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Reduced Enrichment for Research and Test Reactors

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Y-12 NATIONAL SECURITY COMPLEX U-MO FABRICATION FOR MP-1

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ABSTRACT

Y-12 National Security Complex (Y-12 NSC) participates in the Fuel Fabrication Capability (FFC) pillar of the National Nuclear Security Administration (NNSA) Office of Material Minimization and Management (M^3) Office of Conversion Pillar system. Y-12 NSC is primarily responsible for the establishment of the fabrication process for the low-enriched uranium-molybdenum (LEU-Mo) feedstock. This update will focus on the efforts and status of fabricating feedstock in support of the Mini-Plate-1 (MP-1) experiment.

1. Introduction

The Reduced Enrichment for Research and Test Reactors (RERTR) Program was initiated by the U.S. Department of Energy (DOE) to develop the technical means for the conversion of high powered research reactors (HPRRs) from Highly Enriched Uranium (HEU) to Low Enriched Uranium (LEU). The RERTR program cooperates with the research reactor community to achieve this goal of HEU to LEU conversion while maintaining reactor reliability and performance. The Y-12 National Security Complex (Y-12 NSC) is a participant in the NNSA NA-23, Office of Material Management and Minimization's Convert Program, also known as RERTR, by establishing a fabrication process for the low-enriched uranium-molybdenum (LEU-Mo) feedstock.

2. Program Scope

The NA-23 Office of Material Management and Minimization Reactor Conversion Program funded the Y-12 NCS to fabricate U-Mo ingots in support of the Mini-Plate-1 (MP-1) experiment. This effort consists of manufacturing DU-Mo, LEU-Mo and HEU-Mo ingots using the process of shown in Figure 1.

Y-12 begins the process by acquiring a master alloy of depleted uranium-molybdenum (DU-Mo). The master alloy is fabricated by blending a depleted uranium feed with molybdenum. This is typically performed by a vendor and can be accomplished by either arc melting or by a vacuum induction melting (VIM) process. This work is typically performed by a vendor. For the DU-Mo ingot fabrication, Aerojet provided the master alloy, which was fabricated using a VIM process. For the LEU-Mo and HEU-Mo fabrication, Los Alamos National Laboratory (LANL) provided the master alloy, which was fabricated by an arc melt process. The arc melting process uses a tungsten tip to arc melt the uranium feed and molybdenum. The master alloy is then blended with uranium feed in a VIM process. The furnace temperature is taken to a nominal 1400^{o}C and held for 30 minutes before the liquid metal is poured into the mold.

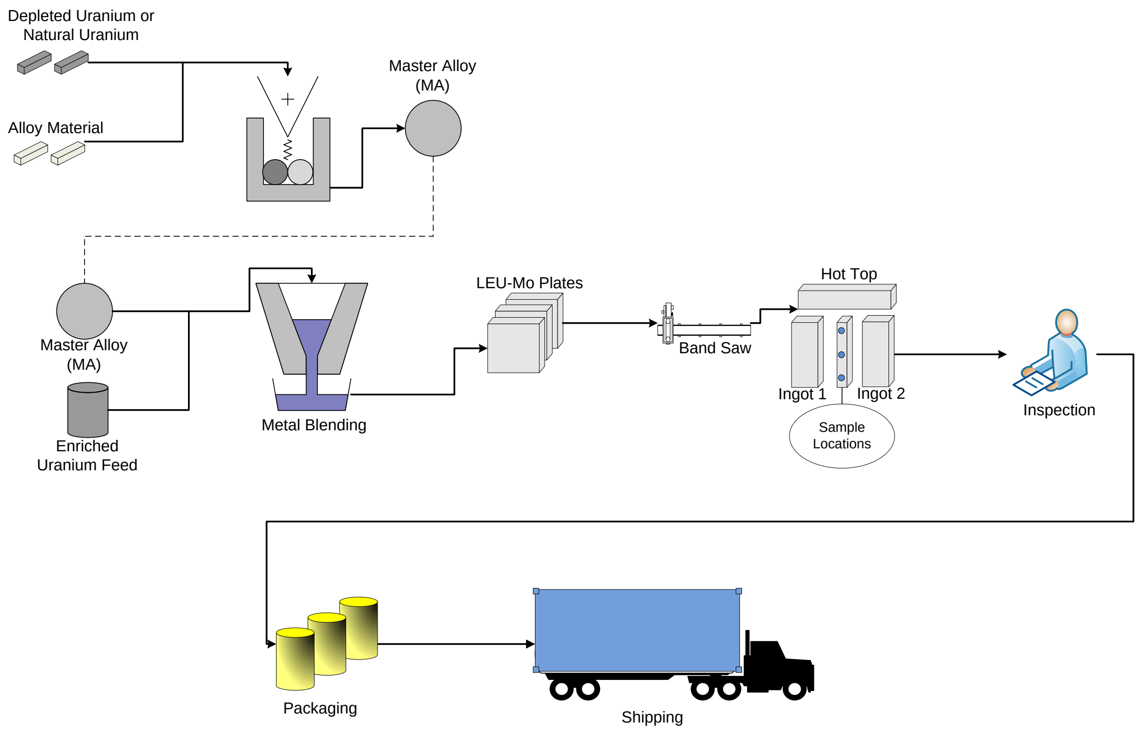

Figure 1: MP-1 U-Mo Feedstock Fabrication Process

3. MP-1 Fabrication Status

3.1 MP-1 DU-Mo Fabrication Status

Y-12 NSC fabricated DU-Mo ingots using the process shown in Figure 1. The melt temperature profile for three DU-Mo Plate castings is shown below in Figure 2. The plot demonstrates that all castings performed as expected with regards to furnace temperature ramp and hold time.

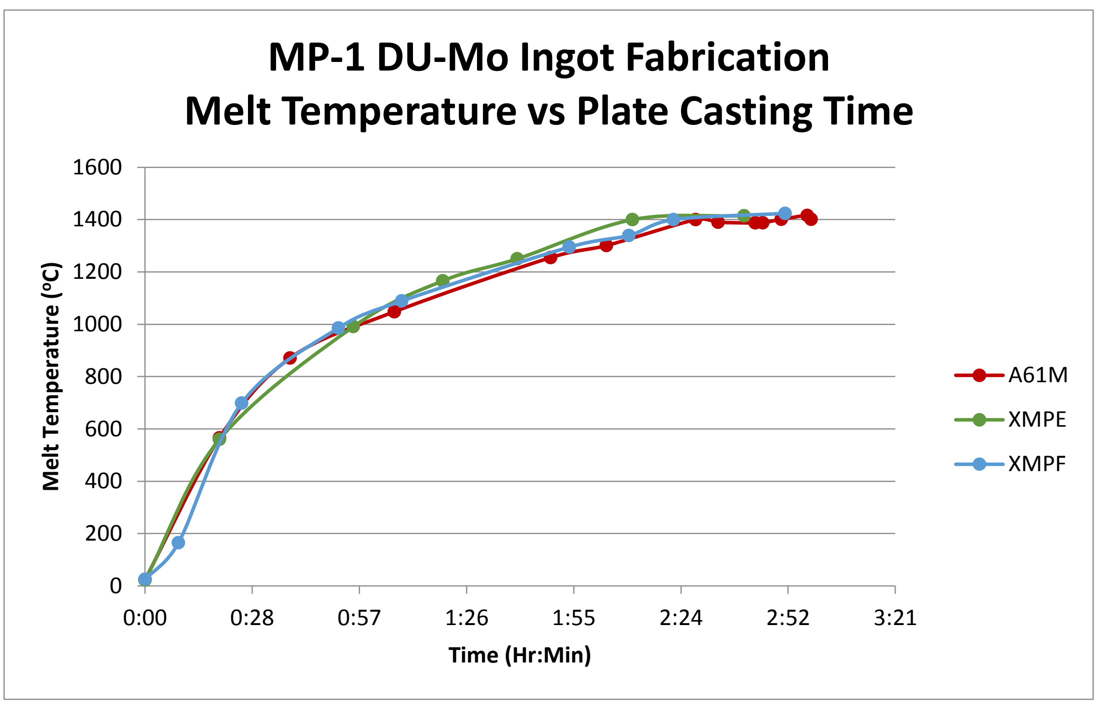

Figure 2: Nominal Melt Temperature Profile for DU-Mo Fabrication

The melted material was then poured into a multi-plate book mold, as shown in Figure 3. The melt yielded three single plates that are approximately 8” by 11” by 0.2”. A representative plate with the hot top removed is shown in Figure 4.

Figure 3: MP-1 Casting Mold

Figure 4: MP-1 Cast Plate

The cast plates are then sectioned into ingots, as shown in Figure 5. The hot top is removed and a strip of cast material in the center provides material for sampling.

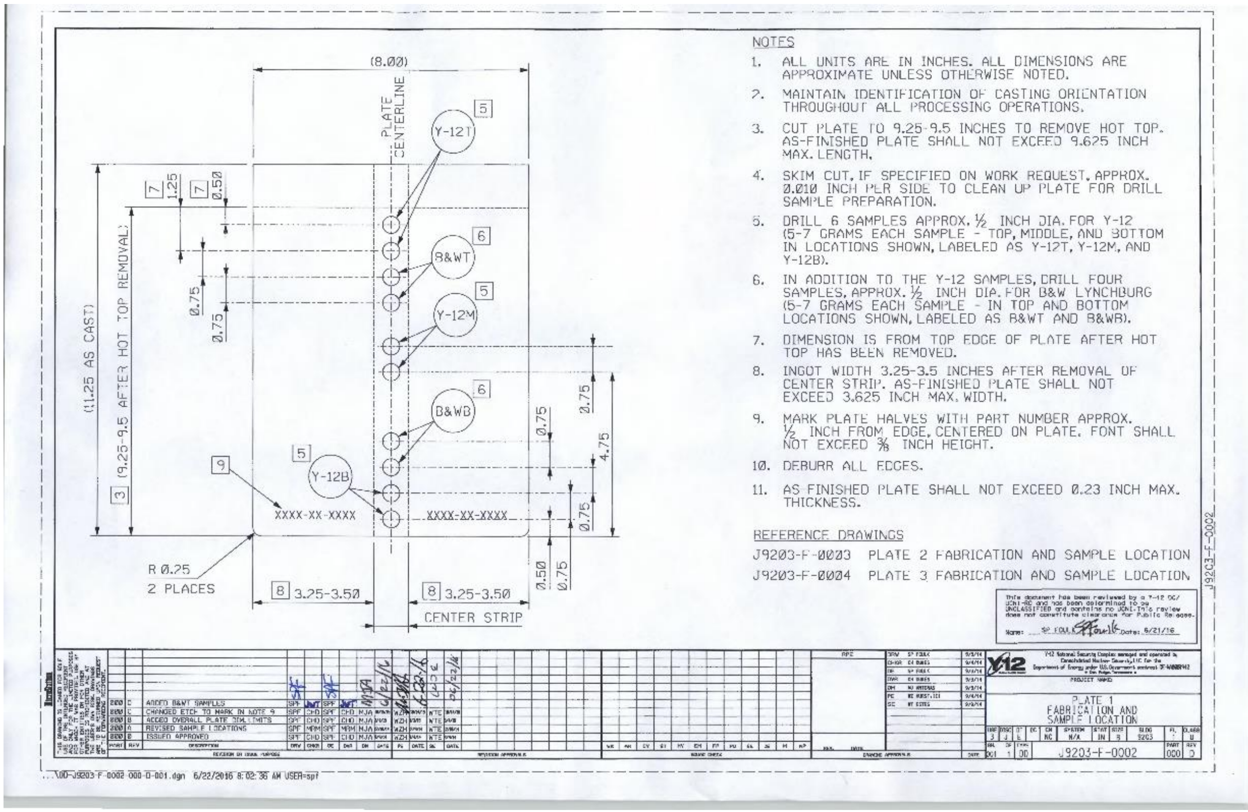

Figure 5: Ingot Sectioning and Sampling Drawing

As the DU-Mo ingots were sectioned from the plates, samples were taken from the center strip, which is representative of the ingot chemical make-up. Samples were taken from the top, middle and bottom of each plate. The resulting chemical analyses were compared to targeted values from the batch make-up. For molybdenum, the target value was 10% ± 1%. For uranium, the target value was 90% ± 1%. The results are shown in Table 1 and graphed in Figure 6.

		1		2		3	
		A61M		**XMPE**		**XMPF**	
		U	**Mo**	**U**	**Mo**	**U**	**Mo**
Plate 1	**Top**	89.45%	10.5%	89.44%	11%	89.55%	10.4%
	Middle	89.99%	10.0%	90.30%	10%	90.77%	9.2%
	Bottom	90.80%	9.2%	90.30%	10%	90.14%	9.8%
Plate 2	**Top**	89.91%	10.0%	89.62%	10%	90.01%	9.9%
	Middle	90.53%	9.4%	90.22%	10%	90.03%	9.9%
	Bottom	90.03%	9.9%	90.09%	10%	90.86%	9.1%
Plate 3	**Top**	89.85%	10.1%	89.34%	11%	89.74%	10.2%
	Middle	89.94%	10.0%	90.42%	10%	89.84%	10.1%
	Bottom	90.17%	9.8%	90.60%	9%	89.75%	10.2%
	Average	90%	10%	90%	10%	90%	10%
	Target	90%	10%	90%	10%	90%	10%
	Δ from Target	0.1%	-0.1%	0.000	-0.1%	0.1%	-0.1%

Table 1: MP-1 DU-Mo Casting Summary

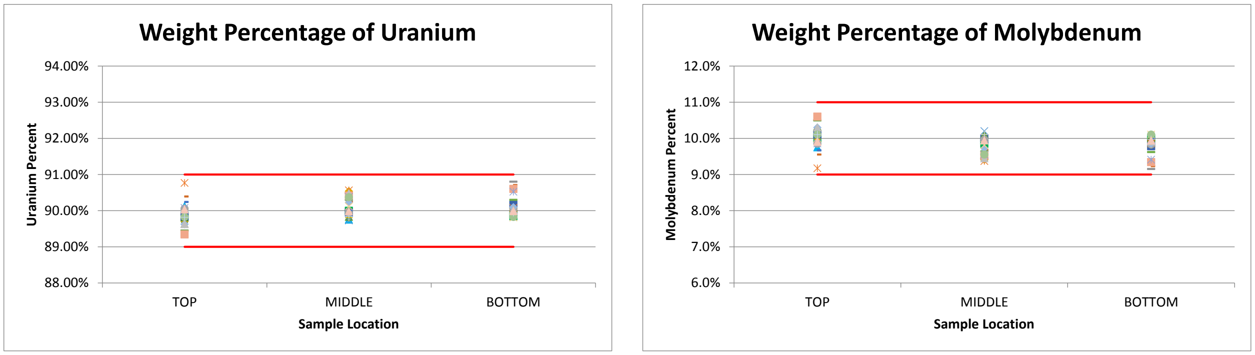

Figure 6: MP-1 DU-Mo Casting Summary

All castings were within the target molybdenum and uranium ranges.

3.2 MP-1 LEU-Mo Fabrication Status

Based upon data analysis from the DU-Mo casting, the program re-entered the Enriched Uranium Production area for the first LEU-Mo casting campaign in three years. The MP-1 campaign is the first attempt at LEU-Mo casting using a single step casting process. The material was cast using the process shown in Figure 1, using LANL master alloy.

Results from the first three castings are shown in Table 2 and Figure 7. Casting #4 was not utilized for the MP-1 experiment. Therefore, no data from this casting was used in the data.

		1		2		3	
		A5MH		AE1K		AHTD	
		U-235	Mo	U-235	Mo	U-235	Mo
Plate 1	Top	19.537	10.50	19.187	10.50	19.865	10.3
	Middle	19.628	10.40	19.214	10.40	19.952	10.3
	Bottom	19.886	10.30	19.202	10.50	19.932	10.4
Plate 2	Top	19.376	10.30	19.196	10.50	19.857	10.5
	Middle	19.314	10.00	19.297	10.50	20.003	10.5
	Bottom	19.318	10.00	19.242	10.60	19.96	10.1
Plate 3	Top	19.396	10.20	19.163	10.50	19.621	10.4
	Middle	19.465	10.20	19.220	10.50	19.612	10.4
	Bottom	19.505	10.20	19.156	10.40	19.425	10.2
	Average	19.492	10.233	19.209	10.489	19.803	10.344
	Target	19.750	10.00	19.478	10.00	19.753	10.00
	Δ from Target	-0.258	0.233	-0.269	0.489	0.050	0.344

Table 2: MP-1 LEU-Mo Casting 1-3 Summary

The data in Table 2 indicates that sufficient blending occurs during the casting process to meet the molybdenum specification. However, the data indicates that the U-235 did not meet the desired target. From the analysis, some mixing is occurring to effectively downblend the material from highly enriched uranium to a low enriched uranium alloy product.

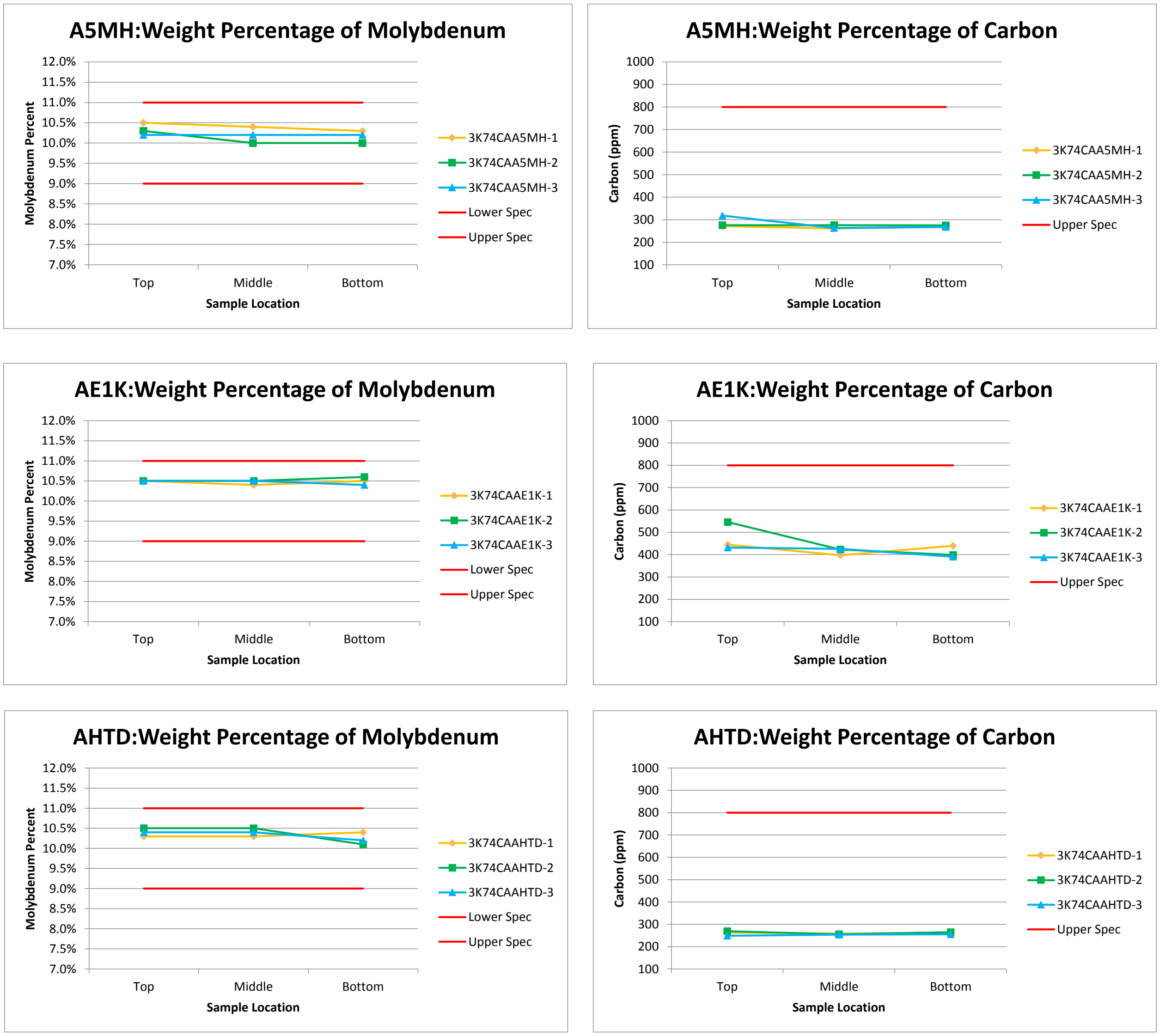

Figure 7: MP-1 LEU-Mo Casting Summary

Figure 7 graphically displays the molybdenum data and carbon data from the first three MP-1 castings. The plots indicate that the process is acceptable to meet the molybdenum target value. Furthermore, the plots indicate that the carbon level are homogenous throughout the casting. Homogeneity of carbon is of concern for downstream fuel processing.

While the DU-Mo fabrication did not adequately simulate uranium downblending, the data indicates some mixing is occurring during the casting process to downblend the enriched uranium to a low enriched uranium. Therefore, the single step casting process is a viable option to fabricate the LEU-Mo material. With the knowledge that the casting process was close to meeting the uranium mixing target for downblending, the program began examining casting parameters to determine which input parameters were the primary contributing factors to influence the degree of mixing. The program developed a U-Mo Separation of Casting Effects Experiment as shown in Figure 8.

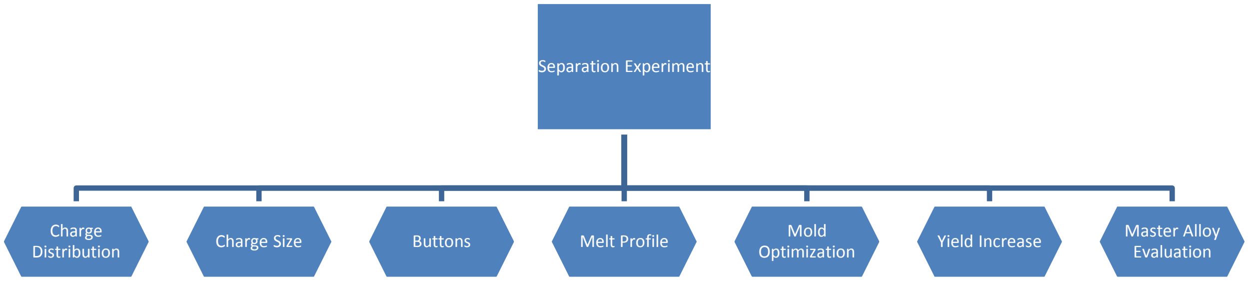

Figure 8: FY16 U-Mo Separation of Casting Effects Experiment

The first parameter examined in the experiment was the crucible charge distribution. Material in the first three castings was comingled in the crucible prior to casting. For castings five through eight, the HEU was placed in the center of the crucible with the master alloy placed on top and outside edges, as shown in Figure 9.

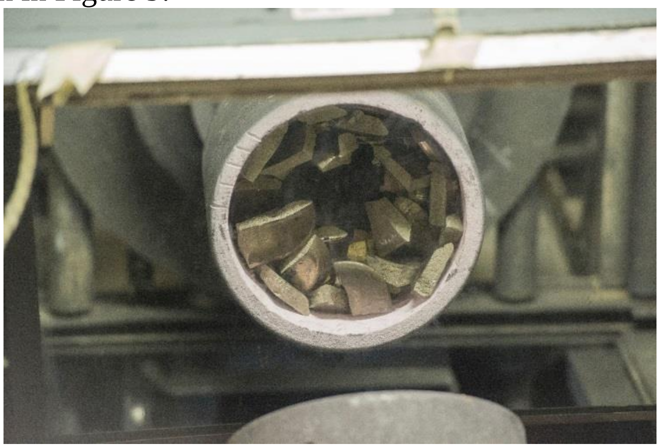

Figure 9: Separation Experiment: Charge Distribution

This parameter was examined with the intent to utilize the thermal gradient across the crucible, which increases radially outwards from the center. This would allow the DU-Mo to melt at the same rate as the HEU and provide an increased time to mix for the two liquids. The casting temperature was the same as previous castings at a nominal1400°C with a 30 minute hold period. The LEU-Mo casting summary date is presented in Table 3 and Figure 10 through Figure 11.

		5		6		7		8	
		AMF9		AMFA		C4DX		AMFC	
		U-235	Mo	U-235	Mo	U-235	Mo	U-235	Mo
Plate 1	Top	19.431	10.30	19.540	10.20	19.304	10.50	19.490	10.40
	Middle	19.489	10.30	19.542	10.30	19.554	10.30	19.993	10.20
	Bottom	19.521	10.30	19.429	10.30	19.572	10.40	20.386	10.20
Plate 2	Top	19.479	10.40	19.692	10.40	19.245	10.20	20.174	10.10
	Middle	20.108	10.30	19.838	10.40	21.686	10.00	20.223	10.00
	Bottom	20.268	10.30	19.894	10.40	21.949	9.94	19.918	10.20
Plate 3	Top	19.524	10.30	19.692	10.30	19.137	10.30	19.237	10.20
	Middle	20.628	10.10	20.025	10.10	19.113	10.40	19.363	10.40
	Bottom	20.669	10.00	20.519	10.30	18.933	10.30	20.830	10.30
	Average	19.902	10.256	19.797	10.300	19.833	10.260	19.957	10.222
	Target	19.705	10.000	19.671	10.000	19.717	10.000	19.702	10.000
	Δ from Target	0.197	0.256	0.126	0.300	0.116	0.260	0.255	0.222

Table 3: MP-1 LEU-Mo Casting 5-8 Summary

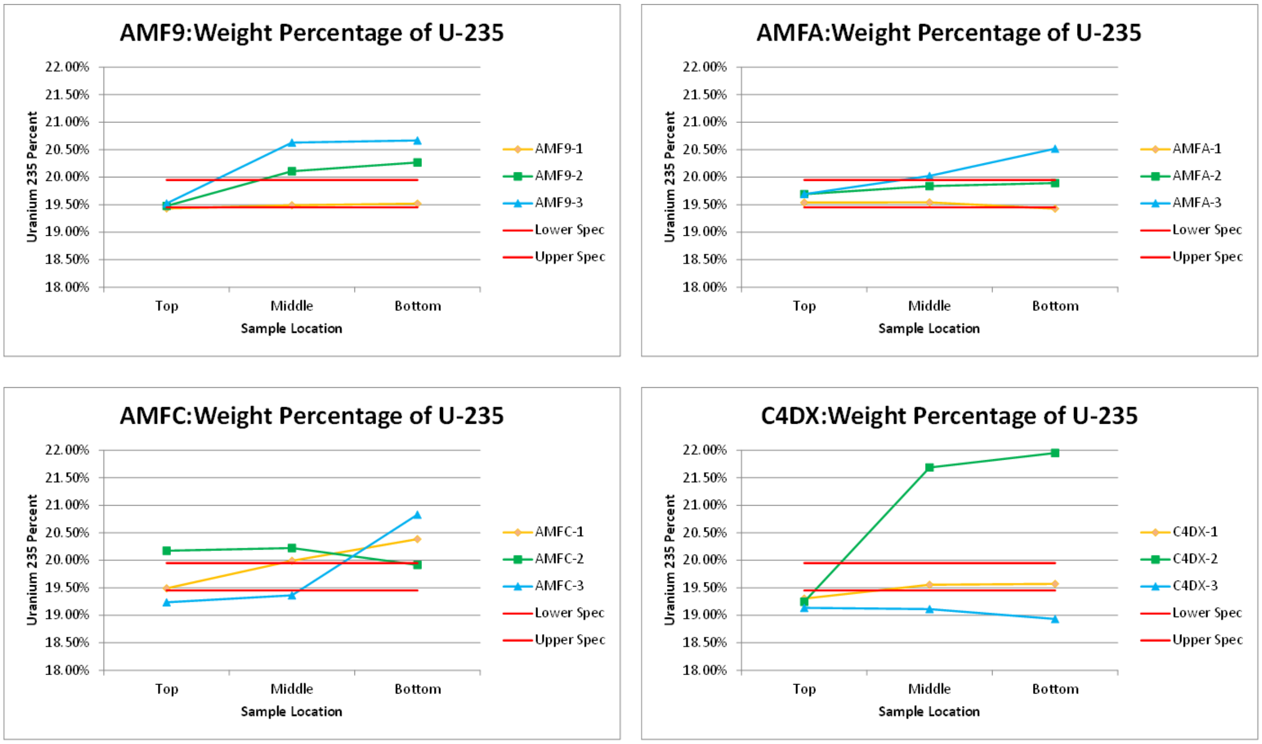

Figure 10: MP-1 LEU-Mo U235 Casting 5-8 Summary

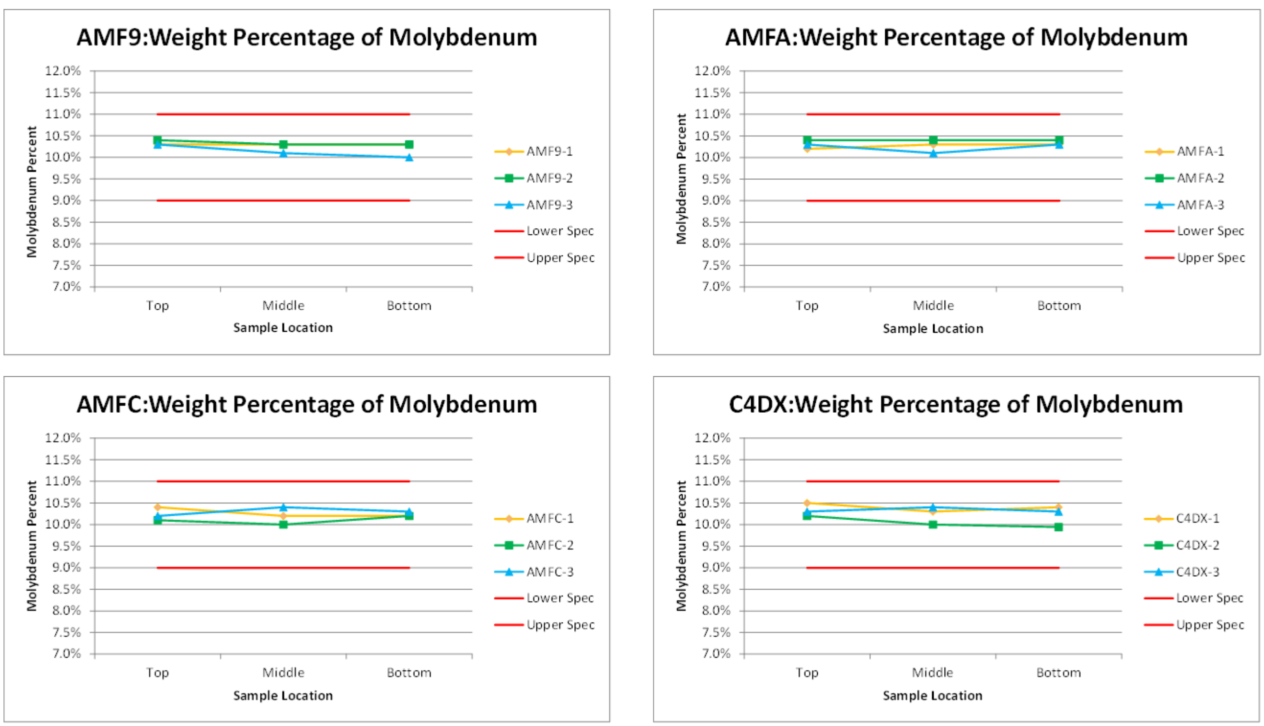

Figure 11: MP-1 LEU-Mo Molybdenum Casting 5-8 Summary

Figure 12 is a summary of the carbon pickup for all LEU-Mo castings and shows a consistent carbon increase. This is valuable information to facilitate a better understanding of carbon effects on downstream processing.

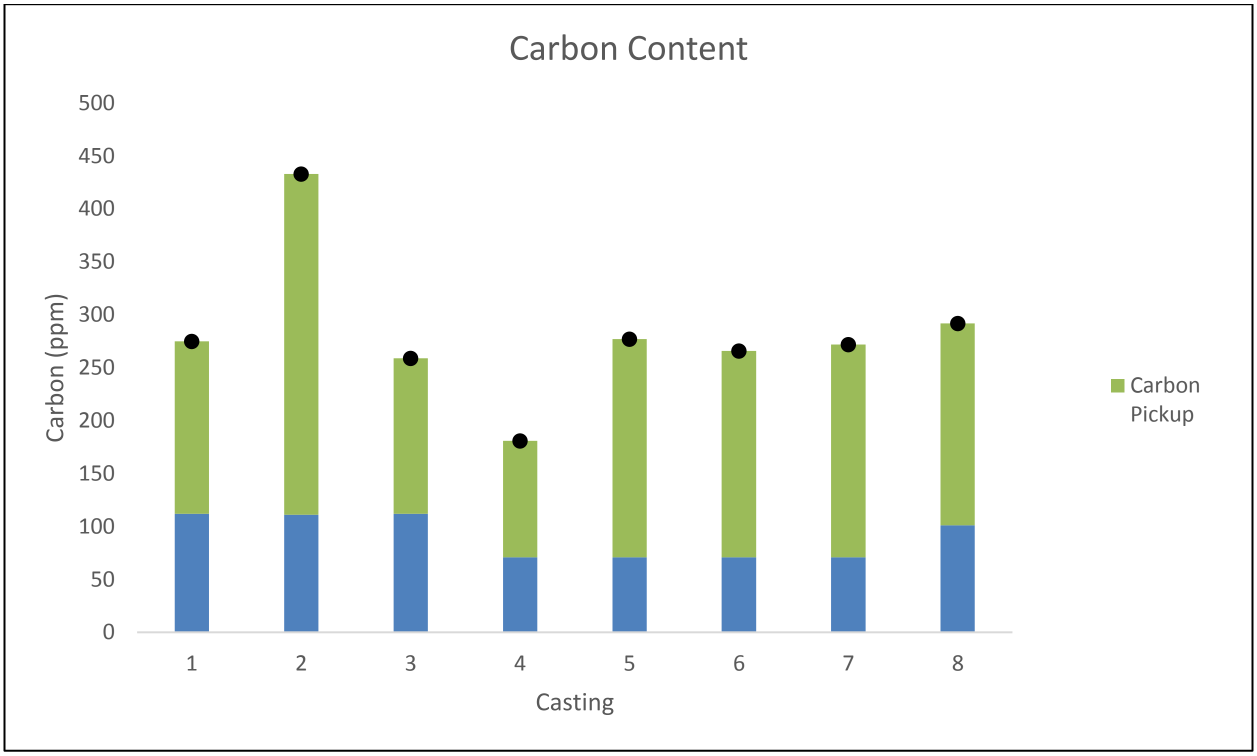

Figure 12: MP-1 LEU-Mo Carbon Casting Summary

Analysis of castings 5-8 indicate that the material placement in the crucible does impact the blending results. However, the placement chosen for these casting was not ideal and, in fact, caused the final U-235 values to be above the target. Review of the data indicates the master alloy may have preferentially oxidized in the process, thus leaving more HEU in the melt and causing the final U-235 to be higher than targeted. At this time, no additional castings are planned with this crucible loading configuration.

Y-12 has additional work scope planned in FY17 to continue the U-Mo Separation of Casting Effects Experiment. Specifically, Y-12 will examine the material weight of the arc melted buttons. This portion of the experiment is expected to determine the significance of the button weight in the crucible to the final blend chemistry. This will compare arc melted buttons that are blended with enriched uranium as whole buttons and broken buttons. The whole buttons have a higher weight and are larger, which would limit the ability to comingle materials in the crucible. The broken buttons have a lower weight per piece, which would allow the material to be more comingled in the crucible.

The experiment will continue with an examination of the mold. Y-12 collaborated with LANL to model and optimize the three-plate mold to reduce casting flaws. The optimized mold is a horizontal geometry and includes a distributor plate to fill all three plates simultaneously. This portion of the experiment is expected to determine the significance of the mold geometry and mold filling process on the final product chemistry.

Finally, Y-12 will procure additional master alloy from Aerojet and perform castings. This portion of the experiment is expected to determine the optimal master alloy fabrication process, i.e. VIM or Arc Melt.

4. Summary

Y-12 NSC completed fabrication and delivery of DU-Mo and LEU-Mo ingots in support of the MP-1 experiment. Based on the result of the DU-Mo fabrication, Y-12 NSC obtained information needed for transferring process activities to the Enriched Uranium Production facility. The single step casting process results in a product that meets the molybdenum specification and reduces the carbon increase, as compared to a two-step casting process. It was learned that, while DU-Mo simulated effects of molybdenum and impurity mixing, it was not a good surrogate for demonstrating downblending. However, while the DU-Mo fabrication did not adequately simulate downblending, data indicates mixing is occurring in the cast to downblend the enriched uranium to a low enriched uranium. Therefore, the single step process is still a viable process to fabricate the LEU-Mo material. The program will continue the U-Mo Separations of Effects Experiment to reduce the U-235 variability in the final product.