RERTR 2009 — 31st International Meeting on
Reduced Enrichment for Research and Test Reactors

November 1-5, 2009
Kempinski Hotel Beijing Lufthansa Center
Beijing, China

UPDATE ON URANIUM-MOLYBDENUM FUEL FOIL FABRICATION DEVELOPMENT ACTIVITIES AT THE Y-12 NATIONAL SECURITY COMPLEX

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ABSTRACT

The Y-12 National Security Complex (Y-12) is a key participant in the NNSA NA-21 Convert Program, also known as RERTR, by developing and validating a production oriented, monolithic uranium molybdenum (U-Mo) foil fabrication process. Between 2006 and 2008, Y-12 developed and validated its foil fabrication process by producing multiple U-Mo foils and coupons to meet customer specifications. During this time, Y-12 also experimented with the vapor deposition process (PVD) and studied the effects of carbon impurities from the source material. In 2009, Y-12 continued the production of U-Mo foils and coupons. This year, twenty-seven foils and eleven coupons have been fabricated. Y-12 looked toward process optimization with the design, development and procurement of a coupon mold. If validated, the mold has the potential to eliminate some processing steps, such as the salt baths, and reduce the processing time in the rolling mill. Validation of the mold is ongoing. Y-12 will also continue to conduct PVD experiments and initiate zirconium (Zr) co-rolling experiments.

1. INTRODUCTION

In support of the Reduced Enrichment for Research and Test Reactors (RERTR) Program, the Y-12 National Security Complex (Y-12) was tasked with developing and validating a production oriented, monolithic uranium molybdenum (U-Mo) foil fabrication process. Between 2006 and 2008, Y-12 developed and validated its foil fabrication process by producing multiple U-Mo foils and coupons to meet customer specifications. During this time, Y-12 also experimented with the physical vapor deposition process (PVD) and studied the effects of carbon impurities from the source material. In 2009, Y-12 fabricated twenty-seven foils and eleven coupons. Y-12 also collaborated with the Colorado School of Mines to perform tensile testing. Twenty eight specimens that represented various thicknesses throughout the hot rolling and cold rolling processes were tested. Y-12 looked toward process optimization with the procurement of a coupon mold. If validated, the mold has the potential to reduce the cycle time of the process. Validation of the mold will continue to determine the viability. Y-12 plans to initiate zirconium (Zr) co-rolling experiments and conduct PVD experiments.

2. MONOLITHIC FUEL DEVELOPMENT ACTIVITIES AT Y-12

2.1. General Fuel Fabrication Process

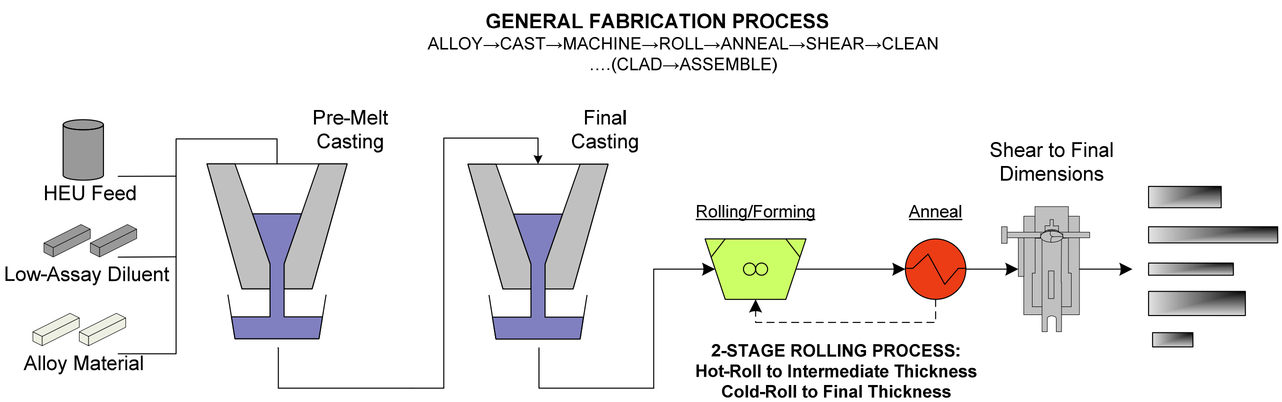

Figure 1: Monolithic U-10Mo Process Flow

Figure 1 displays a general process flow diagram of the fuel fabrication process. The feed material used in the fabrication of monolithic U-Mo foils begins as uranium metal and may be of DU, LEU or HEU assay. At this time, no significant quantities of EU-Mo alloys currently exist to use as feed material.

The initial step in the fabrication process is the blending or alloying of feed material to obtain a homogenous U-10Mo alloy. This is completed in two separate casting steps. In the pre-melt casting, the uranium metal is combined with the molybdenum powder. The final casting ensures the homogeneity of the alloy. The next step of the fabrication process is the initial sizing. The plate is then reduced to an intermediate thickness by hot-rolling (with intermediate heating in a salt-bath) and/or machining. At this point, the plate is then sheared into coupons. The coupons are then rolled to a final foil thickness by a cold-rolling process. Once the desired thickness is obtained, the foil is sheared to the final dimensions.

2.2. Coupon Production

Y-12 fabricated eleven coupons, of varying dimensions, for the AFIP-6 Experiment and ATR element development activities at INL. Three coupons were DU-10Mo. The remaining eight coupons were HEU-10Mo (40% U-235). The fabrication of multiple EU-10Mo foils required the fabrication process to occur in the production facilities, where Y-12 has an extensive history of uranium casting and metalworking. The dimensional measurements of the coupons are listed in Appendix A, *Dimensional Measurements of HEU-10Mo Coupons.* Figure 2 displays an HEU-10Mo coupon.

Figure 2: HEU Coupon

2.3. Foil Production

In addition to the coupons, Y-12 fabricated twenty seven foils, of which twenty two DU-10Mo foils were for the AFIP-6 Experiment and ATR element development activities and five DU-10Mo foils were fabricated for FRM-II conversion work performed at CERCA. Figure 3 displays one of the forty nine inch foils fabricated for ATR. Figure 4 illustrates the hard-back fixtures required for shipment. Typically, the foils are individually wrapped and placed between two hard back fixtures to prevent bending or buckling.

Figure 3: DU-10Mo Foil after Final Shearing Operations

Figure 4: DU-10Mo Foil Prepared for Packaging with Hard-Back Fixture

2.3.1. Dimensional Analysis

As the fuel fabrication process matures, a variety of tests must be done to verify control of the process. To ensure the validity and uniformity of the rolling process, thickness measurements were taken along the length of the foil, as seen in Figure 5.

Thickness Measurements Along Length of Foil				
A	B	C	D	E

Figure 5: DU-10Mo Foil Thickness Measurement

The dimensional measurements of the foils are listed in Appendix B, *Dimensional Measurements of DU-10Mo Foils*. The average standard deviation of the thickness measurement along the foils was 0.47×10^{-3} inches, well within the customer's tolerance specification of $\pm 2 \times 10^{-3}$ inches. A closer look at the data reveals that four foils had a standard deviation of thickness greater than 1.0×10^{-3} inches. While these measurements are within the customer's tolerance range, an examination of the data could provide additional insight to the fabrication process. The higher deviations of the four foils occurred on the longer, forty nine inch foils. The data from these foils indicate the deviations are uniform, meaning the measurements do not fluctuate through the length of the foil. For example, the INL-5, shown in Appendix B, sample starts at 16.3×10^{-3} inches at point A and gradually increases to 19×10^{-3} inches at point E. This indicates a very slight variance in the cold rolling process. The data indicates deviations of the four foils were isolated, meaning the deviations did not occur continuously and did not increase with time.

2.3.2 Tensile Testing

In an effort to understand the properties of the monolithic foils and the effects of the fabrication process on the monolithic foil, tensile specimens were machined representing various thicknesses of the hot rolling and cold rolling process. The tensile testing was performed at the Colorado School of Mines, Golden, CO with the help of Dr. Martin Mataya. The data for the tensile testing is located in Appendix C, *Tensile Test Data from DU-10Mo Specimens*.

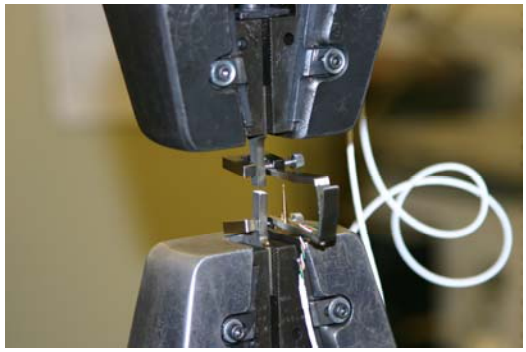

Figure 6: Tensile Test at Colorado School of Mines

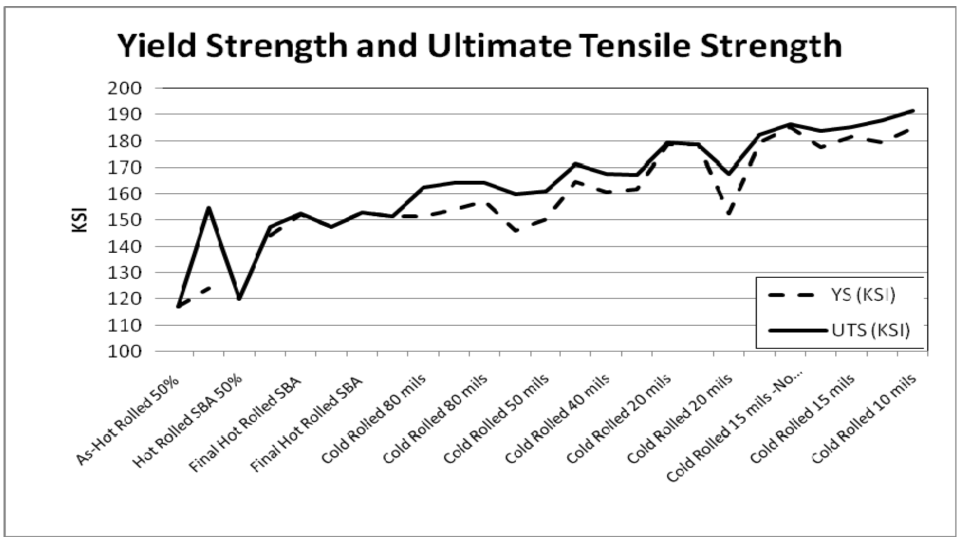

Figure 7: Plots of Tensile Strengths

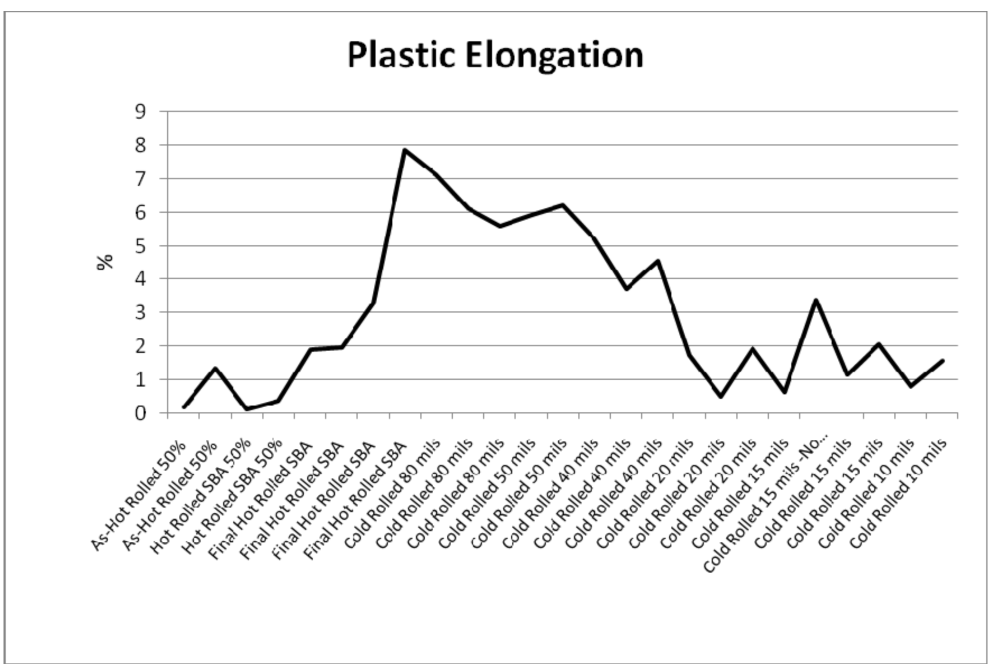

Figure 8: Plastic Elongation

Figure 7 displays the progression of the yield strength and the ultimate tensile strength throughout the fabrication process. As expected, the plot indicates the tensile strength and the yield strength increase as the material is cold-rolled to smaller thickness (cold-working). During the cold-working, the ductility or plastic elongation also decreases as seen in Figure 8.

2.3.3 Coupon Mold

In an effort to optimize the fabrication process and reduce costs, Y-12 is currently testing a coupon mold. The mold may reduce the cycles of intermediate sizing (i.e. reducing amount of passes through rolling process), thus, reducing the cycle time. The mold has the ability to cast twenty coupons during a single casting. The mold still requires validation to ensure the final foil meets the specifications and contains the same material properties. Figure 9 displays the mold being tested. Figure 10 and Figure 11 display coupons cast from the mold.

Figure 9: Coupon Mold

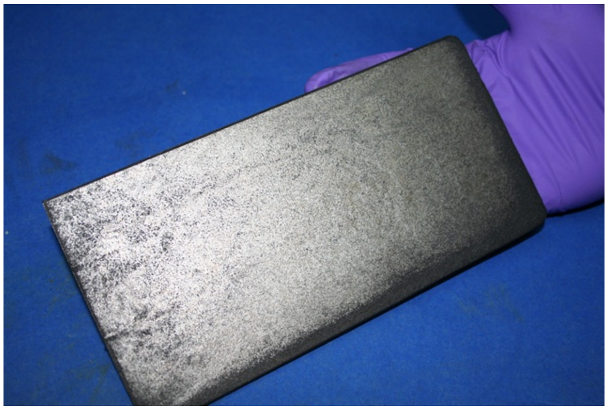

Figure 10: Coupon Taken from Mold

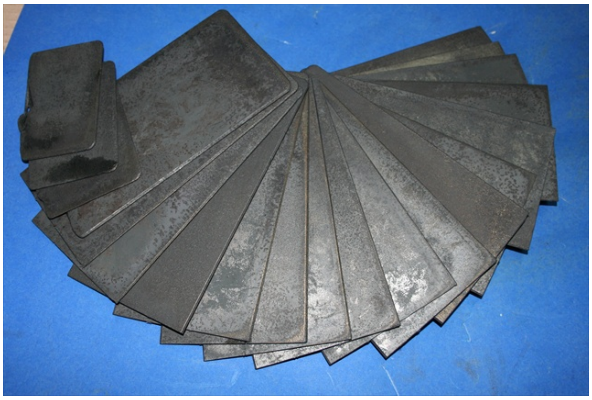

Figure 11: Coupons from Mold

3. SUMMARY

In 2009, Y-12 continued to support the RERTR fuel development with the production of U-Mo foils and coupons. During the year, twenty-seven foils and eleven coupons were fabricated, including HEU-10Mo coupons. The HEU coupons started the transition of the fabrication process to the production facilities. This year, Y-12 continued validation and optimization of the fabrication process, by continuous testing and process improvements, such as the coupon mold.

Plans for the upcoming year include, fabrication of foils and coupons, material testing, coupon mold development, zirconium co-rolling experiments and PVD applications. The material testing will include characteristic analysis and dimensional analysis.

Appendix A: Dimensional Measurements of HEU-10Mo Coupons

ID	Gross wt	Thickness	length	width
	g	in.	in.	in.
PA22	528	0.140	4.510	2.975
PA24	520	0.140	4.475	2.975
PA23	452	0.128	4.450	2.970
PA25	510	0.135	4.470	3.000
PA21	507	0.135	4.450	3.005
PA1X	519	0.140	4.490	2.950
PA20	518	0.135	4.490	3.015
PA1Y	538	0.138	4.540	3.055

Appendix B: Dimensional Measurements of DU-10Mo Foils

ID	Gross wt	A	B	C	D	E	Length	Width	SD of Thickness
	g	(in.x10^{-3})	(in.x10^{-3})	(in.x10^{-3})	(in.x10^{-3})	(in.x10^{-3})	in.	in.	(in.x10^{-3})
INL 3	211g	15.8	15.6	15.6	15.5	15.6	23 9/16"	2 3/32"	0.110
Agent X	192g	13.8	13.4	13.5	13.5	13.7	23 9/16"	2 3/32"	0.164
Agent Z	191g	13.8	13.6	13.6	13.4	13	23 9/16"	2 3/32"	0.303
INL 4-2A	208g	15.6	15.5	15.5	15.6	15.3	23 9/16"	2 3/32"	0.122
INL 6	194g	14.6	14.8	14.5	14.4	14.4	23 9/16"	2 3/32"	0.167
INL 8-1	204g	14.6	14.7	14.8	14.7	14.7	23 9/16"	2 3/32"	0.071
INL 10-1	674g	18.3	18.4	20	18.8	18.7	49"	2.6"	0.680
INL 11-3	677g	20	20	20	20	19	49"	2.4"	0.447
INL 6-2	835g	18.3	18.3	19	18.2	17.7	49"	3.2"	0.464
INL 5-2	769g	17.3	17.8	18	20	19.7	49"	3.161"	1.210
INL 4	736g	21	20	21	21	18	49"	2.6"	1.304
INL 4-2	802g	17.7	17.6	17.5	17.8	17.8	49"	3.2"	0.130
INL 16-2	707g	17.4	17.5	17.6	17.5	16.8	49"	2.8"	0.321
INL 6	759g	19.3	18.9	17.5	16.9	16.9	49"	3.1"	1.131
INL 16-3	627g	15	15	15.3	15.2	15.7	49"	2.8"	0.288
FSM 12	711g	15.7	17.5	16.8	15.9	15.7	49"	3.0"	0.801
INL 10-3	670g	15.7	15.9	15.8	16	15.8	49"	3.0"	0.114
INL 5	715g	16.1	16.3	16.9	18.2	19	49"	2.9"	1.255
INL 12-1	598g	19.2	18.3	18	18.9	18.8	49"	2.3"	0.483
INL 10-2	667g	15.6	16.1	16.1	16.3	15.8	49"	2.9"	0.277
INL 8b	585g	16.3	16.6	16.8	16.5	17	48 5/8"	2.5"	0.270
INL 8a	635g	17.5	17.8	18.3	17.7	17.6	49"	2.5"	0.311
INL 9-3	714g	18.1	18.3	19.3	19.3	18.8	49"	2.7"	0.555
INL 11-2	561g	16.1	16.4	16.4	16.4	15.9	49"	2.4"	0.230
INL 9-1	405g	13.4	13.5	13.4	13.3	13.1	49"	2.13"	0.152
INL 12-3	489g	15.8	15.6	15	15	15.1	49"	2.2"	0.374
INL 16-1	514g	13.2	13.1	13.5	14.6	15	49"	2.7"	0.864

INL 2a	517g	14.8	14.9	15.2	16	15.2	49"	2.3"	0.471

Appendix C: Tensile Test Data from DU-10Mo Specimens

Process Location	Sample #	Width (inch)	Thickness (inch)	Area Square $(inch)^2$	Peak Load (lbf)	Yield Strength (KSI)	Ultimate Tensile Strength (KSI)	Plastic Elongation (%)
As-Hot rolled Longitudinal 50%	1	0.252	0.1964	0.0495	5790.25	117	117	0.2
As-Hot rolled Longitudinal 50%	2	0.2497	0.1962	0.049	7589.059	123.8	154.8	1.35
As-Hot Rolled Trasnverse 50%	1	0.2527	0.1921	0.0485	7740.769	149.7	159.6	1.4
Hot Rolled Longitudinal SBA 50%	1	0.2527	0.1967	0.0497	5971.795	failed	120.1	0.12
Hot Rolled Longitudinal SBA 50%	2	0.2496	0.1978	0.0494	7291.328	144.3	147.6	0.37
Hot Rolled Transverse SBA 50%	1	0.2495	0.194	0.0484	7404.952	152.8	153	0.88
Hot Rolled Transverse SBA 50%	2	0.2505	0.1971	0.0494	7624.707	154	154.3	0.8
Final Hot Rolled Longitudinal SBA	1	0.2523	0.0827	0.0209	3186.301	152.3	152.4	1.9
Final Hot Rolled Longitudinal SBA	2	0.2505	0.0849	0.0213	3141.474	147.5	147.5	1.96
Final Hot Rolled Longitudinal SBA	3	0.2533	0.0836	0.0212	3242.546	152.9	152.9	3.3
Final Hot Rolled Longitudinal SBA	4	0.2496	0.0827	0.0206	3122.703	151.4	151.6	7.85
Cold Rolled 80 mils	1	0.2497	0.0732	0.0183	2971.451	151.4	162.4	7.1
Cold Rolled 80 mils	2	0.25	0.0742	0.0185	3039.634	154.1	164.3	6.1
Cold Rolled 80 mils	3	0.2514	0.0229	0.0188	3090.532	157.5	164.4	5.6
Cold Rolled 50 mils	1	0.2517	0.0495	0.0125	1997.426	145.9	159.8	5.9
Cold Rolled 50 mils	2	0.2513	0.0493	0.0124	1995.382	150.5	160.9	6.2
Cold Rolled 40 mils	1	0.2504	0.0389	0.0097	1650.491	164.8	171.4	5.2
Cold Rolled 40 mils	2	0.252	0.0388	0.0098	1643.751	160.8	167.7	3.7
Cold Rolled 40 mils	3	0.2379	0.0389	0.0093	1555.213	161.9	167.2	4.55
Cold Rolled 20 mils	1	0.2482	0.0214	0.0053	950.719	178.6	179.4	1.74
Cold Rolled 20 mils	2	0.2455	0.0212	0.0052	928.721	178.6	178.6	0.52
Cold Rolled 20 mils	3	0.2482	0.0229	0.0057	954.457	152.8	167.4	1.92
Cold Rolled 15 mils	1	0.2403	0.0157	0.00377	687.015	179.4	182.2	0.64
Cold Rolled 15 mils -No Extensometer	2	0.2516	0.01555	0.00391	728.85	185.3	186.4	3.38
Cold Rolled 15 mils	3	0.2488	0.0159	0.00396	727.328	177.5	183.7	1.15
Cold Rolled 15 mils	4	0.2501	0.0158	0.00395	731.825	181.6	185.2	2.07
Cold Rolled 10 mils	1	0.2518	0.0112	0.00282	529.766	179.3	187.8	0.81

Cold Rolled 10 mils	2	0.2542	0.0115	0.00292	559.062	184.8	191.4	1.58