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RESULTS OF THE GENERAL ANALYTICAL EVALUATION
PROGRAM FOR URANIUM HEXAFLUORIDE, PHASE I

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HEXAFLUORIDE, PHASE I

ABSTRACT

Samples of uranium hexafluoride were submitted monthly to twenty-two laboratories in the USA and Europe for determination of % UF_6 and the enrichment of uranium. Three samples were submitted each month over a twelve-month period. Participants were asked to report chemical data based upon their usual method for high-precision uranium analysis. Four materials, each of purity greater than 99.9% UF_6 were used. A majority of the participating laboratories fell within $\pm 0.1\%$ of the values assigned for the chemical purity.

The enrichment of the uranium ranged from near-normal to approximately 1.7% ^{235}U . Most laboratory results fell within $\pm 0.2\%$ (relative) of the assigned enrichment values. There were wide variations in reported between-day precision. Only ten laboratories measured enrichment with sufficient precision to identify four different enrichments. Of these ten, four laboratories exhibited a bias with respect to the assigned value. This raises some question about the calibration control of mass spectrometric measurements.

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I. Introduction

In early 1971 a consideration was given to require recipients of UF_6 in the United States to determine independently the chemical purity and isotopic composition of UF_6 which they received. It was realized that the capability to perform these measurements might vary widely among laboratories. In an effort to document the state of the art and to attempt to minimize shipper-receiver differences in the transport of UF_6 , a program was developed to provide laboratories an opportunity to demonstrate their measurement capability.

Under the direction of the New Brunswick Laboratory (NBL) the goal of this General Analytical Evaluation (GAE) Program was to demonstrate whether an adequate and consistent level of performance exists for the chemical and isotopic analysis of UF_6 . Because toll-enrichment shipments could be made to recipients outside USA, it was decided to solicit the participation of laboratories outside USA. It was planned to execute the program in three phases. Phase I would involve a determination of the purity of UF_6 in a sample provided by NBL. A separate sample was to be provided for a determination of the ^{235}U content. Phase II would require the participating laboratory to withdraw a sample from a 1S container supplied to them and to perform a chemical and isotopic analysis. Phase III would involve the measurement of impurities in supplied samples of UF_6 . This report documents the results of Phase I of the UF_6 GAE Program. The following laboratories agreed to participate in Phase I.

<u>Laboratory</u>	<u>Location</u>
AVCO	Tulsa, Oklahoma, USA
British Nuclear Fuels, Limited	
Capenhurst Works	Chester, Cheshire, England
Springfield Works	Salwick Preston, Lancashire, England
Commissariat a L'Energie Atomique	
Laboratoire Central de	Pierrelatte, France
Pierrelatte	
Laboratoire Central d'	Grenoble, France
Analyse et de Controle,	
CEN	

<u>Laboratory</u>	<u>Location</u>
Commissariat a L'Energie Atomique (Continued)	
Laboratoire de Spectrometrie de Mass, CEN de Saclay	GIF-sur-YVETTE, France
Laboratoire de la Societe COMURHEX	Narbonne, France
European Economic Community Bureau Central de Mesures Nucleaires	Geel, Belgium
Centro Comune Di Ricerca	Ispra, Italy
Exxon Nuclear Company	Richland, Washington, USA
General Electric Company Chemet Laboratory	Wilmington, North Carolina, USA
Midwest Nuclear Recovery Plant	Morris, Illinois, USA
Vallecitos Nuclear Center	Pleasanton, Calif., USA
Goodyear Atomic Corporation	Piketon, Ohio, USA
Laboratorio Chimica Industriale	Rome, Italy
Reactor Centrum Nederland	Petten, The Netherlands
Ultra-Centrifuge Nederland	Almelo, The Netherlands
Union Carbide Corporation Nuclear Division, Paducah Gaseous Diffusion Plant	Paducah, Kentucky, USA
Nuclear Division, Oak Ridge Gaseous Diffusion Plant	Oak Ridge, Tennessee, USA
United States Energy Research and Development Administration New Brunswick Laboratory	New Brunswick, N. J., USA
Uran-Isotopentrennungs-GmbH	Julich, Germany
Westinghouse-Nuclear Fuel Division	Columbia, South Carolina, USA

II. Conduct of Experiment

UF₆ material was supplied by the Nuclear Division, Union Carbide Corporation. Individual samples were prepared from materials of four different enrichments—two near-normal and two near 1.7% ²³⁵U. Samples for determining UF₆ purity were loaded into fluorothene containers called P-10 tubes (See Figure 1) and samples for isotopic analysis were loaded into polyethylene tubing "pigtailes" (see Figure 2). Transfers from 12A cylinders were made in accordance with methods described in ORO-671-1.¹ All P-10 tubes and components were serial numbered and tare weighed. After the tubes were filled and sealed, gross weights were taken and recorded. Samples were selected and assigned to participating laboratories according to a sequence generated from random numbers. The samples were prepackaged at NBL under an inert atmosphere and sealed into cans (Figure 3) for delivery to the laboratories on a fixed schedule.

Each laboratory received three P-10 tubes and three pigtailes each month. They were asked to hydrolyze the entire contents of a P-10 tube and to assay the resulting solution for uranium by a method normally used for high-precision measurements. Results of replicate measurements, reported to the number of significant figures normally used, were requested. The participants were instructed to use 238.03 for the atomic weight of uranium and to report results as percent UF₆ based upon the weight of the hydrolyzed material.

Samples for ²³⁵U determination could be introduced directly into gas mass spectrometers in those laboratories possessing such equipment; however most laboratories, possessing thermal emission instruments, were required to hydrolyze the material and load an aliquot onto a filament. Participants were requested to report isotopic results, as weight percent, and absolute errors, along with such backup information, e.g. number of ratios per filament, number of filaments/sample, etc., that laboratory results could be compared.

All data were forwarded to NBL for reduction and evaluation.

III. Statistical Treatment of Data

While the methodology of statistics is exact, inferences pertaining to the application of statistics in a particular situation require discretion in order to adequately describe the results of an experiment. An understanding of the inherent problems involved in an analytical procedure is indispensable for the statistical interpretation of the results. The treatment of data in this experiment falls primarily into the category of data analysis rather than statistical analysis, *per se*. The analysis attempts to estimate the parameters which characterize the true state of nature within and between laboratories. It is handicapped by the relatively small number of observations for the number of parameters estimated.

Unless otherwise stated, it may be assumed that a statistical significance level (afterward referred to as significance level) of 5% was used except where otherwise indicated.

PIGTAIL

FIGURE 2

UF₆ SAMPLES · PREPACKAGING DETAILS

FIGURE 3

In this report, the long-term statistically significant difference between the observed values and the assigned value (as discussed below) will be defined as "bias". A "significant difference" (using relative differences defined later in this section) is defined as being statistically different from zero using an approximate t-test² and Student's t-distribution as the criterion.³ The assignment of "bias" to a laboratory was made in consideration of the standard error attached to the assigned value; therefore, where a laboratory exhibits a bias, the estimated limits of error of the assigned value have been taken into account. The results of the approximate t-tests were consistent with the results of the Duncan's New Multiple Range Test (NMRT) mentioned later.

It should be noted that in some cases a laboratory may have a "bias" assigned as a penalty because of a high degree of precision rather than a low degree of accuracy. Some laboratories deviated greatly from the assigned values and yet had no "bias" due to a high degree of imprecision. For example, Lab 1 may have the same absolute difference from the assigned value as Lab 2, but if the precision of Lab 1 is better, a "bias" may be assigned to Lab 1 but not to Lab 2. In those cases where a marked deviation from the assigned value is evident, a need exists to improve measurement accuracy.

Four materials were used in the preparation of samples for this experiment. The distribution of the samples was randomized so that the participating laboratories would not have any prior knowledge of which materials they would be analyzing on a monthly basis. All of the materials had a similar chemical purity (percent UF_6) but for enrichment (percent ^{235}U) they were divided into two distinct groups of materials. There were two materials with an approximately 0.7% enrichment and two with an approximately 1.7% enrichment.

The data were examined for trends or relationships such as dependence on the date of analysis (a time effect indicative of material instability as packaged) or dependence on the sequence in which a sample was taken (indicating some sort of fractionation). No significant trends could be isolated with the amount of information at hand. Additional time and sequence data were accumulated at NBL, but again all evidence indicated that the variation from sample to sample was due to random variation rather than systematic variation.

The data analysis will be divided into two areas. The first area to be considered is the chemical assay; secondly, the enrichment determination.

A. Chemical Assay Results

The chemical laboratories were requested to make 36 analytical measurements of which at least 6, but not more than 15, would be of any particular material. Table I illustrates the number of samples distributed to each laboratory versus the number of samples for which analytical results were reported.

The statistical model used to examine the laboratory effects for the chemical assay could be written as

TABLE I

SAMPLES RECEIVED VERSUS SAMPLES ANALYZED*

<u>Lab</u>	<u>Material 1</u>	<u>Material 2</u>	<u>Material 3</u>	<u>Material 4</u>	<u>Total</u>
A	7(7)	15(15)	7(7)	7(7)	36(36)
B	7(5)	15(12)	7(5)	7(3)	36(25)
C	7(4)	7(3)	15(10)	7(4)	36(21)
E	15(10)	7(6)	7(5)	7(6)	36(27)
G	12(12)	12(10)	6(4)	6(4)	36(30)
H	15(15)	7(6)	7(6)	7(5)	36(32)
I	7(4)	7(5)	7(5)	15(6)	36(20)
J	7(7)	15(15)	7(7)	7(6)	36(35)
K	7(4)	15(6)	7(3)	7(2)	36(15)
L	15(8)	7(5)	7(4)	7(4)	36(21)
N	6(4)	6(6)	12(11)	12(10)	36(31)
P	15(15)	7(7)	7(7)	7(7)	36(36)
R	7(7)	7(7)	7(7)	15(14)	36(35)
T	7(6)	15(14)	7(7)	7(7)	36(34)
V	7(5)	7(4)	7(4)	15(11)	36(24)
W	7(7)	7(7)	15(15)	7(7)	36(36)
Total	148(120)	156(128)	132(107)	140(103)	576(458)

* N(P) indicates that N samples were provided and results of the analysis of P samples were reported.

$$y_{ij} = M + A_i + e_{ij} \text{ where } i=1, \dots, 16 \text{ and } j=1, \dots, n_i$$

Here n_i represents the actual number of observations made by the i^{th} laboratory, M is the true value, A_i is the fixed effect of the i^{th} laboratory, and e_{ij} is the error associated with the j^{th} measurement of the i^{th} laboratory. The assumptions inherent in an analysis of variance were examined and tested where appropriate to insure that the model was not violated. Bartlett's test⁴ for the homogeneity of variances at the 1% significance level was used as a preliminary test since the cell sizes were quite varied and heterogeneity of variance was expected. The assumption of independence of the e_{ij} 's was deemed justifiable.

Due to the extreme variations in precision, the Bartlett's test was used to group the laboratories (by materials) into homogeneous variance groups. An analysis of variance was then made on each group. Where a significant difference in means was indicated, the Duncan's NMRT^{5,6} at the 5% "Protection"⁷ level was used to determine which of the means could be grouped.

The statistical model used to examine the material differences could be written as follows

$$y_{ij} = M + B_i + d_{ij} \text{ where } i=1, \dots, 4 \text{ and } j=1, \dots, n_i$$

Here n_i represents the actual number of observations made on the i^{th} material, M is the true value, B_i is the random effect of the i^{th} material, d_{ij} is the error associated with the j^{th} measurement of the i^{th} material. As in the above model, the pertinent assumptions were tested. An additional assumption due to the random effects (B_i) must be made. They are assumed to be normally distributed with a mean equal to zero and equal variances.

Since the materials were not found to be significantly different, data from the analysis of all the materials were pooled.

A more complex model leading to a two-way, mixed model analysis of variance was avoided due to the extreme variations in cell sizes and variances.

Summary tables have been provided in Appendix 2 for the actual results and the relative differences (RD), defined as follows:

$$RD = \frac{(\text{assay value}) - (\text{median value of labs})}{(\text{median value of labs})} \times 100$$

The median value was chosen as the reference value since it is little affected by extreme deviations in the laboratory means. An examination of the results should indicate the merit of using the median value. The assigned values with their estimated standard errors (assuming an approximately symmetric distribution) were as follows:

Material 1	_____	99.977 ± 0.025% UF ₆
Material 2	_____	99.934 ± 0.025% UF ₆
Material 3	_____	99.954 ± 0.021% UF ₆
Material 4	_____	99.976 ± 0.026% UF ₆
Data from all materials	pooled _____	99.968 ± 0.016% UF ₆

The mean values reported by the laboratories were examined for outliers⁸ at the 1% significance level for the purpose of determining the assigned value (median) and its standard error.

Each month as the replicate analyses for each sample from a given laboratory were received, the replicates were averaged and these values were used to compute a mean and a standard deviation of the values reported for a given material. The values reported in the tables in this report are therefore calculated from means of replicates rather than the individual replicates. This is reasonable since, in a realistic sample analysis situation, the mean of the replicates would be reported by a laboratory as the determined value. Moreover, only a few laboratories reported replicate measurements as requested so that the residual error term in an analysis of variance could not be effectively reduced. In all cases the replicate measurements reported by an individual laboratory for a given month were in very good agreement.

B. Enrichment Determinations

The analyses for isotopic abundance of ²³⁵U were made on the same 4 materials as were utilized in the chemical assays. Table II illustrates the number of samples distributed to each laboratory versus the number of samples for which enrichment results were reported.

The statistical model used to examine the laboratory effects could be written as

$$y_{ij} = M + A_i + e_{ij} \text{ where } i=1, \dots, 18 \text{ and } j=1, \dots, n_i$$

The assumptions and conditions are the same as in the chemical assay model for laboratory effects. The same preliminary tests were run and the variances were also grouped using the Bartlett's test of homogeneity of variance. The Duncan's New Multiple Range Test was again used to group means where a significant difference was indicated by an analysis of variance.⁶

The enrichment results were converted to relative differences (RD), in the following manner

$$RD = \frac{(\text{enrichment determination}) - (\text{assigned value})}{(\text{assigned value})} \times 100$$

The results from five laboratories, all highly experienced in uranium mass spectrometry, were used to determine the enrichment values to be assigned to each material. The assigned values and their standard errors were as follows:

Material 1	_____	0.7109 ± 0.0001 wt. %	²³⁵ U
Material 2	_____	1.7229 ± 0.0002 wt. %	²³⁵ U
Material 3	_____	1.7124 ± 0.0002 wt. %	²³⁵ U
Material 4	_____	0.7092 ± 0.0001 wt. %	²³⁵ U

The ability of the laboratories to distinguish between materials of similar isotopic composition was analyzed using the Satterthwaite approximation for the degrees of freedom in a Student's t-distribution.² This information is particularly valuable in assessing the precision of the laboratories. Only a

TABLE II

SAMPLES RECEIVED VERSUS SAMPLES ANALYZED*
FOR PERCENT ^{235}U

Lab	Material 1	Material 2	Material 3	Material 4	Total
A	7(7)	15(15)	7(7)	7(7)	36(36)
B	7(5)	15(13)	7(5)	7(4)	36(27)
E	15(14)	7(7)	7(7)	7(7)	36(35)
F	7(2)	7(1)	7(4)	15(4)	36(11)
G	12(12)	12(12)	6(6)	6(6)	36(36)
H	15(15)	7(7)	7(7)	7(7)	36(36)
J	7(7)	15(15)	7(7)	7(7)	36(36)
K	7(7)	15(15)	7(7)	7(7)	36(36)
L	15(8)	7(5)	7(4)	7(4)	36(21)
N	6(6)	6(5)	12(12)	12(12)	36(35)
P	15(15)	7(6)	7(7)	7(7)	36(35)
S	7(7)	7(7)	7(7)	15(15)	36(36)
T	7(7)	15(15)	7(7)	7(7)	36(36)
U	7(7)	7(7)	15(15)	7(7)	36(36)
V	7(3)	7(0)	7(0)	15(7)	36(10)
W	7(7)	7(7)	15(15)	7(7)	36(36)
Y	15(15)	7(7)	7(7)	7(7)	36(36)
Z	7(6)	7(7)	7(5)	15(14)	36(32)
Total	170(150)	170(151)	146(129)	162(136)	648(566)

* N(p) indicates that N samples were provided and the results of the analysis of P samples were reported.

relatively precise laboratory would be able to distinguish between two materials of similar isotopic composition, i.e., the two near-natural abundance or two slightly enriched materials as found in this experiment. It would certainly be expected that all laboratories would be able to detect the difference between uranium of approximately natural abundance and uranium of approximately 1.7% enrichment.

Summary tables have been provided in Appendix 2 for the actual results and relative differences.

IV. Results

A. Chemical Assay

1. Material 1 - Estimates of the mean and standard deviation of the RD distribution for each of the participating laboratories are shown in Figure 4 and appear in columns 5 and 6, respectively, of Table III. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table III.

The results of t-tests on the means of the RD's revealed that laboratory T exhibited a positive bias and laboratories B and K exhibited a negative bias. Note that laboratories I and W were not included in the computation of the median and its standard error. They were suspected as outliers and confirmed by appropriate tests.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level.)

B A C G K V H N L R T J E I P W

The laboratories, ranked by increasing mean values, were as follows:

W K B C A J L V G H N R E T P I

The arrow indicates the location of the assigned value ($99.977 \pm 0.025\%$ UF₆) and the underline represents the limits of the standard error.

2. Material 2 - Estimates of the mean and standard deviation of the RD distribution for each of the participating laboratories are shown in Figure 5 and appear in columns 5 and 6, respectively, of Table IV. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table IV.

The results of t-tests on the means of the RD revealed that laboratory T exhibited a positive bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined

TABLE III
 UF_6 CONCENTRATION
(MATERIAL 1)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias²</u>
A	7	99.952	0.011	-0.025	0.011	
B	5	99.920	0.007	-0.057	0.007	*
C	4	99.948	0.016	-0.029	0.016	
E	10	100.041	0.221	0.064	0.221	
G	12	99.978	0.019	0.001	0.019	
H	15	99.979	0.026	0.002	0.026	
(I) ³	4	(100.251)	0.760	0.274	0.760	
J	7	99.957	0.068	-0.020	0.068	
K	4	99.892	0.022	-0.085	0.022	*
L	8	99.960	0.037	-0.017	0.037	
N	4	99.992	0.034	0.015	0.034	
P	15	100.195	0.807	0.218	0.807	
R	7	100.009	0.042	0.032	0.042	
T	6	100.072	0.053	0.095	0.053	*
V	5	99.976	0.024	-0.001	0.024	
(W) ³	7	(99.625)	0.847	-0.352	0.847	

¹ R.D.-relative difference (%) from the median (99.977±0.025)

² Indicates a statistically significant difference at the 5% significance level using a t-test.

³ Parenthesis indicate laboratories which were excluded as outliers in the computation of the median and its standard error.

FIGURE 4

UF₆ CONCENTRATION
(MATERIAL 1)

TABLE IV
 UF_6 CONCENTRATION
(MATERIAL 2)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	15	99.947	0.013	0.012	0.013	
B	12	99.920	0.028	-0.014	0.028	
C	3	99.902	0.030	-0.032	0.030	
E	6	99.796	0.519	-0.138	0.520	
G	10	99.967	0.024	0.033	0.024	
H	6	99.980	0.020	0.046	0.020	
I	5	99.905	0.116	-0.029	0.116	
J	15	99.892	0.313	-0.042	0.314	
K	6	99.922	0.049	-0.012	0.049	
L	5	99.955	0.079	0.021	0.079	
N	6	99.999	0.054	0.065	0.054	
P	7	99.868	0.459	-0.066	0.459	
R	7	99.985	0.057	0.051	0.057	
T	14	100.106	0.090	0.172	0.090	
V	4	99.906	0.102	-0.028	0.102	
W	7	100.115	0.250	0.180	0.250	

¹ R.D.-relative difference (%) from the median (99.934±0.025)

FIGURE 5

UF₆ CONCENTRATION
(MATERIAL 2)

by a common line were not significantly different with respect to precision at the 1% significance level).

A H G B C K N R L T V I W J P E

The laboratories, ranked by increasing mean values, were as follows:

E P J C I V B K ↓ A L G H R N T W

The arrow indicates the location of the assigned value ($99.934 \pm 0.025\%$ UF₆) and the underline represents the limits of the standard error.

3. Material 3 - Estimates of the mean and standard deviation of the RD distributions for each of the participating laboratories are shown in Figure 6 and appear in columns 5 and 6, respectively, of Table V. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table V.

The results of t-tests on the means of the RD revealed that laboratories E and T exhibited a positive bias and laboratory B exhibited a negative bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level).

G H A B L R E C T I K V N W J P

The laboratories, ranked by increasing mean values, were as follows:

I P B J C N K A ↓ L R H W G V T E

The arrow indicates the location of the assigned value ($99.954 \pm 0.021\%$ UF₆) and the underline represents the limits of the standard error.

4. Material 4 - Estimates of the mean and standard deviation of the RD distribution for each of the participating laboratories are shown in Figure 7 and appear in columns 5 and 6, respectively, of Table VI. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table VI.

The results of t-tests on the means of the RD revealed that laboratory T exhibited a positive bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level).

TABLE V
 UF₆ CONCENTRATION
 (MATERIAL 3)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	7	99.931	0.026	-0.023	0.026	
B	5	99.896	0.027	-0.058	0.027	*
C	10	99.899	0.059	-0.055	0.059	
E	5	100.085	0.045	0.131	0.045	*
G	4	99.992	0.014	0.038	0.014	
H	6	99.978	0.021	0.024	0.021	
I	5	99.859	0.113	-0.095	0.113	
J	7	99.898	0.329	-0.056	0.330	
K	3	99.922	0.120	-0.032	0.120	
L	4	99.978	0.028	0.024	0.028	
N	11	99.909	0.182	-0.045	0.182	
P	7	99.884	0.521	-0.070	0.521	
R	7	99.978	0.033	0.024	0.033	
T	7	100.057	0.068	0.103	0.068	*
V	4	100.048	0.137	0.094	0.137	
W	15	99.979	0.274	0.025	0.275	

¹ R.D.-relative difference (%) from the median (99.954±0.021)

Standard Deviation of Relative Difference

FIGURE 8

UF₆ CONCENTRATION
(MATERIAL 3)

K¹ A H B L G C V R J T E N I W P

The laboratories, ranked by increasing mean values, were as follows:

N C B A J V G H ↓ L K R I T E W P

The arrow indicates the location of the assigned value ($99.976 \pm 0.026\%$ UF₆) and the underline represents the limits of the standard error.

5. Pooled Chemical Assay Results - Table VII reveals the results from pooling the data from the laboratories over all material types. The data from the four materials were combined because the results of an analysis of variance indicated no significant difference between the materials. The assigned value is again the median ($99.968 \pm 0.016\%$ UF₆). Figure 8 displays the data from columns 5 and 6 of Table VII.

The variances of each of the laboratory's measurement grouped in the following manner

A G H B L C R K I V N J E I W P

The laboratories, ranked by increasing mean values, were as follows:

C B J K N A L W ↓ V G H R I E P T

The arrow indicates the location of the assigned value ($99.968 \pm 0.016\%$ UF₆) and the underline represents the limits of the standard error. The results of t-tests on the means of the RD revealed that laboratory T had a positive bias and laboratories B and C had a negative bias.

¹ There were only 2 observations reported by laboratory K thus it could not be included in the Bartlett's test.

TABLE VI
 UF_6 CONCENTRATION
(MATERIAL 4)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	7	99.927	0.015	-0.049	0.015	
B	3	99.920	0.020	-0.056	0.020	
C	4	99.898	0.043	-0.078	0.043	
E	6	100.066	0.213	0.090	0.213	
G	4	99.968	0.021	-0.008	0.021	
H	5	99.974	0.018	-0.002	0.018	
I	6	100.013	0.236	0.037	0.236	
J	6	99.951	0.059	-0.025	0.059	
K	2	99.980	0.014	0.004	0.014	
L	4	99.979	0.020	0.003	0.020	
N	10	99.891	0.230	-0.085	0.230	
P	7	100.199	0.487	0.223	0.487	
R	14	99.985	0.057	0.009	0.057	
T	7	100.059	0.060	0.083	0.060	*
V	11	99.960	0.049	-0.016	0.049	
W	7	100.135	0.304	0.159	0.304	

¹ R.D.-relative difference (%) from the median (99.976±0.026)

FIGURE 7
UF₆ CONCENTRATION
(MATERIAL 4)

TABLE VII
 UF_6 CONCENTRATION
(POOLED ASSAY RESULTS)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	36	99.941	0.018	-0.027	0.018	
B	25	99.915	0.025	-0.053	0.025	*
C	21	99.908	0.049	-0.060	0.049	*
E	27	100.000	0.301	0.032	0.301	
G	30	99.975	0.021	0.007	0.021	
H	32	99.978	0.022	0.010	0.022	
I	20	99.995	0.364	0.027	0.364	
J	25	99.916	0.249	-0.052	0.249	
K	15	99.922	0.061	-0.046	0.061	
L	21	99.966	0.044	-0.002	0.044	
N	31	99.931	0.172	-0.037	0.172	
P	36	100.072	0.639	0.104	0.639	
R	35	99.988	0.049	0.020	0.049	
T	34	100.080	0.075	0.112	0.075	*
V	24	99.969	0.082	0.001	0.082	
W	36	99.967	0.462	-0.001	0.462	

¹ Relative difference from median of all materials combined
(99.968±0.016)

FIGURE 8

UF₆ CONCENTRATION
(POOLED ASSAY RESULTS)

Table VIII indicates where biases were observed.

TABLE VIII

PRESENCE OF BIAS IN ASSAY RESULTS¹
(SUMMARY OF TABLES III, IV, V, VI, VII)

	Laboratory Code															
	A	B	C	E	G	H	I	J	K	L	N	P	R	T	V	W
1	-								-						+	
2															+	
3		-		+											+	
4															+	
All	-	-													+	

¹ + or - indicates positive or negative bias using a t-test at the 5% significance level.

It should be emphasized again that the presence of bias may in some cases indicate an excellence in precision rather than a large deviation from the assigned value.

Several laboratories experienced extreme mean values as may be observed in Appendix 2 which displays the mean of the reported replicates as well as its relative difference from the assigned value. Individual replicates were not recorded because of the excellent agreement within a laboratory for a given sample that prevailed without exception.

B. Enrichment Determinations

1. Material 1 - Estimates of the mean and standard deviation of the RD distributions for each of the participating laboratories are shown in Figure 9 and appear in columns 5 and 6, respectively, of Table IX. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table IX.

The results of t-tests on the means of the RD revealed that laboratories E and V exhibited a positive bias and laboratories K, S, T and U exhibited a negative bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level.)

V G H A U N K T S J Y (F)¹ P E L B W Z

The laboratories ranked by increasing mean values, were as follows:

¹ There were only two observations reported by Laboratory F, thus it could not be included in the Bartlett's test.

TABLE IX
²³⁵U ENRICHMENT
(MATERIAL 1)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	7	0.7109	0.0001	-0.0040	0.0157	
B	5	0.7061	0.0121	-0.6752	1.7087	
E	14	0.7235	0.0055	1.7724	0.7680	*
F	2	0.7125	0.0035	0.2251	0.4973	
G	12	0.7111	0.0001	0.0281	0.0101	
H	15	0.7109	0.0001	0.0066	0.0117	
J	7	0.7112	0.0006	0.0422	0.0861	
K	7	0.7105	0.0002	-0.0563	0.0262	*
L	8	0.7132	0.0061	0.3235	0.8532	
N	6	0.7111	0.0001	0.0281	0.0187	
P	15	0.7122	0.0037	0.1829	0.5264	
S	7	0.7094	0.0006	-0.2110	0.0822	*
T	7	0.7103	0.0002	-0.0844	0.0349	*
U	7	0.7102	0.0001	-0.0985	0.0159	*
V	3	0.7113	0.0001	0.0563	0.0081	*
W	7	0.7121	0.0133	0.1688	1.8722	
Y	15	0.7118	0.0027	0.1266	0.3841	
Z	6	0.7192	0.0216	1.1675	3.0431	

¹ R.D.-relative difference from assigned value (0.7109±0.0001)

B S U T K A ↓ H G N J V Y W P F L Z E

The arrow indicates the location of the assigned value (0.7109 ± 0.0001 wt % ^{235}U).

2. Material 2 - Estimates of the mean and standard deviation of the RD distributions for each of the participating laboratories are shown in Figure 10 and appear in columns 5 and 6, respectively, of Table X. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table X.

The results of t-tests on the means of the RD revealed that laboratories K, N, P, S and Z exhibited a positive bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level.)

H N Z U K T A J G P S E B Y L W

The laboratories ranked by increasing mean values, were as follows:

F E B Y A U H J ↓ T G K Z N W P S L

The arrow indicates the location of the assigned value (1.7229 ± 0.0002 wt % ^{235}U).

3. Material 3 - Estimates of the mean and standard deviation of the RD distributions for each of the participating laboratories are shown in Figure 11 and appear in columns 5 and 6, respectively, of Table XI. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table XI.

The results of t-tests on the means of the RD revealed that laboratories N and S exhibited a positive bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level.)

G H U K T J A N S F E L B Y Z P W

The laboratories ranked by increasing mean values, were as follows:

F W Z E P B Y A H G U T K J N S L

The arrow indicates the location of the assigned value (1.7124 ± 0.0002 wt % ^{235}U).

TABLE X
 ^{235}U ENRICHMENT
(MATERIAL 2)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	15	1.7225	0.0007	-0.0232	0.0431	
B	13	1.7182	0.0084	-0.2728	0.4867	
E	7	1.7169	0.0071	-0.3483	0.4124	
F	1	1.7130		-0.5746		
G	12	1.7233	0.0017	0.0232	0.1011	
H	7	1.7226	0.0002	-0.0174	0.0100	
J	15	1.7227	0.0011	-0.0116	0.0628	
K	15	1.7235	0.0005	0.0348	0.0284	*
L	5	1.7320	0.0177	0.5282	1.0277	
N	5	1.7252	0.0003	0.1335	0.0167	*
P	6	1.7272	0.0034	0.2496	0.1957	*
S	7	1.7317	0.0041	0.5108	0.2379	*
T	15	1.7230	0.0006	0.0058	0.0366	
U	7	1.7226	0.0005	-0.0174	0.0266	
W	7	1.7259	0.0375	0.1741	2.1785	
Y	7	1.7224	0.0091	-0.0290	0.5308	
Z	7	1.7247	0.0004	0.1045	0.0214	*

¹ R.D.-relative difference from assigned value (1.7229±0.0002)

FIGURE 10
 ^{235}U ENRICHMENT
 (MATERIAL 2)

TABLE XI
²³⁵U ENRICHMENT
(MATERIAL 3)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	7	1.7120	0.0010	-0.0234	0.0584	
B	5	1.7102	0.0113	-0.1285	0.6602	
E	7	1.7074	0.0081	-0.2920	0.4754	
F	4	1.7045	0.0072	-0.4613	0.4225	
G	6	1.7123	0.0003	-0.0058	0.0163	
H	7	1.7121	0.0003	-0.0175	0.0201	
J	7	1.7129	0.0009	0.0292	0.0525	
K	7	1.7128	0.0005	0.0234	0.0283	
L	4	1.7188	0.0110	0.3737	0.6439	
N	12	1.7149	0.0010	0.1460	0.0611	*
P	7	1.7079	0.0172	-0.2628	1.0021	
S	7	1.7181	0.0035	0.3329	0.2050	*
T	7	1.7126	0.0005	0.0117	0.0295	
U	15	1.7124	0.0004	-0.0031	0.0213	
W	15	1.7059	0.0389	-0.3796	2.2696	
Y	7	1.7109	0.0132	-0.0876	0.7728	
Z	5	1.7073	0.0160	-0.2978	0.9367	

¹ R.D.-relative difference from assigned value (1.7124±0.0002)

4. Material 4 - Estimates of the mean and standard deviation of the RD distribution for each of the participating laboratories are shown in Figure 12 and appear in columns 5 and 6, respectively, of Table XII. Estimates of the mean and the standard deviation of a measurement are shown in columns 3 and 4 of Table XII.

The results of t-tests on the means of the RD revealed that laboratories E and V exhibited a positive bias and laboratories S, T and U exhibited a negative bias.

The variances of each of the laboratory's measurements grouped in the following manner (note: The laboratories underlined by a common line were not significantly different with respect to precision at the 1% significance level.)

G U H V A K N T S J P F Y L E Z B W

The laboratories ranked by increasing mean values, were as follows:

B S U T K H ↓ A G N J V P Y F Z L W E

The arrow indicates the location of the assigned value (0.7092 ± 0.0001).

5. Overall Enrichment Results - Table XIII summarizes where biases were observed in the measurement of ^{235}U enrichment in UF_6 .

TABLE XIII

PRESENCE OF BIAS IN ISOTOPIC ANALYSES¹
(SUMMARY OF TABLES IX, X, XI, XII, XV)

Laboratory Code		A	B	E	F	G	H	J	K	L	N	P	S	T	U	V	W	Y	Z
1			+						-				-	-	-	+			
2									+	+	+	+						+	
3											+		+						
4			+										-	-	-	+			
All		-	+						+	+			-	-	+				

¹ + or - indicates positive or negative bias using a t-test at the 5% significance level

An additional test was made on the data from the isotopic analysis to determine if a given laboratory was capable of distinguishing between two materials of similar isotopic value, for example, materials 1 and 4 or materials 2 and 3. Table XIV summarizes the findings.

TABLE XII
²³⁵U ENRICHMENT
(MATERIAL 4)

<u>Lab</u>	<u>N</u>	<u>Mean</u>	<u>Standard Deviation</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	7	0.7092	0.0002	0.0040	0.0254	
B	4	0.7005	0.0117	-1.2267	1.6544	
E	7	0.7243	0.0064	2.1272	0.9055	*
F	4	0.7105	0.0017	0.1833	0.2442	
G	6	0.7093	0.0001	0.0141	0.0126	
H	7	0.7091	0.0001	-0.0141	0.0160	
J	7	0.7095	0.0005	0.0423	0.0756	
K	7	0.7090	0.0003	-0.0282	0.0402	
L	4	0.7130	0.0044	0.5358	0.6200	
N	12	0.7094	0.0003	0.0282	0.0425	
P	7	0.7098	0.0009	0.0846	0.1253	
S	15	0.7079	0.0005	-0.1833	0.0647	*
T	7	0.7087	0.0004	-0.0705	0.0558	*
U	7	0.7085	0.0001	-0.0987	0.0151	*
V	7	0.7096	0.0001	0.0564	0.0179	*
W	7	0.7136	0.0120	0.6204	1.6898	
Y	7	0.7103	0.0029	0.1551	0.4128	
Z	14	0.7113	0.0086	0.2961	1.2174	

¹ R.D.-relative difference from assigned value (0.7092±0.0001)

TABLE XIV

ABILITY OF LABORATORIES TO DIFFERENTIATE BETWEEN MATERIALS
WITH SIMILAR ENRICHMENT OF ^{235}U ¹

<u>Lab</u>	<u>Material 1 versus Material 4</u>	<u>Material 2 versus Material 3</u>
A	yes	yes
B	no	no
E	no	yes
F	no	no
G	yes	yes
H	yes	yes
J	yes	yes
K	yes	yes
L	no	no
N	yes	yes
P	yes	yes
S	yes	yes
T	yes	yes
U	yes	yes
V	yes	--- ²
W	no	no
Y	no	no
Z	no	no

¹ Test was at the 5% level

² No observations

Table XV and Figure 13 reveal the overall results of all laboratories. In other words this table is an analysis of the overall percent deviations from the assigned values. The materials were statistically different and therefore could not be pooled for a single analysis as was done for chemical purity.

The results of t-tests on the means of the RD revealed that laboratories E, L, N and V had a positive bias and laboratories B, T and U had a negative bias. The information on bias in the isotopic analyses in general is in the preceeding table.

The variances of each of the laboratory's measurements grouped in the following manner:

V H A K U T G J N S F Y P I B E Z W

The laboratories, ranked by increasing mean values, were as follows:

B F U T A H ↓ K J G W S V Y N P Z L E

The arrow indicates the location of the assigned value (all materials included).

TABLE XV
POOLED ISOTOPIC ANALYSIS RESULTS FOR ^{235}U ENRICHMENT

<u>Lab</u>	<u>N</u>	<u>Mean of R.D.¹</u>	<u>Stan.Dev. of R.D.</u>	<u>Bias</u>
A	36	-0.0142	0.0401	
B	27	-0.4619	1.0389	*
E	35	1.0063	1.2906	*
F	11	-0.1124	0.4733	
G	36	0.0184	0.0587	
H	36	-0.0095	0.0170	
J	36	0.0173	0.0700	
K	36	0.0125	0.0476	
L	21	0.4222	0.7714	*
N	35	0.0836	0.0725	*
P	35	0.0855	0.5776	
S	36	0.0466	0.3371	
T	36	-0.0254	0.0555	*
U	36	-0.0417	0.0485	*
V	10	0.0564	0.0151	*
W	36	0.0291	2.0283	
Y	36	0.0602	0.4986	
Z	32	0.3248	1.5619	

¹ R.D.-relative difference from assigned value.

V. Conclusions

A. Chemical Assay

In general, those laboratories performing uranium determination by gravimetry exhibited the best precision of measurement. This precision in determining the purity of UF_6 averaged 0.04% relative standard deviation (RSD) over the nine laboratories performing gravimetric measurements. Even though the method produced excellent precision, it did not always produce unbiased (i.e., accurate) results. Laboratory T consistently exhibited a positive bias of about 0.1%. All other laboratories using gravimetry exhibited accuracies better than $\pm 0.1\%$, averaging within about $\pm 0.06\%$. Accuracy in the gravimetric analysis is dependent upon the assumptions regarding the stoichiometry of the ignited oxide and how impurity corrections, if any, are applied. Either of these conditions could result in a positive bias and should be considered by Laboratory T.

The three laboratories (E, J, P) which performed uranium measurement by a titrimetric procedure exhibited measurements less precise by nearly an order of magnitude compared to gravimetric measurements. Laboratory P exhibited marked deviations from the assigned values (substantial positive deviations for materials 1 and 4, and negative-but smaller-deviations for materials 2 and 3). Because of the large standard deviation of reported values for each material, a bias was not assigned to Laboratory P. Laboratory E, except for material 2, exhibited positive deviations of about 0.1% with precisions on reported values varying from a very good 0.05% RSD to greater than 0.5% RSD. Laboratory J reported titrimetric data with precision nearly comparable to gravimetric measurements, except for material 2. It reported values consistently and slightly below the assigned values but within about 0.05%. Poor precision in titrimetric analyses is generally attributed to inconsistent sensing of the equivalence point. Consistent deviation can be attributed to errors in standardization or to an improper identification of the equivalence point. The three laboratories concerned should review their measurement methods for possible contribution of any of these parameters.

Laboratories L and W measured uranium by controlled-potential coulometry with strikingly different results. Laboratory W exhibited precision averaging nearly 0.5% RSD, whereas Laboratory L averaged better than 0.05% RSD. On all except material 3, Laboratory W exhibited marked positive or negative deviations from the assigned values. Laboratory L was consistently within $\pm 0.05\%$ of the assigned value from all materials. Poor precision in coulometry may be due to instrumental inadequacies-drift in the potentiostat, leakage in the integrating capacitor, cell design, high cell resistance or to inconsistent measurement of background current or blank correction. Negative deviations as large as reported by Laboratory W in material 1 might have been attributed to loss during sample preparation if similar results has been experienced for materials 2, 3 and 4. Since large ($>0.15\%$) deviations were exhibited in materials 2 and 4, it can only be assumed that calibration and/or instrumental problems are being experienced in Laboratory W. Laboratory L was as consistently accurate in its reported values as any other participating laboratory.

B. Enrichment Determinations

As one might have anticipated, those laboratories using mass spectrometers into which the UF_6 could be introduced directly as a gas generally exhibited the best precision. Laboratory Z, for materials 1, 3 and 4, Laboratory P for materials 1, 2 and 3 and Laboratory S for materials 2 and 3 were exceptions to the rule in that substantially poorer precision was exhibited. Poor precision of measurement of the same material over a period of time, assuming that gross instrumental variations do not occur, may be due to slight degrees of cross-contamination ("memory") within an instrument which is used over a range of enrichment values. The laboratories making imprecise gas measurements (P, S, Z) did not exhibit consistent deviations from the assigned values which would indicate calibration errors. Inconsistent differences from the assigned value and large standard deviations of the measurements on a given material indicate improper control of the equipment operating parameters and/or frequent cross-contamination problems.

Of those laboratories using thermal ionization mass spectrometry, Laboratories B, E, F, L, W, and Y experienced generally poorer precision than other laboratories using similar equipment. Very large differences from the assigned values were reported by Laboratories B (materials 1 and 4), E (materials 1, 2, and 4), L (all materials), and W (material 4). Calibration errors could account for consistent relative differences from the assigned values. Each laboratory exhibited good within-sample (internal) precision. In some cases the relatively poor between-sample precision would have been markedly improved if there has been a technical basis for discarding a single reported value. Laboratory Z would have exhibited a mean relative difference in material 1 of -0.07% if one of the six values had been excluded. Laboratory S had a consistent positive bias for slightly enriched material (2 and 3) and a negative bias for natural enrichment material (1 and 4). Laboratory W exhibited a shift from low to high reported values over the time span of the experiment which appears to be indicative of a calibration error.

Of greatest significance in this part of the program is the information in Table XIV. Of the eighteen laboratories participating in the mass spectrometric measurements, only ten laboratories were able to measure with sufficient precision to determine that four different enrichments were involved. Of this ten, four exhibited biases relative to the assigned value. Certain laboratories, known to have been involved in comparisons with other laboratories in the same country, showed good international agreement but did not always agree with the assigned values. This could be indicative of calibration or standardization differences between countries.

VI. Acknowledgements

The contributions of the participating laboratories to this program are gratefully recognized.

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Early experimental modeling was performed by Jack Whichard, formerly at NBL, now at ERDA Headquarters. The tedious and demanding task of data tabulating and reduction was performed by Mrs. Elaine Jacob whose contributions are expecially acknowledged.

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APPENDIX 1

Methods of Analysis Used by Participating Laboratories

I. Chemical Assay for UF₆

Laboratory A - Contents of P-10 tube are cooled with liquid nitrogen, then hydrolyzed in distilled water. The UO₂F₂ solution produced by the hydrolysis is evaporated to dryness then converted to U₃O₈ by pyrohydrolysis at 900°C. The uranium content is determined from the weight of U₃O₈ after correcting for impurities found by spectrographic analysis. Net sample weight is determined by subtracting the weight of the cleaned and dried P-10 tube components from the gross weight of the sample and container. UF₆ content is calculated from the uranium weight by use of a gravimetric factor (UF₆/U).

Laboratory B - Contents of P-10 are cooled in liquid nitrogen and hydrolyzed in iced distilled water. To the hydrolyzed solution in a teflon beaker, 5 ml of H₂SO₄ is added and evaporated to fumes. After redissolving in water, the sample is transferred to a platinum dish and the solution evaporated to dryness under an infra-red lamp. Conversion to U₃O₈ is by ignition at 900°C for three hours. UF₆ is calculated using a gravimetric factor (3 UF₆/U₃O₈).

Laboratory C - Same as Laboratory A.

Laboratory E - Sample is hydrolyzed as in Laboratory B. Sulfuric acid (5 ml) is added to weighed aliquots containing ~ 200 mg U evaporated to fumes and fumed for 5 minutes. Uranium is reduced by ferrous ion in concentrated phosphoric acid to which has been added 1.5M sulfamic acid. Excess ferrous ion is destroyed by sulfamic acid. Excess ferrous ion is destroyed by nitrate-molybdate. After standing 3 minutes after the blackish color disappears, the solution is diluted with 100 ml 1M H₂SO₄. Vanadyl sulfate solution (10 ml, 0.05M) is added and solution is titrated with 0.027N K₂Cr₂O₇ potentiometrically detected end-point. UF₆ is calculated from a factor (UF₆/U).

Laboratory G - Contents of the P-10 tube are cooled in liquid nitrogen then hydrolyzed in iced water in a tared platinum dish. The solution is evaporated to dryness under heat lamps and pyrohydrolyzed to U₃O₈ at 850°C. The U₃O₈ is weighed and percent UF₆ calculated.

Laboratory H - Same as Laboratory G.

Laboratory I - not reported.

Laboratory J - Same as Laboratory E.

Laboratory K - Gravimetric - no details provided.

Laboratory L - After cooling the P-10 tube overnight in a refrigerator, the contents are hydrolyzed in cold water. After hydrolysis, dilute H_2SO_4 is added when evaporated to fumes. After cooling, the sample is diluted with water to ~ 400 g. Weighed aliquots (~ 10 g) are taken for controlled-potential coulometry in 1N H_2SO_4 .

Laboratory N - not reported.

Laboratory P - Uranium determined by "Davies and Gray" method. No other details provided.

Laboratory R - Contents of the P-10 are cooled in liquid nitrogen, then hydrolyzed in distilled water. The solution is evaporated under an infra-red lamp, dissolved in 10 ml concentrated HNO_3 and evaporated a second time. The sample is calcined at $920^\circ \pm 10^\circ\text{C}$ and weighed as U_3O_8 . Percent UF_6 is calculated from gravimetric factors.

Laboratory T - An aliquot of the hydrolyzed sample (12-13 g), is taken to fumes with sulphuric acid for one hour in a 250 ml Teflon beaker to remove fluoride. After cooling 200 ml hot water is added and when solution is complete 0.880 ammonia is added until a permanent precipitate is obtained followed by 10 ml in excess. The beaker is placed on a cool hot plate for 5 minutes until the precipitate has settled and the precipitate is then separated by filtration through a 13 cm No. 40 Whatman filter paper, using hot 2% v/v ammonia to transfer the precipitate to the filter. Any precipitate adhering to the sides of the beaker is redissolved with a few drops of hot 1% v/v nitric acid and reprecipitated by addition of 0.880 ammonia (5 drops excess after neutralization to litmus) and this precipitate is then added to the bulk using the hot ammonia wash. The paper and precipitate are transferred to a platinum crucible and after drying at the front of a muffle furnace are ignited to constant weight at 900°C . Percent UF_6 is calculated from gravimetric factors.

Laboratory W - Contents of the P-10 tube were cooled in liquid nitrogen, then hydrolyzed in iced distilled water. Weight aliquots were treated with sulfuric acid then titrated by controlled-potential coulometry.

Laboratory V - same as Laboratory A.

II. Isotopic Distribution

The following laboratories analyzed UF_6 directly in gas mass spectrometers-some using single standard and others using double standard techniques: A, G, H, N, P, S, U, V and Z. Some laboratories operate under computer control of the switching sequence from standard to sample and for data collection and reduction.

The remaining laboratories used thermal ionization mass spectrometers. Few details were provided as to filament material, whether single, double or triple filament methods were used or the method of standardizing the instrument. Some laboratories are known to utilize computers for control of peak switching and data collection and reduction.

APPENDIX 2

Tabulation of Data

This appendix provides a tabulation of the results reported by participating laboratories (mean of replicates given). In the appropriate cases the chemical assay results were corrected for actual uranium atomic weight, therefore the results may appear slightly different than records of the participants may indicate.

No observations have been excluded or set aside from the analysis. This policy was adhered to in order to determine a laboratory's total capability not optimal capability. Obviously some observations indicated definite problems in the analysis or preparation. A good example of such an occurrence was in laboratory Z for material 1 in the enrichment determination. In that case they reported a value with a relative difference of 7.4%. In looking at the remaining observations for material 1, however, they were consistently very good. This same laboratory had similar problems in materials 3 and 4. The virtues of not excluding these observations from the analysis are obvious. Each laboratory should carefully examine its results for similar occurrences which might show a characterization much different than only a mean and standard deviation may indicate.

In each of the tables of this appendix the mean and standard deviations of the columns appear immediately below the column.

SUMMARY OF UF₆ ASSAY DATA

Laboratory A

Material 1			Material 2		Material 3		Material 4	
<u>% UF₆</u>	<u>RD</u>		<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
99.931	-0.046		99.941	0.007	99.929	-0.025	99.935	-0.041
99.950	-0.027		99.922	-0.012	99.919	-0.035	99.900	-0.076
99.950	-0.027		99.960	0.026	99.882	-0.072	99.930	-0.046
99.966	-0.011		99.920	-0.014	99.932	-0.022	99.941	-0.035
99.950	-0.027		99.958	0.024	99.962	0.008	99.920	-0.056
99.954	-0.023		99.952	0.018	99.937	-0.017	99.940	-0.036
99.960	-0.017		99.962	0.028	99.952	-0.002	99.920	-0.056
			99.962	0.028				
			99.942	0.008				
			99.952	0.018				
			99.952	0.018				
			99.952	0.018				
			99.942	0.008				
			99.942	0.008				
			99.940	0.006				
Mean	99.952	-0.025	99.947	0.012	99.931	-0.023	99.927	-0.049
SD	0.011	0.011	0.013	0.013	0.026	0.026	0.015	0.015

SUMMARY OF UF₆ ASSAY DATA

Laboratory B

Material 1		Material 2		Material 3		Material 4	
<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
99.930	-0.047	99.912	-0.022	99.932	-0.022	99.920	-0.056
99.920	-0.057	99.952	0.018	99.912	-0.042	99.940	-0.036
99.910	-0.067	99.952	0.018	99.862	-0.092	99.900	-0.076
99.920	-0.057	99.922	-0.012	99.892	-0.062		
99.920	-0.057	99.962	0.028	99.882	-0.072		
		99.922	-0.012				
		99.922	-0.012				
		99.902	-0.032				
		99.922	-0.012				
		99.892	-0.042				
		99.912	-0.022				
		99.862	-0.072				
Mean	99.920 -0.057	99.920 -0.014	99.896 -0.058	99.920 -0.056			
SD	0.007 0.007	0.028 0.028	0.027 0.027	0.020 0.020			

SUMMARY OF UF₆ ASSAY DATA

Laboratory C

	Material 1		Material 2		Material 3		Material 4	
	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
	99.952	-0.025	99.892	-0.042	99.888	-0.066	99.888	-0.088
	99.962	-0.015	99.935	0.001	99.901	-0.053	99.897	-0.079
	99.951	-0.026	99.877	-0.057	99.873	-0.081	99.955	-0.021
	99.925	-0.052			99.926	-0.028	99.850	-0.126
					99.944	-0.010		
					99.883	-0.071		
					99.974	0.020		
					99.940	-0.014		
					99.756	-0.198		
					99.900	-0.054		
Mean	99.948	-0.029	99.902	-0.032	99.899	-0.055	99.898	-0.078
SD	0.016	0.016	0.030	0.030	0.059	0.059	0.043	0.043

SUMMARY OF UF₆ ASSAY DATA

Laboratory E

	<u>Material 1</u>		<u>Material 2</u>		<u>Material 3</u>		<u>Material 4</u>	
	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
	100.130	0.153	100.069	0.135	100.111	0.157	99.990	0.014
	99.905	-0.072	98.844	-1.091	100.044	0.090	99.925	-0.051
	99.910	-0.067	100.054	0.120	100.134	0.180	99.970	-0.006
	100.105	0.128	100.034	0.100	100.029	0.075	99.860	-0.116
	100.185	0.208	100.224	0.290	100.104	0.150	100.240	0.264
	99.855	-0.122	99.549	-0.386			100.410	0.434
	100.480	0.503						
	100.215	0.238						
	99.895	-0.082						
	99.735	-0.242						
Mean	100.041	0.064	99.796	-0.138	100.085	0.131	100.066	0.090
SD	0.221	0.221	0.519	0.520	0.045	0.045	0.213	0.213

SUMMARY OF UF₆ ASSAY DATA

Laboratory G

Material 1		Material 2		Material 3		Material 4		
<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	
99.990	0.013	99.992	0.058	100.002	0.048	99.970	-0.006	
99.990	0.013	99.942	0.008	99.972	0.018	99.990	0.014	
100.000	0.023	99.972	0.038	100.002	0.048	99.940	-0.036	
99.940	-0.037	100.002	0.068	99.992	0.038	99.970	-0.006	
99.990	0.013	99.972	0.038					
99.960	-0.017	99.992	0.058					
99.970	-0.007	99.942	0.008					
99.960	-0.017	99.962	0.028					
100.000	0.023	99.962	0.028					
99.990	0.013	99.932	-0.002					
99.970	-0.007							
99.970	-0.007							
Mean	99.978	0.001	99.967	0.033	99.992	0.038	99.968	-0.008
SD	0.019	0.019	0.024	0.024	0.014	0.014	0.021	0.021

SUMMARY OF UF₆ ASSAY DATA

Laboratory H

	Material 1		Material 2		Material 3		Material 4	
	% UF ₆	RD	% UF ₆	RD	% UF ₆	RD	% UF ₆	RD
	99.895	-0.082	100.001	0.067	99.984	0.030	99.991	0.015
	99.985	0.008	99.941	0.007	100.005	0.051	99.975	-0.001
	99.991	0.014	99.986	0.052	99.986	0.032	99.981	0.005
	99.994	0.017	99.986	0.052	99.943	-0.011	99.944	-0.032
	99.991	0.014	99.977	0.043	99.965	0.011	99.981	0.005
	99.996	0.019	99.987	0.053	99.986	0.032		
	99.951	-0.026						
	99.984	0.007						
	99.985	0.008						
	99.988	0.011						
	99.962	-0.015						
	99.999	0.022						
	99.979	0.002						
	99.987	0.010						
	99.993	0.016						
Mean	99.979	0.002	99.980	0.046	99.978	0.024	99.974	-0.002
SD	0.026	0.026	0.020	0.020	0.021	0.021	0.018	0.018

SUMMARY OF UF₆ ASSAY DATA

Laboratory I

	<u>Material 1</u>		<u>Material 2</u>		<u>Material 3</u>		<u>Material 4</u>	
	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
	100.000	0.023	99.992	0.058	100.022	0.068	99.890	-0.086
	101.383	1.407	99.943	0.009	99.804	-0.150	99.965	-0.011
	99.829	-0.148	100.000	0.066	99.806	-0.148	99.794	-0.182
	99.792	-0.185	99.719	-0.216	99.922	-0.032	100.408	0.432
			99.870	-0.064	99.739	-0.215	99.842	-0.134
							100.178	0.202
Mean	100.251	0.274	99.905	-0.029	99.859	-0.095	100.013	0.037
SD	0.760	0.760	0.116	0.116	0.113	0.113	0.236	0.236

SUMMARY OF UF₆ ASSAY DATA

Laboratory J

Material 1		Material 2		Material 3		Material 4	
<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
99.870	-0.107	98.774	-1.161	100.099	0.145	99.930	-0.046
99.905	-0.072	99.954	0.020	100.094	0.140	99.995	0.019
99.940	-0.037	99.974	0.040	99.839	-0.115	99.955	-0.021
100.030	0.053	99.994	0.060	99.184	-0.770	100.030	0.054
99.970	-0.007	100.054	0.120	99.964	0.010	99.935	-0.041
100.060	0.083	99.904	-0.030	99.999	0.045	99.860	-0.116
99.925	-0.052	100.009	0.075	100.109	0.155		
		100.079	0.145				
		99.994	0.060				
		99.934	0				
		99.946	0.012				
		99.972	0.038				
		99.899	-0.035				
		99.969	0.035				
		99.919	-0.015				
Mean	99.957 -0.020	99.892 -0.042	99.898 -0.056	99.951 -0.025			
SD	0.068 0.068	0.313 0.314	0.329 0.330	0.059 0.059			

SUMMARY OF UF₆ ASSAY DATA

Laboratory K

	Material 1		Material 2		Material 3		Material 4	
	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
	99.880	-0.097	99.992	0.058	100.042	0.088	99.990	0.014
	99.900	-0.077	99.892	-0.042	99.802	-0.152	99.970	-0.006
	99.870	-0.107	99.862	-0.072	99.922	-0.032		
	99.920	-0.057	99.962	0.028				
			99.932	-0.002				
			99.892	-0.042				
Mean	99.892	-0.085	99.922	-0.012	99.922	-0.032	99.980	0.004
SD	0.022	0.022	0.049	0.049	0.120	0.120	0.014	0.014

SUMMARY OF UF₆ ASSAY DATA

Laboratory L

	Material 1		Material 2		Material 3		Material 4	
	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
	99.946	-0.031	99.820	-0.115	99.988	0.034	99.975	-0.001
	99.962	-0.015	99.965	0.031	99.954	0	100.000	0.024
	99.912	-0.065	99.980	0.046	99.957	0.003	99.952	-0.024
	99.910	-0.067	100.023	0.089	100.012	0.058	99.987	0.011
	99.963	-0.014	99.988	0.054				
	100.002	0.025						
	99.977	0						
	100.008	0.031						
Mean	99.960	-0.017	99.955	0.021	99.978	0.024	99.979	0.003
SD	0.037	0.037	0.079	0.079	0.028	0.028	0.020	0.020

SUMMARY OF UF₆ ASSAY DATA

Laboratory N

Material 1		Material 2		Material 3		Material 4	
<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
99.958	-0.019	100.000	-0.066	99.395	-0.559	99.243	-0.734
100.040	0.063	100.022	0.088	100.048	0.094	100.015	0.039
99.982	0.005	99.960	0.026	100.048	0.094	99.950	-0.026
99.990	0.013	100.062	0.128	99.990	0.036	99.910	-0.066
		99.915	-0.020	99.890	-0.064	99.925	-0.051
		100.035	0.101	99.838	-0.116	99.970	-0.006
				99.945	-0.009	99.978	0.002
				99.962	0.008	99.962	-0.014
				99.968	0.014	99.978	0.002
				99.905	-0.049	99.980	0.004
				100.010	0.056		
Mean	99.992 0.015	99.999 0.065		99.909 -0.045		99.891 -0.085	
SD	0.034 0.034	0.054 0.054		0.182 0.182		0.230 0.230	

SUMMARY OF UF₆ ASSAY DATA

Laboratory P

Material 1			Material 2			Material 3			Material 4		
<u>% UF₆</u>	<u>RD</u>		<u>% UF₆</u>	<u>RD</u>		<u>% UF₆</u>	<u>RD</u>		<u>% UF₆</u>	<u>RD</u>	
100.390	0.413		99.774	-0.161		100.444	0.490		100.100	0.124	
100.435	0.458		100.199	0.265		100.354	0.400		100.650	0.674	
100.510	0.533		100.334	0.400		100.469	0.515		100.350	0.374	
101.370	1.394		99.854	-0.080		99.439	-0.515		100.133	0.157	
100.530	0.553		100.104	0.170		99.704	-0.250		100.700	0.724	
101.550	1.574		99.874	-0.060		99.519	-0.435		99.233	-0.744	
100.340	0.363		98.934	-1.001		99.259	-0.695		100.225	0.249	
99.300	-0.677										
101.467	1.491										
99.500	-0.477										
99.400	-0.577										
99.100	-0.877										
99.520	-0.457										
99.745	-0.232										
99.775	-0.202										
Mean											
SD											
100.195	0.218		99.868	-0.066		99.884	-0.070		100.199	0.223	
0.807	0.807		0.459	0.459		0.521	0.521		0.487	0.487	

SUMMARY OF UF₆ ASSAY DATA

Laboratory R

Material 1		Material 2		Material 3		Material 4		
% UF ₆	RD	% UF ₆	RD	% UF ₆	RD	% UF ₆	RD	
99.970	-0.007	99.942	0.008	99.942	-0.012	99.990	0.014	
99.950	-0.027	99.942	0.008	100.032	-0.078	100.050	0.074	
100.050	0.073	100.102	0.168	99.952	-0.002	99.950	-0.026	
100.020	0.043	99.942	0.008	99.972	0.018	99.980	0.004	
100.070	0.093	99.982	0.048	99.992	0.038	100.100	0.124	
100.000	0.023	100.002	0.068	99.952	-0.002	100.020	0.044	
100.000	0.023	99.982	0.048	100.002	0.048	99.980	0.004	
						99.990	0.014	
						100.000	0.024	
						100.000	0.024	
						99.990	0.014	
						99.870	-0.106	
						99.890	-0.086	
						99.980	0.004	
Mean	100.009	0.032	99.985	0.051	99.978	0.024	99.985	0.009
SD	0.042	0.042	0.057	0.057	0.033	0.033	0.057	0.057

SUMMARY OF UF₆ ASSAY DATA

Laboratory T

Material 1		Material 2		Material 3		Material 4		
<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	
100.067	0.090	100.054	0.120	100.075	0.121	100.073	0.097	
100.147	0.170	100.084	0.150	100.089	0.135	100.073	0.097	
100.040	0.063	100.119	0.185	100.006	0.052	100.110	0.134	
100.116	0.139	100.009	0.075	99.955	0.001	100.023	0.047	
100.000	0.023	100.059	0.125	100.102	0.148	99.943	-0.033	
100.063	0.086	100.096	0.162	100.015	0.061	100.077	0.101	
		100.015	0.081	100.155	0.201	100.117	0.141	
		100.109	0.175					
		100.267	0.333					
		100.019	0.085					
		100.269	0.335					
		100.015	0.081					
		100.215	0.281					
		100.145	0.211					
Mean	100.072	0.095	100.106	0.172	100.057	0.103	100.059	0.083
SD	0.053	0.053	0.090	0.090	0.068	0.068	0.060	0.060

SUMMARY OF UF₆ ASSAY DATA

Laboratory W

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Material 1			Material 2		Material 3		Material 4	
<u>% UF₆</u>	<u>RD</u>		<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
97.898	-2.079		99.830	-0.105	99.352	-0.602	100.131	0.155
99.091	-0.886		100.328	0.394	100.195	0.241	100.501	0.525
100.142	0.165		100.530	0.596	99.608	-0.346	100.471	0.495
100.075	0.098		100.000	0.066	99.643	-0.311	100.255	0.279
100.050	0.073		99.985	0.051	100.176	0.222	99.925	-0.051
100.100	0.123		100.210	0.276	100.131	0.177	100.010	0.034
100.020	0.043		99.920	-0.015	100.062	0.108	99.650	-0.326
					100.392	0.438		
					99.985	0.031		
					100.150	0.196		
					100.175	0.221		
					99.980	0.026		
					100.040	0.086		
					99.755	-0.199		
					100.035	0.081		
Mean	99.625	-0.352	100.115	0.180	99.979	0.025	100.135	0.159
SD	0.847	0.847	0.250	0.250	0.274	0.275	0.304	0.304

SUMMARY OF UF₆ ASSAY DATA

Laboratory Y

Material 1		Material 2		Material 3		Material 4	
<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>	<u>% UF₆</u>	<u>RD</u>
100.001	0.024	99.893	-0.041	99.980	0.026	99.988	0.012
99.983	0.006	99.951	0.017	100.251	0.297	99.983	0.007
99.994	0.017	100.009	0.075	100.011	0.057	99.996	0.020
99.957	-0.020	99.771	-0.163	99.951	-0.003	100.003	0.027
99.946	-0.031					99.917	-0.059
						100.011	0.035
						99.992	0.016
						99.966	-0.010
						99.926	-0.050
						99.856	-0.120
						99.918	-0.058
Mean	99.976 -0.001	99.906 -0.028	100.048 0.094	99.960 -0.016			
SD	0.024 0.024	0.102 0.102	0.137 0.137	0.049 0.049			

Laboratory A

	Material 1		Material 2		Material 3		Material 4	
	$\delta^{235}\text{U}$	RD	$\delta^{235}\text{U}$	RD	$\delta^{235}\text{U}$	RD	$\delta^{235}\text{U}$	RD
	0.7107	-0.0281	1.7230	0.0058	1.7140	0.0934	0.7094	0.0282
	0.7110	0.0141	1.7230	0.0058	1.7120	-0.0234	0.7091	-0.0141
	0.7110	0.0141	1.7240	0.0638	1.7110	-0.0818	0.7093	0.0141
	0.7109	0	1.7240	0.0638	1.7120	-0.0234	0.7092	0
	0.7108	-0.0141	1.7220	-0.0522	1.7110	-0.0818	0.7095	0.0423
	0.7108	-0.0141	1.7230	0.0058	1.7120	-0.0234	0.7091	-0.0141
	0.7109	0	1.7230	0.0058	1.7120	-0.0234	0.7090	-0.0282
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
			1.7220	-0.0522				
Mean	0.7109	-0.0040	1.7225	-0.0232	1.7120	-0.0234	0.7092	0.0040
SD	0.0001	0.0157	0.0007	0.0431	0.0010	0.0584	0.0002	0.0254

SUMMARY OF ENRICHMENT DATA

Laboratory B

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.6920	-2.6586	1.7060	-0.9809	1.6990	-0.7825	0.6930	-2.2843
	0.6940	-2.3773	1.7140	-0.5166	1.7280	0.9110	0.6950	-2.0023
	0.7140	0.4361	1.7110	-0.6907	1.7045	-0.4613	0.6960	-1.8612
	0.7180	0.9987	1.7180	-0.2844	1.7055	-0.4029	0.7180	1.2408
	0.7125	0.2251	1.7120	-0.6327	1.7140	0.0934		
			1.7100	-0.7487				
			1.7300	0.4121				
			1.7280	0.2960				
			1.7110	-0.6907				
			1.7170	-0.3424				
			1.7225	-0.0232				
			1.7280	0.2960				
			1.7290	0.3541				
Mean	0.7061	-0.6752	1.7182	-0.2728	1.7102	-0.1285	0.7005	-1.2267
SD	0.0121	1.7087	0.0084	0.4867	0.0113	0.6602	0.0117	1.6544

SUMMARY OF ENRICHMENT DATA

Laboratory E

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7250	1.9834	1.7150	-0.4585	1.7110	-0.0818	0.7250	2.2279
	0.7290	2.5461	1.7210	-0.1103	1.7080	-0.2570	0.7200	1.5228
	0.7310	2.8274	1.7060	-0.9809	1.6940	-1.0745	0.7330	3.3559
	0.7340	3.2494	1.7240	0.0638	1.7000	-0.7241	0.7330	3.3559
	0.7230	1.7021	1.7170	-0.3424	1.7110	-0.0818	0.7200	1.5228
	0.7170	0.8581	1.7100	-0.7487	1.7090	-0.1986	0.7220	1.8048
	0.7260	2.1241	1.7250	0.1219	1.7190	0.3854	0.7170	1.0998
	0.7240	1.8427						
	0.7250	1.9834						
	0.7190	1.1394						
	0.7160	0.7174						
	0.7180	0.9987						
	0.7180	0.9987						
	0.7240	1.8427						
Mean	0.7235	1.7724	1.7169	-0.3483	1.7074	-0.2920	0.7243	2.1272
SD	0.0055	0.7680	0.0071	0.4124	0.0081	0.4754	0.0064	0.9055

SUMMARY OF ENRICHMENT DATA

Laboratory F

		<u>Material 1</u>		<u>Material 2</u>		<u>Material 3</u>		<u>Material 4</u>	
		<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
65		0.7100	-0.1266	1.7130	-0.5746	1.7110	-0.0818	0.7120	0.3948
		0.7150	0.5767			1.7010	-0.6657	0.7110	0.2538
						1.6960	-0.9577	0.7080	-0.1692
						1.7100	-0.1402	0.7110	0.2538
	Mean	0.7125	0.2251	1.7130	-0.5746	1.7045	-0.4613	0.7105	0.1833
	SD	0.0035	0.4973			0.0072	0.4225	0.0017	0.2442

SUMMARY OF ENRICHMENT DATA

Laboratory G

	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7111	0.0281	1.7231	0.0116	1.7120	-0.0234	0.7093	0.0141
	0.7110	0.0141	1.7226	-0.0174	1.7125	0.0058	0.7094	0.0282
	0.7111	0.0281	1.7226	-0.0174	1.7123	-0.0058	0.7092	0
	0.7112	0.0422	1.7226	-0.0174	1.7120	-0.0234	0.7094	0.0282
	0.7112	0.0422	1.7230	0.0058	1.7127	0.0175	0.7093	0.0141
	0.7111	0.0281	1.7228	-0.0058	1.7122	-0.0117	0.7092	0
	0.7110	0.0141	1.7228	-0.0058				
	0.7111	0.0281	1.7226	-0.0174				
	0.7110	0.0141	1.7231	0.0116				
	0.7111	0.0281	1.7228	-0.0058				
	0.7111	0.0281	1.7288	0.3424				
	0.7110	0.0141	1.7228	-0.0058				
Mean	0.7111	0.0281	1.7233	0.0232	1.7123	-0.0058	0.7093	0.0141
SD	0.0001	0.0101	0.0017	0.1011	0.0003	0.0163	0.0001	0.0126

SUMMARY OF ENRICHMENT DATA

Laboratory H

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7109	0	1.7224	-0.0290	1.7115	-0.0526	0.7093	0.0141
	0.7110	0.0141	1.7225	-0.0232	1.7118	-0.0350	0.7092	0
	0.7110	0.0141	1.7229	0	1.7123	-0.0058	0.7091	-0.0141
	0.7109	0	1.7226	-0.0174	1.7123	-0.0058	0.7090	-0.0282
	0.7110	0.0141	1.7226	-0.0174	1.7122	-0.0117	0.7092	0
	0.7110	0.0141	1.7227	-0.0116	1.7124	0	0.7092	0
	0.7111	0.0282	1.7228	-0.0058	1.7124	0	0.7090	-0.0282
	0.7109	0						
	0.7110	0.0141						
	0.7110	0.0141						
	0.7109	0						
	0.7109	0						
	0.7110	0.0141						
	0.7108	-0.0141						
	0.7108	-0.0141						
Mean	0.7109	0.0066	1.7226	-0.0174	1.7121	-0.0175	0.7091	-0.0141
SD	0.0001	0.0117	0.0002	0.0100	0.0003	0.0201	0.0001	0.0160

SUMMARY OF ENRICHMENT DATA

Laboratory J

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	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7116	0.1055	1.7240	0.0638	1.7125	0.0058	0.7093	0.0141
	0.7123	0.1969	1.7220	-0.0522	1.7135	0.0642	0.7089	-0.0423
	0.7110	0.0141	1.7215	-0.0813	1.7115	-0.0526	0.7104	0.1622
	0.7106	-0.0352	1.7205	-0.1393	1.7135	0.0642	0.7100	0.1058
	0.7109	0	1.7235	0.0348	1.7140	0.0934	0.7097	0.0705
	0.7106	-0.0422	1.7240	0.0638	1.7120	-0.0234	0.7089	-0.0423
	0.7110	0.0070	1.7215	-0.0813	1.7130	0.0350	0.7096	0.0494
			1.7230	0.0058				
			1.7230	0.0058				
			1.7240	0.0638				
			1.7235	0.0348				
			1.7235	0.0348				
			1.7225	-0.0232				
			1.7220	-0.0522				
			1.7220	-0.0522				
Mean	0.7112	0.0422	1.7227	-0.0116	1.7129	0.0292	0.7095	0.0423
SD	0.0006	0.0861	0.0011	0.0628	0.0009	0.0525	0.0005	0.0756

SUMMARY OF ENRICHMENT DATA

		Laboratory K							
		Material 1		Material 2		Material 3		Material 4	
		<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
		0.7103	-0.0844	1.7236	0.0406	1.7125	0.0058	0.7086	-0.0846
		0.7103	-0.0844	1.7223	-0.0348	1.7125	0.0058	0.7095	0.0423
		0.7108	-0.0141	1.7238	0.0522	1.7121	-0.0175	0.7088	-0.0564
		0.7104	-0.0703	1.7234	0.0290	1.7134	0.0584	0.7091	-0.0141
		0.7106	-0.0422	1.7237	0.0464	1.7127	0.0175	0.7089	-0.0423
		0.7106	-0.0422	1.7232	0.0174	1.7129	0.0292	0.7089	-0.0423
		0.7106	-0.0422	1.7237	0.0464	1.7134	0.0584	0.7091	-0.0141
				1.7241	0.0697				
				1.7236	0.0406				
				1.7240	0.0638				
				1.7227	-0.0116				
				1.7232	0.0174				
				1.7238	0.0522				
				1.7237	0.0464				
				1.7239	0.0580				
Mean		0.7105	-0.0563	1.7235	0.0348	1.7128	0.0234	0.7090	-0.0282
SD		0.0002	0.0262	0.0005	0.0284	0.0005	0.0283	0.0003	0.0402

SUMMARY OF ENRICHMENT DATA

Laboratory L

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7150	0.5767	1.7410	1.0506	1.7350	1.3198	0.7110	0.2538
	0.7150	0.5767	1.7300	0.4121	1.7130	0.0350	0.7080	-0.1692
	0.7150	0.5767	1.7570	1.9792	1.7160	0.2102	0.7180	1.2408
	0.7160	0.7174	1.7200	-0.1683	1.7110	-0.0818	0.7150	0.8178
	0.7210	1.4207	1.7120	-0.6327				
	0.7130	0.2954						
	0.7000	-1.5333						
	0.7110	0.0141						
Mean	0.7132	0.3235	1.7320	0.5282	1.7188	0.3737	0.7130	0.5358
SD	0.0061	0.8532	0.0177	1.0277	0.0110	0.6439	0.0044	0.6200

SUMMARY OF ENRICHMENT DATA

Laboratory N

Material 1		Material 2		Material 3		Material 4	
<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
0.7111	0.0281	1.7250	0.1219	1.7148	0.1402	0.7089	-0.0423
0.7111	0.0281	1.7255	0.1509	1.7150	0.1518	0.7093	0.0141
0.7111	0.0281	1.7250	0.1219	1.7123	-0.0058	0.7094	0.0282
0.7109	0	1.7256	0.1567	1.7143	0.1110	0.7093	0.0141
0.7113	0.0563	1.7251	0.1277	1.7140	0.0934	0.7093	0.0141
0.7112	0.0422			1.7150	0.1518	0.7092	0
				1.7150	0.1518	0.7090	-0.0282
				1.7153	0.1694	0.7098	0.0846
				1.7154	0.1752	0.7099	0.0987
				1.7154	0.1752	0.7097	0.0705
				1.7161	0.2161	0.7095	0.0423
				1.7163	0.2278	0.7095	0.0423
Mean	0.7111 0.0281	1.7252 0.1335	1.7149 0.1460	0.7094 0.0282			
SD	0.0001 0.0187	0.0003 0.0167	0.0010 0.0611	0.0003 0.0425			

SUMMARY OF ENRICHMENT DATA

Laboratory P

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7110	0.0141	1.7260	0.1799	1.7130	0.0350	0.7110	0.2538
	0.7100	-0.1266	1.7260	0.1799	1.7150	0.1518	0.7095	0.0423
	0.7100	-0.1266	1.7340	0.6443	1.7150	0.1518	0.7095	0.0423
	0.7210	1.4207	1.7260	0.1799	1.7150	0.1518	0.7091	-0.0141
	0.7110	0.0141	1.7260	0.1799	1.7130	0.0350	0.7090	-0.0282
	0.7105	-0.0563	1.7250	0.1219	1.7150	0.1518	0.7112	0.2820
	0.7110	0.0141			1.6690	-2.5344	0.7096	0.0564
	0.7200	1.2801						
	0.7110	0.0141						
	0.7108	-0.0141						
	0.7088	-0.2954						
	0.7112	0.0422						
	0.7103	-0.0844						
	0.7099	-0.1407						
	0.7162	0.7455						
Mean	0.7122	0.1829	1.7272	0.2496	1.7079	-0.2628	0.7098	0.0846
SD	0.0037	0.5264	0.0034	0.1957	0.0172	1.0021	0.0009	0.1253

SUMMARY OF ENRICHMENT DATA

Laboratory S

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7086	-0.3292	1.7247	0.1022	1.7133	0.0508	0.7065	-0.3751
	0.7090	-0.2715	1.7269	0.2316	1.7149	0.1454	0.7080	-0.1650
	0.7090	-0.2715	1.7342	0.6588	1.7168	0.2558	0.7082	-0.1410
	0.7100	-0.1308	1.7337	0.6257	1.7167	0.2534	0.7080	-0.1763
	0.7100	-0.1322	1.7332	0.5961	1.7220	0.5583	0.7085	-0.1001
	0.7099	-0.1435	1.7346	0.6768	1.7216	0.5343	0.7078	-0.1918
	0.7097	-0.1632	1.7344	0.6681	1.7212	0.5168	0.7077	-0.2143
							0.7079	-0.1777
							0.7080	-0.1720
							0.7079	-0.1833
							0.7076	-0.2186
							0.7082	-0.1466
							0.7082	-0.1466
							0.7085	-0.1015
							0.7077	-0.2143
Mean	0.7094	-0.2110	1.7317	0.5108	1.7181	0.3329	0.7079	-0.1833
SD	0.0006	0.0822	0.0041	0.2379	0.0035	0.2050	0.0005	0.0647

SUMMARY OF ENRICHMENT DATA

Laboratory T

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7102	-0.0985	1.7218	-0.0638	1.7129	0.0292	0.7087	-0.0705
	0.7102	-0.0985	1.7236	0.0406	1.7134	0.0584	0.7082	-0.1410
	0.7103	-0.0844	1.7237	0.0464	1.7123	-0.0058	0.7085	-0.0987
	0.7102	-0.0985	1.7223	-0.0348	1.7129	0.0292	0.7087	-0.0705
	0.7106	-0.0422	1.7234	0.0290	1.7123	-0.0058	0.7087	-0.0705
	0.7100	-0.1266	1.7229	0	1.7119	-0.0292	0.7095	0.0423
	0.7107	-0.0281	1.7228	-0.0058	1.7124	0	0.7086	-0.0846
			1.7226	-0.0174				
			1.7224	-0.0290				
			1.7232	0.0174				
			1.7226	-0.0174				
			1.7225	-0.0232				
			1.7228	-0.0058				
			1.7234	0.0290				
			1.7242	0.0755				
Mean	0.7103	-0.0844	1.7230	0.0058	1.7126	0.0117	0.7087	-0.0705
SD	0.0002	0.0349	0.0006	0.0366	0.0005	0.0295	0.0004	0.0558

SUMMARY OF ENRICHMENT DATA

Laboratory U

	<u>Material 1</u>		<u>Material 2</u>		<u>Material 3</u>		<u>Material 4</u>	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7102	-0.0985	1.7228	-0.0058	1.7120	-0.0234	0.7086	-0.0846
	0.7102	-0.0985	1.7221	-0.0464	1.7121	-0.0175	0.7085	-0.0987
	0.7102	-0.0985	1.7220	-0.0522	1.7128	0.0234	0.7085	-0.0987
	0.7104	-0.0703	1.7228	-0.0058	1.7127	0.0175	0.7085	-0.0987
	0.7104	-0.0703	1.7233	0.0232	1.7124	0	0.7084	-0.1128
	0.7102	-0.0985	1.7224	-0.0290	1.7125	0.0058	0.7083	-0.1269
	0.7101	-0.1125	1.7228	-0.0058	1.7126	0.0117	0.7086	-0.0846
					1.7122	-0.0117		
					1.7124	0		
					1.7120	-0.0234		
					1.7125	0.0058		
					1.7131	0.0409		
					1.7122	-0.0117		
					1.7119	-0.0292		
					1.7118	-0.0350		
Mean	0.7102	-0.0985	1.7226	-0.0174	1.7124	-0.0031	0.7085	-0.0987
SD	0.0001	0.0159	0.0005	0.0266	0.0004	0.0213	0.0001	0.0151

SUMMARY OF ENRICHMENT DATA

Laboratory V

<u>Material 1</u>	
<u>^{235}U</u>	<u>RD</u>
0.7113	0.0563
0.7112	0.0422
0.7113	0.0563

Material 4	
<u>235U</u>	<u>RD</u>
0.7093	0.0141
0.7095	0.0423
0.7096	0.0564
0.7096	0.0564
0.7097	0.0705
0.7096	0.0564
0.7096	0.0564
0.7096	0.0564
0.0001	0.0179

76

Mean	0.7113	0.0563
SD	0.0001	0.0081

SUMMARY OF ENRICHMENT DATA

Laboratory W

Material 1			Material 2			Material 3			Material 4		
<u>%²³⁵U</u>		<u>RD</u>	<u>%²³⁵U</u>		<u>RD</u>	<u>%²³⁵U</u>		<u>RD</u>	<u>%²³⁵U</u>		<u>RD</u>
0.7050	-0.8299		1.7120	-0.6327		1.6950	-1.0161		0.7140	0.6768	
0.7060	-0.6893		1.7030	-1.1550		1.6790	-1.9505		0.7030	-0.8742	
0.7060	-0.6893		1.7000	-1.3292		1.6800	-1.8921		0.7050	-0.5922	
0.6960	-2.0959		1.6960	-1.5613		1.6740	-2.2425		0.7050	-0.5922	
0.7110	0.0141		1.7120	-0.6327		1.6820	-1.7753		0.7080	-0.1692	
0.7300	2.6867		1.7920	4.0107		1.7020	-0.6073		0.7260	2.3689	
0.7310	2.8274		1.7660	2.5016		1.7000	-0.7241		0.7340	3.4969	
						1.7090	-0.1986				
						1.6950	-1.0161				
						1.6730	-2.3009				
						1.6640	-2.8264				
						1.7050	-0.4321				
						1.7780	3.8309				
						1.7760	3.7141				
						1.7760	3.7141				
Mean	0.7121	0.1688	1.7259	0.1741		1.7059	-0.3796		0.7136	0.6204	
SD	0.0133	1.8722	0.0375	2.1785		0.0389	2.2696		0.0120	1.6896	

SUMMARY OF ENRICHMENT DATA

Laboratory Y

	<u>Material 1</u>		<u>Material 2</u>		<u>Material 3</u>		<u>Material 4</u>	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7100	-0.1266	1.7220	-0.0522	1.7150	0.1518	0.7090	-0.0282
	0.7120	0.1547	1.7250	0.1219	1.7110	-0.0818	0.7050	-0.5922
	0.7090	-0.2673	1.7310	0.4701	1.7110	-0.0818	0.7110	0.2538
	0.7120	0.1547	1.7190	-0.2264	1.6820	1.7753	0.7120	0.3948
	0.7110	0.0141	1.7040	-1.0970	1.7200	0.4438	0.7140	0.6768
	0.7090	-0.2673	1.7260	0.1799	1.7180	0.3270	0.7090	-0.0282
	0.7180	0.9987	1.7300	0.4121	1.7190	0.3854	0.7120	0.3948
	0.7140	0.4361						
	0.7160	0.7174						
	0.7140	0.4361						
	0.7090	-0.2673						
	0.7100	-0.1266						
	0.7100	-0.1266						
	0.7130	0.2954						
	0.7100	-0.1266						
Mean	0.7118	0.1266	1.7224	-0.0290	1.7109	-0.0876	0.7103	0.1551
SD	0.0027	0.3841	0.0091	0.5308	0.0132	0.7728	0.0029	0.4128

SUMMARY OF ENRICHMENT DATA

Laboratory Z

	Material 1		Material 2		Material 3		Material 4	
	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>	<u>%²³⁵U</u>	<u>RD</u>
	0.7104	-0.0731	1.7251	0.1300	1.7144	0.1162	0.7104	0.1678
	0.7634	7.3780	1.7246	0.0975	1.6786	-1.9744	0.7087	-0.0747
	0.7105	-0.0535	1.7247	0.1051	1.7143	0.1115	0.7086	-0.0874
	0.7102	-0.0985	1.7241	0.0702	1.7145	0.1244	0.7412	4.5079
	0.7104	-0.0703	1.7248	0.1103	1.7146	0.1285	0.7105	0.1777
	0.7103	-0.0844	1.7252	0.1335			0.7088	-0.0620
			1.7246	0.0987			0.7086	-0.0804
							0.7086	-0.0846
							0.7085	-0.1043
							0.7086	-0.0846
							0.7088	-0.0620
							0.7088	-0.0564
							0.7089	-0.0423
							0.7088	-0.0564
Mean	0.7192	1.1675	1.7247	0.1045	1.7073	-0.2978	0.7113	0.2961
SD	0.0216	3.0431	0.0004	0.0214	0.0160	0.9367	0.0086	1.2174

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