Update on Uranium-Molybdenum Fuel Foil Fabrication Development Activities at the Y-12 National Security Complex in 2007

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ABSTRACT

In support of the RERTR Program, efforts are underway at Y-12 to develop and validate a production oriented, monolithic uranium molybdenum (U-Mo) foil fabrication process adaptable for potential implementation in a manufacturing environment. These efforts include providing full-scale prototype depleted and enriched U-Mo foils in support of fuel qualification testing. The work has three areas of focus; develop and demonstrate a feasible foil fabrication process utilizing depleted uranium-molybdenum (DU-Mo) source material, transition these production techniques to enriched uranium (EU-Mo) source material, and evaluate full-scale implementation of the developed production techniques. In 2006, Y-12 demonstrated successful fabrication of full-size DU-10Mo foils. In 2007, Y-12 activities were expanded to include continued DU-Mo foil fabrication with a focus on process refinement, source material impurity effects (specifically carbon), and the feasibility of physical vapor deposition (PVD) on DU-10Mo mini-foils. FY2007 activities also included a transition to EU-Mo and fabrication of full-size enriched foils. The purpose of this report is to update the RERTR audience on Y-12 efforts in 2007 that support the overall RERTR Program goals.

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1. INTRODUCTION

The Reduced Enrichment for Research and Test Reactors (RERTR) Program was initiated in 1978 by the U.S. Department of Energy (DOE) to develop the technical means for the conversion of research reactors from HEU to 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 goal of the RERTR program is to complete the conversion of all targeted research reactors by 2014. One hundred six (106) research reactors around the world have been identified for conversion to LEU. Of these 106 reactors, 28 require new LEU fuel for conversion.

The RERTR program has focused recent efforts in new LEU fuel development on the production of high density, low-enriched, monolithic U-Mo fuel. This monolithic LEU fuel would be theoretically capable of converting every research reactor currently operating in the world today. In monolithic U-Mo fuel plates, the entire plate fuel matrix is comprised of a single U-Mo alloy foil. The existence of the single alloy fuel provides the maximum uranium loading, limited only by the fuel alloy density as the fuel is absent of the dispersing material matrix found in dispersion fuel. This results in much higher uranium loading densities than are available in the traditional LEU fuels.

The development, testing, and qualification of new LEU monolithic fuel technologies is being pursued very aggressively as the RERTR is working to make this fuel available to support targeted research reactor conversion dates.

In support of RERTR program goals, efforts are underway at Y-12 to develop and validate a production oriented, monolithic U-Mo foil fabrication process adaptable for potential implementation in a manufacturing environment. Y-12 involvement in the RERTR monolithic fuel development program began in 2006 with the development of a fundamental fabrication process for monolithic fuel foils. In 2007, Y-12 continued its participation in the RERTR fuel development program through further monolithic foil production and process development.

2. SUMMARY OF 2006 MONOLITHIC FUEL DEVELOPMENT ACTIVITIES AT Y-12

In 2006, Y-12 activities included development of an understanding of the monolithic foil fabrication process and, using existing equipment at Y-12, to test the fabrication process using depleted uranium alloyed with 10 weight percent molybdenum (DU-10Mo).

The goal in developing the rolling process at Y-12 was to produce “full-size” foils (1.5” X 20.5”) at a thickness of 10 mils. A parent batch of DU-10Mo source material was developed through melting via a vacuum induction furnace for roll-forming. Successful rolling of DU-Mo foils to the desired size was eventually accomplished via a two stage

rolling process: 1) hot-rolling (with intermediate heat treatment) to an intermediate thickness, and 2) cold-roll finishing to the final thickness.

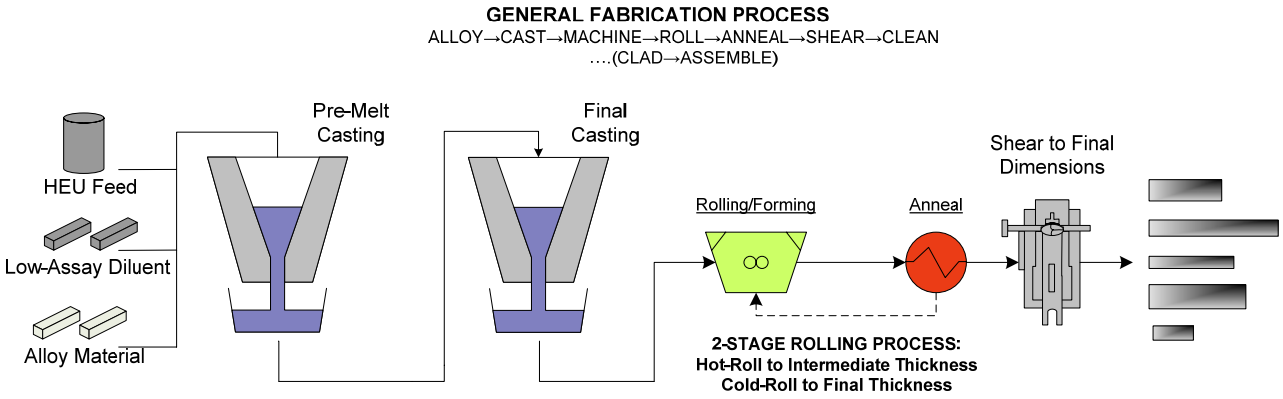

Figure 1. Fundamental Monolithic U-10Mo Process Flow

These process steps were successfully repeated for numerous iterations, using the same parent batch of material, to ensure reproducibility. The process proved to be both consistent and reliable in its results, and seemed feasible for eventual scale-up to large scale production quantities. However, it was also understood that the monolithic foil fabrication process required further development, validation, and optimization. 2007 activities were then planned to continue the foil production process development with more DU-10Mo foil fabrication (focusing on source material impurity effects) and eventually transition to provide full-size LEU-10Mo foils for qualification testing.

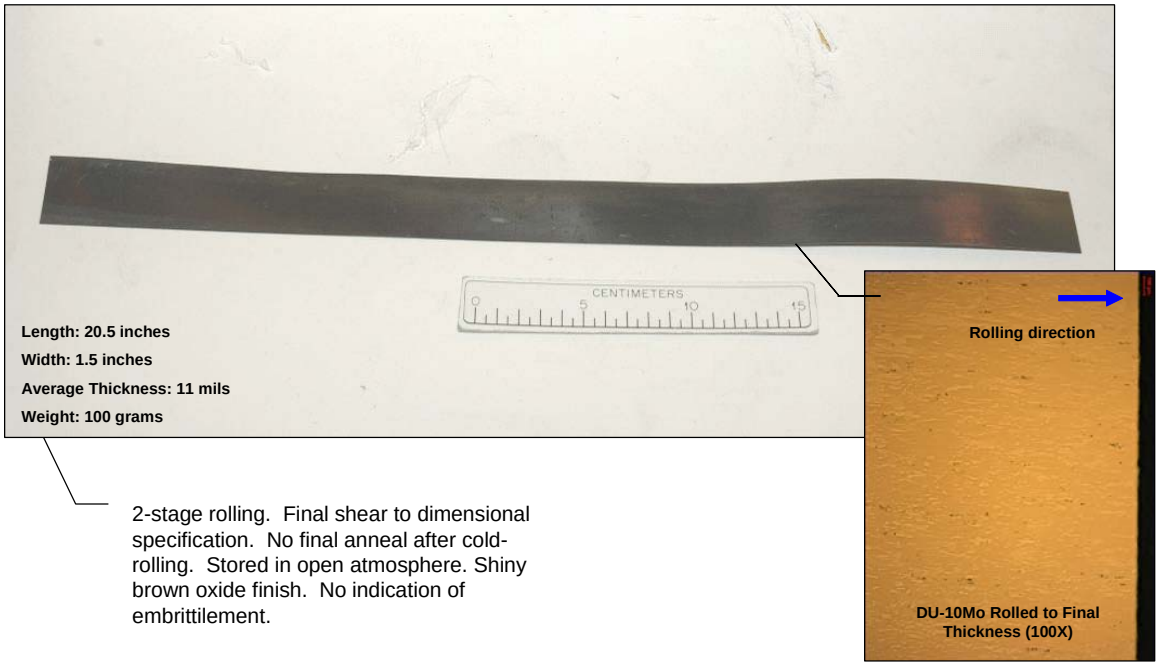

Figure 2. Typical Y-12 DU-10Mo Foil

3. UPDATE ON 2007 MONOLITHIC FUEL DEVELOPMENT ACTIVITIES AT Y-12

In 2007, Y-12 activities were expanded to include continued DU-Mo foil fabrication with a focus on process refinement, source material impurity effects (specifically carbon), and the feasibility of physical vapor deposition (PVD) on DU-10Mo mini-foils. FY2007 activities also included a transition to EU-Mo and fabrication of full-size enriched foils.

3.1. DU-10Mo Foil Fabrication Activities

Full-size DU-10Mo monolithic foils (typical size: 1.5” X 20.5” X 10 mils) were fabricated to support fuel fabrication process development and bonding qualification efforts. The DU-10Mo foils were fabricated utilizing the 2-stage rolling methodology described previously in Section 2 from a single parent batch of DU-10Mo alloy material.

Note that it is necessary to begin to develop an understanding, not just of the fabrication process, but also of the other variables which may affect the process results. One of these variables is the chemical composition of the U-Mo alloy source material. The chemical composition of the U-Mo alloy could have distinctive effects on the fabrication process, in particular in regards to process yields, as the research and test reactor fuel fabrication industry transitions from dispersion to metal-worked uranium alloys.

Carbon is of particular interest in the metalworking of uranium due to its potential effects on the metalworking process and due to its inherent presence in uranium source material. Therefore, to investigate its effects during the fabrication of the full-size foils, source material containing varying levels of carbon, was developed for use in fabrication of the DU-10Mo foils. The source material was from a single parent alloy batch of DU-10Mo with spiked carbon levels ranging from approximately 150 – 500 ppmU carbon. There were noticeable differences in metalworking the material. Foils were successfully fabricated for carbon levels in the range of 150 – 400 ppmU carbon. The primary difference in fabrication for the different carbon level materials was in the process yields between higher and lower carbon source material. Higher carbon material developed more edge cracking than lower carbon material resulting in less usable material upon final rolling (lower process yields).

It should be noted that this is only a preliminary look at the potential effects of carbon on monolithic foil fabrication. The results of this initial investigation should be taken as positive as they indicate that, while carbon level does affect process yields, it does not appear that source material availability will be severely limited by the carbon (i.e. there does not appear to be a need for extremely “clean” material). In fact, it appears that a suitable carbon limit for the monolithic foils may be approximately close to the value listed in Y-12’s current LEU specification, 350 ppmU. More work is planned to develop a more thorough understanding of carbon effects relative to fabrication reliability and process yields and to potential develop a limit on acceptable carbon content.

Table 1. Existing Y-12 Research Reactor Specifications for Some Typical Major Impurities [1]

			Y-12 LEU Metal Specification
Element	**Symbol**	**Units**	**Y/GNSS-05-02 r1**
Carbon	C	ppmU	350
Iron	Fe	ppmU	250
Molybdenum	Mo	ppmU	100
Nickel	Ni	ppmU	100
Silicon	Si	ppmU	100
Zirconium	Zr	ppmU	250
Total Impurities	TotImp	ppmU	1,200

3.2. Physical Vapor Deposition Activities

Typical research reactor fuel plates are clad in 6061 aluminum. Interaction between the U-Mo foil and the aluminum cladding is of particular interest in order to better understand how these interactions may affect the performance of monolithic fuel plates. It has been shown in previous work performed by Idaho National Lab [2], [3] that a methodology of minimizing the interaction layer between the U-Mo alloy and the aluminum cladding requires investigation.

One method to limit the interaction between the fuel foil and the cladding material is to include a diffusion barrier at the foil/cladding interface to physically and chemically separate the two materials. Y-12 is working to perform physical vapor deposition on mini-foils (approximately 1” X 4” X 10 mils) to provide an initial look at the potential role of PVD technology in diffusion barrier application on monolithic U-Mo foils.

Physical vapor deposition processes are capable of building substrates by the vaporization (sputter) of the desired metal alloy in a vacuum. The PVD system (“ion plater”) consists of a vacuum chamber into which the work-piece (item to be plated) and a target disk (source material) of the plating material are loaded. The chamber is evacuated then backfilled with inert gas (typically argon, neon, etc.) to the desired operating pressure. Processing voltages are applied to the work-piece and target. The target is bombarded with ionized (electrically charged) inert gas, which removes atoms from the target. These atoms are attracted to the work-piece and are deposited on its surface. Niobium and Zirconium are to be used as diffusion barrier material. 4 to 5 mini-foils are planned for each of the diffusion barrier material types. The coated mini-foils will be provided to INL for analysis of the effectiveness of this fundamental test of the PVD process. PVD of the mini-foils is expected to be complete by the end of September.

3.3. EU-10Mo Foil Fabrication Activities

Steps to transition to EU-10Mo fabrication at Y-12 are underway. Y-12 has an extensive history in the realm of uranium casting and metalworking which has proven to be very valuable in this process. One of Y-12's key roles in the DOE complex is as the primary storage facility for unirradiated uranium. Y-12 currently serves to supply enriched uranium metal, in the form of broken metal pieces, to the RERTR program and other entities, both foreign and domestic, for subsequent fuel fabrication and research. Full-size EU-10Mo foils will be fabricated using enriched uranium source material representative of typical research reactor LEU fuel (i.e. relative to chemical composition and isotopics).

Figure 3 depicts the fundamental process steps and material flow in the fabrication of the EU-10Mo foils at Y-12.

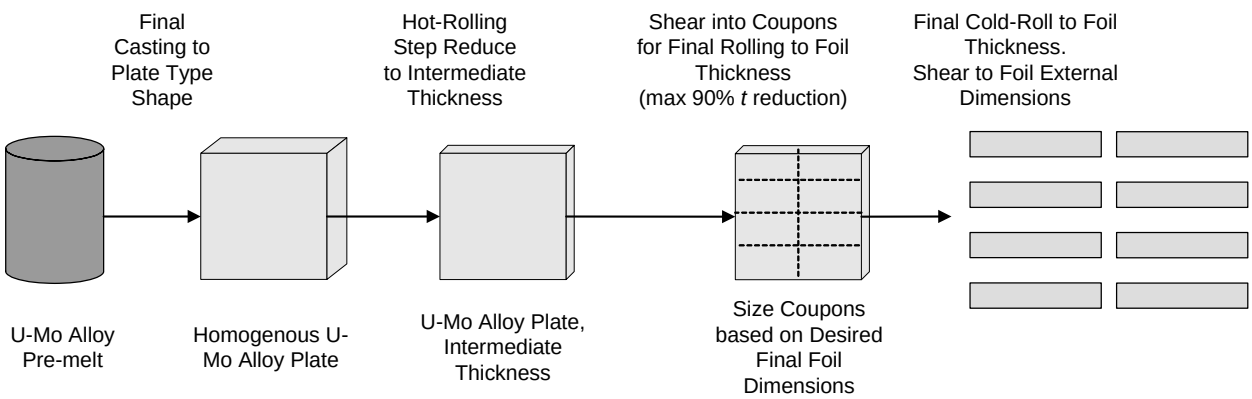

Figure 3. Fundamental EU-Mo Foil Fabrication

The source material available for use in the fabrication of monolithic U-Mo foils begins as uranium metal and may be of LEU or HEU assay. No significant quantities of EU-Mo alloys currently exist to use as source material. Therefore the initial step in the process is in developing a homogenous U-10Mo alloy for subsequent rolling and forming operations. This is performed in 2 separate casting steps. The first casting step is called the pre-melt. In the pre-melt step the uranium metal is combined with molybdenum and, if necessary, diluent depleted or natural uranium, to achieve the desired assay and molybdenum content. A second, final-melt is then performed to ensure that the molybdenum is homogenously mixed within the newly developed alloy. Future studies are planned which will focus on casting homogeneity and the potential of eliminating one of the casting steps to improve process efficiency. The initial casting is made in a large batch (approximately 20 kgU) with the final casting being smaller batches of material in slab-type shapes. Once a homogenous source material is developed, the next phase of the process is the initial size reduction, which is typically

accomplished by hot-rolling (with intermediate heating in a salt-bath) and/or machining to an intermediate thickness. The intermediate thickness is determined based on a final cold-rolling limitation of 90% reduction in thickness. Once an intermediate thickness material is reached, the cast shape is then sheared into "coupons" which are then individually rolled to final foil thickness. The coupons size is based on the desired final foil dimensions and they are sized accordingly. Individual coupons may be sized to allow for the fabrication of multiple foils per coupon. If required the final rolled foil is trimmed to the desired external dimensions. Final fabrication of the initial EU-Mo foils is expected to be complete by the end of September.

4. SUMMARY

Y-12 is an operating production facility with the resources for enriched uranium material handling, processing, and transportation to leverage in support of RERTR fuel development. U-10Mo foils have been successfully fabricated at Y-12 utilizing production scale equipment, which indicates that a transition to production level capacity of U-Mo foil fabrication is feasible. The results to date have been promising in terms of realizing a fundament monolithic U-Mo foil fabrication process. The ultimate efficiency and reliability of the U-Mo foil fabrication will be driven by equipment capabilities and manufacturing expertise. Future consideration on equipment requirements and key process parameters is necessary as the RERTR fuel development program focus transitions to the optimization and qualification of the foil fabrication process.

Y-12 intends to continue its support of the goals of the RERTR programs through leveraging the site capabilities and expertise. In 2008, Y-12 plans to continue its work in the realm of monolithic foil fabrication process development along with providing test specimens and prototype foils for qualification testing.

5. REFERENCES

[1] Y/GNSS/05-05 Revision 1, "The Y-12 Standard Specification Low Enriched Uranium Metal Supply to Research and Test Reactors", December 2005

[2] C.R. Clark, J.F. Jue, G.A. Moore, N.P. Hallinan, B.H. Aand Park, "Update on Monolithic Fuel Foil Fabrication Methods", Presented at the 28th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR), Cape Town, South Africa, October 29-November 3, 2006

[3] D. D. Keiser, Jr., J. F. Jue, and C. R. Clark, "U-Mo Foil/Cladding Interaction in Friction Stir Welded Monolithic Fuel Plates", Presented at the 28th International Meeting on Reduced Enrichment for Research and Test Reactors (RERTR), Cape Town, South Africa, October 29-November 3, 2006