casting hearth. Once the fuel alloy was fully molten and heated the plug was withdrawn. Several variations of this basic set-up were attempted using various plug withdrawal rates with no success. Therefore, this method of casting was never transferred to the glovebox environment.

The next design modification, like the last, was an attempt to allow more superheat into the fuel alloy. Based on the extensive use of the copper casting insert a similar graphite casting insert was fabricated and used in place of the copper insert. The graphite insert, like the copper insert, was in direct contact with the copper hearth, but because the thermal conductivity of the graphite is substantially less than that of copper the graphite hearth removed less heat from the molten material. The disadvantage of using a graphite insert was the likelihood of increasing the carbon contamination in the final fuel form. Some evidence of this was seen in the presence of carbide precipitates in the fuel microstructure. In general, contamination was controlled by controlling the amount of time the alloy was kept molten. Just as with the copper hearths once the material was molten it flowed easily; therefore, the time could not be increased substantially. In order to further increase the amount of super heat and to control when the material flowed toward the mold, the taper to the center of the hearth and mold opening insert was decreased to 15°. Although the reduction of the taper angle did allow more heat input into the material before flow towards the mold began, the overall success of the graphite insert was marginal. Improvements observed from this modification were less than those obtained with suction casting. Also, the risks of excessive carbide formation or bonding with the graphite were disadvantages over the use of the copper insert. Records indicate that several charges did bond with the graphite, and the bonded graphite had to be mechanically removed from the button. Due to the limited improvements coupled with the increased failure risks , the casting campaigns largely reverted back to the suction method although that method was still less than ideal.

As seen throughout this report the major focus of the casting system modifications has been to increase the possible superheat of the melt. The method of arc casting used by the AFC program, implicitly limited super heat by using the "cold" copper or graphite hearths and inserts. The final modification made to the system in the casting laboratory prior to the majority of the casting work being transferred to a similar system in another facility, was again an attempt to increase the superheat. The final modification involved fabricating a ZrO_2 insert, or crucible, that would sit on top of the hearth. As with the graphite inserts, by changing to a less thermally conductive material, less heat is transferred to the copper hearth and thus more heat could build up in the fuel alloy. There are two major differences between the graphite or copper inserts and the ZrO_2 inserts. The first is the ZrO_2 is not electrically conductive and has a much lower thermal conductivity and the second, is that ZrO_2 is much less reactive, although not totally inert, with the fuel alloys. A simple measure of "inertness" is an Ellingham diagram comparing free energy or formation of the various oxides, as shown in Figure 3. Although this is based on equilibrium thermal dynamics which is a simplification, it is still useful.

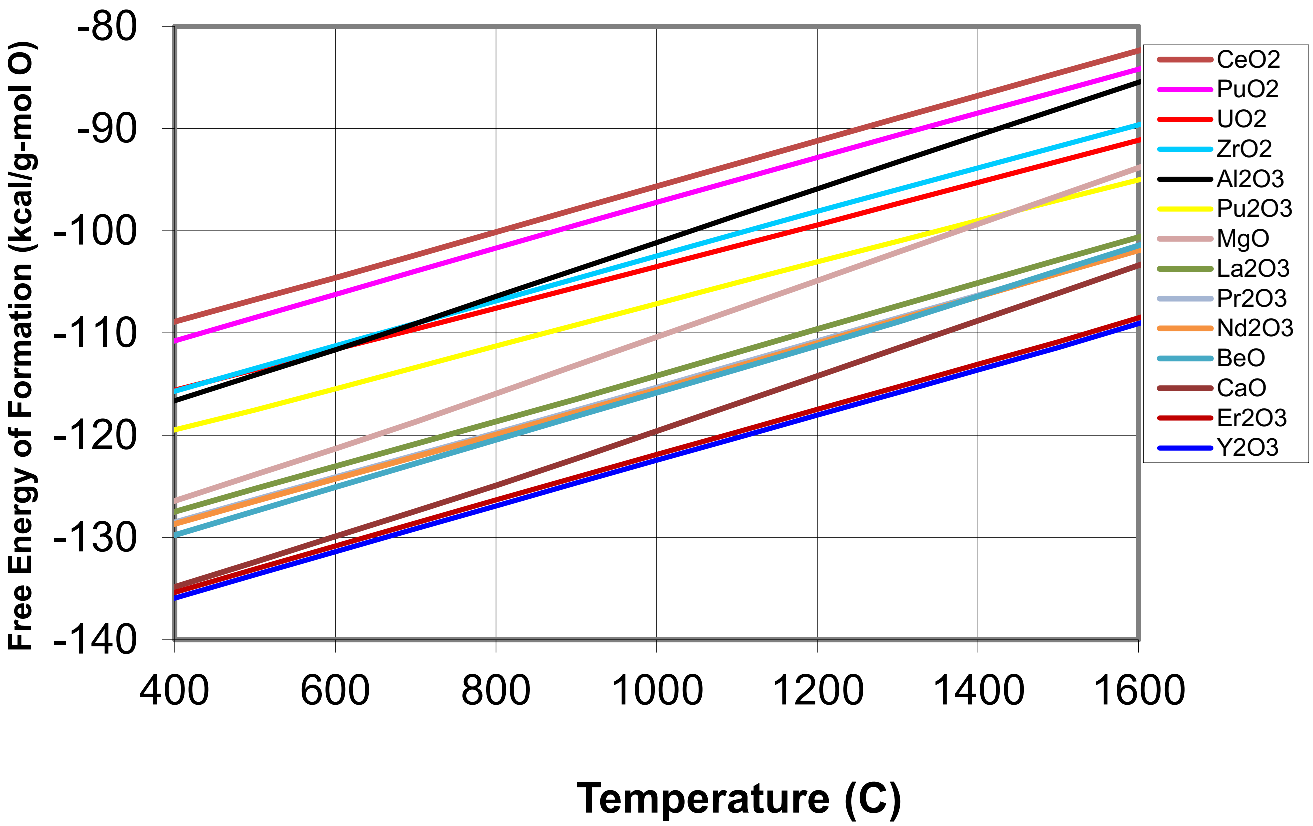


Figure 3- Ellingham diamgram showing free energy of formation of various oxide phases. Note- the more negative the value the more stable the oxide. Graph is provided courtesy of Dr. Brian Westphal, INL (A. Roine et al., "Outokumpu HSC Chemistry" Version 6, 2007).

As shown in Figure 3 ZrO_2 is more stable than PuO_2 and very similar to UO_2. ZrO_2 was chosen based on its commercial availability of a castable product. The inserts were shaped with a roughly 35° taper toward the center of the insert that provided a deeper molten pool of material. A small opening at the bottom of the taper was incorporated into the insert design in order to expose a small amount of copper to the metallic charge thus providing an electrical contact. The inserts were made by casting or pressing the precursor slurry or powder material into a die, which provided a green structure. The green structure was then fired at a high temperature to remove any binders and provide structural integrity. Figure 4 shows a fuel button contained in the ZrO_2 insert loaded into an arc melter.

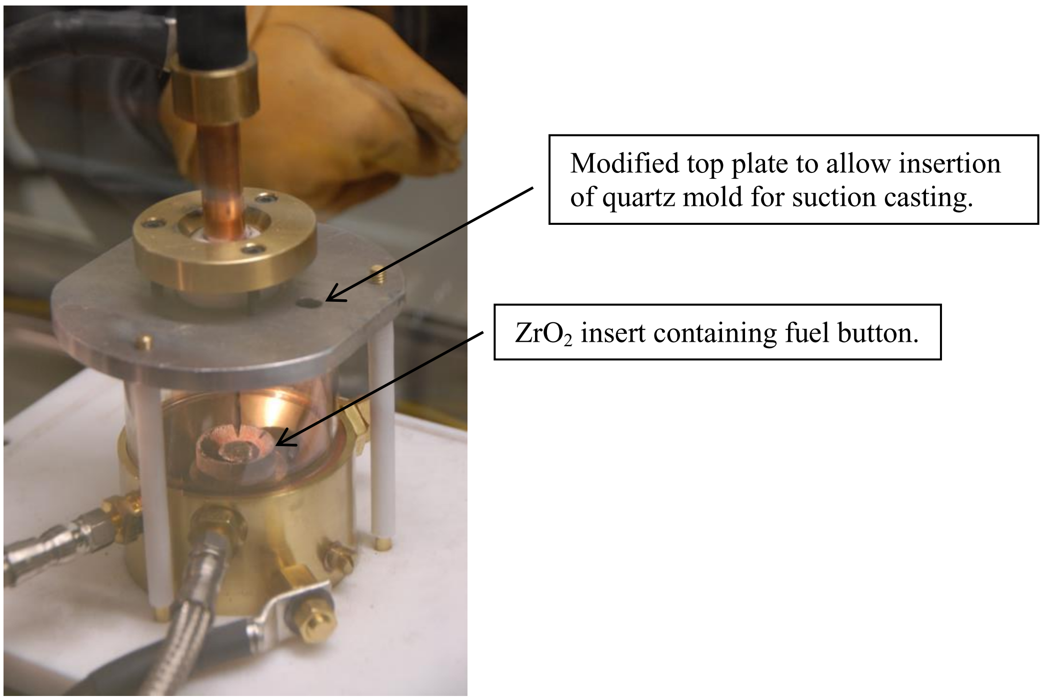


Figure 4- Arc melter configured for suction casting using a ceramic insert.

Although the ceramic insert is not completely inert the casting process is very quick, therefore significant reactions are prevented from occurring. This particular modification resulted in the highest success rate of those that have been discussed. As such, this is the configuration that was transferred to the AFCI glovebox in the Fuel Manufacturing Facility (FMF). Although it was successful in that it provided more consistent casting behavior and results, it still had some disadvantages. The first disadvantage was although reaction with the ZrO_2 was reduced by the short heat cycles some reaction was still present. This disadvantage was further compounded by the inherent need to have a significant heel at the end of the casting process. Because the insert was not completely inert, recycling of that heel was often impossible. Many times during the casting process the heel would start to bond to the ZrO_2, the ZrO_2 would be slightly reduced by the melt, or and the melt would infiltrate the porous insert. The second main disadvantage was do to the extreme heat of the arc and speed of heating. This would cause the inserts to receive thermal shocks, which would break off ceramic particles. These particles were then incorporated into the heel, thereby changing the overall chemical composition and rendering recycling of the material nearly impossible. Therefore, if a casting was not successful on the first casting attempt, the material was heavily contaminated which made further casting success unlikely and the overall alloy composition was changed due to reduction of the ceramic. Also, often the melt material was not retrievable form the insert. In spite of these disadvantages the technique was the most successful and was transferred to the AFCI glovebox in FMF.

2.2 FMF/FASB Fuel Casting

After fuel casting was moved to the AFCI glovebox, casting continued using the ceramic insert. Although it was more successful, the suction technique was complicated because it generally required two people; one to control the arc and observe the pool while the second person would insert the quartz and draw material into the mold when conditions appeared favorable based on the first operator's visual observations. The necessity to have two people working simultaneously is difficult in a glovebox set up due to space limitations and glove port locations. To simplify the casting operation the hearth and insert were slightly modified for gravity casting. The casting hearth was modified to allow a quartz mold to be inserted from the bottom while still maintaining electrical contact with the charge through the small opening at the center of the insert. An additional step was added to the buttoning process to shape the button to fit into the tapered ceramic insert in order to ensure electrical contact could be made at the bottom of the insert. Utilizing this process was quite successful and the technique was used for characterization alloys as well as irradiation test specimen fabrication. Throughout the casting campaigns different operators found different heating techniques to be most successful. The most favored technique was to heat the alloy button slowly by sweeping the arc over the button using a low amperage, but concentrating the most heat at the center of the button. As the center of the button continued to heat and just started to melt, the amperage applied was increased to the maximum amount very quickly and the entire button melted and was cast. Although this was successful the concerns over melt contamination by the ceramic insert and the inability to recycle failed casting remained.

As the AFC program moved away from transuranic bearing fuel alloys to binary uranium based alloys casting was moved into the Fuel and Applied Science Building (FASB). With the move to FASB the decision was made to return to copper inserts in order to maintain the cleanliness of the alloys and to continue the re-use of alloys from failed castings. The new copper hearths included a buttoning hearth, shaping insert, and casting insert. The buttoning process was the same as previously described in this document. The shaping and casting inserts were based on the ceramic insert taper and diameter. The differences between the two inserts were that the casting insert was open on bottom to allow flow into the quartz mold and the shaping insert was closed. After the charge was buttoned it was shaped using the shaping insert, the resulting button was shaped much like an upside down (apex down) short and squat cone. The cone was then placed in the casting insert with the apex up. This cone shape was kept from the ceramic insert in order to maximize separation of the button from the hearth during heating. In general the heating process was the same; a lower amperage was applied to heat the button concentrating on the cone apex, after the center started to melt the amperage was increased and the material melted and flowed into the casting insert and quartz mold. Although results were less consistent i.e. sometimes the casting would flow into the quartz and sometimes it would simply pool in the insert, the alloys were less contaminated, because there was no ZrO_2 or graphite and contact with the quartz while heating is minimized. Also, the melts could be re-used if the casting failed. A number of variations in heating techniques were tried which included; heating slowly with the heat concentrated in the center, heating the material quickly all over, heating the material quickly concentrating in the center, centering the shaped button or laying the shaped button on the tapered side, and varying gas purge rates, or combinations of techniques. Varying amounts of success was obtained from each heating technique. It appeared that for different casting batches, even those with the same composition, a different technique might be more successful. Over the course of several fabrication campaigns it was determined that the original casting insert taper was too steep and would not allow the material placed on the side of the taper to be heated to an adequate superheat. A new insert was fabricated with a slightly less shallower taper that was used in most of the casting campaigns. However, even though several techniques were developed, a consistently successful technique was not identified. It was left up to the operator experience to determine which of the techniques may work based on the molten materials behavior. It was found to be more of an art than a science making reproducibility nearly impossible.

Recently the AFC program has again included transuranic fuel in the latest irradiation test and additional transuranic bearing alloys were needed to support the current revision of the Metals Fuel handbook. Due to the need for transuranic alloys casting operations have restarted in FMF. Due to the levels of success seen with the copper casting and shaping insert, this method was chosen for implementation in FMF in order to avoid any additional melt contamination resulting from the ceramic insert. During the fabrication of the AFC-3F irradiation test alloys, 3F-2 through 3F-4, casting again presented a challenge. Personnel changes and changing from the ceramic insert to the all copper technique required process development. The basic configuration remained the same; however, several alloy compositions would not drop into the mold to form a solid rod of sufficient length for testing. One of the first changes made was removal of the plug inserted into the bottom of the quartz mold. The quartz tube was instead placed on a hexagonal standoff with gas pathways machined onto the top surface to ensure gas movement during the casting process. As development continued the success of the technique seemed to depend largely on operator experience. The taper angle of the casting insert was reduced further to 10°. At this amount of taper, once the material is fully molten additional heat could be briefly applied before the charge began to flow to the mold opening. This change appeared to be the most significant. The current hearth set up is shown in Appendix A Sketch 1-5. These sketches will serve as the starting point for continued technique or hearth development. Shown in sketches 1-5 are the overall hearth assembly, casting hearth, casting insert for 4-5 mm diameter quartz, buttoning insert, and the mold supporting components.

In addition to AFC-3F alloys, several characterization alloys were also cast. Characterization alloys are generally used for chemical, microstructure, and thermal analysis. The size requirements for these samples are less stringent than those for irradiation testing samples. Because of the relaxed size requirement another casting technique was introduced; casting into a split copper mold. Buttoning and shaping were done essentially the same way, but instead of casting into a quartz tube, the material was cast into a split block with the appropriate size cavity machined into it along with a gas relief. Sketches of the split block molds are shown in Appendix A Sketch 6-10. The sketches show a split block mold for pins 4-6 mm in diameter and 10 mm in diameter. Also shown is a shaping insert used to produce a flatter, less conical button. In addition, the sketches show other molds made to change the height of the molten pool in the arc melting chamber. Because the glovebox configuration is not standardized as far as arc melter location is concerned some arc melters may use a higher hearth than others depending on operator comfort and experience.

Using the above modifications, technique development, and the hardware documented in Appendix A several transmutation alloys were successfully cast in FMF. In addition to the transmutation alloys listed in the following section, additional optimized and integral FCCI barrier fuel specimens were cast using the techniques and hardware documented in this report in the FASB facility.

3. FY16 FUEL CASTING

During the FY16 transmutation fuel casting campaign 7 transmutation alloys were cast, including 3 optimized fuel alloy compositions. Three AFC-3F irradiation test alloys were also cast. Casting parameters of the individual alloys are recorded on INL Form-1598. These forms have been included in Appendix B of this document. Table 1 below summarizes the casting parameters and resulting masses. Unless noted on the Form-1598, all individual components are placed on the wire brushed buttoning hearth together and buttoned. During melting of some alloys an unknown soot type material was left on the hearth and in the arc melting chamber. This soot was wire brushed off between melts to maintain cleanliness. All molds were coated with a slurry of ZrO_2 powder and ethyl alcohol. The coating was applied using a cotton swab. The ZrO_2 powder is from a legacy EBR-II stockpile; however, the label shows the material to be from Ferro Corporation (www.ferro.com). No measurements are taken of the ZrO_2, because it is quite thin and fragile. Again, based on individual experience it has been found that a thinner coating was better because a thick coating might leave pockets of alcohol which would evaporate quickly when contacted by the flowing metal and this would affect the surface finish of the pin at a minimum and might dramatically affect the flow of the material. A thick coating might also transfer the surface roughness to the finished pin. A subjective thickness gauge was made based on the visual appearance of the coating; a coating thin enough to be seen, yet not totally opaque was determined to be adequate. As mentioned earlier often during the casting process casting attempts were made, but the alloy did not flow fully into the mold or form a solid usable rod. Whenever possible the alloy was re-buttoned and casting was attempted again. The disadvantage of recycling the failed castings is the possible buildup of contaminates such as oxygen, nitrogen, etc. Although no direct correlation has been made, it is expected that the more times an alloy is melted the more likely contaminates are to build up which may affect casting, irradiation, and general characterization behavior. During casting operations the number of melts was recoded on Form-1598 or other appropriate documentation. Table 2 below shows a summary of the number of times each alloy was melted.

Table 1- Summary of FY16 transmutation fuel casting campaign

Casting ID	Composition (wt%)	Mold Used	Initial Mass (g)	Final Mass (g)	Final Use
AFC-P10Z-1015-SLUG1	90Pu-10Zr	5 mm copper	22.01	21.649	characterization
AFC-P30Z-1015-SLUG1	70Pu-30Zr	5 mm copper	16.992	16.899	characterization
AFC-U20P-10Z-1115-SLUG1	70U-20Pu-10Zr	4.3 mm quartz	19.924	19.749	ANDE†
AFC-U20P2A3N10Z-115-SLUG1	65U-20Pu-10Zr-2Am-3Np	4.3 mm quartz	27.013	26.886	ANDE†
AFC-U20Pu10Z-3.86Pd-1215-SLUG1	66.14U-20Pu-10Zr-3.86Pd	5 mm copper	11.991	11.951	Optimized alloy characterization
AFC-U20Pu10Z-3.86Pd-4.3Ln-1215-SLUG1	61.84U-20Pu-10Zr-3.86Pd-4.3Ln*	5 mm copper	12.994	12.936	Optimized alloy characterization
AFC-U19P-.7Z-4.3T-5M-1215-SLUG1	71U-19Pu-0.7Zr-4.3Ti-5Mo	5 mm copper	13.009	12.960	Optimized alloy characterization
AFC-3F-2	90U-10Zr**	4.3 mm quartz	14.96	14.945	
AFC-3F-3	70U-20Pu-10Zr**	4.3 mm quartz	24.152	23.925	
AFC-3F-4	90U-10Zr**	4.3 mm quartz	15.044	15.001	

*- Ln- lanthanides, 53Nd-25Ce-16Pr-6La
**- U was made up of DU and HEU pieces
†- ANDE- Advanced Non Destructive Evaluation development at Los Alamos National Laboratory

Table 2- Summary of the number of times each transmutation alloy was melted

Casting ID	# buttoning	# of casting attmpts	Total Melts
AFC-P10Z-1015-SLUG1	4	2	6
AFC-P30Z-1015-SLUG1	8	6	14
AFC-U20P-10Z-1115-SLUG1	6	4	12
AFC-U20P2A3N10Z-115-SLUG1	4	2	6
AFC-U20Pu10Z-3.86Pd-1215-SLUG1	Not Recorded-Specific alloying sequence see Appendix B		
AFC-U20Pu10Z-3.86Pd-4.3Ln-1215-SLUG1	Not Recorded-Specific alloying sequence see Appendix		
AFC-U19P-.7Z-4.3T-5M-1215-SLUG1	Not Recorded-Specific alloying sequence see Appendix		
AFC-3F-2	5	3	8
AFC-3F-3	6	4	10
AFC-3F-4	3	1	4

4. CONCLUSIONS/DISCUSSION

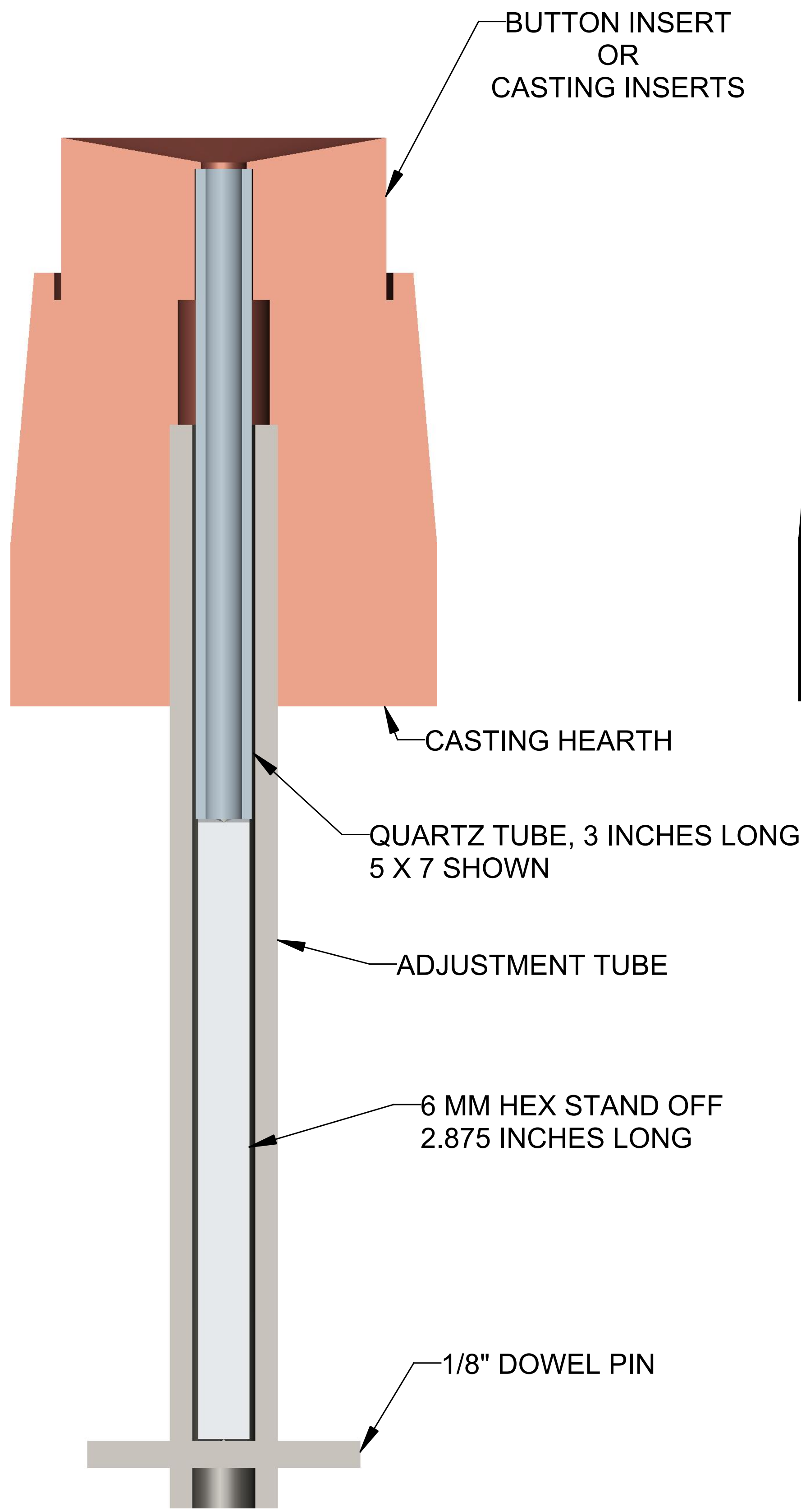
Arc casting has been used to cast AFC samples since 2002 and has been used to cast nearly all AFC irradiation tests and characterization samples. The only notable departure from arc melting was the casting of the AFC-3A/B alloys. During the course of these casting campaigns a number of modifications were made to the original casting technique. Technique development has included several changes in hardware design, multiple materials, and multiple heating rates. Nearly all of these changes were made during the casting campaign itself and were accompanied by minimal documentation. An attempt has been made through this document to capture some of the historical developments. Throughout these changes improvements seemed to be quite variable, depending on the composition of the alloys to be cast, original feedstock forms and/or source, glovebox atmosphere, and most importantly, operator experience. Anecdotally it has been reported that during some tests only one casting operator could successfully cast alloys, while during the next campaign only another could successfully cast. Although this statement is not wholly supported by accompanying documentation, the arc casting process is very operator dependent, and substantial experience is needed to be consistently successful. It is only through experience that an operator learns what modifications need to be made or when and how to apply appropriate heat. While results were slightly more consistent when a ceramic insert was used, this introduces an unacceptable risk of high contamination. The variability of the process stems from the lack of temperature feedback and the inability to control the amount of superheat applied to the alloys.

Appendix A contains sketches of the currently used arc melting hardware for both quartz and copper molds. These will be used as an informal configuration control method going forward. Improvement may be made on the existing systems. Various monitoring systems exist that can will record arc amperage and voltage. If these parameters are recorded versus time, successful casting could be compared to unsuccessful casting and differences determined. During FY17 casting campaigns the feasibility of incorporating such a system will be investigated. A significant finding of the most recent casting campaign is the importance of the casting insert angle. This was previously alluded to in laboratory notebooks, however, had not been passed onto new personnel. Based on results from the most recent casting campaign the angle is a very important parameter that can be modified through additional hardware changes. Improvements can also be made to the process by changing the heat input method. The nature of the arc metlting process presents certain advantages and disadvantages. The main advantage is the ability to quickly produce lab scale quantities of a number of small fuel alloys, while maintaining even volatile elemental compositions. However, because of the difficulty in controlling the arc temperature and hearth material contamination concerns control of the casting process is limited. Other methods of heating may provide adequate mixing, especially if the starting material is an arc melted master alloy, quick heating times, and controllable heating rates and hold times and temperatures. During FY17 a conceptual design will be developed to investigate if induction heating can meet these requirements. If it is deemed feasible a prototype system will be fabricated and casting development initiated.

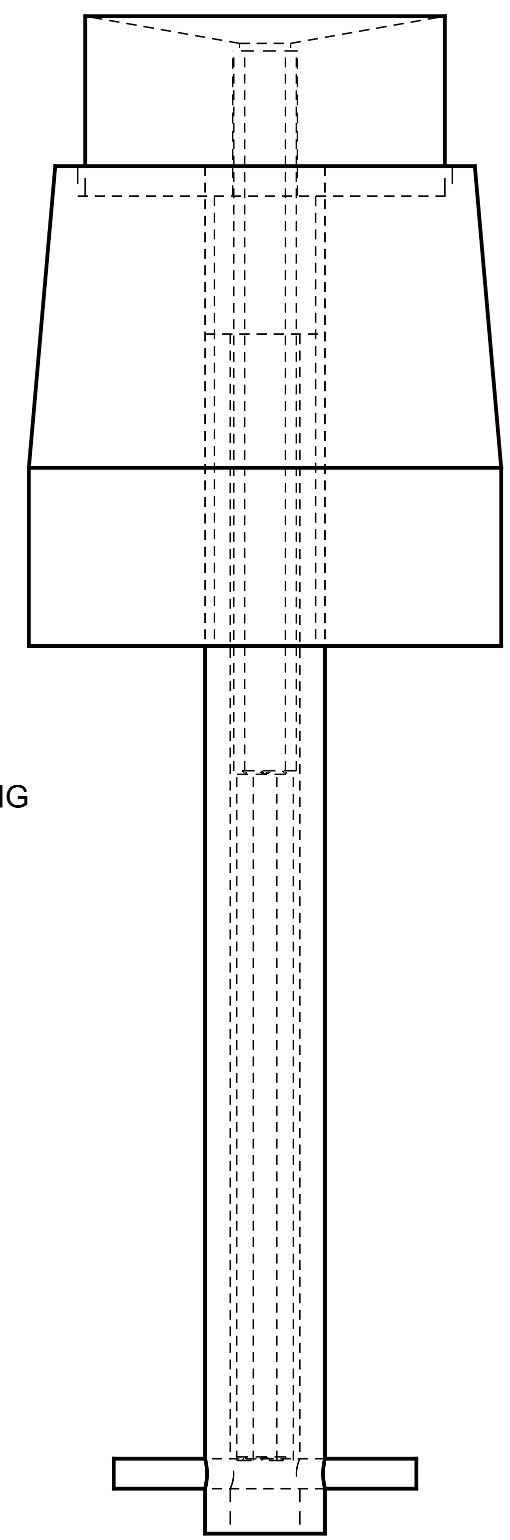
5. Acknowledgements

The authors would like to gratefully acknowledge contributions of various casting operators in the Casting Laboratory, FMF, and FASB. Without the previous and ongoing improvements of all these skilled personnel casting could not take place, which would bring the on-going research to a stand-still.

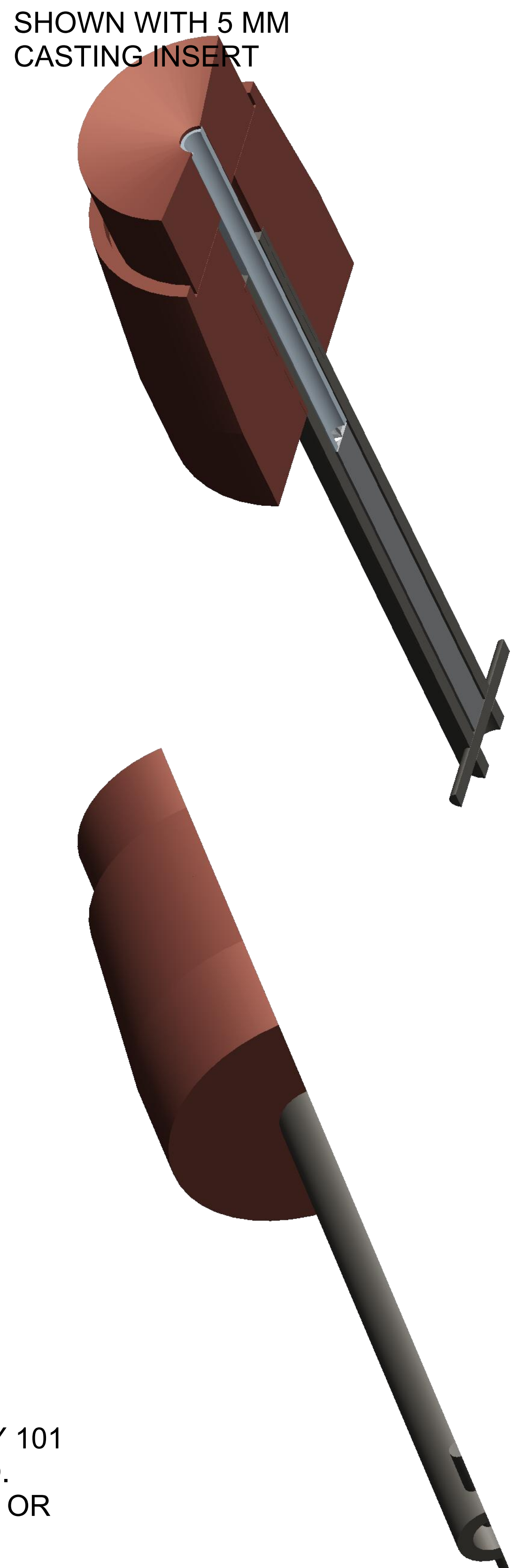
1. Appendix A- Arc Melter Hardware Sketches



SCALE 5/4



SCALE 5/4



SCALE 7/8

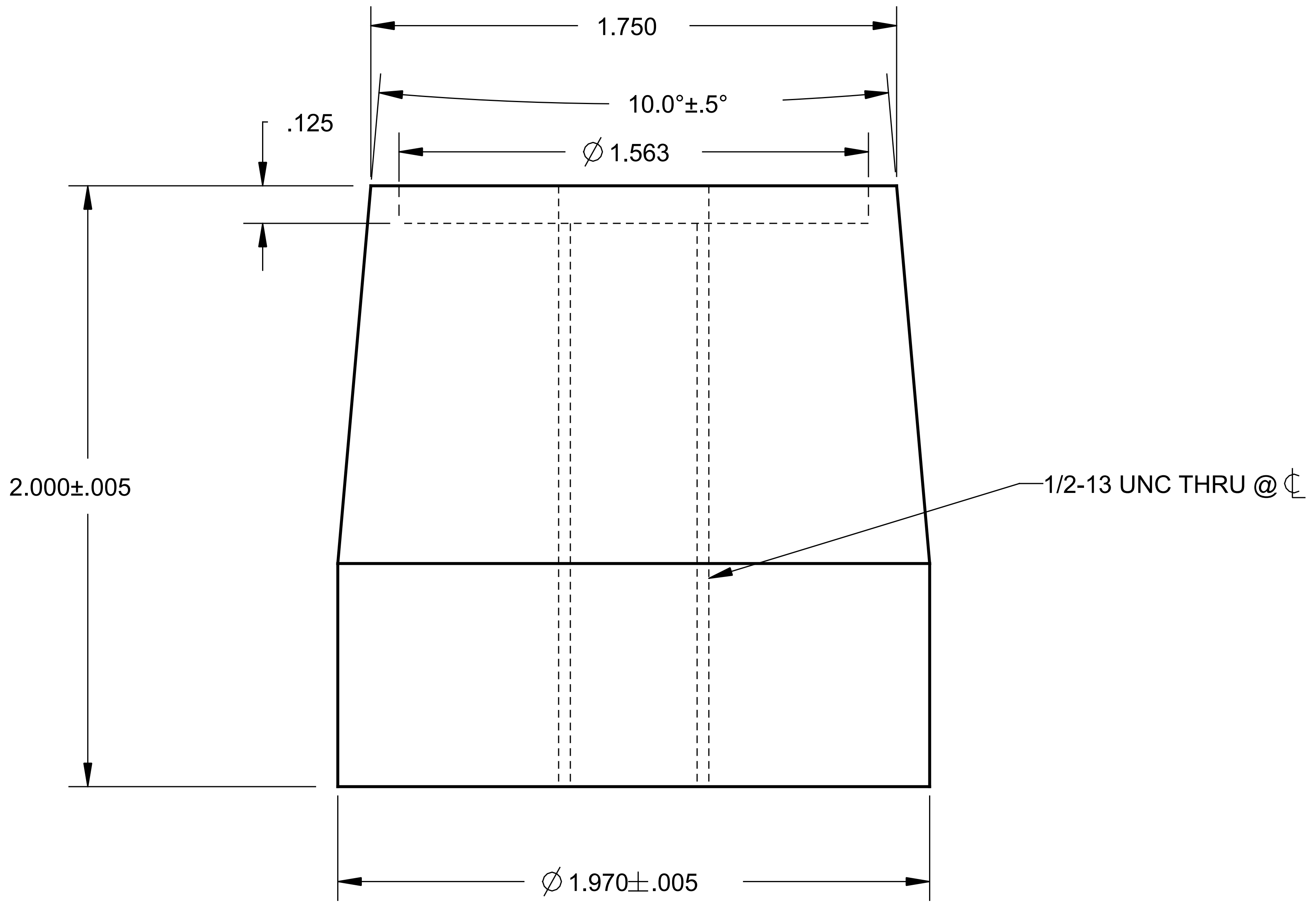
NOTES:

1. ROUND ALL SHARP CORNERS AND EDGES.
2. PROVIDE ALL MATERIALS.
3. DOWEL PIN, McMASTER CARR PART # 97395A452.
4. MAKE COPPER ITEMS FROM ALLOY 101 102, 110 OR CUSTOMER APPROVED.
5. MAKE STAINLESS ITEMS FROM 304 OR 316 SST.

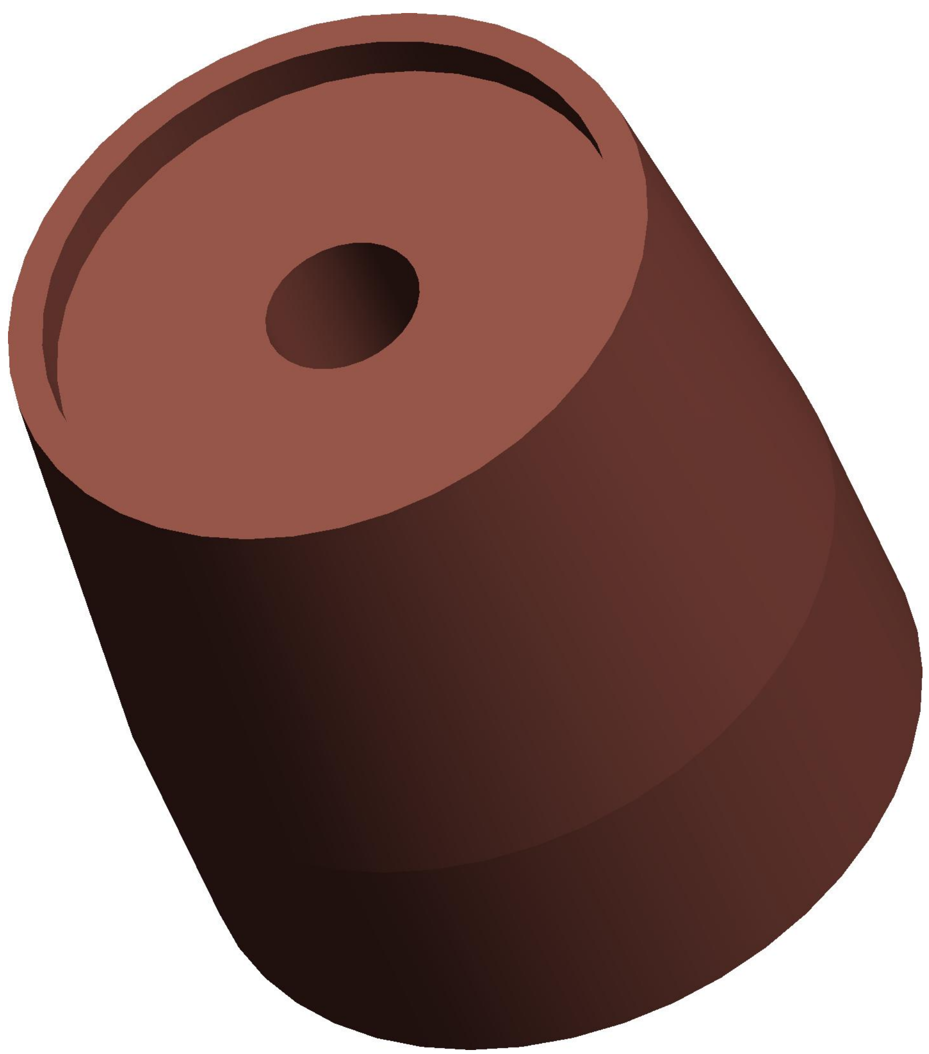
ARC MELTING HEARTH ASSY

SKETCH A REV 6
SHEET 1 OF 10
April 5, 2016
Blair Grover

NOTES:
1. ROUND ALL SHARP CORNERS
AND EDGES.
2. FABRICATE FROM COPPER.



SCALE 2/1

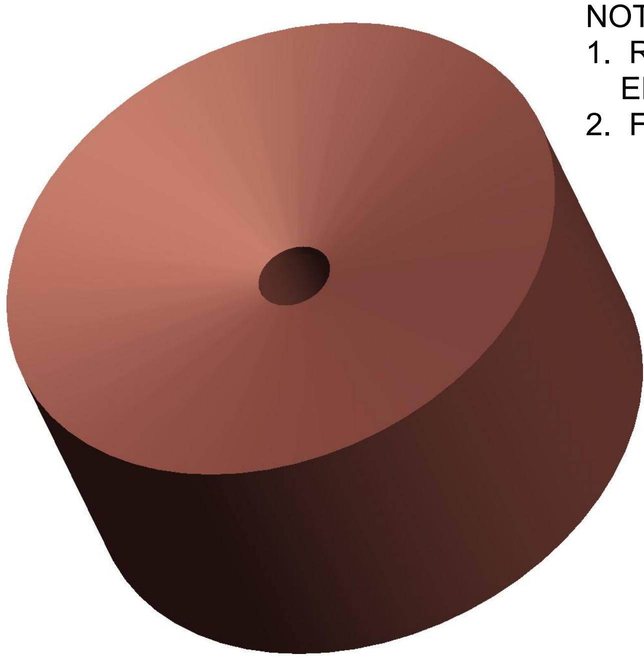


SCALE 2/1

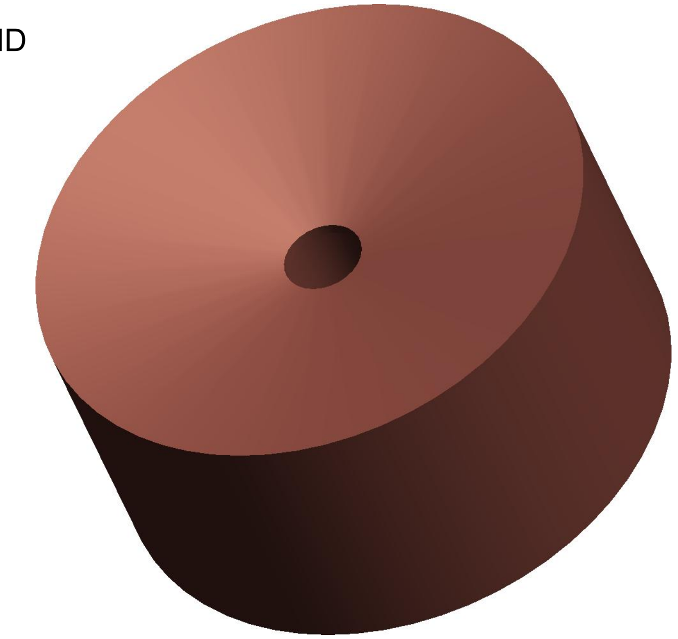
CASTING HEARTH

SKETCH A REV 6
SHEET 2 OF 10
April 5, 2016
Blair Grover

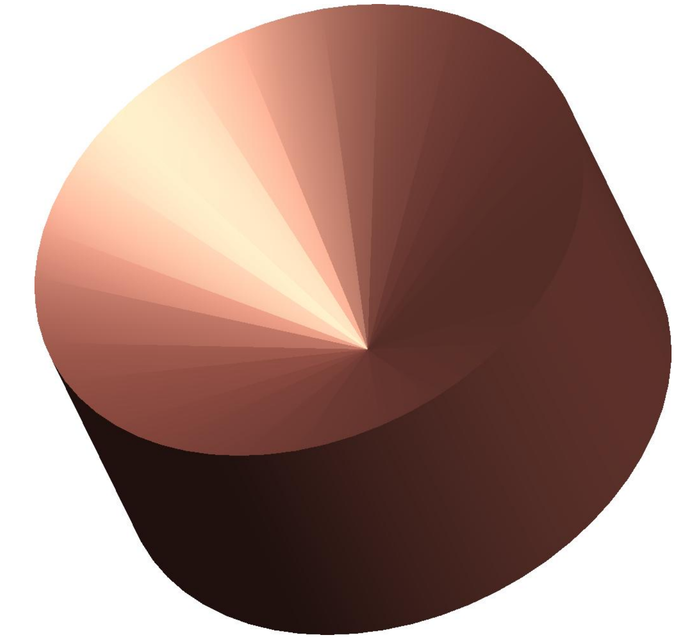
NOTES:
1. ROUND ALL SHARP CORNERS AND
   EDGES.
2. FABRICATE FROM COPPER.



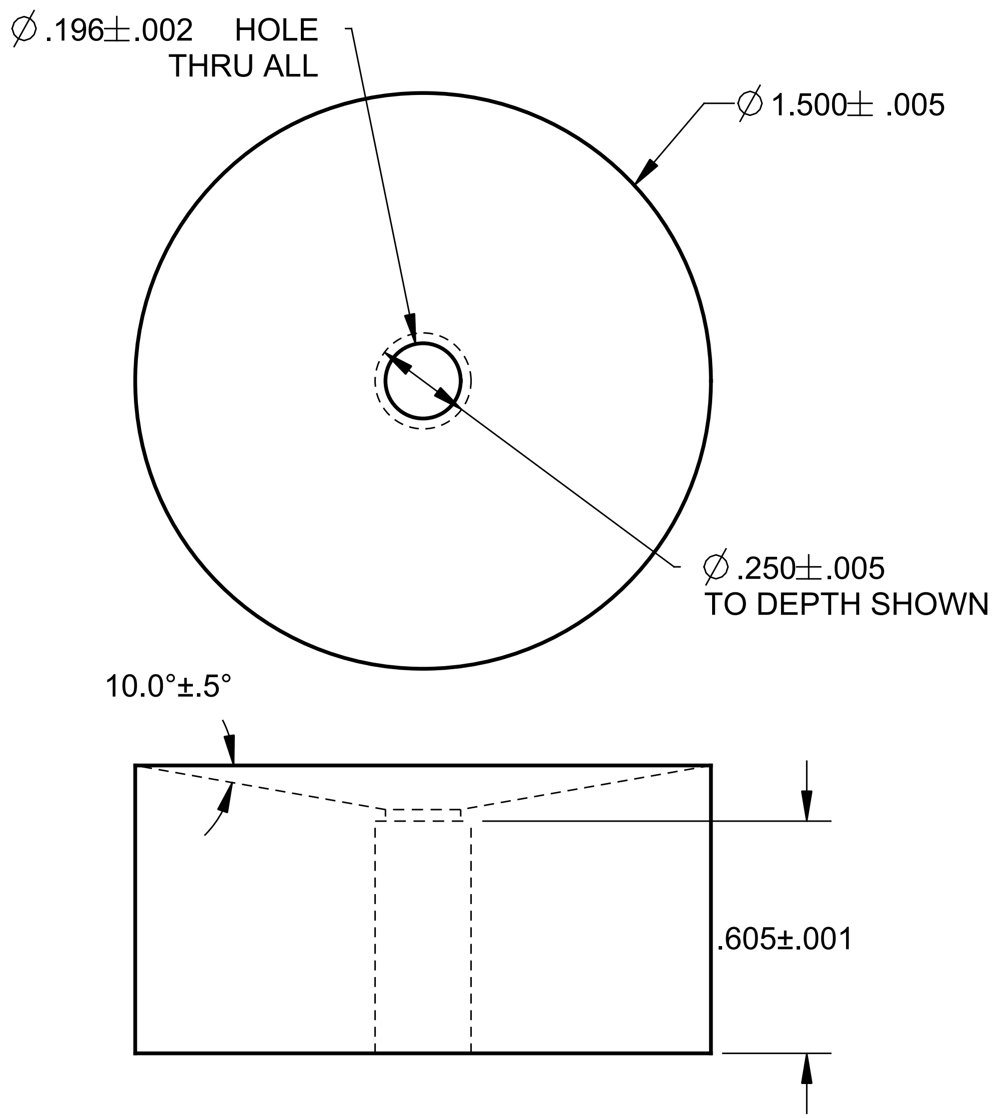
4 mm CASTING INSERT
SCALE 2/1



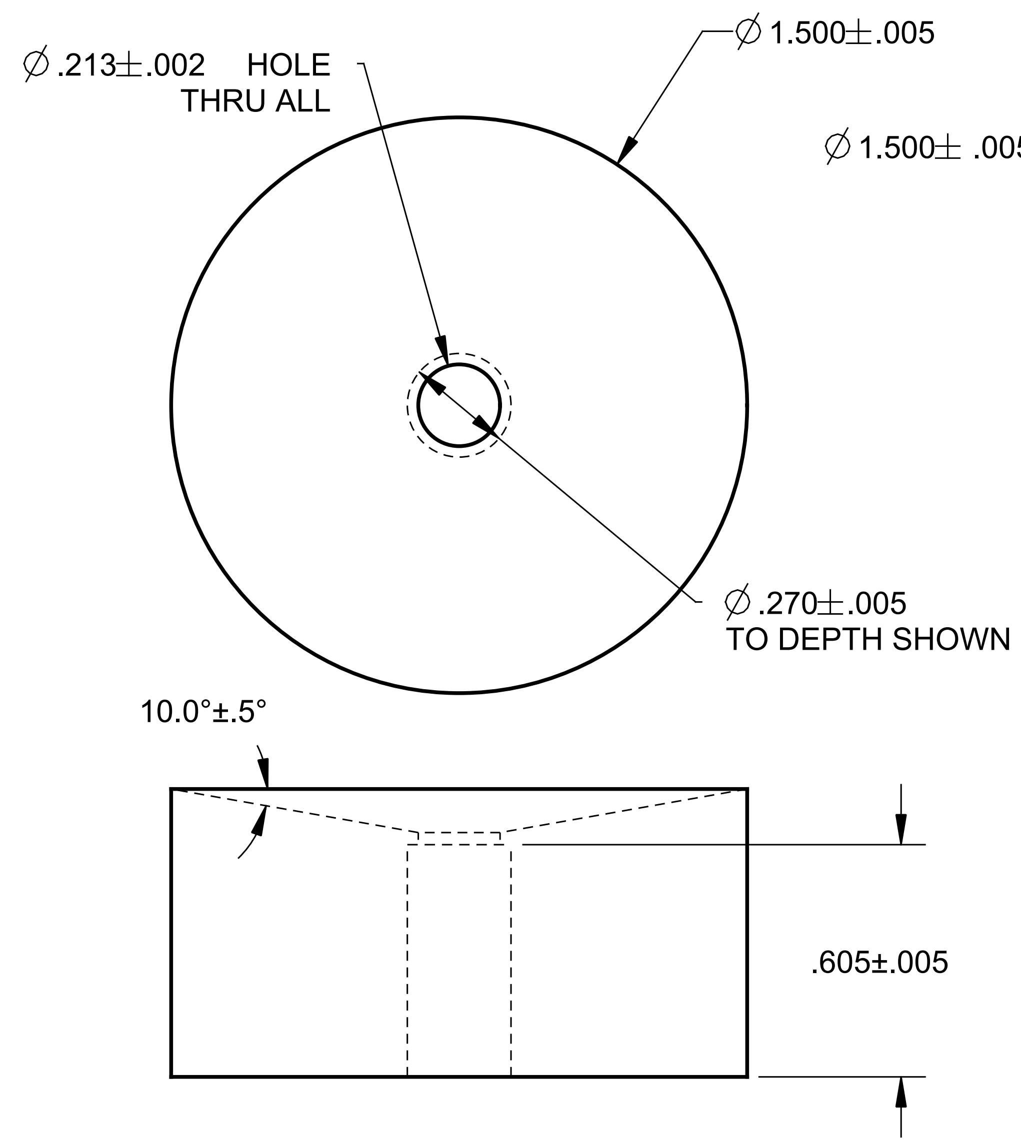
EBR II CASTING INSERT
SCALE 2/1



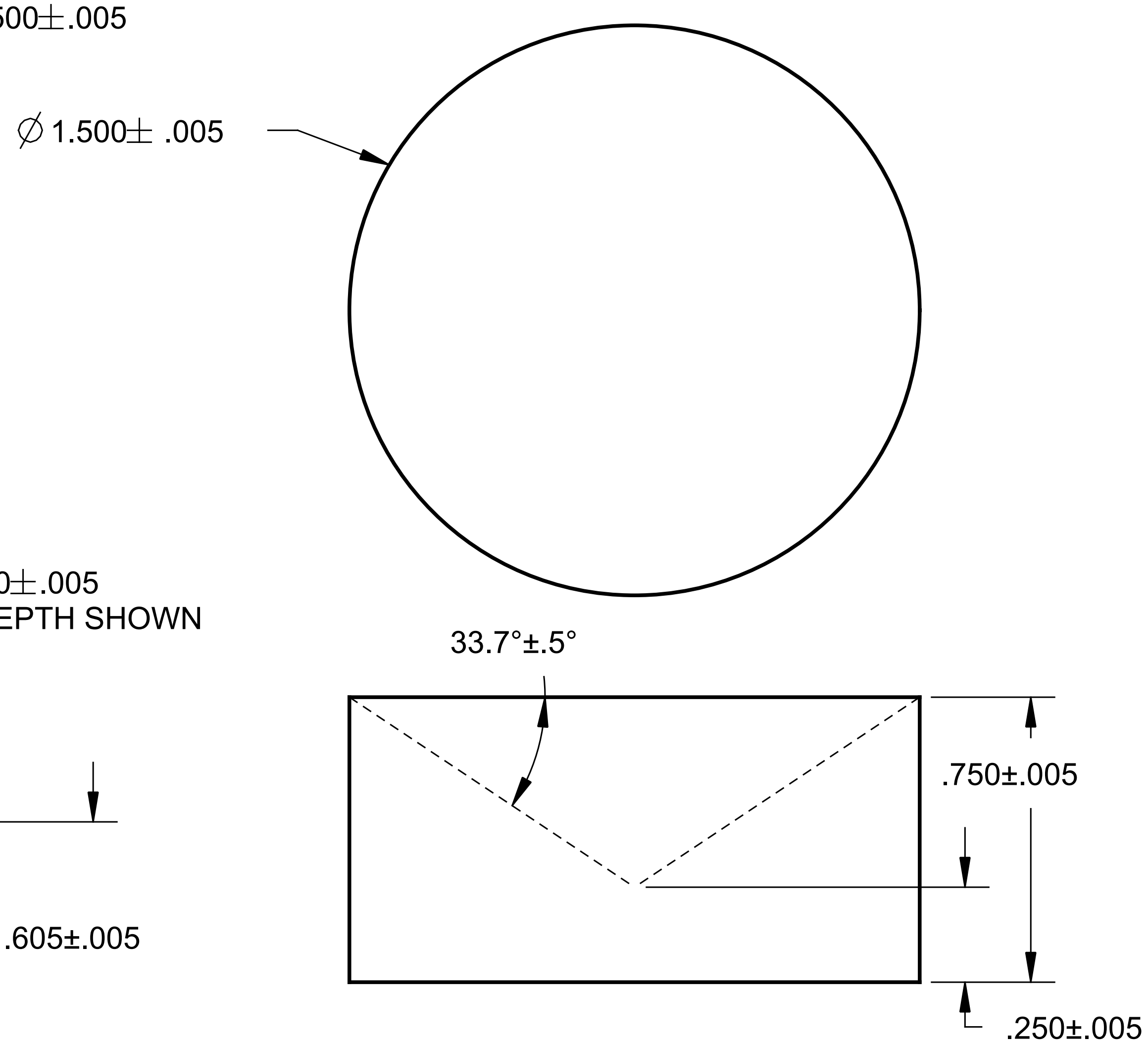
BUTTON INSERT
SCALE 2/1



4 MM CASTING INSERT
SCALE 2/1



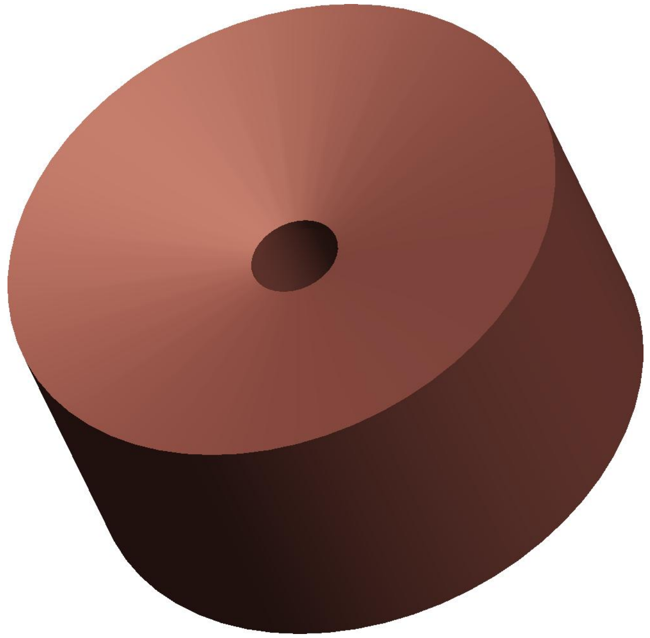
EBR II CASTING INSERT
SCALE 2/1



BUTTON INSERT
SCALE 2/1

HEARTH INSERTS

SKETCH A REV 6
SHEET 3 OF 10
April 5, 2016
Blair Grover

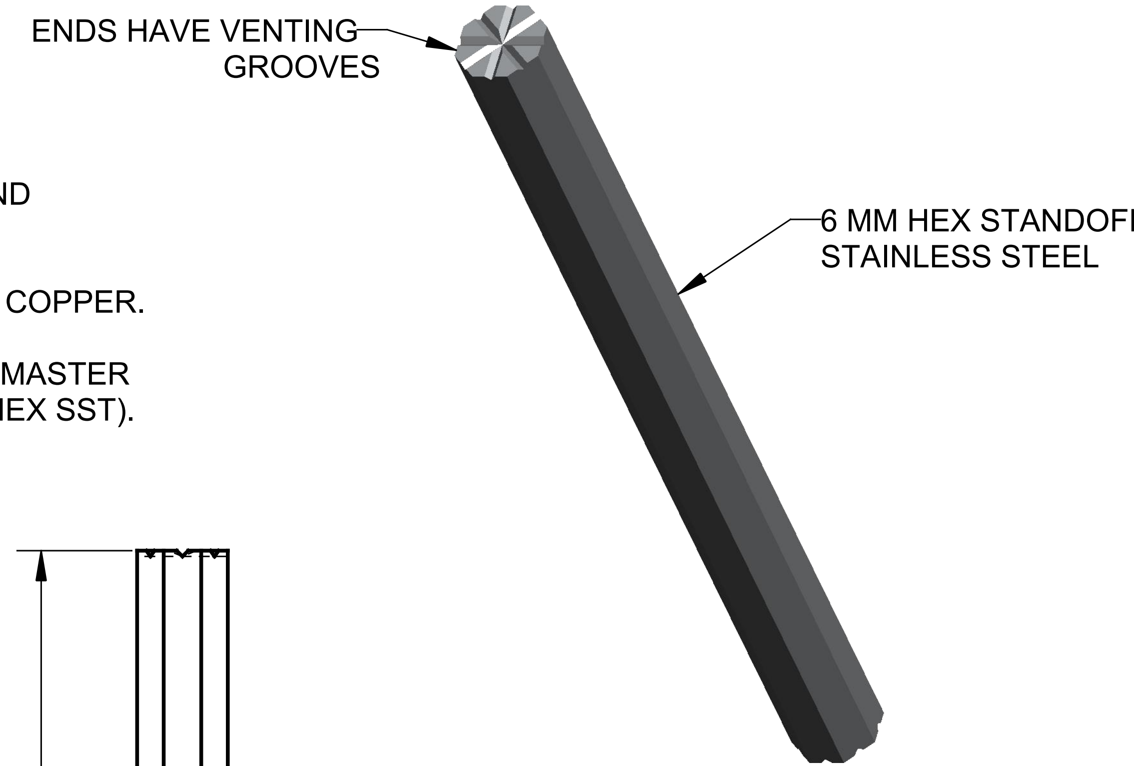


SCALE 2/1

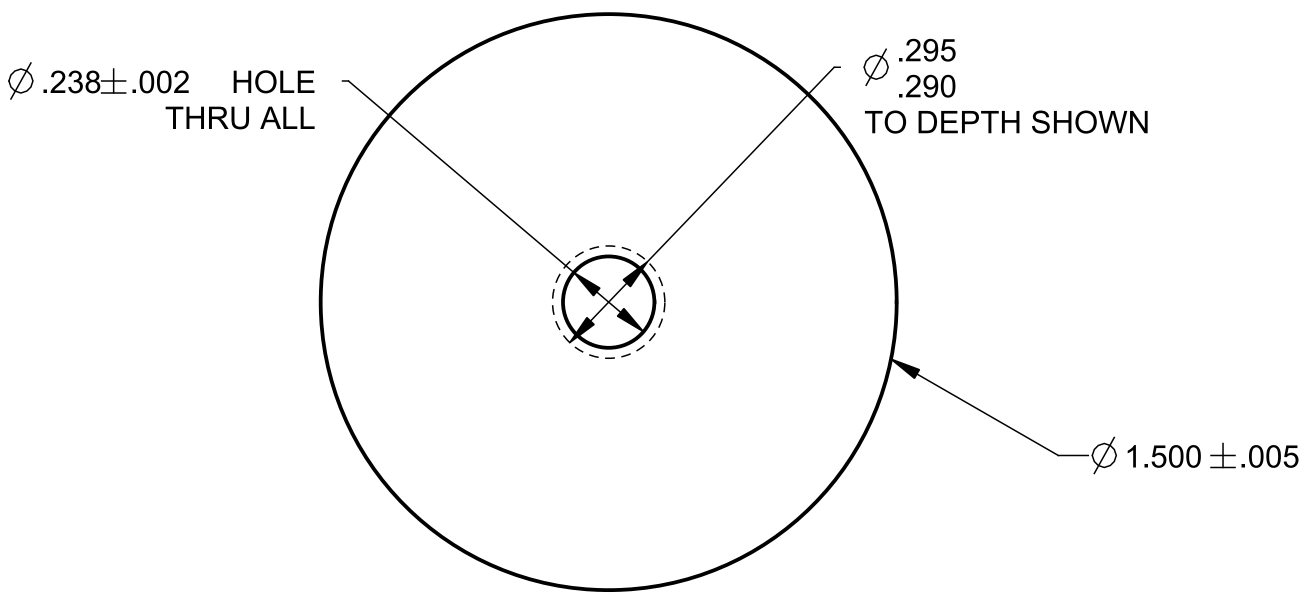
NOTES:
1. ROUND ALL SHARP CORNERS AND EDGES.

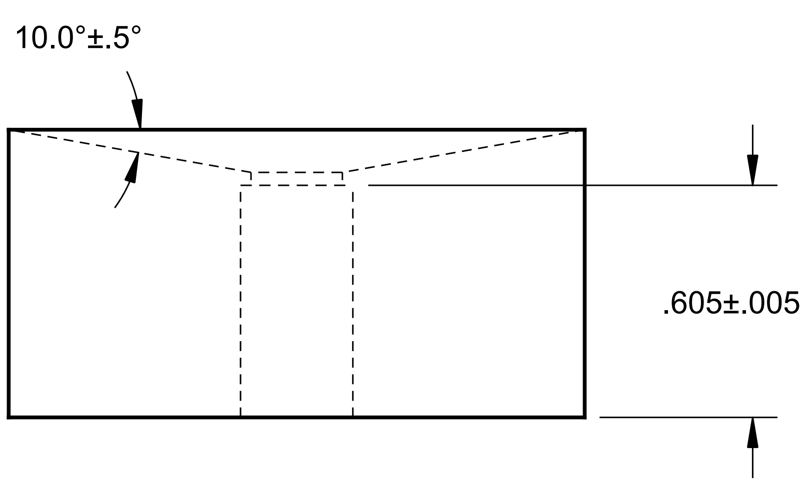
2. FABRICATE FROM INSERT FROM COPPER.

3. FABRICATE STANDOFF FROM McMASTER CARR PART No. 89205K25 (6 MM HEX SST).

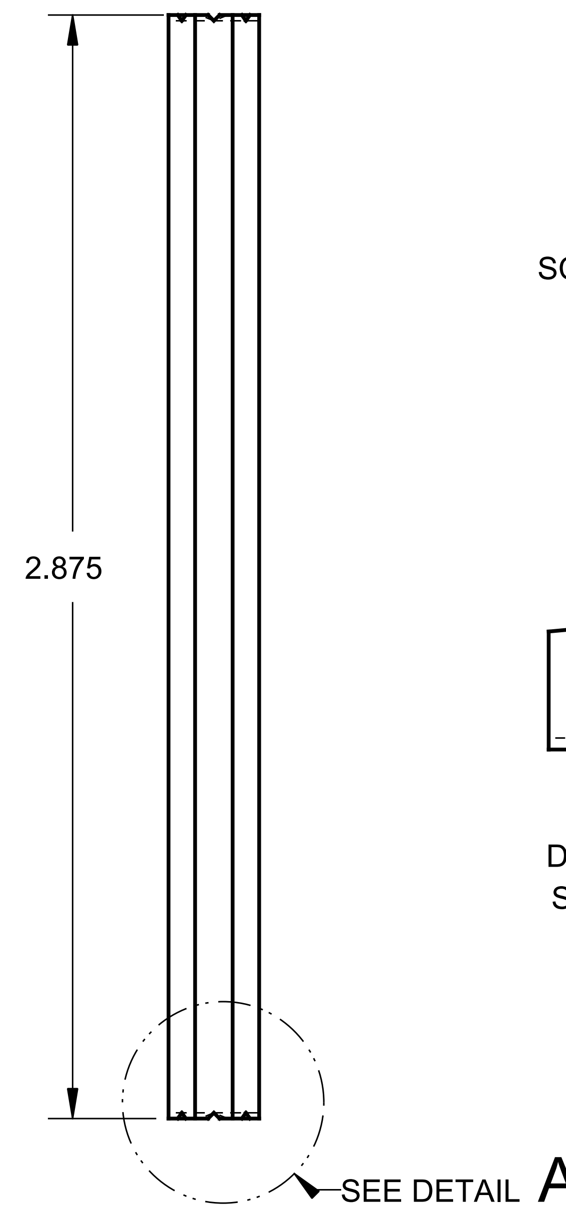


SCALE 2/1

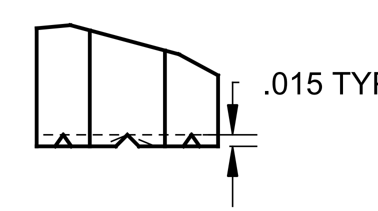




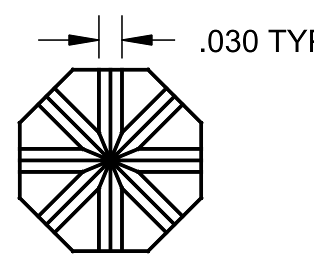
5 MM CASTING INSERT
SCALE 2/1



STANDOFF
SCALE 2/1



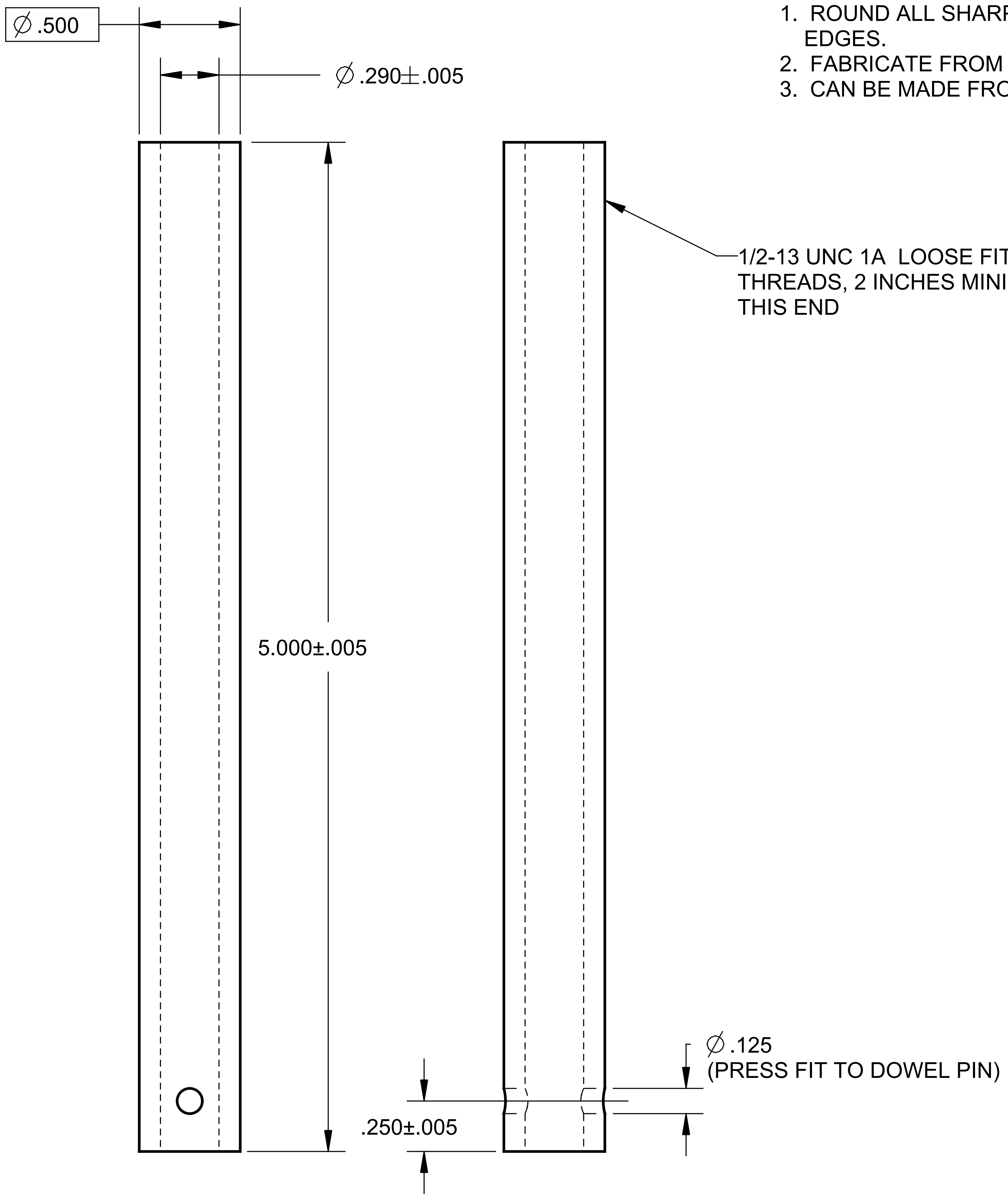
DETAIL A
SCALE 4/1



STANDOFF END VIEW
SCALE 4/1

HEARTH INSERT AND STANDOFF

SKETCH A REV 6
SHEET 4 OF 10
April 5, 2016
Blair Grover



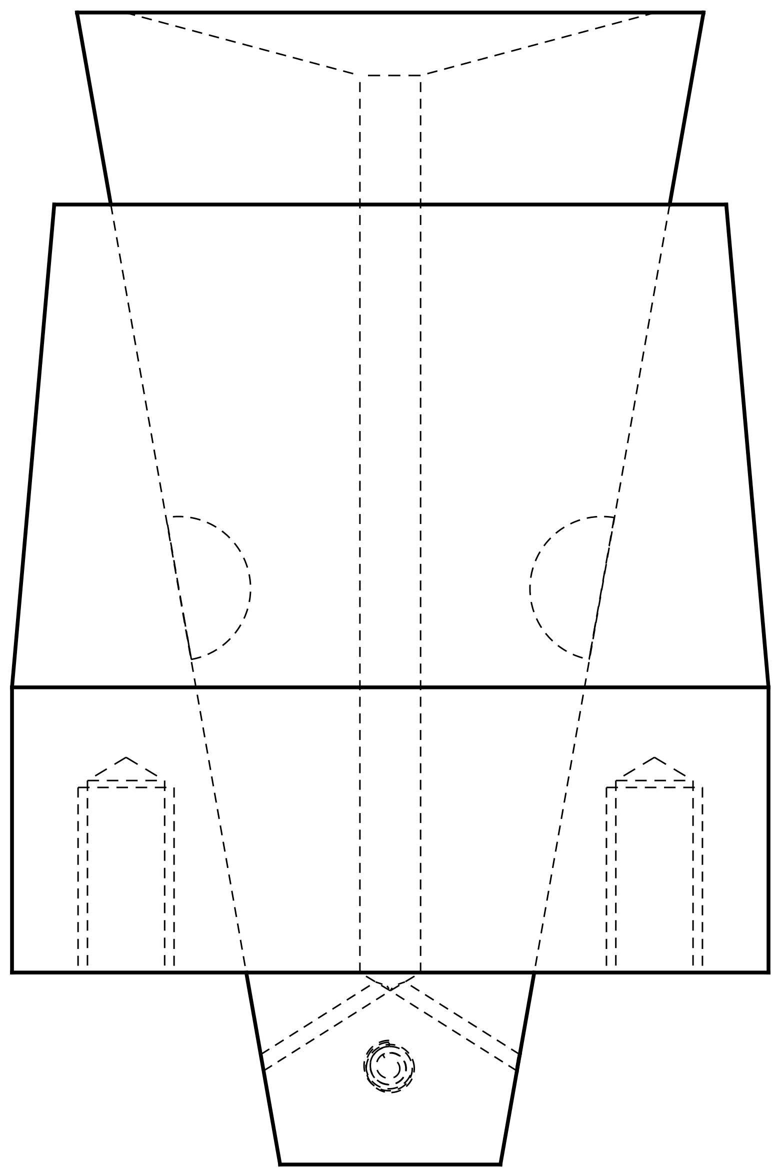
NOTES:

1. ROUND ALL SHARP CORNERS AND EDGES.
2. FABRICATE FROM 304 OR 316 SST.
3. CAN BE MADE FROM BAR OR BOLT.

SCALE 3/2

ADJUSTMENT TUBE

SKETCH A REV 6
SHEET 5 OF 10
April 5, 2016
Blair Grover



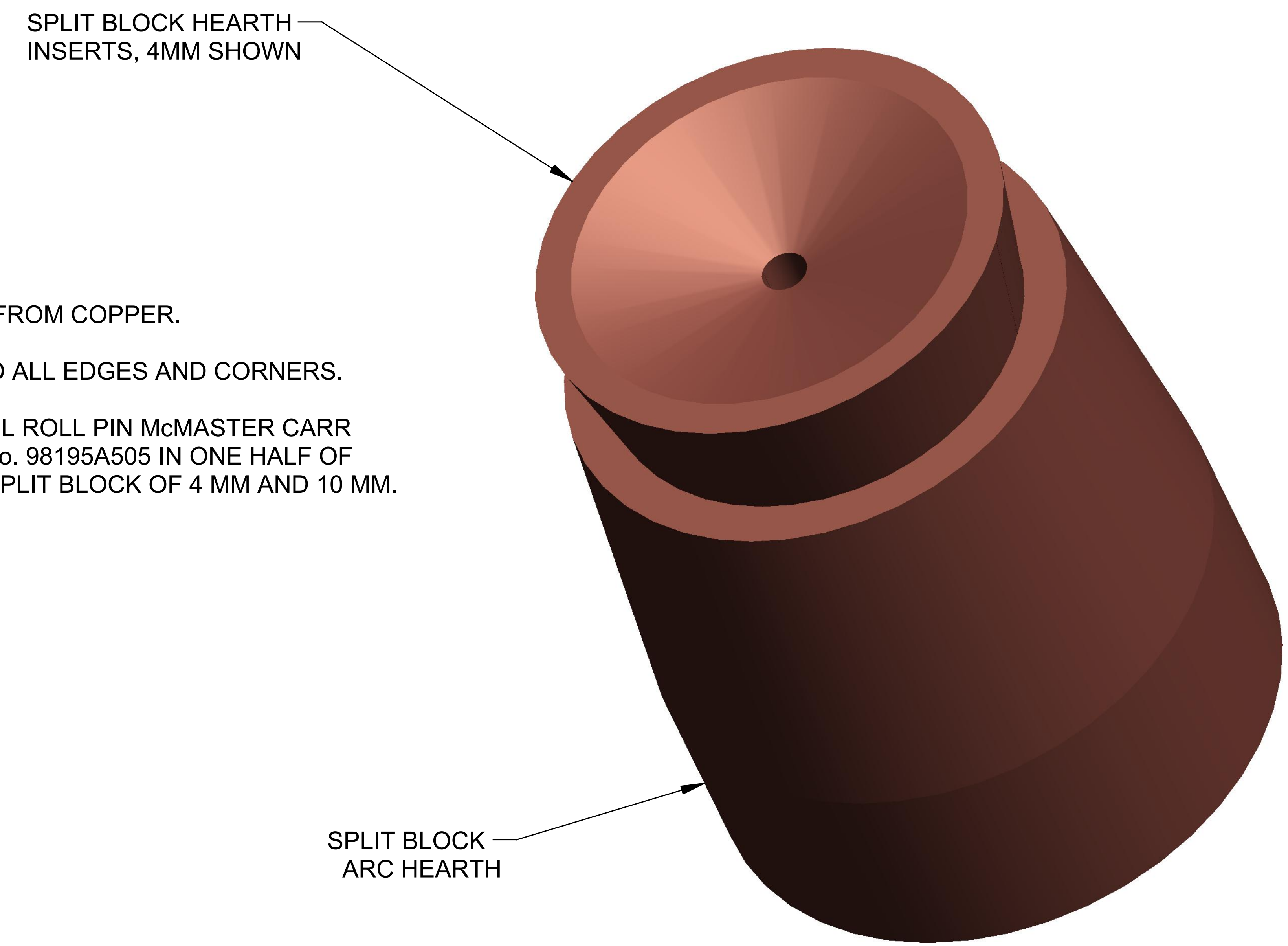
SCALE 2/1

NOTES:

1. MAKE FROM COPPER.

2. ROUND ALL EDGES AND CORNERS.

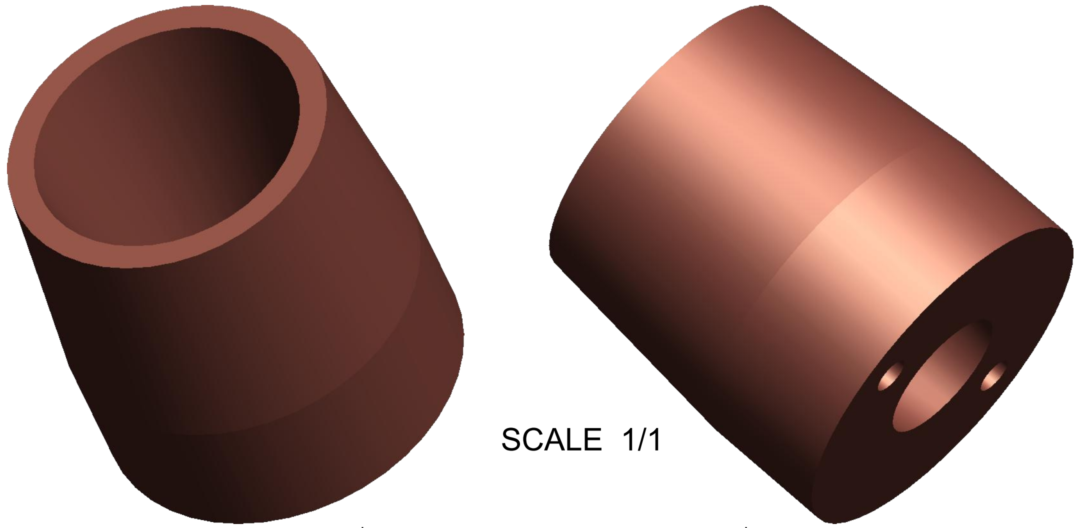
3. INSTALL ROLL PIN McMASTER CARR PART No. 98195A505 IN ONE HALF OF EACH SPLIT BLOCK OF 4 MM AND 10 MM.



SCALE 2/1

SPLIT BLOCK CASTING HEARTH ASSEMBLY

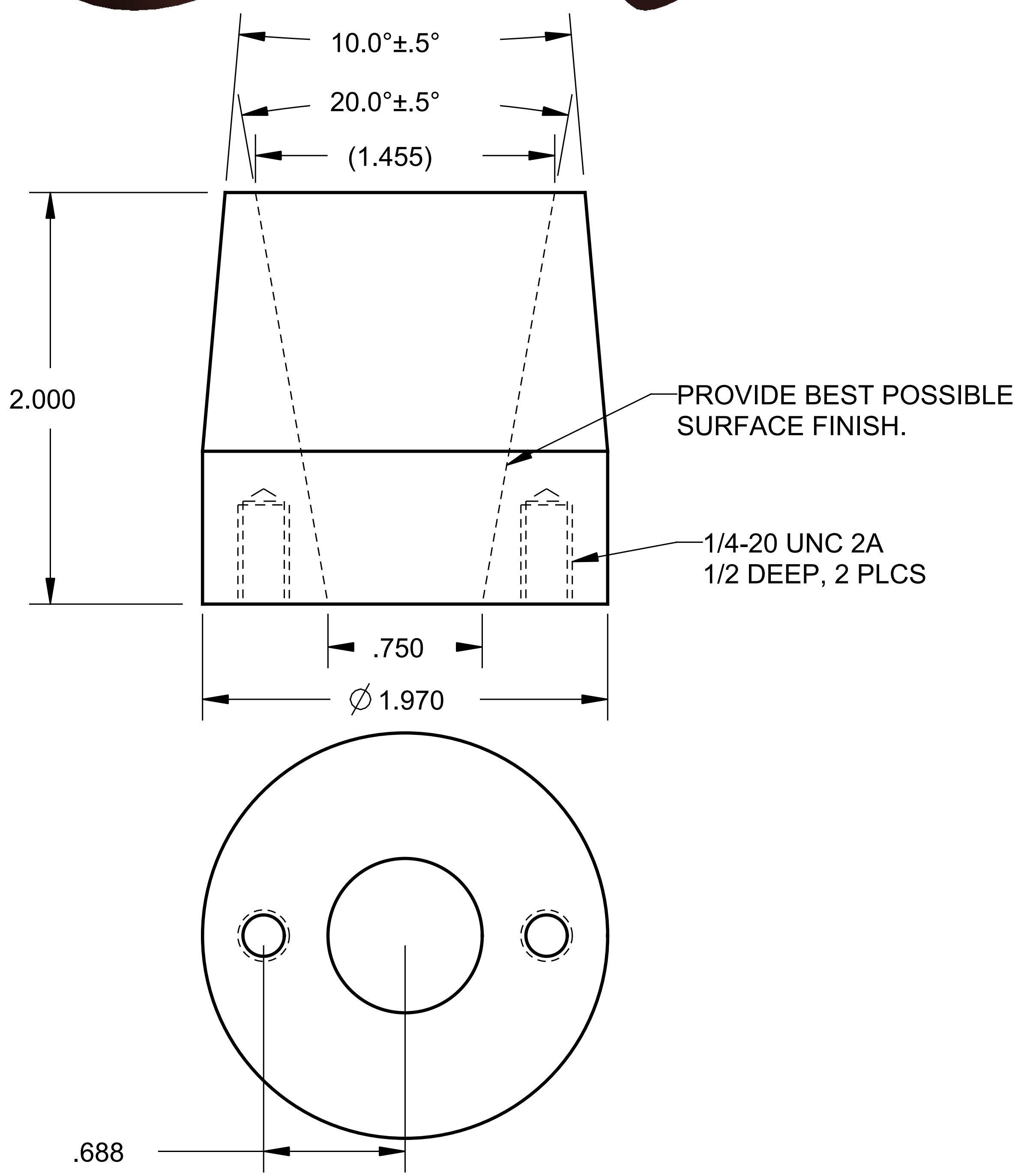
SKETCH A REV 6
SHEET 6 OF 10
April 5, 2016
Blair Grover



SCALE 1/1

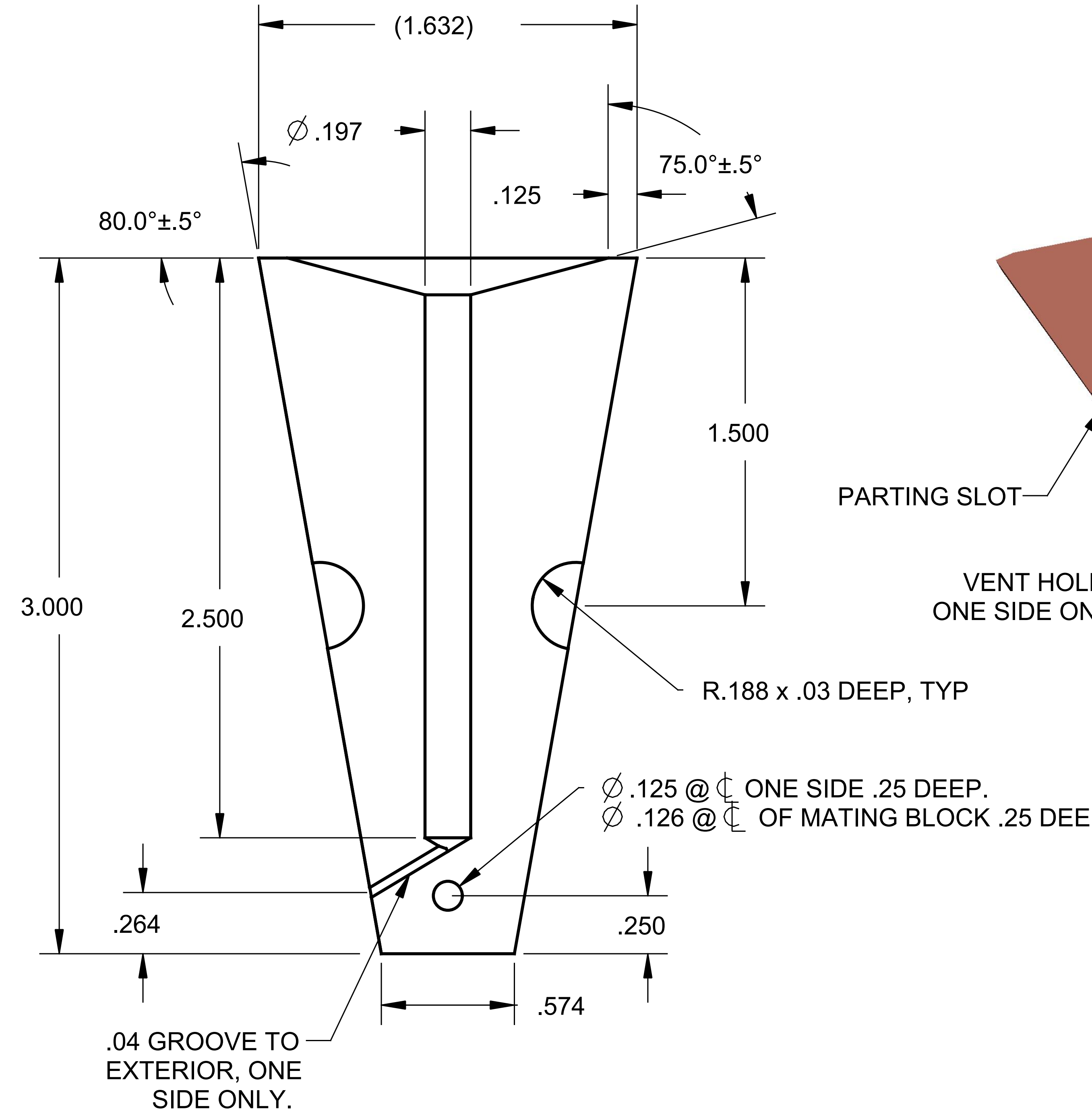
NOTES:

1. MAKE FROM COPPER.
2. ROUND ALL EDGES AND CORNERS.
3. PROVIDE BEST SURFACE FINISH POSSIBLE ON INTERIOR MATING SURFACE OF ARC HEARTH TO SPLIT BLOCK INSERT.

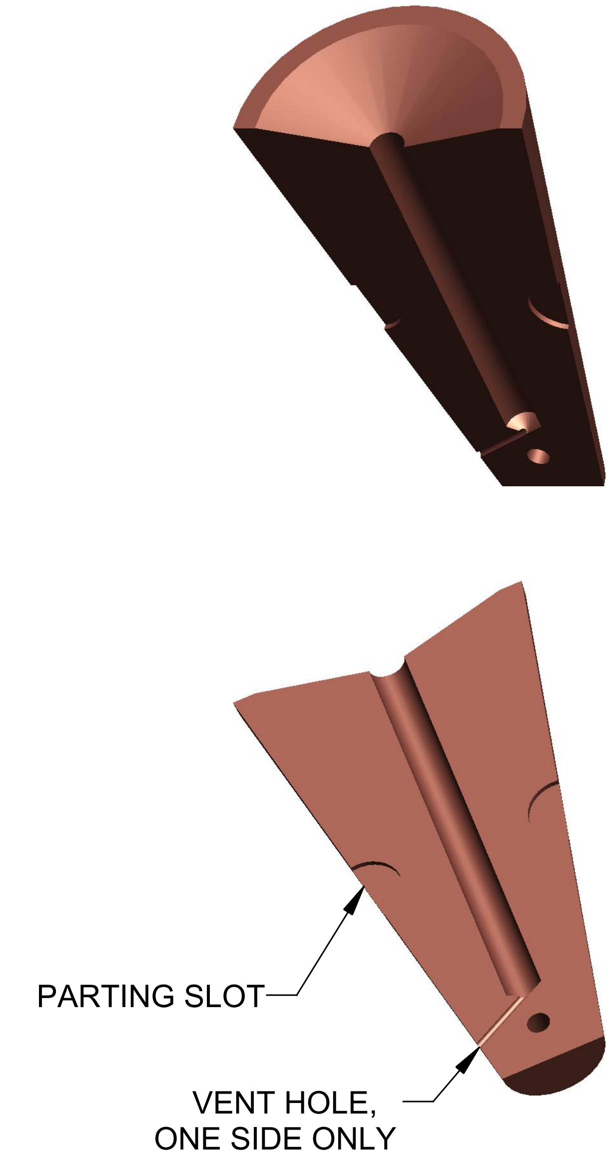


SCALE 5/4

SPLIT BLOCK ARC HEARTH



SCALE 3/2



5 MM SPLIT BLOCK HEARTH INSERT

SKETCH A REV 6
SHEET 7 OF 10
April 6, 2016
Blair Grover

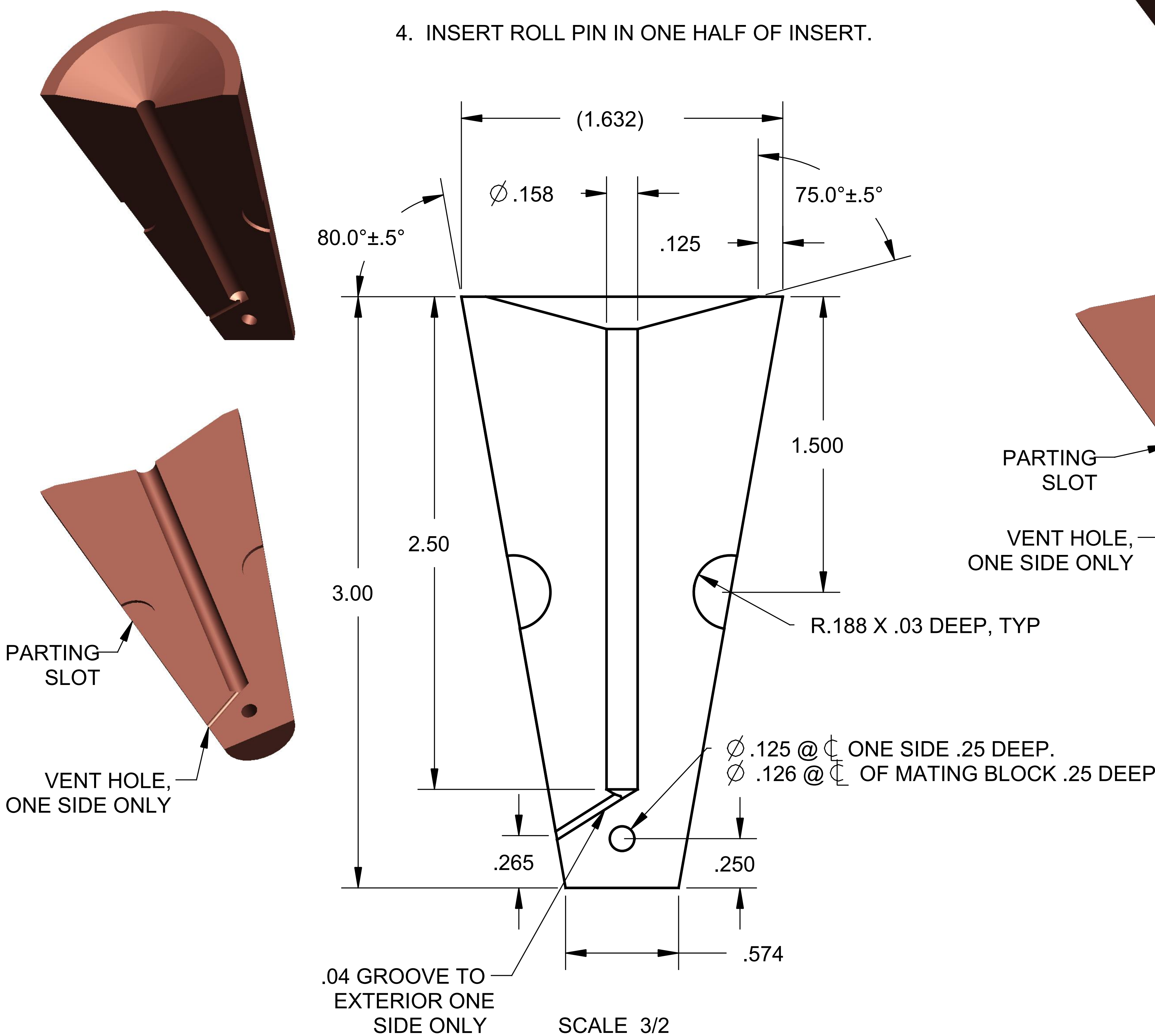
NOTES:

1. MAKE FROM COPPER.

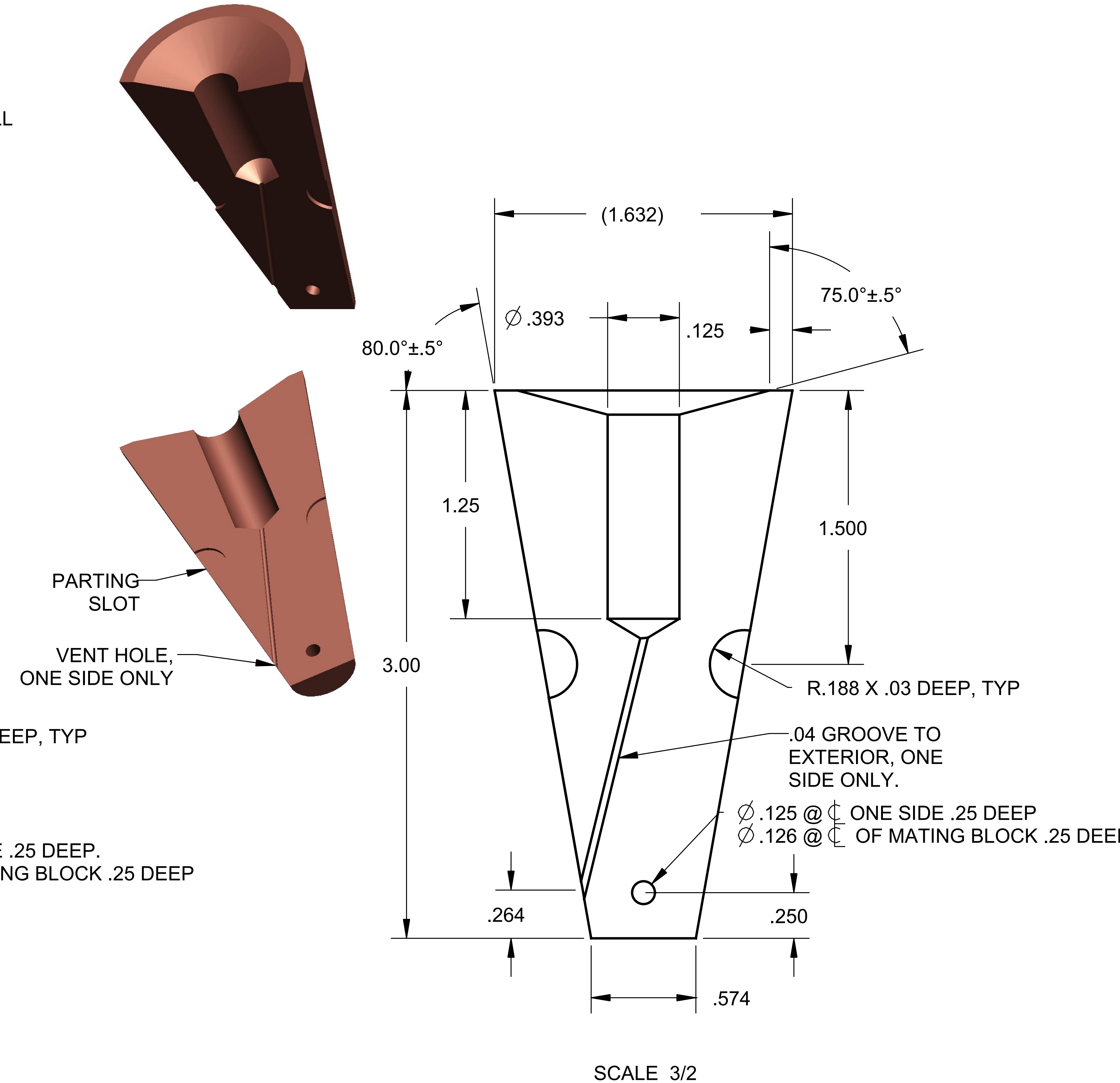
2. ROUND ALL EDGES AND CORNERS.

3. PROVIDE BEST SURFACE FINISH POSSIBLE ON ALL SURFACES.

4. INSERT ROLL PIN IN ONE HALF OF INSERT.



4 MM SPLIT BLOCK HEARTH INSERT



10 MM SPLIT BLOCK HEARTH INSERT

SKETCH A REV 6
SHEET 8 OF 10
April 5, 2016
Blair Grover

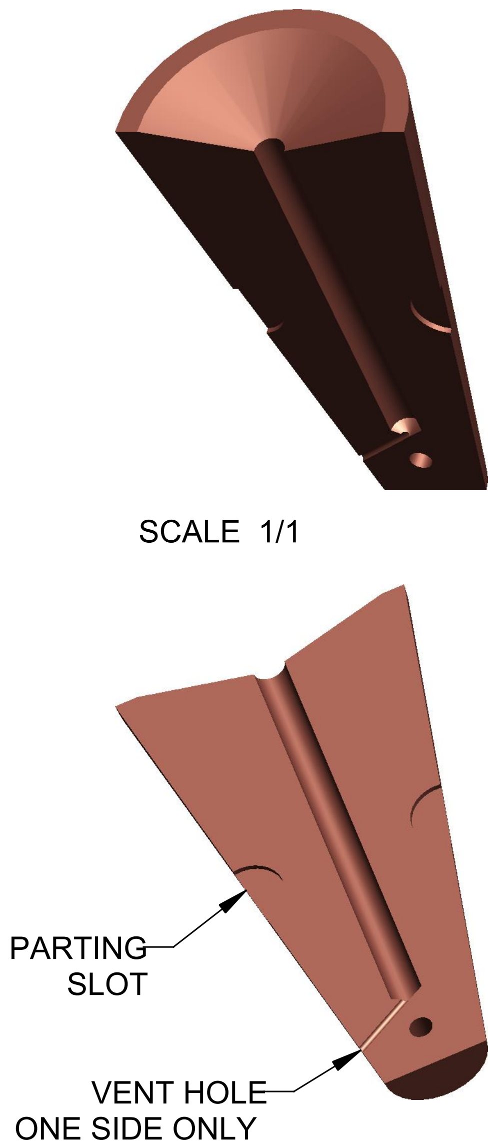
NOTES:

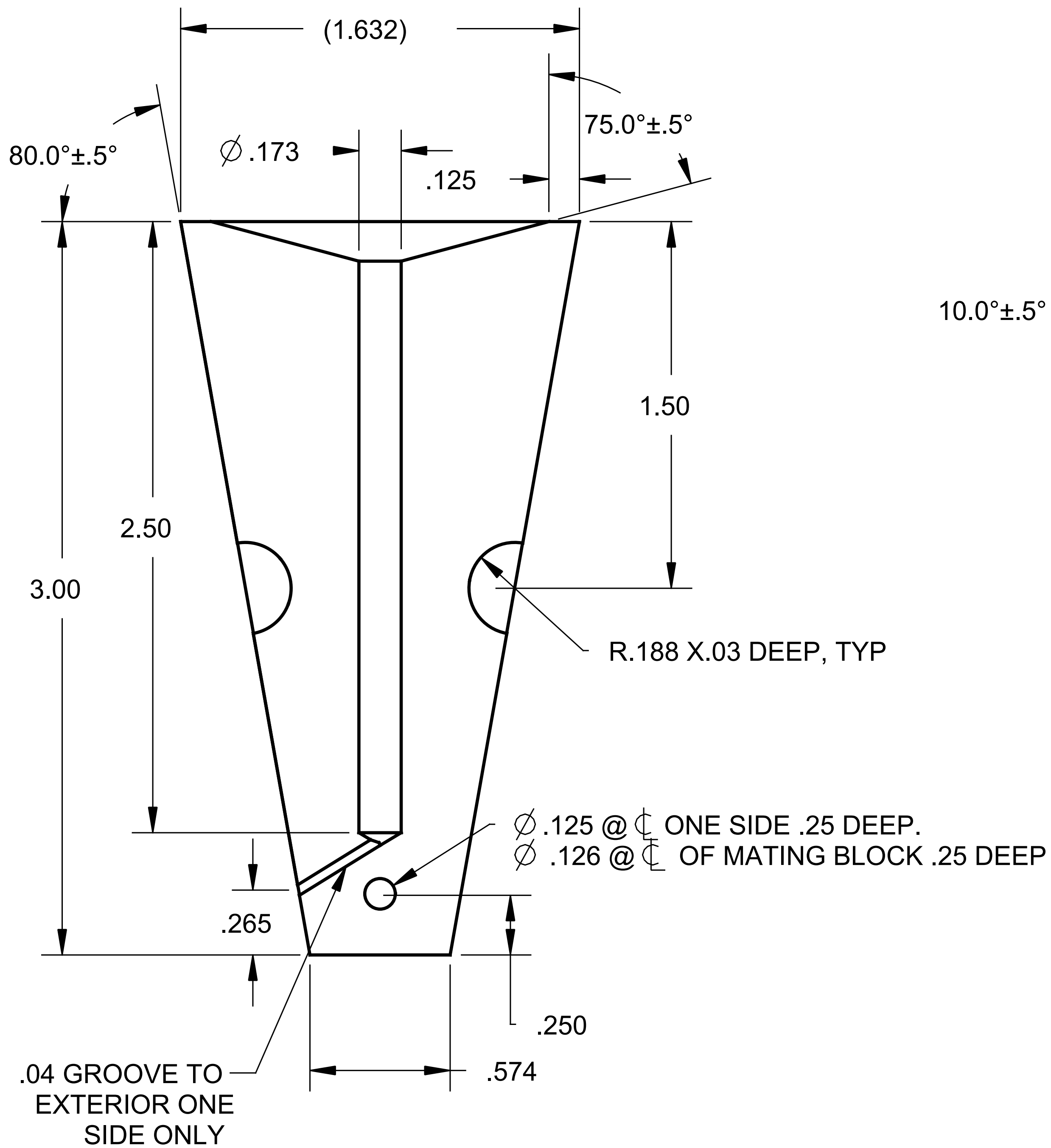
1. MAKE FROM COPPER.

2. ROUND ALL EDGES AND CORNERS.

3. PROVIDE BEST SURFACE FINISH POSSIBLE ON ALL SURFACES.

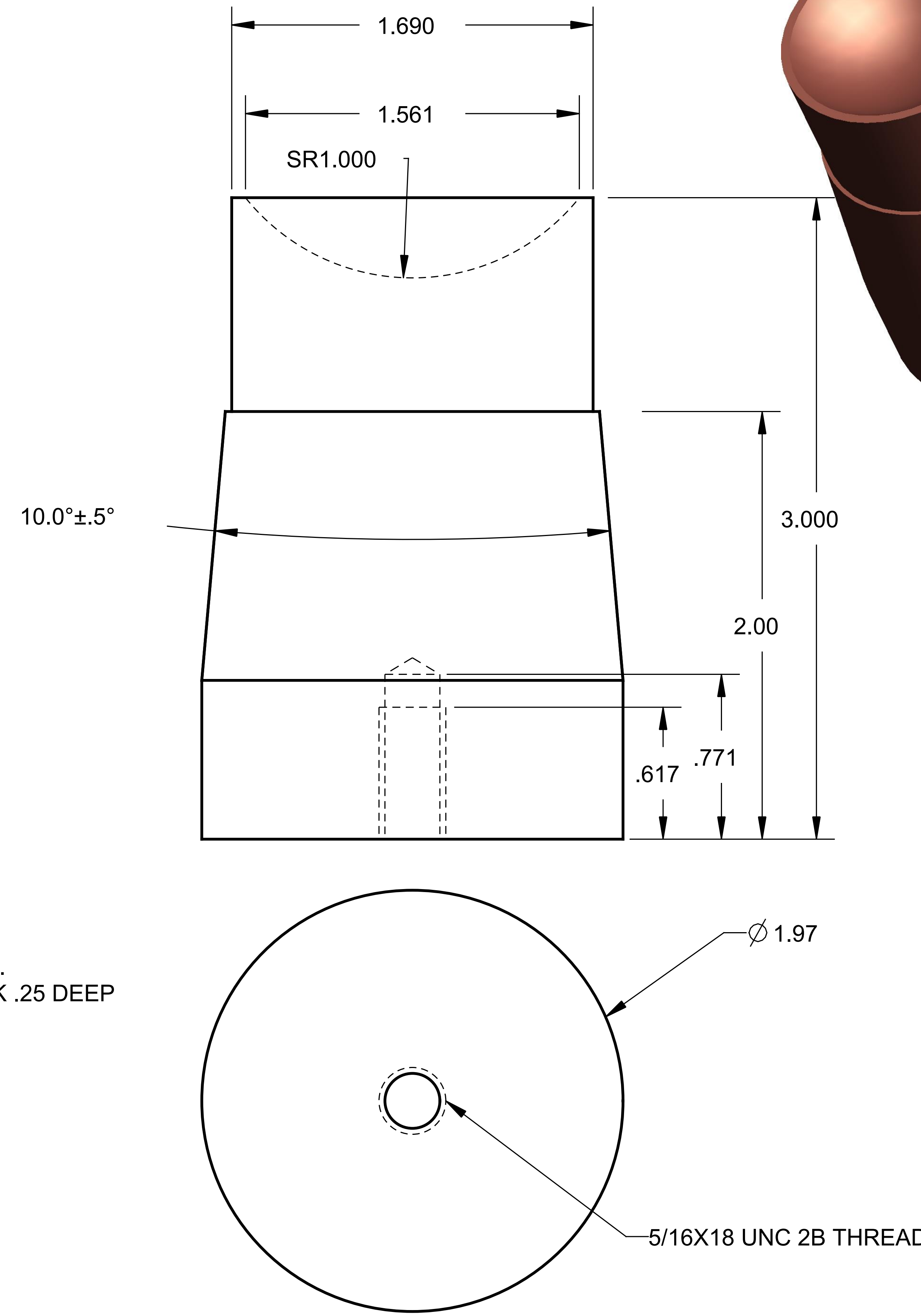
4. INSERT ROLL PIN IN ONE HALF OF INSERT.

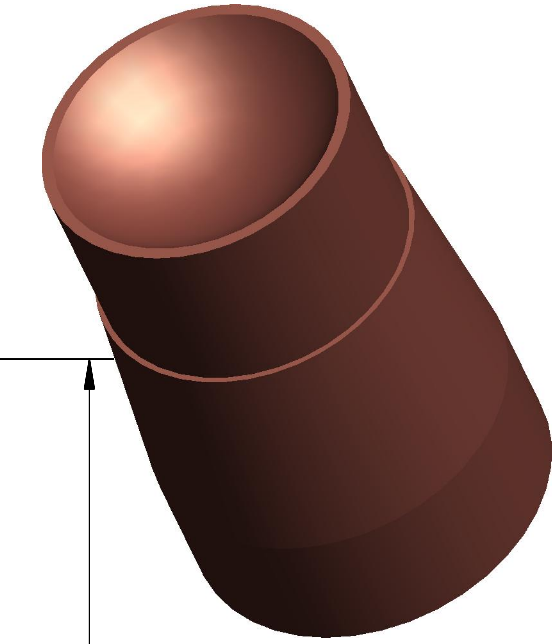




SCALE 3/2

EBR II SPLIT BLOCK HEARTH INSERT





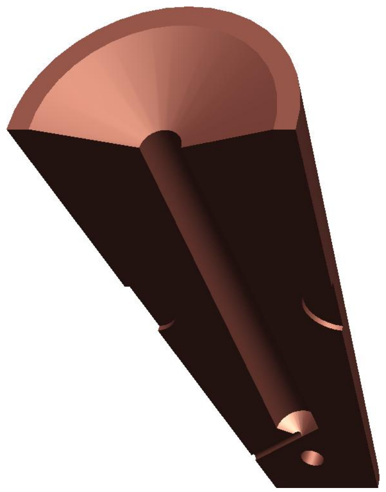
SCALE 3/2

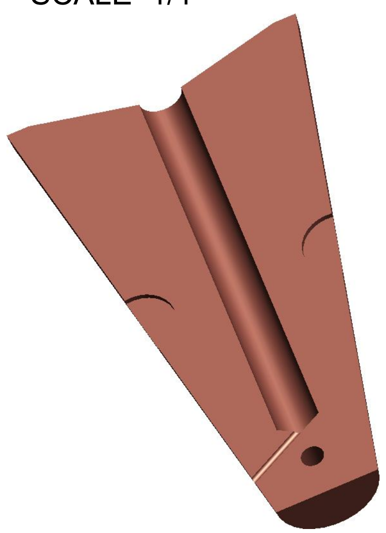
ROUND TOP HEARTH

SKETCH A REV 6
SHEET 9 OF 10
April 5, 2016
Blair Grover

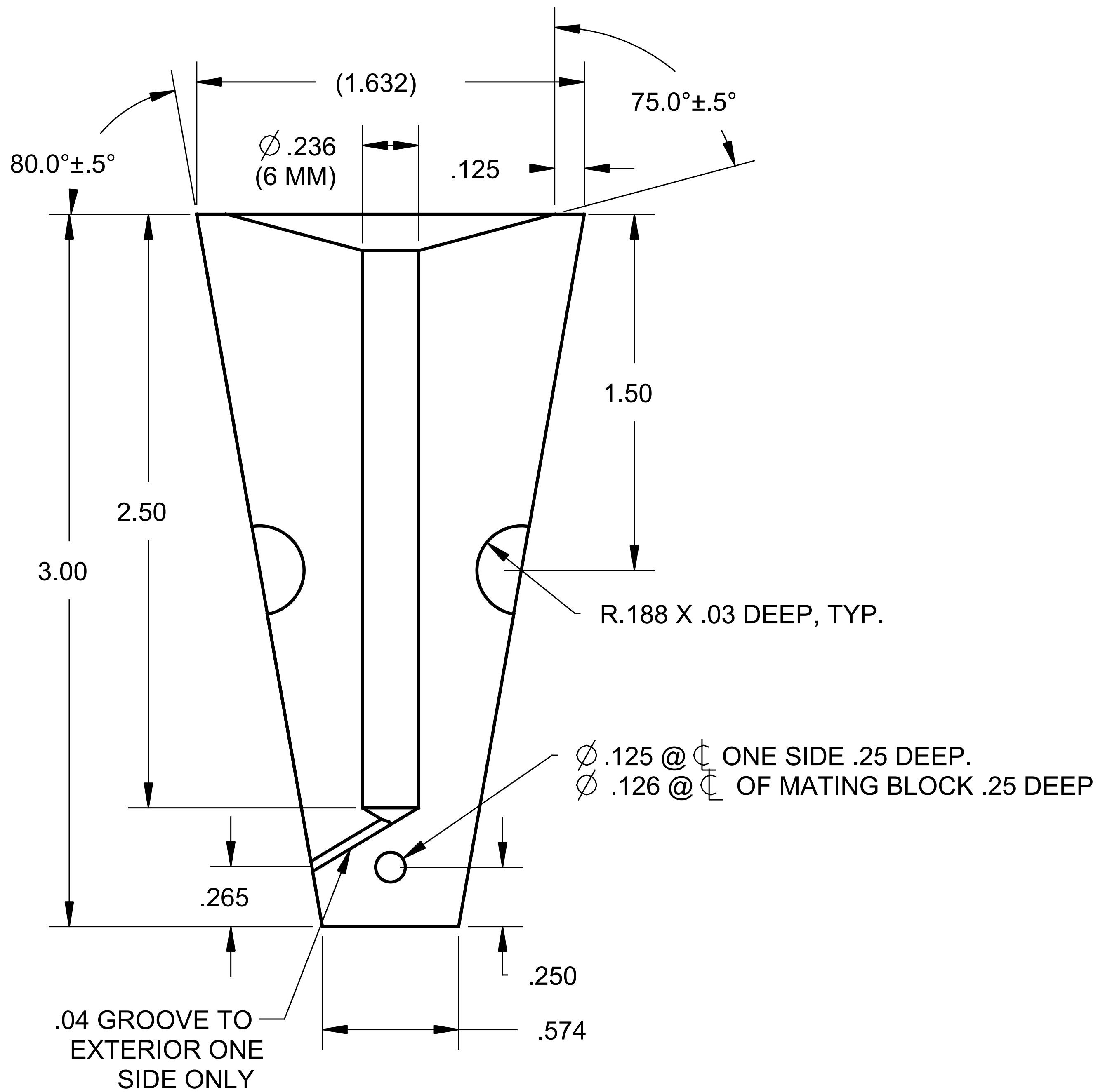
NOTES:

1. MAKE FROM COPPER.
2. ROUND ALL EDGES AND CORNERS.
3. PROVIDE BEST SURFACE FINISH POSSIBLE ON ALL SURFACES.
4. INSERT ROLL PIN IN ONE HALF OF INSERT.



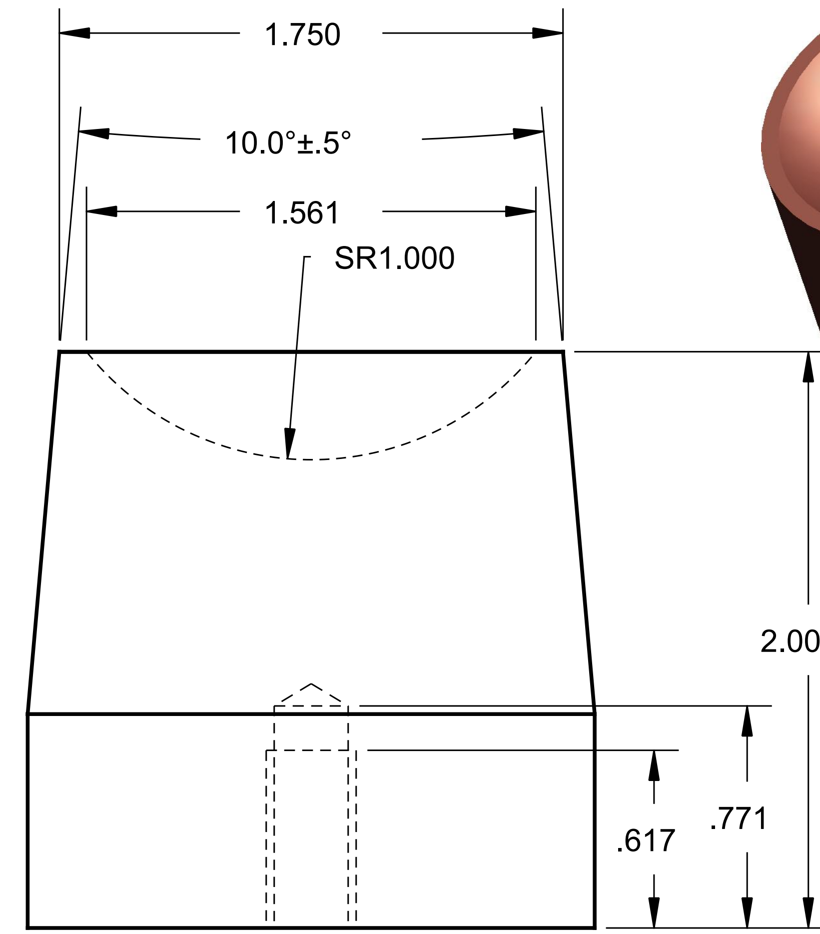


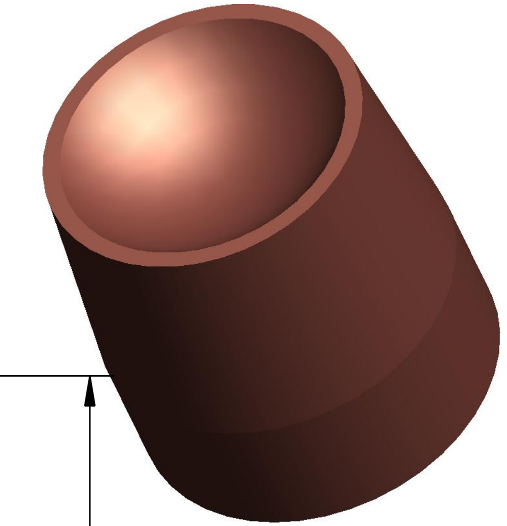
SCALE 1/1

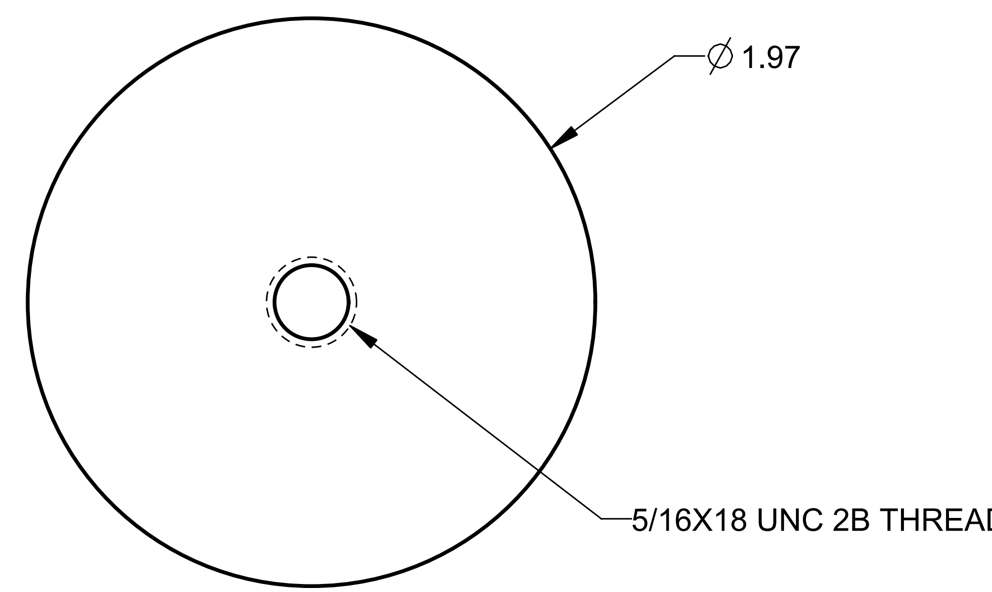


SCALE 3/2

6 MM SPLIT BLOCK HEARTH INSERT



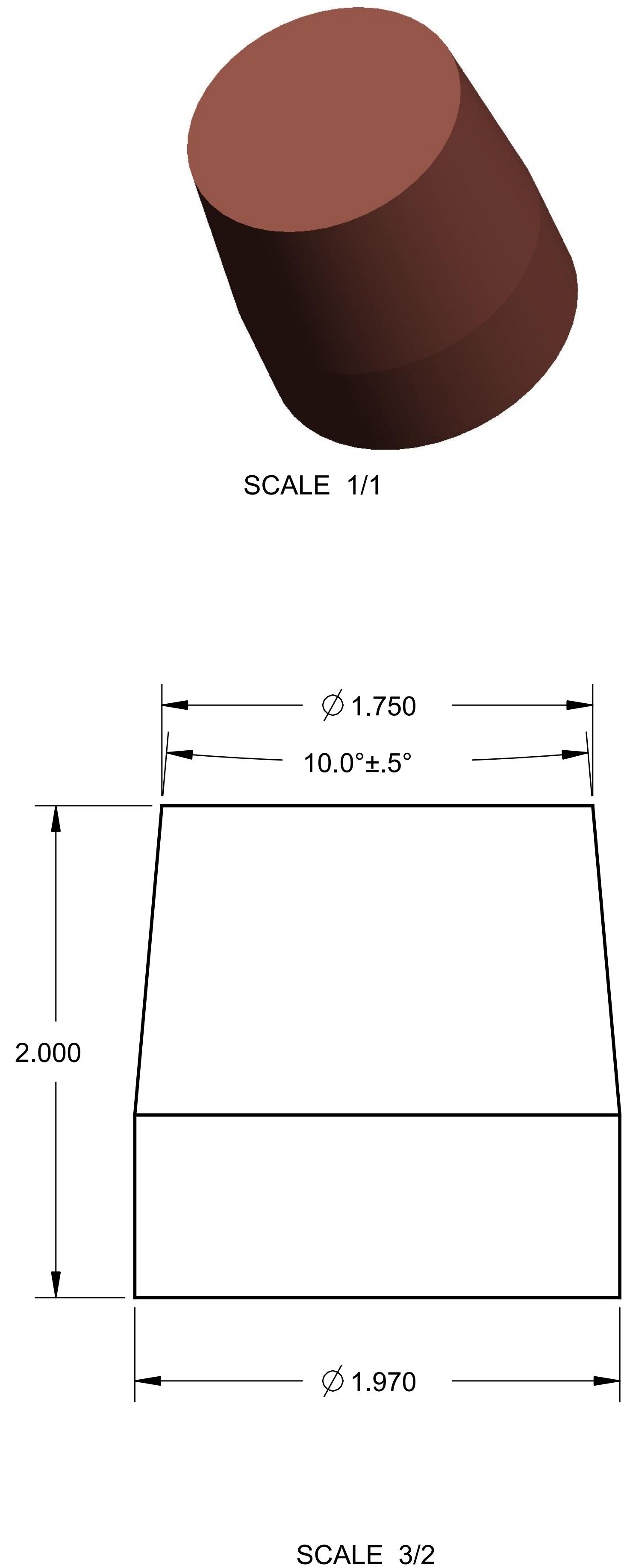




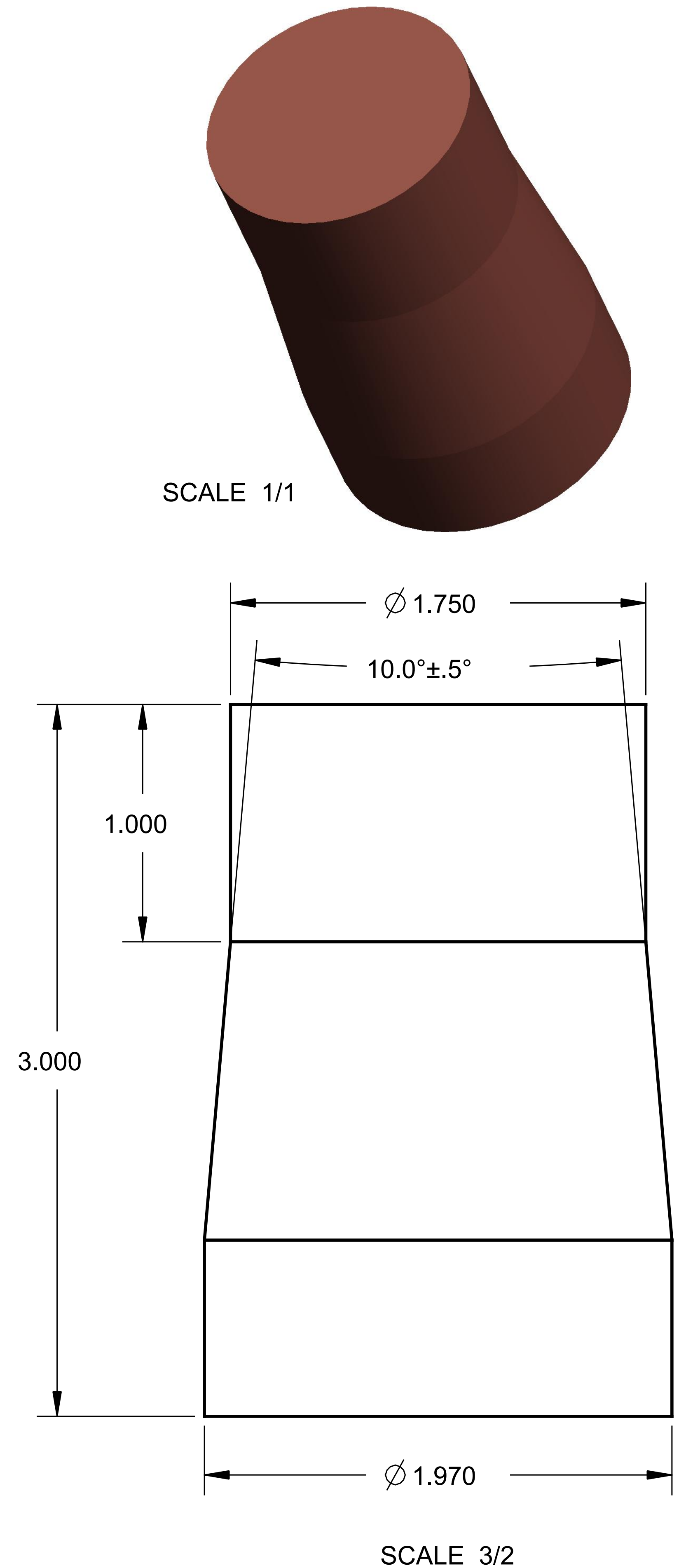
SCALE 3/2

SHORT ROUND TOP HEARTH

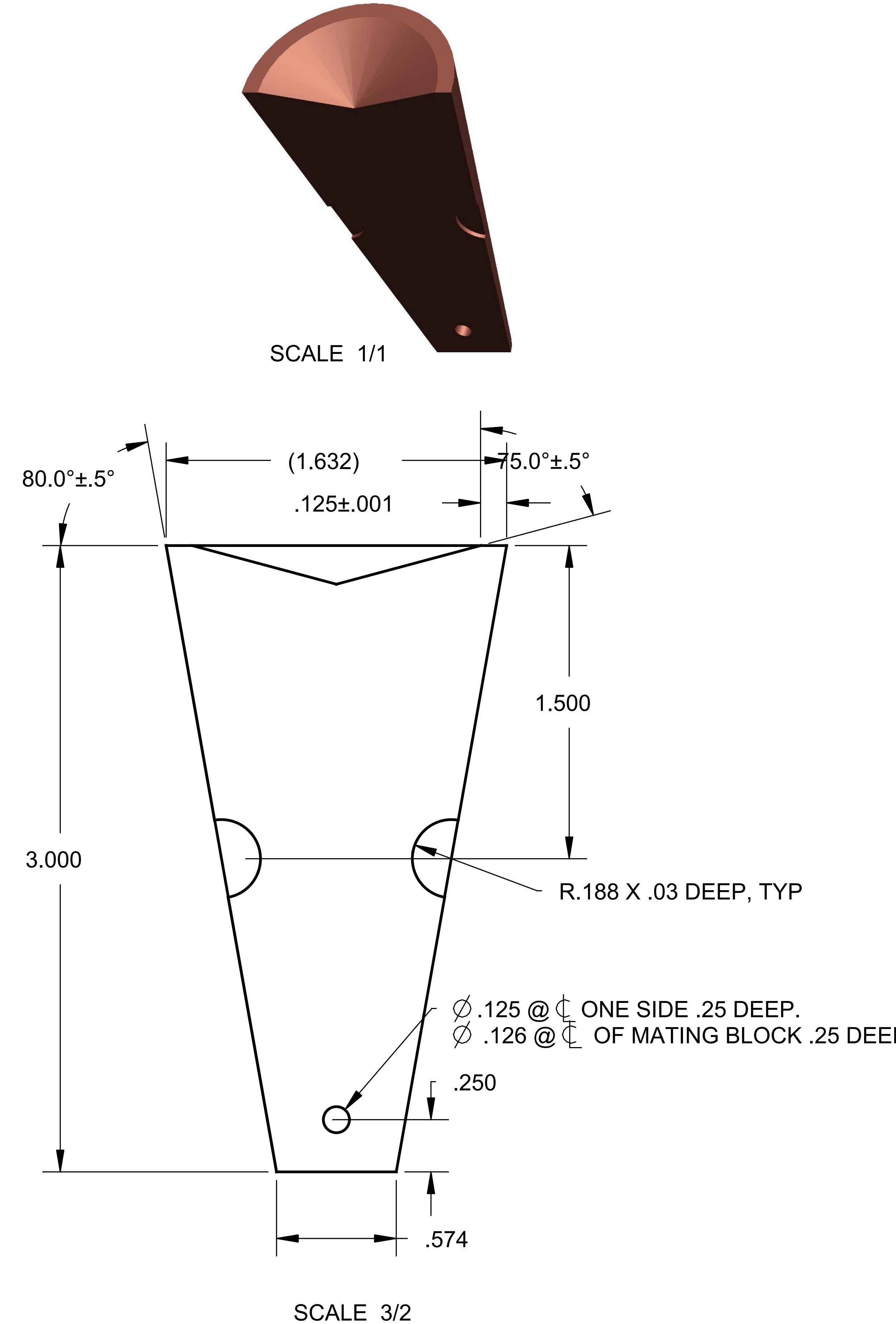
SKETCH A REV 6
SHEET 10 OF 10
April 5, 2016
Blair Grover



#1 SHORT CASTING HEARTH



#2 TALL CASTING HEARTH



#3 SPLIT BLOCK INSERT

2. Appendix B- Completed FRM-1598

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-P10Z-1015-SLUG1
Total Batch Weight:	22 grams

(1)

SADZ 336 (scrap)
SADZ 343 (slug)

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium		^{235}Uranium/Zirconium Alloy	
Plutonium	90	^{238}Uranium	
Americium		Plutonium	19.8 ± .01
Neptunium		Plutonium/Americium Alloy	
Zirconium	10	Americium	
Rare Earth		Neptunium	
		Zirconium	2.2 ± .01
		Rare Earth	

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Isotope[a]	Mass (g)
U235[b]	350
Np237	100
Pu239[c]	225
Am241	50
Am242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted.

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons or reactorgrade Pu isotopes.

d. Am242m quantities may be conservatively counted as 0.5% of the total Am241 present. As a result of its properties, Am242m cannot be chemically or isotopically separated from Am241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 5 mm
Mold: ZrO2 coated copper
Hearth: Copper

Fuel Casting Parameters:
Total cast length (minimum): 1.5 in (38.1 cm)
Slug length (minimum): 1.5 in (38.1 cm)

METAL FUEL FABRICATION PARAMETERS

Sample length (minimum): Sample length will be determined after casting

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
235Uranium % Enrichment				
235Uranium/Zirconium Alloy				
238Uranium				
Plutonium	19.807	TN	RSS	11-19-15
Plutonium/Americium Alloy				
Americium				
Neptunium				
Zirconium	2.203	TN	RSS	11-19-15
Rare Earth				
Total Weight (grams)	22.01	TN	RSS	11-19-15
Weight of Alloyed/Casted Material (grams)	21.649	TN	RSS	11-19-15
Material Difference (grams)	- 0.361	TN	RSS	11-19-15

Material Accountability by: (MBA Custodian) [signature] Date: 11-19-15

Slug Information:

Slug No.	Weight aftercutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
1	4.970	0.195	0.77"	RSS	RJ	12-15-15
SAD2 227 2	Chem Sample 0.411			TN	RSS	1-27-16
SAD2-371 3	PIE 0.695	5.02 mm	2.71 mm	TN	RSS	1-27-16
4						
5						
6						
7						

Total weight aftercutting (grams):	21.453 After Chem Sample	16.375 + 4.970 = 21.
Total weight of alloyed/casted material (grams):	21.649g	~~21.453~~ 21.4
Material differences (grams):	0.196	0.108g

Material Accountability by: (MBA Custodian) [signature] Date: 12-15-15

Balance Information: Fisher Scientific / L.E. I 0.001g / PO# 723566 / CAL 4-6-15 / Due 4-6-16

METAL FUEL FABRICATION PARAMETERS

Manufacturer:	Model No:	Serial No:	Calibration Due Date:
Caliper Information:			
Manufacturer:	Model No:	Serial No:	Calibration Due Date:

Narrative:
Alloy shall be melted a minimum of 3X before casting. Record the number of time the alloy is melted.
Note any changes in appearance during the casting/heating process i.e. surface discoloration, dross, etc.
Note the number of times the casting is attempted.
Sample taken. 0.427g As Feedstock
11-19-15:
BUTTONED 3 TIMES
ATTEMPTED DROP -
BUTTONED 1 TIME
DROPPED -
USED SPLIT HEARTH.

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-P30Z-1015-SLUG1
Total Batch Weight:	17 grams

(2)

SADZ 340

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium		^{235}Uranium/Zirconium Alloy	
Plutonium	70	^{238}Uranium	
Americium		Plutonium	11.9 ± .01
Neptunium		Plutonium/Americium Alloy	
Zirconium	30	Americium	
Rare Earth		Neptunium	
		Zirconium	5.1 ± .01
		Rare Earth	

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

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b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons or reactorgrade Pu isotopes.

d. Am242m quantities may be conservatively counted as 0.5% of the total Am241 present. As a result of its properties, Am242m cannot be chemically or isotopically separated from Am241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 5 mm
Mold: ZrO2 coated copper
Hearth: Copper

Fuel Casting Parameters:
Total cast length (minimum): 1.5 in. (3.8 cm)
Slug length (minimum): 1.5 in (3.8 cm)

METAL FUEL FABRICATION PARAMETERS

Sample length (minimum): Sample length will be determined after casting

Batch Information:				
Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
^{235}Uranium % Enrichment				
^{235}Uranium/Zirconium Alloy				
^{238}Uranium	11-19-15 [illegible]			
Plutonium	~~11.903~~ 11.901	[illegible]	[illegible]	11-30-15
Plutonium/Americium Alloy				
Americium				
Neptunium	11-19-15 [illegible]			
Zirconium	~~5.106~~ 5.091	[illegible]	[illegible]	11-30-15
Rare Earth				
	11-19-15 [illegible]			
Total Weight (grams)	~~17.009~~ 16.992	[illegible]	[illegible]	11-30-15
Weight of Alloyed/Casted Material (grams)	16.899g	[illegible]	[illegible]	11-30-15
Material Difference (grams)	0.093g	[illegible]	[illegible]	11-30-15
Material Accountability by: (MBA Custodian)	[illegible]		Date: 11-30-15	

Slug Information:							
	Slug No.	Weight aftercutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
5402	~~313~~ 1 [illegible]	1-27-16 ~~4.087~~ 4.073	12-16-15 ~~0.185~~ [illegible]	0.771"	[illegible]	[illegible]	12-15-15
	2		0.202				
5402	227 3	Chem Sample 0.355			[illegible]	[illegible]	1-27-16
5402	3M 4	met 0.601	5.04 mm ~~[illegible]~~ 1-27-16 [illegible]	0.285 mm	[illegible]	[illegible]	1-27-16
	5						
	6						
	7						

Total weight aftercutting (grams):	16.730g	After Chem Sample	16.635
Total weight of alloyed/casted material (grams):	16.899g		16.730g
Material differences (grams):	0.169g		0.095
Material Accountability by: (MBA Custodian)	[illegible]	Date:	12-15-15
Balance Information:	Fisher Scientific / L.E. ± 0.004g / ID # 723566 / Cal 4-6-15 / Due 4-6-16		

METAL FUEL FABRICATION PARAMETERS

Manufacturer:	Model No:	Serial No:	Calibration Due Date:
Caliper Information:			
Manufacturer: Starrett	Model No:	Serial No: 11/250305-1	Calibration Due Date:

Narrative:
Alloy shall be melted a minimum of 3X before casting. Record the number of time the alloy is melted.
Note any changes in appearance during the casting/heating process i.e. surface discoloration, dross, etc.
Note the number of times the casting is attempted.

11-19-15
Buttoned 3 Times
Attempted Drop
Buttoned 1 Time
Attempted Drop

11-24-15
Button
Attempted Drop
Button
Attempted Drop

11-30-15
Button
Attempted Drop
Button
Drop.

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-U20P10Z-1115-SLUG1 (LANL-4)
Total Batch Weight:	20 grams

(3)

SADZ 349

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium	70	^{235}Uranium/Zirconium Alloy	
Plutonium	20	^{238}Uranium	14 ± .05
Americium		Plutonium	4 ± .05
Neptunium		Plutonium/Americium Alloy	
Zirconium	10	Americium	
Rare Earth		Neptunium	
		Zirconium	2 ± .05
		Rare Earth	

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Isotope[a]	Mass (g)
U-235[b]	350
Np-237	100
Pu-239[c]	225
Am-241	50
Am-242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted.

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu-239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons- or reactor-grade Pu isotopes.

d. Am-242m quantities may be conservatively counted as 0.5% of the total Am-241 present. As a result of its properties, Am-242m cannot be chemically or isotopically separated from Am-241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 4.3 mm
Mold: ZrO2 coated quartz
Hearth: Copper

Fuel Casting Parameters:
Total cast length (minimum): 1.5 in (38.1 cm)
Slug length (minimum): 1.5 in (38.1 cm)
Sample length (minimum): Sample length will be determined after casting

METAL FUEL FABRICATION PARAMETERS

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
^{235}Uranium % Enrichment				
^{235}Uranium/Zirconium Alloy				
^{238}Uranium	13.952g	JW	CSS	11-30-15
Plutonium	4.009g	JW	CSS	11-30-15
Plutonium/Americium Alloy				
Americium				
Neptunium				
Zirconium	1.963g	JW	CSS	11-30-15
Rare Earth				
Total Weight (grams)	19.924g	JW	CSS	11-30-15
Weight of Alloyed/Casted Material (grams)	19.749g	JW	CSS	11-30-15
Material Difference (grams)	0.175g	JW	CSS	11-30-15

Material Accountability by: (MBA Custodian) [signature]	Date: 11-30-15

Slug Information:

	Slug No.	Weight after-cutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
5402	363 1	4.040	0.165	0.765	JW	CSS	12-16-15
	2	4.114	0.164	0.750	JW	CSS	12-16-15
5401	227 3	chem sample 0.291			JW	CSS	1-27-16
5402	374 4	met sample 0.612	4.13 mm	3.00 mm	JW	CSS	1-27-16
	5						
	6						
	7						

Total weight after-cutting (grams):	19.391
Total weight of alloyed/casted material (grams):	19.749g
Material differences (grams):	0.358g

Material Accountability by: (MBA Custodian)	[signature]	Date:	12-16-15

METAL FUEL FABRICATION PARAMETERS

Balance Information:	Fisher Scientific		
Manufacturer:	Model No: ACCL-413	Serial No: 723566	Calibration Due Date: 4-6-16
Caliper Information:	Digimatic Absolute		
Manufacturer:	Model No: CD-6" ASX	Serial No: 731845	Calibration Due Date: 1-13-17

Narrative:

Melt alloy a minimum of 3X before casting to shape, record total number of times alloy is melted or casting is attempted but didn't drop. Also note any changed in alloy appearance after melting, especially multiple times, i.e. darker surface color, visible dross, etc.

11-30-15: NEW HEARTH HANDLE JAMES, ATTEMPTED WITH OLD HEARTH
BUTTONED 3 TIMES
DROPPED – 1.5" DROP BUT NOT A VERY CLEAN SLUG.

RE-BUTTONED
ATTEMPTED DROP
BUTTON
ATTEMPTED DROP
BUTTON
DROP.

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-U20P2A3N10Z-1115-SLUG1 (LANL-5)
	Use 150-80-61646-66764 for Pu/Am alloy
Total Batch Weight:	27 grams

(4)

SADZ 323

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium	64.4	^{235}Uranium/Zirconium Alloy	
Plutonium	20.1	^{238}Uranium	17.387 ± .05
Americium	2.3	Plutonium	2.7 ± .05
Neptunium	2.9	Plutonium/Americium Alloy	6.913 ± .05*
Zirconium	10.3	Americium	
Rare Earth		Neptunium	
		Zirconium	
		Rare Earth	

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Isotope[a]	Mass (g)
U-235[b]	350
Np-237	100
Pu-239[c]	225
Am-241	50
Am-242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu-239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons- or reactor-grade Pu isotopes.

d. Am-242m quantities may be conservatively counted as 0.5% of the total Am-241 present. As a result of its properties, Am-242m cannot be chemically or isotopically separated from Am-241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 4.3 mm
Mold: ZrO2 coated quartz
Hearth: Copper

Fuel Casting Parameters:
Total cast length (minimum): 1.5 in (38.1 cm)
Slug length (minimum): 1.5 in (38.1 cm)
Sample length (minimum): Sample length will be determined after casting

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METAL FUEL FABRICATION PARAMETERS

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
^{235}Uranium % Enrichment				
^{235}Uranium/Zirconium Alloy				
^{238}Uranium	17.376g	JN	CSS	12-2-15
Plutonium	2.724g	JN	CSS	12-2-15
Plutonium/Americium Alloy	6.913g	JN	CSS	12-2-15
Americium				
Neptunium				
Zirconium				
Rare Earth				
Total Weight (grams)	27.013g	JN	CSS	12-2-15
Weight of Alloyed/Casted Material (grams)	26.886g	JN	CSS	12-2-15
Material Difference (grams)	0.127g	JN	CSS	12-2-15

Material Accountability by: (MBA Custodian) [signature] Date: 12-2-15

Slug Information:

Slug No.	Weight after-cutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
32 361 1	4.259g	0.167"	0.748"	JN	CSS	1-6-16
2	4.218g	0.168"	0.757"	JN	CSS	1-6-16
102 362 3	Chem. Sample 0.232			JN	CSS	1-6-16
102 375 4	met sample 0.636	4.31 mm	2.96 mm	JN	CSS	1-6-16
5						
6						
7						

Total weight after-cutting (grams):	26.519
Total weight of alloyed/casted material (grams):	26.886g
Material differences (grams):	0.347g

Material Accountability by: (MBA Custodian) [signature] Date: 1-6-16

METAL FUEL FABRICATION PARAMETERS

Balance Information:	Fisher Scientific		
Manufacturer:	Model No: Accu-413	Serial No: 723566	Calibration Due Date: 4-6-16
Caliper Information:	Digimatic Absolute		
Manufacturer:	Model No: CO-6" ASX	Serial No: 731245	Calibration Due Date: 1-13-17

Narrative:

*150-80-61646-66764 contains appropriate Am, Zr, and Np amounts, but 2.7 g of additional Pu will be needed. 150-80-61646-66764 is contained in SADZ-FMF-323.

Melt alloy a minimum of 3X before casting to shape, record total number of times alloy is melted or casting is attempted but didn't drop. Also note any changed in alloy appearance after melting, especially multiple times, i.e. darker surface color, visible dross, etc.

11-30-15 - USED OLD HEARTH SET UP
BUTTONED 3 TIMES
ATTEMPTED DROP

12-2-15 - BUTTONED
DROPPED } USED NEW HEARTH SET UP.

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-U20P10Z3.86Pd-1215-Slug1
Total Batch Weight:	13 grams

(5)
SADZ-341

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium	66.14	^{235}Uranium/Zirconium Alloy	
Plutonium	20	^{238}Uranium	8.598 ± 0.01 8.588
Americium		Plutonium	2.6 ± 0.01 2.597
Neptunium		Plutonium/Americium Alloy	
Zirconium	10	Americium	
Rare Earth		Neptunium	
Palladium	3.86	Zirconium	1.3 ± 0.01 1.3095
		Rare Earth	
		Palladium	0.501 ± 0.01 ~~0.499~~ 0.5001

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

Net Act. Cost: 12.936

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Isotope[a]	Mass (g)
U235[b]	350
Np237	100
Pu239[c]	225
Am241	50
Am242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted.

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons or reactorgrade Pu isotopes.

d. Am242m quantities may be conservatively counted as 0.5% of the total Am241 present. As a result of its properties, Am242m cannot be chemically or isotopically separated from Am241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 5mm
Mold: ZrO_2 coated Copper
Hearth: Copper

12999

METAL FUEL FABRICATION PARAMETERS

Fuel Casting Parameters:
Total cast length (minimum): 1.25 inches (31.75 mm)
Slug length (minimum): 1.25 inches (31.75 mm)
Sample length (minimum): sample length will be determined after casting

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
²³⁵Uranium % Enrichment				
²³⁵Uranium/Zirconium Alloy				
²³⁸Uranium	8.588	[initials]	[initials]	12-2-15
Plutonium	2.597	[initials]	[initials]	12-2-15
Plutonium/Americium Alloy				
Americium				
Neptunium				
Zirconium	1.3095	[initials]	[initials]	12-2-15
Rare Earth				
Palladium	0.5001	[initials]	[initials]	12-2-15
Total Weight (grams)	12.9946	[initials]	[initials]	12-2-15
Weight of Alloyed/Casted Material (grams)	12.936	[initials]	[initials]	12-2-15
Material Difference (grams)	0.0586	[initials]	[initials]	12-2-15

Material Accountability by: (MBA Custodian) [signature] Date: 12-2-15

Slug Information:

Slug No.	Weight aftercutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
1	5.153 slug	0.194"	0.74"	[initials]	[initials]	1-26-16
2	chem sample 0.354		~~0.74"~~	[initials]	[initials]	1-26-16
3	met sample 0.665	4.72 mm	2.53 mm 1-26-16 [initials]	[initials]	[initials]	1-26-16
4						
5	Total 12.658			[initials]	[initials]	1-26-16
6	Difference 0.278			[initials]	[initials]	1-26-16
7						

Total weight aftercutting (grams): 12.658	

METAL FUEL FABRICATION PARAMETERS

Total weight of alloyed/casted material (grams):	12.936			
Material differences (grams):	0.278			
Material Accountability by: (MBA Custodian)	[illegible]		Date:	1-26-16
Balance Information:				
Manufacturer:	Model No:	Serial No:	Calibration Due Date:	
Caliper Information:				
Manufacturer:	Model No:	Serial No:	Calibration Due Date:	

Narrative:

Alloy according to the buttoning sequence below, record total number of times alloy is melted or casting is attempted but didn't drop. Also not any changes in alloy appearance after melting, especially multiple times, i.e. darker surface color, visible dross, etc.

Buttoning Sequence

1) Alloy U and Pd, flip and remelt 1X
2) Add Zr to the U+Pd button, flip and remelt 1X
3) Add Pu to the U+Pd+Zr button, flip and remelt 3X

Initial cut to square ends only leaving length as long as possible.

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-U20P10Z3.86Pd-4.3Ln-1215-Slug1
Total Batch Weight:	12 grams

(6)

SADZ-167

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium	61.84	^{235}Uranium/Zirconium Alloy	
Plutonium	20	^{238}Uranium	7.421 ± 0.01 7.421
Americium		Plutonium	2.4 ± 0.01 2.390
Neptunium		Plutonium/Americium Alloy	
Zirconium	10	Americium	
Rare Earth	4.3	Neptunium	
Palladium	3.86	Zirconium	1.2 ± 0.01 1.2070
Lanthanum		Rare Earth	0.516 ± 0.01 ~~[illegible]~~ 0.509
		Palladium	0.463 ± 0.01 0.4644
		Lanthanum	

*** AC 5.404.11 AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Net Wt. After Cast = 11.951g

Isotope[a]	Mass (g)
U235[b]	350
Np237	100
Pu239[c]	225
Am241	50
Am242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted.

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons or reactorgrade Pu isotopes.

d. Am242m quantities may be conservatively counted as 0.5% of the total Am241 present. As a result of its properties, Am242m cannot be chemically or isotopically separated from Am241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 5mm
Mold: ZrO_2 coated Copper
Hearth: Copper

#12

METAL FUEL FABRICATION PARAMETERS

Fuel Casting Parameters:
Total cast length (minimum): 1.25 inches (31.75 mm)
Slug length (minimum): 1.25 inches (31.75 mm)
Sample length (minimum): sample length will be determined after casting

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
²³⁵Uranium % Enrichment				
²³⁵Uranium/Zirconium Alloy				
²³⁸Uranium	7.421	[signature]	[signature]	12-7-15
Plutonium	2.390	[signature]	[signature]	12-7-15
Plutonium/Americium Alloy				
Americium				
Neptunium				
Zirconium	1.2670	[signature]	[signature]	12-7-15
Rare Earth	0.509	[signature]	[signature]	12-7-15
Palladium	0.4644	[signature]	[signature]	12-7-15
Total Weight (grams)	11.9914	[signature]	[signature]	12-7-15
Weight of Alloyed/Casted Material (grams)	11.951	[signature]	[signature]	12-7-15
Material Difference (grams)	0.0404	[signature]	[signature]	12-7-15
Material Accountability by: (MBA Custodian)	[signature]		Date:	

Slug Information:

Slug No.	Weight aftercutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
AD2 409 1	5.077 slug	0.192"	0.751"	RD	[signature]	1-26-16
AD2 362 2	chem sample 0.470			RD	[signature]	1-26-16
AD2 375 3	met sample 0.621	4.92 mm	2.4 mm	[signature]	[signature]	1-26-16
4						
5						
6						
7						

Total weight aftercutting (grams):	11.659

METAL FUEL FABRICATION PARAMETERS

Total weight of alloyed/casted material (grams):		11.951			
Material differences (grams):		0.292			
Material Accountability by: (MBA Custodian)	[signature]			Date:	1-26-16
Balance Information:					
Manufacturer:	Model No:		Serial No:	Calibration Due Date:	
Caliper Information:					
Manufacturer:	Model No:		Serial No:	Calibration Due Date:	

Narrative:

NOTE: Ln mean lanthanides which is the same as RE or rare earths

Melt alloy according to the directions below, record total number of times alloy is melted or casting is attempted but didn't drop. Also not any changes in alloy appearance after melting, especially multiple times, i.e. darker surface color, visible dross, etc.

Buttoning Sequence

1) Melt U + Pd flip and remelt 1X
2) Add Zr to U + Pd button - flip and remelt 1X
3) Add Pu to the U+Pd+Zr button – flip and remelt 1X
4) Add Lanthanides to the U+Pd+Zr+Pu button- Flip and remelt 3X

Initial cut to square ends only leaving length as long as possible.

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-U19P0.7Z4.3T-5M-1215-Slug1
Total Batch Weight:	13 grams

SADZ-348
(7)

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium		^{235}Uranium % Enrichment	
^{238}Uranium	71	^{235}Uranium/Zirconium Alloy	
Plutonium	19	^{238}Uranium	9.23 ± 0.01 9.238
Americium		Plutonium	2.47 ± 0.01 2.472
Neptunium		Plutonium/Americium Alloy	
Zirconium	0.7	Americium	
Rare Earth		Neptunium	
Titanium	4.299	Zirconium	0.091 ± 0.01 0.0964
Molybdenum	5.001	Rare Earth	
		Titanium	0.559 ± 0.01 0.5526
		Molybdenum	0.650 ± 0.01 0.6495

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Net Wt After Cast: 12.960g

Isotope[a]	Mass (g)
U235[b]	350
Np237	100
Pu239[c]	225
Am241	50
Am242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted.

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons or reactorgrade Pu isotopes.

d. Am242m quantities may be conservatively counted as 0.5% of the total Am241 present. As a result of its properties, Am242m cannot be chemically or isotopically separated from Am241.

Arc Melting Parameters:
Amperage adjust setting: 300
Inner Mold diameter: 5mm
Mold: ZrO_2 coated Copper
Hearth: Copper

METAL FUEL FABRICATION PARAMETERS

Fuel Casting Parameters:
Total cast length (minimum): 1.25 inches (31.75 mm)
Slug length (minimum): 1.25 inches (31.75 mm)
Sample length (minimum): sample length will be determined after casting

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
235Uranium % Enrichment				
235Uranium/Zirconium Alloy				
238Uranium	9.238	JN	CSS	12-7-15
Plutonium	2.412	JN	CSS	12-7-15
Plutonium/Americium Alloy				
Americium				
Neptunium				
Zirconium	0.0964	JN	CSS	12-7-15
Rare Earth				
Titanium	0.5526	JN	CSS	12-7-15
Molybdenum	0.6495	JN	CSS	12-7-15
Total Weight (grams)	13.0085	JN	CSS	12-7-15
Weight of Alloyed/Casted Material (grams)	12.960	JN	CSS	12-7-15
Material Difference (grams)	0.0485	JN	CSS	12-7-15
Material Accountability by: (MBA Custodian)	CSS		Date:	

Slug Information:

Slug No.	Weight aftercutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
1	5.312 slug	0.189"	0.749"	JN	CSS	1-27-16
2	chem Sample 0.437			JN	CSS	1-27-16
3	met sample 0.751	4.93 mm	2.73 mm	JN	CSS	1-27-16
4						
5						
6						
7						

Total weight aftercutting (grams):	12.613

METAL FUEL FABRICATION PARAMETERS

Total weight of alloyed/casted material (grams):	12.960			
Material differences (grams):	0.347			
Material Accountability by: (MBA Custodian)	[signature]		Date:	1-27-16
Balance Information:				
Manufacturer:	Model No:	Serial No:	Calibration Due Date:	
Caliper Information:				
Manufacturer:	Model No:	Serial No:	Calibration Due Date:	

Narrative:

Alloy composition- 61.84% DU – 19% Pu – 0.7% Zr – 4.299% Ti- 5.001% Mo

Charge targets- DU 9.23 g ± .01

Pu 2.47 g ± .01

Zr 0.091 g ± .01 0.0964

Ti 0.559 g ± .01 0.5526g

Mo 0.650 g ± .01 0.6495g

Button according to the buttoning sequence below, record total number of times alloy is melted or casting is attempted but didn't drop. Also note any changed in alloy appearance after melting, especially multiple times, i.e. darker surface color, visible dross, etc.

Buttoning Sequence

1) Alloy Mo+Ti+Zr first- flip and re-melt 3X
2) Add U and Pu to Mo+Ti+Zr button, flip and re-melt 3X

Initial cut to square ends only leaving length as long as possible

METAL FUEL FABRICATION PARAMETERS

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...ion Required	☒ Yes ☐ No
...que ID (SPM No., SADZ No., etc.)	AFC-3F-2
Total Batch Weight:	14.995 grams

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium	43%	^{235}Uranium % Enrichment	6.386 ±0.05 (69% U-235) 6.344
^{238}Uranium	67%	^{235}Uranium/Zirconium Alloy	
Plutonium		^{238}Uranium	7.107±0.05 (Depleted) 7.099
Americium		Plutonium	
Neptunium		Plutonium/Americium Alloy	
Zirconium	10%	Americium	
Rare Earth		Neptunium	
		Zirconium	1.502 ±0.02 1.517
		Rare Earth	

Arc Melting Parameters:
Amperage adjust setting: 300 amps
Inner Mold diameter: 4.3 mm
Mold: ZrO2 coated quartz
Hearth: Copper

Fuel Casting Parameters:
Total cast length (minimum): 2.5 in.
Slug length (minimum): 1.5 in.
Sample length (minimum): 1-2 mm (Chem), 2-3 mm (Metallography)

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
^{235}Uranium % Enrichment	6.344	[signature]	[signature]	3-10-16
^{235}Uranium/Zirconium Alloy				
^{238}Uranium	7.099	[signature]	[signature]	3-10-16
Plutonium				
Plutonium/Americium Alloy				

METAL FUEL FABRICATION PARAMETERS

Americium				
Neptunium				
Zirconium	1.517	[signature]	[signature]	3-10-16
Rare Earth				
Total Weight (grams)	14.960	[signature]	[signature]	3-10-16
Weight of Alloyed/Casted Material (grams)	~~14.242~~	14.945 [initials]	[signature]	3-10-16
Material Difference (grams)	~~2.118~~	0.015 [initials]	[signature]	3-10-16
Material Accountability by: (MBA Custodian)	[signature]		Date: 3-10-16	

Slug Information:

Slug No.	Weight after-cutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/Measured by FMH	Verified by FMH	Date
40 385 1	slug 8.515g	0.169 inch	1.491 inch	[signature]	[signature]	3-24-16
2	melt 0.647g	4.36 mm	3.02 mm	[signature]	[signature]	3-24-16
3	chem 0.473g	4.29 mm	2.15 mm	[signature]	[signature]	3-24-16
4						
5						
6						
7						

Total weight after-cutting (grams):	14.561 3-24-16 [initials]		
Total weight of alloyed/casted material (grams):	~~14.960~~ 14.945		
Material differences (grams):	3-24-16 [initials] ~~0.399g~~ 0.384		
Material Accountability by: (MBA Custodian)	[signature]	Date:	3-24-16
Balance Information:	Fisher Scientific		
Manufacturer:	Model No: Accu-413	Serial No: 723566	Calibration Due Date: 4-6-16
Caliper Information:	Mitutoyo · Absolute AOS Digimatic		
Manufacturer:	Model No: CD-6" ASX	Serial No: A1308167	Calibration Due Date: 1-13-17

METAL FUEL FABRICATION PARAMETERS

Narrative:

5x buttoned 3x casting attemps recorded from
as-built data package R. Fyf 19 Dec 2016

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-3F-3
Total Batch Weight:	24.177 grams

~~SADZ 358~~ SADZ 359

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium	8.4%	^{235}Uranium % Enrichment	2.867 ±0.05 (69% U-235) 2.746g
^{238}Uranium	61.6%	^{235}Uranium/Zirconium Alloy	
Plutonium	20%	^{238}Uranium	14.045 ±0.05 (Depleted) 14.045g
Americium		Plutonium	4.844 ±0.05 4.828g
Neptunium		Plutonium/Americium Alloy	
Zirconium	10%	Americium	
Rare Earth		Neptunium	
		Zirconium	2.422 ±0.05 2.453g
		Rare Earth	

* AC 5.404.11 **AFCI Glovebox Radioactive Material Mass Limit**

The mass of radioactive process material in the AFCI glovebox enclosure shall be limited to any combination of the following isotopes, provided that the individual mass limits are not exceeded:

Isotope[a]	Mass (g)
U235[b]	350
Np237	100
Pu239[c]	225
Am241	50
Am242m[d]	6.5

a. Radioactive contaminants associated with isotopes listed in the table that result from the irradiation and separations processes used to create the listed isotopes are also permitted.

b. Other naturally occurring isotopes of uranium (U-234, U-238) are permitted and do not count against this limit. Uranium resulting from U-233 production activities is not permitted.

c. All Pu shall be counted as Pu239. Plutonium resulting from Pu-238 production activities is not permitted. This allows the Pu in the glovebox to consist of any mixture of weapons or reactorgrade Pu isotopes.

d. Am242m quantities may be conservatively counted as 0.5% of the total Am241 present. As a result of its properties, Am242m cannot be chemically or isotopically separated from Am241.

Arc Melting Parameters:
Amperage adjust setting: 300 amps
Inner Mold diameter: 4.3 mm
Mold: ZrO_2 coated quartz
Hearth: Copper

FRM1598
12/03/15
Rev. 1

METAL FUEL FABRICATION PARAMETERS

Fuel Casting Parameters:
Total cast length (minimum): 2.5 in.
Slug length (minimum): 1.5 in.
Sample length (minimum): 1-2 mm (Chem), 2-3 mm (Metallography)

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
235Uranium % Enrichment	2.846	[signature]	[signature]	2-7-16
235Uranium/Zirconium Alloy				
238Uranium	14.045	[signature]	[signature]	2-7-16
Plutonium	4.808	[signature]	[signature]	2-7-16
Plutonium/Americium Alloy				
Americium				
Neptunium				
Zirconium	2.453	[signature]	[signature]	2-7-16
Rare Earth				
Total Weight (grams)	24.152	[signature]	[signature]	2-7-16
Weight of Alloyed/Casted Material (grams)	~~23.993~~ 23.925	[signature]	[signature]	2-7-16
Material Difference (grams)	~~0.159~~ 0.227	[signature]	[signature]	2-7-16
Material Accountability by: (MBA Custodian)	[signature]		Date: 2-7-16	

Slug Information:

Slug No.	Weight aftercutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/ Measured by FMH	Verified by FMH	Date
.5 SAD 394	Slug 8.167g	T - 0.1615 - 0.1645 B - 0.1655 - 0.1715	1.4965"	[signature]	[signature]	2-24-16
m 2	Chem 0.315g	4.24mm	1.89 mm	[signature]	[signature]	2-24-16
3	Met 0.536g	4.14mm	2.70mm	[signature]	[signature]	2-24-16
4						
5						
6						
7						

Total weight aftercutting (grams): 23.588g	

* 6.101g - USED IN Rodlet 3
The Rest IS STILL IN SADZ 394

METAL FUEL FABRICATION PARAMETERS

Total weight of alloyed/casted material (grams):	23.925g		
Material differences (grams):	0.337g		
Material Accountability by: (MBA Custodian)	[signature]	Date:	2-24-16
Balance Information:	Fisher Scientific		
Manufacturer:	Model No: ACCU-413	Serial No: 723566	Calibration Due Date: 4-6-16
Caliper Information:	Mitutoyo - Absolute AOS Digimatic		
Manufacturer:	Model No: CD-6" ASX	Serial No: 14308167	Calibration Due Date: 1-13-17

Narrative:

Please use the 69% enriched feedstock for the U-235 source. Button a minimum of 3X before dropping into the quartz mold. Record the number of times the alloy was buttons and drop attempts. Remaining material after samples have been cut shall be AFC-3F-3 ARCHIVE.

Button 𝍸 I

Whole Button 22.065 Cast IIII

14.548g Buttoned 3 times ~~cast~~ 3 times

↳14.353 After cast weight

~~23.993~~ - (23.925) Total in ...

Slug- Top- ~~.580~~ 40° - 0.1645
.1615

Bottom - .1655 - 0.1715

5-10-16

METAL FUEL FABRICATION PARAMETERS

Alloy Fabrication Required	☒ Yes ☐ No
Unique ID (SPM No., SADZ No., etc.)	AFC-3F-4
Total Batch Weight:	14.994 grams

SA02 368

Alloy Formulae	Weight %	Component Mass*	grams ± tolerance value
^{235}Uranium	39%	^{235}Uranium % Enrichment	5.803 ±0.05 (69% U-235) 5.807
^{238}Uranium	51%	^{235}Uranium/Zirconium Alloy	
Plutonium		^{238}Uranium	7.689 ±0.05 (Depleted) 7.716
Americium		Plutonium	
Neptunium		Plutonium/Americium Alloy	
Zirconium	10%	Americium	
Rare Earth		Neptunium	
		Zirconium	1.502 ±0.02 1.521
		Rare Earth	

Arc Melting Parameters:
Amperage adjust setting: 300 amps
Inner Mold diameter: 4.3 mm
Mold: ZrO2 coated quartz
Hearth: Copper

Fuel Casting Parameters:
Total cast length (minimum): 2.5 in.
Slug length (minimum): 1.5 in.
Sample length (minimum): 1-2 mm (Chem), 2-3 mm (Metallography)

Batch Information:

Component	Mass (grams)	Weighed by FMH	Verified by FMH	Date
^{235}Uranium % Enrichment	5.807	[signature]	[signature]	3-7-16
^{235}Uranium/Zirconium Alloy				
^{238}Uranium	7.716	[signature]	[signature]	3-7-16
Plutonium				
Plutonium/Americium Alloy				

METAL FUEL FABRICATION PARAMETERS

Americium				
Neptunium				
Zirconium	1521	[signature]	[signature]	3-7-16
Rare Earth				
Total Weight (grams)	15.044	[signature]	[signature]	3-7-16
Weight of Alloyed/Casted Material (grams)	15.001	[signature]	[signature]	3-7-16
Material Difference (grams)	0.043	[signature]	[signature]	3-7-16
Material Accountability by: (MBA Custodian)	[signature]		Date: 3 7-16	

Slug Information:

Slug No.	Weight after-cutting (grams)	Diameter (inches/mm)	Length (inches/mm)	Weighed/Measured by FMH	Verified by FMH	Date
SAD 372	Slug 8.638g	0.1700 inch	1.4945 inch	[signature]	[signature]	3-10-16
2	Chem 0.317g	0.1700 inch	1.44 mm	[signature]	[signature]	3-10-16
3	Met 0.568g	0.1700 inch	2.50 mm	[signature]	[signature]	3-10-16
4						
5						
6						
7						

Total weight after-cutting (grams):	14.697g		
Total weight of alloyed/casted material (grams):	15.001g		
Material differences (grams):	0.304g		
Material Accountability by: (MBA Custodian)	[signature]	Date:	3-10-16
Balance Information:	Fisher scientific		
Manufacturer:	Model No: Accu-413	Serial No: 723566	Calibration Due Date: 4-6-16
Caliper Information:	Digimatic Absolute		
Manufacturer:	Model No: CD-6"ASX	Serial No: ~~143~~ 731845	Calibration Due Date: 1-13-17

METAL FUEL FABRICATION PARAMETERS

Narrative:

3x buttoning 1x casting attempt recorded from As-Built data package R. Fief 19 Dec 2016