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DEVELOPMENT AND APPLICATION OF
ISOTOPE CORRELATION TECHNIQUES

SELECTED ISOTOPIC FUNCTIONS: A DESCRIPTION
AND DEMONSTRATION OF THEIR USES

OCTOBER 1978

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Department of Energy
Safeguards & Security

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SELECTED ISOTOPIC FUNCTIONS: A
DESCRIPTION AND DEMONSTRATION OF
THEIR USES

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SUMMARY

This report has been prepared as part of the U.S. program to provide technical assistance to the International Atomic Energy Agency (IAEA). This report includes a description of eleven selected isotopic functions useful in the safeguards verification of input accountability measurements at a reprocessing facility. Table 1 provides a summary of how various factors affect the selected isotopic functions for pressurized water reactors (PWR). A similar summary table is provided for boiling water reactors (BWR) in Table 2. These two tables summarize the descriptive portion of this report.

A brief explanation of the terms in these tables will be provided to aid in understanding the tables. The eleven isotopic functions shown are pairings of various combination variables of uranium and plutonium isotopes and totals. A description and explanation of these variables and functions are provided in the body of the report. The column headings of the tables are explained as follows:

Enrichment Averaging - combining irradiated fuels of more than one initial enrichment in a reprocessing batch

Exposure Averaging - combining fuels of varying exposures (burnups) in a reprocessing batch

Fringe Effects - differences resulting from fuel being irradiated in the outer extremity of the core

Unirradiated Assembly - effects resulting from an unirradiated assembly being dissolved in a reprocessing batch

Cladding Effects - effects due to the differences between cladding type (e.g. Zircaloy compared to stainless steel)

Moderator Void Fraction - differences resultant from a change in the void fraction in BWRs.

Also included in this report is a demonstration of the verification process utilizing isotopic safeguards techniques. The example used is the verification (or nonverification) of various Pu/U measurements. The technique demonstrates both the internal consistency check and the external data source verification which uses a similar reference data source.

TABLE 1. Summary of the Effects on Selected Isotopic Functions for PWRs

Functions	Enrichment Averaging	Exposure Averaging	Fringe Effects	Unirradiated Assembly	Cladding Effects
Pu/U versus ^{235}U	no effect	no effect	no effect	10%-20% increase in IR*	no effect
Pu/U versus $(100 - ^{239}\text{Pu})$	no effect	slight IR increase	5%-10% IR reduction	30% IR reduction	5% lower IR for Zr* over SS*
$^{239}\text{Pu}^2$ versus ^{235}U	slight IR increase	slight IR increase	5%-10% IR increase	10%-30% strong increase	no effect
^{236}U versus ^{235}U	no effect	no effect	5% increase in IR	10% decrease in IR	no effect
^{240}Pu versus $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$	no effect	no effect	no effect	no effect	IR slightly increased for Zr
$^{239}\text{Pu} \times ^{240}\text{Pu}$ versus $^{235}\text{U} \times ^{241}\text{Pu}$	no effect	no effect	5% increase in IR	10% reduction in IR	5% increase IR for Zr over SS
$^{240}\text{Pu} \times ^{241}\text{Pu}$ versus $^{235}\text{U} \times ^{242}\text{Pu}$	no effect	no effect	5%-10% IR reduction	20% reduction in IR	Zr reduces IR slightly
^{240}Pu versus $\Delta(^{235}\text{U}^2)$	no effect	no effect	no effect	~35% IR increase	no effect
$(^{239}\text{Pu})^2 \times (100 - ^{239}\text{Pu}) / (^{235}\text{U})^2$ versus $(100 - ^{239}\text{Pu})$	no effect	no effect	slight IR reduction	~30% reduction in IR	slight reduction in IR for Zr
$(^{239}\text{Pu} \times ^{240}\text{Pu})^2$ versus ^{240}Pu	no effect	no effect	no effect	no effect	5% IR increase for Zr over SS
$^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ versus $\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$	no effect	no effect	no effect	IR increases ~20%	no effect

* IR - Isotopic Ratio
Zr - Zircaloy
SS - Stainless Steel

TABLE 2. Summary of the Effects on Selected Isotopic Functions for BWRs

Functions	Enrichment Averaging	Exposure Averaging	Fringe Effects	Unirradiated Assembly	Cladding Effects	Moderator Void Fraction
Pu/U versus ^{235}U	no effect	no effect	5%-10% reduction in IR*	no effect	no effect	IR fluctuates with in- creasing void
Pu/U versus $(100 - ^{239}\text{Pu})$	no effect	slight IR increase	5%-10% reduction in IR	40% IR reduction	5% lower IR for Zr* over SS*	6% IR decrease for 25% void increase
$^{239}\text{Pu}^2$ versus ^{235}U	slight IR increase	slight IR increase	<5% IR increase	10%-30% IR increase	5%-10% increase for SS	some influence
^{236}U versus ^{235}U	slight IR increase	slight IR increase	5% IR increase	10% decrease in IR	IR slightly higher for SS	IR decreases slightly with increase
^{240}Pu versus $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$	no effect	no effect	no effect	no effect	IR slightly higher for Zr	no effect
$^{239}\text{Pu} \times ^{240}\text{Pu}$ versus $^{235}\text{U} \times ^{241}\text{Pu}$	no effect	no effect	slight increase in IR	10%-30% reduc- tion in IR	slight decrease in IR for Zr	12% IR reduction for 25% void increase
$^{240}\text{Pu} \times ^{241}\text{Pu}$ versus $^{235}\text{U} \times ^{242}\text{Pu}$	no effect	5%-20% reduc- tion in IR	no effect	20% reduction in IR	no effect	possible effects
^{240}Pu versus $\Delta(^{235}\text{U}^2)$ $(^{239}\text{Pu})^2 \times (100 - ^{239}\text{Pu}) / (^{235}\text{U})^2$ versus $(100 - ^{239}\text{Pu})$	no effect	no effect	no effect	~35% IR increase	no effect	no effect
$(^{239}\text{Pu} \times ^{240}\text{Pu})^2$ versus ^{240}Pu	slight IR increase	slight IR decrease	slight IR reduction	~30% IR reduction	slight reduc- tion in IR for Zr	no effect
$^{239}\text{Pu} \times (100 \times ^{239}\text{Pu})$ versus $\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$	no effect	no effect	no effect	no effect	Zr increases IR 5% over SS	small influence
	no effect	no effect	no effect	IR increases ~20%	no effect	no effect

* IR - Isotopic Ratio
Zr - Zircaloy
SS - Stainless Steel

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INTRODUCTION

The necessity of avoiding nuclear weapons proliferation dictates that fissile nuclide inventories should be double-checked at each stage of the nuclear fuel cycle. At the head end of a reprocessing plant, for example, fissile content of the spent fuel solution can be sent off site for measurement by an independent laboratory. The need for these independent remeasurements can be minimized while maintaining the quality of fissile accounting through the application of Isotopic Safeguards Techniques (IST).

The fissile isotopes of concern are: ^{235}U , ^{239}Pu , and ^{241}Pu . The amounts of uranium and plutonium in spent fuel and the isotopic makeup of each are determined by two things: the initial uranium and isotopic composition, and the neutron flux exposure history.

The initial chemical and nuclidic composition of fuel assemblies in a reprocessing batch is known from fabrication plant measurements. For commercial LWR fuel, there will be no plutonium initially, only uranium isotopes ^{234}U , ^{235}U , ^{238}U , and possibly ^{236}U from enrichment plant residue of recycle fuels.

The neutron flux exposure history is subject to many variables, and anything affecting this also affects the isotopic makeup of the heavy metals. The heavy metal isotopes are influenced by reactor type, length and intensity of irradiation, position in the reactor core, cladding material, power history, or anything affecting flux magnitude and energy spectrum. The basis of IST is discovering relationships that maintain a consistency over some of these variations and utilizing this consistency in the verification of accountability tank measurements at the head end of a reprocessing facility.

This report establishes for the International Atomic Energy Agency (IAEA) the usefulness of eleven selected isotopic functions for the verification of reprocessing input accountability measurements. It includes a description of each function's specified use, an indication of each function's accuracy using available reprocessing data, and a demonstration of the technique.

CONCLUSION

This report has established a description and demonstration of selected isotopic functions for use in the verification of input accountability measurements using isotopic safeguards techniques. The demonstration illustrates how the technique may be applied to indicate which samples are in need of remeasurement. This reduction in the remeasurement needs while maintaining the accountability quality is the significant safeguarding asset of IST.

The descriptions have provided insight into the specific usefulness of each function. The accuracies or the percent standard deviations ($\% \sigma$) of the isotopic ratios and the slopes have been supplied along with other informational data in Appendix A for all available measured reprocessing data. These accuracies are used to depict the specific accuracy of a data group for each isotopic function which leads to the general accuracy limits of each function. These accuracy limits from reference data sources can be used as the decision criteria for the verification of incoming data.

Use of this document for internal and/or external verification of accountability measurement along with the in-depth analysis provided by the computer code MISTY,⁽⁶⁾ sent to the IAEA earlier this year, should provide the IAEA with excellent verification tools for the implementation of isotopic safeguards techniques.

ISOTOPIC VARIABLES AND FUNCTIONS

The data used by IST are the uranium and plutonium mass totals and the isotopic concentrations of ^{234}U , ^{235}U , ^{236}U , ^{238}U , ^{238}Pu , ^{239}Pu , ^{240}Pu , ^{241}Pu , and ^{242}Pu both before and after irradiation. The units used throughout this report for these quantities are: total plutonium - grams, total uranium - metric tons, plutonium isotopics - weight percent of plutonium, and uranium isotopics - weight percent of uranium. These isotopic (or total) quantities are combined to form isotopic variables through numerical shifts, exponentiation, multiplication, and division. Examples of isotopic variables are:

$$\begin{aligned} &^{239}\text{Pu} \times ^{240}\text{Pu} \\ &(100 - ^{239}\text{Pu}) \\ &^{239}\text{Pu} \times (100 - ^{239}\text{Pu}) \\ &[(^{239}\text{Pu})^2 \times (100 - ^{239}\text{Pu})]/(^{235}\text{U})^2 \\ &\text{Pu/U} \\ &\Delta(^{235}\text{U}) \text{ or } ^{235}\text{D} \end{aligned}$$

A variable may be evaluated using data solely obtained after irradiation or a combination of irradiated and initial data forming a delta (Δ) variable. For example, the isotopic variable $\Delta(^{235}\text{U})$ is (^{235}U final - ^{235}U initial). Because the term $\Delta^{235}\text{U}$ is used so frequently, it has been further simplified to ^{235}D to indicate the depletion of the ^{235}U isotope. Another delta variable is $(100 - ^{239}\text{Pu})$ in which the 100 indicates the initial isotopic composition of ^{239}Pu to be 100%. Even though no plutonium exists in UO_2 fresh fuel, the initial ^{239}Pu content is considered to be 100% because the first plutonium nucleus to be formed must be ^{239}Pu .

Isotopic functions are formed by plotting one variable against another variable. The isotopic ratio for a given function is the slope of the line

connecting the initial and irradiated points of a batch or sample. As an example, the isotopic ratio for the function ^{236}U versus ^{235}U is:

$$\frac{(^{236}\text{U})_{\text{irradiated}} - (^{236}\text{U})_{\text{initial}}}{(^{235}\text{U})_{\text{irradiated}} - (^{235}\text{U})_{\text{initial}}}$$

The most valuable isotopic ratios are those that remain constant as a function of exposure. If the isotopic ratios are constant within a monoenriched data group, the points on the functional plot will form a linear line over a large exposure range. Because differing exposure histories result in dissimilar isotopic compositions, this functional consistency is the feature of IST that supplies the common factor needed in the process of verification of accountability tank measurements.

THE SELECTED FUNCTIONS

Several useful, linear functions have been identified⁽¹⁾ and are listed below.

Total Plutonium Functions

Pu/U	versus	^{235}D
Pu/U	versus	$(100 - ^{239}\text{Pu})$

Isotopic Concentration Functions

$^{239}\text{Pu}^2$	versus	^{235}U
^{236}U	versus	^{235}U
^{240}Pu	versus	$^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$
$^{239}\text{Pu} \times ^{240}\text{Pu}$	versus	$^{235}\text{U} \times ^{241}\text{Pu}$
$^{240}\text{Pu} \times ^{241}\text{Pu}$	versus	$^{235}\text{U} \times ^{242}\text{Pu}$
^{240}Pu	versus	$\Delta(^{235}\text{U}^2)$
$(^{239}\text{Pu})^2 \times (100 - ^{239}\text{Pu}) / (^{235}\text{U})^2$	versus	$(100 - ^{239}\text{Pu})$

Backup Functions

$(^{239}\text{Pu} \times ^{240}\text{Pu})^2$	versus	^{240}Pu
$^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$	versus	$\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$

DESCRIPTION OF SELECTED FUNCTIONS

As mentioned previously, each function can be influenced by many parameters--core position, averaging of exposures and/or enrichments within a reprocessing batch, presence of unirradiated assemblies in a batch, etc. Each function is sensitive to some of these parameters and insensitive to others, and the degree of sensitivity is also variable. The sections that follow describe the effect of these parameters on each isotopic function, for each

type of reactor, as observed in measured reprocessing data. A summary of the effect of the parameters is also provided in Tables 1 and 2 for PWRs and BWRs, respectively.

The tables supplying the actual numbers of statistics associated with each of these functions are provided in Appendix A. The tables of Appendix A supply data from available reprocessing information for each of the eleven isotopic functions. Appendix A supplies the following for each of the eleven isotopic functions: 1) identification information such as number of batches, reactor, initial enrichment, cladding material, data source, and exposure levels; 2) mean isotopic ratio and percent standard deviation ($\% \sigma$); 3) slope, intercept, and percent standard deviation of the slope for Deming's ⁽²⁾ intercept model; 4) slope and its percent standard deviation for Deming's initial point model; and 5) any effects shown by the data. The $\% \sigma$ for the isotopic ratio and the slopes are the indications of the accuracies of each of the isotopic functions. The summary descriptions and tables in Appendix A of the isotopic functions will be presented in the order listed on the previous page.

Pu/U versus ^{235}D

The function Pu/U versus ^{235}D is an index of plutonium production. The units of Pu/U are grams of plutonium per tonne of uranium, and ^{235}D represents the change (or depletion) in weight percent of the uranium isotope ^{235}U . This function has been found to be linear over burnup from zero to 30,000 MWd/MTU for fuels of natural to 5% enriched ^{235}U content. The slope of the line is dependent on the initial ^{235}U enrichment of the fuel. The slope, $(\text{Pu/U})/^{235}\text{D}$, is defined to be the isotopic ratio associated with this function.

For PWRs the isotopic ratio varies inversely with enrichment (e.g. 5600 to 4900 for enrichments of 2.7%, to 4.9%). Effects that are due to weighted (to total uranium) enrichment averaging in reprocessing plant dissolver batches are negligible. The results are the same as if the fuel has initially all been of the average enrichment. Effects from mixing fuels of differing exposure are similarly negligible. Fringe effects, changes in the isotopic ratio from fuel assemblies being irradiated solely at the edge of the reactor core in a softer neutron spectrum, are also not evident. The inclusion of an

unirradiated assembly in a dissolver batch results in lowering both the Pu/U ratio and the value of ^{235}D , and the isotopic ratio increases by about 12%. The Deming's regression models give similar results for both the slope/intercept and initial point models.

For BWRs there are fewer data points than for PWRs, and the initial point regression model tends to be superior. Neither exposure averaging nor enrichment averaging has any effect. The effects of cladding change from stainless steel to Zircaloy are also small. BWR fuels are more sensitive to core location; fringe elements have an isotopic ratio 5% to 10% lower than core center fuel. An unirradiated fuel element dissolved in with others is not readily apparent in the isotopic ratio; however, Pu/U and ^{235}D are both significantly lowered by it. The isotopic ratio values are slightly higher than those for PWRs, ranging from 6200 to 3800 for 1.47% to 3.66% enrichments. A change in moderator void fraction from 0 to 25% raises the value of the ratio 8.5%, a further increase to 50% void lowers the value 4.3%.

The (Pu/U)/ ^{235}D isotopic ratios for heavy water reactors (HWRs) are consistent with those for BWRs at lower enrichment and low burnup. The British graphite moderator reactor (GMR) has a slope about 40% less than those of PWRs.

The values of the isotopic ratio are quite consistent within random measurement variation. For those enrichments with sufficient data, the standard deviation is regularly less than 2% and largely represents the propagation of random measurement errors in the individual parts of the ratio. Very little variation as a result of reactor operation history has been observed, beyond those of fringe position fuel assemblies.

Summary

Pu/U versus ^{235}D is a good function for verification of the Pu/U ratio for fuels from natural to 5% enrichment, zero to 30,000 MWd/MTU exposure.

	PWR	BWR
Enrichment averaging	no effect	no effect
Exposure averaging	no effect	no effect
Fringe effects	no effect	5%-10% reduction in IR ^(a)
Unirradiated assembly	10%-20% IR increase	no effect on IR
Cladding effects	no effect	no effect
Moderator void fraction	--	IR change fluctuates

Pu/U versus $(100 - {}^{239}\text{Pu})$

The function Pu/U versus $(100 - {}^{239}\text{Pu})$ is also an index of plutonium production. The units of Pu/U are grams plutonium per tonne of uranium. The variable $(100 - {}^{239}\text{Pu})$ is the change in weight percent of the isotope ${}^{239}\text{Pu}$. This function has been found to vary smoothly over burnup from zero to 30,000 MWd/MTU for fuels of natural to 5% enriched uranium. The slope of the curve is largely dependent on the initial enrichment of the fuel, and to a lesser degree on the burnup. The slope increases both with increased enrichment and with increased burnup. The slope, $(\text{Pu/U})/(100 - {}^{239}\text{Pu})$, is defined to be the isotopic ratio associated with this function.

For PWRs, values of the isotopic ratio range from 250 to 300 for 3.4% enriched fuel of burnup from 4000 to 12,000 MWd/MTU, and from 318 to 357 for 4.1% enriched fuel at burnups from 9700 to 25,600 MWd/MTU. The ratio varies smoothly; for exposure ranges of ≥ 5000 MWd/MTU, Deming's slope-intercept linear regression model is a good predictor of the ratio for a given enrichment. Above about 15,000 MWd/MTU total exposure, the intercept model is especially good. For fuel reprocessing plant dissolver batches, enrichment averaging has no effect; the resultant curve resembles that which would occur in actual fuel of the average enrichment. However, since the ratio varies with exposure, the effect of exposure averaging in reprocessing batches is noticeable. Reactor core fuel position effects or fringe effects are also noticeable. A fuel assembly that has been irradiated solely in the softer spectrum at the edge of the core will have an isotopic ratio value about 5% to 10% lower than a core center element. Also noticeable are unirradiated fuel assemblies dissolved

(a) Isotopic ratio

in a reprocessing batch. Unirradiated assemblies show strong lowering of the isotopic ratio value by about 30%. The use of Zircaloy cladding also results in about 5% lowering of the ratio over elements clad in stainless steel.

Most of the comments applying to PWRs apply also to BWRs. The function remains slightly nonlinear. The average values are somewhat lower than those for PWRs. Deming's initial point regression model generally gives the best results for BWRs because there are not as many points widely spaced in exposure as there are for PWRs, and also because the average burnup for the BWR data is lower than that for PWRs. Like PWRs, fringe position assemblies lower the isotopic ratio by about 5% to 10%. Unirradiated assemblies lower reprocessing plant batch ratios strongly, by about 40%. Use of stainless steel cladding raises the ratio over that from elements clad with Zircaloy. There is core-to-core variation that may be due to differing moderator void fraction. Calculated data for the Big Rock Point reactor shows that an increase in reactor void percent of 25% (i.e., from 0% to 25% or from 25% to 50%) results in a 6.5% decrease in the value of the isotopic ratio.

The isotopic function for HWRs is an exception to those for PWRs and BWRs. The function is quite linear, with a lower slope than for PWRs or BWRs at about 115. Deming's intercept and initial point regression models correspond well. For graphite moderated reactors, the mean is even lower than for HWRs, but there is too much scatter in the data to obtain a good regression expression.

There is little difference between the values of the isotopic ratio calculated from the measured and remeasured data. Variation is generally well within the standard deviation. The standard deviation for data sets with less than about a 10,000 MWd/MTU exposure range is generally less than 2%.

Summary

The function $\text{Pu/U versus } (100 - {}^{239}\text{Pu})$ is a good backup function for verification of the Pu/U ratio; it should probably be used in conjunction with $\text{Pu/U versus } {}^{235}\text{D}$.

	PWR	BWR
Enrichment averaging	no effect	no effect
Exposure averaging	slight IR increase	slight IR increase
Fringe effects	5%-10% IR reduction	5%-10% IR reduction
Unirradiated assembly	30% IR reduction	40% IR reduction
Cladding effects	5% lower IR for Zr ^(a) than SS ^(b)	5% lower IR for Zr than SS
Moderator void fraction	--	6% IR decrease for 25% void increase

$^{239}\text{Pu}^2$ versus ^{235}U

The function $^{239}\text{Pu}^2$ versus ^{235}U can be used to verify ^{239}Pu measurements. Values are in weight percent. The function is fairly linear even at low burnup because it involves no higher plutonium isotopes, which take time to build up. The isotopic ratios are constant within a 2% or less standard deviation over wide burnup ranges. The slope increases with decreasing enrichment and with decreasing exposure, with enrichment the dominant effect.

For PWR fuels, the isotopic ratio varies from 2236 for 4.935 wt% enriched Yankee Rowe fuel to 4846 for 3.454 wt% enriched Trino fuel. The ratio may be slightly increased by averaging of enrichments or exposures in a reprocessing plant dissolver batch. A larger increase, 5%-10%, is seen for fuels irradiated at the outer fringe of their cores. The type of cladding material has no discernible influence. The presence of an unirradiated fuel assembly in a batch strongly increases the ratio, the amount depending on the number of assemblies in the batch. The function exhibits its best linearity at high burnup (over 15,000 MWD/MTU) but is also fairly linear at lower burnup, especially with a wide range of exposures within an enrichment group.

BWR fuels have higher isotopic ratios because the enrichment is lower; the ratios span the range 3600-7500. The function is not as linear as for the PWR, because of the lower enrichments and narrower burnup spans. Enrichment and exposure averaging raises the isotopic ratio slightly, as do fringe effects; these affect the ratios less than 5%. Stainless steel clad BWR fuels have ratios 5%-10% higher than fuels clad in Zircaloy. Again, the presence of an

(a) Zr - Zircaloy
(b) SS - stainless steel

unirradiated assembly sharply increases the isotopic ratio, by 10%-30% depending on batch size. Also, there are differences from core to core for a single reactor that suggest a dependence on moderator void fraction.

HWR and GMR data also seem linear, but the scatter is too high to recommend the use of this function for measurement verification for these fuels.

Summary

The function $^{239}\text{Pu}^2$ versus ^{235}U can be used to check ^{239}Pu measurements for spent LWR fuels and possibly HWR and GMR fuels as well. At least the low enrichment of HWR fuels forces their ratios high enough to distinguish them unmistakably from LWR values, making the function useful as an identifier of HWR assemblies. Another possible use is for back-calculation of initial enrichment.

	<u>PWR</u>	<u>BWR</u>
Averaging	slight IR increase	slight IR increase
Fringe effects	5%-10% IR increase	<5% IR increase
Unirradiated assembly	strong increase, 10%-30%	strong increase, 10%-30%
Cladding effects	no effect	5%-10% increase for SS
Moderator void fraction	--	some influence possible

^{236}U versus ^{235}U

The function ^{236}U versus ^{235}U can be used to verify measurements of both of these uranium isotopes. The values are in weight percent. This function is fairly linear over all burnups from zero to 30,000 MWd/MTU, for fuels enriched up to 5% in ^{235}U .

For PWR fuels, the isotopic ratio ranges from -0.19 to -0.23, increasing in absolute value with increasing enrichment. Averaging of enrichments or exposures in a reprocessing plant dissolver batch has very little, if any, effect on the isotopic ratio. Fringe position in the reactor core causes the ratio to increase somewhat, about 5%. The presence of an unirradiated assembly in a batch reduces its isotopic ratio about 10%. Cladding material has no discernible influence on the ratio.

BWR fuels have isotopic ratios slightly smaller than PWR fuels because the enrichment is generally lower in a BWR. The ratio increases with high enrichment because ^{235}U dominates the use of the neutron supply, limiting the depletion of ^{236}U . Because this effect is slight, the range of BWR isotopic ratios is about -0.17 to -0.20. Averaging in reprocessing batches has the same effect as for the PWRs, a very slight increase in the isotopic ratio. An unirradiated assembly will decrease the ratio by about 10%. Fringe effects are the same as for a PWR--a slight increase in the ratio. The ratio for stainless-steel clad fuels is slightly higher than for Zircaloy or Inconel-clad fuels.

The small amount of data available on HWRs and GMRs are not as linear as LWR data. The function does not seem useful for those reactor types, but with more data it may prove useful.

Summary

The function ^{236}U versus ^{235}U can be used to verify ^{236}U and ^{235}U content of LWR spent fuels. There are few data on other reactor types (HWR and GMR), and what data exist are not encouraging. The use of this function for these reactors is not recommended at this time.

	<u>PWR</u>	<u>BWR</u>
Averaging	very little effect, perhaps slight increase	very little effect, perhaps slight increase
Fringe effects	5% increase in ratio	5% increase in ratio
Unirradiated assembly	10% decrease	10% decrease
Cladding effects	no effect	ratio slightly higher for SS
Moderator void fraction	--	ratio

^{240}Pu versus $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$

The function ^{240}Pu versus $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ is a very stable function for verifying the ^{240}Pu content of reprocessed fuels. The units of the variables ^{240}Pu and ^{239}Pu are in weight percent of total plutonium. The value of the function is dependent only on the response of plutonium to irradiation, therefore, many of the effects noticeable in other functions are not apparent. Specifically, this function is only slightly dependent on initial ^{235}U enrichment.

As an example for PWRs, the isotopic ratio $^{240}\text{Pu}/^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ for the Indian Point 1 reactor ranges only from 8.152×10^{-3} for 2.87% enriched fuel at 12,400 MWd/MTU to 7.868×10^{-3} for 4.08% enriched fuel at 24,000 MWd/MTU, a change of only 3.67% for quite different enrichments and exposures. The stability of the function is reflected in its properties described below. Effects due to averaging enrichment or exposure are negligible. The function does not exhibit fringe effects. Presence of an unirradiated assembly in a dissolver batch is undetectable. There are not enough data points to say definitely, but it appears that use of Zircaloy cladding raises the ratio slightly over that for fuel clad in stainless steel.

The isotopic ratio for BWRs is slightly more reactor specific than for PWRs. Average values are around 8.8×10^{-3} for Big Rock Point, 1.0×10^{-2} for Dresden 1, and 9.1×10^{-3} for Humboldt Bay. These values are very stable for each reactor. The isotopic ratio does not show effects from enrichment or exposure averaging, from fringe effects, or from the presence of an unirradiated assembly. Use of stainless steel cladding instead of Zircaloy lowers the value of the ratio by about 5%.

The values of the isotopic ratio for HWRs and GMRs are slightly higher than for LWRs, but by no more than 10%. Since the enrichment is lower in these reactor types, this is to be expected.

Summary

The function ^{240}Pu versus $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ is not sensitive to the quantity of plutonium present in spent fuel, and the formation of the denominator makes it insensitive to minor ^{239}Pu variations as well. It is an excellent function for verification of ^{240}Pu if ^{239}Pu is well known.

	<u>PWR</u>	<u>BWR</u>
Averaging	no effect	no effect
Fringe effects	no effect	no effect
Unirradiated assembly	no effect	no effect
Cladding effects	IR slightly raised for Zr	IR slightly raised for Zr over SS

$^{239}\text{Pu} \times ^{240}\text{Pu}$ versus $^{235}\text{U} \times ^{241}\text{Pu}$

The function $^{239}\text{Pu} \times ^{240}\text{Pu}$ versus $^{235}\text{U} \times ^{241}\text{Pu}$ is useful for checking the ^{240}Pu and ^{241}Pu concentration values, if the exposure limits are not ignored. The value of the isotopic ratio, $(^{239}\text{Pu} \times ^{240}\text{Pu})/(^{235}\text{U} \times ^{241}\text{Pu})$, is reasonably constant for exposures greater than 15,000 MWd/MTU for PWRs or 12,000 MWd/MTU for BWRs, but below these limits the ratio increases rapidly. This is a result of the small amounts of ^{241}Pu at low exposures.

For PWR fuel above 15,000 MWd/MTU, Deming's intercept linear regression model works well. Good examples are for Yankee Rowe fuel, 3.404% and 4.935% enriched fuel. The average isotopic ratios for these fuels are $64.01 \pm 5.6\%$ and $36.56 \pm 0.6\%$, but the linear regression gives slope/intercept combinations of 31.71/500.3 and 30.09/183.7, respectively. This difference between the ratios and the slopes stems from the fact that the ratios are forced to pass linearly through the initial point while the intercept model strictly fits the data points available. The intercept model determines a slope linear for the data in the higher exposure range but differing largely from the ratio and initial point model's slope because the intercept model's slope is not forced through this nonlinear region at the lower exposure levels. In general, for PWRs the function is little affected by enrichment or exposure averaging in dissolver batches. Fringe effects are small. The presence of an unirradiated assembly in the reprocessing batch lowers the value of the isotopic ratio by about 10%. The use of Zircaloy cladding instead of stainless steel raises the value of the ratio about 5%.

The nonlinearity of the function makes analysis of BWR properties difficult. Since little available BWR data exceeds 12,000 MWd/MTU, none of Deming's intercept models appears valid. Part of the difficulty lies in the fact that the function is sensitive to reactor moderator void fraction. Analysis of calculated data for Big Rock Point indicates that there is a 12% reduction in the value of the function for a 25% increase in void (i.e., from 0% to 25%, or from 25% to 50% voids). The presence of cold scrap or an unirradiated assembly in the dissolver batch lowers the value of the ratio up to 30%. Also, it appears that use of stainless steel cladding raises the ratio value over those from fuels clad in Zircaloy.

Values for GMRs and HWRs are similarly difficult to determine accurately. GMR ratio values are considerably higher than those of PWRs or BWRs. Values for HWRs are greater than 10 times those of LWRs. This is due to the low enrichment and low burnup of HWR fuels. Both circumstances act to raise the ratio values.

Summary

$(^{239}\text{Pu} \times ^{240}\text{Pu})/(^{235}\text{U} \times ^{241}\text{Pu})$ could be a useful function for PWRs.

With further data in the useful burnup range it would also be useful for BWRs. One advantage to the ratio is its sensitivity to initial ^{235}U enrichment without requiring knowledge of that value. Under the proper circumstances, it could be used to verify ^{235}U initial enrichment.

	<u>PWR</u>	<u>BWR</u>
Averaging	no effect	no effect
Fringe effects	5% increase in IR	slight IR increase
Unirradiated assembly	10% reduction in IR	10%-30% reduction in IR
Cladding effects	Zircaloy raises IR 5% over SS	slight decrease in IR for Zr compared to SS
Moderator void fraction	--	12% IR reduction for 25% void increase (from 0-25% or from 25%-50%)

$^{240}\text{Pu} \times ^{241}\text{Pu}$ versus $^{235}\text{U} \times ^{242}\text{Pu}$

The function $^{240}\text{Pu} \times ^{241}\text{Pu}$ versus $^{235}\text{U} \times ^{242}\text{Pu}$ is well suited for verification of measurements of concentrations of the higher plutonium isotopes. Within the measurement scatter of the higher isotopes it is very linear. The isotopic ratio $(^{240}\text{Pu} \times ^{241}\text{Pu})/(^{235}\text{U} \times ^{242}\text{Pu})$ is independent of the initial ^{235}U enrichment of the fuel. The units of all variables are weight percent.

For PWRs, Deming's slope/intercept linear regression model often gives results very similar to the initial point model. Values range from an isotopic ratio of $56.70 \pm 0.1\%$, with a slope/intercept of 54.67/3.96 (standard deviation of $\pm 1.3\%$) for 3.130% enriched fuel to $33.07 \pm 1.5\%$ with a slope/intercept of 33.45/-1.56 (standard deviation of $\pm 4.5\%$) for 4.935% enriched

fuel. The isotopic ratio is not affected by averaging of exposure or enrichment in a dissolver batch. The presence of an unirradiated assembly in the dissolver batch lowers the ratio by about 20% (depending on how many fuel elements are dissolved together). The use of Zircaloy cladding instead of stainless steel lowers the value of the ratio slightly. Only fuel from the Trino reactor shows evidence of fringe effects; elements irradiated at the outer edge of the Trino core appear to have an isotopic ratio value around 5% lower than others.

The function is also quite linear for BWRs. The initial point and intercept regression models again correspond. Examples range from a ratio of $137.7 \pm 2.1\%$ with a slope/intercept combination of $142.1/-2.797 (\pm 9.9\% \sigma)$ for 1.474% enriched fuel to $73.26 \pm 1.2\%$ with a slope/intercept of $73.97/-0.534 (\pm 4.7\% \sigma)$ for 2.578% enriched fuel. In contrast to PWRs, there do seem to be effects in the ratio from exposure averaging, tending to strongly lower the ratio. Also noticeable are differences between core loadings of the same reactor. This indicates a possibility that varying moderator void concentrations may affect the ratio by over 15%, although calculated results from the Big Rock Point reactor do not indicate such strong variations. Like PWRs (other than Trino), fringe effects seem negligible. The presence of an unirradiated assembly also strongly lowers the magnitude of the isotopic ratio.

Values of the function for GMRs and HWRs range from 3 to 10 times higher than those for LWRs. There is too much scatter in the limited data for these reactor types to specify any other parameters.

There are more data outliers for this function than for others because it uses the high plutonium isotopes for which measurement precision is less. Nevertheless, the majority of the data lie within a standard deviation of 3%.

Summary

The function $^{240}\text{Pu} \times ^{241}\text{Pu}$ versus $^{235}\text{U} \times ^{242}\text{Pu}$ is quite linear over burnup and should be an excellent function for verification of ^{241}Pu and ^{242}Pu in light water reactors, and possibly others if better data can be obtained.

	PWR	BWR
Enrichment averaging	no effect	no effect
Exposure averaging	no effect	reduction in IR, 5%-20%
Fringe effects	5%-10% reduction	no effect
Unirradiated assembly	20% reduction in IR	20% reduction in IR
Cladding effects	Zr may reduce IR slightly	no effect
Moderator void fraction	--	effects possible; data conflict

^{240}Pu versus $\Delta(^{235}\text{U}^2)$

The function of ^{240}Pu versus $\Delta(^{235}\text{U}^2)$ is an indicator of ^{240}Pu concentration for fuels above about 15,000 MWd/MTU for PWRs or about 12,000 MWd/MTU for BWRs. The function is nonlinear below these exposures because of the slow initial ^{240}Pu buildup with exposure. The units on ^{240}Pu are weight percent and the variable $\Delta(^{235}\text{U}^2)$ represents the change of the square of the ^{235}U concentration in weight percent from the initial enrichment.

Deming's intercept linear regression model is valid for PWR fuels above the minimum burnup limit (15,000 MWd/MTU). Functional values observed in fuel from three separate reactors with a 3.5% ^{235}U enrichment are an isotopic ratio of about -2.1, and slope/intercept of -1.6/3.3. This difference again is due to the forcing of the ratio through the nonlinear region to the initial point. The isotopic ratio decreases with increasing burnup to about 15,000 MWd/MTU. The function is not significantly affected by averaging of fuels of differing exposures or initial enrichments in a reprocessing plant dissolver batch. The use of Zircaloy instead of stainless steel for cladding is similarly indistinguishable. Effects attributable to neutron energy spectrum variations, such as fringe effects, are small--less than 5% change in the isotopic ratio. The presence of an unirradiated assembly in a dissolver batch does result in a ratio about 35% greater than normal.

Those comments applying to PWRs apply also to BWRs. The function is non-linear below about 12,000 MWd/MTU. A representative value for the slope/intercept combination is -3.2/4.0 for 2.5% ^{235}U enriched BWR fuels of higher exposure. This isotopic function for BWRs also is not affected by changes in the moderator void percent.

For GMRs and HWRs the magnitude of the isotopic ratio $^{240}\text{Pu}/\Delta(^{235}\text{U}^2)$ is considerably higher than for LWRs. For HWRs it is over ten times larger than for LWRs. This is partially explained by the fact that the value of the function increases with decreasing enrichment, and the HWRs are fueled with natural uranium. The basic reason is that while there is almost as much plutonium formed, there is considerably less change in the ^{235}U concentration, being small initially.

The standard deviation on values of the isotopic ratio is generally less than 2% for light water reactors. The results of measured and remeasured data sets generally fall well within one standard deviation. The results for GMRs and HWRs are not as good, having considerably more scatter.

Summary

The function $^{240}\text{Pu}/\Delta(^{235}\text{U}^2)$ appears to be a good function for verifying ^{240}Pu in medium to high burnup fuels. This function would work in conjunction with the function $^{240}\text{Pu}/^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ for ^{240}Pu verification.

	<u>PWR</u>	<u>BWR</u>
Averaging	no effect	no effect
Fringe effects	no effect	no effect
Unirradiated assembly	~35% IR increase	~35% IR increase
Cladding effects	no effect	no effect
Moderator void fraction	--	no effect

$$\frac{^{239}\text{Pu}^2 \times (100 - ^{239}\text{Pu})}{^{235}\text{U}^2} \text{ versus } (100 - ^{239}\text{Pu})$$

This function may be used to verify measurements of ^{239}Pu for LWR spent fuels. The slope of the function, $^{239}\text{Pu}^2/^{235}\text{U}^2$, increases with decreased

enrichment and, to a lesser degree, with increased burnup. All values are measured in weight percent; $(100 - {}^{239}\text{Pu})$ denotes the change in ${}^{239}\text{Pu}$ weight percent during irradiation.

Isotopic ratios for PWR fuels range from 623 to 2054, for 4.935% and 2.719% enrichment, respectively. The value of the ratio is unaffected by averaging of enrichments or exposures in a reprocessing plant dissolver batch. Influences tending to soften the neutron spectrum cause a slight reduction in the ratio, specifically, fringe position and Zircaloy cladding (opposed to stainless steel). Inclusion of an unirradiated fuel assembly in a batch reduces its isotopic ratio about 30%. The function is reasonably linear for almost any burnup, since little time is needed to build up ${}^{239}\text{Pu}$, but its best performance is at higher burnups or wide burnup spans within an enrichment group.

BWR values are higher (because of lower enrichment) and have somewhat higher standard deviations. The function is not quite as linear as for PWR fuels, but is still useful. The isotopic ratios fall in the range 900-10,000. The influence of cladding type and core position is the same as for PWRs, as is the response to an unirradiated assembly. Very small variations can be observed due to averaging: enrichment averaging increases the ratio, exposure averaging decreases it. There seems to be no dependence on moderator void fraction.

Fuels from HWRs and GMRs show promise of linearity, but the available data are too limited and have too much scatter to indicate definitely how useful the function will be for these reactor types. Because the slope is enrichment dominated, the HWR isotopic ratios are higher (factor of 10) than LWR values, different enough to serve as indicators for natural-enrichment fueled reactors.

Summary

The function ${}^{239}\text{Pu}^2 \times (100 - {}^{239}\text{Pu}) / {}^{235}\text{U}^2$ versus $(100 - {}^{239}\text{Pu})$ can be used to verify ${}^{239}\text{Pu}$ content of spent LWR fuels. The strong enrichment dependence of the slope makes it possible for this function to distinguish natural uranium fuels from LWR fuels on the basis of isotopic ratio.

	PWR	BWR
Enrichment averaging	no effect	slight increase
Exposure averaging	no effect	slight increase
Fringe effects	slight reduction of IR	slight IR reduction
Unirradiated assembly	strong reduction of IR (~30%)	IR drops ~30%
Cladding effects	slight reduction of IR for Zr	slight drop for Zr
Moderator void fraction	--	no effect

$^{239}\text{Pu}^2 \times ^{240}\text{Pu}^2$ versus ^{240}Pu

The isotopic function $^{239}\text{Pu}^2 \times ^{240}\text{Pu}^2$ versus ^{240}Pu reduces to the function $^{239}\text{Pu}^2 \times ^{240}\text{Pu}$, which can be used to verify the ^{240}Pu concentration measurements of intermediate to high burnup fuel. The variables are in units of weight percent of total plutonium. Since there are no uranium isotopes included in the function, it is only very slightly dependent on initial ^{235}U enrichment. Other effects not directly related to the responses of plutonium to irradiation are also not noticeable.

For PWRs, the function is nonlinear below about 14,000 MWd/MTU. Above this point both Deming's initial point and slope/intercept linear regression models tend to give similar results, the slope of the intercept model being somewhat less than that of the initial point model. Averaging of dissolved fuel by enrichment or by exposure does not have an effect on the value of the function. The function is not extremely sensitive to the position of the fuel in the core during irradiation, fringe effects are small. The presence of an unirradiated assembly in the reprocessing batch is naturally not noticeable, since it would bring in no plutonium. The use of Zircaloy cladding instead of stainless steel appears to result in an increase of about 5% in the value of the function.

The function $^{239}\text{Pu}^2 \times ^{240}\text{Pu}$ for BWRs also appears to be nonlinear below 14,000 MWd/MTU burnup. Because little of the BWR data exceed this burnup, it is difficult to accurately predict the functional properties. As with PWRs, the function does not show effects from fringe position or

unirradiated assemblies. Calculated data from the Big Rock Point reactor indicate that there is a possibility of small changes in the value of the function with varying moderator void fraction. Differences in the measured data from separate cores or fuel lots show variations of up to 4% from fuel lot to lot that could be attributed to differing reactor void conditions. As in PWRs, use of stainless steel cladding results in a lower value of the function than use of Zircaloy.

Data from GMRs and HWRs are from a small amount of fuel at low exposures. The results are fairly linear. The overall values are higher than those from light water reactors. There seems to be a dominant effect because of moderator atomic mass; LWRs have the lowest average isotopic ratios, HWRs the next highest, and GMRs the highest isotopic ratios of all.

Summary

The slope, $^{239}\text{Pu}^2 \times ^{240}\text{Pu}$, of the function increases with increasing burnup to about 14,000 MWd/MTU for LWRs. Above this point, it remains fairly constant and the function would be useful as a backup in verification of the ^{240}Pu content of spent fuel.

Also, since the slope is so specific for each reactor type, it can serve to identify the reactor type.

	<u>PWR</u>	<u>BWR</u>
Averaging	no effect	no effect
Fringe effects	no effect	no effect
Unirradiated assembly	no effect	no effect
Cladding effects	Zr increases IR 5% over SS	Zr increases IR 5% over SS
Moderator void fraction	--	small influence

$^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ versus $\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$

The function $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ versus $\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$ is very nearly linear for exposures greater than about 4000 MWd/MTU. However, the linearity is obtained at the expense of sensitivity, for the function is not a reliable indicator of plutonium diversion. That is, a large perturbation

in ^{239}Pu will produce little or no change in the isotopic ratio. The units of the variables ^{235}U and ^{239}Pu are weight percent and the symbol " Δ " represents the difference between the irradiated and initial values for the product ($^{235}\text{U} \times ^{239}\text{Pu}^2$).

For PWRs, values of the isotopic ratio range from -0.105 for 2.7% enriched fuel at 12,500 MWd/MTU to -0.058 for 4.94% enriched fuel at 24,000 MWd/MTU. Effects of enrichment and exposure averaging in reprocessing batches are not noticeable. Core position effects (changes in the ratio from fuel irradiated in the outer fringes of the core) are also not evident. Use of stainless steel or Zircaloy cladding does not make a difference. The presence of an unirradiated fuel assembly in the dissolver batch does raise the ratio about 20%--the only circumstance that makes a significant change in the ratio. Above about 5000 MWd/MTU, the Deming's intercept linear regression model is superior, the function is slightly nonlinear at low burnup.

The magnitudes of the isotopic ratio for BWRs are somewhat larger than for PWRs, since BWRs generally have lower enrichments. Values range from -0.191 for 1.47% enriched fuel at 5000 MWd/MTU to -0.081 for 3.66% fuel at 6000 MWd/MTU. Comments applying to PWRs are also true for BWRs. BWR moderator void changes do not significantly affect the ratio.

Values of the isotopic ratio for graphite moderated reactors are approximately the same as those for light water reactors. Heavy water reactors, however, have ratio values about three times as high as LWRs.

Summary

The function $^{239}\text{Pu} \times (100 - ^{239}\text{Pu})$ versus $\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$ has poor diversion sensitivity and is probably only useful as a backup identifier of unirradiated assemblies or as an identifier of HWR fuel.

	PWR	BWR
Averaging	no effect	no effect
Fringe effects	no effect	no effect
Unirradiated assembly	IR increases ~20%	IR increases ~20%
Cladding effects	no effect	no effect
Moderator void fraction	--	no effect

DEMONSTRATION OF THE TECHNIQUE

Isotopic Safeguards Techniques are used to check accountability tank measurements of total plutonium, and plutonium and uranium isotopic compositions without resorting to off-site remeasurements for every batch. Instead of remeasuring every batch, IST indicates those batches whose measurements are most questionable, and only those batches need to be remeasured.

Isotopic functions that are linear with respect to burnup are used to facilitate batch comparisons. Since the isotopic ratios of mono-enriched batches of various exposures should be constant for a linear function, those batches with ratios differing significantly from the mean are indicated for remeasurement.

How large a percentage of all batches is indicated for remeasurement depends on the tolerance. For the purpose of this demonstration analysis, a batch with an isotopic ratio more than two standard deviations (2σ) from the mean shall be considered a statistical outlier and be recommended for remeasurement. If a tighter tolerance is defined (less than two standard deviations), more batches will be identified as outliers. A wider tolerance will indicate fewer batches to remeasure.

INTERNAL CONSISTENCY

Incorrectly measured and anomalous batch data can be identified by IST, if, by using isotopic functions, they are shown to be inconsistent with other data in the reprocessing campaign, provided that the data are from the same core and of the same enrichment. As mentioned above, this is done by calculating the isotopic ratios for each batch and then the mean and standard deviation (SD) for all batches, followed by an analysis to determine outliers.

Midcampaign Analysis

It is sometimes possible to identify a batch as an outlier before the campaign is over, if the data is analyzed batch-by-batch as it is measured. This is done by recalculating the mean and SD after each batch is measured and checking for outliers. Since a midcampaign statistical analysis has fewer data points available, the mean and SD are not as reliable as those calculated when the campaign is completed.

Two recommendations on the proper use of midcampaign analysis follow:

1. Early commitment to remeasurement of a sample is necessary only in the case of truly wild variance that cannot be explained by foreknowledge of the function's behavior and is unlikely to be reconfirmed as an acceptable data point by upcoming samples and the final campaign analysis.
2. A sample shown to be acceptable by midcampaign analysis statistics must not be forgotten; all sample or batch data must be verified by the final campaign analysis.

The usefulness of a midcampaign analysis is that the isotopic ratios can be formed and evaluated on a batch-by-batch basis. In this way some insight into the final analysis can be obtained during actual reprocessing, and any wildly anomalous data can be detected as early as possible.

DEMONSTRATION OF THE INTERNAL ANALYSIS

A demonstration analysis is provided using 24 small sample burnup data⁽³⁾ from assembly A-20 of the Japan Power Demonstration Reactor I (JPDR-I). These data were chosen for the demonstration analysis because JPDR-I fuel has recently been reprocessed in campaign I at the Tokai-mura reprocessing facility. The data from those reprocessed batches will be analyzed next year using IST. The analysis presented here provides useful information for the upcoming analysis of the reprocessing data. This demonstration will also show that IST has broader applicability to any irradiated data samples as well as reprocessing data.

The fuel from assembly A-20 was initially enriched to 2.629 atom percent (2.597 weight percent) ^{235}U . The isotopic functions used in the demonstration are Pu/U versus ^{235}D and Pu/U versus $(100 - ^{239}\text{Pu})$, the functions designed to verify total plutonium using the Pu/U ratio method.^(4,5) The data from these burnup samples yield the isotopic ratios and associated statistics shown in Table 3.

TABLE 3. IST Data from JPDR-1 Assembly A-20.

Ident*	Pu/U	σ	Pu/U	σ
	$\frac{235}{238}\text{D}$	Fraction	$(100 - \frac{239}{238}\text{Pu})$	Fraction
2275	-4305.0	-.005	188.44	.111
2641	-5038.9	-1.163	204.43	.784
4142	-5000.1	-1.102	206.53	.872
3974	-4313.2	-.018	186.10	.013
4964	-4168.5	.211	178.18	-.320
5143	-5007.1	-1.113	212.93	1.141
5173	-4233.9	.107	184.35	-.061
5252	-4045.1	.405	176.51	-.390
5621	-4654.1	-.556	199.77	.588
5651	-4634.4	-.528	195.83	.422
5422	-4001.9	.474	175.33	-.440
5366	-3956.1	.546	173.92	-.499
5772	-4446.8	-.229	187.71	.081
5944	-4933.5	-.997	206.66	.878
5963	-4807.3	-.798	205.98	.849
6145	-4888.6	-.926	208.10	.938
6071	-4457.9	-.246	295.50	.408
6331	-4383.6	-.129	193.15	.310
6565	-4419.3	-.185	193.28	.315
6562	-3822.6	.757	173.99	-.496
6232	-2049.4	3.556	957.60	-3.786
7011	-4060.6	.381	183.11	-.113
6712	-3452.6	1.341	155.23	-1.285
7061	-4162.4	.220	178.26	-.317
Mean	-4301.9		185.79	
Std. Dev (σ)	633.46		23.779	
%SD	-14.725		12.799	

- * The ident number supplies two pieces of information. The two right-most digits indicate a batch or sample identification number, while the remaining digits give the burnup in hundreds of MWd/MTU (e.g., ident number 2275 indicates sample number 75 with an exposure of 2200 MWd/MT).

Using the two standard deviation (2σ) criteria, sample ident 6232 was found to be an outlier, for both isotopic ratios differed by greater than 3σ . This outlier determination was confirmed by performing a regression analysis on this group of data points. The computer output for Pu/U versus ^{235}D is illustrated in Table 4 and Table 5. Table 4 shows the regression analysis that detects the outlier point, while Table 5 illustrates the analysis after the outlier point has been removed. Tables 6 and 7 are similar regression analyses performed for the function Pu/U versus $(100 - ^{239}\text{Pu})$. Both of these functions again show that sample ident 6232 is indicated as being an outlier point. It would therefore be recommended that the sample corresponding to the 6232 ident be remeasured for this set of data.

The regression analysis verification of outliers using the computer code MISTY⁽⁶⁾ is illustrated in Tables 4-7 to show another source of outlier confirmation. This computer analysis is not a necessary part of the verification process in the field, but it could be performed when the data have been received at IAEA headquarters.

EXTERNAL DATA SOURCE VERIFICATION

The internal analysis as illustrated using the burnup data in the preceding section will be performed similarly for every campaign with enough batches (≥ 3) for meaningful statistics. If a statistical analysis of data from a similar campaign is available, it can be used to check the internal analysis.

The function to be confirmed is plotted, using the data from the prior (reference) campaign, and a line (slope and intercept) is fitted, using Deming's method to allow for uncertainties in both variables. This linear model is then used to predict measurement values for the campaign currently being analyzed. For example, using a model for Pu/U versus ^{235}D , one can use the ^{235}D measurement to predict Pu/U for a batch.

TABLE 4. Pu/U versus ^{235}U Regression Analysis

PU/U

MURKUP SET

UPDR 1 (Rev 12.5M) JOUR OF NUCLEAR SCI & TECH 027 J H
VS 11-235 ENRICHMENT

VS 11-435

LNK[CHMEN] = 2,59614

I	IDENT	X VALUE	Y VALUE	PRED X	X RESIDUAL	PRED Y	Y RESIDUAL	PRED X	X RESIDUAL	PRED Y	Y RESIDUAL	PRED X	X RESIDUAL	PRED Y	Y RESIDUAL
1	2275	-2.351-001	1.012-003	-2.342-001	4.782-003	9.951-004	1.694-005	-2.366-001	1.678-003	1.005-003	7.115-006				
2	2641	-2.687-001	1.358-003	-2.690-001	2.716-002	1.240-003	1.342-004	-2.439-001	2.516-002	1.247-001	1.067-004				
3	4142	-4.051-001	2.025-003	-4.023-001	3.727-002	1.670-003	1.554-004	-4.411-001	3.600-002	1.872-003	1.570-004				
4	3974	-4.000-001	1.751-003	-4.135-001	4.467-003	1.733-003	1.668-005	-4.403-001	3.291-003	1.737-001	1.395-004				
5	4464	-5.033-001	2.100-003	-4.994-001	4.414-003	2.117-003	-1.679-005	-4.994-001	-4.507-003	2.120-003	-1.911-005				
6	5113	-5.160-001	2.557-003	-5.171-001	4.673-003	2.364-003	1.430-004	-5.167-001	4.591-002	2.363-003	1.947-004				
7	5173	-5.268-001	2.229-003	-5.278-001	3.111-004	2.121-003	-1.310-006	-5.259-001	-4.500-004	2.232-003	-2.758-006				
8	6762	-3.513-001	2.230-003	-3.520-001	-1.279-002	2.283-003	-3.347-005	-3.520-001	-1.279-002	2.285-003	-5.490-005				
9	5021	-3.502-001	2.607-003	-3.471-001	2.714-002	2.494-003	1.135-004	-3.472-001	2.709-002	2.492-001	1.147-004				
10	6051	-3.022-001	2.600-003	-3.002-001	2.805-002	2.497-003	1.090-004	-3.001-001	2.597-002	2.494-003	1.101-004				
11	5422	-5.861-001	2.203-003	-5.850-001	-1.611-002	2.331-003	-6.743-005	-5.849-001	-1.611-002	2.333-003	-6.662-005				
12	5360	-5.871-001	2.433-003	-5.874-001	-1.992-002	2.324-003	-6.303-005	-5.870-001	-1.927-002	2.325-003	-6.172-005				
13	4772	-3.780-001	2.378-003	-3.717-001	1.377-002	2.513-003	5.754-005	-3.710-001	1.375-002	2.512-003	5.847-005				
14	5744	-5.004-001	2.400-003	-5.246-001	4.713-002	2.609-003	1.971-004	-5.241-001	4.713-002	2.601-003	2.001-004				
15	5943	-5.024-001	2.400-003	-5.215-001	3.600-002	2.641-003	1.814-004	-5.216-001	3.600-002	2.638-003	1.840-004				
16	6145	-5.030-001	2.403-003	-5.348-001	4.467-002	2.697-003	1.698-004	-5.340-001	4.460-002	2.694-003	1.999-004				
17	6071	-5.135-001	2.453-003	-5.327-001	1.292-002	2.609-003	6.369-005	-5.330-001	1.550-002	2.607-003	6.588-005				
18	6331	-5.234-001	2.433-003	-5.133-001	4.001-003	2.697-003	4.132-005	-5.336-001	1.023-002	2.684-003	4.337-005				
19	6003	-5.151-001	2.631-003	-5.179-001	1.270-002	2.797-003	5.332-005	-5.194-001	1.310-002	2.795-003	5.633-005				
20	5500	-5.030-001	2.500-003	-5.337-001	4.337-002	2.703-003	-1.420-004	-5.365-001	-3.336-002	2.702-003	-1.412-004				
21	6252	-5.410-001	1.499-003	-5.669-001	-1.757-001	2.100-003	-7.472-005	-5.674-001	-1.779-001	2.103-003	-7.543-004				
22	6011	-5.030-001	2.400-003	-5.338-001	-1.579-002	2.609-003	6.369-005	-5.347-001	-1.494-002	2.604-003	6.170-005				
23	6112	-5.099-001	2.415-003	-5.171-001	-6.611-002	2.797-003	-6.769-004	-6.342-001	-6.528-002	2.697-003	-2.760-004				
24	6011	-5.030-001	2.400-003	-5.348-001	4.467-002	2.697-003	1.698-004	-5.340-001	4.460-002	2.694-003	1.999-004				

AVC-AUTS -5,554-041 2,330-103

at least

AVENUE S - 5.54E-001 7.31E-009

УДК 62-50

$$Y - YU = E^{(2)}(X - XU)$$

BLOCK ESTIMATE

-4- 304-1113

٥٥٠ - ٥٥٠ - ٥٥٠

451. 100% 100%

-10,000

• 344 •

INTERPRETATION

-J, 41 J-f, 15

VARIANTE 7F R

1. 100 + 000

A VARIANCE ESTIMATE

1. 673-604

2.174-003

4 5 3 1 - 1 2 4 6 7 8

- 2.478

-B. 146

Variable of Interest: Y

1. 400-000

Y VANDERBILT ESTIMATE

3.40 f-005

3.910-004

* 519 106 Y UF Y

2,477

8. 142

CORRELATION COEFFICIENT:

- 714

-987

BATCH IDENT NO. 6212 IS AN OUTLIER

TABLE 5. Pu/U versus ²³⁵D Regression Analysis with Outlier Removed

I	IDENT	X VALUE	Y VALUE	Y = H*X + A		Y - Y0 = H*(X - X0)		Y - Y0 = H*(X - X0)		Y - Y0 = H*(X - X0)	
				PRED X	PRED Y	PRED X	PRED Y	PRED X	PRED Y	PRED X	PRED Y
1	2275	-2.351-001	1.012-003	-2.216-001	-1.375-002	1.075-003	-0.290-005	-2.340-001	-1.161-003	1.017-003	-5.169-006
2	2041	-2.687-001	1.354-003	-2.790-001	1.024-002	1.304-003	4.829-005	-2.900-001	2.126-002	1.261-003	9.301-005
3	4142	-4.051-001	2.025-003	-4.242-001	2.412-002	1.912-003	1.130-004	-4.353-001	3.024-002	1.893-003	1.323-004
4	3974	-4.060-001	1.751-003	-3.944-001	-7.651-003	1.707-003	-3.609-005	-4.046-001	-1.658-003	1.754-003	-7.251-006
5	4964	-5.039-001	2.106-003	-4.910-001	-1.245-002	2.101-003	-6.060-005	-4.935-001	-1.041-002	2.145-003	-4.555-005
6	5143	-5.102-001	2.557-003	-5.470-001	3.621-002	2.307-003	1.700-004	-5.493-001	3.854-002	2.309-003	1.686-004
7	5173	-5.282-001	2.229-003	-5.150-001	-8.557-003	2.270-003	-4.037-005	-5.176-001	-6.433-003	2.260-003	-3.033-005
8	5272	-5.513-001	2.230-003	-5.314-001	-1.984-002	2.324-003	-9.379-005	-5.321-001	-1.919-002	2.314-003	-8.394-005
9	5021	-5.602-001	2.607-003	-5.773-001	1.912-002	2.517-003	9.016-005	-5.748-001	1.961-002	2.521-003	8.578-005
10	5051	-5.672-001	2.606-003	-5.503-001	1.612-002	2.521-003	8.540-005	-5.607-001	1.854-002	2.525-003	8.109-005
11	5422	-5.661-001	2.203-003	-5.434-001	-2.282-002	2.372-003	-1.069-004	-5.436-001	-2.251-002	2.362-003	-9.549-005
12	5366	-5.671-001	2.243-003	-5.415-001	-2.584-002	2.304-003	-1.207-004	-5.416-001	-2.553-002	2.355-003	-1.117-004
13	5772	-5.780-001	2.576-003	-5.647-001	6.084-003	2.539-003	3.150-005	-5.645-001	6.497-003	2.542-003	8.642-005
14	5744	-5.904-001	2.660-003	-5.701-001	3.914-002	2.661-003	1.040-004	-5.749-001	3.894-002	2.696-003	1.704-004
15	5903	-5.829-001	2.802-003	-5.618-001	3.093-002	2.806-003	1.459-004	-5.615-001	3.004-002	2.864-003	1.340-004
16	5145	-5.894-001	2.283-003	-5.267-001	3.753-002	2.709-003	1.747-004	-5.261-001	3.650-002	2.724-003	1.597-004
17	6071	-6.175-001	2.753-003	-6.208-001	4.334-003	2.704-003	4.400-005	-6.252-001	7.724-003	2.714-003	3.379-005
18	6331	-6.234-001	2.733-003	-6.277-001	4.314-003	2.712-003	2.045-005	-6.259-001	2.464-003	2.727-003	1.089-005
19	6065	-6.451-001	2.451-003	-5.730-001	7.600-003	2.614-003	3.090-005	-5.803-001	3.214-003	2.620-003	2.241-005
20	6502	-6.646-001	2.560-003	-6.331-001	-3.075-002	2.734-003	-1.734-004	-6.294-001	-4.040-002	2.737-003	-1.767-004
22	7011	-6.890-001	2.800-003	-6.711-001	-1.867-002	2.807-003	-6.714-005	-6.806-001	-2.276-002	2.900-003	-4.967-005
23	6712	-6.995-001	2.415-003	-6.324-001	-6.794-002	2.731-003	-3.103-004	-6.276-001	-7.186-002	2.724-003	-3.144-004
24	7043	-7.024-001	2.424-003	-6.422-001	-1.028-002	2.972-003	-4.840-005	-6.874-001	-1.501-002	2.984-003	-6.567-005

AVE-AGES -5.496-001 2.397-003

WEIGHTED
AVE-AGES -5.493-001 2.385-003

$$Y = H \cdot X + A$$

$$Y - Y_0 = H \cdot (X - X_0)$$

SLOPE ESTIMATE -4.033-003

-4.346-003

% STD DEV OF SLOPE -9.927

-2.006

INTERCEPT ESTIMATE 1.000-004

VARIANCE OF X 1.000-000

X VARIANCE ESTIMATE 6.781-005

7.605-004

% STD DEV OF X -1.496

-5.017

VARIANCE OF Y 1.000-000

Y VARIANCE ESTIMATE 1.290-009

1.455-008

% STD DEV OF Y 1.496

5.032

CORRELATION COEFFICIENT -0.8925

-0.9954

TABLE 6. Pu/U versus (100 - ²³⁹Pu) Regression Analysis

PU/U		BURNUP SET		JOUR 1 (B4N 12.5M) VS (100-Pu-239)		JOUR OF NUCLEAR SCI + TECH 027 J 8		ENRICHMENT= 2.59674			
I	IDENT	X VALUE	Y VALUE	(PRED) X	Y = B*X + A X RESIDUAL	(PRED) Y	Y RESIDUAL	(PRED) X	Y=Y0+B*(X-X0) X RESIDUAL	(PRED) Y	Y RESIDUAL
1	2275	5.372+000	1.012-003	5.791+000	-4.147-001	9.418+004	7.040-005	5.422+000	-4.974-002	1.003-003	9.146-006
2	2641	6.624+000	1.354-003	7.282+000	-6.574-001	1.244+003	1.105-004	6.977+000	-3.485-001	1.290-003	6.408-005
3	4142	9.807+000	2.025-003	1.054+001	-7.294-001	1.903+003	1.220-004	1.058+001	-5.718-001	1.920-003	1.051-004
4	4974	9.411+000	1.751-003	9.417+000	-2.064-001	1.717+003	3.470-005	9.438+000	-2.761-002	1.744-003	5.076-006
5	4944	1.174+001	2.100-003	1.164+001	1.511+001	2.126+003	-2.536-005	1.157+001	2.188+001	2.141+003	-4.022-005
6	5143	1.201+001	2.557-003	1.257+001	-9.611+001	2.396+003	1.614+004	1.292+001	-9.088+001	2.390+003	1.671+004
7	5173	1.204+001	2.224+003	1.212+001	-3.044+002	2.224+003	5.111+006	1.207+001	2.195+002	2.231+003	-4.036+006
8	5252	1.263+001	2.230+003	1.237+001	2.637+001	2.274+003	-4.428+005	1.234+001	2.918+001	2.264+003	-5.362+005
9	5621	1.305+001	2.607-003	1.358+001	-5.264+001	2.514+003	8.843+005	1.357+001	-5.217+001	2.511+003	4.593+005
10	5651	1.331+001	2.600+003	1.364+001	-3.641+001	2.542+003	8.434+005	1.370+001	-3.900+001	2.535+003	7.170+005
11	5422	1.292+001	2.265+003	1.266+001	3.247+001	2.320+003	-5.455+005	1.254+001	3.394+001	2.322+003	-6.241+005
12	5306	1.290+001	2.243+003	1.253+001	3.721+001	2.308+003	-6.250+005	1.251+001	3.880+001	2.315+003	-7.134+005
13	5772	1.304+001	2.570+003	1.377+001	-7.607+001	2.557+003	1.278+005	1.379+001	-9.961+002	2.552+003	1.635+005
14	5944	1.337+001	2.606+003	1.465+001	-7.787+001	2.735+003	1.307+004	1.468+001	-8.134+001	2.711+003	1.475+004
15	5963	1.366+001	2.602+003	1.435+001	-7.564+001	2.676+003	1.266+004	1.438+001	-7.729+001	2.660+003	1.421+004
16	6145	1.384+001	2.483+003	1.467+001	-6.120+001	2.744+003	1.397+004	1.472+001	-8.608+001	2.724+003	1.594+004
17	6071	1.408+001	2.753+003	1.444+001	-3.567+001	2.693+003	3.991+005	1.448+001	-4.001+001	2.674+003	7.356+005
18	6331	1.415+001	2.733+003	1.441+001	-2.644+001	2.698+003	4.462+005	1.446+001	-3.118+001	2.679+003	5.734+005
19	6563	1.475+001	2.651+003	1.501+001	-2.544+001	2.608+003	4.241+005	1.508+001	-3.302+001	2.790+003	6.072+005
20	6552	1.472+001	2.500+003	1.467+001	5.047+001	2.644+003	-8.580+005	1.462+001	4.399+001	2.641+003	-8.060+005
21	6236	1.472+001	1.407+003	1.110+001	3.617+000	2.617+003	-6.075+004	1.115+001	3.561+000	2.604+003	-6.547+004
22	7011	1.722+001	2.800+003	1.771+001	1.777+001	2.830+003	-2.980+005	1.721+001	7.928+002	2.815+003	-1.458+005
23	6712	1.756+001	2.415+003	1.420+001	1.367+000	2.644+003	-2.288+004	1.430+001	1.256+000	2.644+003	-2.310+004
24	7081	1.640+001	2.724+003	1.595+001	4.550+001	2.944+003	-7.572+005	1.610+001	3.007+001	2.974+003	-5.529+005
AVERAGE		1.270+001	2.350+003								
WEIGHTED AVERAGE		1.283+001	2.312+003								

	Y = B*X + A	Y-Y0 = B*(X-X0)
SLOPE ESTIMATE	2.025-004	1.850-004
% STD DEV OF SLOPE	13.678	2.840
INTERCEPT ESTIMATE	-2.312-004	
VARIANCE OF X	1.000+000	
X VARIANCE ESTIMATE	7.074-002	8.276-001
% STD DEV OF X	2.003	7.121
VARIANCE OF Y	1.000+000	
Y VARIANCE ESTIMATE	2.400-004	2.790-008
% STD DEV OF Y	2.003	7.094
CORRELATION COEFFICIENT	.7840	.9907

BATCH IDENT NO. 6236 IS AN OUTLIER

TABLE 7. Pu/U versus (100 - ²³⁹Pu) Regression Analysis with Outlier Removed

I	IDENT	X VALUE	Y VALUE	PRED. A	Y = 0.044A		Y RESIDUAL	PRED. A	Y - Y0 = 44(X - X0)		Y RESIDUAL
					X RESIDUAL	Y			X RESIDUAL	Y	
1	2275	5.372+000	1.012-003	5.245+000	7.641-002	1.027-003	-1.473-005	5.347+000	4.805-003	1.013-003	-9.083-007
2	2041	6.024+000	1.354-003	6.448+000	-2.142-001	1.313-003	4.125-005	6.048+000	-2.745-001	1.302-003	5.149-005
3	4142	4.007+000	2.025-003	1.024+001	-4.247-001	1.443-003	6.277-005	1.027+001	-4.609-001	1.930-003	8.713-005
4	3974	4.411+000	1.751-003	4.510+000	1.012-001	1.771-003	-1.940-005	4.344+000	6.055-002	1.764-003	-1.258-005
5	4744	1.174+001	2.100-003	1.144+001	3.447-001	2.107-003	-6.615-005	1.144+001	3.307-001	2.163-003	-6.252-005
6	5143	1.201+001	2.557-003	1.277+001	-7.571-001	2.412-003	1.450-004	1.270+001	-7.660-001	2.412-003	1.452-004
7	5173	1.204+001	2.224-003	1.146+001	1.511-001	2.254-003	-2.919-005	1.145+001	1.416-001	2.254-003	-2.677-005
8	5252	1.263+001	2.230-003	1.222+001	4.157-001	2.310-003	-7.447-005	1.222+001	4.103-001	2.304-003	-7.756-005
9	5021	1.365+001	2.007-003	1.343+001	-3.742-001	2.534-003	7.280-005	1.343+001	-3.797-001	2.534-003	7.176-005
10	5651	1.311+001	2.000-003	1.350+001	-2.444-001	2.554-003	4.807-005	1.350+001	-2.405-001	2.554-003	4.640-005
11	5422	1.242+001	2.265-003	1.240+001	4.041-001	2.454-003	-6.849-005	1.240+001	4.541-001	2.352-003	-8.692-005
12	5300	1.240+001	2.243-003	1.234+001	5.044-001	2.342-003	-7.013-005	1.234+001	5.070-001	2.334-003	-9.545-005
13	5772	1.304+001	2.570-003	1.304+001	3.344-002	2.577-003	-6.530-005	1.305+001	3.854-002	2.577-003	-7.240-005
14	5944	1.301+001	2.000-003	1.453+001	-6.024-001	2.738-003	1.270-004	1.452+001	-6.503-001	2.742-003	1.241-004
15	5973	1.301+001	2.002-003	1.423+001	-6.232-001	2.602-003	1.200-004	1.422+001	-6.145-001	2.602-003	1.171-004
16	6145	1.300+001	2.453-003	1.457+001	-7.144-001	2.740-003	1.370-004	1.450+001	-7.080-001	2.740-003	1.340-004
17	6071	1.400+001	2.753-003	1.454+001	-2.544-001	2.701-003	4.940-005	1.453+001	-2.507-001	2.701-003	4.740-005
18	6331	1.415+001	2.733-003	1.432+001	-1.727-001	2.844-003	3.320-005	1.431+001	-1.644-001	2.702-003	3.649-005
19	4505	1.475+001	2.751-003	1.444+001	-1.444-001	2.614-003	3.605-005	1.443+001	-1.754-001	2.614-003	3.325-005
20	6002	1.472+001	2.000-003	1.471+001	5.015-001	2.804-003	-1.051-004	1.474+001	5.157-001	2.804-003	-1.088-004
21	7011	1.524+001	2.000-003	1.504+001	2.100-001	2.841-003	-4.644-005	1.505+001	2.243-001	2.844-003	-4.336-005
22	6712	1.550+001	2.415-003	1.420+001	1.544+000	2.677-003	-2.617-004	1.410+001	1.301+000	2.676-003	-2.611-004
23	7001	1.640+001	2.724-003	1.547+001	4.274-001	3.000-003	-6.223-005	1.545+001	4.500-001	3.010-003	-8.631-005

AVERAGES 1.264+001 2.347-003

WEIGHTED AVERAGES 1.260+001 2.305-003

	Y = 0.044A	Y - Y0 = 44(X - X0)
SLOPE ESTIMATE	1.053-004	1.040-004
* STD DEV OF SLOPE	0.203	1.010
INTERCEPT ESTIMATE	4.573-005	
VARIANCE OF X	1.000+000	
X VARIANCE ESTIMATE	2.175-002	2.033-001
* STD DEV OF X	1.270	4.043
VARIANCE OF Y	1.000+000	
Y VARIANCE ESTIMATE	0.548-010	9.411-009
* STD DEV OF Y	1.220	4.046
CORRELATION COEFFICIENT	.9252	.9970

Since the reference data describe fuel irradiated under different conditions--differing enrichment, reactor, reactor type, cladding material, core positions, etc.--the reference line model will not precisely fit the current data. The slopes of the two data sets, when plotted together on a functional plot, will differ; the vertical position (y-intercept) will also differ. These biases must be eliminated.

The first step in dealing with biases is making a good choice of a reference data set. The slopes of the reference and current sets must match as closely as possible to minimize the differences. A reference set should be chosen to have as similar an enrichment, burnup range, and reactor type (ideally, the same reactor) to those of the current data set as possible.

Once a reference set is chosen and its linear model obtained, the model is used to predict the value of the measurement in question for each batch of the current campaign. The percent difference between the measured and predicted values of the parameter is calculated for each batch, and then the mean and standard deviation of the percent differences are found.

The percent differences of those batches designated as questionable by the internal analysis are then checked for their magnitude of deviation. If a questionable batch's percent difference is far from the mean ($>2\sigma$), then its outlier status is confirmed. However, a batch designated as a definite outlier by the internal analysis should not be reaffirmed as an acceptable batch on the basis of an external analysis. The external analysis is a check, an additional base for decision-making in the case of questionable batches, batches that are borderline outliers.

Internal Analysis

The procedure for the internal verification is illustrated below. The example is the processing of nine batches of 4.076 weight percent enriched fuel from the Indian Point PWR by Nuclear Fuel Service (NFS). The reference data are from an eleven-batch campaign at NFS of 4.101 weight percent Yankee Rowe PWR fuel.

First, the internal analysis of the Indian Point data:

Batch Ident	$\frac{\text{Pu/U}}{^{235}\text{D}}$	σ Fraction	$\frac{\text{Pu/U}}{(100 - ^{239}\text{Pu})}$	σ Fraction
25101	4547.4	.22	290.30	.17
23802	4602.1	.93	290.59	.23
23203	4535.9	.07	289.63	.03
23304	4542.5	.16	291.62	.45
23005	4578.7	.63	294.19	1.00
23006	4563.1	.42	289.62	.03
22607	4560.5	.39	292.40	.62
22908	4505.5	-.33	289.41	-.02
23409	4338.9	-2.49	277.77	-2.51
Mean	4530.5		289.50	
SD(σ)	76.8		4.67	
%SD	1.7		1.61	

Batch ident 23409 is -2.49σ and -2.51σ off the respective means and is a definite outlier. Because 23409 biased the statistics greatly, no other batch is even outside 1σ for either ratio. To obtain more realistic statistics, the mean and SD should be recalculated without batch ident 23409. These calculations yield the following:

Batch Ident	$\frac{\text{Pu/U}}{^{235}\text{D}}$	σ Fraction	$\frac{\text{Pu/U}}{(100 - ^{239}\text{Pu})}$	σ Fraction
25101	4547.4	-.24	290.30	-.40
23802	4602.1	1.64	290.59	-.23
23203	4535.9	-.64	289.63	-.80
23304	4542.5	-.41	291.62	.30
23005	4578.7	.83	294.19	1.93
23006	4563.1	.30	289.62	-.81
22607	4560.5	.21	292.40	.86
22908	4505.5	-1.69	289.41	-.93
Mean	4554.5		290.97	
SD(σ)	29.0		1.67	
%SD	.6		.57	

The elimination of the outlier slightly increased the means and greatly reduced the standard deviations.

Applying the new statistics, it is seen that although no batch is outside 2σ , one is close: 23005 is 1.93σ high in the ratio $(\text{Pu/U})/(100 - ^{239}\text{Pu})$. Two others are nearing the 2σ limit, 23802 and 22908, respectively 1.64σ and -1.69σ off in the ratio $(\text{Pu/U})/^{235}\text{D}$.

External Analysis

The Yankee Rowe line models for the external verification are:

	<u>Slope</u>	<u>Intercept</u>	<u>Initial Point Slope</u>
Pu/U versus ^{235}D	5344	106.7	5411
Pu/U versus $(100 - ^{239}\text{Pu})$	391.4	-1179	348.8

The slope/intercept model's numbers will be used in this illustration with the initial point model's slopes given strictly for comparative purposes. The computations using the Yankee Rowe slope/intercept model to predict comparison values for the Indian Point data are provided in Table 8.

Note that batch 23409, already identified as a definite outlier, has been included in the upper portion of Table 8. The analysis is redone eliminating the outlier with the results shown in the lower portion of Table 8. This external analysis confirms the outlier status of batch ident 23409.

The models' predictions consistently exceed the measured Pu/U values by 18% and 21%. This is the effect of the difference in vertical position between the line plots of the two data sets. Looking for statistical outliers using the percent differences eliminates this bias between the two sets.

The other type of bias, difference in slopes between the two functional plots, will show itself differently. If the slopes are tilted with respect to one another, then higher absolute differences will evince themselves at one end of the burnup range than at the other. This is not evident here, because the data set under analysis has a low burnup range, and the two data sets do have similar slopes.

No batch (except 23409) has a percent difference outside 2σ , but three are close--23802 and 22908 detected by Pu/U versus ^{235}D , and 23005 detected by Pu/U versus $(100 - ^{239}\text{Pu})$. These were also detected as potential outliers by the internal analysis. Note that because of an appropriate choice of reference data set, the number of standard deviations each percent difference varied from its mean is close in magnitude to the number of standard deviations by which the corresponding isotopic ratio differed from its mean.

TABLE 8. Computations to Predict Comparison Values for Indian Point Data

Batch Ident	Measured Pu/U	Pu/U vs ^{235}D				Pu/U vs $(100 - ^{239}\text{Pu})$			
		^{235}D	Predicted* Pu/U	% Difference	σ Fraction	$(100 - ^{239}\text{Pu})$	Predicted* Pu/U	% Difference	σ Fraction
25101	9326.7	2.051	11067	18.66	-.25	32.128	11395	22.19	.11
23802	9038.5	1.964	10602	17.30	-.90	31.104	10995	21.65	-.16
23203	8849.5	1.951	10533	19.02	-.08	30.554	10780	21.81	-.08
23304	8948.7	1.970	10634	18.84	-.16	30.686	10831	21.04	-.46
23005	9047.5	1.976	10666	17.84	-.64	30.754	10858	20.01	-.97
23006	8601.5	1.885	10180	18.35	-.40	29.699	10445	21.43	-.27
22607	8952.2	1.963	10597	18.37	-.39	30.616	10804	20.69	-.64
22908	8848.8	1.964	10602	19.82	.31	30.575	10788	21.92	-.03
23409	8500.0	1.959	10576	24.42	2.51	30.601	10798	27.04	2.51
Mean				19.18				21.98	
SD(σ)				2.09				2.02	
%SD				10.90				9.19	
With batch ident 23409 eliminated:									
25101	9326.7	2.051	11067	18.66	.18	32.128	11395	22.19	1.17
23802	9038.5	1.964	10602	17.30	-1.61	31.104	10995	21.65	.42
23203	8849.5	1.951	10533	19.02	.65	30.554	10780	21.81	.65
23304	8948.7	1.970	10634	18.84	.41	30.686	10831	21.04	-.42
23005	9047.5	1.976	10666	17.84	-.90	30.754	10858	20.01	-1.84
23006	8601.5	1.885	10180	18.35	-.23	29.699	10445	21.43	.12
22607	8952.2	1.963	10597	18.37	-.20	30.616	10804	20.69	-.90
22908	8848.8	1.964	10602	19.82	1.70	30.575	10788	21.92	.80
Mean				18.53				21.34	
SD(σ)				.76				.72	
%SD				4.10				3.37	

* Obtained from calculations using the Yankee Rowe slope/intercept line equations on the previous page

<u>Batch Ident</u>	<u>Deviation Of Isotopic Ratio</u>	<u>Deviation Of % Difference</u>	<u>Function</u>
23802	+1.64 σ	-1.61 σ	Pu/U vs ^{235}D
23005	+1.93 σ	-1.84 σ	Pu/U vs (100 - ^{239}Pu)
22908	-1.69 σ	+1.70 σ	Pu/U vs ^{235}D

RECOMMENDATIONS BASED ON THE ANALYSIS

The internal consistency analysis identified batch 23409 as an outlier. The isotopic ratios for both Pu/U verification functions were unacceptably low, and since this batch illustrated none of the effects described earlier (averaging, fringe effects, unirradiated assembly, etc.) a bad Pu/U measurement is indicated. This batch must be remeasured.

Three other batches (23802, 23005, and 22908) were close enough to the deviation tolerance to warrant external corroboration. The external analysis confirmed the magnitude of their deviations, and they need not be remeasured.

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APPENDIX A

REPROCESSING DATA APPLIED TO SELECTED ISOTOPIC FUNCTIONS

The tables of Appendix A supply data from available reprocessing information for selected isotopic function. Appendix A supplies the following for each of the eleven isotopic functions: 1) identification information such as quantity of batches, reactor, enrichment, cladding, data source, and exposure levels; 2) isotopic ratio and percent standard deviation ($\% \sigma$); 3) slope, intercept, and percent standard deviation of the slope for Demings intercept model; 4) slope and its percent standard deviation for Deming's initial point model; and 5) any effects shown by the data. The $\% \sigma$ for the ratio and the slopes are the indications of the accuracies of each of the isotopic functions.

REPROCESSING BATCHES

Pu/U versus ^{235}U

No. of Batches	Reactor Name	Lot or Core	^{235}U Core	Clad Mat'l	Data* Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
BOILING WATER REACTORS													
17	Dresden 1	1	1.474	Zr	NFS	5000	6234	1.4	8187/-1038	8.7	6237	0.3	Outlier Fringe
18	Dresden 1	2	1.474	Zr	NFS	10000	6100	2.6	6650/-410	18.7	6089	0.6	
5	Dresden 1	4	1.474	Zr	NFS	8500-9800	5695	2.6	9704/-3048	9.3	5704	1.1	Fringe
7	Dresden 1	4	1.474	Zr	NFS	10900-12000	6138	1.1	5880/219	35.7	6137	0.4	
1	Dresden 1	4	1.586	Zr	NFS	11500	5537						
1	Dresden 1	4	1.586	Zr	NFS	10800	5749						
1	Dresden 1	4	1.617	Zr	NFS	10400	5383						
1	Dresden 1	4	1.767	Zr	NFS	13400	5237						
1	Dresden 1	4	1.831	Zr	NFS	13100	5203						Fringe
5	Dresden 1	4	1.474	Zr	NATCO	8500-9800	5738	3.1	10820/-3860	16.3	5748	1.4	
7	Dresden 1	4	1.474	Zr	NATCO	10900-12000	6246	0.8	10120/-3249	13.0	6247	0.3	
1	Dresden 1	4	1.586	Zr	NATCO	11500	5544						
1	Dresden 1	4	1.586	Zr	NATCO	10900	5803						
1	Dresden 1	4	1.617	Zr	NATCO	10400	5458						
1	Dresden 1	4	1.767	Zr	NATCO	13400	5299						
1	Dresden 1	4	1.831	Zr	NATCO	13100	5164						
18	Garigliano	1	2.020	Zr	WS	6500-14000	5547	1.2	5391/153	2.1	5540	0.3	Unirradiated Assembly
13	Garigliano	2	2.020	Zr	WS	13400-17600	5345	1.0	5390/55	10.7	5344	0.3	
1	Dresden 1	4	2.180	Zr	NFS	9800	4651						
1	Dresden 1	4	2.180	Zr	NATCO	9800	4689						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	4903						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	4774						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	4808	1.9	2590/2430	21.9	4804	1.1	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	4762						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	4749						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	4941						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	4917						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	4846	0.9	3747/1198	18.3	4844	0.5	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	4805						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	4799						
9	Dresden 1	3	2.50	SS	NFS	5000	4638	3.7	4023/456	23.8	4631	1.3	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	4620						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	4643						Fringe
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	4247	4.6	7783/-2542	19.2	4262	1.9	
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	4723	1.6	3722/854	22.2	4720	0.7	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	4681						
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	4778						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	4279	5.4	9301/-3589	19.7	4298	2.2	
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	4704	1.7	4126/492	26.4	4702	0.8	Fringe
2	VAK	1	2.33	Zr	OR	15300-15900	3847	0.4					
1	VAK	1	2.51	Zr	OR	17400	3761						
2	VAK	1	2.33	Zr	EU	15300-15900	3858						
1	VAK	1	2.403	Zr	EU		3902						
1	VAK	1	2.51	Zr	EU	17400	3792						
1	Big Rock Point	2	2.9926		NFS	10800	4388						
1	Big Rock Point	2	3.0062		NFS	11200	4275						Averaging
1	Big Rock Point	2	3.0108		NFS	10500	4148						Averaging
1	Big Rock Point	2	3.2170		NFS	12300	4245						Averaging
1	Big Rock Point	2	3.2600		NFS	20900	4145						Averaging
1	Big Rock Point	2	3.0910		NFS	Core Avg.	4160						Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	4633						
1	Big Rock Point	1	3.1166	Zr	NFS	7400	4592						
1	Big Rock Point	1	3.1343	Zr-SS	NFS	17700	4329						
1	Big Rock Point	1	3.1977	SS	NFS	7400	4435						
4	Big Rock Point	1	3.212	SS	NFS	8400-8700	4208	2.2	335900/-302800	70.7	4207	1.08	Averaging
1	Big Rock Point	1	3.236	SS	NFS	10000	4348						
1	Big Rock Point	1	3.252	SS-Zr	NFS	9000	4106						
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	4064						
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	4240						Averaging
1	Big Rock Point	1	3.463	Zr	NFS	11000	4007						
1	Big Rock Point	1	3.494	Zr	NFS	13000	3958						Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	3943						
2	Big Rock Point	1	3.6605	IncB Zr	NFS	5700-6400	3865	1.5					
1	Big Rock Point	1	3.672	Zr	NFS	9400	4054						
1	Big Rock Point	1	3.298	IncB Zr Inc-SS	NFS	Total	4177						Averaging

*NFS — Nuclear Fuel Service
NATCO — Nuclear Audit and Testing Company
NBS — National Bureau of Standards

EU — Eurochemic
OR — Oak Ridge Laboratories
WS — Windscale

REPROCESSING BATCHES
Pu/U versus ²³⁵U (continued)

No. of Batches	Reactor Name	Lot or Core	²³⁵ U	Clad Mat'l	Data* Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	5684	2.5	-152000/169100	35.0	5685	0.8	Averaging
1	Trino	2	2.925	SS	OR	13200	5462						
3	Trino	1	3.130	SS	OR	12700-13400	5233	0.9	3189/2291	24.2	5232	0.5	
9	Trino	2	3.130	SS	EU	19900-22200	5109	1.4	8475/-2184	20.5	5109	0.5	Averaging Fringe
2	Trino	1	3.112	SS	OR	9900-10300	5328	4.4					
1	Trino	2	3.386	SS	EU	21100	4861						
1	Trino	2	3.308	SS	OR	10300	5163						Averaging Fringe
1	Trino	2	3.454	SS	EU	14800	5286						
3	Trino	2	3.897	SS	EU	21300-21700	4556	0.7	6294/-2998	44.5	4556	0.4	
6	Trino	1	2.719	SS	EU	12500-12900	5818	2.9	39340/-35390	50.1	5817	1.2	Unirradiated Assembly
1	Trino	2	2.925	SS	EU	13200	5562						
2	Trino	1	3.130	SS	EU	12700-13000	5273						
1	Trino	2	3.310	SS	EU	10300	5150						Averaging
4	Indian Point I	1	2.872	SS	NFS	12100-12600	5692	0.4	5035/696	5.3	5691	0.2	
1	Indian Point I	1	2.900	SS	NFS	13100	5594						
1	Indian Point I	1	3.020	SS	NFS	15400	5480						Averaging
1	Indian Point I	1	3.220	SS	NFS	17900	5197						
4	Indian Point I	1	3.263	SS	NFS	18900-19500	5218	1.7	-40510/68710	54.8	5219	0.8	
9	Indian Point I	2	4.076	SS	NFS	22600-25100	4531	1.7	6224/-3328	23.8	4531	0.6	Averaging
4	Indian Point I	1	2.872	SS	NATCO	12100-12600	5769	0.9	5095/711	20.0	5767	0.4	
1	Indian Point I	1	2.900	SS	NATCO	13100	5637						
1	Indian Point I	1	3.020	SS	NATCO	15400	5615						Averaging
1	Indian Point I	1	3.220	SS	NATCO	17900	5204						
4	Indian Point I	1	3.263	SS	NATCO	18900-19500	5241	1.5	105100/-150100	53.2	5241	0.8	
9	Indian Point I	2	4.076	SS	NATCO	22600-25100	4573	1.6	4515/112	25.4	4572	0.5	Averaging
13	Sena	1	2.958	SS	OR	12900	5704	1.9	8721/-3312	31.3	5703	0.5	
1	Sena	1	3.357	SS	OR	2920	5749						
12	Sena	2	3.358	SS	OR	18600-20600	4944	3.8	18070/21150	29.1	4947	1.1	Averaging
14	Sena	1	2.958	SS	EU	12900	6157	2.9	1867/4367	40.2	6150	0.8	
1	Sena	1	3.357	SS	EU	2920	7490						
1	Sena	2	2.968	SS	EU		4801						Averaging
12	Sena	2	3.358	SS	EU	18600-20600	4991	3.6	21640/-26580	28.0	4995	1.1	
1	Sena	2	3.121	SS	EU		5078						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	5767						Averaging Fringe
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	5666	2.0	5942/-212	2.2	5687	0.5	
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	5781	0.7	5721/61	1.7	5770	0.2	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	5682						Averaging
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	5052						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	5501	0.4	5237/393	1.51	5500	0.2	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	5415	0.9	5344/107	1.7	5411	0.3	Averaging
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	5343	1.2	6555/-1703	12.0	5344	0.5	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	4993	1.2	5638/-1274	4.61	4994	0.4	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	4950	1.4	5435/-1044	5.1	4954	0.4	Averaging
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	4918	0.7	4701/445	5.4	4917	0.2	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	5792						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	5409	0.6	5357/76	1.01	5406	0.2	Averaging
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	4973	1.4	5709/-1442	4.3	4979	0.4	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	5867						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	5813						Averaging
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	5220						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	5440	1.4	5265/251	1.61	5428	0.3	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	5022	1.4	5734/-1395	5.11	5025	0.4	Averaging
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	4975	1.5	5464/-1050	5.41	4979	0.4	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	4908	0.9	2580/-763	6.1	4909	0.3	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		7734	2.2	9576/-790	23.4	7743	1.2	Averaging
9	NPD-Candu		0.7714	Zr	OR	4000-7000	7348	1.2	8109/-328	6.7	7352	0.4	
6	Douglas Point		0.7114	Zr	EU		9093	12.5	1214/2922	***	8933	5.0	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	7458	1.5	8233/-329	8.2	7463	0.5	Averaging
11	NPR Hanford		0.94	Zr	NFS		9327	3.7	9232/15	7.5	9319	1.1	
10	Windscale AGR		2.50	SS-NB		5000-10000	3108	11.4	4460/-1119	28.6	3109	3.6	
Outlier													

*NFS — Nuclear Fuel Service
NATCO — Nuclear Audit and Testing Company
NBS — National Bureau of Standards

EU — Eurochemic
OR — Oak Ridge Laboratories
WS — Windscale

REPROCESSING BATCHES

Pu/U versus $(100 - {}^{239}\text{Pu})$

No. of Batches	Reactor Name	Lot or Core	235U ₀	Clad Mat'l	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	Intercept Model		Initial Point Model		Effects	
								% α	Slope/Intercept	% α	Slope		% α
BOILING WATER REACTORS													
17	Dresden 1	1	1.474	Zr	NFS	5000	146.7	1.6	215.5/-1554	8.6	146.8	0.4	Outlier Fringe
18	Dresden 1	2	1.474	Zr	NFS	10000	145.7	5.1	75.4/2183	40.0	145.4	1.1	
5	Dresden 1	4	1.474	Zr	NFS	8500-9800	136.2	2.5	229.2/2955	9.2	136.4	1.1	
7	Dresden 1	4	1.474	Zr	NFS	10900-12000	147.2	1.2	148.4/44.4	37.9	147.2	0.4	
1	Dresden 1	4	1.586	Zr	NFS	11500	142.1						
1	Dresden 1	4	1.596	Zr	NFS	10800	145.5						
1	Dresden 1	4	1.617	Zr	NFS	10400	139.6						
1	Dresden 1	4	1.767	Zr	NFS	13400	150.4						
1	Dresden 1	4	1.831	Zr	NFS	13100	152.8						
5	Dresden 1	4	1.474	Zr	NATCO	8500-9800	137.2	2.6	232.6/3031	11.2	137.4	1.2	Fringe
7	Dresden 1	4	1.474	Zr	NATCO	10900-12000	148.6	0.6	175.2/940.0	15.1	148.6	1.5	
1	Dresden 1	4	1.586	Zr	NATCO	11500	142.1						
1	Dresden 1	4	1.596	Zr	NATCO	10800	146.6						
1	Dresden 1	4	1.617	Zr	NATCO	10400	141.6						
1	Dresden 1	4	1.767	Zr	NATCO	13400	151.8						
1	Dresden 1	4	1.831	Zr	NATCO	13100	152.3						
18	Garigliano	1	2.020	Zr	WS	6600-14000	175.9	11.7	3186/95490	23.1	177.1	2.7	Unirradiated Assembly
13	Garigliano	2	2.020	Zr	WS	13400-17600	176.2	1.0	225.3/-1813	9.6	176.2	0.3	
1	Dresden 1	4	2.180	Zr	NFS	9800	159.8						
1	Dresden 1	4	2.180	Zr	NATCO	9800	158.4						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	175.1						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	172.8						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	172.1	1.3	142.0/920.9	52.4	172.1	0.7	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	169.4						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	172.9						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	174.3						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	172.5						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	176.6	1.1	169.1/107.2	43.5	172.6	0.6	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	168.8						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	174.0						
9	Dresden 1	3	2.50	SS	NFS	5000	176.1	3.2	217.0/806.6	21.5	176.1	1.1	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	174.6						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	181.8						
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	166.5	5.0	323.3/2878	21.6	167.1	2.1	Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	184.7	1.7	152.2/708.7	26.8	184.6	0.8	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	173.4						
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	182.7						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	167.2	4.7	308.9/2592	16.6	167.8	1.9	
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	184.0	1.5	168.9/327.9	24.3	183.9	0.7	
2	VAK	1	2.33	Zr	OR	15300-15900	148.1						
1	VAK	1	2.51	Zr	OR	17400	151.3						
2	VAK	1	2.33	Zr	EU	15300-15900	147.3						
1	VAK	1	2.403	Zr	EU		158.9						
1	VAK	1	2.51	Zr	EU	17400	155.4						
1	Big Rock Point	2	2.9926		NFS	10800	175.7						Averaging
1	Big Rock Point	2	3.0062		NFS	11200	176.3						
1	Big Rock Point	2	3.0108		NFS	10500	158.1						
1	Big Rock Point	2	3.2170		NFS	12300	170.6						Averaging
1	Big Rock Point	2	3.2600		NFS	20900	191.0						
1	Big Rock Point	2	3.0910		NFS	Core Avg.	172.0						
1	Big Rock Point	1	3.074	SS	NFS	7600	192.6						Averaging
1	Big Rock Point	1	3.1186	Zr	NFS	7400	201.0						
				Inc-SS									
1	Big Rock Point	1	3.1343	Zr-SS	NFS	17700	198.5						Averaging
1	Big Rock Point	1	3.1977	SS	NFS	7400	198.9						
				IncB									
4	Big Rock Point	1	3.212	SS	NFS	8400-8700	196.8	2.0	142.3/1062	75.5	196.7	1.0	Averaging
1	Big Rock Point	1	3.236	SS	NFS	10000	185.0						
				IncB-Zr									
1	Big Rock Point	1	3.252	SS-Zr	NFS	9000	193.6						Averaging
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	175.3						
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	197.6						
1	Big Rock Point	1	3.453	Zr	NFS	11000	184.9						Averaging
				IncB									
1	Big Rock Point	1	3.494	Zr	NFS	13000	182.7						
1	Big Rock Point	1	3.525	Zr	NFS	16100	187.9						Averaging
				IncB									
2	Big Rock Point	1	3.6605	Zr	NFS	5700-6400	197.7	0.4					
1	Big Rock Point	1	3.672	Zr	NFS	9400	199.5						Averaging
				IncB									
1	Big Rock Point	1	3.298	Zr	NFS	Total	186.8						
				Inc-SS									

REPROCESSING BATCHES
Pu/U versus (100 ²³⁹Pu) (continued)

No. of Batches	Reactor Name	Lot or Core	²³⁵ U O	Clad Mat'l	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% O	Intercept Model Slope/Intercept	% O	Initial Point Model Slope	% O	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	240.1	2.5	25910/-651700	37.8	240.2	0.8	Averaging
1	Trino	2	2.925	SS	OR	13200	251.5						
3	Trino	1	3.130	SS	OR	12700-13400	249.1	0.1	246/52.0	8.8	249.2	0.1	
9	Trino	2	3.130	SS	EU	19900-22200	253.8	1.4	299.8/-1482	19.8	253.8	0.4	Fringe
2	Trino	1	3.112	SS	OR	9900-10300	232.8	3.5					
1	Trino	2	3.386	SS	EU	21100	253.8						Fringe
1	Trino	2	3.308	SS	OR	10300	237.0						
1	Trino	2	3.454	SS	EU	14800	182.1						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	270.4	1.6	-1760/59020	33.7	270.4	0.9	
6	Trino	1	2.719	SS	EU	12500-12900	242.8	3.1	-854.9/27760	33.7	242.8	1.3	
1	Trino	2	2.925	SS	EU	13200	246.8						Averaging
2	Trino	1	3.130	SS	EU	12700-13000	250.2						
1	Trino	2	3.310	SS	EU	10300	234.3						
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	245.4	1.1	358.4/-2781	24.0	245.5	0.6	Averaging
1	Indian Point 1	1	2.900	SS	NFS	13100	244.9						
1	Indian Point 1	1	3.020	SS	NFS	15400	249.4						
1	Indian Point 1	1	3.220	SS	NFS	17900	257.7						Averaging
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	262.9	1.6	-11290/34400	70.6	262.9	0.8	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	289.5	1.6	410.5/-3721	22.4	289.6	0.5	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	247.0	1.7	405.3/-3910	42.9	247.0	0.8	Averaging
1	Indian Point 1	1	2.900	SS	NATCO	13100	241.5						
1	Indian Point 1	1	3.020	SS	NATCO	15400	253.1						
1	Indian Point 1	1	3.220	SS	NATCO	17900	256.4						Averaging
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	262.2	1.0	483.4/-6646	42.7	262.2	0.5	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	291.3	1.2	334.5/-1332	20.2	291.3	0.4	
13	Sena	1	2.958	SS	OR	12900	255.5	3.3	217.3/93.4	40.9	255.4	0.6	Averaging
1	Sena	1	3.357	SS	OR	2920	255.8						
12	Sena	2	3.358	SS	OR	18600-20600	263.4	3.7	1172/-275100	28.4	263.4	1.1	
14	Sena	1	2.958	SS	EU	12900	255.5	2.1	218.0/9182	39.2	255.5	0.6	Averaging
1	Sena	1	3.357	SS	EU	2920	255.8						
1	Sena	2	2.968	SS	EU		223.7						
12	Sena	2	3.358	SS	EU	18600-20600	261.7	3.8	1359/-344.0	28.9	261.9	1.1	Fringe
1	Sena	2	3.121	SS	EU		236.8						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	252.4						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	273.4	6.3	354.0/-1285	4.6	278.2	1.5	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	296.6	2.0	334.0/-747.1	3.9	297.4	0.6	
		III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	274.7						Averaging
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	275.7						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	328.4	1.3	272.3/1388	4.0	327.9	0.7	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	335.2	1.4	467.8/-3015	10.5	335.4	0.5	Averaging
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	341.6	2.8	391.4/-1179	1.6	343.8	0.7	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	380.9	1.8	469.6/-2298	6.5	381.4	0.5	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	380.7	1.6	467.9/-2441	3.0	381.3	0.5	Averaging
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	373.9	1.1	383.9/-270.7	8.9	373.9	0.3	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	254.4						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	341.0	2.6	382.7/945.7	1.2	343.5	0.5	Averaging
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	379.1	1.9	474.5/-2455	5.2	379.7	0.5	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	254.6						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	274.2						Averaging
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	272.7						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	340.8	2.2	383.1/984.4	2.4	342.8	0.7	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	381.1	1.6	453.7/-1872	6.2	381.5	0.5	Averaging
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	382.4	1.8	472.4/-2514	2.5	383.1	0.5	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	375.5	1.2	401.3/-693.6	6.9	375.5	0.4	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		118.3	1.2	105.5/357.8	11.0	118.2	0.7	Averaging
9	NPD-Candu		0.7114	Zr	OR	4000-7000	114.0	1.4	114.4/-10.8	8.1	114.0	0.5	
6	Douglas Point		0.7114	Zr	EU		118.1	1.1	101.9/462.6	7.2	118.0	0.5	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	113.7	1.5	115.6/-54.3	9.0	113.7	0.5	Averaging
11	NPR Hanford		0.94	Zr	NFS		124.5	6.6	195.9/907.2	8.3	125.9	1.9	
10	Windscale AGR		2.50	SS-NB		5000-10000	102.4	7.5	117.1/365.6	16.9	102.6	2.1	

REPROCESSING BATCHES

(²³⁹Pu)² versus ²³⁵U

No. of Batches	Reactor Name	Lot or Core	²³⁵ U	Clad Mat'l	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
BOILING WATER REACTORS													
17	Dresden I	1	1.474	Zr	NFS	5000	7538	1.0	5831/403.2	7.0	7535	0.2	
18	Dresden I	2	1.474	Zr	NFS	10000	7081	3.6	11700/-3804	26.1	7077	0.9	Outliers
5	Dresden I	4	1.474	Zr	NFS	8500-9800	7031	1.1	5767/538.4	16.6	7029	0.5	Fringe
7	Dresden I	4	1.474	Zr	NFS	10900-12000	6870	0.5	5125/970.7	15.5	6870	0.2	
1	Dresden I	4	1.586	Zr	NFS	11500	6444						
1	Dresden I	4	1.596	Zr	NFS	10800	6589						
1	Dresden I	4	1.617	Zr	NFS	10400	6452						
1	Dresden I	4	1.767	Zr	NFS	13400	5680						
1	Dresden I	4	1.831	Zr	NFS	13100	5596						
5	Dresden I	4	1.474	Zr	NATCO	8500-9800	7035	0.9	6279/170	16.7	7034	0.4	Fringe
7	Dresden I	4	1.474	Zr	NATCO	10900-12000	6925	0.5	7484/-562	20.6	6925	0.2	
1	Dresden I	4	1.586	Zr	NATCO	11500	6444						
1	Dresden I	4	1.596	Zr	NATCO	10800	6596						
1	Dresden I	4	1.617	Zr	NATCO	10400	6454						
1	Dresden I	4	1.767	Zr	NATCO	13400	5691						
1	Dresden I	4	1.831	Zr	NATCO	13100	5573						
18	Gargliano	1	2.020	Zr	WS	6600-14000	5440	2.2	217.4/4442	64.4	5268	2.8	Unirradiated Assembly
13	Gargliano	2	2.020	Zr	WS	13400-17600	4948	1.3	2976/-1590	11.0	4946	0.4	
1	Dresden I	4	2.180	Zr	NFS	9800	5008						
1	Dresden I	4	2.180	Zr	NATCO	9800	5099						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	4682						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	4633						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	4733	2.0	2450/1840	31.1	4729	1.2	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	4854						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	4731						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	4735						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	4683						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	4756	1.3	3059/1084	25.9	4754	0.8	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	4894						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	4756						
9	Dresden I	3	2.50	SS	NFS	5000	4750	2.6	3178/884.2	10.9	4739	0.9	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	4695						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	4514						
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	4634	1.0	4010/-786	7.6	4632	0.4	Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	4555	1.1	3820/-476	13.8	4553	0.5	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	4788						
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	4622						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	4650	1.1	4863/-2383	11.6	4650	0.4	Fringe
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	4556	1.1	3857/-539	14.8	4554	0.5	
2	VAK	1	2.33	Zr	OR	15300-15900	4328	0.3					
1	VAK	1	2.51	Zr	OR	17400	4070						
2	VAK	1	2.33	Zr	EU	15300-15900	4360	1.0					
1	VAK	1	2.403	Zr	EU		4099						
1	VAK	1	2.51	Zr	EU	17400	4019						
1	Big Rock Point	2	2.9926		NFS	10800	4393						Averaging
1	Big Rock Point	2	3.0062		NFS	11200	4249						Averaging
1	Big Rock Point	2	3.0108		NFS	10500	4605						Averaging
1	Big Rock Point	2	3.2170		NFS	12300	4305						UO ₂ Scrap
1	Big Rock Point	2	3.2600		NFS	20900	3604						
1	Big Rock Point	2	3.0910		NFS	Core Avg.	4164						Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	4380						
1	Big Rock Point	1	3.1186	Zr	NFS	7400	4170						
1	Big Rock Point	1	3.1343	Inc-SS									
1	Big Rock Point	1	3.1977	Zr-SS	NFS	17700	3681						
1	Big Rock Point	1	3.1977	SS	NFS	7400	4066						
4	Big Rock Point	1	3.212	Inc8									
1	Big Rock Point	1	3.236	SS	NFS	8400-8700	3860	1.1	7065/-9767	36.4	3860	0.6	Averaging
1	Big Rock Point	1	3.252	SS	NFS	10000	4162						
1	Big Rock Point	1	3.252	Inc6-Zr									
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9000	3807						
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	4121						Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	3895						
1	Big Rock Point	1	3.463	Zr	NFS	11000	3830						Averaging
1	Big Rock Point	1	3.494	Inc8									
1	Big Rock Point	1	3.494	Zr	NFS	13000	3753						Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	3590						Averaging
2	Big Rock Point	1	3.6505	Inc6									
1	Big Rock Point	1	3.672	Zr	NFS	5700-6400	3620	0.6					
1	Big Rock Point	1	3.672	Inc8									
1	Big Rock Point	1	3.298	Zr	NFS	9400	3632						
1	Big Rock Point	1	3.298	Inc-SS									
1	Big Rock Point	1	3.298	Zr	NFS	Total	3999						

REPROCESSING BATCHES
(²³⁹Pu)² versus ²³⁵U (continued)

No. of Batches	Reactor Name	Lot or Core	²³⁵ U	Clad Mat'l	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/intercept % σ	Initial Point Model Slope % σ	Effects
PRESSURIZED WATER REACTORS											
9	Trino	1	2.719	SS	OR	12500-12900	4133	0.6	82860/-130900	37.5	4133 0.2
1	Trino	2	2.925	SS	OR	13200	3803				
3	Trino	1	3.130	SS	OR	12700-13400	3708	1.1	1959/1910	33.2	3705 0.6
9	Trino	2	3.130	SS	EU	19900-22200	3379	1.3	2874/198	25.3	3378 0.4
2	Trino	1	3.112	SS	OR	9900-10300	4052	0.9			Fringe
1	Trino	2	3.386	SS	EU	21100	3234				
1	Trino	2	3.308	SS	OR	10300	3885				Fringe
1	Trino	2	3.454	SS	EU	14800	4846				Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	2880	1.2	372/5841	***	2880 0.7
6	Trino	1	2.719	SS	EU	12500-12900	4187	2.1	545/6488	***	4186 0.9
1	Trino	2	2.925	SS	EU	13200	3803				
2	Trino	1	3.130	SS	EU	12700-13000	3724	0.1			
1	Trino	2	3.310	SS	EU	10300	3914				
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	4068	1.6	2137/1813	19.1	4066 0.8
1	Indian Point 1	1	2.900	SS	NFS	13100	3989				
1	Indian Point 1	1	3.020	SS	NFS	15400	3798				
1	Indian Point 1	1	3.220	SS	NFS	17900	3457				
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	3377	0.2	4884/-3672	42.4	3377 0.1
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	2649	0.7	2081/403	10.5	2648 0.2
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	4095	1.9	1974/2089	37.1	4093 0.9
1	Indian Point 1	1	2.900	SS	NATCO	13100	4070				
1	Indian Point 1	1	3.020	SS	NATCO	15400	3830				
1	Indian Point 1	1	3.220	SS	NATCO	17900	3479				
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	3397	0.7	23100/-35770	17.1	3397 0.3
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	2657	0.9	1889/796	10.6	2656 0.3
13	Sena	1	2.958	SS	OR	12900	3919	1.8	6613/-6604	29.9	3919 0.5
1	Sena	1	3.357	SS	OR	2920	4340				
12	Sena	2	3.358	SS	OR	18600-20600	3188	0.9	2132/1139	8.6	3187 0.2
14	Sena	1	2.958	SS	EU	12900	4230	3.4	718/4308	71.7	4225 0.9
1	Sena	1	3.357	SS	EU	2920	5654				
1	Sena	2	2.968	SS	EU		3555				
12	Sena	2	3.358	SS	EU	18600-20600	3234	0.7	2509/418	12.2	3234 0.2
1	Sena	2	3.121	SS	EU		3673				
1	Yankee Rowe	V	2.902	Zr	NFS	12300	4031				
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	3818	6.9	2859/-457	4.2	3737 1.5
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	3508	3.1	2728/-85	4.5	3486 0.9
III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	3640				
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	3226				
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	2932	0.5	2845/-1240	5.0	2931 0.3
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	2825	1.0	2163/184	6.7	2824 0.3
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	2796	5.2	2092/386	2.7	2752 1.4
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	2281	1.4	1784/214	2.6	2278 0.4
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	2236	1.9	1685/557	3.5	2231 0.6
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	2267	1.1	1800/132	5.1	2274 0.3
2	Yankee Rowe	V	2.902	Zr	NBS	12300	4021	0.0			
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	2805	4.9	2170/198	1.9	2761 1.1
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	2285	1.5	1789/198	2.4	2282 0.4
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	4070				
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	3726				
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	3361				
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	2816	5.1	2108/331	3.3	2773 1.4
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	2295	1.5	1873/-691	5.4	2292 0.4
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	2238	2.0	1659/571	4.5	2233 0.6
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	2263	1.0	1939/-244	6.7	2262 0.3
HEAVY WATER AND GRAPHITE MODERATED REACTORS											
3	Douglas Point		0.7114	Zr	OR		11234	1.2	12830/1557	13.2	11240 0.7
9	NPD-Candu		0.7714	Zr	OR	4000-7000	11094	0.9	10280/2335	5.4	11090 0.3
6	Douglas Point		0.7114	Zr	EU		13199	12.8	1294/4864	18.9	12950 5.1
9	NPD-Candu		0.7114	Zr	EU	4000-7000	11287	1.7	10150/2295	11.2	11280 0.6
11	NPR Hanford		0.94	Zr	NFS		14085	8.0	8243/1273	11.7	13860 2.3
10	Windscale AGR		2.50	SS-NB		5000-10000	5301	5.6	5475/-3535	16.8	5291 1.7
Outlier											

REPROCESSING BATCHES

236U versus 235U

No. of Batches	Reactor Name	Lot or Core	235U _o	Clad Matl	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects	
BOILING WATER REACTORS														
17	Dresden I	1	1.474	Zr	NFS	5000	-0.1715	1.69	-0.237/0.323	11.4	-0.172	0.4		
18	Dresden I	2	1.474	Zr	NFS	10000	-0.1705	3.70	-0.196/0.278	25.4	-0.170	0.8		
5	Dresden I	4	1.474	Zr	NFS	8500-9800	-0.1692	0.99	-0.177/0.263	15.9	-0.169	0.4	Fringe	
7	Dresden I	4	1.474	Zr	NFS	10900-12000	-0.1680	0.59	-0.195/0.273	15.7	-0.168	0.2		
1	Dresden I	4	1.586	Zr	NFS	11500	-0.1725							
1	Dresden I	4	1.596	Zr	NFS	10800	-0.1712							
1	Dresden I	4	1.617	Zr	NFS	10400	-0.1746							
1	Dresden I	4	1.767	Zr	NFS	13400	-0.1749							
1	Dresden I	4	1.831	Zr	NFS	13100	-0.1767							
5	Dresden I	4	1.474	Zr	NATCO	8500-9800	-0.1659	2.32	-0.252/0.315	25.6	-0.166	1.1	Fringe	
7	Dresden I	4	1.474	Zr	NATCO	10900-12000	-0.1706	2.04	-0.486/0.460	23.4	-0.171	0.9		
1	Dresden I	4	1.586	Zr	NATCO	11500	-0.1663							
1	Dresden I	4	1.596	Zr	NATCO	10800	-0.1734							
1	Dresden I	4	1.617	Zr	NATCO	10400	-0.1730							
1	Dresden I	4	1.767	Zr	NATCO	13400	-0.1711							
1	Dresden I	4	1.831	Zr	NATCO	13100	-0.1749							
18	Garigliano	1	2.020	Zr	WS	6600-14000	-0.1791	4.43	-0.159/0.358	7.5	-0.178	0.9	Unirradiated Assembly	
13	Garigliano	2	2.020	Zr	WS	13400-17600	-0.1744	2.26	-0.249/0.429	16.8	-0.175	0.6		
1	Dresden I	4	2.180	Zr	NFS	9800	-0.1741							
1	Dresden I	4	2.180	Zr	NATCO	9800	-0.1667							
1	Humboldt Bay	1	2.258	Zr	NFS	15200	-0.1802							
1	Humboldt Bay	1	2.276	Zr	NFS	14600	-0.1781							
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	-0.1788	1.42	-0.177/0.352	20.0	-0.179	0.8		
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	-0.1790							
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	-0.1762							
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	-0.1799							
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	-0.1806							
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	-0.1768	0.86	-0.201/0.452	22.2	-0.177	0.5		
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	-0.1799							
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	-0.1788							
9	Dresden I	3	2.50	SS	NFS	5000	-0.1756	3.33	-0.166/0.439	20.7	-0.175	1.2		
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	-0.1833							
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	-0.1798							
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	-0.1791	1.47	-0.221/0.550	8.4	-0.179	0.6		
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	-0.1836	0.84	-0.155/0.435	9.2	-0.184	0.4	Fringe	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	-0.1847							
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	-0.1856							
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	-0.1785	3.68	-0.304/0.705	25.2	-0.179	1.5		
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	-0.1831	1.27	-0.132/0.394	9.0	-0.183	0.6		
2	VAK	1	2.33	Zr	OR	15300-15900	-0.1735	0.84						
1	VAK	1	2.51	Zr	OR	17400	-0.1751							
2	VAK	1	2.33	Zr	EU	15300-15900	-0.1781	1.36						
1	VAK	1	2.403	Zr	EU		-0.1720							
1	VAK	1	2.51	Zr	EU	17400	-0.1802							
1	Big Rock Point	2	2.9926		NFS	10800	-0.1908						Averaging	
1	Big Rock Point	2	3.0062		NFS	11200	-0.1909						Averaging	
1	Big Rock Point	2	3.0108		NFS	10500	-0.1927						Averaging	
1	Big Rock Point	2	3.2170		NFS	12300	-0.1936						UO ₂ Scrap	
1	Big Rock Point	2	3.2606		NFS	20900	-0.1936							
1	Big Rock Point	2	3.0910		NFS	Core Avg.	-0.1925						Averaging	
1	Big Rock Point	1	3.074	SS	NFS	7600	-0.1944							
1	Big Rock Point	1	3.1186	Zr	NFS	7400	-0.1923							
1	Big Rock Point	1	3.1343	Inc-SS										
1	Big Rock Point	1	3.1977	Zr-SS	NFS	17700	-0.1916							
1	Big Rock Point	1		SS	NFS	7400	-0.1958							
4	Big Rock Point	1	3.212	Inc8	SS	NFS	8400-8700	-0.1917	1.63	-0.487/1.307	43.9	-0.1918	0.8	
1	Big Rock Point	1	3.236	SS	NFS	10000	-0.1918						Averaging	
1	Big Rock Point	1	3.252	Inc6-Zr	SS-Zr	NFS	9000	-0.1928					Averaging	
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	-0.1918							
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	-0.1917							
1	Big Rock Point	1	3.463	Zr	NFS	11000	-0.1935						Averaging	
1	Big Rock Point	1		Inc8										
1	Big Rock Point	1	3.494	Zr	NFS	13000	-0.1929						Averaging	
1	Big Rock Point	1	3.525	Zr	NFS	16100	-0.1929						Averaging	
2	Big Rock Point	1	3.6605	Inc6	Zr	NFS	5700-6400	-0.2009	1.10					
1	Big Rock Point	1	3.672	Zr	NFS	9400	-0.2038							
1	Big Rock Point	1	3.298	Inc8	Zr	NFS	Total	-0.1861						
				Inc-SS										

REPROCESSING BATCHES
236U versus 235U (continued)

No. of Batches	Reactor Name	Lot or Core	235U 0	Clad Matl	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% U	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	0.1879	1.15	2.953/5.093	35.8	-0.188	0.4	
1	Trino	2	2.925	SS	OR	13200	-0.1886						
3	Trino	1	3.130	SS	OR	12700-13400	-0.2096	3.01	-7.217/14.75	100.0	-0.210	1.7	
9	Trino	2	3.130	SS	EU	19900-22200	-0.1966	2.85	-0.390/0.931	35.1	-0.197	1.0	
2	Trino	1	3.112	SS	OR	9900-10300	-0.1929	2.57					Fringe
1	Trino	2	3.386	SS	EU	21100	-0.1974						
1	Trino	2	3.308	SS	OR	10300	-0.1958						Fringe
1	Trino	2	3.454	SS	EU	14800	-0.1875						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	-0.2004	2.37	0.293/-0.246	58.3	-0.200	1.4	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	-0.1977	3.42	-1.223/2.273	48.2	-0.198	1.4	
1	Trino	2	2.925	SS	EU	13200	-0.1997						
2	Trino	1	3.130	SS	EU	12700-13000	-0.2172	4.21					
1	Trino	2	3.310	SS	EU	10300	-0.1998						
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	-0.1849	1.10	-0.127/0.448	12.9	-0.186	0.5	
1	Indian Point 1	1	2.900	SS	NFS	13100	-0.1866						Averaging
1	Indian Point 1	1	3.020	SS	NFS	15400	-0.1919						Averaging
1	Indian Point 1	1	3.220	SS	NFS	17900	-0.1927						Averaging
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	-0.1932	0.40	-0.485/1.162	72.1	-0.193	0.2	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	-0.1995	0.81	-0.197/0.824	14.3	-0.199	0.3	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	-0.1898	1.90	-0.0889/0.378	38.1	-0.186	0.9	
1	Indian Point 1	1	2.900	SS	NATCO	13100	-0.1894						Averaging
1	Indian Point 1	1	3.020	SS	NATCO	15400	-0.1880						Averaging
1	Indian Point 1	1	3.220	SS	NATCO	17900	-0.1916						Averaging
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	-0.1920	1.07	-1.943/3.727	19.3	-0.192	0.9	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	-0.1989	1.01	-0.152/0.728	15.6	-0.199	0.5	
13	Sena	1	2.958	SS	OR	12900	-0.1854	0.10	-0.154/0.518	21.0	-0.185	0.3	
1	Sena	1	3.357	SS	OR	2920	-0.2062						
12	Sena	2	3.358	SS	OR	18600-20600	-0.1909	1.24	-0.146/0.582	19.3	-0.191	0.4	
14	Sena	1	2.958	SS	EU	12900	-0.2120	7.23	-5.341/10.61	28.8	-0.212	1.9	
1	Sena	1	3.357	SS	EU	2920	-0.2751						
1	Sena	2	2.968	SS	EU		-0.1675						
12	Sena	2	3.358	SS	EU	18600-20600	-0.1987	6.74	-1.795/3.50	28.3	-0.199	2.0	
1	Sena	2	3.121	SS	EU		-0.1882						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	-0.1978						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	-0.2022	1.82	-0.203/0.710	2.4	-0.202	0.5	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	-0.1956	1.08	-0.188/0.669	2.1	-0.195	0.3	
		III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	-0.2248						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	-0.1973						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	-0.2009	1.00	-0.183/0.770	8.7	-0.201	0.5	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	-0.2031	1.33	-0.226/0.927	17.4	-0.203	0.4	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	-0.2033	1.19	-0.196/0.845	1.9	-0.203	0.4	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	-0.2091	0.56	-0.210/1.090	3.1	-0.209	0.2	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	-0.2069	0.86	-0.209/1.082	3.7	-0.207	0.2	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	-0.2090	0.47	-0.203/1.061	3.5	-0.209	0.1	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	-0.2011	0.06					
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	-0.2036	1.06	-0.196/0.847	1.3	-0.203	0.3	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	-0.2100	2.05	-0.193/1.041	8.1	-0.210	0.5	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	-0.2034						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	-0.2343						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	-0.2067						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	-0.2046	1.50	-0.199/0.857	2.5	-0.204	0.4	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	-0.2107	1.82	-0.227/1.144	9.4	-0.211	0.5	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	-0.2087	1.24	-0.220/1.117	4.9	-0.209	0.3	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	-0.2086	0.59	-0.220/1.108	4.0	-0.207	0.20	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		-0.1483	2.05	-0.180/0.115	22.3	-0.149	1.2	
9	NPD-Candu		0.7114	Zr	OR	4000-7000	-0.1523	1.40	-0.151/0.108	9.0	-0.152	0.5	
6	Douglas Point		0.7114	Zr	EU		-0.2022	24.94	-0.224/-0.007	42.0	-0.197	10.1	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	-0.1638	3.56	-0.224/0.134	15.4	-0.164	1.2	
11	NPR Hanford		0.94	Zr	NFS		-0.2921	15.51	-0.280/0.256	32.2	-0.286	4.6	Scatter
10	Windscale AGR		2.50	SS-NB		5000-10000	No 236U data						

REPROCESSING BATCHES

240Pu versus 239Pu x (100 - 239Pu)

No. of Batches	Reactor Name	Lot or Core	235U ₀	Clad Mat:	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
BOILING WATER REACTORS													
17	Dresden I	1	1.474	Zr	NFS	5000	9.411-3	0.4	1.139-2/3.456	0.9	9.412-3	0.1	
18	Dresden I	2	1.474	Zr	NFS	10000	9.887-3	1.8	1.685-2/14.92	3.6	9.896-3	0.4	Outlier
5	Dresden I	4	1.474	Zr	NFS	8500-9800	1.033-2	0.4	1.131-2/2.124	9.5	1.033-2	0.2	Fringe
7	Dresden I	4	1.474	Zr	NFS	10900-12000	1.028-2	0.5	1.794-2/17.47	11.2	1.028-2	0.2	
1	Dresden I	4	1.586	Zr	NFS	11500	1.035-2						
1	Dresden I	4	1.596	Zr	NFS	10800	1.012-2						
1	Dresden I	4	1.617	Zr	NFS	10400	1.019-2						
1	Dresden I	4	1.767	Zr	NFS	13400	1.037-2						
1	Dresden I	4	1.831	Zr	NFS	13100	1.020-2						
5	Dresden I	4	1.474	Zr	NATCO	8500-9800	1.035-2	0.5	1.188-2/3.329	10.1	1.035-2	0.2	Fringe
7	Dresden I	4	1.474	Zr	NATCO	10900-12000	1.031-2	0.5	1.775-2/16.98	10.6	1.031-2	0.2	
1	Dresden I	4	1.586	Zr	NATCO	11500	1.044-2						
1	Dresden I	4	1.596	Zr	NATCO	10800	1.011-2						
1	Dresden I	4	1.617	Zr	NATCO	10400	1.021-2						
1	Dresden I	4	1.767	Zr	NATCO	13400	1.037-2						
1	Dresden I	4	1.831	Zr	NATCO	13100	1.022-2						
18	Garigliano	1	2.020	Zr	WS	6500-14000	9.558-3	0.5	1.464-3/11.00	5.3	9.559-3	0.1	Unirradiated Assembly
13	Garigliano	2	2.020	Zr	WS	13400-17600	1.000-2	1.1	2.112-2/25.90	12.2	1.000-2	0.3	
1	Dresden I	4	2.180	Zr	NFS	9800	9.543-3						
1	Dresden I	4	2.180	Zr	NATCO	9800	9.535-3						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	9.569-3						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	9.591-3						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	9.563-3	0.7	1.338-3/8.123	29.4	9.564-3	0.4	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	9.325-3						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	9.131-3						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	9.545-3						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	9.607-3						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	9.570-3	0.8	1.397-2/9.390	23.1	9.550-3	0.4	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	9.293-3						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	9.133-3						
9	Dresden I	3	2.50	SS	NFS	5000	8.988-3	0.4	9.484-3/0.783	3.3	8.989-3	0.1	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	9.048-3						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	9.025-3						
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	9.163-3	1.3	7.757-3/2.105	17.3	9.157-3	0.5	Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	8.956-3	0.6	9.981-3/1.750	10.3	8.957-3	0.3	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	9.088-3						
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	9.041-3						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	9.176-3	1.2	7.733-3/2.155	14.2	9.172-3	0.5	Fringe
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	8.975-3	0.6	1.022-2/2.177	9.5	8.976-3	0.3	
2	VAK	1	2.33	Zr	OR	15300-15900	1.009-2	1.0					
1	VAK	1	2.51	Zr	OR	17400	1.021-2						
2	VAK	1	2.33	Zr	EU	15300-15900	1.007-2	0.8					
1	VAK	1	2.403	Zr	EU		9.911-3						
1	VAK	1	2.51	Zr	EU	17400	1.017-2						
1	Big Rock Point	2	2.9926		NFS	10800	8.858-3						Averaging
1	Big Rock Point	2	3.0062		NFS	11200	8.907-3						Averaging
1	Big Rock Point	2	3.0108		NFS	10500	8.794-3						Averaging
1	Big Rock Point	2	3.2170		NFS	12300	8.862-3						Averaging
1	Big Rock Point	2	3.2800		NFS	20900	9.432-3						
1	Big Rock Point	2	3.0910		NFS	Core Avg.	8.988-3						Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	8.705-3						
1	Big Rock Point	1	3.1186	Zr	NFS	7400	8.748-3						
1	Big Rock Point	1	3.1343	Inc-SS									
1	Big Rock Point	1	3.1977	Zr-SS	NFS	17700	9.163-3						
1	Big Rock Point	1		SS	NFS	7400	8.636-3						
4	Big Rock Point	1	3.212	Inc8									
1	Big Rock Point	1	3.236	SS	NFS	8400-8700	8.784-3	1.1	1.422-2/8.533	19.9	8.788-3	0.6	
1	Big Rock Point	1		SS	NFS	10000	8.624-3						Averaging
1	Big Rock Point	1	3.252	Inc6-Zr									
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9000	8.842-3						
1	Big Rock Point	1	3.3576	SS-Zr	NFS	9700	8.848-3						Averaging
1	Big Rock Point	1		SS-Zr	NFS	8100	8.731-3						
1	Big Rock Point	1	3.463	Zr	NFS	11000	8.631-3						Averaging
1	Big Rock Point	1		Inc8									
1	Big Rock Point	1	3.494	Zr	NFS	13000	8.948-3						Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	9.046-3						Averaging
2	Big Rock Point	1	3.6005	Inc6									
1	Big Rock Point	1	3.672	Zr	NFS	5700-6400	8.774-3	0.2					
1	Big Rock Point	1		Zr	NFS	9400	9.774-3						
1	Big Rock Point	1	3.298	Inc8									
1	Big Rock Point	1		Zr	NFS	Total	8.720-3						Averaging
1	Big Rock Point	1		Inc-SS									

REPROCESSING BATCHES
²⁴⁰Pu versus ²³⁹Pu x (100/²³⁹Pu) (continued)

No. of Batches	Reactor Name	Lot or Core	²³⁵ U ₀	Clad Mat'l	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	8.280-3	0.4	1.018-2/-3.591	24.8	8.280-3	0.1	
1	Trino	2	2.925	SS	OR	13200	8.235-3						
3	Trino	1	3.130	SS	OR	12700-13400	8.086-3	0.1	8.971-3/-1.593	7.0	8.086-3	0.1	
9	Trino	2	3.130	SS	EU	19900-22200	8.345-3	0.4	1.013-2/-3.895	7.8	8.345-3	0.1	
2	Trino	1	3.112	SS	OR	9900-10300	8.154-3	0.3					Fringe
1	Trino	2	3.386	SS	EU	21100	8.257-3						
1	Trino	2	3.308	SS	OR	10300	8.127-3						Fringe
1	Trino	2	3.454	SS	EU	14800	8.368-3						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	7.930-3	1.1	9.755-2/-184.8	71.4	7.930-3	0.6	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	8.299-3	0.3	7.074-3/2.315	22.4	8.299-3	0.1	
1	Trino	2	2.925	SS	EU	13200	8.213-3						
2	Trino	1	3.130	SS	EU	12700-13000	8.158-3	0.1					
1	Trino	2	3.310	SS	EU	10300	8.127-3						
4	Indian Point I	1	2.872	SS	NFS	12100-12500	8.152-3	0.2	9.031/-1.631	4.5	8.152-3	0.1	
1	Indian Point I	1	2.900	SS	NFS	13100	8.133-3						Averaging
1	Indian Point I	1	3.020	SS	NFS	15400	8.087-3						Averaging
1	Indian Point I	1	3.220	SS	NFS	17900	8.079-3						Averaging
4	Indian Point I	1	3.263	SS	NFS	18900-19500	8.107-3	0.1	9.865-3/-3.680	5.6	8.107-3	0.1	
9	Indian Point I	2	4.076	SS	NFS	22600-25100	7.868-3	0.3	9.922-3/-4.373	3.9	7.868-3	0.1	
4	Indian Point I	1	2.872	SS	NATCO	12100-12500	8.152-3	0.2	9.256-3/-2.052	7.7	8.152-3	0.1	
1	Indian Point I	1	2.900	SS	NATCO	13100	8.141-3						
1	Indian Point I	1	3.020	SS	NATCO	15400	8.066-3						
1	Indian Point I	1	3.220	SS	NATCO	17900	8.091-3						
4	Indian Point I	1	3.263	SS	NATCO	18900-19500	8.129-3	0.4	1.294-2/-10.11	16.5	8.129-3	0.2	
9	Indian Point I	2	4.076	SS	NATCO	22600-25100	7.873-3	0.3	9.909-3/-4.335	5.1	7.873-3	0.1	
13	Sena	1	2.958	SS	OR	12900	8.143-3	1.2	1.620-2/-14.90	6.3	8.143-3	0.3	
1	Sena	1	3.357	SS	OR	2920	8.816-3						
12	Sena	2	3.358	SS	OR	18600-20600	8.176-3	0.2	9.773/-3.369	3.2	8.176-3	0.1	
14	Sena	1	2.958	SS	EU	12900	8.140-3	1.1	1.624-2/-14.99	6.2	8.142-3	0.6	
1	Sena	1	3.357	SS	EU	2920	8.816-3						
1	Sena	2	2.968	SS	EU		8.491-3						
12	Sena	2	3.358	SS	EU	18600-20600	8.116-3	0.3	8.739-3/-1.319	9.2	8.116-3	0.1	
1	Sena	2	3.121	SS	EU		8.128-3						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	8.140-3						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	7.945-3	2.0	7.107-3/1.116	0.7	7.908-3	0.4	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	7.802-3	0.8	7.171-3/1.004	1.2	7.793-3	0.2	
III													
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	8.008-3						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	8.049-3						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	7.619-3	0.2	7.819-3/0.374	1.2	7.620-3	0.1	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	7.562-3	0.1	7.342-3/0.387	2.1	7.562-3	0.1	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	7.519-3	1.2	7.395-3/0.218	2.8	7.514-3	0.3	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	7.303-3	0.3	7.722-3/0.804	1.9	7.304-3	0.1	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	7.352-3	0.3	7.944-3/-1.193	1.1	7.354-3	0.1	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	7.381-3	0.2	7.486-3/-0.351	2.7	7.309-3	0.1	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	8.197-3						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	7.534-3	1.5	7.067-3/0.813	2.0	7.518-3	0.3	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	7.297-3	0.2	7.561-2/-0.504	1.5	7.298-3	0.1	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	8.193-3						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	7.973-3						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	7.989-3						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	7.529-3	1.3	7.179-3/0.617	2.2	7.518-3	0.3	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	7.293-3	0.5	7.704-3/0.795	4.1	7.294-3	0.2	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	7.356-3	0.4	7.968-3/-1.110	2.2	7.358-3	0.1	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	7.317-3	0.3	7.121-3/0.385	4.2	7.317-3	0.1	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		1.116-2	1.8	1.529-2/-8.314	3.0	1.118-2	1.1	
9	NPD-Candu		0.7714	Zr	OR	4000-7000	1.135-2	1.2	1.433-2/-5.987	4.3	1.135-2	0.4	
6	Douglas Point		0.7114	Zr	EU		1.119-2	1.4	1.545-2/-8.676	4.3	1.120-2	0.6	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	1.132-2	1.2	1.425-2/-5.885	4.2	1.133-2	0.4	
11	NPR Hanford		0.94	Zr	NFS		9.547-3	0.4	1.001-2/-0.513	0.4	9.553-3	0.1	
10	Windscale AGR		2.50	SS-NB		5000-10000	1.041-2	2.4	1.281-2/-4.439	3.4	1.045-2	0.7	

REPROCESSING BATCHES

^{239}Pu x ^{240}Pu versus ^{235}U x ^{241}Pu

No. of Batches	Reactor Name	Lot or Core	$^{235}\text{U}_0$	Clad Mat'l	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% α	Intercept Model Slope/Intercept	% α	Initial Point Model Slope	% α	Effects
BOILING WATER REACTORS													
17	Dresden 1	1	1.474	Zr	NFS	5000	254.5	0.7	213.4/205.6	9.1	254.4	0.2	Outlier Fringe
18	Dresden 1	2	1.474	Zr	NFS	10000	253.8	3.6	102.0/871.7	22.7	253.3	0.8	
5	Dresden 1	4	1.474	Zr	NFS	8500-9800	301.1	2.7	18.69/1432.	178.9	300.8	1.2	
7	Dresden 1	4	1.474	Zr	NFS	10900-12000	280.5	1.1	-1017/2070.	41.9	280.5	0.4	
1	Dresden 1	4	1.586	Zr	NFS	11500	264.7						
1	Dresden 1	4	1.596	Zr	NFS	10800	245.3						
1	Dresden 1	4	1.617	Zr	NFS	10400	254.8						
1	Dresden 1	4	1.767	Zr	NFS	13400	232.7						
1	Dresden 1	4	1.831	Zr	NFS	13100	213.6						
5	Dresden 1	4	1.474	Zr	NATCO	8500-9800	301.5	2.8	29.12/1381	123.6	301.2	1.3	
7	Dresden 1	4	1.474	Zr	NATCO	10900-12000	276.9	1.4	22.93/1649	***	276.8	0.5	
1	Dresden 1	4	1.586	Zr	NATCO	11500	267.0						
1	Dresden 1	4	1.596	Zr	NATCO	10800	246.3						
1	Dresden 1	4	1.617	Zr	NATCO	10400	256.7						
1	Dresden 1	4	1.767	Zr	NATCO	13400	232.0						
1	Dresden 1	4	1.831	Zr	NATCO	13100	216.0						
18	Gargliano	1	2.020	Zr	WS	6600-14000	166.2	8.3	-3.5/1443	50.6	163.7	2.8	Unirradiated Assembly
13	Gargliano	2	2.020	Zr	WS	13400-17600	189.5	3.7	-34.8/1739.	32.9	189.1	1.1	
1	Dresden 1	4	2.180	Zr	NFS	9800	163.3						
1	Dresden 1	4	2.180	Zr	NATCO	9800	162.2						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	144.8						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	146.7						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	143.3	1.3	-428.4/5615	2.4	143.3	0.7	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	134.6						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	122.5						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	142.3						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	145.8						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	142.4	1.3	-1018/11460	***	142.4	0.7	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	132.6						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	123.0						
9	Dresden 1	3	2.50	SS	NFS	5000	136.8	2.5	82.5/451.6	17.9	136.6	0.8	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	126.9						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	124.5						
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	150.6	7.3	24.85/934.7	64.2	149.3	3.1	Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	124.2	2.0	74.78/475.4	46.8	124.2	0.9	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	126.6						
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	123.9						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	151.2	1.1	28.28/909.6	47.2	149.8	3.2	
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	125.0	2.3	69.08/534.8	48.0	124.9	1.0	
2	VAK	1	2.33	Zr	OR	15300-15900	174.8	1.8					
1	VAK	1	2.51	Zr	OR	17400	156.5						
2	VAK	1	2.33	Zr	EU	15300-15900	170.9	1.7					
1	VAK	1	2.403	Zr	EU		165.5						
1	VAK	1	2.51	Zr	EU	17400	159.5						
1	Big Rock Point	2	2.9926		NFS	10800	97.02						Averaging
1	Big Rock Point	2	3.0062		NFS	11200	96.47						Averaging
1	Big Rock Point	2	3.0108		NFS	10500	96.27						Averaging
1	Big Rock Point	2	3.2170		NFS	12300	80.54						Averaging
1	Big Rock Point	2	3.2600		NFS	20900	88.65						
1	Big Rock Point	2	3.0910		NFS	Core Avg.	90.19						Averaging
1	Big Rock Point	1	3.074	SS	NFS	7500	102.5						
1	Big Rock Point	1	3.1186	Zr	NFS	7400	103.8						
1	Big Rock Point	1	3.1343	Inc-SS	NFS	17700	89.69						
1	Big Rock Point	1	3.1977	SS	NFS	7400	96.97						
4	Big Rock Point	1	3.212	Inc8	NFS	8400-8700	98.40	3.0	-178.1/3122.	79.4	98.37	1.5	Averaging
1	Big Rock Point	1	3.236	SS	NFS	10000	83.89						
1	Big Rock Point	1	3.252	Inc6-Zr									
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9000	97.56						
1	Big Rock Point	1	3.2595	SS-Zr	NFS	8700	93.11						Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	92.81						
1	Big Rock Point	1	3.463	Zr	NFS	11000	77.77						Averaging
1	Big Rock Point	1	3.494	Inc8	NFS	13000	78.70						Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	76.73						Averaging
2	Big Rock Point	1	3.6605	Inc6	NFS	5700-6400	97.80	3.9					
1	Big Rock Point	1	3.672	Zr	NFS	9400	79.68						
1	Big Rock Point	1	3.298	Inc8	NFS	Total	89.09						Averaging
				Inc-SS									

REPROCESSING BATCHES
 ^{239}Pu x ^{240}Pu versus ^{235}U x ^{241}Pu (continued)

No. of Batches	Reactor Name	Lot or Core	^{235}U	Clad Mat'l	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	87.40	1.0	11.36/1018	105.7	87.39	0.3	
1	Trino	2	2.925	SS	OR	13200	81.62						
3	Trino	1	3.130	SS	OR	12700-13400	72.75	0.7	39.75/504.7	96.8	72.74	0.4	
9	Trino	2	3.130	SS	EU	19900-22200	76.31	3.0	3.73/1295	***	76.22	1.0	Outlier
2	Trino	1	3.112	SS	OR	9900-10300	73.09	0.7					Fringe
1	Trino	2	3.386	SS	EU	21100	66.91						
1	Trino	2	3.308	SS	OR	10300	69.83						Fringe
1	Trino	2	3.454	SS	EU	14800	49.35						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	53.59	2.1	-56.10/2374	72.9	53.58	1.2	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	87.99	1.9	2.385/1140	249.1	87.95	0.8	
1	Trino	2	2.925	SS	EU	13200	78.61						
2	Trino	1	3.130	SS	EU	12700-13000	74.91	0.3					
1	Trino	2	3.310	SS	EU	10300	69.33						
4	Indian Point I	1	2.872	SS	NFS	12100-12600	79.21	0.5	74.91/61.84	39.1	79.21	0.2	
1	Indian Point I	1	2.900	SS	NFS	13100	77.53						Averaging
1	Indian Point I	1	3.020	SS	NFS	15400	72.79						Averaging
1	Indian Point I	1	3.220	SS	NFS	17900	67.97						Averaging
4	Indian Point I	1	3.263	SS	NFS	18900-19500	66.94	0.2	26.36/72.18	44.1	66.94	0.1	
9	Indian Point I	2	4.076	SS	NFS	22600-25100	51.00	0.7	36.04/34.01	62.7	51.00	0.2	
4	Indian Point I	1	2.872	SS	NATCO	12100-12500	78.74	1.1	35.97/620	81.5	78.73	0.5	
1	Indian Point I	1	2.900	SS	NATCO	13100	76.31						
1	Indian Point I	1	3.020	SS	NATCO	15400	72.14						
1	Indian Point I	1	3.220	SS	NATCO	17900	67.99						
4	Indian Point I	1	3.263	SS	NATCO	18900-19500	66.85	0.8	22.99/784.1	49.5	66.84	0.4	
9	Indian Point I	2	4.076	SS	NATCO	22600-25100	51.10	0.9	37.48/2012	51.2	51.10	0.3	
13	Sena	1	2.958	SS	OR	12900	77.43	1.9	1569/-21,900	30.1	77.43	0.5	
1	Sena	1	3.357	SS	OR	2920	150.3						
12	Sena	2	3.358	SS	OR	18600-20600	67.18	0.7	8.46/1052	201.0	67.17	0.2	
14	Sena	1	2.958	SS	EU	12900	74.20	2.7	-16.90/1396	***	74.16	0.7	
1	Sena	1	3.357	SS	EU	2920	146.9						
1	Sena	2	2.968	SS	EU		78.66						
12	Sena	2	3.358	SS	EU	18600-20600	64.49	1.2	-5.258/1293	***	64.48	0.4	
1	Sena	2	3.121	SS	EU		69.36						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	80.66						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	72.25	14.0	35.53/445.7	2.3	69.39	2.5	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	64.01	5.6	31.71/500.3	4.1	63.47	1.3	
III													
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	60.74						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	63.89						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	49.91	1.0	35.89/300.1	5.7	49.89	0.5	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	47.72	0.9	26.19/462.9	8.5	47.71	0.4	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	47.69	6.5	29.00/399.8	10.0	47.26	1.4	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	36.56	0.6	30.09/183.7	6.4	36.56	0.2	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	36.85	1.1	47.19/-298.9	20.5	36.85	0.3	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	36.45	0.5	35.70/21.39	13.5	36.45	0.1	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	80.43						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	49.06	8.0	26.21/457.7	6.2	47.37	1.5	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	36.41	0.7	28.18/233.7	5.3	36.40	0.2	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	80.22						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	60.53						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	61.76						
12	Yankee Rowe	V	4.181	SS	NATCO	9700-25600	47.67	6.7	26.99/441.5	8.8	47.20	1.5	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	36.46	1.0	25.41/313.6	9.5	36.45	0.3	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	37.02	1.3	52.59/-448.4	25.9	37.02	0.4	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	36.91	0.9	21.77/430.7	14.3	36.90	0.3	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		1348	2.2	2061/-955	66.9	1349	1.3	
9	NPD-Candu		0.7114	Zr	OR	4000-7000	1491	4.8	462.1/1132	53.6	1486	1.6	
6	Douglas Point		0.7114	Zr	EU		1128	14.1	58.51/1543	153.9	1098	5.9	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	1437	6.2	291.5/1306	67.7	1430	2.1	
11	NPR Hanford		0.94	Zr	NFS		626.7	4.6	405.0/325.2	4.3	621.4	1.3	
10	Windscale AGR		2.50	SS-NB		5000-10000	196.6	6.6	115.1/594.8	8.6	194.4	1.7	Outlier

REPROCESSING BATCHES

²⁴⁰Pu x ²⁴¹Pu versus ²³⁵U x ²⁴²Pu

No. of Batches	Reactor Name	Lot or Core	²³⁵ U _o	Clad Mat'l	Data Source	Exposure Range INWD/MTMI	Isotopic Ratio	% α	Intercept Model Slope/Intercept	% α	Initial Point Model Slope	% α	Effects
BOILING WATER REACTORS													
17	Dresden 1	1	1.474	Zr	NFS	5000	137.7	2.1	142.1/-2.797	9.9	137.7	0.5	
18	Dresden 1	2	1.474	Zr	NFS	10000	132.3	4.6	168.3/-45.50	13.9	132.4	1.0	Outlier
5	Dresden 1	4	1.474	Zr	NFS	8500-9800	124.6	3.2	116.2/16.55	21.9	124.4	1.4	Fringe
7	Dresden 1	4	1.474	Zr	NFS	10900-12000	124.1	2.6	74.67/80.50	42.3	124.0	1.0	
1	Dresden 1	4	1.586	Zr	NFS	11500	118.3						
1	Dresden 1	4	1.586	Zr	NFS	10800	111.1						
1	Dresden 1	4	1.617	Zr	NFS	10400	111.0						
1	Dresden 1	4	1.767	Zr	NFS	13400	111.8						
1	Dresden 1	4	1.831	Zr	NFS	13100	101.6						
5	Dresden 1	4	1.474	Zr	NATCO	8500-9800	127.9	4.7	106.0/27.08	30.8	127.5	2.1	Fringe
7	Dresden 1	4	1.474	Zr	NATCO	10900-12000	130.6	4.7	40.76/140.2	51.1	130.2	1.7	Outlier
1	Dresden 1	4	1.586	Zr	NATCO	11500	127.2						
1	Dresden 1	4	1.586	Zr	NATCO	10800	111.8						
1	Dresden 1	4	1.617	Zr	NATCO	10400	111.4						
1	Dresden 1	4	1.767	Zr	NATCO	13400	114.1						
1	Dresden 1	4	1.831	Zr	NATCO	13100	102.8						
18	Garigliano	1	2.020	Zr	WS	6600-14000	88.68	8.9	-0.794/177.0	***	87.22	2.3	Unirradiated Assembly
13	Garigliano	2	2.020	Zr	WS	13400-17600	92.12	2.4	79.96/29.63	20.1	92.07	0.7	
1	Dresden 1	4	2.180	Zr	NFS	9800	77.61						
1	Dresden 1	4	2.180	Zr	NATCO	9800	82.39						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	82.27						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	82.28						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	77.73	2.6	137.7/-126.7	42.4	77.80	1.5	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	66.70						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	68.98						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	79.24						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	81.29						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	77.62	3.4	160.1/-174.8	63.1	77.69	2.0	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	66.29						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	68.15						
9	Dresden 1	3	2.50	SS	NFS	5000	73.75	4.8	64.74/8.156	17.2	73.50	1.7	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	66.95						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	68.36						
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	73.26	1.2	73.97/-0.534	4.7	73.27	0.5	Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	71.03	1.9	57.72/15.95	5.5	70.85	0.8	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	66.95						
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	10300	67.41						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	72.98	1.6	74.25/-0.959	5.8	73.00	0.7	
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	71.56	3.1	57.75/16.31	16.1	71.35	1.3	
2	VAK	1	2.33	Zr	OR	15300-15900	82.86	0.4					
1	VAK	1	2.51	Zr	OR	17400	74.18						
2	VAK	1	2.33	Zr	EU	15300-15900	82.28	0.9					
1	VAK	1	2.403	Zr	EU		90.09						
1	VAK	1	2.51	Zr	EU	17400	78.35						
1	Big Rock Point	2	2.9926		NFS	10800	41.08						Averaging
1	Big Rock Point	2	3.0062		NFS	11200	44.45						Averaging
1	Big Rock Point	2	3.0108		NFS	10500	34.79						Averaging
1	Big Rock Point	2	3.2170		NFS	12300	38.83						UO ₂ Scrap
1	Big Rock Point	2	3.2600		NFS	20900	44.03						
1	Big Rock Point	2	3.0910		NFS	Core Avg.	39.55						Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	52.91						
1	Big Rock Point	1	3.1186	Zr	NFS	7400	57.05						
				Inc-SS									
1	Big Rock Point	1	3.1343	Zr-SS	NFS	17700	50.35						
1	Big Rock Point	1	3.1977	SS	NFS	7400	55.26						
				IncB									
4	Big Rock Point	1	3.212	SS	NFS	8400-8700	54.89	3.0	35.68/23.68	40.9	54.81	1.5	
1	Big Rock Point	1	3.236	SS	NFS	10000	41.24						Averaging
				IncB-Zr									
1	Big Rock Point	1	3.252	SS-Zr	NFS	9000	52.01						Averaging
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	38.70						Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	51.10						
1	Big Rock Point	1	3.463	Zr	NFS	11000	37.56						Averaging
				IncB									
1	Big Rock Point	1	3.494	Zr	NFS	13000	37.46						Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	40.33						Averaging
				IncB									
2	Big Rock Point	1	3.6605	Zr	NFS	5700-6400	47.04	0.6					
1	Big Rock Point	1	3.672	Zr	NFS	9400	-2.229						
				IncB									
1	Big Rock Point	1	3.298	Zr	NFS	Total	-2.721						Averaging
				Inc-SS									

REPROCESSING BATCHES
 ^{240}Pu x ^{241}Pu versus ^{235}U x ^{242}Pu (continued)

No. of Batches	Reactor Name	Lot or Core	^{235}U	Clad Matl	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	Intercept Model		Initial Point Model		Effects	
								% σ	Slope/Intercept	% σ	Slope	% σ	
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	-3.350	0.6	32.25/166.7	36.1	-3.350	0.2	
1	Trino	2	2.925	SS	OR	13200	-2.856						
3	Trino	1	3.130	SS	OR	12700-13400	-2.527	0.8	1.487/5.986	40.9	-2.526	0.5	
9	Trino	2	3.130	SS	EU	19900-22200	-2.444	0.7	2.512/-0.509	18.8	-2.444	0.2	
2	Trino	1	3.112	SS	OR	9900-10300	-2.754	1.0					Fringe
1	Trino	2	3.386	SS	EU	21100	-2.118						
1	Trino	2	3.308	SS	OR	10300	-2.467						Fringe
1	Trino	2	3.454	SS	EU	14800	-2.819						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	-1.562	2.0	2.43/41.79	0.6	-1.562	1.1	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	-3.391	1.5	0.142/16.33	438.8	-3.390	0.6	
1	Trino	2	2.925	SS	EU	13200	-2.924						
2	Trino	1	3.130	SS	EU	12700-13000	-2.558	0.1					
1	Trino	2	3.310	SS	EU	10300	-2.482						
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	-3.044	1.2	1.762/6.367	23.6	-3.043	0.6	
1	Indian Point 1	1	2.900	SS	NFS	13100	-2.955						
1	Indian Point 1	1	3.020	SS	NFS	15400	-2.694						
1	Indian Point 1	1	3.220	SS	NFS	17900	-2.317						
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	-2.248	0.2	3.980/-13.08	44.2	-2.248	0.1	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	-1.378	0.4	1.353/0.309	10.4	-1.378	0.1	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	-3.060	1.3	1.683/6.822	33.1	-3.059	0.6	
1	Indian Point 1	1	2.900	SS	NATCO	13100	-3.005						
1	Indian Point 1	1	3.020	SS	NATCO	15400	-2.704						
1	Indian Point 1	1	3.220	SS	NATCO	17900	-2.331						
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	-2.263	0.8	2.392/-163.5	16.7	-2.263	0.4	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	-1.382	0.6	1.213/2.050	12.9	-1.382	0.2	
13	Sena	1	2.958	SS	OR	12900	-2.849	2.3	17.59/-77.91	29.3	-2.850	0.6	
1	Sena	1	3.357	SS	OR	2920	-2.878						
12	Sena	2	3.358	SS	OR	18600-20600	-2.098	0.4	1.694/3.321	7.9	-2.098	0.1	
14	Sena	1	2.958	SS	EU	12900	-3.024	3.1	1.480/7.683	50.6	-3.022	0.8	
1	Sena	1	3.357	SS	EU	2920	-3.709						
1	Sena	2	2.968	SS	EU		-2.760						
12	Sena	2	3.358	SS	EU	18600-20600	-2.103	0.4	1.739/2.970	9.3	-2.103	0.1	
1	Sena	2	3.121	SS	EU		-2.539						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	-2.979						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	-2.298	7.5	1.561/3.373	3.4	-2.248	1.5	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	-2.103	2.8	1.553/3.243	3.5	-2.092	0.8	
		III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	-2.178						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	-1.952						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	-1.515	0.4	1.525/-0.097	5.6	-1.515	0.2	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	-1.374	0.7	1.043/3.202	6.6	-1.374	0.3	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	-1.358	4.4	1.033/3.202	1.6	-1.344	1.1	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	-0.898	0.9	0.755/2.234	3.8	-0.898	0.3	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	-0.892	1.0	0.729/2.707	3.8	-0.891	0.3	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	-0.896	0.7	0.735/2.596	4.1	-0.896	0.2	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	-2.993						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	-1.363	4.9	1.022/3.274	1.2	-1.347	1.0	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	-0.899	1.0	0.741/2.454	3.5	-0.898	0.3	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	-3.020						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	-2.209						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	-2.000						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	-1.367	4.8	1.009/3.479	2.7	-1.352	1.1	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	-0.901	1.3	0.782/1.850	8.2	-0.901	0.3	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	-0.893	1.3	0.722/2.830	4.4	-0.892	0.3	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	-0.894	0.7	0.755/2.228	5.7	-0.894	0.2	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		-52.81	3.4	107.7/23.36	10.6	-52.91	2.0	
9	NPD-Candu		0.7714	Zr	OR	4000-7000	-53.26	1.9	80.66/-11.71	4.8	-53.32	0.6	
6	Douglas Point		0.7114	Zr	EU		-58.60	8.8	10.34/18.79	***	-58.23	3.5	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	-53.68	1.9	79.40/-10.90	7.3	-53.74	0.6	
11	NPR-Hanford		0.94	Zr	NFS		-36.64	6.8	22.62/4.025	11.7	-36.15	2.0	
10	Windscale AGR		2.50	SS-NB		5000-10000	-5.66	5.4	6.658/-3.455	18.2	-5.667	1.8	Outlier

REPROCESSING BATCHES

 ^{240}Pu versus ^{235}U

No. of Batches	Reactor Name	Lot or Core	^{235}U	Clad Mat'l	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
BOILING WATER REACTORS													
17	Dresden I	1	1.474	Zr	NFS	5000	-12.810	0.6	-12.62/0.244	6.9	-12.81	0.1	Outliers
18	Dresden I	2	1.474	Zr	NFS	10000	-12.945	4.1	-103.9/-139.1	24.7	-12.95	1.0	
5	Dresden I	4	1.474	Zr	NFS	8500-9800	-13.463	0.4	-12.32/1.892	8.8	-13.46	0.2	Fringe
7	Dresden I	4	1.474	Zr	NFS	10900-12000	-13.204	0.5	-16.93/-6.615	18.9	-13.20	0.2	
1	Dresden I	4	1.586	Zr	NFS	11500	-11.540						
1	Dresden I	4	1.596	Zr	NFS	10800	-11.360						
1	Dresden I	4	1.617	Zr	NFS	10400	-11.094						
1	Dresden I	4	1.767	Zr	NFS	13400	-9.208						
1	Dresden I	4	1.831	Zr	NFS	13100	-8.545						
5	Dresden I	4	1.474	Zr	NATCO	8500-9800	-13.490	0.2	-13.98/0.819	6.1	-13.49	0.1	Fringe
7	Dresden I	4	1.474	Zr	NATCO	10900-12000	-13.299	0.7	-25.22/-21.10	24.3	-13.30	0.3	
1	Dresden I	4	1.586	Zr	NATCO	11500	-11.643						
1	Dresden I	4	1.596	Zr	NATCO	10800	-11.354						
1	Dresden I	4	1.617	Zr	NATCO	10400	-11.103						
1	Dresden I	4	1.767	Zr	NATCO	13400	-9.217						
1	Dresden I	4	1.831	Zr	NATCO	13100	-8.540						
18	Garigliano	1	2.020	Zr	WS	6600-14000	-6.912	15.6	-0.383/19.54	56.3	-6.778	2.3	Unirradiated Assembly
13	Garigliano	2	2.020	Zr	WS	13400-17600	-6.779	1.1	-8.217/4.939	18.5	-6.780	0.3	
1	Dresden I	4	2.180	Zr	NFS	9800	-5.887						
1	Dresden I	4	2.180	Zr	NATCO	9800	-5.959						
1	Humboldt Bay	1	2.258	Zr	NFS	15200	-5.383						
1	Humboldt Bay	1	2.276	Zr	NFS	14600	-5.303						
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	-5.255	1.5	-3.587/6.442	61.8	-5.254	0.9	
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	-4.979						
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	-4.699						
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	-5.410						
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	-5.349						
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	-5.270	1.0	-4.871/1.538	48.9	-5.270	0.6	
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	-4.985						
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	-4.719						
9	Dresden I	3	2.50	SS	NFS	5000	-4.472	1.9	-3.240/3.940	10.3	-4.466	0.6	
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	-4.351						
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	-4.188						
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	-4.303	2.0	-3.172/3.606	23.5	-4.299	0.8	Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	-4.161	1.1	-3.957/0.747	20.1	-4.160	0.5	
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	-4.440						
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	-4.275						
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	-4.320	1.6	-3.873/1.417	21.5	-4.318	0.7	Fringe
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	-4.170	0.8	-4.092/0.284	15.4	-4.169	0.4	
2	VAK	1	2.33	Zr	OR	15300-15900	-5.175	0.9					
1	VAK	1	2.51	Zr	OR	17400	-4.541						
2	VAK	1	2.33	Zr	EU	15300-15900	-5.186	0.0					
1	VAK	1	2.403	Zr	EU		-4.706						
1	VAK	1	2.51	Zr	EU	17400	-4.481						
1	Big Rock Point	2	2.8926		NFS	10800	-3.346						Averaging
1	Big Rock Point	2	3.0062		NFS	11200	-3.256						Averaging
1	Big Rock Point	2	3.0108		NFS	10500	-3.428						Averaging
1	Big Rock Point	2	3.2170		NFS	12300	-3.609						UO ₂ Scrap
1	Big Rock Point	2	3.2600		NFS	20900	-2.728						
1	Big Rock Point	2	3.0910		NFS	Core Avg.	-3.118						Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	-3.181						
1	Big Rock Point	1	3.1186	Zr	NFS	7400	-3.041						
				Inc SS									
1	Big Rock Point	1	3.1343	Zr-SS	NFS	17700	-2.842						
1	Big Rock Point	1	3.1977	SS	NFS	7400	-2.830						
				Inc 8									
4	Big Rock Point	1	3.212	SS	NFS	8400-8700	-2.743	1.7	-7.481/-23.83	17.9	-2.744	0.8	
1	Big Rock Point	1	3.236	SS	NFS	10000	-2.842						Averaging
				Inc 6-Zr									
1	Big Rock Point	1	3.252	SS-Zr	NFS	9000	-2.692						
1	Big Rock Point	1	3.2585	SS-Zr	NFS	9700	-2.869						Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	-2.609						
1	Big Rock Point	1	3.463	Zr	NFS	11000	-2.453						Averaging
				Inc 8									
1	Big Rock Point	1	3.494	Zr	NFS	13000	-2.468						Averaging
1	Big Rock Point	1	3.525	Zr	NFS	18100	-2.379						Averaging
				Inc 6									
2	Big Rock Point	1	3.6605	Zr	NFS	5700-8400	-2.226	0.4					
1	Big Rock Point	1	3.672	Zr	NFS	9400	-42.41						
				Inc 8									
1	Big Rock Point	1	3.298	Zr	NFS	Total	-42.03						Averaging
				Inc SS									

REPROCESSING BATCHES
 ^{240}Pu versus $\Delta(^{235}\text{U})_2$ (continued)

No. of Batches	Reactor Name	Lot or Core	$^{235}\text{U}_2$	Clad Matl	Date Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	66.79	1.2	51.72/28.77	27.4	66.78	0.4	
1	Trino	2	2.925	SS	OR	13200	62.95						
3	Trino	1	3.130	SS	OR	12700-13400	56.70	0.1	54.67/3.96	1.3	56.70	0.1	
9	Trino	2	3.130	SS	EU	19900-22200	55.29	1.6	53.97/4.581	14.2	55.28	0.5	
2	Trino	1	3.112	SS	OR	9900-10300	51.83	1.4					Fringe
1	Trino	2	3.386	SS	EU	21100	48.92						
1	Trino	2	3.308	SS	OR	10300	47.58						Fringe
1	Trino	2	3.454	SS	EU	14800	35.89						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	44.55	2.9	9.856/199.0	***	44.52	1.7	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	65.68	1.7	33.48/61.51	20.9	65.63	0.7	
1	Trino	2	2.925	SS	EU	13200	60.22						
2	Trino	1	3.130	SS	EU	12700-13000	57.53	0.7					
1	Trino	2	3.310	SS	EU	10300	46.18						
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	59.06	1.5	84.23/-53.38	23.2	58.35	0.8	
1	Indian Point 1	1	2.900	SS	NFS	13100	57.16						Averaging
1	Indian Point 1	1	3.020	SS	NFS	15400	50.71						Averaging
1	Indian Point 1	1	3.220	SS	NFS	17900	49.92						Averaging
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	49.79	0.6	30.61/66.03	21.5	49.79	0.3	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	39.93	1.1	35.11/21.75	11.1	39.92	0.4	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	58.27	0.8	73.40/-28.87	8.1	59.29	0.4	
1	Indian Point 1	1	2.900	SS	NATCO	13100	57.49						
1	Indian Point 1	1	3.020	SS	NATCO	15400	52.81						
1	Indian Point 1	1	3.220	SS	NATCO	17900	49.79						
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	50.04	1.6	85.10/-121.6	56.5	50.04	0.8	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	39.80	0.9	35.88/17.71	9.3	39.79	0.3	
13	Sena	1	2.958	SS	OR	12900	59.29	2.4	33.05/52.58	16.9	59.21	0.7	
1	Sena	1	3.357	SS	OR	2920	57.44						
12	Sena	2	3.358	SS	OR	18600-20600	52.94	0.8	57.06/-13.76	7.4	52.95	0.2	
14	Sena	1	2.958	SS	EU	12900	56.88	2.3	32.40/51.15	16.6	56.81	0.6	
1	Sena	1	3.357	SS	EU	2920	56.12						
1	Sena	2	2.968	SS	EU		57.57						
12	Sena	2	3.358	SS	EU	18600-20600	51.97	1.7	45.68/21.85	16.8	51.95	0.5	
1	Sena	2	3.121	SS	EU		49.56						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	54.16						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	51.04	9.6	52.27/-1.311	6.6	51.18	2.0	Fringe & Outliers
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	51.13	5.5	43.63/11.56	5.3	50.16	1.5	Outliers
		III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	48.57						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	57.71						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	41.03	8.1	23.51/53.37	5.3	39.92	4.8	Outlier
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	41.31	0.9	41.18/0.32	6.6	41.31	0.3	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	41.11	2.6	38.96/5.58	1.2	40.72	0.5	Outlier
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	33.07	1.5	33.45/-1.56	4.5	33.07	0.4	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	33.21	1.2	30.84/10.96	2.4	33.15	0.3	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	31.78	3.5	23.26/38.42	11.0	31.66	1.0	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	62.72						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	42.12	4.9	38.60/8.144	0.6	41.29	0.6	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	33.54	0.5	32.34/4.803	1.0	33.52	0.1	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	62.11						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	47.11						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	51.03						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	41.62	4.6	38.42/7.853	1.1	40.96	0.6	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	33.26	1.8	31.21/8.155	5.0	33.21	0.5	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	32.87	1.9	29.13/17.37	3.8	32.78	0.5	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	31.15	4.3	21.90/41.92	13.5	30.99	1.3	Outlier
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		298.3	4.7	375.2/-24.68	21.1	300.4	2.9	Scatter
9	NPD-Candu		0.7114	Zr	OR	4000-7000	323.6	8.7	597.5/-77.36	12.0	327.8	2.6	Scatter
6	Douglas Point		0.7114	Zr	EU		247.3	15.3	104.6/57.14	56.6	23.88	7.0	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	337.9	9.2	683.6/-92.36	8.9	342.9	2.8	
11	NPR Hanford		0.94	Zr	NFS		186.77	5.2	198.5/-1.262	6.7	187.7	1.4	Outliers
10	Windusale AGR		2.50	SS-NB		5000-10000	60.05	6.3	54.58/7.534	9.0	59.41	2.2	Scatter

REPROCESSING BATCHES

$$^{239}\text{Pu}^2 \times (100 - ^{239}\text{Pu}) / (^{235}\text{U})^2 \text{ versus } (100 - ^{239}\text{Pu})$$

No. of Batches	Reactor Name	Lot or Core	$^{235}\text{U}_0$	Clad Matl	Isotopic Ratio	Exposure Range (MWD/MTM)	Isotopic Ratio	Intercept Model % σ Slope/Intercept	Initial Point Model % σ Slope	Effects
BOILING WATER REACTORS										
17	Dresden I	1	1.474	Zr	NFS	5000	6753	1.8 10980/-92800	5.0 16759	0.4
18	Dresden I	2	1.474	Zr	NFS	10000	8903	6.8 25410/-514800	23.6 18906	1.5 Outliers
5	Dresden I	4	1.474	Zr	NFS	8500-9800	9159	4.5 20450/-358900	17.7 19186	2.0 Fringe
7	Dresden I	4	1.474	Zr	NFS	10900-12000	10615	2.5 30290/-693400	15.4 10820	0.9
1	Dresden I	4	1.586	Zr	NFS	11500	8804			
1	Dresden I	4	1.586	Zr	NFS	10800	7822			
1	Dresden I	4	1.617	Zr	NFS	10400	7580			
1	Dresden I	4	1.767	Zr	NFS	13400	7938			
1	Dresden I	4	1.831	Zr	NFS	13100	6735			
5	Dresden I	4	1.474	Zr	NATCO	8500-9800	9139	3.8 18440/-295300	17.2 19161	1.7 Fringe
7	Dresden I	4	1.474	Zr	NATCO	10900-12000	10395	1.7 21060/-376200	21.5 10400	0.6
1	Dresden I	4	1.586	Zr	NATCO	11500	8839			
1	Dresden I	4	1.596	Zr	NATCO	10800	7820			
1	Dresden I	4	1.617	Zr	NATCO	10400	7520			
1	Dresden I	4	1.767	Zr	NATCO	13400	7915			
1	Dresden I	4	1.831	Zr	NATCO	13100	6817			
18	Garigliano	1	2.020	Zr	WS	6800-14000	4661	14.0 84620/-2536000	22.2 1711	3.2 Unirradiated Assembly
13	Garigliano	2	2.020	Zr	WS	13400-17600	6187	5.8 22930/-617700	11.3 16209	1.8
1	Dresden I	4	2.180	Zr	NFS	9800	3486			
1	Dresden I	4	2.180	Zr	NATCO	9800	3380			
1	Humboldt Bay	1	2.258	Zr	NFS	15200	3823			
1	Humboldt Bay	1	2.276	Zr	NFS	14600	3737			
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	3274	5.0 10110/-209300	31.0 3281	2.9
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	2565			
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	2579			
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	3744			
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	3659			
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	3242	3.7 7990/-145400	25.9 3247	2.1
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	2545			
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	2555			
9	Dresden I	3	2.50	SS	NFS	5000	2104	3.3 3385/-25170	9.6 12110	1.1
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	2063			
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	2148			
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	1931	1.8 2600/-12270	5.0 1934	0.7 Fringe
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	2058	1.9 3039/-21440	10.1 2080	0.9
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	2027			
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	2092			
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	1924	1.3 2322/-7276	6.4 1926	0.5 Fringe
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	2056	1.9 2999/-20550	10.4 2058	0.8
2	VAK	1	2.33	Zr	OR	15300-15900	4072	3.5		
1	VAK	1	2.51	Zr	OR	17400	3679			
2	VAK	1	2.33	Zr	EU	15300-15900	4017	1.2		
1	VAK	1	2.403	Zr	EU		3879			
1	VAK	1	2.51	Zr	EU	17400	3706			
1	Big Rock Point	2	2.9926		NFS	10800	1401			Averaging
1	Big Rock Point	2	3.0062		NFS	11200	1437			Averaging
1	Big Rock Point	2	3.0108		NFS	10500	1314			Averaging
1	Big Rock Point	2	3.2170		NFS	12300	1172			UO ₂ Scrap
1	Big Rock Point	2	3.2600		NFS	20900	1518			
1	Big Rock Point	2	3.0910		NFS	Core Avg.	1384			Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	1242			
1	Big Rock Point	1	3.1186	Zr	NFS	7400	1229			
1	Big Rock Point	1	3.1343	Inc-SS	NFS	17700	1631			
1	Big Rock Point	1	3.1977	SS	NFS	7400	1171			
4	Big Rock Point	1	3.212	Inc8	NFS	8400-8700	1225	0.5 1113/2194	17.1 1225	0.3
1	Big Rock Point	1	3.236	SS	NFS	10000	1162			Averaging
1	Big Rock Point	1	3.252	Inc6-Zr	NFS	9000	1209			
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	1143			Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	1066			
1	Big Rock Point	1	3.463	Zr	NFS	11000	1031			Averaging
1	Big Rock Point	1	3.494	Inc8	NFS	13000	1051			Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	1096			Averaging
2	Big Rock Point	1	3.6605	Inc6	NFS	5700-6400	861	0.4		
1	Big Rock Point	1	3.672	Zr	NFS	9400	899			
1	Big Rock Point	1	3.298	Inc8	NFS	Total	1124			Averaging
				Inc-SS						

REPROCESSING BATCHES
(^{239}Pu)² < (100-239Pu)/(^{235}U)² versus (100-239Pu) (continued)

No. of Batches	Reactor Name	Lot or Core	^{235}U O	Clad Mat'l	Date Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	2054	0.5	902/29240	36.8	2054	0.2	
1	Trino	2	2.925	SS	OR	13200	1782						
3	Trino	1	3.130	SS	OR	12700-13400	1449	1.6	3235/-42060	26.6	1450	1.0	
9	Trino	2	3.130	SS	EU	19900-22200	1913	3.1	4484/-81130	23.8	1964	1.0	
2	Trino	1	3.112	SS	OR	9900-10300	1334	0.8					Fringe
1	Trino	2	3.386	SS	EU	21100	1531						
1	Trino	2	3.308	SS	OR	10300	1147						Fringe
1	Trino	2	3.454	SS	EU	14800	836						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	1067	1.8	-10950/349200	72.5	1067	1.0	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	2018	2.5	-46170/1067000	49.7	2018	1.0	
1	Trino	2	2.925	SS	EU	13200	1720						
2	Trino	1	3.130	SS	EU	12700-13000	1435	0.3					
1	Trino	2	3.310	SS	EU	10300	1142						
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	1734	2.4	3868/-52500	15.1	1736	1.2	
1	Indian Point 1	1	2.900	SS	NFS	13100	1743						
1	Indian Point 1	1	3.020	SS	NFS	15400	1666						
1	Indian Point 1	1	3.220	SS	NFS	17900	1569						
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	1589	0.3	1969/-11330	38.3	1589	0.1	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	1077	2.3	2247/-35980	9.5	1078	0.8	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	1723	2.5	4110/-58930	29.7	1723	1.2	
1	Indian Point 1	1	2.900	SS	NATCO	13100	1703						
1	Indian Point 1	1	3.020	SS	NATCO	15400	1653						
1	Indian Point 1	1	3.220	SS	NATCO	17900	1554						
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	1580	0.6	551/3092	10.4	1580	0.3	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	1071	2.6	2436/-41960	9.0	1072	0.9	
13	Sena	1	2.958	SS	OR	12900	1647	1.7	2033/-9455	26.7	1647	0.5	
1	Sena	1	3.357	SS	OR	2920	931						
12	Sena	2	3.358	SS	OR	18600-20600	1595	2.5	3851/-682500	8.3	1597	0.7	
14	Sena	1	2.958	SS	EU	12900	1515	3.4	6619/-125000	26.4	1516	0.9	
1	Sena	1	3.357	SS	EU	2920	889						
1	Sena	2	2.968	SS	EU		2304						
12	Sena	2	3.358	SS	EU	18600-20600	1559	1.9	3239/-51120	11.5	1560	0.5	
1	Sena	2	3.121	SS	EU		1600						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	1671						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	1033	6.2	1352/-5068	3.3	1053	1.4	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	1139	6.2	1780/-12780	4.6	1156	1.8	
		III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	1083						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	1174						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	967	3.4	1413/-11110	3.0	972	1.8	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	835.3	1.8	1360/-11940	4.6	838	0.7	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	882.2	12.7	1606/-17050	7.2	921	3.9	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	630	4.2	1102/-12230	2.2	633	1.3	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	674	6.4	1372/-19500	4.4	681	1.9	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	640	3.2	1119/-12920	4.6	642	0.9	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	1671						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	868	12.1	1497/-14330	6.7	907	3.1	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	626	4.4	1091/-11960	1.9	630	1.1	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	1647						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	1060						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	1127						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	870	12.6	1594/-16870	7.5	908	3.8	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	623	3.9	1043/-10820	3.7	628	1.1	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	673	6.4	1371/-19490	4.8	679	1.9	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	643	2.9	1063/-11270	5.8	645	0.9	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		65827	12.9	172600/-2991000	13.5	67160	7.6	
9	NPD-Candu		0.7714	Zr	OR	4000-7000	67725	12.2	19230/-3461000	8.0	69000	3.8	
6	Douglas Point		0.7114	Zr	EU		47846	30.3	684500/-1.8+7		50170	12.4	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	64546	12.1	186300/-3393000	12.8	65680	3.8	
11	NPR Hanford		0.94	Zr	NFS		12910	4.5	18040/-65380	5.9	13010	1.3	
10	Windscale AGR		2.50	SS-NB		5000-10000	2008	5.4	2197/-4630	11.6	2013	1.4	Outlier

REPROCESSING BATCHES

($^{239}\text{Pu} \times ^{240}\text{Pu}$)² versus ^{240}Pu

No. of Batches	Reactor Name	Lot or Core	^{235}U Core	Clad Mat'l	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	% of Intercept Model Slope/Intercept	% of Initial Point Model Slope	% of Effects	
BOILING WATER REACTORS											
17	Dresden 1	1	1.474	Zr	NFS	5000	98580	0.8	131800/-546500	0.5	98520 0.2
18	Dresden 1	2	1.474	Zr	NFS	10000	100300	1.0	113900/-28640	4.2	100400 0.2
5	Dresden 1	4	1.474	Zr	NFS	8500-9800	104100	1.3	51628/1175000	31.7	104100 0.5 Fringe
7	Dresden 1	4	1.474	Zr	NFS	10900-12000	98370	0.5	68560/699600	23.6	98370 0.2
1	Dresden 1	4	1.586	Zr	NFS	11500	99960				
1	Dresden 1	4	1.596	Zr	NFS	10800	100100				
1	Dresden 1	4	1.617	Zr	NFS	10400	101900				
1	Dresden 1	4	1.767	Zr	NFS	13400	96250				
1	Dresden 1	4	1.831	Zr	NFS	13100	96880				
5	Dresden 1	4	1.474	Zr	NATCO	8500-9800	104300	1.2	61310/963800	28.0	104300 0.5 Fringe
7	Dresden 1	4	1.474	Zr	NATCO	10900-12000	98570	0.6	64600/799300	23.2	98560 0.2
1	Dresden 1	4	1.586	Zr	NATCO	11500	100600				
1	Dresden 1	4	1.596	Zr	NATCO	10800	99880				
1	Dresden 1	4	1.617	Zr	NATCO	10400	102000				
1	Dresden 1	4	1.767	Zr	NATCO	13400	96060				
1	Dresden 1	4	1.831	Zr	NATCO	13100	97000				
18	Garigliano	1	2.020	Zr	WS	6600-14000	96490	0.4	88590/163600	6.5	96490 0.1
13	Garigliano	2	2.020	Zr	WS	13400-17600	92640	1.2	84970/178600	19.0	92630 0.3
1	Dresden 1	4	2.180	Zr	NFS	9800	99790				
1	Dresden 1	4	2.180	Zr	NATCO	9800	103000				
1	Humboldt Bay	1	2.258	Zr	NFS	15200	95260				
1	Humboldt Bay	1	2.276	Zr	NFS	14600	96172				
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	97650	0.7	96150/30300	36.5	97650 0.4
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	97930				
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	95570				
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	94820				
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	96270				
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	97590	0.6	96330/25450	27.8	97590 0.3
1	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	97580				
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	95650				
9	Dresden 1	3	2.50	SS	NFS	5000	91540	1.8	129100/-532000	1.4	91660 0.5
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	94770				
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	94880				
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	91460	1.5	128100/-503100	8.7	91530 0.6 Fringe
6	Humboldt Bay	1	2.578	SS	NFS	9100-10000	93360	1.0	123600/-462000	5.6	93400 0.5
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	95260				
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	95040				
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	91490	1.5	125800/-470000	7.5	91560 0.6 Fringe
6	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	93510	1.1	125200/-484100	4.9	93560 0.5
2	VAK	1	2.33	Zr	OR	15300-15900	99530	0.4			
1	VAK	1	2.51	Zr	OR	17400	95810				
2	VAK	1	2.33	Zr	EU	15300-15900	98980	1.2			
1	VAK	1	2.403	Zr	EU		99750				
1	VAK	1	2.51	Zr	EU	17400	97130				
1	Big Rock Point	2	2.9926		NFS	10800	93340				Averaging
1	Big Rock Point	2	3.0062		NFS	11200	93940				Averaging
1	Big Rock Point	2	3.0108		NFS	10500	92500				Averaging
1	Big Rock Point	2	3.2170		NFS	12300	93080				Scrap
1	Big Rock Point	2	3.2600		NFS	20900	92240				
1	Big Rock Point	2	3.0910		NFS	Core Avg.	93990				Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	86310				
1	Big Rock Point	1	3.1186	Zr	NFS	7400	85900				
				Inc-SS							
1	Big Rock Point	1	3.1343	Zr-SS	NFS	17700	93120				
1	Big Rock Point	1	3.1977	SS	NFS	7400	85130				
				Inc8							
4	Big Rock Point	1	3.212	SS	NFS	8400-8700	89370	1.6	144900/-765800	4.9	89430 0.8
1	Big Rock Point	1	3.236	SS	NFS	10000	90510				Averaging
				Inc6-Zr							
1	Big Rock Point	1	3.252	SS-Zr	NFS	9000	91040				
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	92520				Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	87390				
1	Big Rock Point	1	3.463	Zr	NFS	11000	90690				Averaging
				Inc8							
1	Big Rock Point	1	3.494	Zr	NFS	13000	94080				Averaging
1	Big Rock Point	1	3.525	Zr	NFS	16100	93930				Averaging
				Inc6							
2	Big Rock Point	1	3.6605	Zr	NFS	5700-6400	80230	2.4			
1	Big Rock Point	1	3.672	Zr	NFS	9400	91040				
				Inc8							
1	Big Rock Point	1	3.298	Zr	NFS	Total	90410				Averaging
				Inc SS							

REPROCESSING BATCHES
($^{239}\text{Pu} \times ^{240}\text{Pu}$)² versus ^{240}Pu (continued)

No. of Batches	Reactor Name	Lot or Core	$^{235}\text{U}_0$	Clad Mat'l	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	87310	0.4	129000/-654500	14.8	87310	0.1	
1	Trino	2	2.925	SS	OR	13200	86850						
3	Trino	1	3.130	SS	OR	12700-13400	85080	0.2	101800/-244100	5.0	85080	0.1	
9	Trino	2	3.130	SS	EU	19900-22200	83730	0.8	51890/579600	19.9	83720	0.3	
2	Trino	1	3.112	SS	OR	9900-10300	85580	0.3					Fringe
1	Trino	2	3.386	SS	EU	21100	83960						
1	Trino	2	3.308	SS	OR	10300	84670						Fringe
1	Trino	2	3.454	SS	EU	14800	83020						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	82260	1.1	156100/-1207000	6.2	82280	0.6	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	87510	0.3	94540/-110100	24.7	87510	0.1	
1	Trino	2	2.925	SS	EU	13200	86610						
2	Trino	1	3.130	SS	EU	12700-13000	85753	0.1					
1	Trino	2	3.310	SS	EU	10300	84820						Averaging
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	85950	0.2	97190/-170,000	3.0	85950	0.1	
1	Indian Point 1	1	2.900	SS	NFS	13100	85760						Averaging
1	Indian Point 1	1	3.020	SS	NFS	15400	84890						
1	Indian Point 1	1	3.220	SS	NFS	17900	84110						
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	83550	0.1	66080/296400	8.1	83550	0.1	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	80330	0.5	57950/37480	7.3	80320	0.2	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12600	85960	0.2	99090/-199100	6.1	85960	0.1	
1	Indian Point 1	1	2.900	SS	NATCO	13100	85820						Averaging
1	Indian Point 1	1	3.020	SS	NATCO	15400	84570						
1	Indian Point 1	1	3.220	SS	NATCO	17900	84220						
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	83610	0.2	91540/-135400	14.6	83610	0.1	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	80370	0.5	57370/385500	9.7	80360	0.2	
13	Sena	1	2.958	SS	OR	12900	85840	1.2	130700/-675000	2.0	85890	0.3	
1	Sena	1	3.357	SS	OR	2920	49050						
12	Sena	2	3.358	SS	OR	18600-20600	83900	0.4	62570/367900	5.1	83890	0.1	
14	Sena	1	2.958	SS	EU	12900	85810	1.1	130800/-677200	2.0	85860	0.3	
1	Sena	1	3.357	SS	EU	2920	49050						
1	Sena	2	2.968	SS	EU		82540						
12	Sena	2	3.358	SS	EU	18600-20600	83130	0.6	60230/393500	18.9	83130	0.2	
1	Sena	2	3.121	SS	EU		84710						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	85670						
16	Yankee Rowe	I	3.404	SS	NFS	4000-12100	74980	7.1	109700/-368800	0.3	76310	1.5	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	79460	2.1	99390/-247800	1.2	79700	0.5	
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	84370						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	84790						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	80110	0.2	76060/57750	1.1	80100	0.1	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	79270	0.3	89800/-139800	1.9	79280	0.1	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	77910	2.5	87050/-122900	4.4	78160	0.6	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	76800	0.1	75710/15190	0.9	76800	0.1	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	76600	0.9	61460/224000	3.1	76550	0.3	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	76680	0.4	69390/105000	4.2	76670	0.1	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	86220						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	77710	2.7	88250/-138800	3.3	78020	0.6	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	76750	0.2	74710/28360	1.1	76740	0.5	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	86150						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	84040						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	84230						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	77970	2.2	85460/-100100	4.0	78160	0.5	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	76710	0.5	76010/9800	3.9	76710	0.1	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	76660	0.9	61580/223200	4.3	76620	0.3	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	76800	0.6	66420/14900	5.8	76790	0.2	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		116200	0.2	118500/-53480	0.9	116200	0.1	
9	NPD-Candu		0.7114	Zr	OR	4000-7000	118300	0.6	128200/-225600	3.1	118400	0.2	
6	Douglas Point		0.7114	Zr	EU		116200	0.3	120900/-106500	2.6	116200	0.1	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	118000	0.6	127800/-220100	2.8	118100	0.2	
11	NPR Hanford		0.94	Zr	NFS		80780	6.2	134900/-572200	0.4	81750	1.8	
10	Windscale AGR		2.50	SS-NB		5000-10000	108620	3.5	137400/-549700	2.2	109300	0.9	

REPROCESSING BATCHES

$$239_{Pu} \times (100 - 239_{Pu}) \text{ versus } (235_{U} \times 239_{Pu})$$

No. of Batches	Reactor Name	Lot or Core	^{235}U	Clad Matl	Data Source	Exposure Range (MWd/MTM)	Isotopic Ratio	Intercept Model		Initial Point Model		Effects
								% σ	Slope/Intercept	% σ	Slope	
BOILING WATER REACTORS												
17	Dresden 1	1	1.474	Zr	NFS	5000	-0.1923	0.3	-0.182/90.3	3.6	-0.1923	0.1
18	Dresden 1	2	1.474	Zr	NFS	10000	-0.1901	1.5	-0.2911/-1139.	15.4	-0.1901	0.3
5	Dresden 1	4	1.474	Zr	NFS	8500-9800	-0.1899	0.3	-0.1784/130.7	8.5	-0.1898	0.1
7	Dresden 1	4	1.474	Zr	NFS	10900-12000	-0.1886	0.2	-0.1600/345.3	8.7	-0.1886	0.1
1	Dresden 1	4	1.586	Zr	NFS	11500	-0.1758					
1	Dresden 1	4	1.596	Zr	NFS	10800	-0.1762					
1	Dresden 1	4	1.617	Zr	NFS	10400	-0.1736					
1	Dresden 1	4	1.767	Zr	NFS	13400	-0.1568					
1	Dresden 1	4	1.831	Zr	NFS	13100	-0.1523					
5	Dresden 1	4	1.474	Zr	NATCO	8500-9800	-0.1899	0.3	-0.1859/46.0	8.1	-0.1899	0.1
7	Dresden 1	4	1.474	Zr	NATCO	10900-12000	-0.1890	0.1	-0.1935/-54.3	9.6	-0.1890	0.1
1	Dresden 1	4	1.586	Zr	NATCO	11500	-0.1758					
1	Dresden 1	4	1.596	Zr	NATCO	10800	-0.1762					
1	Dresden 1	4	1.617	Zr	NATCO	10400	-0.1735					
1	Dresden 1	4	1.767	Zr	NATCO	13400	-0.1568					
1	Dresden 1	4	1.831	Zr	NATCO	13100	-0.1521					
18	Garigliano	1	2.020	Zr	WS	6600-14000	-0.1402	4.3	-0.0155/1926.	45.6	-0.1399	0.9
13	Garigliano	2	2.020	Zr	WS	13400-17600	-0.1370	0.4	-0.1000/627.6	6.6	-0.1369	0.1
1	Dresden 1	4	2.180	Zr	NFS	9800	-0.1302					
1	Dresden 1	4	2.180	Zr	NATCO	9800	-0.1309					
1	Humboldt Bay	1	2.258	Zr	NFS	15200	-0.1247					
1	Humboldt Bay	1	2.276	Zr	NFS	14600	-0.1236					
3	Humboldt Bay	1	2.310	Zr	NFS	13100-14100	-0.1231	0.6	-0.0899/573.2	18.9	-0.1231	0.3
1	Humboldt Bay	1	2.402	Zr-SS	NFS	11500	-0.1207					
1	Humboldt Bay	1	2.433	Zr-SS	NFS	12100	-0.1186					
1	Humboldt Bay	1	2.258	Zr	NATCO	15200	-0.1251					
1	Humboldt Bay	1	2.276	Zr	NATCO	14600	-0.1240					
3	Humboldt Bay	1	2.310	Zr	NATCO	13100-14100	-0.1233	0.4	-0.1014/377.2	14.6	-0.1233	0.2
7	Humboldt Bay	1	2.402	Zr-SS	NATCO	11500	-0.1209					
1	Humboldt Bay	1	2.433	Zr-SS	NATCO	12100	-0.1188					
9	Dresden 1	3	2.50	SS	NFS	5000	-0.1154	0.8	-0.1009/1980	5.6	-0.1154	0.3
1	Humboldt Bay	1	2.557	SS-Zr	NFS	9700	-0.1138					
1	Humboldt Bay	1	2.567	SS-Zr	NFS	10300	-0.1122					
6	Humboldt Bay	1	2.578	SS	NFS	7000-8500	-0.1119	0.3	-0.1103/217.7	3.6	-0.1119	0.1
5	Humboldt Bay	1	2.578	SS	NFS	9100-10000	-0.1119	0.3	-0.1090/44.6	6.6	-0.1119	0.1
1	Humboldt Bay	1	2.557	SS-Zr	NATCO	9700	-0.1146					
1	Humboldt Bay	1	2.567	SS-Zr	NATCO	10300	-0.1130					
6	Humboldt Bay	1	2.578	SS	NATCO	7000-8500	-0.1120	0.5	-0.1203/-110.2	5.0	-0.1120	0.2
5	Humboldt Bay	1	2.578	SS	NATCO	9100-10000	-0.1119	0.3	-0.1095/37.0	6.9	-0.1119	0.2
2	VAK	1	2.33	Zr	OR	15300-15900	-0.1195	0.1				
1	VAK	1	2.51	Zr	OR	17400	-0.1110					
2	VAK	1	2.33	Zr	EU	15300-15900	-0.1195					
1	VAK	1	2.403	Zr	EU		-0.1146					
1	VAK	1	2.51	Zr	EU	17400	-0.1106					
1	Big Rock Point	2	2.9926		NFS	10800	-0.1003					Averaging
1	Big Rock Point	2	3.0062		NFS	11200	-0.0990					Averaging
1	Big Rock Point	2	3.0108		NFS	10500	-0.1012					Averaging
1	Big Rock Point	2	3.2170		NFS	12300	-0.0947					Averaging
1	Big Rock Point	2	3.2600		NFS	20900	-0.0890					
1	Big Rock Point	2	3.0910		NFS	Core Avg.	-0.0965					Averaging
1	Big Rock Point	1	3.074	SS	NFS	7600	-0.0977					
1	Big Rock Point	1	3.1186	Zr	NFS	7400	-0.0952					
1	Big Rock Point	1	3.1343	Inc-SS	NFS	17700	-0.0922					
1	Big Rock Point	1	3.1977	SS	NFS	7400	-0.0928					
4	Big Rock Point	1	3.212	SS	NFS	8400-8700	-0.0912	0.4	-0.1181/-463.5	11.6	-0.0912	0.2
1	Big Rock Point	1	3.236	SS	NFS	10000	-0.0933					Averaging
1	Big Rock Point	1	3.252	Inc8-Zr	NFS	9000	-0.0902					
1	Big Rock Point	1	3.2595	SS-Zr	NFS	9700	-0.0925					Averaging
1	Big Rock Point	1	3.3576	SS-Zr	NFS	8100	-0.0887					
1	Big Rock Point	1	3.463	Zr	NFS	11000	-0.0868					Averaging
1	Big Rock Point	1	3.494	Inc8	NFS	13000	-0.0859					
1	Big Rock Point	1	3.525	Zr	NFS	16100	-0.0842					Averaging
2	Big Rock Point	1	3.6606	Inc6	NFS	5700-6400	-0.081	0.4				
1	Big Rock Point	1	3.672	Zr	NFS	9400	-0.0819					
1	Big Rock Point	1	3.298	Inc8	NFS	Total	-0.0909					Averaging
				Inc SS								

REPROCESSING BATCHES
 $^{239}\text{Pu} \times [100 - ^{239}\text{Pu}]$ versus $\Delta(^{235}\text{U} \times ^{239}\text{Pu}^2)$ (continued)

No. of Batches	Reactor Name	Lot or Core	$^{235}\text{U}_0$	Clad Mat'l	Data Source	Exposure Range (MWD/MTM)	Isotopic Ratio	% σ	Intercept Model Slope/Intercept	% σ	Initial Point Model Slope	% σ	Effects
PRESSURIZED WATER REACTORS													
9	Trino	1	2.719	SS	OR	12500-12900	-0.1051	0.2	-0.1896/-1523.	11.0	-0.1051	0.1	
1	Trino	2	2.925	SS	OR	13200	-0.0973						
3	Trino	1	3.130	SS	OR	12700-13400	-0.0920	0.3	-0.0708/415.4	19.7	-0.0920	0.2	
9	Trino	2	3.130	SS	EU	19900-22200	-0.0899	0.4	-0.0892/18.6	12.9	-0.0899	0.1	
2	Trino	1	3.112	SS	OR	9900-10300	-0.0951	0.3					Fringe
1	Trino	2	3.386	SS	EU	21100	-0.0840						
1	Trino	2	3.308	SS	OR	10300	-0.0899						Fringe
1	Trino	2	3.454	SS	EU	14800	-0.0916						Unirradiated Assembly
3	Trino	2	3.897	SS	EU	21300-21700	-0.0735	0.4	+0.0231/2710	129.2	-0.0735	0.2	Fringe
6	Trino	1	2.719	SS	EU	12500-12900	-0.1055	0.7	-0.0942/203.7	62.4	-0.1055	0.3	
1	Trino	2	2.925	SS	EU	13200	-0.0985						
2	Trino	1	3.130	SS	EU	12700-13000	-0.0922						
1	Trino	2	3.310	SS	EU	10300	-0.0901						
4	Indian Point 1	1	2.872	SS	NFS	12100-12600	-0.1007	0.5	-0.0762/451.2	11.3	-0.1007	0.2	
1	Indian Point 1	1	2.900	SS	NFS	13100	-0.0995						
1	Indian Point 1	1	3.020	SS	NFS	15400	-0.0954						Averaging
1	Indian Point 1	1	3.220	SS	NFS	17900	-0.0887						Averaging
4	Indian Point 1	1	3.263	SS	NFS	18900-19500	-0.0874	0.1	-0.1055/-435.4	17.1	-0.0874	0.1	
9	Indian Point 1	2	4.076	SS	NFS	22600-25100	-0.0695	0.2	-0.0634/188.5	5.5	-0.0695	0.1	
4	Indian Point 1	1	2.872	SS	NATCO	12100-12500	-0.1009	0.6	-0.0754/470.7	22.0	-0.1009	0.3	
1	Indian Point 1	1	2.900	SS	NATCO	13100	-0.1001						
1	Indian Point 1	1	3.020	SS	NATCO	15400	-0.0958						
1	Indian Point 1	1	3.220	SS	NATCO	17900	-0.0889						
4	Indian Point 1	1	3.263	SS	NATCO	18900-19500	-0.0875	0.2	-0.1447/-1373	1.9	-0.0875	0.1	
9	Indian Point 1	2	4.076	SS	NATCO	22600-25100	-0.0696	0.3	-0.0603/292.0	5.8	-0.0696	0.1	
13	Sena	1	2.958	SS	OR	12900	-0.0975	0.1	-0.1300/-617.0	15.6	-0.0975	0.2	
1	Sena	1	3.357	SS	OR	2920	-0.0900						
12	Sena	2	3.358	SS	OR	18600-20600	-0.0841	0.2	-0.0712/323.7	4.8	-0.0841	0.1	
14	Sena	1	2.958	SS	EU	12900	-0.0999	1.1	0.0751/458.6	24.9	-0.0999	0.3	
1	Sena	1	3.357	SS	EU	2920	-0.0986						
1	Sena	2	2.958	SS	EU		-0.0948						
12	Sena	2	3.358	SS	EU	18600-20600	-0.0845	0.2	-0.0777/170.4	6.2	-0.0845	0.1	
1	Sena	2	3.121	SS	EU		-0.0923						
1	Yankee Rowe	V	2.902	Zr	NFS	12300	-0.0996						
15	Yankee Rowe	I	3.404	SS	NFS	4000-12100	-0.0896	1.9	-0.0794/115.5	1.9	-0.0866	0.4	Fringe
14	Yankee Rowe	II	3.406	SS	NFS	8000-15900	-0.0850	0.8	-0.0799/94.4	2.1	-0.0849	0.2	
		III											
11	Yankee Rowe	VII	3.470	Zr	NFS	8500	-0.0854						
1	Yankee Rowe	VII	3.527	Zr	NFS	8500	-0.0812						
4	Yankee Rowe	IV	3.905	SS	NFS	15400-22500	-0.0736	0.2	-0.0756/-52.4	2.3	-0.0736	0.1	
7	Yankee Rowe	IV	4.101	SS	NFS	14900-17700	-0.0701	0.2	-0.0651/127.3	3.4	-0.0701	0.1	
11	Yankee Rowe	V	4.101	SS	NFS	9700-25600	-0.0700	1.2	-0.0640/152.2	1.2	-0.0698	0.3	
11	Yankee Rowe	VI	4.935	SS	NFS	18600-26500	-0.0580	0.3	-0.0539/136.1	1.3	-0.0580	0.1	
12	Yankee Rowe	VII	4.935	SS	NFS	21200-29300	-0.0577	0.5	-0.0520/200.4	1.9	-0.0577	0.1	
11	Yankee Rowe	VIII	4.941	SS	NFS	21300-26700	-0.0579	0.3	-0.0541/132.2	2.5	-0.0579	0.1	
2	Yankee Rowe	V	2.902	Zr	NBS	12300	-0.0995						
15	Yankee Rowe	V	4.101	SS	NBS	9700-25600	-0.0700	1.1	-0.0651/121.7	0.8	-0.0698	0.3	
15	Yankee Rowe	VI	4.935	SS	NBS	11200-26500	-0.0580	0.3	-0.0539/134.0	1.2	-0.0580	0.1	
1	Yankee Rowe	V	2.902	Zr	NATCO	12300	-0.0999						
1	Yankee Rowe	VII	3.470	Zr	NATCO	8500	-0.0860						
1	Yankee Rowe	VII	3.527	Zr	NATCO	8500	-0.0824						
12	Yankee Rowe	V	4.101	SS	NATCO	9700-25600	-0.0701	1.2	-0.0643/147.8	1.4	-0.0699	0.3	
12	Yankee Rowe	VI	4.935	SS	NATCO	18600-26500	-0.0581	0.3	-0.0554/96.3	0.3	-0.0581	0.1	
12	Yankee Rowe	VII	4.935	SS	NATCO	21200-29300	-0.0577	0.5	-0.0519/202.3	2.4	-0.0577	0.2	
11	Yankee Rowe	VIII	4.941	SS	NATCO	21300-26700	-0.0578	0.3	-0.0563/112.9	3.2	-0.0578	0.1	
HEAVY WATER AND GRAPHITE MODERATED REACTORS													
3	Douglas Point		0.7114	Zr	OR		-0.3782	4.4	-0.2017/950.9	60.4	-0.3775	1.8	
9	NPD-Candu		0.7114	Zr	OR	4000-7000	-0.3574	0.8	-0.3939/-205.3	6.7	-0.3575	0.3	
6	Douglas Point		0.7114	Zr	EU		-0.3569	1.1	-0.4480/-514.3	8.1	-0.3571	0.6	
9	NPD-Candu		0.7114	Zr	EU	4000-7000	-0.3522	0.5	-0.3920/-209.5	3.2	-0.3550	0.2	
11	NPR Hanford		0.94	Zr	NFS		-0.3144	2.7	-0.2572/201.0	6.3	-0.3133	0.8	
10	Windscale AGR		2.50	SS-NB		5000-10000	-0.1202	1.9	-0.1233/-49.2	5.9	-0.1202	0.6	

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