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DENSITY PREDICTION OF URANIUM-6 NIOBIUM INGOTS

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ABSTRACT

The densities of uranium-6 niobium (U-Nb) alloys have been compiled from a variety of literature sources such as Y-12 and Rocky Flats datasheets. We also took advantage of the 42 well-pedigreed, homogeneous baseline U-Nb alloys produced under the Enhanced Surveillance Program for density measurements. Even though U-Nb alloys undergo two-phase transitions as the Nb content varies from 0 wt. % to 8 wt %, the theoretical and measured densities vary linearly with Nb content. Therefore, the effect of Nb content on the density was modeled with a linear regression. From this linear regression, a homogeneous ingot of U-6 wt.% Nb would have a density of 17.382 ± 0.040 g/cc (95% CI). However, ingots produced at Y-12 are not homogeneous with respect to the Nb content. Therefore, using the 95% confidence intervals, the density of a Y-12 produced ingot would vary from 17.310 ± 0.043 g/cc at the center to 17.432 ± 0.039 g/cc at the edge. Ingots with larger Nb inhomogeneities will also have larger variances in the density.

John Benner, ESA-WR, has requested MST-6 perform an evaluation of the best estimate of the density of U6Nb ingots that can be produced by Y-12.

The densities of U-Nb alloys have been compiled from a variety of literature sources such as Y-12 and Rocky Flats datasheets. We also took advantage of the 42 well-pedigreed, homogeneous baseline U-Nb alloys produced under the Enhanced Surveillance Program for density measurements. Theoretical x-ray and neutron densities, shown in Figure 1 from measurements of these alloys, were considered to evaluate the trends of density with composition. Typically, theoretical densities are not a good measure for actual part densities because the actual part will have a lower density due to defects such as porosity, dislocations, grain boundaries and twins. This is illustrated by comparing the immersion density measurements done by MST-6 with the calculated theoretical densities from x-ray and neutron diffraction measurements, see Figure 2. The measured densities are ~2% lower than the theoretical densities.

For the purposes of this report, the data used for the analysis are only the measured values in Table 1. Unfortunately, most of the published reports do not provide information regarding the technique used for the density value. If the method was not reported, our assumption is that the density value comes from immersion density measurements. However, it is possible that the density value was measured with an alternative technique or calculated from x-ray diffraction data.

An additional concern with this analysis is in the accuracy of the Nb concentration measurement. Some of the literature sources are unclear as to whether the composition is a nominal composition or a measured composition. Also, the homogeneity of the material evaluated is in question. U-6Nb material from Y-12 is usually heavily banded and Rocky Flats material is less banded. Also, if the material used for analysis was a special laboratory ingot, it may have no banding. No mention of homogeneity was given in any of the reports. The 42 baseline alloys produced by MST-6 are homogeneous and have been accurately measured using chemical analysis. Due to the high pedigree that exists, these alloys would be the best source for further studies of the measured densities to use in calculations of average densities in parts with varying Nb content.

The theoretical x-ray and neutron density follows a linear relationship with Nb composition up to about 7% Nb as shown in Figure 1. Therefore, for this analysis a linear regression was applied to the data up to U-7.1Nb. Figure 3 shows the fitted regression and the 95% confidence and prediction limits. The equation for the fitted regression is:

$$\rho \text{ (g/cc)} = 18.998 - 0.26926 \times (\text{wt.\%Nb}) .$$

The standard errors on the intercept and slope are 0.0274 and 0.00575 respectively. Therefore, a homogeneous ingot of U-6Nb would have a density of 17.382 ± 0.040 g/cc (95% CI). However, recent results from the Y-12 production line show that the Nb composition is not homogeneous and varies approximately 0.25% Nb between the ingot center and edge.

Chemical analysis on a U-6Nb vacuum induction melting, vacuum arc remelt (VIM-VAR-VAR) ingot has been performed as a function of position along the radius of the ingot and also along the length of the ingot under the current special induction engineering release (SIER) to evaluate whether the new process replicates the old process, VIM-Skull-VAR. The Nb composition is highest in the center of the ingot and lowest at the edge. Also, along the length of the ingot the Nb content is highest at the top and lowest at the bottom. For purposes of calculating the potential density variation existing in a VIM-VAR-VAR ingot, the Nb composition at the center was analyzed along the length of the ingot to give a high-end average and standard deviation while the edge of the ingot was analyzed along the length of the ingot to give a low-end average and standard deviation. Table 2 summarizes these results. An upper- and lower-bound Nb content was determined by adding one standard deviation to the center mean Nb content and by subtracting one standard deviation from the edge mean Nb content. The 95% confidence and prediction limits were then calculated at these two extremes in Nb content to give a range of possible densities. These results are summarized in Table 3. If during production the Nb composition varies larger than this, then the density variations will also be larger.

Therefore, using the 95% confidence interval, the density of a Y-12 produced ingot would vary from 17.310 ± 0.043 g/cc at the center to 17.432 ± 0.039 g/cc at the edge.

To provide more confidence in the predicted density of Y-12 produced material, further measurements should be performed on the 42 baseline U-Nb alloys and Y-12 produced material using the immersion and ultrapycnometry techniques. Also, the effect of impurities and inclusion content should be determined to better understand the resulting density variation.

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Figure 1: Calculated theoretical densities from x-ray and neutron diffraction measurements of homogeneous U-Nb alloys.

Figure 2: Plot of all sources of density of U-Nb alloys (calculated and measured).

Figure 3: Linear regression of the densities of U-Nb alloys

Table 1: Densities of U-Nb alloys.

Nb Composition (wt. %)	Density (g/cc)	Source
0	19.02	[1]
0	19.05	Theor. x-ray
0	18.98	[2]
2	18.42	Theor. x-ray
4.3	17.9	[3]
4.7	17.65	[4]
5	17.6	[1]
5.5	17.48	[3]
5.8	17.41	Theor. x-ray
6	17.411	[4]
6	17.38	[2]
6.3	17.3	[3]
7.1	17.18	[3]

Table 2: Chemistry variation within a U-6Nb VIM-VAR-VAR ingot.

Location	Mean Nb Content	Standard Deviation
Center of ingot, 1 st target	6.120	0.150
Edge of ingot, 6 th target	5.857	0.040

Table 3: 95% Confidence and prediction limits

Density 95% Confidence Intervals				
	Nb Content	UCL	mean	LCL
Center, mean + 1stdev	6.270	17.352	17.310	17.267
Edge, mean - 1stdev	5.817	17.470	17.432	17.393
Density 95% Prediction Intervals				
		UCL	mean	LCL
Center, mean + 1stdev	6.270	17.432	17.310	17.188
Edge, mean - 1stdev	5.817	17.552	17.432	17.311

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