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WANL-TME-1652

August 15, 1967

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Westinghouse Astronuclear Laboratory

RESULTS OF FURTHER BETA BACKSCATTER EVALUATION DATA

(Title Unclassified)

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SECTION 1. (CRD) INTRODUCTION

When design requirements for Uranium loadings of fuel elements are released by WANL Engineering, WNCO Quality Engineering immediately initiates fabrication of standards to be used in the calibration of beta backscatter equipment. The steps taken in the fabrication of standards are briefly described as follows:

- 1) A minimum of two sections from one or more uncoated elements for each loading code are cut;
- 2) Sheets of Niobium foil of various thicknesses are carefully measured several times;
- 3) Sections from the Niobium foil sheets having reasonably consistent thicknesses are cut to dimensions comparable to those of a channel in the sectioned elements; and
- 4) Niobium foil sections are formed into cylinders and inserted into the channels of the sectioned elements.

These steps result in at least two standards for each loading code; each standard generally has six different thicknesses of Niobium foil inserted in six different channels.

Established procedures for evaluating Niobium-Carbide thicknesses in coated elements are such, that these standards must be used to calibrate the beta backscatter equipment response at least once during each shift and more often if various loading codes are involved. The calibration is performed by obtaining three beta backscatter counts for each Niobium foil thickness (including 0.0 thickness, i.e., no foil) for a particular standard (loading code) and introducing these data into a computer program to estimate the coefficients of the calibration curve. As count response data are obtained on coated elements, the appropriate calibration curve is used to convert the count data for these elements to "apparent Niobium" coating thickness. Finally, these Niobium values are converted to "equivalent metallographic Niobium-Carbide" thicknesses by an empirical relationship.

This report presents results obtained in some analyses relative to relationships that could be used to express the calibration curve, the evaluation of beta backscatter standards, and the conversion of apparent Niobium to equivalent Niobium-Carbide.

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As further background, in "Results of Beta Backscatter Data Evaluation", WANL-TME-1244, Revision 1, dated August 1965, a functional form for expressing the calibration curve and an empirical relationship for converting to equivalent Niobium-Carbide were recommended. These two expressions were used for evaluating all WNCO coated elements during NRX-A4 and A5 production. TME-1244 also indicated that a discontinuity in the relationship between counts and Niobium foil thickness was seen to occur between foil thickness values of 1.7 and 2.1 mils. For this reason foil thicknesses of 1.7 mils or less were suggested for use in the determination of the calibration curve. Using the empirical conversion formula recommended, an apparent thickness of 1.7 mils would convert to 2.7 mils equivalent Niobium-Carbide, thus, TME-1244 pointed out that some difficulty might be expected if thicknesses greater than 2.7 mils were to be evaluated. As stated earlier, all A4 and A5 WNCO coated elements were evaluated according to the recommended expressions of TME-1244 and with no apparent difficulty.

Beginning with the evaluation of NRX-A6/1 coated elements, much thicker Niobium-Carbide values were encountered and erratic beta backscatter thicknesses (as converted) presented a problem. To alleviate this problem, WNCO Quality Engineering changed both the functional form of the calibration curve and the empirical relationship to convert to equivalent Niobium-Carbide. These changes are summarily compared to the expressions recommended in TME-1244 in the following table:

	<u>Calibration Curve</u>	<u>Conversion Function</u>
TME-1244	$\log (\text{Nb} + 1.0) = a + b (\text{Counts})$ using foil thickness of 0.0, 0.5, 1.3, 1.7	$\text{NbC} = c + d(\text{Nb}) + e (\text{Nb})^2$
NRX-A6/1	$\log (\text{Nb}) = f + g \log (\text{Counts})$ using foil thicknesses of 0.5, 1.3, 1.7, 2.1, 2.5, 3.2	$\text{NbC} = h + j (\text{Nb})$

These changes were made from an additional evaluation of the data in TME-1244. The effectiveness of the changes was more a function of the linearity of the conversion formula than the change in the form of the calibration curve.

NRX-A6/2 design requirements introduced practically a new set of Uranium loadings and subsequently, a need for new beta backscatter standards. At this time, a redesign of the beta backscatter probe to utilize an aluminum encapsulated source rather than the stainless steel encapsulation was also considered. These added conditions, and a desire on the part of WNCO Quality Engineering to make general the conversion of all NDT Niobium-Carbide thickness determinations, led to a further set of changes in the functional form of the calibration curve and the conversion formula.

These changes (new standards, new source design, a different form for the calibration curve, and a different conversion formula) and their effects are evaluated in the following sections.

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SECTION 2.

(CRD) THE FUNCTIONAL FORM OF THE CALIBRATION CURVE

Table 1 contains data for eleven calibration runs as reported in TME-1244 and data for eight calibration runs obtained during NRX-A6 PAX production; the TME-1244 data reflects the use of stainless steel encapsulated sources and NRX-A4 standards, and the second grouping of data reflects the use of aluminum encapsulated sources and NRX-A6/2 standards. As noted in the table, each set of data consists of three readings for seven Niobium foil thicknesses. These data were processed with a standard "least squares" computer program to evaluate "linear fits" to several functional relationships using all seven or selected Niobium foil thicknesses. (A "linear fit" is a fit to estimate the coefficients in a linear function such as $Y = a + bX$ where a and b are the coefficients.) Table 2 enumerates the functional relationships and corresponding Niobium foil thicknesses evaluated in the "linear fits."

As seen in Table 2, the logarithms of Niobium thickness plus 1.0 (to enable the use of 0.0 thickness), the logarithms of Niobium thickness, and arithmetic Niobium thicknesses were evaluated as functions of counts, logarithms of counts, square roots of counts, reciprocals of counts, and reciprocals of square roots of counts (exception: arithmetic thickness versus counts) using all seven thicknesses, where possible, as well as selected thicknesses for special comparisons. The functional expression, $\log(Nb) = a + b \log(\text{Counts})$, using the last six thickness values, was used during NRX-A6/1; and the functional expression $\log(Nb) = a + b \sqrt{\text{Counts}}$, using the last six thickness values was scheduled for use during NRX-A6/2. A total of nineteen equations for each of the nineteen sets of calibration data were processed. The purpose of this processing was not to evaluate the coefficients in the linear expressions but to obtain quantities termed, standard errors of estimate, which would indicate the magnitude of the deviations of the observed values from the fitted equations and, in turn, would indicate the "goodness" of the fit.

If, in expressing the calibration curve, a functional form involving $\log(Nb + 1.0)$ were used, a standard error of estimate of 0.0050 yields 99 percent confidence limits (when

TABLE 1
CALIBRATION DATA FOR EVALUATION OF FUNCTIONAL FORM OF CALIBRATION CURVE

(Table Entries are Beta Backscatter Count Data)							
Calibration Identify	Standard Niobium Thickness (mils)						
1 Stainless Steel Encapsulated Source Data Excerpted from TME-1244							
	0 0	0 5	1 3	1 7	2 1	2 5	3 2
3-2	436	584	737	784	827	838	904
	435	583	738	788	828	844	904
	435	582	735	789	828	839	903
4-2	446	593	739	796	810	870	896
	445	597	742	796	812	869	892
	445	593	742	799	810	869	896
5-1	469	611	748	813	831	875	915
	470	610	745	813	835	874	914
	472	610	750	814	835	874	913
5-2	474	606	744	809	827	855	898
	474	607	744	806	831	855	900
	473	611	748	807	831	852	899
6-1	482	617	744	801	831	871	902
	485	619	738	802	835	874	902
	482	616	736	803	832	875	904
6-2	477	608	747	817	828	874	909
	479	612	743	816	826	872	909
	477	610	740	818	831	870	910
7-1	510	641	770	821	866	879	905
	509	643	769	824	864	876	906
	508	640	770	822	865	877	907
7-2	503	636	772	814	858	864	908
	500	635	773	817	858	868	907
	505	636	772	818	856	864	906
8-1	545	663	792	838	863	888	938
	546	668	788	842	865	885	938
	542	667	789	841	859	886	942
8-2	529	652	780	825	854	885	945
	529	648	778	824	855	885	941
	527	649	778	820	849	885	942
9-AA	5-15	652	783	831	846	878	927
	514	653	782	830	847	879	929
	515	650	783	829	845	876	929
2 Aluminum Encapsulated Source Data on NRX-A6/2 Standards							
	0 0	0 55	1 1	1 7	2 0	2 9	3 6
59012	584	654	722	770	793	821	857
	584	655	722	773	795	823	858
	585	655	725	773	795	824	859
59013	579	647	719	761	787	832	851
	579	648	719	762	790	832	853
	579	650	721	765	791	834	854
59014	585	657	726	775	794	826	854
	585	659	728	775	794	828	855
	586	659	728	775	794	830	856
59015	559	630	688	728	760	789	811
	561	632	689	729	761	791	812
	563	632	691	732	761	793	814
59016	560	629	694	740	763	789	810
	561	629	695	740	763	791	815
	561	631	695	741	767	792	816
59017	561	630	694	726	759	793	809
	563	632	695	728	760	795	814
	563	633	696	729	762	796	816
59018	554	630	689	725	750	789	807
	555	630	690	726	751	789	808
	555	631	693	727	752	794	810
59019	550	627	689	731	756	790	812
	552	628	692	731	758	796	814
	552	628	692	732	758	797	817

TABLE 2

FUNCTIONAL RELATIONSHIPS AND CORRESPONDING THICKNESSES
 USED TO EVALUATE CALIBRATION CURVE FUNCTIONAL FORM

(Data Used Is As Given in Table 1)

<u>Y</u>	=	a + b <u>X</u>	<u>Nb Thicknesses Used</u>
Log (Nb + 1.0)		Counts	First 4, Last 6, All 7
Log (Nb + 1.0)		Log Counts	All 7
Log (Nb + 1.0)		$\sqrt{\text{Counts}}$	All 7
Log (Nb + 1.0)		1/Counts	All 7
Log (Nb + 1.0)		$1/\sqrt{\text{Counts}}$	All 7
Log (Nb)		Counts	Last 6
Log (Nb)		Log Counts	Last 6, 2-5
Log (Nb)		$\sqrt{\text{Counts}}$	Last 6, 2-5
Log (Nb)		1/Counts	Last 6
Log (Nb)		$1/\sqrt{\text{Counts}}$	Last 6
Nb		Log Counts	First 4, All 7
Nb		$\sqrt{\text{Counts}}$	All 7
Nb		1/Counts	All 7
Nb		$1/\sqrt{\text{Counts}}$	All 7

converted to arithmetic thickness) of 0.94 - 1.06 at 1.0 mils and 1.91 - 2.09 at 2.0 mils. Similarly, a standard error of estimate of 0.0100 yields 99 percent confidence limits of 0.88 - 1.12 at 1.0 mils and 1.83 - 2.19 at 2.0 mils. In contrast, if a functional form involving $\log(Nb)$ were used, standard errors of estimate of 0.0100 and 0.0180 yield 99 percent confidence limits of 0.94 - 1.06 and 0.90 - 1.11 at 1.0 mils and 1.88 - 2.12 and 1.80 - 2.23 at 2.0 mils respectively. Thus, to be equivalent, functional expressions involving $\log(Nb + 1.0)$ must attain standard errors of estimate at least one-half of those for functional forms involving $\log(Nb)$. This implies that the maximum standard errors of estimate for calibration curves expressed in terms of $\log(Nb + 1.0)$ and $\log(Nb)$ should be less than 0.0100 and 0.0180 respectively.

In examining the standard errors of estimate for the functional relationships given in Table 2, applying the maximum tolerable value as implied in the previous paragraph, only three expressions should be considered. These are:

- 1) $\log(Nb) + 1.0 = a + b \text{ Counts}$, using the first 4 thicknesses;
- 2) $\log(Nb) = a + b \sqrt{\text{Counts}}$, using the last 6 thicknesses; and
- 3) $\log(Nb) = a + b \log(\text{Counts})$, using the last 6 thicknesses.

Of the last four expressions given in Table 2 and considering Nb as some function of counts, the expression, $Nb = a + b \log(\text{Counts})$, for which the first 4 thicknesses were used, was by far the best; this was undesirable because of the rather large standard errors of estimate.

Table 3 tabulates the standard errors of estimate as derived from the "least squares" fits of the three expressions given in the previous paragraphs to the calibration data of Table 1. Readily observed in this table are the significantly lower values for the TME-1244 data as treated by the expression recommended in the same TME (equation 1. of the table). The standard errors for the aluminum source data indicate that the differences between the three equations as seen for the TME-1244 data are not as clearly defined.

TME-1244 stated that the variability in counts for repeated determinations during a calibration run is approximately ± 4 counts independent of the thickness being measured. If

TABLE 3
STANDARD ERRORS OF ESTIMATE FOR THREE DIFFERENT
CALIBRATION EXPRESSIONS

(Using Calibration Data from Table 1)

1. Stainless Steel Encapsulated Source Data Excerpted from TME-1244)

<u>Calibration Identity</u>	<u>Equation* 1.</u>	<u>Equation* 2.</u>	<u>Equation* 3.</u>
3-2	0.0040	0.0163	0.0181
4-2	0.0036	0.0243	0.0247
5-1	0.0059	0.0185	0.0182
5-2	0.0050	0.0180	0.0206
6-1	0.0083	0.0248	0.0218
6-2	0.0105	0.0262	0.0259
7-1	0.0037	0.0248	0.0267
7-2	0.0048	0.0189	0.0225
8-1	0.0036	0.0186	0.0163
8-2	0.0032	0.0214	0.0148
9-AA	0.0053	0.0180	0.0173

2. Aluminum Encapsulated Source Data (Data taken on NRX-A6/2 Standards)

<u>Identity</u>	<u>Equation* 1.</u>	<u>Equation* 2.</u>	<u>Equation* 3.</u>
59012	0.0131	0.0176	0.0182
59013	0.0144	0.0137	0.0135
59014	0.0155	0.0093	0.0128
59015	0.0073	0.0230	0.0224
59016	0.0115	0.0193	0.0222
59017	0.0129	0.0246	0.0239
59018	0.0093	0.0189	0.0169
59019	0.0077	0.0157	0.0153

* Equation 1. $\log(Nb + 1.0) = a + b \text{ Counts}$, using first 4 thicknesses

2. $\log(Nb) = a + b \sqrt{\text{Counts}}$, using last 6 thicknesses

3. $\log(Nb) = a + b \log(\text{Counts})$, using last 6 thicknesses

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SECTION 3

(CRD) EVALUATION OF NRX-A6/2 CALIBRATION STANDARDS

The closing paragraphs of the previous section indicated the possibility of some low quality NRX-A6/2 calibration standards and a means for assessing their quality by evaluating the standard errors of estimate associated with the calibration curves. Low quality standards actually are quite probable whenever the uncertainty of the gauging of the Niobium foil thickness and the insertion of the proper dimension (circumferential) in the channel of the sectioned element is considered. Tie these two uncertainties into the urgency created by the rather late release of NRX-A6/2 fuel element loadings and the probability increases even more. Nevertheless, NRX-A6/2 required new standards and these were hurried in their fabrication.

As stated earlier, standards generally have seven thicknesses (0.0 mils plus six thicknesses of Niobium foil). Some foil sheet stock still remained from NRX-A4 standards fabrication and was used in the fabrication of the new standards; however, the thickness values assigned to this foil were changed. One change was that of 0.5 to 0.55 mils; possibly this change was associated with the increased variability noted for the aluminum source data of Tables 1 and 3. Subsequent to the analyses summarized in Table 3, another foil thickness was changed. These changes are indicated in the following table:

<u>NRX-A4 Standards</u> <u>Nb Foil Thicknesses (mils)</u>		<u>NRX-A6/2 Standards</u> <u>Nb Foil Thicknesses (mils)</u>	
0.0		0.0	
0.5	became	0.55	
1.3	different sheet stock	1.1	
1.7	became	1.6	
2.1	became	2.0	
2.5	different sheet stock	2.9	
3.2	different sheet stock	3.6	

Since the calibration expression recommended in TME-1244 would use only the first four thicknesses (0.0 plus the first three foil thicknesses), the changes of 0.5 to 0.55 mils and 1.7 to 1.6 mils would be expected to affect the standard errors of estimate for the calibration curves. Similarly, these changes would also affect the standard errors if the expression $\log(Nb)$ versus $\sqrt{\text{Counts}}$ were used for the last six thicknesses, though not as much and in a different direction.

Twelve sets of four standards each had been fabricated for NRX-A6/2, and calibration data had been obtained on all 48 standards within a two day period. To evaluate these standards, their calibration data were processed by the "least squares" program to consider $\log(Nb + 1.0)$ and $\log(Nb)$ as linear functions of either Counts or $\sqrt{\text{Counts}}$ (the computer program would choose either Counts or $\sqrt{\text{Counts}}$ so as to yield the lower standard error). Using the first four thicknesses, four equations were evaluated for $\log(Nb + 1.0)$, each equation generated by considering the four combinations of 0.5 or 0.55 mils and 1.7 or 1.6 mils coupled with 0.0 and 1.1 mils. Similarly, using the last six thicknesses, four equations were evaluated for $\log(Nb)$. Using thicknesses values of 0.0, 0.5, 1.1, and 1.7 mils, the equation expressing $\log(Nb + 1.0)$ as a function of Counts, if the computer chose Counts, it would be similar to that recommended in TME-1244. Using thickness values of 0.55, 1.1, 1.6, 2.0, 2.9, and 3.6 mils, the equation expressing $\log(Nb)$ as a function of $\sqrt{\text{Counts}}$, if the computer chose $\sqrt{\text{Counts}}$, it would be that presently used for NRX-A6/2. The only information of interest in the examination of all the fitted expressions (a total of 384) was the apparent changes in the intercepts, slopes, and standard errors of estimate as the different thickness values were interchanged. Such changes would naturally be expected, but these can contribute little to the evaluation of the standards.

Information that does contribute significantly to the selection of high quality standards is given in Tables 4 and 5. Table 4 summarizes the evaluation of the standards as though the TME-1244 calibration curve were to be used. Using as a selection guide a maximum standard error of estimate of 0.0100, 34 of the 48 standards evaluated should give acceptable calibration data with 5 additional standards having standard errors slightly above 0.0100. Also seen in this table is a decrease in the intercept plus an increase in the slope as loading increases.

TABLE 4

TME-1244 EVALUATION OF NRX-A6/2 CALIBRATION STANDARDS

(Data derived from using Nb thickness values of 0.0, 0.5, 1.1 and 1.7 mils and functional form, $\log [(Nb+1.0) \times 100] = a+b(\text{Counts})$.)		
Standard	Standard Error of Estimate	Equation
12-37128-1	0.0046*	$Y = 0.94188 + 0.00201C$
12-37137-2	0.0067*	$Y = 1.01038 + 0.00188C$
12-37128-2	0.0137	$Y = 0.90879 + 0.00206C$
12-37137-2	0.0066*	$Y = 0.94125 + 0.00201C$
13-38086-1	0.0124	$Y = 0.92667 + 0.00201C$
13-38090-1	0.0055*	$Y = 0.89478 + 0.00208C$
13-38086-2	0.0045*	$Y = 0.94878 + 0.00198C$
13-38090-2	0.0058*	$Y = 0.93907 + 0.00200C$
14-38100-1	0.0084*	(1)
14-38103-1	0.0105	$Y = 0.92533 + 0.00200C$
14-38100-2	0.0068*	$Y = 0.88097 + 0.00207C$
14-38103-2	0.0120	$Y = 0.86879 + 0.00209C$
15-38105-1	0.0125	$Y = 0.85185 + 0.00208C$
15-38109-1	0.0038*	$Y = 0.83512 + 0.00212C$
15-38105-2	0.0037*	$Y = 0.87763 + 0.00206C$
15-38109-2	0.0082*	$Y = 0.83790 + 0.00213C$
16-38112-1	0.0105	$Y = 0.83417 + 0.00211C$
16-38116-1	0.0033*	$Y = 0.81570 + 0.00214C$
16-38112-2	0.0153	$Y = 0.82710 + 0.00213C$
16-38116-2	0.0092*	$Y = 0.82816 + 0.00211C$
16-38121-1	0.0095*	$Y = 0.80413 + 0.00214C$
16-38125-1	0.0102	$Y = 0.75984 + 0.00222C$
16-38121-2	0.0054*	$Y = 0.73331 + 0.00226C$
16-38125-2	0.0042*	$Y = 0.79633 + 0.00215C$
17-38126-1	0.0096*	$Y = 0.75292 + 0.00219C$
17-38130-1	0.0067*	$Y = 0.76456 + 0.00217C$
17-38126-2	0.0063*	$Y = 0.75586 + 0.00218C$
17-38130-2	0.0072*	$Y = 0.73010 + 0.00222C$
18-38135-1	0.0072*	$Y = 0.67582 + 0.00229C$
18-38138-1	0.0093*	$Y = 0.71884 + 0.00222C$
18-38135-2	0.0080*	$Y = 0.64093 + 0.00235C$
18-38138-2	0.0129	$Y = 0.73615 + 0.00221C$
19-38141-1	0.0191	$Y = 0.72788 + 0.00230C$
19-38144-1	0.0104	(1)
19-38141-2	0.0107	$Y = 0.71501 + 0.00234C$
19-38144-2	0.0049*	$Y = 0.72313 + 0.00233C$
20-37175-1	0.0069*	$Y = 0.64431 + 0.00243C$
20-37178-1	0.0128	$Y = 0.67002 + 0.00240C$
20-37175-2	0.0076*	$Y = 0.64871 + 0.00243C$
20-37178-2	0.0053*	(1)
21-38151-1	0.0058*	(1)
21-38152-1	0.0036*	$Y = 0.59897 + 0.00249C$
21-38151-2	0.0093*	(1)
21-38152-2	0.0132	$Y = 0.57808 + 0.00252C$
24-38093-1	0.0070*	$Y = 0.94713 + 0.00198C$
24-38098-1	0.0084*	$Y = 0.90116 + 0.00205C$
24-38093-2	0.0077*	$Y = 0.88595 + 0.00208C$
24-38098-2	0.0099*	$Y = 0.92825 + 0.00200C$

* Indicates an acceptable standard error of estimate, thus indicates an acceptable standard.

(1) Computer program chose fit to $\sqrt{\text{Counts}}$, thus equation is not available; however, value for standard error represents that value that would have been obtained if a fit to linear counts were made.

TABLE 5

NRX-A6/2 EVALUATION OF CALIBRATION STANDARDS

(Data derived from using Nb thickness values of 0.55, 1.1, 1.6, 2.0, 2.9 and 3.6 mils and functional form, $\log(100 \text{ Nb}) = a + b \sqrt{\text{Counts}}$.)

Standard	Standard Error Of Estimate	Equation
12-37128-1	0.0113*	$Y = -2.89700 + 0.18784 \sqrt{C}$
12-37137-1	0.0161*	(1)
12-37128-2	0.0195	$Y = -2.96677 + 0.19026 \sqrt{C}$
12-37137-2	0.0066*	$Y = -2.85728 + 0.18619 \sqrt{C}$
13-38086-1	0.0111*	$Y = -3.07497 + 0.19332 \sqrt{C}$
13-38090-1	0.0211	$Y = -2.89559 + 0.18725 \sqrt{C}$
13-38086-2	0.0146*	(1)
13-38090-2	0.0076*	$Y = -2.90947 + 0.18761 \sqrt{C}$
14-38100-1	0.0164*	(1)
14-38103-1	0.0145*	(1)
14-38100-2	0.0126*	$Y = -3.24990 + 0.19989 \sqrt{C}$
14-38103-2	0.0186	$Y = -3.09310 + 0.19348 \sqrt{C}$
15-38105-1	0.0116*	$Y = -3.51167 + 0.20802 \sqrt{C}$
15-38109-1	0.0104*	$Y = -3.30401 + 0.20104 \sqrt{C}$
15-38105-2	0.0102*	$Y = -3.32903 + 0.20236 \sqrt{C}$
15-38109-2	0.0095*	$Y = -3.32017 + 0.20200 \sqrt{C}$
16-38112-1	0.0110*	$Y = -3.43699 + 0.20533 \sqrt{C}$
16-38116-1	0.0127*	$Y = -3.39110 + 0.20422 \sqrt{C}$
16-38112-2	0.0166*	$Y = -3.26203 + 0.19943 \sqrt{C}$
16-38116-2	0.0092*	$Y = -3.38739 + 0.20334 \sqrt{C}$
16-38121-1	0.0091*	$Y = -3.45381 + 0.20532 \sqrt{C}$
16-38125-1	0.0152*	$Y = -3.41416 + 0.20469 \sqrt{C}$
16-38121-2	0.0260	$Y = -3.38118 + 0.20312 \sqrt{C}$
16-38125-2	0.0118*	$Y = -3.51503 + 0.20799 \sqrt{C}$
17-38126-1	0.0220	(1)
17-38130-1	0.0106*	$Y = -3.60322 + 0.20971 \sqrt{C}$
17-38126-2	0.0106*	(1)
17-38130-2	0.0146*	(1)
18-38135-1	0.0129*	$Y = -3.94141 + 0.22236 \sqrt{C}$
18-38138-1	0.0083*	$Y = -3.85293 + 0.21831 \sqrt{C}$
18-38135-2	0.0169*	$Y = -3.89903 + 0.22095 \sqrt{C}$
18-38138-2	0.0084*	$Y = -3.88665 + 0.22028 \sqrt{C}$
19-38141-1	0.1111	$Y = -3.03389 + 0.19203 \sqrt{C}$
19-38144-1	0.0217	(1)
19-38141-2	0.0084*	(1)
19-38144-2	0.0143*	(1)
20-37175-1	0.0131*	$Y = -4.11465 + 0.23352 \sqrt{C}$
20-37178-1	0.0128*	$Y = -3.90688 + 0.22586 \sqrt{C}$
20-37175-2	0.0121*	$Y = -4.04387 + 0.23097 \sqrt{C}$
20-37178-2	0.0189	(1)
21-38151-1	0.0204	(1)
21-38152-1	0.0192	$Y = -4.19132 + 0.23610 \sqrt{C}$
21-38151-2	0.0157*	(1)
21-38152-2	0.0192	(1)
24-38093-1	0.0100*	(1)
24-38098-1	0.0097*	$Y = -3.10039 + 0.19426 \sqrt{C}$
24-38093-2	0.0155*	$Y = -2.97598 + 0.19001 \sqrt{C}$
24-38098-2	0.0095*	(1)

*Indicates an acceptable standard error estimate, thus indicates an acceptable standard
(1) Computer program chose fit to linear counts, thus equation is not available; however,
value for standard error represents that value that would have been obtained if a fit to
 $\sqrt{\text{Counts}}$ were made.

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Table 5 summarizes the evaluation of the standards for the functional form presently being used for NRX-A6/2 production. Using as a selection guide a maximum standard error of estimate of 0.0180, 37 of the 48 standards evaluated should give acceptable calibration data with 2 additional standards having standard errors slightly above 0.0180. In this table it is noted that the intercept decreases and the slope increases as loading increases.

The data in Table 4 also indicates that the equipment response from the aluminum encapsulated sources is comparable to that discussed in TME-1244 and as derived from the stainless steel sources. As for a direct comparison between using the functional form of TME-1244 and that form presently being used, none can be made due to the use of different thickness values for the calibration data. Using their own particular thicknesses, each leads to calibration curves equally as effective, in so far as expected deviations from the fitted curve are concerned; however, this is not to say that both result in the same apparent Niobium thicknesses. Each will require its own empirical conversion formula to return data readily comparable to metallographic Niobium-Carbide thickness.

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SECTION 4

(CRD) THE CONVERSION OF APPARENT NIOBIUM TO EQUIVALENT NIOBIUM-CARBIDE

To convert apparent Niobium thickness as derived from beta backscatter response to equivalent Niobium-Carbide thickness as derived from metallographic examination, WANL-TME-1244 recommended an empirical relationship obtained from an analysis of the data given in that report. This relationship expressed Niobium-Carbide thickness as a quadratic function of apparent Niobium thickness and was used for all of the NRX-A4 and A5 production. With the introduction of NRX-A6/1, production and thicker Niobium-Carbide coatings, difficulty with respect to their evaluation was encountered. WNCO Quality Engineering re-evaluated the data of TME-1244 and adopted as the expression for calibration the functional form log thickness versus log counts and as the conversion function, an expression relating Niobium-Carbide as a linear function of apparent Niobium.

TME-1244, in one of its recommendations, stated that the expression for conversion is an empirical one and that periodic checks should be made of the agreement that the relationship implies. From the difficulty experienced in NRX-A6/1 production, it is apparent that the implied agreement of the TME-1244 relationship was no longer the rule, probably because of thicker coatings.

NRX-A6/2 production, introduced new Uranium loadings and the need for new calibration standards. During this period, a redesign of the beta backscatter probe to consider aluminum encapsulated sources became desirable. These two factors led WNCO Quality Engineering to re-evaluate both the calibration and conversion expressions. As given earlier, calibration curves expressing log Niobium thickness as a function of the square root of Counts were adopted. This particular functional form was chosen consistent with Quality Engineering's desire to make general the conversion of all NDT Niobium-Carbide thickness determinations. As for the conversion of apparent Niobium to equivalent Niobium-Carbide, the following expressions are to be used for NRX-A6/2 production:

- 1) For all values of apparent Niobium thicknesses less than 1.06 mils,

$$NbC = \frac{Nb}{1.0463 - 0.3459 Nb} ;$$

- 2) For all values of apparent Niobium thicknesses equal to or greater than 1.06 mils but less than or equal to 2.93 mils,

$$NbC = 1.442 + 4.6849 \log Nb; \text{ and,}$$

- 3) For all values of apparent Niobium thicknesses greater than 2.93 mils,

$$NbC = -0.651 + 1.4604 Nb.$$

The coefficients for the above equations were obtained from beta backscatter and metallographic data for four NRX-A6/2 (PAX) production elements.

Table 6 contains Niobium-Carbide thickness values as determined by metallographic examination for these four NRX-A6/2 (PAX) production elements. As noted from the data in this table, a cross section of the loading codes for NRX-A6/2 production is represented. Note also, a) metallographic data have been obtained at positions along the length of these elements comparable to the mid-points of the beta backscatter incremental determinations, b) data have been obtained on two channels for each element and, c) the Niobium-Carbide thicknesses cover a range from 0.8 to 3.1 mils. Actually, higher thickness values are seen only for element 11-62165 which has thicknesses more nearly those of NRX-A6/1 requirements.

Prior to the sectioning of these elements for metallographic examination, beta backscatter count data were obtained following routine procedures in both channel 9 and channel 11. For three of the elements, these data were obtained twice (day turn and night turn), but only once for element 11-62165 (night turn). Using the appropriate calibration data (calibration data were obtained on each loading code during each turn), the element beta backscatter count data were processed to yield apparent Niobium thickness values. Finally, these apparent Niobium values were used to estimate the coefficients for the three expressions given earlier for conversion of apparent Niobium to equivalent Niobium-Carbide.

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TABLE 6

METALLOGRAPHIC NIOBIUM-CARBIDE DATA FOR FOUR
NRX-A6/2 (PAX) ELEMENTS

(Table entries are metallographic Niobium-Carbide thicknesses in mils)

Position From S/N	<u>21-38922</u>		<u>19-38855</u>		<u>14-62611</u>		<u>11-62165</u>	
	Channel		Channel		Channel		Channel	
	<u>9</u>	<u>11</u>	<u>9</u>	<u>11</u>	<u>9</u>	<u>11</u>	<u>9</u>	<u>11</u>
4.5	0.78	0.81	0.86	0.82	0.76	0.79	0.94	0.95
7.5	0.88	0.91	0.92	0.88	0.86	0.85	0.99	1.00
10.5	0.94	0.96	0.91	0.93	0.92	0.90	1.07	1.10
13.5	1.04	0.98	1.09	1.04	1.01	1.00	1.26	1.25
16.5	1.12	1.10	1.13	1.13	1.10	1.11	1.34	1.26
19.5	1.17	1.20	1.09	1.04	1.09	1.19	1.40	1.42
22.5	1.24	1.20	1.18	1.26	1.17	1.16	1.58	1.50
25.5	1.14	1.22	1.24	1.25	1.30	1.25	1.63	1.66
28.5	1.33	1.27	1.28	1.27	1.27	1.29	1.84	1.89
31.5	1.34	1.36	1.36	1.34	1.32	1.34	2.08	2.14
34.5	1.40	1.42	1.42	1.41	1.32	1.36	2.18	2.21
37.5	1.48	1.51	1.54	1.44	1.50	1.54	2.44	2.48
40.5	1.55	1.47	1.58	1.51	1.57	1.57	2.42	2.55
43.5	1.51	1.59	1.52	1.52	1.61	1.57	2.76	2.83
46.5	1.66	1.62	1.63	1.65	1.64	1.63	2.88	2.93
49.5	1.71	1.66	1.83	1.81	1.68	1.66	3.08	3.16

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Using the same calibration and element count data, these data were also processed by the calibration technique recommended in TME-1244. Thus, the calibration curve form used was that expressing $\log (Nb + 1.0)$ as a function of counts; for the calibration curves, Niobium thicknesses of 0.0, 0.5 (not 0.55), 1.1 and 1.7 (not 1.6) mils were assumed. From the calibration curves, beta backscatter count data for the four elements were processed to yield apparent Niobium thicknesses values. Finally, these apparent Niobium values were processed with the metallographic data of Table 6 to obtain an empirical relationship for conversion of apparent Niobium to equivalent Niobium-Carbide.

In obtaining the empirical relationship, two expressions were derived. The first of these was derived from a use of all the data and is

$$NbC = -0.045 + 1.420 Nb,$$

the second is

$$NbC = -0.053 + 1.427 Nb,$$

and was derived excluding the data for the code 11 element having the much thicker Niobium-Carbide coating. As is evident, there is little difference in these two expressions. Thus, the second expression, intended for a range of thickness from 0.8 to 1.8 mils, could be used to cover effectively a thickness range of 0.8 to 3.1 mils.

Beta backscatter count data for the four elements were converted to equivalent Niobium-Carbide thicknesses by the two approaches discussed in this section. These equivalent Niobium-Carbide thicknesses are given in Table 7 and may be directly compared to the metallographic data of Table 6. The agreement between metallography and beta backscatter, using either approach, is essentially the same and as expressed by 99 percent confidence limits would be approximately ± 0.17 mils over the range of thicknesses from 0.8 to 1.8 mils and approximately ± 0.21 over the range of thicknesses from 1.8 to 3.1 mils.

A comparison of the equivalent thicknesses as determined by the two approaches (see Table 7) will reveal that the TME-1244 approach will yield higher thickness values from 0.8 to 1.5 mils, lower values from 1.5 to 2.5 mils, and higher values from 2.5 to 3.2 mils. These

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TABLE 7

BETA BACKSCATTER EQUIVALENT NIOBIUM-CARBIDE THICKNESSES

(Table entries are equivalent beta backscatter Niobium-Carbide thicknesses in mils.)

Count Increment (Inches)	TME-1244 Approach				NRX-A6/2 Approach			
	Day Turn Channel		Night Turn Channel		Day Turn Channel		Night Turn Channel	
	9	11	9	11	9	11	9	11
Element 21-38922								
3-6	0.84	0.77	0.80	0.81	0.81	0.76	0.78	0.79
6-9	0.88	0.92	0.92	0.91	0.84	0.87	0.88	0.87
9-12	1.04	1.00	0.94	0.97	0.98	0.94	0.89	0.92
12-15	1.15	1.09	1.03	1.04	1.08	1.02	0.97	0.98
15-18	1.15	1.18	1.14	1.14	1.08	1.11	1.07	1.07
18-21	1.24	1.21	1.17	1.24	1.18	1.14	1.10	1.16
21-24	1.24	1.29	1.22	1.24	1.18	1.23	1.14	1.16
24-27	1.25	1.29	1.25	1.25	1.19	1.23	1.18	1.18
27-30	1.32	1.35	1.29	1.32	1.26	1.30	1.21	1.24
30-33	1.37	1.38	1.37	1.44	1.32	1.34	1.30	1.38
33-36	1.47	1.40	1.44	1.48	1.44	1.36	1.38	1.42
36-39	1.48	1.54	1.48	1.51	1.46	1.53	1.42	1.46
39-42	1.55	1.54	1.51	1.55	1.55	1.53	1.46	1.51
42-45	1.52	1.50	1.55	1.57	1.50	1.48	1.51	1.53
45-48	1.62	1.62	1.59	1.64	1.63	1.63	1.55	1.62
48-51	1.73	1.77	1.72	1.80	1.75	1.79	1.70	1.78
Element 19-38855								
3-6	0.81	0.78	0.81	0.76	0.80	0.78	0.81	0.77
6-9	0.89	0.92	0.88	0.88	0.87	0.89	0.86	0.86
9-12	1.03	1.06	1.02	1.00	0.99	1.02	0.99	0.97
12-15	1.08	1.15	1.08	1.05	1.03	1.10	1.04	1.01
15-18	1.12	1.12	1.09	1.11	1.07	1.07	1.05	1.07
18-21	1.24	1.15	1.25	1.23	1.20	1.10	1.21	1.19
21-24	1.23	1.23	1.25	1.19	1.18	1.18	1.21	1.14
24-27	1.21	1.23	1.27	1.28	1.16	1.18	1.23	1.24
27-30	1.32	1.34	1.33	1.32	1.28	1.30	1.30	1.28
30-33	1.37	1.45	1.40	1.38	1.34	1.44	1.37	1.35
33-36	1.42	1.47	1.43	1.43	1.40	1.46	1.41	1.41
36-39	1.47	1.45	1.48	1.52	1.46	1.44	1.48	1.52
39-42	1.45	1.52	1.43	1.54	1.44	1.53	1.41	1.54
42-45	1.57	1.54	1.52	1.55	1.59	1.55	1.52	1.57
45-48	1.64	1.68	1.64	1.63	1.67	1.71	1.66	1.65
48-51	1.77	1.81	1.76	1.78	1.80	1.84	1.78	1.80
Element 14-62611								
3-6	0.74	0.75	0.72	0.73	0.75	0.76	0.75	0.76
6-9	0.84	0.85	0.81	0.81	0.83	0.84	0.82	0.82
9-12	0.97	0.93	0.89	0.89	0.95	0.91	0.89	0.89
12-15	1.02	1.03	0.99	0.97	0.99	1.00	0.98	0.96
15-18	1.07	1.08	1.00	1.05	1.04	1.05	0.99	1.04
18-21	1.16	1.16	1.07	1.05	1.13	1.13	1.05	1.04
21-24	1.15	1.18	1.10	1.13	1.12	1.14	1.09	1.12
24-27	1.20	1.23	1.16	1.17	1.17	1.20	1.15	1.16
27-30	1.22	1.27	1.20	1.24	1.19	1.24	1.19	1.23
30-33	1.27	1.36	1.24	1.28	1.24	1.34	1.23	1.28
33-36	1.33	1.42	1.31	1.31	1.31	1.41	1.31	1.31
36-39	1.37	1.46	1.38	1.41	1.36	1.47	1.40	1.44
39-42	1.42	1.52	1.42	1.42	1.41	1.54	1.46	1.47
42-45	1.49	1.55	1.44	1.48	1.50	1.58	1.48	1.53
45-48	1.52	1.60	1.57	1.54	1.54	1.63	1.64	1.61
48-51	1.67	1.72	1.65	1.62	1.72	1.77	1.73	1.70
Element 11-62165								
3-6	NO DATA		0.92	0.90	NO DATA		0.91	0.89
6-9			1.01	1.04			0.98	1.02
9-12			1.12	1.12			1.09	1.09
12-15			1.24	1.22			1.21	1.20
15-18			1.32	1.28			1.30	1.26
18-21			1.40	1.40			1.40	1.40
21-24			1.52	1.56			1.55	1.60
24-27			1.65	1.65			1.70	1.70
27-30			1.78	1.80			1.84	1.86
30-33			1.93	1.98			1.99	2.04
33-36			2.20	2.20			2.25	2.25
36-39			2.33	2.45			2.36	2.46
39-42			2.66	2.60			2.64	2.59
42-45			2.60	2.79			2.59	2.73
45-48			2.94	3.09			2.84	2.96
48-51			3.18	3.09			3.02	2.96

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differences, though comparatively small, are a reflection of the three expressions for conversion as used in the NRX-A6/2 approach versus the single expression used in the TME-1244 approach. Actually, equivalent thickness values from one approach will be lower (higher) than the other over approximately the first half, and higher (lower) than the other over the remaining part of the range of thicknesses covered by each of the three expressions of the NRX-A6/2 approach.

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SECTION 5

(CRD) CONCLUSIONS AND RECOMMENDATIONS

With the beginning of the NRX-A6/2 production of fuel elements, WNCO introduced four general changes in the evaluation of Niobium-Carbide thickness by beta backscatter. The changes were:

- 1) A redesign of the beta backscatter probe to consider an aluminum encapsulated source rather than the stainless steel encapsulation,
- 2) A new set of beta backscatter standards, due to changes in Uranium loadings,
- 3) A different functional form for the calibration curve, and
- 4) A set of expressions for use in converting apparent Niobium per beta backscatter to equivalent Niobium-Carbide as obtained metallographically.

All data analyzed, for the preparation of this report, lead to the conclusion that probes with aluminum encapsulated sources have responses equally as effective as those with stainless steel encapsulation. Count data taken with the new probes for calibration vary within the ± 4 units reported in WANL-TME-1244 as that expected for the three measurements obtained for each standard Niobium foil thickness and is independent of the thickness being measured. Since the probe redesign was primarily to attain longer probe life, the new probes should be continued in service.

In evaluating the functional form of the calibration curve, the first set of data appeared to indicate that calibration data deviated significantly--more than could be expected from the information reported in TME-1244. This can be attributed to two different events; 1) the use of improper Niobium foil thickness values in the calibration formulation, and 2) the inadvertent use of some poorer quality calibration standards. In the latter case, all NRX-A6/2 calibration standards were new, with meager experience in their use. To prevent any further difficulty relative to the inadvertent use of poorer quality standards, all were evaluated and the results of this evaluation summarized in Tables 4 and 5.

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Referring to these tables, those standards not indicated as acceptable should be discarded; of those that are acceptable, those standards having the smallest standard errors of estimate within each loading code should be used as the primary calibration standards.

Also to be noted in Table 4 or 5 is the large number of standards that have been made. This number is a function of the number of different fuel loadings and the requirements for calibration. Since each standard uses foil difficult to measure and is difficult to make, in future applications, consideration should be given to reducing the number of standards needed while, at the same time, improving the overall quality of the set. A possible way of reducing the number required may rest in a method using a limited number of loadings wherein loading effects may be inferred. With fewer standards, greater care with respect to the quality of each should prove to be beneficial.

Again referring to Tables 4 and 5, the evaluation of standards was based upon what should be considered as the maximum limit tolerable for a standard error of estimate for a calibration curve. If the functional form of the calibration curve considers the fit of $\log(Nb + 1.0)$ as a function of Counts, then the maximum limit would be 0.0100. On the other hand, if the functional form considers the fit of $\log(Nb)$, then the maximum limit would be 0.0180. Not only can limits such as these be used to evaluate the acceptability of new standards but these should be used to evaluate the acceptance of each and every calibration curve.

TME-1244 considered the functional form of the calibration curve to be that of $\log(Nb + 1.0)$ as a linear function of Counts, whereas the functional form presently being used is that of $\log(Nb)$ as a linear function of the square root of Counts. In expressing the calibration curve in terms of $\log(Nb + 1.0)$, the 0.0 mils thickness plus any foil thicknesses less than 1.8 mils (generally 3 different thicknesses) would be used. If the calibration curve is expressed in terms of $\log(Nb)$, the 0.0 mils thickness is ignored but all foil thicknesses (generally 6 different thicknesses with the maximum less than 4.0 mils) would be used. From the data covered in this report, these two functional forms were found to be essentially equivalent but only if certain foil thicknesses (different for each expression) were assumed. It should be apparent from the previous statement that the functional form of the calibration curve has

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not been explicitly determined. This will be accomplished only if Niobium foil thicknesses used in the calibration standards are better defined and controlled more rigorously in their placement in the standards.

From metallographic examination of four NRX-A6/2 (PAX) elements, Niobium-Carbide thicknesses were used to establish relationships for converting apparent Niobium thickness from beta backscatter to equivalent Niobium-Carbide. A single linear expression, $NbC = -0.053 + 1.427 Nb$, using the TME-1244 calibration approach was found to be sufficient over the range of Niobium-Carbide thicknesses observed. WNCO, using the same data and the NRX-A6/2 calibration approach, derived three expressions. These also were found to be sufficient to cover the range of thicknesses observed with differences in equivalent Niobium-Carbide thicknesses as computed from either approach negligible.

Since the conversion expressions are empirical as well as semi-dependent upon the calibration form, these should be reviewed every 3 to 6 months to ensure their effectiveness. At the present time, either of the two approaches and their data as discussed herein could be used.

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