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Improved Casting Furnace Conceptual Design

Nuclear Technology Research and Development

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SUMMARY

In an attempt to ensure more consistent casting results and remove some schedule variance associated with casting, an improved casting furnace concept has been developed. The improved furnace uses the existing arc melter hardware and glovebox utilities. The furnace concept was designed around physical and operational requirements such as; a charge sized of less than 30 grams, high heating rates and minimal additional footprint. The conceptual model is shown in the report as well as a summary of how the requirements were met.

IMPROVED CASTING FURNACE CONCEPTUAL DESIGN

1. INTRODUCTION

Many Advanced Fuel Cycle metallic fuel test have been conducted since the beginning of the program. Throughout this time nearly all of the metallic fuel has been cast using the arc casting method. In this method the alloy components are heated by means of an electric arc to above the melting point and then dropped into a mold using gravity as the main driving force, or drawn into a mold using a pressure differential. Arc melting has the advantages of being very fast, flexible in regards to mold size and alloy composition, easily deployed in a glovebox environment, and is suitable to the small laboratory scale quantities used in transmutation fuel research. The main disadvantage of the small arc melting system is that the system is very much operator dependent, which has a large effect on the success of casting. This dependency is based on the lack of operational parameter feedback, such as temperature and atmospheric pressure control, as well as on the design of the furnace itself. Although this system has been used to fabricate many irradiation tests and characterization samples successfully, casting has always proven to be inconsistent and unpredictable. In order to produce fuel specimens consistently and reliably a new casting system is required that can replace the arc melting system for laboratory and irradiation test sample quantities which are generally less than 30 grams.

2. SYSTEM REQUIREMENTS

The most important requirement of the new furnace system is it must be suitable for glovebox use. All AFC transuranic fuels have been cast using an inert glovebox, therefore the new system will need to be installed and used in existing glovebox. For installation this means that all components that are internal to the glovebox must fit through a standard 8.5 in. glove port. Because glovebox space is limited, the system footprint must be minimized as much as possible. Ideally, the system should make use of existing utilities and hardware currently in the AFCI glovebox, where transmutation fuels are currently cast, or it should replace hardware so as not to increase the overall equipment footprint in the glovebox. The current arc melting system can cast/melt fuel on approximately a 30 gram scale or less since and many characterization and test samples are approximately 10-15 grams total. The new system must be capable of casting on this same laboratory scale. Transmutation fuels will ultimately contain americium. Past experience with arc melting has shown that if the alloys are brought up to melting, cast, and cooled in a rapid fashion; americium content in the fuel will be maintained. Based on this experience any new system should also be able to cast rapidly, preferably on the order of 2-3 minutes or less. Samples sizes needed may vary based on the end use of the sample. Standard AFC fuel slugs are 4.3 mm (0.168 in.) diameter and 37.5 mm (1.5 in.) long. However, samples for microstructural or thermal-physical characterization may have different dimensional requirements. Also, advanced fuel forms may dictate other dimensional and form requirements. Based on these varied dimensional requirements the advanced system must be flexible enough to cast a variety of fuel forms and dimensions. Finally, because fuel alloys are generally multi-component alloy systems~~,~~ such as U-Pu-Zr-Am-Np or U-Pu-Zr-Pd-Ce-Pr-Nd-La, mixing during the melt cycle is very desirable. In the arc melting system this is generally accomplished by impingement of the arc on the melt and by convective forces due to the extreme localized heating of the arc plasma. Although it is not necessary to have this capability in a new system since master alloys could be made using the arc melter, it is desirable.

3. CONCEPTUAL DESIGN

A model of the basic design is shown in Figure 1. The basic concept is a small induction heated furnace which will use a pressure over vacuum arrangement to ensure fuel flows into the mold. The current concept will use a yttria coated graphite crucible with a mold of either copper or quartz positioned below the crucible. The mold portion will be connected to a vacuum accumulator. The concept will use the induction heating technique to heat the sample to the casting temperature. Once the charge is molten, it will flow over the crucible exit. However, because there will be no gas vent and the system is closed, the gas pressure combined with surface tension will obstruct the material flow into the mold. The mold will connected to a vacuum accumulator with a valve isolating the two components. After the material is molten and flows over the crucible exit, the valve will be opened providing the driving force to pull the molten material into the mold. As shown in Figure 1 the crucible temperature will be monitored with a thermocouple. The current concept will locate the thermocouple between the crucible and the surrounding refractory. The furnace will use the existing arc melter stand, base assembly, and quartz chamber glass. A new top assembly will be fabricated to allow access for the induction could leads, thermocouple, and to remove the arc melter electrode.

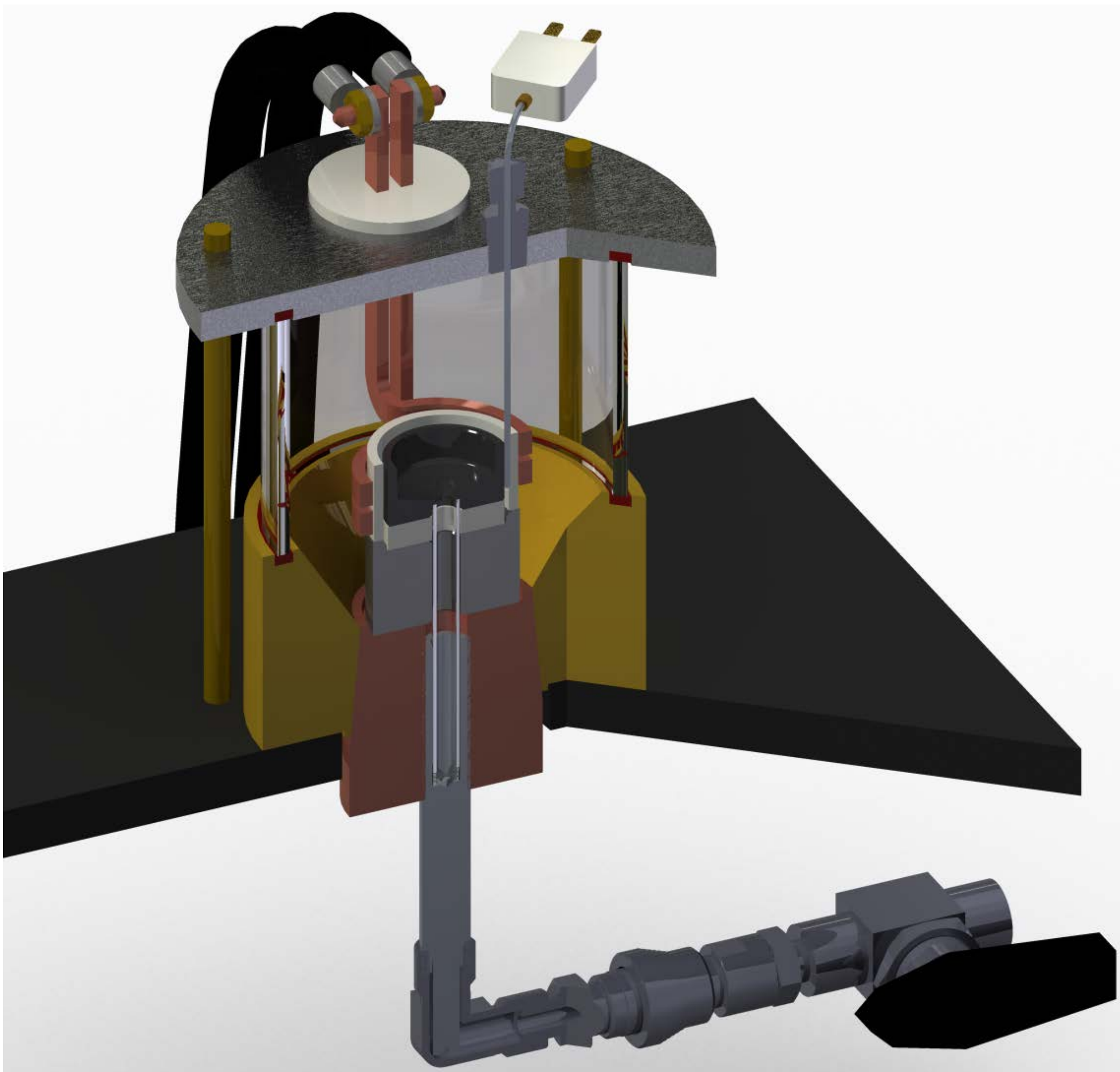


Figure 1. Cut away conceptual model of the improved laboratory scale casting furnace.

3.1 Glovebox Interfaces and Utilities

As stated in the requirements section, existing utilities and glovebox interfaces should be used to the extent possible. The improved casting furnace needs a total of three interfaces; two for power and one for thermocouple signal. The current arc melter also uses two electrical feedthroughs which are sized sufficiently large enough that they can also be used for this application. The crucible thermocouple will need to be capable of measuring temperatures in excess of 1600° C. A B-type thermocouple will be used for this operation and is also currently used for the americium distillation furnace. Thermocouples locations and monitoring can be relocated from the distillation system to allow use in the improved casting system. Under normal operation the melting atmosphere will be maintained by the glovebox, therefore no specific gas feedthroughs will be needed. The vacuum accumulator requires only a rough vacuum level, therefore an elaborate evacuation system and feedthroughs are not needed. Rather, a small hand operated vacuum pump will provide the needed reduced pressures in the vacuum accumulator.

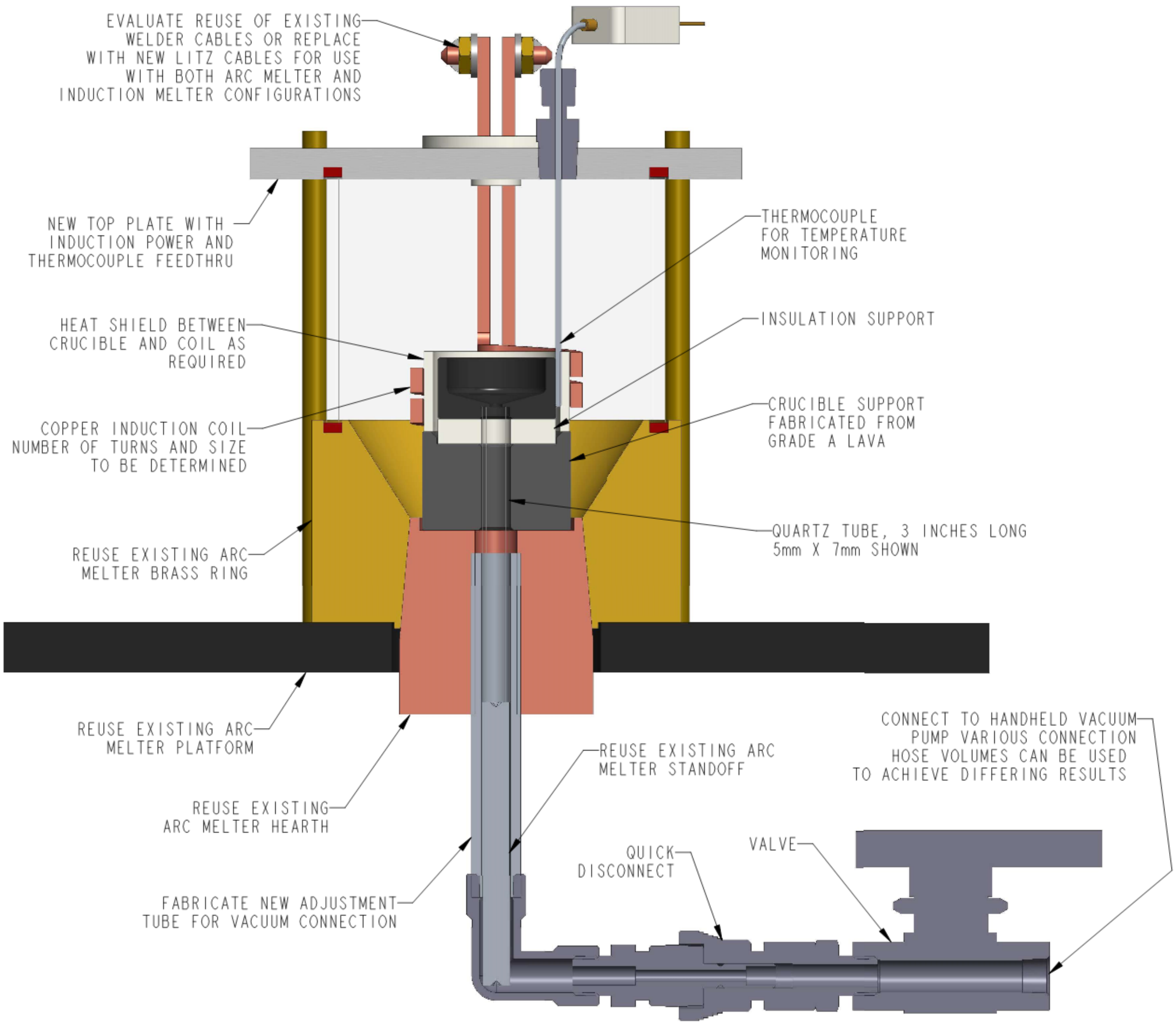
4. CONCLUSION

The conceptual design for an improved casting furnace suitable for casting of characterization and irradiation testing samples has been completed. The basic design is shown in Figure 1 with a more detailed rendering showing labelled individual components included in Appendix A. The furnace uses the existing arc melter stand, base, and enclosure with only a new top plate and hearth/mold assembly and gas handling system being added. All of the components that will be added are small and can be inserted through a standard 8.5 in. glove port. The total footprint will only be slightly larger than the existing arc melter due to the gas handling system. Because much of the same arc melter hardware is being used, only a small amount of additional hardware will need to be stored in the glovebox. Existing power and instrumentation feedthroughs and utilities will be used for the new furnace design. The current power feedthroughs are large enough that they can be used for induction power as well as arc melting power. Although testing will be needed, it is likely that the existing arc melter power cables will also be adequate for the new furnace~~,~~ further reducing needed new hardware. The americium distillation furnace uses type –B thermocouples which have a maximum use temperature of 1700° C. These will be adequate for the improved furnace and can be temporarily re-routed and use the same feedthroughs. Process size of the furnace will be set by the size of the graphite crucible. The current configuration assumes a crucible of approximately 2.54 cm (1 in.) in diameter. This size should provide the same charge size flexibility as the arc melter, with the possibility of increasing the maximum charge size. Transmutation fuels which contain americium need to be heated and cast in a short time period in order to maintain americium amounts. Induction heating has been shown to heat up charges quickly. In the current concept the Ajax Toccotron 5-10KW induction power supply will be used as the power source. In order to be effective for the small crucible, the power supply will need to run at a high frequency. The proposed power supply has a standard frequency upper limit of 50 Khz. It will be determined through prototype testing whether the Ajax Toccotron power supply is adequate. If this power supply is adequate this should provide a large excess of power needed for melting which will provide additional assurance that heating rates can be very fast. In addition to providing high heating rates the induction heating may also provide additional mixing in addition to the convectional mixing that is present in small diameter crucibles.

The next step in the design process will be to develop fabrication sketches and assemble the melting system. The applicability of the proposed power supply will be verified through prototype testing. This will be necessary to ensure enough power is available for a very fast heating rate and determine if the frequency is adequate to provide a high level of mixing. In addition to power supply verifications the prototype system will be used to determine if the concept of pressure over vacuum without a physical plug in the crucible is valid. During prototype testing the design will be optimized and documented. After testing, a similar system will be fabricated and installed into the AFCI glovebox.

Appendix A

Improved Casting System


EVALUATE REUSE OF EXISTING WELDER CABLES OR REPLACE WITH NEW LITZ CABLES FOR USE WITH BOTH ARC MELTER AND INDUCTION MELTER CONFIGURATIONS
NEW TOP PLATE WITH INDUCTION POWER AND THERMOCOUPLE FEEDTHRU
THERMOCOUPLE FOR TEMPERATURE MONITORING
HEAT SHIELD BETWEEN CRUCIBLE AND COIL AS REQUIRED
INSULATION SUPPORT
COPPER INDUCTION COIL NUMBER OF TURNS AND SIZE TO BE DETERMINED
CRUCIBLE SUPPORT FABRICATED FROM GRADE A LAVA
QUARTZ TUBE, 3 INCHES LONG 5mm X 7mm SHOWN
REUSE EXISTING ARC MELTER BRASS RING
REUSE EXISTING ARC MELTER PLATFORM
CONNECT TO HANDHELD VACUUM PUMP VARIOUS CONNECTION HOSE VOLUMES CAN BE USED TO ACHIEVE DIFFERING RESULTS
REUSE EXISTING ARC MELTER STANDOFF
REUSE EXISTING ARC MELTER HEARTH
QUICK DISCONNECT
VALVE
FABRICATE NEW ADJUSTMENT TUBE FOR VACUUM CONNECTION