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Spent-Fuel Composition:

A Comparison of Predicted and Measured Data

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SPENT-FUEL COMPOSITION: A COMPARISON OF PREDICTED AND MEASURED DATA

by

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ABSTRACT

The uncertainty in predictions of the nuclear materials content of spent light-water reactor fuel was investigated to obtain guidelines for nondestructive spent-fuel verification and assay. Values predicted by the reactor operator were compared with measured values from fuel reprocessors for six reactors (three PWR and three BWR). The study indicates that total uranium, total plutonium, fissile uranium, fissile plutonium, and total fissile content can be predicted with biases ranging from 1-6% and variabilities (1-σ) ranging from 2-7%. The higher values generally are associated with BWRs. Based on the results of this study, nondestructive assay measurements that are accurate and precise to 5-10% (1σ) or better should be useful for quantitative analyses of typical spent fuel.

I. INTRODUCTION

In future away-from-reactor (AFR) storage facilities, spent fuel will be stored for extended periods prior to permanent disposal or reprocessing. Nondestructive measurements on spent fuel are being developed[1] for timely verification of the reactor operator's predicted values of burnup, cooling time, and fissile content. Verification of the reactor operator's predicted values will be necessary at AFR storage facilities to satisfy safeguards and operational requirements.

An investigation of the precision and accuracy of operator-predicted values of nuclear materials content of spent fuel was undertaken to establish guidelines for nondestructive assay (NDA) development efforts. The question to be resolved by the study was what precision and accuracy would be required for NDA measurements on spent fuel for them to be of comparable quality with reactor calculations.

II. DATA BASE

Data for the study were obtained from several sources,[2-4] and data sets were selected for which reactor operator's predicted values could be correlated with reprocessor's measured values. Data sets meeting this requirement that included more than five reprocessing batches are shown in Table I. The data comprise 6 reactors (3 PWR and 3 BWR), 7 reactor cores, fuel burnup ranging from 1300 to 27 000 MWD/tU, 3 reprocessors, and 104 reprocessing batches.

With the exception of the Japanese Power Demonstration Reactor (JPDR) measured values, duplicate analytical results were available for most of the reprocessing batches. The duplicate analyses were performed by independent laboratories. The reprocessor's values agreed well with those obtained by the referee laboratories for the batches reprocessed at Nuclear Fuel Services (NFS) - West Valley. Thus, we used the average of the values obtained by NFS and Nuclear Audit and Testing Company (NATCO) as the measured values for the NFS reprocessed cores. The Sena Core-2 data, taken from Beets et al.,[4] include Oak Ridge National Laboratory (ORNL) measurements of uranium isotopic abundances and Eurochemic measurements of plutonium isotopic abundances. Trino Core-1 and -2 data were taken from the ISTLIB[2] data base. The uranium and plutonium isotopic abundances for Trino Core 1 were determined by Eurochemic and ORNL, whereas the measured values for Core 2 were determined by Eurochemic.

All of the measured plutonium values were corrected for ^{241}Pu decay for the time between reactor discharge and measurement. The PNC-Tokai and Eurochemic reprocessing measurements also were corrected for mixing from the previous reprocessing batch heel. Heel corrections were not made by NFS because the heels were small (a few liters) and the correction was thought to be negligible.

Raw data for the seven reactor cores are shown in Tables II-VIII. The first row of data for each reprocessing batch contains the reactor operator-predicted (calculated) values, and the second row contains the reprocessor-measured values (corrected for ^{241}Pu decay).

III. COMPARISON OF PREDICTED AND MEASURED SPENT-FUEL PARAMETERS

The data were used to calculate relative predicted-measured differences for the following spent-fuel parameters: (1) total uranium, (2) total plutonium, (3) fissile uranium (^{235}U), (4) fissile plutonium (^{239}Pu and ^{241}Pu), and (5) total fissile (^{239}Pu, ^{241}Pu, and ^{235}U). The relative difference is defined as:

$$\text{Relative Difference (\%)} = \left(\frac{\text{Predicted - Measured}}{\text{Measured}}\right)100 \quad . \qquad (1)$$

Because predicted values of plutonium isotopic abundances were not available, comparisons of fissile plutonium and total fissile content could not be made for Sena Core 2.

Relative differences for each of the five spent-fuel parameters are shown in Figs. 1-5. Each point in each plot corresponds to a single reprocessing batch.* Relative differences in total uranium (Fig. 1) tend to be evenly distributed around zero, whereas relative differences in total plutonium (Fig. 2) tend to be

*The high and low JPDR data points have been omitted from the figures to provide better resolution of the remaining data points.

biased positive. The ^{235}U differences (Fig. 3) tend to be negative, in contrast to the ^{239}Pu plus ^{241}Pu differences (Fig. 4), which tend to be positive. Relative differences in total fissile values (Fig. 5), like those for total uranium, tend to be evenly distributed about zero. The JPDR data exhibit the largest spread of any reactor for each of the five parameters.

Sample values of the mean, standard deviation, and range for each parameter and each reactor core are presented in Table IX. Mean burnup, burnup range, and the number of reprocessing batches also are listed in Table IX. The results were also pooled by reactor type and for all reactors. The pooled data are presented in Tables X-A and B. Because of the variability exhibited by the JPDR data, a set of pooled results eliminating the JPDR values is also included. As expected, elimination of the JPDR data decreases the sample standard deviations. The absence of predicted plutonium isotopic abundances for Sena Core 2 decreases the number of datum points used in the pooled comparisons of total fissile and fissile plutonium content.

The pooled data were tested (Table XI) for the presence of relative bias using Student's t test. Comparisons of the calculated t values with the critical values for $\alpha = 0.01$ and a two-tailed test support the following conclusions.

- There is no significant difference between the predicted and measured total uranium content.
- There is a significant positive bias between the predicted and measured total plutonium content.
- There is a significant negative bias between the predicted and measured ^{235}U content.
- There is a significant positive bias between the predicted and measured fissile plutonium content for the pooled PWR and for the pooled PWR and BWR data (with and without JPDR). Variability in the JPDR data masks possible biases between the predicted and measured data for the BWRs. A negative bias is, in fact, obtained between the predicted and measured fissile plutonium content for the BWRs if the JPDR data are eliminated.

- The pooled data for PWRs and BWRs, excluding the JPDR data, show a significant negative bias for the total fissile content.

IV. DISCUSSION

It is reasonable that for all except the JPDR data the significant differences observed between reactor operator's and reprocessor's values are caused primarily by inaccurate reactor predictions. This is plausible because the analytical chemistry and mass-spectrometric methods should be more accurate and precise than is indicated by the observed differences, and, for all but the JPDR data, there are independent confirmatory measurements that agree well with the reprocessor's data.

Under the hypothesis that most of the observed differences are caused by inaccurate burnup calculations, we restate the conclusions of this study as follows.

- Total uranium content of spent fuel can be predicted with a positive bias of 1% or less and a variability (1σ) of 2-4%.
- Total plutonium content can be predicted with a positive bias of 3-5% and a varability (1σ) of 4-6%.
- Fissile uranium (^{235}U) content can be predicted with a negative bias of 3-4% and a variability (1σ) of 4-6%.
- Fissile plutonium (^{239}Pu + ^{241}Pu) can be predicted with a bias of -1 to +6% and a variability (1σ) of 3-7%.
- Total fissile content can be predicted to 1-3% (possible negative bias) with a variability (1σ) of 3-6%.

In most cases the larger values of the ranges quoted for accuracy and precision are associated with BWRs and the lower values with PWRs. Also, it is important to note that there are two obvious outliers in the JPDR data and possible outliers in the other data sets. Considering only total uranium and plutonium and neglecting the JPDR data, a range of $\sim$10% is observed in the PWR data and of ∿20% in the BWR data. Differences might be even larger for individual fuel assemblies because each reprocessing batch consists of two or more assemblies so that there is some averaging of the assembly data.

It is also important to keep in mind that the data base used for this study does not include any data for large, present-day nuclear power plants because fuel from such plants currently is not being reprocessed. Therefore, the conclusions of this study may have to be modified when reprocessor's data become available for fuel from modern plants.

Based on the results of this study, NDA measurements on spent fuel that are accurate and precise to 5-10% (1σ) or better should be useful for quantitative verification of "typical" spent fuel. Measurements of "atypical" fuel, that is, fuel with inhomogeneous burnup or unusual irradiation history, may be considerably worse (up to 20% or so).

REFERENCES

1. D. D. Cobb, Ed., "Spent-Fuel Storage Facility Project," Los Alamos National Laboratory report LA-8237-PR (June 1980).

2. C. L. Timmerman, "Isotopic Safeguards Data Bank (ISTLIB) and Control Program (MISTY)," Battelle Pacific Northwest Laboratory report ISPO-34 (PNL-2726) (September 1978).

3. H. Umezawa, "Isotope· Safeguards Techniques at the Tokai Reprocessing Plant Tastex; Task-K," Japan Atomic Energy Research Institute report (April 1979).

4. C. Beets, H. Balriot, P. Bemelmans, F. Franssen, "Application of the CEN/SCK Data Bank to the Reprocessed Fuel," in Isotopic Correlation and its Application to the Nuclear Fuel Cycle, Proc. Symp., Stresa, Italy, May 9-11, 1978 (European Safeguards Research and Development Association), ICT-25.

TABLE I

SPENT-FUEL DATA BASE

Reactor and Power	Type and Core	Burnup (MWd/tU)[a] Mean	Burnup (MWd/tU)[a] Range	Reprocessor	No. of Batches Processed
JPDR 12.5 MWe	BWR 1	3 816	1 362 5 449	PNC[b] - Tokai	12
Dresden-1 210 MWe	BWR 4	10 855	8 500 13 400	NFS - West Valley	18
KRB 1250 MWe	BWR 1	13 957	8 700 15 300	Eurochemic - Mol	21
Trino 257 MWe	PWR 1	12 306	9 900 13 400	Eurochemic - Mol	16
Sena 325 MWe	PWR 2	19 877	18 637 20 612	Eurochemic - Mol	12
Trino 257 MWe	PWR 2	20 864	14 800 22 200	Eurochemic - Mol	14
Yankee-Rowe 185 MWe	PWR 8	23 654	21 300 26 700	NFS - West Valley	11

[a]MWd/tU - megawatt day/tonne U; ranges are based on average burnup for accountability tank batch.

[b]Power Reactor and Nuclear Fuel Development Corporation.

TABLE II

REACTOR: JPDR, 12.5 MWe BWR, CORE 1
REPROCESSOR: PNC-TOKAI[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
2	1362	230.201	5.6079	0.1583	0.0000	0.1521	0.5750E-02	0.4100E-03	0.1000E-04
		202.769	4.9658	0.1247	0.0000	0.1203	0.4180E-02	0.2500E-03	0.7000E-05
3	2851	231.180	5.2627	0.2846	0.0000	0.2610	0.2030E-01	0.2970E-02	0.3800E-03
		171.050	3.9487	0.1779	0.0000	0.1643	0.1240E-01	0.1190E-02	0.6000E-04
4	3030	231.039	5.2288	0.2887	0.0000	0.2641	0.2150E-01	0.2740E-02	0.3700E-03
		309.907	7.0175	0.3674	0.0000	0.3365	0.2760E-01	0.3110E-02	0.1900E-03
5	3152	231.139	5.1816	0.3304	0.0000	0.2993	0.2600E-01	0.4550E-02	0.5300E-03
		223.899	5.0874	2.6868	0.0000	0.2625	0.2150E-02	0.2620E-02	0.1400E-03
6	3197	173.265	3.8909	0.2284	0.0000	0.2083	0.1750E-01	0.2300E-02	0.3100E-03
		190.279	4.2679	0.1609	0.0000	0.1461	0.1320E-01	0.1550E-02	0.7000E-04
7	3775	231.066	5.0307	0.3849	0.0000	0.3440	0.3370E-01	0.6230E-02	0.9200E-03
		235.216	5.1523	0.3705	0.0000	0.3352	0.3110E-01	0.3920E-02	0.2300E-03
8	4377	230.585	4.8859	0.4478	0.0000	0.3861	0.4650E-01	0.1300E-01	0.2220E-02
		222.306	4.7651	0.4469	0.0000	0.3959	0.4260E-01	0.7800E-02	0.5700E-03
9	4347	230.573	4.8933	0.4307	0.0000	0.3776	0.4230E-01	0.9300E-02	0.1500E-02
		213.227	4.5323	0.3922	0.0000	0.3483	0.3760E-01	0.5870E-02	0.4400E-03
10	4621	230.450	4.8221	0.4759	0.0000	0.4098	0.4970E-01	0.1400E-01	0.2380E-02
		226.104	4.8202	0.4864	0.0000	0.4297	0.4740E-01	0.8700E-02	0.6300E-03
11	4671	230.257	4.8154	0.4629	0.0000	0.4002	0.4830E-01	0.1230E-01	0.2140E-02
		239.242	5.0835	0.5020	0.0000	0.4439	0.4880E-01	0.8700E-02	0.6500E-03
12/13	4960	460.775	9.4873	1.0014	0.0000	0.8628	0.1064	0.2750E-01	0.4710E-02
		467.368	9.8236	0.9824	0.0000	0.8665	0.9780E-01	0.1680E-01	0.1260E-02
14/15	5449	458.094	9.1988	1.1111	0.0000	0.9445	0.1238	0.3630E-01	0.6520E-02
		470.629	9.6232	1.0545	0.0000	0.9214	0.1104	0.2100E-01	0.1700E-02

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 3.

[c]Data in kilograms.

TABLE III

REACTOR: DRESDEN 1, 210 MWe BWR, FUEL LOT 4
REPROCESSOR: NFS-WEST VALLEY[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
8	8 500	1303.396	9.5280	5.6530	0.0000	3.7730	1.366	0.4260	0.8800E-01
		1277.757	9.6090	5.1120	0.0220	3.57[illegible]	1.107	0.3320	0.7500E-01
9	9 100	1293.405	9.0020	5.8410	0.0000	3.8050	1.467	0.4650	0.1040
		1280.174	9.2180	5.5330	0.0260	3.7820	1.234	0.3920	0.9900E-01
12	9 100	1082.499	7.5260	4.8960	0.0000	3.1880	1.231	0.3900	0.8700E-01
		1093.857	7.8210	4.7030	0.0230	3.2130	1.054	0.3310	0.8200E-01
7	9 700	1254.925	8.4410	5.8610	0.0000	3.7170	1.528	0.4900	0.1260
		1245.659	8.6760	5.7700	0.0300	3.8680	1.316	0.4380	0.1180
3	9 800	860.768	5.6230	4.0720	0.0000	2.5790	1.066	0.3440	0.8300E-01
		874.330	5.9850	4.0470	0.0210	2.7270	0.9260	0.2980	0.7500E-01
15	11 300	1304.359	7.5670	6.6410	0.0000	3.9590	1.879	0.6210	0.1820
		1291.352	8.3360	6.7450	0.0380	4.4010	1.568	0.5710	0.1670
16	11 000	1309.953	7.7110	6.6180	0.0000	3.9810	1.853	0.6110	0.1730
		1344.943	8.6010	7.0440	0.380	4.5890	1.640	0.6100	0.1670
18	10 900	1300.744	7.7420	6.5250	0.0000	3.9420	1.817	0.5980	0.1680
		1301.909	8.2870	6.7730	0.0380	4.4020	1.588	0.5760	0.1690
13	11 400	1316.399	7.5170	6.7640	0.0000	4.0050	1.930	0.6390	0.1900
		1312.189	8.3390	6.8580	0.0390	4.4630	1.600	0.5880	0.1680
10	11 700	1300.017	7.2300	6.7710	0.0000	3.9660	1.956	0.6500	0.1990
		1293.664	8.1240	6.7990	0.0460	4.3970	1.602	0.5830	0.1710
11	12 000	1319.113	7.2680	6.9210	0.0000	4.0090	2.023	0.6740	0.2150
		1307.143	8.1300	6.9600	0.0420	4.4520	1.666	0.6120	0.1880
20	11 900	1309.894	7.1920	6.8610	0.0000	3.9900	1.997	0.6650	0.2090
		1302.323	8.0090	7.0730	0.0430	4.5360	1.678	0.6220	0.1940
2	11 500	1257.763	7.9740	6.3470	0.0000	3.8340	1.760	0.5870	0.1660
		1242.135	8.6260	6.1820	0.0360	4.0330	1.457	0.5140	0.1420
21	10 800	1244.183	8.6790	6.1450	0.0000	3.7960	1.657	0.5440	0.1480
		1292.950	9.7560	6.3480	0.0360	4.2370	1.426	0.5120	0.1370
5	10 400	1250.176	9.0650	5.8910	0.0000	3.7170	1.542	0.5040	0.1280
		1238.901	9.5890	5.6960	0.0300	3.8450	1.274	0.4340	0.1130
1	13 400	1217.410	7.9450	6.4810	0.0000	3.7890	1.860	0.6380	0.1940
		1192.088	8.4520	6.6970	0.0480	4.2270	1.616	1.6190	0.1870
6	13 100	797.003	5.6980	4.1380	0.0000	2.4580	1.164	0.3980	0.1180
		789.104	6.1670	4.3250	0.0280	2.7820	1.013	0.3880	0.1140
22	9 600	756.273	9.1090	3.3950	0.0000	2.3680	0.7440	0.2390	0.4400E-01
		797.685	9.8290	3.5580	0.0160	2.5680	0.6810	0.2450	0.4800E-01

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 2.

[c]Data in kilograms.

TABLE IV

REACTOR: KRB, 250 MWe BWR, FUEL LOT 1
REPROCESSOR: EUROCHEMIC-MOL[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
14	8 700	670.062	9.6470	2.7600	0.0000	2.0990	0.4730	0.1690	0.1900E-01
		627.137	9.0740	2.3530	0.0070	1.8160	0.3840	0.1260	0.2000E-01
4	12 300	746.710	8.9810	3.8600	0.0000	2.6540	0.8220	0.3290	0.5500E-01
		757.007	9.2560	3.8630	0.0200	2.7260	0.7400	0.3160	0.6100E-01
3	13 200	707.714	8.1180	3.8260	0.0000	2.5720	0.8480	0.3450	0.6100E-01
		687.954	8.3400	3.4880	0.0180	2.4520	0.6720	0.2880	0.5800E-01
1	13 100	717.549	8.2750	3.8640	0.0000	2.6080	0.8510	0.3450	0.6000E-01
		714.489	8.5320	3.6950	0.0180	2.5810	0.7370	0.2970	0.6200E-01
20	10 900	785.740	9.6150	3.9720	0.0000	2.7330	0.8420	0.3380	0.5900E-01
		772.912	9.1560	3.9650	0.0200	2.7510	0.8000	0.3240	0.7000E-01
17	13 800	717.146	7.9810	3.9770	0.0000	2.6280	0.9040	0.3730	0.7200E-01
		720.853	8.2080	3.9130	0.0210	2.7050	0.7930	0.3220	0.7200E-01
2	13 900	723.211	8.0760	4.0010	0.0000	2.6530	0.9060	0.3720	0.7000E-01
		731.334	8.5[illegible]20	3.8620	0.0240	2.6560	0.7700	0.3330	0.7900E-01
6	14 600	744.535	7.9100	4.2900	0.0000	2.7800	1.006	0.4200	0.8400E-01
		748.766	8.3800	4.1520	0.0240	2.8200	0.8550	0.3720	0.8100E-01
8	14 300	744.286	8.0550	4.2250	0.0000	2.7640	0.9770	0.4060	0.7800E-01
		741.377	8.2860	4.1170	0.0230	2.8190	0.8440	0.3550	0.7600E-01
7	14 400	742.509	8.0320	4.2270	0.0000	0.0000	2.761	0.9800	0.4070
		748.180	8.2780	4.1770	0.0240	2.8630	0.8510	0.3550	0.8400E-01
16	14 800	496.512	5.2240	2.8790	0.0000	1.8600	0.6790	0.2840	0.5600E-01
		502.853	5.3170	2.8190	0.0170	1.9110	0.5990	0.2350	0.5700E-01
5	14 900	744.167	7.7800	4.3350	0.0000	2.7940	1.027	0.4300	0.8400E-01
		643.486	7.0680	3.6640	0.0220	2.4980	0.7490	0.3220	0.7300E-01
18	14 700	744.519	7.8740	4.3030	0.0000	2.7840	1.012	0.4230	0.8400E-01
		738.945	8.0220	4.0310	0.0240	2.7280	0.8440	0.3540	0.8100E-01
15	14 800	744.143	7.8340	4.3060	0.0000	2.7870	1.018	0.4270	0.7400E-01
		715.390	7.7200	4.0580	0.0240	2.7640	0.8600	0.3280	0.8200E-01
19	14 900	744.835	7.9030	4.3290	0.0000	2.7920	1.024	0.4290	0.8400E-01
		768.313	8.3040	4.3910	0.0260	2.9760	0.9150	0.3840	0.9000E-01
12	14 700	726.290	7.6870	4.1930	0.0000	2.7150	0.9860	0.4120	0.8000E-01
		722.561	7.8060	4.1560	0.0250	2.8160	0.8710	0.3620	0.8200E-01
21	14 900	742.533	7.7640	4.3260	0.0000	2.7870	1.026	0.4290	0.8400E-01
		706.729	7.5820	4.0460	0.0230	2.7360	0.8640	0.3390	0.8400E-01
9	15 100	741.957	7.6750	4.3570	0.0000	2.7940	1.038	0.4360	0.8900E-01
		725.591	7.7460	4.1970	0.0260	2.8370	0.8800	0.3690	0.8500E-01
13	14 800	749.462	7.8030	4.2970	0.0000	2.7740	1.015	0.4240	0.8400E-01
		679.495	7.2150	3.9480	0.0250	2.6660	0.8350	0.3440	0.7800E-01
11	15 300	743.145	7.6220	4.3890	0.0000	2.8040	1.052	0.4430	0.9000E-01
		719.679	7.5920	3.7720	0.0230	2.5520	0.8130	0.3040	0.8000E-01
10	15 000	744.007	7.7590	4.3420	0.0000	2.7940	1.030	0.4320	0.8600E-01
		700.099	7.4090	4.0800	0.0250	2.7390	0.8620	0.3640	0.9000E-01

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 2.

[c]Data in kilograms.

TABLE V

REACTOR: YANKEE-ROWE, 185 MWe BWR, CORE VIII
REPROCESSOR: NFS-WEST VALLEY[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
12	22 400	704.548	20.5230	7.1620	0.0000	5.4250	0.9780	0.6730	0.8600E-01
		701.700	21.4320	6.5360	0.0520	4.9130	0.8940	0.5960	0.8100E-01
14	21 300	529.651	15.8990	5.1680	0.0000	3.9460	0.6910	0.4700	0.6100E-01
		548.500	16.5020	5.1990	0.0490	3.8850	0.7160	0.4810	0.6800E-01
5	22 200	1411.031	41.4650	14.1710	0.0000	10.7430	1.927	1.325	0.1760
		1404.500	41.6490	13.6760	0.1270	10.1130	1.925	1.311	0.2000
10	23 600	703.400	20.0390	7.3410	0.0000	5.4780	1.025	0.7300	0.1080
		702.900	20.3230	7.1460	0.0770	5.2090	1.032	0.7110	0.1170
3	23 800	1406.951	39.7500	14.8400	0.0000	11.0720	2.080	1.478	0.2100
		1397.500	40.0950	14.3400	0.1480	10.4580	2.076	1.433	0.2250
1	25 100	1405.167	38.3010	15.4520	0.0000	11.4060	2.215	1.599	0.2320
		1387.600	39.5400	14.4230	0.1420	10.5260	2.089	1.445	0.2210
11	23 600	704.846	20.0810	7.3560	0.0000	5.4900	1.027	0.7320	0.1070
		685.600	19.4910	7.0090	0.0810	5.0590	1.028	0.7180	0.1230
7	23 300	703.943	20.1050	7.3310	0.0000	5.4970	1.020	0.7150	0.9900E-01
		691.000	19.6340	7.1120	0.0780	5.1590	1.033	0.7190	0.1230
9	23 400	704.393	20.0780	7.3510	0.0000	5.5020	1.024	0.7220	0.1030
		700.500	19.8420	7.2290	0.0790	5.2360	1.056	0.7370	0.1210
13	24 800	527.319	14.5090	5.7360	0.0000	4.2390	0.8180	0.5910	0.8800E-01
		514.700	14.4800	5.4130	0.0610	3.9060	0.7950	0.5570	0.9400E-01
8	26 700	700.908	18.4660	7.9840	0.0000	5.7980	1.171	0.8730	0.1420
		709.300	19.6390	7.6170	0.0920	5.4520	1.133	0.8010	0.1390

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 2.

[c]Data in kilograms.

TABLE VI

REACTOR: SENA, 325 MWe PWR, CORE 2
REPROCESSOR: EUROCHEMIC-MOL[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
100	18 637	922.414	16.4740	6.8720	0.0000	0.0000	0.0000	0.0000	0.0000
		936.650	16.9720	6.9010	0.0510	4.8920	1.164	0.6730	0.1210
200	20 293	917.171	15.0600	7.4570	0.0000	0.0000	0.0000	0.0000	0.0000
		933.020	16.0110	7.6370	0.0670	5.2780	1.330	0.8060	0.1560
300	19 407	919.871	15.8040	7.1440	0.0000	0.0000	0.0000	0.0000	0.0000
		941.148	16.8280	7.3280	0.0540	5.1320	1.261	0.7420	0.1390
400	20 203	920.254	13.3440	7.4400	0.0000	0.0000	0.0000	0.0000	0.0000
		920.590	16.0460	7.6920	0.0610	5.3490	1.329	0.7940	0.1590
500	19 395	921.369	15.8480	7.1500	0.0000	0.0000	0.0000	0.0000	0.0000
		930.710	16.6410	7.4100	0.0510	5.2100	1.261	0.7470	0.1410
600	20 313	918.622	15.0660	7.4700	0.0000	0.0000	0.0000	0.0000	0.0000
		939.780	16.2960	7.5490	0.0600	5.2420	1.309	0.7850	0.1530
700	19 367	919.926	15.8410	7.1300	0.0000	0.0000	0.0000	0.0000	0.0000
		934.860	16.4720	7.2560	0.0540	5.0810	1.241	0.7390	0.1410
800	20 137	918.865	15.2070	7.4120	0.0000	0.0000	0.0000	0.0000	0.0000
		909.050	15.7720	7.6820	0.0580	5.3520	1.333	0.7860	0.1530
900	20 253	918.708	15.1130	7.4540	0.0000	0.0000	0.0000	0.0000	0.0000
		945.770	16.4090	7.6050	0.0590	5.2870	1.321	0.7790	0.1590
1000	20 612	919.692	14.8360	7.5900	0.0000	0.0000	0.0000	0.0000	0.0000
		923.660	15.6470	7.1480	0.0590	4.9440	1.244	0.7530	0.1480
1100	20 253	917.226	15.0880	7.4430	0.0000	0.0000	0.0000	0.0000	0.0000
		912.450	15.6030	7.1650	0.0500	4.9870	1.243	0.7390	0.1460
1200	19 655	614.007	10.4200	5.3130	0.0000	0.0000	0.0000	0.0000	0.0000
		625.970	10.8980	5.3130	0.0360	3.7240	0.9100	0.5380	0.1050

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 4.

[c]Data in kilograms.

TABLE VII

REACTOR: TRINO, 257 MWe PWR, CORE 1
REPROCESSOR: EUROCHEMIC-MOL[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
1	12 700	923.027	14.9290	5.7770	0.0000	4.2960	0.9330	0.5200	0.2800E-01
		922.631	15.1870	5.6780	0.0270	4.2290	0.8950	0.4600	0.6700E-01
2	12 500	923.705	15.0300	5.7740	0.0000	4.3070	0.9260	0.5140	0.2700E-01
		929.893	15.2830	5.6120	0.0260	4.1910	0.8840	0.4470	0.6400E-01
3	12 900	921.971	14.7600	5.7550	0.0000	4.2610	0.9380	0.5270	0.2900E-01
		927.831	15.2650	5.6010	0.0270	4.1720	0.8800	0.4550	0.6700E-01
4	12 600	923.196	14.9910	5.7870	0.0000	4.3130	0.9290	0.5170	0.2800E-01
		917.343	15.0920	5.7050	0.0250	4.2770	0.8880	0.4510	0.6400E-01
5	12 800	922.407	14.8270	5.7650	0.0000	4.2770	0.9360	0.5230	0.2900E-01
		918.143	15.1130	5.7170	0.0260	4.2710	0.8970	0.4570	0.6600E-01
6	12 500	924.052	15.0660	4.7450	0.0000	4.2970	0.9160	0.5060	0.2600E-01
		923.467	15.2490	5.9430	0.0250	4.4560	0.9280	0.4680	0.6600E-01
12	12 700	922.540	14.9510	5.8140	0.0000	4.3270	0.9360	0.5220	0.2900E-01
		922.082	15.1770	5.5520	0.0200	4.1590	0.8650	0.4450	0.[illegible]300E-01
13	12 600	922.441	15.0100	5.7670	0.0000	4.3030	0.9230	0.5140	0.2700E-01
		925.517	15.2710	5.5270	0.0200	4.1240	0.8670	0.4500	0.6400E-01
14	12 800	615.014	9.9050	3.8510	0.0000	2.8570	0.6230	0.3520	0.1900E-01
		610.442	10.0420	3.7720	0.0160	2.8090	0.5940	0.3090	0.4400E-01
10	10 300	926.46[illegible]	19.3740	5.2110	0.0000	3.9960	0.7640	0.4310	0.2000E-01
		926.627	19.6110	5.1050	0.0180	3.9350	0.7370	0.3670	0.4800E-01
11	9 900	925.987	19.5000	5.1790	0.0000	3.9710	0.7600	0.4270	0.2100E-01
		918.908	19.3500	4.8050	0.0180	3.70[illegible]	0.6900	0.3450	0.4600E-01
7	12 700	924.005	18.1550	5.7950	0.0000	4.37[illegible]0	0.8710	0.4900	0.5500E-01
		929.257	18.7750	5.4380	0.0220	4.17[illegible]0	0.7900	0.3980	0.5000E-01
8	13 000	925.721	18.2020	5.8160	0.0000	4.3910	0.8760	0.4930	0.5600E-01
		929.754	18.8220	5.4650	0.0240	4.1880	0.7980	0.4040	0.5100E-01
9	13 400	615.603	11.9360	3.9580	0.0000	2.9690	0.6020	0.3450	0.4200E-01
		619.146	12.2630	3.7170	0.0160	2.8280	0.5470	0.2880	0.3800E-01
1A	13 200	616.001	10.7080	3.9450	0.0000	2.9410	0.6200	0.3510	0.3300E-01
		568.800	10.1220	3.6050	0.0160	2.6860	0.5590	0.3020	0.4200E-01
2A	10 300	617.706	14.2900	3.2880	0.0000	2.5500	0.4610	0.2650	0.1200E-01
		609.958	14.0990	3.1720	0.0110	2.4720	0.4410	0.2200	0.2800E-01

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 2.

[c]Data in kilograms.

TABLE VIII

REACTOR: TRINO, 257 MWe PWR, CORE 2
REPROCESSOR: EUROCHEMIC-MOL[a,b,c]

Batch No.	MWd/MTU	Final U	U-235	Final Pu	Pu-238	Pu-239	Pu-240	Pu-241	Pu-242
10	19 900	916.827	13.8500	7.7150	0.0000	5.1800	1.398	0.9150	0.2220
		913.232	14.6850	7.0730	0.0710	4 8940	1.249	0.7180	0.1410
8	21 000	914.024	13.1270	8.0050	0.0000	5.2770	1.484	0.9840	0.2600
		922.857	14.2300	7.6240	0.0760	5.1800	1.386	0.8110	0.1710
1	21 100	914.570	13.1180	8.0120	0.0000	5.2790	1.487	0.9850	0.2610
		915.91[illegible]	14.0960	7.4710	0.0860	5.1270	1.342	0.7550	0.1610
5	21 300	914.166	12.9620	8.0790	0.0000	5.3020	1.506	1.001	0.2700
		921.954	14.1430	7.5560	0.0860	5.1200	1.376	0.8010	0.1730
4	22 100	912.842	12.5250	8.2460	0.0000	5.3540	1.557	1.041	0.2940
		925.617	14.1620	7.6810	0.0900	5.1730	1.411	0.8260	0.1810
3	21 000	913.505	13.2320	7.9510	0.0000	5.2570	1.469	0.9720	0.2530
		903.335	13.7310	7.5690	0.0840	5.1120	1.380	0.8210	0.1720
9	22 200	914.450	12.4850	8.2870	0.0000	5.3730	1.567	1.049	0.2980
		918.392	13.8680	7.8560	0.0920	5.2560	1.454	0.8640	0.1900
2	21 000	914.117	13.1280	8.0060	0.0000	5.2780	1.484	0.9840	0.2600
		914.058	13.6740	7.5350	0.0870	5.1260	1.375	0.7710	0.1760
7	22 200	913.756	12.4680	8.2840	0.0000	5.3700	1.567	1.049	0.2980
		919.584	13.7200	7.6590	0.0910	5.1340	1.416	0.8310	0.1870
8	21 100	923.824	15.1170	7.9150	0.0000	5.2890	1.425	0.9530	0.2480
		912.218	16.0550	7.2800	0.0690	5.0140	1.289	0.7530	0.1550
12	14 800	916.241	20.6430	5.5020	0.0000	3.5690	1.040	0.6960	0.1970
		910.456	21.0860	5.5330	0.0700	3.7060	1.024	0.5990	0.1340
11	21 700	913.601	18.6800	7.9400	0.0000	5.4640	1.338	0.9310	0.2070
		920.459	20.1760•	7.2160	0.0770	5.1160	1.195	0.7040	0.1240
21	21 300	914.107	18.9260	7.8500	0.0000	5.4270	1.314	0.9100	0.1990
		887.703	19.1390	7.1520	0.0780	5.0800	1.157	0.7180	0.1190
22	21 400	609.360	12.5870	5.2410	0.0000	3.6210	0.8780	0.6090	0.1330
		597.914	12.9630	4.7220	0.0490	3.3480	0.7700	0.4760	0.7900

[a]First row: calculated data; second row: measured data.

[b]Data taken from Ref. 2.

[c]Data in kilograms.

TABLE IX

SPENT-FUEL COMPOSITION
COMPARISON OF PREDICTED AND MEASURED VALUES

Reactor and Power	Type and Core	Burnup (MWd/tU)[a] Mean	Burnup (MWd/tU)[a] Range	No. of Batches Processed	Relative Difference (%)[b] U Mean[c]	U Range	Pu Mean[c]	Pu Range	U^{235} Mean[c]	U^{235} Range	$^{239}Pu + ^{241}Pu$ Mean[c]	$^{239}Pu + ^{241}Pu$ Range	Total Fissile Mean[c]	Total Fissile Range
JPDR	BWR	3 816	1 362	12	1.81	-25.45	11.16	-24.42	0.734	-25.49	10.49	-24.13	1.11	-25.30
12.5 MWe	1		5 449		±14.23	35.15	±22.34	59.98	±13.93	33.28	±22.60	59.51	±14.03	34.30
Dresden-1	BWR	10 855	8 500	18	-0.058	-5.19	0.19	-6.05	-7.14	-11.00	-5.25	-11.68	-6.53	-10.24
210 MWe	4		13 400		±2.02	2.12	±4.24	10.58	±3.19	-0.84	±5.07	7.44	±3.57	1.55
KRB	BWR	13 957	8 700	21	2.46	-3.06	5.67	-1.41	-0.037	-5.68	3.26	-4.14	0.81	-4.63
1250 MWe	1		15 300		±4.44	15.64	±5.69	18.31	±4.52	10.07	±5.64	16.79	±4.39	8.16
Trino	PWR	12 306	9 900	16	0.57	-0.67	3.74	-3.33	-1.10	-3.31	4.39	-2.46	0.063	-1.72
257 MWe	1		13 400		±2.14	8.30	±3.14	9.43	±2.25	5.79	±2.97	10.17	±2.10	6.79
Sena	PWR	19 877	18 637	12	-1.16	-2.86	-1.62	-9.09	-6.02	-16.84	-	-	-	-
325 MWe	2		20 612		±1.21	0.52	±3.82	6.18	±3.76	-2.93				
Trino	PWR	20 864	14 800	14	0.23	-1.38	7.11	-0.56	-6.17	-11.36	6.68	-0.93	-2.61	-6.16
254 MWe	2		22 200		±1.23	2.97	±2.89	10.99	±3.11	-1.11	±2.89	10.62	±2.11	1.31
Yankee-Rowe	PWR	23 654	21 300	11	0.54	-3.44	4.22	-0.60	-1.17	-5.97	6.27	1.15	0.51	-2.92
185 MWe	8		26 700		±1.74	2.81	±2.74	9.58	±2.85	3.03	±2.55	10.69	±2.24	4.10

[a] MWd/tU – megawatt day/tonne U; ranges are based on average burnup for accountability tank batch.

[b] $100\left(\frac{\text{Predicted} - \text{Measured}}{\text{Measured}}\right)$

[c] The ± are standard deviations.

TABLE X

SPENT-FUEL COMPOSITION
POOLED COMPARISONS OF PREDICTED AND MEASURED VALUES

A: Uranium, Plutonium

Reactor Type	Number of Batches	Burnup[a] MWd/tU Mean	Burnup[a] MWd/tU Range	Relative Difference (%)[b] U Mean	U Range	Pu Mean	Pu Range	^{235}U Mean	^{235}U Range
BW (JPDR, Dresden and KRB)	51	10 476	1 362	1.42	-25.45	4.90	-21.42	-2.36	-25.49
			15 300	±7.42	35.15	±12.16	59.98	±8.19	33.28
BWRs (Dresden and KRB)	39	12 525	8 600	1.30	-5.19	2.97	-6.05	-3.32	-11.00
			15 300	±3.72	15.64	±5.82	18.31	±5.31	10.07
PWRs	53	18 636	9 900	0.081	-3.44	3.52	-9.09	-3.57	-16.84
			26 700	±1.75	8.30	±4.37	10.99	±3.84	5.79
BWRs and PWRs	104	14 634	1 362	0.74	-25.45	4.19	-21.42	-2.98	-25.49
			26 700	±5.36	35.15	±9.05	59.98	±6.36	33.28
BWRs and PWRs (excluding JPDR)	92	16 045	8 500	0.60	-5.19	3.29	-9.09	-3.46	-16.84
			26 700	±2.81	15.64	±5.01	18.31	±4.50	10.07

B: Fissile Pu and Total Fissile

Reactor Type	Number of Batches	Burnup[a] MWd/tU Mean	Burnup[a] MWd/tU Range	Relative Difference (%)[b] $^{239}Pu + ^{241}Pu$ Mean	$^{239}Pu + ^{241}Pu$ Range	Total Fissile Mean	Total Fissile Range
BWRs (JPDR, Dresden and KBR)	51	10 476	1 362	1.96	-21.43	-1.71	-25.30
			1 530	±13.07	59.51	±8.26	34.30
BWRs (Dresden and KRB)	39	12 525	8 500	-0.67	-11.68	-2.58	-10.24
			15 300	±6.84	16.79	±5.44	8.16
PWRs (excluding Sena)	41	18 273	9 900	5.68	-2.46	-0.73	-6.16
			26 700	±2.96	10.69	±2.50	6.79
PWRs and BWRs (excluding Sena)	92	13 951	1 362	3.61	-24.13	-1.27	-25.30
			26 700	±10.06	59.51	±6.36	34.30
PWRs and BWRs (excluding Sena and JPDR)	80	15 471	8 500	2.58	-11.68	-1.63	-10.24
			26 700	±6.09	16.79	±4.27	6.79

[a] MWd/tU = megawatt day/tonne U; ranges are based on average burnup for accountability batches.

[b] $100\left(\frac{\text{Predicted - Measured}}{\text{Predicted}}\right)$

TABLE XI

SPENT-FUEL COMPOSITION
COMPARISON OF PREDICTED - MEASURED VALUES: t-TEST RESULTS[a]

	Tested Difference														
	U			Pu			^{235}U			$^{239}Pu + ^{241}Pu$			Total Fissile		
Reactor Type	t	n	Critical Value[b]	t	n	Critical Value[b]	t	n	Critical Value[b]	t	n	Critical Value[b]	t	n	Critical Value[b]
BWR	1.367	51	2.678	2.878	51	2.678	-2.058	51	2.678	1.071	51	2.678	-1.478	51	2.678
BWR[c]	2.182	39	2.712	3.187	39	2.712	-3.905	39	2.712	-2.971	39	2.712	-0.611	39	2.712
PWR	0.337	53	2.674	5.864	53	2.674	-6.768	53	2.674	12.287	41[d]	2.705	-1.870	41[d]	2.705
BWR & PWR	1.408	104	2.625	4.722	104	2.625	-4.778	104	2.625	3.442	92[d]	2.631	-1.915	92[d]	2.681
BWR & PWR[c]	2.048	92	2.631	6.299	92	2.631	-7.375	92	2.631	3.789	80[d]	2.640	-3.414	80[d]	2.640

[a]
$$t = \frac{\bar{d}\sqrt{n}}{S_d}$$

where d = mean relative difference $= \frac{1}{n} \sum_{i=1}^{n} 100\left(\frac{\text{Predicted - Measured}}{\text{Measured}}\right)_i$

n = number of observations, and
S_d = standard deviation.

[b]Critical values for $\alpha = 0.01$ and a two-tailed test.

[c]JPDR data eliminated.

[d]No Pu isotopic data available for Sena.

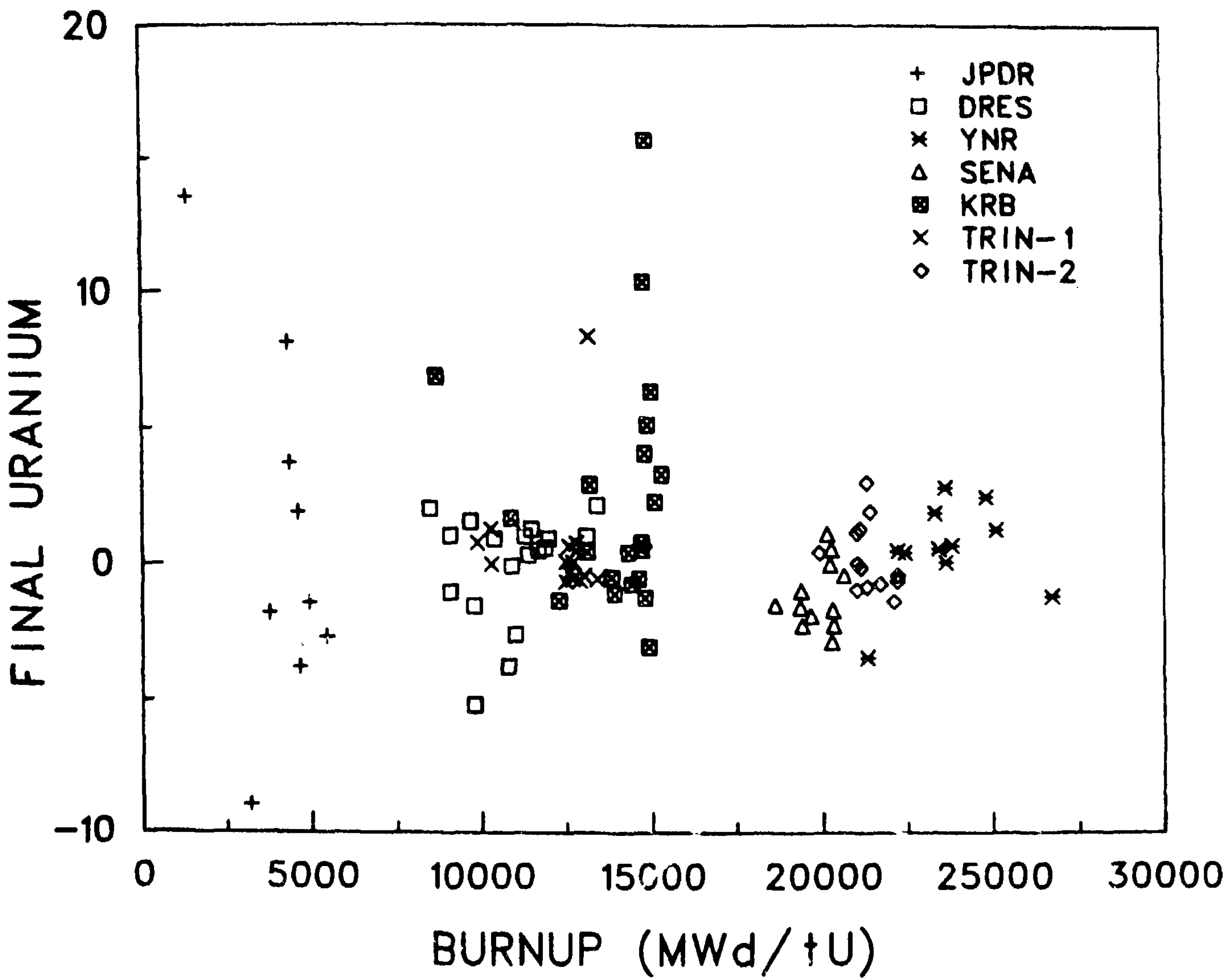

Fig. 1. Relative difference (%) vs burnup: total uranium.

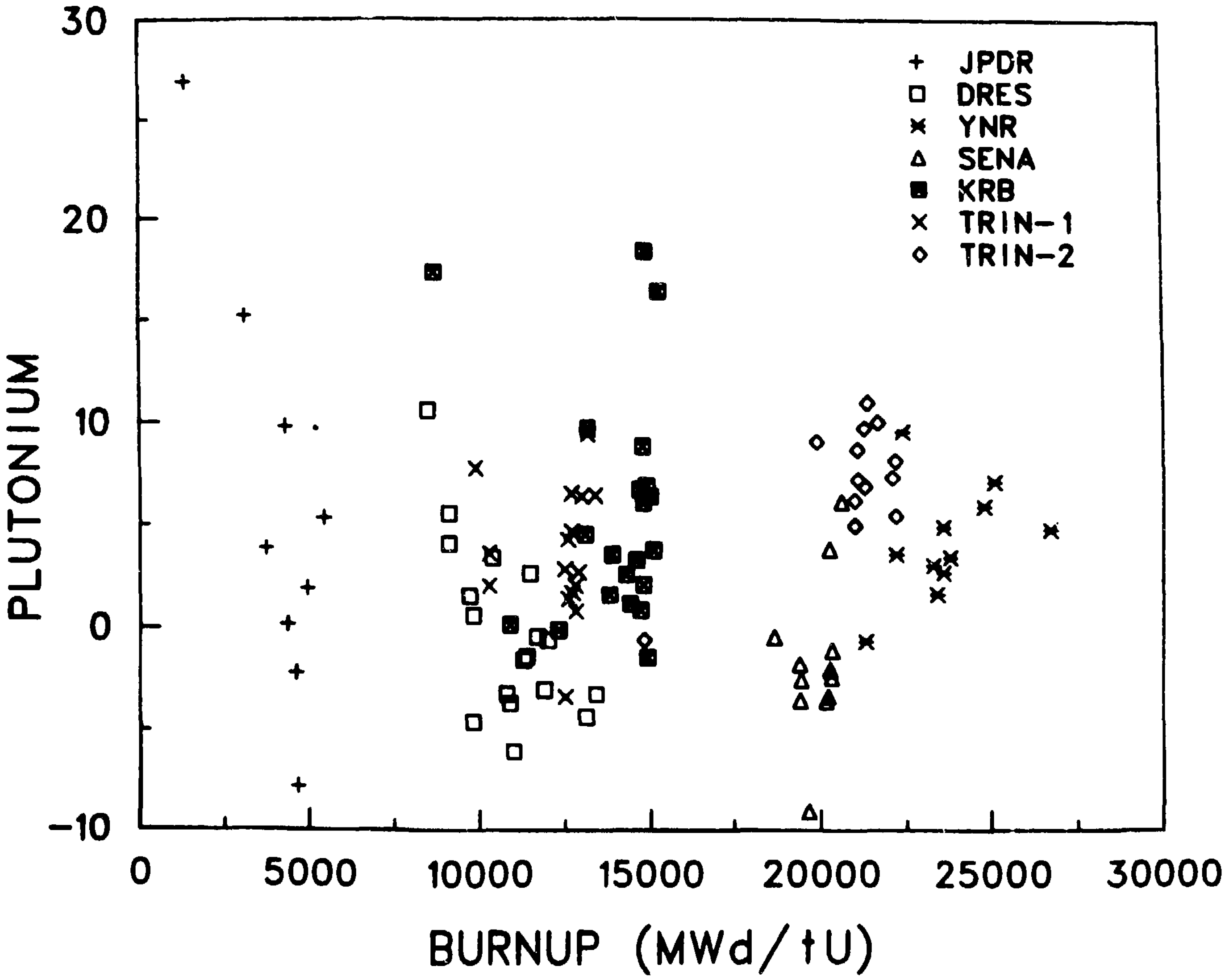

Fig. 2. Relative difference (%) vs burnup: total plutonium.

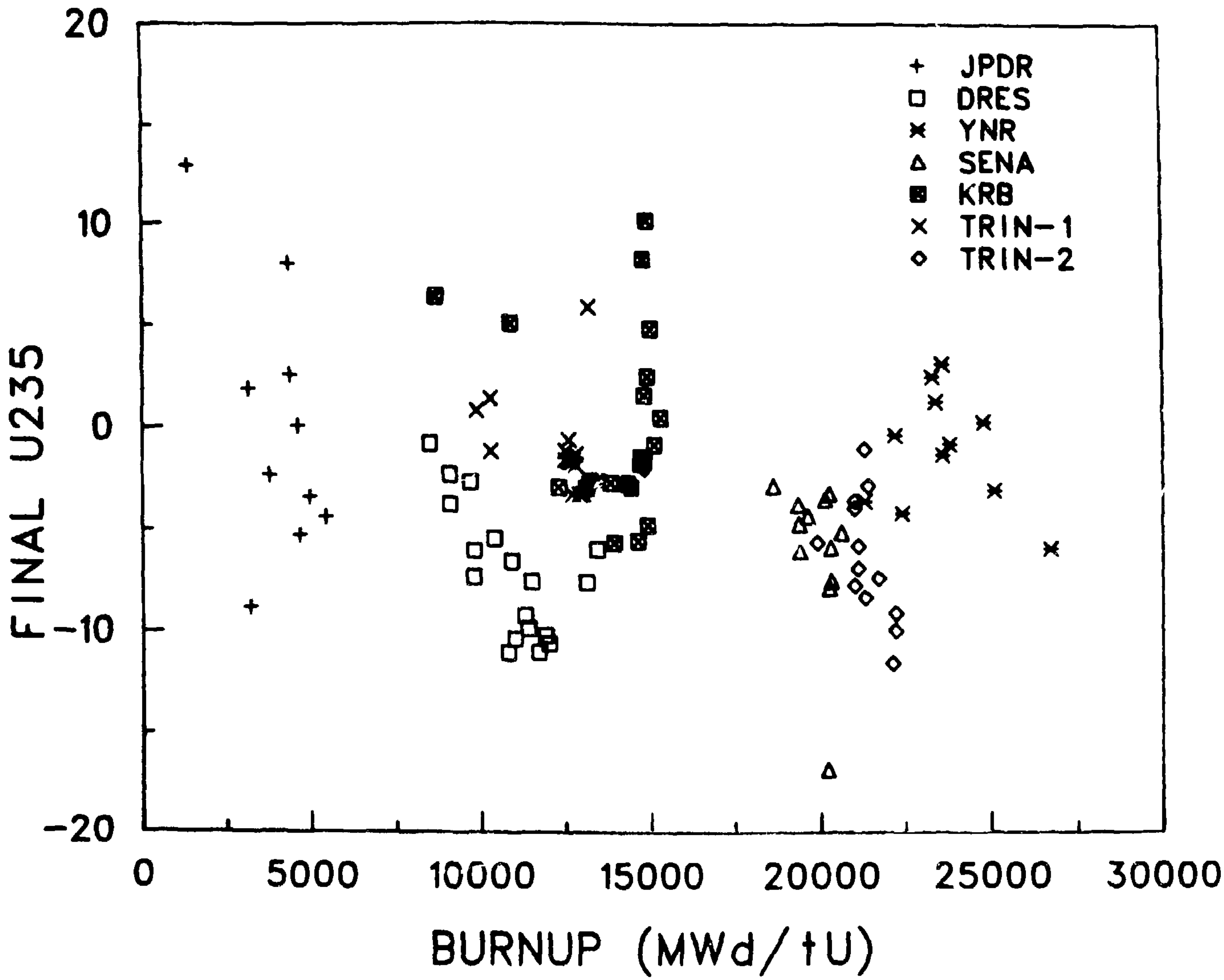

Fig. 3. Relative difference (%) vs burnup: fissile uranium.

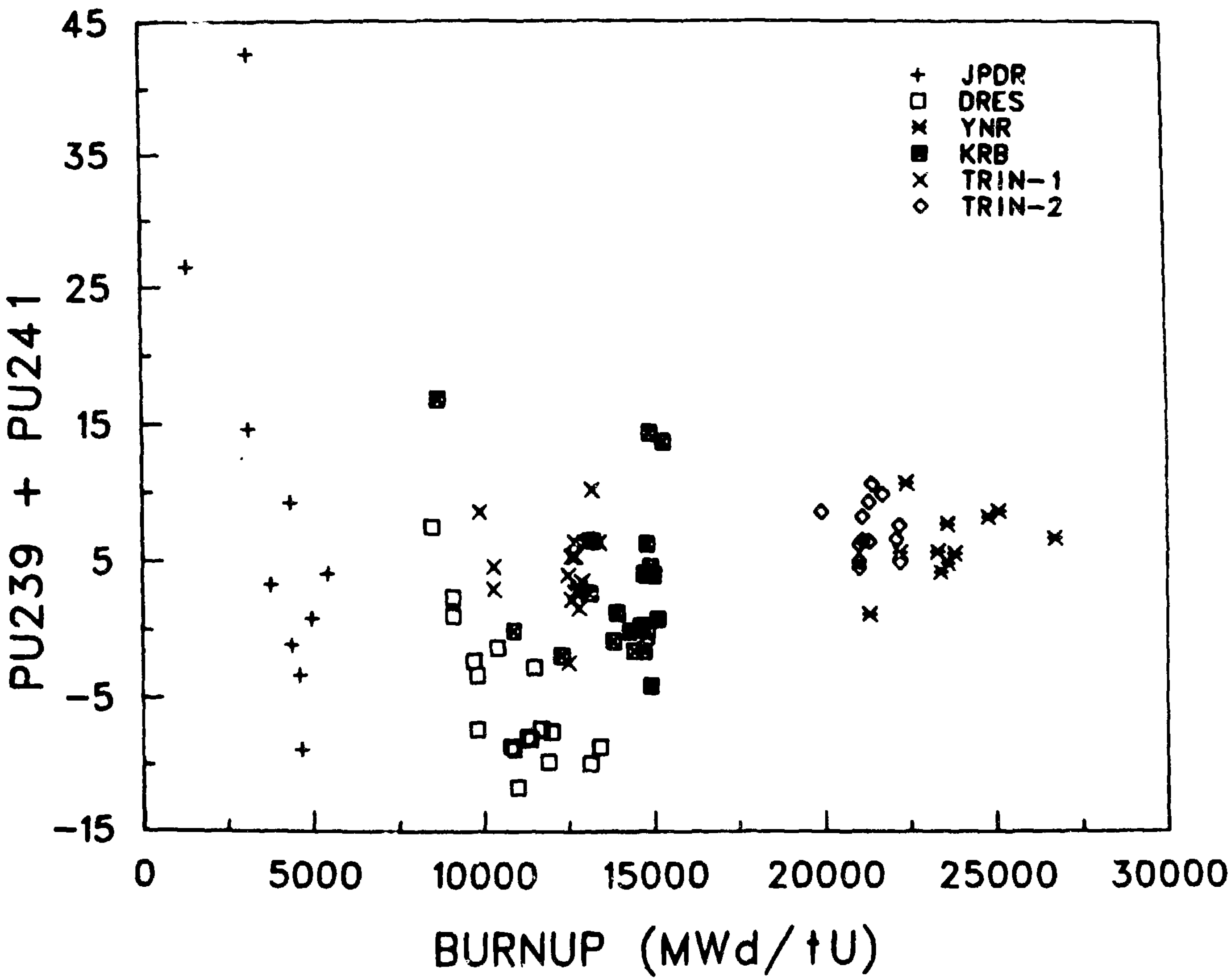

Fig. 4. Relative difference (%) vs burnup: fissile plutonium.

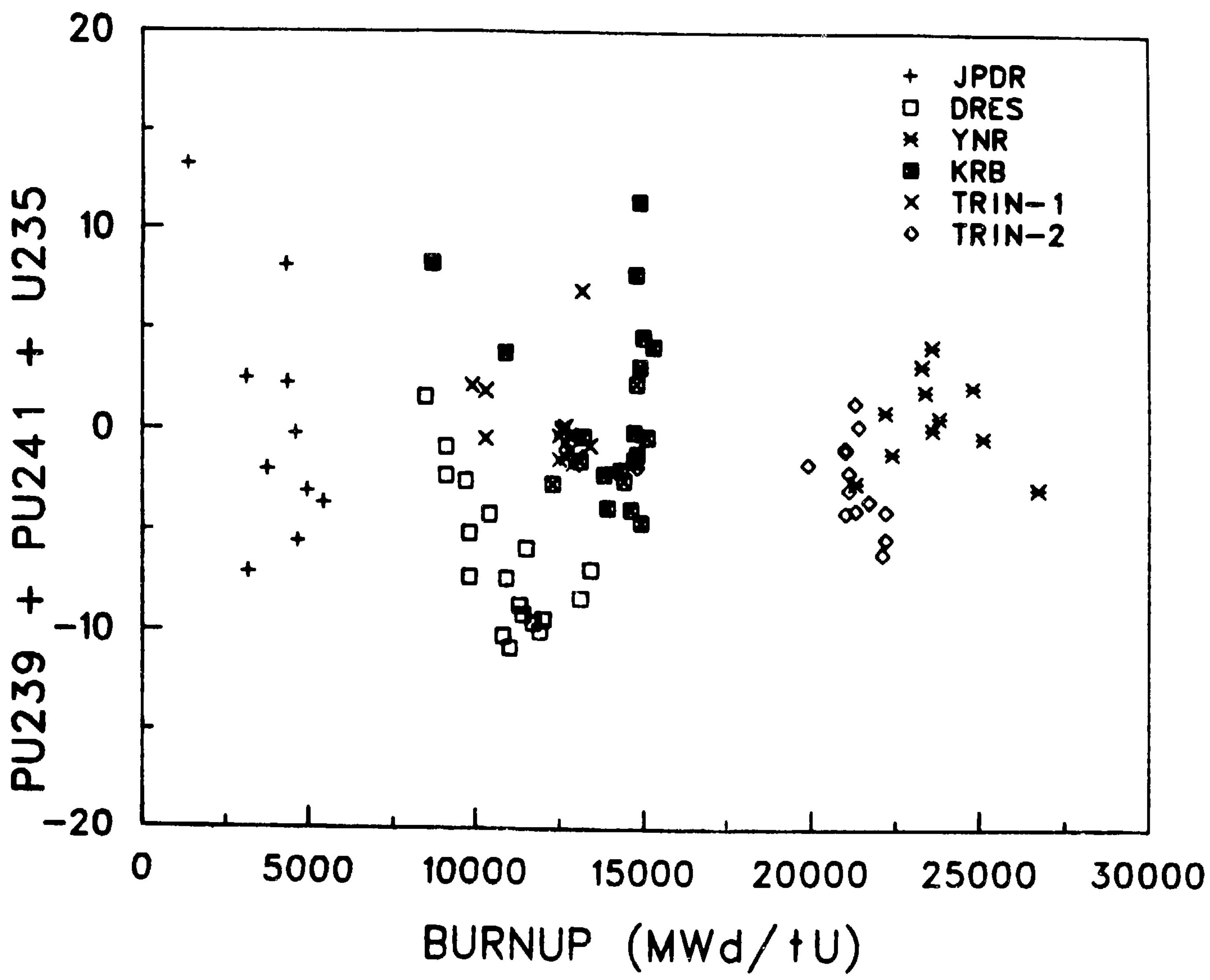

Fig. 5. Relative difference (%) vs burnup: total fissile content.

APPENDIX

SPENT-FUEL DATA ANALYSIS: MULTIPLE RANGE TESTS

Duncan's New Multiple Range[1] test with Kramer's adjustment[2] was applied to the spent-fuel data sets. The test is designed to augment the F test for testing the hypothesis that there is no significant difference in a set of treatment means (in this case reactor means) in an analysis of variance (ANOVA). The F test can reject the hypothesis, but gives no decisions as to which of the differences among the treatment means may be considered significant and which may not. Duncan's New Multiple Range test[1] is designed to provide a basis for such decisions for the case where each treatment contains an equal number of observations. Kramer[2] modified the test to handle cases where the number of observations in the treatments are unequal. The results that were obtained are shown in Tables A-I and A-II. JPDR data have been eliminated from Table A-II. Means connected by a single row of Xs are not significantly different, although those not connected by such a line are significantly different. All data sets except for the total uranium set for all the reactors (including JPDR) contain significantly different sets of means. This was confirmed by the ANOVA F tests. As might be expected, elimination of the JPDR data that exhibit large variances alters the pattern of significant differences appreciably.

REFERENCES

1. D. B. Duncan, "Multiple Range and Multiple F Tests," Biometrics 11, 1-42 (March 1955).

2. C. Y. Kramer, "Extension of Multiple Range Tests to Group Means with Unequal Numbers of Replications," Biometrics 12, 307-310 (September 1956).

TABLE A-I

SPENT-FUEL COMPOSITION
COMPARISON OF PREDICTED AND MEASURED VALUES;
DUNCAN'S MULTIPLE RANGE TEST WITH KRAMER'S EXTENSION FOR UNEQUAL REPLICATION[a]

Total U

Reactor	Mean (%)[b]	
Sena Core 2	-1.164	X[c]
		X
		X
Dresden-1	-0.0582	X
Fuel Lot 4		X
		X
Trino	0.228	X
Core 2		X
		X
Yankee-Rowe	0.541	X
Core VIII		X
		X
Trino	0.570	X
Core 1		X
		X
JPDR Core 1	1.809	X
		X
		X
KRB	2.460	X
Fuel Lot 1		X

Total Pu

Reactor	Mean (%)[b]	
Sena Core 2	-1.615	X[c]
		X
		X
Dresden-1	-0.188	X
Fuel Lot 4		X
		X
Trino	3.744	XX
Core 1		XX
		XX
Yankee-Rowe	4.223	XXX
Core VIII		XXX
		XX
KRB	5.675	XX
Fuel Lot 1		XX
		XX
Trino	7.106	XX
Core 2		XX
		X
JPDR Core 1	11.160	X
		X

^{235}U

Reactor	Mean (%)[b]	
Dresden-1	-7.140	X[c]
Fuel Lot 4		X
		X
Trino	-6.170	X
Core 2		X
		X
Sena Core 2	-5.024	XX
		XX
		XX
KRB	-3.675	XXX
Fuel Lot 1		XXX
		XX
Yankee-Rowe	-1.171	XX
Core VIII		XX
		X
Trino	-1.096	X
Core 1		X
		X
JPDR Core 1	0.734	X
		X

$^{239}Pu + ^{241}Pu$

Reactor	Mean (%)[b]	
Dresden-1	-5.254	X[c]
Fuel Lot 4		X
		X
KRB	2.066	XX
Fuel Lot 1		XX
		X
Trino	4.390	X
Core 1		X
		X
Yankee-Rowe	6.274	X
Core VIII		X
		X
Trino	6.678	X
Core 2		X
		X
JPDR Core 1	10.491	X
		X
d	d	

Total Fissile

Reactor	Mean (%)[b]	
Dresden-1	-6.533	X[c]
Fuel Lot 4		X
		X
Trino	-2.605	XX
Core 2		XX
		X
KRB	-0.100	X
Fuel Lot 4		X
		X
Trino	0.0631	X
Core 1		X
		X
Yankee-Rowe	0.506	X
Core VIII		X
		X
JPDR Core 1	1.118	X
		X
d	d	

[a]Refs. 1 and 2.

[b] $\bar{d}$ = mean relative difference = $\frac{1}{n} \sum_{i=1}^{n} 100\left(\frac{\text{Predicted - Measured}}{\text{Measured}}\right)_i$ and

n = number of observations, Mean relative difference as defined in footnote a, Table X.

[c]Means connected by a single line are not significantly different, and those not connected by a single line are significantly different.

[d]Plutonium isotopic data not available for Sena.

TABLE A-II

SPENT-FUEL COMPOSITION
COMPARISON OF PREDICTED AND MEASURED VALUES:
DUNCAN'S MULTIPLE RANGE TEST WITH KRAMER'S EXTENSION FOR UNEQUAL REPLICATION[a]
(JPDR Data Eliminated)

Total U			Total Pu			^{235}U			^{239}Pu + ^{241}Pu			Total Fissile		
Reactor	Mean (%)[b]		Reactor	Mean (%)[b]		Reactor	Mean (%)[b]		Reactor	Mean (%)[b]		Reactor	Mean (%)[b]	
Sena Core 2	-1.164	X[c]	Sena Core 2	-1.615	X[c]	Dresden-1	-7.140	X[c]	Dresden-1	-5.254	X[c]	Dresden-1	-6.533	X[c]
		X			X	Fuel Lot 4		X	Fuel Lot 4		X	Fuel Lot 4		X
		X			X			X						
Dresden-1	-0.0582	X	Dresden-1	-0.188	X	Trino	-6.170	X	KRB	2.066	X	Trino	-2.605	X
Fuel Lot 4		X	Fuel Lot 4		X	Core 2		X	Fuel Lot 1		X	Core 2		X
		X						X			X			X
Trino	0.228	X	Trino	3.744	X	Sena Core 2	-6.024	XX	Trino	4.390	X	KRB	-0.100	X
Core 2		X	Core 1		X			XX	Core 1		X	Fuel Lot 4		X
		X			X			X			X			X
Yankee-Rowe	0.541	XX	Yankee-Rowe	4.223	XX	KRB	-3.675	XX	Yankee-Rowe	6.274	X	Trino	0.0631	X
Core VIII		XX	Core VIII		XX	Fuel Lot [illegible]		XX	Core VIII		X	Core 1		X
		XX			XX			X			X			X
Trino	0.570	XX	KRB	5.675	XX	Yankee-Rowe	-1.171	XX	Trino	6.678	X	Yankee-Rowe	0.506	X
Core 1		XX	Fuel Lot 1		XX	Core VIII		XX	Core 2		X	Core VIII		X
		X			X			X			X			X
KRB	2.460	X	Trino	7.106	X	Trino	-1.096	X	d	d		d	d	
		X	Core 2		X	Core 1		X						

[a]Refs. 1 and 2.

[b]Mean relative difference as defined in footnote b, Table A-I.

[c]Means connected by a single line are not significantly different, and those not connected by a single line are significantly different.

[d]Plutonium isotopic data not available for Sena.