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A SURVEY OF URANIUM METAL-TESTING METHODS

By
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Physics Division

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SUMMARY

The purpose of metal testing is to measure the quality of uranium, as affected by the impurities which it contains. The subject has not been concisely documented, and is apt to be confusing to anyone not familiar with the field.

The present report discusses the theory and practice of the reactor testing of uranium, as carried out at Argonne National Laboratory and at the Hanford Works. Methods are described in some detail, and formulas are given for expressing results. The historical background, including the "shotgun test," is outlined. Some new figures, applicable to the testing of rods in CP-2, are included.

Some difficulties in present methods, as well as discrepancies in available information, are apparent from the discussion.

I. IMPORTANCE OF METAL TESTING

If impurities are present in uranium which is used as fuel in a nuclear reactor operating on thermal neutrons, some of the neutrons which might otherwise produce fissions are lost owing to absorption by the impurities. This results in a decrease in the effective thermal utilization (f) of the reactor. If the other quantities in the four-factor formula $k = \eta \epsilon p f$ remain constant, a decrease in the reproduction factor (k) will result. If it is desired to keep the critical mass small, the purity of both the uranium and the moderator is of paramount importance. A method of testing the metal to determine the fraction of the neutrons absorbed in uranium which are lost to impurities, or some closely related quantity, is therefore necessary.

The importance of using uranium of extremely high purity in a reactor will depend on the type of reactor. Most reactors built before about 1950 were designed for maximum resonance escape probability (p), and conservation of neutrons was of the utmost importance. In some present-day designs, however, reactors are designed for less than maximum p in order to insure more captures by U^{238} (to produce plutonium) or by other materials deliberately introduced. In other words, merely insuring operation of the reactor is no longer the main problem in such cases, and a considerable excess of uranium may be present. In such instances the question of the purity of uranium becomes economic; i.e., will the cost of high-purity uranium be too great for the benefits to be gained? Although no good answer to this question is apparent to the writer, some method for testing the quality of uranium (as measured by neutron loss to impurities) is still necessary. Such a test can help answer the economic question, and will ensure quality control of uranium for the present.

II. THE DANGER SUM(7,10,26)

The effect of impurities in uranium on the reproduction factor of a Hanford 105 production pile (hereafter denoted as W105) is given by the following equation:

$$\Delta k\,\% = \frac{100 \cdot \sum_i \frac{\text{wt. of } X_i}{\text{atomic wt. of } X_i} \cdot \sigma_{X_i}}{\frac{\text{wt. of U}}{\text{atomic wt. of U}} \cdot \sigma_U} \cdot f_{W105}$$

or

$$\Delta k\,\% = f_{W105} \cdot \Sigma\,(\% X_i) \cdot D_{X_i}$$

where X_i = any element present as an impurity

D_{X_i} = danger coefficient of X_i = $\frac{\text{atomic wt. of U}}{\text{atomic wt. of } X_i} \cdot \frac{\sigma_{X_i}}{\sigma_U}$

σ_U = thermal fission cross section of natural uranium

σ_{X_i} = thermal capture cross section of the impurity X_i

f_{W105} = thermal utilization of W105 $\cong$ 0.87

$\Delta k\,\% = 100 \frac{\Delta k_\infty}{k_\infty} = 100 \frac{\Delta k_{eff.}}{k_{eff.}}$

Δk = loss in reproduction factor due to impurities; actually Δk here is a negative number, but will be written as positive.

The quantity $\Delta k\,\%$ is to be thought of as the per cent loss in k if an entire W105 pile were loaded with metal of this quality instead of pure uranium.

The effect of any individual impurity X_i is proportional to its "danger product," equal to $(\% X_i) \cdot D_{X_i}$. The combined effect of all impurities is proportional to the "danger product sum," equal to $\sum_i (\% X_i \cdot D_{X_i})$. This quantity, when expressed as $\Delta k\,\%$ (i.e., after multiplying by f_{W105}), has been called the TDS, or "total danger sum."

Up to the present, the quantity TDS always has referred to the W105 reactors. Furthermore, results of metal testing for a number of years have been expressed as TDS, defined as above. Since new production reactors having different values for f will be built, it might be desirable to go back to the older "danger product sum" in designating metal quality, so as to give a result independent of any particular type of reactor.

III. HISTORICAL BACKGROUND

The obvious method for determining the "danger product sum" is by chemical analysis, together with spectrographic analysis, using values for the cross sections of the various elements as determined by pile measurements, transmission experiments, etc. The chemical method[1,7] was first used for obtaining the danger product sum and was developed to give good precision. Chemical analysis will continue to be used for special purposes, but is excessively laborious and expensive for a routine method.

The "shotgun test" was a modified chemical method designed to save labor.[6,17,22,24] This consisted in extracting the impurities from a 22-lb. sample of uranium metal by dissolving the metal in acid and precipitating the impurities as oxides.[2] These oxides were compressed into a pellet whose effect on neutron density near a source in a paraffin block was measured by a method conceived by E. Fermi. The sample was placed between a neutron source and a detector (a foil or counter), all being contained in the block of paraffin. After proper calibration, the "per cent absorption" was measured relative to boron. This quantity was proportional to "danger product sum," and an absorption of less than 0.05 per cent was considered satisfactory. The "shotgun test" had the disadvantage of missing several elements, including boron, and had to be supplemented by chemical analysis. It was used at the Metallurgical Laboratory until at least 1945 but was finally abandoned because of the large amount of metal consumed (up to 1/2 ton per month). Typical results are described in references 7, 9, 11, 13, 15, 18-21.

The shotgun test was partially replaced in 1943, after CP-2 became available at Argonne, by a nondestructive "functional test."[10,26] This consisted in using a nuclear reactor (CP-2) as a sensitive measuring instrument in a way similar to the method for measurement of cross sections, and has been called the "danger method."[3,4] The pile reactivity, or "excess k" measured in inhours, was determined when the metal sample was inserted into the reactor and compared with the excess k measured when a standard sample was used instead. The inhour difference between these two conditions was converted into Δk % (for W105) for the test sample, with reference to the standard metal. The TDS was then found by adding the TDS of the standard, which had been found by chemical analysis of drillings taken from the standard.

The TDS (or $\Delta k\%$) determined by reactor tests showed good correlation with the "danger product sum" found by chemical analysis.[16]

The determination of the TDS of uranium "eggs" has continued in this way up to the present, both at Argonne and at Hanford after the W305 test reactor was built. A further discussion is given in Section VIIIA.[3]

After the completion of W305, it was desired to test samples of fuel slugs which were to be loaded into the W105 reactors. This has been done to an appreciable extent only at Hanford. At first, $\Delta k\%$ was also calculated for the fuel slugs, but this was soon abandoned in favor of expressing the results simply as dih, measured in W305. The quantity dih simply means the inhour difference between test sample and standard, when introduced into W305, with no weight correction. Since weight differences between machined slugs were fairly small, and the main emphasis was on whether the W105 reactors would operate satisfactorily, the quantity dih as a measure of metal quality was adequate. This was reportedly correlated with observed values of $\Delta k\%$ when the W105 reactors were loaded.

The dih for slugs showed only a moderate correlation with the TDS of the corresponding eggs (correlation coefficient = 0.54; reference 23). Also, only 29 per cent of the dih variation in slugs could be traced to TDS variation. This is a strong argument for testing slugs rather than eggs, as an index of quality of the metal actually loaded into a reactor.

The disadvantages of using dih (measured in W305) as a more generally useful quantity (i.e., at locations other than Hanford) for expressing metal quality are obvious. Among others, it applies to a particular measuring instrument (W305), a particular slug shape, a particular testing arrangement, and a particular set of standards; it includes no correction for size, weight, or density differences; and it was set up for a particular purpose. Nevertheless, it has satisfactorily served the purpose for which it was intended at Hanford.

IV. TEST REACTORS

The only two reactors so far used in this country for metal testing in the usual sense are CP-2 at Argonne and W305 at Hanford. A reactor of similar characteristics (S305) will soon be completed at the Savannah River Plant. These are all graphite-moderated reactors employing natural uranium as fuel. The testing stringers are capable of taking samples 10 ft. or more in length, making them suitable for testing fuel assemblies of considerable size.

The CP-2 lattice consists of lumps of uranium, as well as lumps of UO_2 and U_3O_8, arranged in an 8-1/4 in. cubical lattice in a graphite matrix.

The lattice of W305 (and also S305) consists of rough-rolled uranium rods, 8.25 in. long and about 1.44 in. in diameter, separated by 1-1/16 in. graphite spacers and arranged in holes in the graphite to form an 8-3/8 in. square lattice. So far as metal testing is concerned, the principal physical difference between these reactors is the difference in neutron density (or flux) distribution, with resultant differences in statistical weights along the testing stringers.

V. TYPES OF SAMPLES AND STANDARDS

A. Eggs

Eggs are the ends of cast ingots, which are cast in such a way that the eggs can be easily sawed off as samples before rolling the ingots into billets. Each egg is approximately 2-1/4 in. in diameter by 1-3/4 in. high and weighs between 1900 and 2000 grams.

Although the egg is supposed to represent the billet, there is reportedly some evidence, obtained at Hanford, that this is not true. The egg is at the bottom of the billet as cast, and would not be expected to retain any floating impurities present in the melt, unless these are frozen at the surface of the relatively cool mold at the beginning of the pour. The evidence seems to indicate, however, that this may happen. If so, the slugs finally obtained from the billet after rolling and machining should consist of higher-quality metal than the eggs, since surface impurities would be machined off.

The original standard eggs are still used at Argonne. These were chosen in 1943 as representing good quality production.

W305 also has a set of standard eggs, which have been checked against the Argonne standards. S305 will also have standard eggs, which will have been checked against the Argonne standards in CP-2.

B. Hanford Slugs

The original bare Hanford slugs were 8.00 in. long by 1.359 in. in diameter. Both bare and canned standards were set up at Hanford so that the extent of neutron loss to cans and canning materials could be determined. By testing canned slugs against canned standards, the absorption by all impurities, including the cans, can be evaluated.

When Hanford changed to shorter slugs of bare size 4.05 in. long by 1.35 in. in diameter, only canned standards of the new size were set up. All testing of the 4 in. slugs must therefore be done against canned standards. It is believed that Hanford has been trying to set up a conversion factor to permit testing the new bare slugs against the 8 in. bare standards.

At present, the metal quality of Hanford slugs can be accurately tested only at Hanford, since no adequate standards exist elsewhere. It is believed that results for all testing of Hanford slugs are reported simply as dih, or inhour difference in W305. These dih values are presumed to have adequate correlation in the W105 reactors.

C. Savannah River Slugs

These slugs before canning will be 8.07 in. long by 0.997 in. in diameter. Bare and canned standards will be set up, after checking against each other before canning. The bare standards will, if possible, be correlated with the Hanford bare standards, as well as with the Argonne standard eggs, via a suitable testing program.

VI. TESTING ARRANGEMENTS; STATISTICAL WEIGHTS; WEIGHT COEFFICIENTS

A. Egg Testing Arrangement at ANL

At Argonne, the standard eggs are arranged in the 16 holes in the eight center blocks of the metal-testing stringer of CP-2. The order of arrangement, in terms of weights in grams, is designed to minimize the effect of weight differences between eggs. The object of the arrangement is to make the weighted average weight in grams of the 16 standard eggs weighted according to their statistical weights in the reactor equal to their actual average weight in grams.

The order previously chosen at Argonne results in a stringer arrangement which is slightly unsymmetrical about the center with regard to weight (Table I). If the statistical weights are accurately known, this should make no difference. However, a balanced arrangement, as shown in the last column of Table I, would help to minimize the effect of errors in positioning the samples, as well as slight errors in statistical weights.

In using the ANL standard eggs, it is probably inadvisable to change the arrangement at this late date. However, for samples to be checked against the ANL standards and in setting up any additional groups of standard eggs (as for S305), the balanced arrangement may be preferable.

B. Egg Weight Coefficient

Since eggs are of different weights, some method is necessary to reduce the measured dih (vs. standard eggs) to a standard weight. The standard weight (weighted average weight; or average weight if this is sufficiently close) has been taken as 1900 grams, which is the average weight of the ANL North Standards.

Table I

ARRANGEMENT OF ANL NORTH STANDARDS

Position	Statistical Weight		ANL No.	North Standards		Balanced Arrangement
South	Previously Used[1]	Redetermined[2]		Wt. (gm.)	Rank by Wt.[3]	Rank by Wt.
1	0.50	0.45	A3457	1936	1	1
2	0.60	0.55	A3472	1865	15	16
3	0.70	0.61	A3458	1923	3	3
4	0.80	0.78	A3437	1876	13	14
5	0.87	0.85	A3436	1916	5	5
6	0.93	0.92	A3449	1897	11	12
7	0.98	0.97	A3470	1906	7	7
8	1.00	1.00	A3446	1905	9	10
9	1.00	0.99	A3461	1905	8	9
10	0.98	0.98	A3453	1911	6	8
11	0.93	0.92	A3466	1897	10	11
12	0.87	0.83	A3469	1916	4	6
13	0.80	0.76	A3435	1882	12	13
14	0.70	0.66	A3440	1876	14	4
15	0.60	0.55	A3471	1926	2	15
16	0.50	0.44	A3441	1858	16	2
North						

ANL North Standards

Average weight = 1899.69

Weighted av. wt. = 1900.49 (from previous statistical weights) (Note 1)

Weighted av. wt. = 1901.18 (from new statistical weights) (Note 2)

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1. From Classified Notebook of Rubin Fields (ANL No. 621B)
2. Calculated from flux distribution formulae (cf. Section VI, G, 1) to be given in forthcoming ANL report on re-calibration of CP-2, by J. L. Hyde, P. D. Deans, D. J. Pellarin, and G. W. McManaway.
3. The nominal order by weight rank, as given in the reference of Note 1, is - - - 8, 10, 6, 12, 4, 14 - - - . It is obvious that the eggs of ranks 10 and 6 were interchanged; likewise those of ranks 12 and 4. This apparently was an oversight. The resulting improper order has been retained through the years; the effect on measurements is very slight.

It was necessary to determine the value of the weight coefficient, dih/dw, for eggs in the standard ANL arrangement. This was done[8] by adding 1, 2, 3, 4, . . . Westinghouse cubes to each hole in the test stringer, normally occupied by an egg during testing. A figure of 0.00535 ih/gm, when w $\cong$ 1900 gm per egg, was obtained in this way.

There is some objection to this procedure, since the average thermal flux in an aggregation of cubes should be somewhat different from that in a single egg. Therefore the weight coefficient was redetermined by two other methods, both of which gave a figure of 0.00515 for dih/dw when w $\cong$ 1900 gm per egg. The latter figure is believed to be more reliable.

The two methods used were as follows:

(1) A slice of uranium, cut from a remelt egg of approximately the same metal quality as the standards, was laid on top of each of the 16 standard eggs. Each slice was 1/4 in. thick and machined to practically uniform size and weight. The observed inhour difference was divided by the weighted average weight per slice to obtain dih/dw = 0.00515.

(2) A light group and heavy group, each containing 16 eggs, were selected from the complete collection of ANL North and South Standards. The observed inhour difference was divided by the difference between the weighted average weights to obtain dih/dw = 0.00515.

C. Egg Testing Arrangement at Hanford

At Hanford a weight correction is omitted because of the testing arrangement used; namely, a closer spacing, only 4-1/4 in. between eggs (16 eggs are used). According to Hanford experience, the inhour difference between standards and test samples is independent of weight variation for a 4-1/4 in. spacing, if the average weight is between 1700 and 2000 grams. To prove this, they say they have plotted a curve of dih (for a full vs. an empty stringer) against average weight per egg and have found that the curve becomes flat below 1700 grams and stays flat up to more than 2000 grams. The curve was obtained by adding slices to each egg to increase the weight. In obtaining this curve the eggs were paired, a heavy one with a light one in a manner roughly similar to the standard arrangement at Argonne. This pairing is standard for testing in W305.

Some single-egg testing is now being done at Hanford. Only one of the 16 standard eggs is replaced by the test egg, and the resulting dih is converted to TDS by employing statistical weights in conjunction with the regular formula.

D. Slug Testing Arrangement at Hanford

At the present time, each end of a full metal stringer in W305 contains a continuous length of 42 canned slugs (each about 4-1/2 in. long when canned) in graphite blocks with U-shaped slots. In testing canned slugs, the middle 22 slugs are removed (leaving 10 at each end) and replaced by standards or test samples. In testing bare slugs, the same 22 slugs are removed, and the test samples are introduced. Since bare slugs are shorter than canned slugs, the load is preferably centered by inserting graphite spacers at each end of the load; i.e., between the load and the remaining 10 canned slugs on each end.

E. Temporary Slug Testing Arrangement at ANL

The middle six graphite blocks in the metal stringer are removed for this purpose, being replaced by two 48 in. graphite V-blocks. The load is centered by graphite spacers. This arrangement has been used for checking differences between metal rods, using an internal standard.

F. Weight Coefficient for Rods in CP-2

For an 81.0 in. length of uranium rod (composed of slugs) at the center of the metal stringer of CP-2, the weight coefficient dih/dw has been evaluated for rods of 1.00 in. to 1.35 in. diameter. This was done by measuring a rod before and after machining the diameter. Three points were obtained, and a curve was drawn through these and the zero point. Tangents were determined graphically, and represent only approximate slopes. More points would be necessary for an accurate determination. Data are given in Table II. The result for 1 in. rod, for example, is:

dih/dw = 0.372 ih/kg., when the weight of the entire 81 in. length is used.

Table II

WEIGHT COEFFICIENT FOR RODS IN CP-2

Diameter (inches)	Total Length (inches)	Total Weight (kg.)	dih vs. Empty Stringer	ih/kg. (vs. empty)	dih/dw (ih/kg.)
0	(81.0)	0	0	- - -	(1.1)
0.997	80.75	19.496	13.229	0.6785	0.372
1.20	81.00	28.260	15.850	0.5609	0.228
1.35	81.00	35.587	17.238	0.4844	0.151

G. Statistical Weights

1. Statistical Weights in CP-2

Statistical weights previously used for the 16 eggs in the metal stringer are shown in Table I. In the recalibration of CP-2 (see Table I, Note 2) analytical expressions were obtained for the flux distribution in the testing stringers of CP-2, namely:

$$\text{for } 0 < x < 62 \text{ in.} \quad \phi/\phi_0 = \cos(0.0140x)$$

$$\text{for } 53 \text{ in.} < x < 120 \text{ in.} \quad \phi/\phi_0 = 0.9 \cos(0.0123x)$$

(x is given in inches from the reactor center)

Statistical weights may be obtained by squaring these expressions.

2. Statistical Weights in W305

These may be obtained by squaring the flux distribution, which is given in reference 26 as:

$$\phi/\phi_0 = \cos \frac{\pi x}{228} \text{ ; x is given in inches.}$$

VII. CALIBRATION IN METAL TESTING

Calibration is performed by poisoning the uranium at its surface, as described for eggs in reference 10, and for slugs in reference 26. Iron wire was used as the standard poison in both cases.

This type of calibration assumes that the ratio of flux at the surface to average flux inside the uranium is known. In the case of eggs, it was assumed that a sphere of equal weight was a sufficient approximation to the shape of a uranium egg. A diffusion-theory calculation, taking $\kappa = 0.796$, gave the ratio $\phi_{surface}/\bar{\phi} = 1.32$ (cf. reference 10). (Note: If κ is taken as 0.700, this ratio becomes 1.25). Subsequent experimental measurements with copper foils (12,14) showed that the flux distribution in a sphere could not be described by a single value of κ. No direct measurements of flux distribution in eggs have been made, to the writer's knowledge. It is very possible that the figure 1.32 for the flux ratio is several per cent in error.

In the case of Hanford slugs (diameter = 1.359 in.), the ratio $\phi_{surface}/\bar{\phi} = 1.21$ was assumed, probably as a result of diffusion-theory calculations (26).

Direct measurements have been made in the case of Savannah River slugs of diameter = 1.00 in. (5). The results for a single long rod show:

$\phi_{surface}/\overline{\phi}$ = 1.19, as measured in the 8-1/4 in. lattice of CP-2.

The results of poisoning 81 in. lengths of rods in CP-2 are shown in Table III. Poisoning was done with 80 Puron rods 0.091 in. in diameter by 4 in. long (see report on recalibration of CP-2; Table I, Note 2), distributed at the rod surface along 81 in. length. Taking the cross section of iron as 2.43 barns (AEC Cross Section Committee, 1951), we obtain the result that for an 81 in. length of Savannah River slugs in CP-2, 3.08 cm^2 of 1/v absorber is required per inhour, if uniformly distributed throughout the uranium.

If the ratio of $\phi_{surface}/\overline{\phi}$ = 1.21 is assumed to be correct for rods of both 1.375 in. and 1.35 in. diameter, figures for uniform poison distribution of 3.63 and 3.58 cm^2/ih, respectively, are obtained.

Table III

POISON CALIBRATIONS FOR URANIUM RODS IN CP-2

Rod Diameter (inches)	Rod Length (inches)	Fe Poison Used Wt. (gm)	Fe Poison Used Cm^2 Absorber	dih	At Rod Surface gm Fe/ih	At Rod Surface cm^2/ih	Uniform Distribution cm^2/ih
1.375	81.00	269.7	7.06	2.353	114.7	3.00	(3.63)
1.35	81.00	269.7	7.06	2.382	113.0	2.96	(3.58)
0.997	80.75	269.7	7.06	2.725	98.9	2.59	3.08

VIII. FORMULAS USED FOR CALCULATION OF Δk% AND TDS

A. Egg Tests

1. In CP-2

According to CP-718, a calibration for egg tests using iron wire as poison yielded the result, Δk% = 0.49 Δih. This, it is stated, applies to CP-2, whose thermal utilization is given as 0.83. In order to make this apply to W105, for which f = 0.87 (26), one must multiply by $\frac{0.87}{0.83}$ (cf. Section II of this report) to obtain:

$$\Delta k\% \text{ (for W105)} = 0.514 \Delta ih \text{ (measured in CP-2)}$$

According to existing metal-testing procedure at Argonne, which is not well-documented since 1943, the formula now in use is:

$$\Delta k\% \text{ (for W105)} = \frac{1}{1.82} \cdot \Delta ih = 0.550\, \Delta ih \text{ (measured in CP-2)}$$

It is not known just how this factor was obtained. It must be assumed that a subsequent recalibration with iron, or some cross-calibration involving W305, is responsible.

The foregoing factor applies to the standard 8-1/4 in. spacing for eggs as used in CP-2, after correcting the average weight to 1900 grams (cf. Section V B).

2. <u>In W305</u>

Although W305 was not originally calibrated for egg testing, and reports on the calibration are not at hand, we have been informed that the expression in current use is:

$$\Delta k\% \text{ (for W105)} = 0.41\, \Delta ih \text{ (measured in W305)} + (-0.016)$$

This expression applies to the 4-1/4 in. spacing for eggs as used in W305, and no weight correction is required (cf. Section V C). The term, -0.016, arises from a cross-calibration with Argonne (see Section IX) and is used to bring the results into agreement.

It should be noted that Δ ih is a <u>negative</u> quantity, as is $\Delta k\%$. The effect of the term, -0.016, is therefore to <u>increase</u> the magnitude of $\Delta k\%$. This convention of sign must be observed in order to use the Hanford equations as they stand.

3. <u>Calculation of TDS</u>

The equation used at Hanford is:

$$TDS = -[\Delta k\% + (-0.13)]$$

This results in TDS being a positive quantity larger in magnitude than $\Delta k\%$. The term, 0.13, is supposed to represent the TDS of the Argonne standard eggs, and the convention of sign is observed.

This equation will apply to $\Delta k\%$ measured at Argonne as well as at Hanford, since the two have been brought into agreement.

B. <u>Slug Tests</u>

Although the results of slug tests at Hanford are generally left as dih (measured in W305), $\Delta k\%$ can be calculated. The following relation was obtained[26] by poisoning the slugs with iron wire whose cross section is stated to be 2.53 barns:

$$\Delta k\,\%\ (\text{for W105}) = 0.32\ \Delta ih\ (\text{measured in W305})$$

This applies to a continuous rod of twelve slugs, each 8.00 in. long and 1.359 in. in diameter. For a shorter length, the corresponding figure could be computed from the statistical weights (Section VI G (2)).

IX. CROSS-CALIBRATION BETWEEN CP-2 AND W305

By 1947, a systematic discrepancy between egg tests in CP-2 and in W305 was apparent. A recheck of the Hanford standard eggs at Argonne then showed a difference of 0.01 per cent in Δk between the standards, as compared with a previously measured difference of 0.02 per cent [25]. Thus, if the TDS of the Argonne standards is 0.13 (expressed as Δk% in W105), the TDS of the Hanford standards is 0.12. Use of these values is said to have cleared up the difficulty.

The present expression used to obtain Δk% for egg tests in W305, however, contains the term 0.016 (Section VII A (2)). One would expect this term to be 0.010 if the difference between the two sets of standards is actually 0.01 per cent in Δk. The reason for this difference has not come to our attention.

X. LIMITATIONS OF METAL TESTING

A. Limits of Accuracy

It has been established by measurements in CP-2 that a testing error of ± 0.016 ih (for 95 per cent confidence) exists for the average of carefully made duplicate measurements. At Hanford a standard deviation of ± 0.007 ih (equivalent to ± 0.014 ih for 95 per cent confidence) has been reported for careful work. For routine work in W305, a standard deviation of ± 0.02 ih (or ± 0.04 ih for 95 per cent confidence) has been given. No more can be expected of these two reactors. It is believed that fluctuations in barometric pressure are the largest single source of error, since barometric corrections are slightly uncertain, and the pile cannot follow rapid pressure changes.

It is anticipated that S305, now under construction at the Savannah River Plant, will overcome the barometric difficulty because of its helium atmosphere.

B. - Limits of Usefulness

It is possible that extremely high-purity uranium will not be necessary in certain reactors of the near future (cf. Section I). However, it is highly probable that quality control will have to be maintained at some level. Nondestructive testing of uranium in a low-power reactor is a convenient way to do this, as well as to aid in determining where this level should be fixed. It may also be very useful in testing the metal after exposure in a high-power reactor to evaluate nuclear changes.

Although metal-testing may be carried out for different purposes in the future, it is likely to be a valuable adjunct to reactor design and reactor maintenance for some time to come.

XI. BIBLIOGRAPHY

1. A-2912 — A Manual of Analytical Methods, January 1946
   Vol. I, Analysis of Ores
   Vol. II, Pts. I & II, Analysis of Refined Materials and By-Products
   Vol. III, Pts. I & II, Analysis of Purified Materials
2. A-2912 — Vol. III, pp. 242-253
3. Anderson, H. L., et al. A Method for Measuring Neutron Absorption Cross Sections by the Effect on the Reactivity of a Chain-Reacting Pile, Phys. Rev. 72, 16-23 (1947)
4. ANL-4342 — Alexander Lansdorf, Jr. The Thermal Neutron Reactor as an Instrument for Measuring Neutron Cross Sections. January 20, 1950
5. ANL-4705 — Neutron Producer (CP-6) Reactor Program Quarterly Report, July through September 1951. October 22, 1951
6. C-218 — H. M. Agnew, H. L. Anderson, W. H. Burgus. The Measurement of Neutron Absorption of Impurities in Metal. July 30, 1942
7. CC-523 — Chemical Research, Analytical. Report for month ending March 15, 1943
8. CP-641 — E. Fermi, et al. Physics Research. Report for month ending May 10, 1943
9. CC-660 — R. E. Curtis, et al. Chemical Research, Analytical. Report for month ending April 17, 1943
10. CP-718 — E. Fermi, et al. Physics Research. Report for month ending June 12, 1943

11. CC-737 G. E. Boyd, et al. Chemical Research, Analytical. Report for month ending June 18, 1943

12. CP-781 E. Fermi, Physics Division. Report for month ending July 10, 1943

13. CC-870 H. A. Potrotz. Chemistry Research, Analytical. Report for period ending August 7, 1943

14. CP-871 E. Fermi, Physics Division. Report for month ending August 14, 1943

15. CS-874 Laboratory Council - Information (Chemistry) August 17, 1943

16. CP-964 E. Fermi, et al. Physics Research. Report for month ending September 25, 1943

17. CC-981 L. Myers, Jr. The Determination of Neutron Absorption by the "Shotgun" Method. September 8, 1943

18. CC-984 G. E. Boyd, et al. Chemical Research, Analytical. Report for period ending October 9, 1943

19. CC-1047 H. A. Potrotz. Analytical Chemistry. Report for the period ending November 6, 1943

20. CC-1105 H. A. Potrotz. Analytical Chemistry. Report for the period ending December 13, 1943

21. CC-1448 H. A. Potrotz. Chemical Research, Analytical. Report for the month ending March 1, 1944

22. CS-3072 G. T. Seaborg. Plutonium Chemistry. Summary Report for June, 1945

23. HEW-7378 C. W. J. Wendi. Hanford Engineer Works. Technical Progress Letter No. 164, August 17 through August 23, 1947

24. N-1974 L. Myers (Revised by M. Asprey and G. Cowen). The Determination of Neutron Absorption by the "Shotgun" Method. (No date)

25. N-2427 C. W. Wendi, et al. HEW technical progress letter No. 151, May 18 through May 24, 1947

26. W-305-P2 G. L. O'Neil. 305 Test Pile Calibrations. July 5, 1944

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