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FINAL REPORT - PITA-18
USE OF NONPOISONOUS SPLINES FOR
LONGITUDINAL FLUX TRAVERSING

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FINAL REPORT - PITA-18
USE OF NONPOISONOUS SPLINES FOR
LONGITUDINAL FLUX TRAVERSING

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I. INTRODUCTION AND OPERATION

The main purpose of PITA-18/¹/ was "to authorize the use of nonpoisonous splines for the single purpose of obtaining longitudinal flux traverse data at all reactors." It is a well-recognized fact that complete optimization of the reactor process involves an accurate knowledge of the longitudinal flux distribution on a semicontinuous, routine basis; the nonpoisonous spline was proposed as a convenient means for obtaining flux traverses at any time during reactor operation, and in virtually any location in the reactor core. This report summarizes the findings of a feasibility study conducted in conjunction with PITA-18, and thus serves as a termination of the test phase of spline traversing.

II. SUMMARY AND CONCLUSIONS

Although the stated purpose of the parent PITA was that of "obtaining longitudinal flux traverse data at all reactors," spline traverses taken under the PITA have proven quite useful as indicators in axial flux control efforts. The achievement of actual production increases was not an objective; however, it is felt that certain economic gains have been realized even during this initial testing phase. Direct, measurable gains are easily foreseen as the result of optimum, routine traversing, but no attempt will be made in this report to quantitatively predict them.

It is concluded that the spline traverse method for obtaining routine flux distribution information is quite satisfactory, and compares favorably with alternative methods previously used.* Accompanying benefits include faster access to data and elimination (or certainly minimizing) of attendant control problems.

This report summarizes the following results of PITA-18:

1. The detailed procedure for performing spline traverses.
2. Complete descriptions and specifications of the equipment currently in use.
3. An IBM analysis code, the NOLA-2./²/
4. A summary of the project history.
5. A compilation of traverse data taken under the PITA, and a statistical comparison between it and uranium traverse data.

*Data from consecutive spline traverses in the same tube indicate good reproducibility of data. (See Figure 17).

/1/ HW-71653, PITA-18, Use of Nonpoisonous Splines for Longitudinal Flux Traversing, JH Ferguson, 11-10-61
/2/ Analysis code written by GF Bailey

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III. FINDINGS

Based upon favorable experience gained over two years of spline traversing experience, and subsequent analysis of almost a hundred different sets of traverse data, the following conclusions are submitted:

1. Routine longitudinal flux traverses should be made at all reactors, using the spline traverse method, at a minimum frequency of 5-7 traverses per equilibrium month per reactor at the "old" reactors, and 8-10 per month per K reactor.
2. Traverse locations and exact minimum frequency should be under the direction of the assigned reactor physicist.
3. Operation of all traverse equipment, with the exception of spline insertion and withdrawal equipment, should be directed by the Irradiation Testing Operation.
4. Actual spline insertion and withdrawal operations should be accomplished by Processing personnel as per standard (current) operating procedure.
5. A re-evaluation of the desirability of continuing traversing under PT IP-394/3/ may be practical at this time.

IV. DISCUSSION

A. Project History

The value of timely and accurate axial flux information became apparent by 1958-59. In 1960 two possible methods of obtaining this information were proposed;^{4/} the Traveling Wire Flux Monitor (TWFM) and the Spline Flux-traverse. Several factors tended to favor the use of splines over the TWFM: 1) the TWFM could only be used in a few, permanent locations; 2) these would have to be made inactive channels, while the spline traverse could be made in any active channel equipped with a spline cap; 3) furthermore, development and equipment costs of the TWFM would have been considerably higher than for splines. Uranium and solid aluminum traverses were not assumed to be final solutions to the problem of routine monitoring because of the relative inflexibility in choosing times and locations for traverses. A complete development report containing the project history and description of the development and testing of the spline traverse equipment was issued in April 1961.^{5/} The equipment discussed therein is essentially the same as that in current use.

In May, 1961, "NOLA-2", an IBM-7090 code^{6,7/} was written to process the raw traverse data, calculate a fitted flux distribution and rupture

/3/ HW-68469, PT IP-394, Use of PT-216 Fuel Columns for Routine Axial Flux Determination, SM Graves, 11-8-62

/4/ Letter, GF Owsley to EC Wood, 9-30-60, Spline Flux Traversing

/5/ HW-69066, Development of Equipment for Spline Monitoring, W. Dalos, 4-6-61

/6/ HW-69486, The NOLA-2 Code, GF Bailey, DG Montague, 5-5-61

/7/ HW-69486, ADD, The NOLA-2 Code, GF Bailey, DG Montague, 5-26-61

DECLASSIFIED

HW-77403

Page 4

potential, and compare both to those of a cosine distribution. (The latest revision to NOLA-2 was made in February 1963.)/8/

Specifications and description of a nonpoison (no boron) spline specifically for flux traversing were issued in March, 1961./9/

By June, 1961, poison splines were being monitored for flux traverses, but routine traversing awaited development of the nonpoison spline. The splines described in H-1-12920 were used on a test basis/10/ but proved to be too thin for complete satisfaction; several minor changes as to thickness, material, and marking were made in the original specifications for the nonpoison spline. On May 3, 1962, H-1-12920, Rev. 3, was issued, which describes the spline currently in use; no major difficulties have been encountered with this spline, and no changes are currently planned for it. Since the introduction of this new spline, a sizable quantity of data has been taken, comparing spline traverses to: 1) Uranium traverses, 2) solid aluminum traverses, 3) poison splines, and 4) other spline traverses to obtain flux distribution changes. A quantitative discussion of the analysis of this data appears in the Appendix of this document.

B. Spline Traversing Procedure/11/

1. Spline Insertion

Insertion of the nonpoison (traverse) splines is accomplished under the same procedures and with the same inserter used for poison splines. Traverse splines are inserted to 35-36 feet at old reactors and to 40 feet at the K's; a several-inch portion of spline is left protruding from the nozzle cap so that in attaching the coiler for spline withdrawal, no movement of the spline is necessary. The Panellit reading for the tube with the spline fully inserted must be such that the spline may be fully withdrawn without interruption for gauge rolling.

2. Spline Withdrawal

After the spline has been in the reactor at least 12-15 minutes, the coiler is attached. This must be done without disturbing the portion of the spline in the reactor. The timer or counter on the coiler is set to allow complete withdrawal of the spline. After all personnel have reached remote shielded areas (specified at the particular reactor), the withdrawal is started; the coiler must not be stopped until withdrawal of the spline is completed, unless a reactor scram would otherwise result. The spline coiler and the recorder chart drive must be started simultaneously to provide a time reference for data analysis.

/8/ Letter, Revisions to NOLA-2, PD Gross, 2-28-63

/9/ H-1-12920, Flux Distribution Spline

/10/ HW-71206, Test of Nonpoisonous Splines, JH Ferguson, 9-29-61

/11/ Based upon preliminary work of ER Perl

DECLASSIFIED

HW-77403

Page 5

3. Equipment

a. Description and Hookup

Two major pieces of electronic equipment, a Victoreen "r" meter with probe and a Varian strip chart recorder, are used in conjunction with a specially designed lead brick shield. (Equipment details and hookup are shown in Figures 1-4.) The lead brick shield and probe are installed on the spline coiler, the "r" meter is located on the front work platform, and the recorder is located in the shielded area containing the remote spline coiler control panel so that sensitivity adjustments may be made during the withdrawal.

b. Checkout Before Traversing

After connecting all equipment, the "r" meter and recorder are turned on and allowed to warm up for several minutes.

A functional check of the "r" meter should be made preceding each set of traverses by the following procedure:

- (1) The toggle switch on the rear of the "r" meter is switched to the "internal meter only" position.
- (2) The range selector on the front is set on "3".
- (3) The "Z" (zero) control on the front is rotated to check for meter movement through its full range from 0 to 50 mv. Failure of the unit to so respond indicates a need for a complete check of probe, cable, connectors, and/or the meter itself.
- (4) Once a satisfactory range response is achieved, the "Z" control is set to "Zero."

A range calibration of the recorder is then performed by the following procedure:

- (1) Set the "r" meter toggle switch to "external, to recorder."
- (2) Set the recorder range selector switch to "3".
- (3) Rotate the "Z" control of the "r" meter to full scale.
- (4) The stylus of the recorder should then be at full scale. If it is off, adjustment may be made with the millivolt selector switch on the front of the recorder.
- (5) Set the "Z" control of the "r" meter to "Zero." The stylus of the recorder should then ride slightly above its zero position.

SECRET

DECLASSIFIED

HW-77403
Page 6

- (6) Set the range selector switch on the recorder to "30".

After satisfying the above checkout, the equipment should be ready for the traverse; range changes for a signal that is too large or too small can be made at the recorder.

The maximum signal during the spline withdrawal should be almost full scale on the recorder. If the trace goes off scale on one range, but is only about half scale on the next range, the probe position should be adjusted to give satisfactory magnitudes.

C. Equipment Specifications and Descriptions

1. Nonpoisonous Spline

The spline currently in use is described in drawing H-1-12920, Rev. 3, a copy of which is shown in Figure 5. (At present only the 0.040" spline is used; see PT. No. 3 on print.) These splines are painted orange by the factory to distinguish them from poison splines. They are designed for insertion with the concave side up, beginning with the rounded end.

2. Lead Shield and Supporting Bracket

There are currently three different shields in use; however, all use the same bracket (Figure 6). The slanted shield shown in Figure 7 is used at B, C, DR, F and H; the vertical shield of Figure 8 is used at D; the cylindrical shield of Figure 9 is used at KE and KW.

A modification of this assembly is currently being completed which will add a roller to keep the spline at a constant distance from the probe during withdrawal (a desirable condition for optimum accuracy).

3. The "r" Meter

The Victoreen Model 510 "r" meter equipped with a special ion chamber probe (modified as shown in Figures 10 and 11) is used as the sensing component.

4. The Recorder

A Varian Model G-11A recorder, with the modifications shown in Figures 12 and 13, is used as the recording component.

This modification consists essentially of the addition of a remote chart drive switch and a remote range changing switch. These were added to allow recorder adjustment from remote shielded areas during traversing.

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D. The NOLA-2 Code

An IBM 7090 code has been specially written for the program, and is used to analyze all traverse data. The steps for preparing the data from the recorder tracings for analysis are given below.

1. A typical trace (see example, Figure 14) shows a significant dip at the center of each fuel element, with the exception of the mixer, which gives a peak. After picking out the point that corresponds to the center of each element, the recorder deflections for all points are listed in suitable format.
2. The code requires for each data point the elapsed time taken for that point on the spline to reach the probe. A time scale for each reactor is built into the code, but an input time scale may be used instead, if indicated; a decision on whether to use the programmed time scale is made by measuring the total traverse time; if it is within about two seconds of that used by the code, there is little to be gained by using an input time scale. When it is necessary to use an input time scale, the time for each data point is read directly from the tracing, using the starting time as a reference.
3. The following data must be submitted for each tube:
 - a. The tube outlet water temperature minus its inlet water temperature (ΔT) in $^{\circ}\text{C}$.
 - b. The tube flow in gpm.
 - c. The tube inlet temperature in $^{\circ}\text{C}$.

The above variables are all to be taken from the reactor control room instrumentation at the time of traverse.

4. The input for the code is prepared by filling in a provided data sheet; the completed sheet is then submitted to EDPO for transferring the data to punched cards. The input format is given on pages 8 through 10. A sample (completed) data sheet is shown in Figure 16.

DECLASSIFIED

HW-77403

Page 8

Card Number	Spaces	Format	Information
First card of data deck	1-6	-	Blank
	7	X	1 if output is classified, otherwise blank
	8-10	X.X	Power exponent in rupture relation ("a+c" in HW-69486; use 8.3)
	11-13	X.X	Temperature exponent in rupture relation ("b" in HW-69486; use 8.7)
	14-17	XX.X	Augmentation distance at five old reactors*
	18-21	X.XX	RA (HW-60876) for O-slugs (old piles only)
	22-26	X.XXX	BA (HW-60876) for O-slugs (old piles only)
	27-39		Used for C Pile only; same information as 14-26
	40-52		Used for K Piles only; same information as 14-26
1	1-6	(any)	Reactor name, or other identification
	7-18	(any)	Date of traverse
	19-24	(any)	Tube number
	25-30		Blank
	31-35	(any)	Page number of first page
2	3-5	XXX	Number of data points (maximum of 500) (Example: 005, 050, or 500)
	9-10	XX	Number of natural slugs in charge (Maximum of 38)
	14-15	XX	Mixer location-number of slugs from upstream end
	19-20	XX	<u>Order of equation:</u> This is normally blank. In special cases when a flux fit by the program is not required, the coefficients of the flux equation may be used to replace the raw data input. In such a case the input to spaces 19 and 20 of card 2 is one less than the number of coefficients used. The coefficients are entered in spaces 1-10 of card 4, et seq., in "floating-point" form. (For example, 0.0387 would be written 3.87000-02.) One card is used for each coefficient (beginning with card 4); a final blank card is not used with this option.

*See Table 1 for input values for "augmentation distance," "RA", and "BA" for the old, C, and K Reactor types.

DECLASSIFIED

HW-77403

Page 9

Card Number	Spaces	Format	Information																					
2 (Cont'd)	25	X	Reactor code:	<table><tr><th>Reactor</th><th>Input</th></tr><tr><td>B, D, DR, F, H</td><td>1</td></tr><tr><td>C</td><td>2</td></tr><tr><td>KE, KW</td><td>3</td></tr></table>	Reactor	Input	B, D, DR, F, H	1	C	2	KE, KW	3												
			Reactor	Input																				
			B, D, DR, F, H	1																				
C	2																							
KE, KW	3																							
30	X	Code for partial traverse correction (normally zero)	<table><tr><th>Condition</th><th>Input</th></tr><tr><td>correction made</td><td>1</td></tr><tr><td>no correction</td><td>0</td></tr></table>	Condition	Input	correction made	1	no correction	0															
Condition	Input																							
correction made	1																							
no correction	0																							
(If the spline was not fully inserted, a correction can be made with this option. The code makes a symmetric extrapolation for the missing data points)																								
	35	X	Time scale code:	<table><tr><th>Condition</th><th>Input</th></tr><tr><td>Input time scale</td><td>0</td></tr><tr><td>Programmed time scale for B</td><td>1</td></tr><tr><td>Programmed time scale for C</td><td>2</td></tr><tr><td>Programmed time scale for D</td><td>3</td></tr><tr><td>Programmed time scale for DR</td><td>4</td></tr><tr><td>Programmed time scale for F</td><td>5</td></tr><tr><td>Programmed time scale for H</td><td>6</td></tr><tr><td>Programmed time scale for KE</td><td>7</td></tr><tr><td>Programmed time scale for KW</td><td>8</td></tr></table>	Condition	Input	Input time scale	0	Programmed time scale for B	1	Programmed time scale for C	2	Programmed time scale for D	3	Programmed time scale for DR	4	Programmed time scale for F	5	Programmed time scale for H	6	Programmed time scale for KE	7	Programmed time scale for KW	8
			Condition	Input																				
			Input time scale	0																				
			Programmed time scale for B	1																				
			Programmed time scale for C	2																				
			Programmed time scale for D	3																				
			Programmed time scale for DR	4																				
			Programmed time scale for F	5																				
			Programmed time scale for H	6																				
			Programmed time scale for KE	7																				
Programmed time scale for KW	8																							
39-40	XX	Number of supplementary data cards (max. of 10). (These cards may be inserted between cards 3 and 4 and may contain any information desired; this information is printed directly on the output sheets.)																						
3	1-5	XXX.X	ΔT (°C)																					
	6-10	XXX.X	Flow (gpm)																					
	11-15	XXX.X	Inlet temperature (°C)																					
Supplementary data cards		(any)	All 80 spaces are available, maximum 10 cards																					
4 (et. seq)	4-5	XX	Slug number (or 1-10 +X.XXXX +XX if spaces 19-20 of card 2 are not zero)*																					
	11-20	XXXXX.XXXX	Distance between data points (Cm.) *																					

*Slug numbers are not used if distance between data points is used, and vice versa.

DECLASSIFIED

HW-77403
Page 10

<u>Card Number</u>	<u>Spaces</u>	<u>Format</u>	<u>Information</u>
4	21-30	XXXXX.XXXX	Activity
et.seq (Cont'd)	31-40	XXXXX.XXXX	Time to probe (sec)
Last card			Blank (Omit if spaces 19-20 of card 2 are not zero.)

Table 1

Miscellaneous Input Factors

	<u>Augmentation Distance (Cm.)</u>	<u>RA</u>	<u>BA</u>
Old	43.0	1.30	1.092
C	43.0	1.45	0.983
K's	31.0	1.30	0.814

Darryl G. Albertson

File Physics Unit
Operational Physics Sub-Section
Research and Engineering Section

CE Bowers

Supervisor, File Physics Unit
Operational Physics Sub-Section
Research and Engineering Section

DG Albertson:CE Bowers:gs

VICTOREEN r METER

PROBE AND SHIELD
MOUNTING DETAIL

FRONT FACE ARRANGEMENT

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Figure 4

HM-77403
Page 14

ASCCB RICHLAND, WASH.

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D PROBE SHIELD DETAIL

KE, KW PROBE SHIELD DETAIL

STOCK MODEL CIRCUIT DIAGRAM

Victoreen r Meter

Figure 10

HW-77403
Page 20

STOCK MODEL CIRCUIT DIAGRAM

Victoreen r Meter

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SECTION OF μ METER CIRCUIT DIAGRAM SHOWING CIRCUIT CHANGES AND ADDITIONS

1 510 Ω Balancing
Resistor

2 Double Pole Single
Throw Switch

3 5 Pin Chassis Connector

Note: Point X is connected to Point Y as indicated on Figure 1 3 by cable connectors and $\sim$ 125 feet of five conductor cable.

Figure 12

MODIFIED RECORDER
Schematic Circuit Diagrams

- 1 5 Pin Chassis Connector
- 2 Recorder Load Resistance
- 3 Signal To Recorder, Connect to P 203 - P 204, See Figure 12

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Figure 14
Sample Recorder Trace

Figure 15

Traverse Locations - C Reactor

80 - 80

Figure 16

S

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45									
1										8.3	8.7	4.3	0.1	.3	0.1	.0	9.2	4.3	.0	1.4	5.0	.9	8.3	3.1	.0	1.0	1.0																											
2	D	P	I	L	E	A	P	R	I	L	1	,	1	9	6	3					3	9	6	4																														
3										3.2					3.2					2.7																																		
4										95.0					45.0					10.0																																		
5	N	O	T	E	*	H	A	L	F	R	O	D	S		P	O	S	I	T	I	O	N	E	D		A	T		1	0	0																							
6										1																																												
7										2																																												
8										3																																												
9										↓																																												
10										3.2																																												
11																																																						
12																																																						
13	D	P	I	L	E	A	P	R	I	L	1	,	1	9	6	3																																						
14										3.2					3.2						2.7																																	
15										93.4					47.0						10.0																																	
16										1																																												
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23	D	P	I	L	E	A	P	R	I	L	1	,	1	9	6	3																																						
24										4.1					3.2						3.0																																	
25										94.0					45.0						10.0																																	

'e 16

Sample Data Sheet

DATE _____

PROBLEM NO.[illegible]

Figure 16

BM-77403
Page 26

DECLASSIFIED

"NOLA-2" OUTPUT

REACTOR	100C	DATE	5-7-63
TUBE	2884	NUMBER	32
MIXER LOCATION	18	MIXER REACTIVITY	0.012784
SKewing-UNITS D.S.	-2	LEAKAGE FACTOR	0.935069
PEAKING	5.708	MAX./AVG. RATIO	1.502534
RUPTURE POTENTIAL RELATIVE TO		COSINE	1.392217
FLUX-SQUARED WEIGHTED AVERAGE		BUCKLING	16.048390

(Prevarsetaken at zero time)

TRAVERSE REPRODUCIBILITY TEST

Figure 17

HM-77403
Page 27

APPENDIX

DECLASSIFIED

Statistical Analysis of Data Collected Under Program To Date

Since November 1961, approximately 400 traverses have been made at the reactors, using the nonpoisonous spline. (The use of poisonous splines for this purpose dates back to April 1961, and routine "heavy metal" (uranium) traverses were begun in February 1961, as authorized by PT IP-394-I.) This appendix is included to illustrate the methods used in statistically comparing spline traverse data gathered during this three-year period with similar data from heavy metal traverses taken during the same time period.

It is important to note that H.M. (heavy metal) and spline traverse data are not strictly comparable on a one-to-one basis; this is due to the fact that H.M. data represents an average axial flux over the entire metal cycle, while the spline data gives an "instantaneous" flux profile. It is felt, however, that the two methods should give comparable results if averaged over a long period of time (i.e., in indicating long range trends).

The procedure utilized in this report for comparison of the two methods is outlined below. (C Reactor was chosen for this sample analysis, since the greatest amount of traverse data is recorded for C.)

1. Accumulate all available spline and H.M. traverse data.
2. Divide the reactor into zones for analysis on a regional basis (with consideration given to H.M. traverse locations).
3. Group all the spline traverse data according to zone; discard all traverses in a given zone taken during a time period when no H.M. traverse was taken in that zone.
4. Compare the results of the two methods by means of some suitable correlation test. (The well-known F test was used in the present analysis.^{/12/} The F test provides a quantitative answer to the question: "With a given variation for each method, how much variation can one reasonably expect between the averages for the two methods?" In other words, is the variation statistically significant?)

Figure 15 is a front-face map of C Reactor showing the locations of H.M. and spline traverses for each zone. Table 2 gives the date of traverse, tube number, and values of the traverse parameters for each zone.

The three parameters that were chosen for statistical comparison are:

1. RRP (Rupture Potential Relative to a cosine flux distribution, or "Relative Rupture Potential"). This quantity is calculated from the raw traverse data by NOLA-2; it is an analytical measure of the ratio of the expected rupture rate of the charge in the observed flux distribution to the rupture rate of the same charge in a cosine flux distribution. (Since this quantity depends on both the "peaking" and "skewing" of the measured flux distribution, it was subjected to a more rigorous analysis than the other two parameters described below.)

^{/12/} Waugh, A.E. Elements of Statistical Method, McGraw-Hill, 1952, pp. 264 ff

2. % Peaking: This quantity is defined as the ratio of the maximum value of the measured flux to the maximum value of a cosine flux expressed as per cent. It is a measure of degree of peaking of the measured flux.
3. Skewing: This quantity describes the location of the flux peak, in number of slugs downstream from the charge center (thus, where the peak in the measured flux occurs); it is thus a measure of the asymmetry of the measured flux distribution about the charge center.

Table 3 summarizes observed average values for the individual parameters listed in Table 2. A first glance at pairs of averages indicates at least some degree of correspondence between the two methods, since in most of the pairs the values from the two methods agree to one significant figure.

The more rigorous comparison of the F test was applied to the values of RRP. The results of this test indicate that there is "no significant variation"* between the two traverse methods so far as the calculated rupture potential is concerned. Table 4 gives the variance between methods (VB), the variance within the methods (VW), the "F" value (a standard quantity used for statistical comparisons), the associated number of degrees of freedom (n_1 , n_2), and the probability of finding this size variation by pure chance alone (P).

In all cases the value of P is greater than five per cent, and in all but two cases, 40 per cent or greater. As discussed in Waugh^{/12/}, a P value greater than five per cent indicates that "the variation is not significant"; a value between one per cent and five per cent indicates that "the variation is significant"; and a value less than one per cent indicates that "the variation is highly significant." Thus a reasonably close correlation is indicated between the two methods. At any rate, it appears safe to predict that spline traverse data will be at least as useful as other traverse methods in predicting rupture potential and other process variables. Furthermore, accuracy and utility of the data and analysis are expected to increase in the future, so hypothetical future comparisons should produce even more favorable results.

*This term as commonly applied means that the probability of finding the observed variation between the two methods by pure chance alone is greater than five per cent.

/12/ Waugh, A.E., ibid

Table 2

Flux Distribution Parameters (C Reactor)

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ZONE 1

<u>Date</u>	<u>Tube</u>	<u>RRP</u>	<u>% Peaking</u>	<u>Skewing Units D.S.</u>	<u>Method of Traverse</u>
10-12-61	3353	1.63	6.65	-1	Spline
11-7-61	3460	2.29	11.96	2	H.M.
12-8-61	3359	1.30	14.88	-1	Spline
		1.27	11.81	-1	H.M.
1-16-62	3460	1.48	15.20	-3	H.M.
1-23-62	3353	0.84	8.01	-5	Spline
2-9-62	3362	0.65	6.45	-3	Spline
3-10-62	3359	1.76	16.81	-4	H.M.
5-5-62	3461	2.68	14.87	-2	H.M.
8-9-62	3360	2.90	13.23	-2	Spline
	3461	1.22	16.19	-3	H.M.
9-11-62	3259	8.94	25.79	-1	Spline
9-21-62	3259	1.66	10.09	-3	Spline
9-23-62	3460	3.39	16.64	-3	H.M.

ZONE 2

9-16-61	3091	0.39	-12.75	2	Spline
	3382	0.35	-13.51	3	Spline
10-23-61	3386	0.79	5.43	-3	H.M.
		0.98	15.90	-2	Spline
11-7-61	3287	0.99	6.86	-2	H.M.
11-8-61	3382	1.01	0.24	-4	Spline
12-8-61	3387	0.78	3.36	-1	H.M.
	3285	1.91	17.41	-5	Spline
1-16-62	3386	0.58	-1.65	-4	H.M.
2-16-62	3387	0.94	0.67	-3	H.M.
2-19-62	3387	0.96	-0.42	-1	Spline
4-16-62	3386	1.15	5.86	-3	H.M.
5-25-62	3480	0.52	-4.46	-2	Spline
	3386	1.34	5.36	-3	H.M.
	3387	1.46	8.82	-3	H.M.
8-9-62	3388	1.37	5.46	-2	Spline
	3287	1.54	7.44	-3	H.M.
	3387	1.40	6.52	-3	H.M.
9-11-62	3382	2.42	12.48	-3	Spline
9-23-62	3386	1.42	6.96	-3	H.M.

ZONE 3

8-19-61	2776	0.66	11.00	-3	Spline
10-12-61	2669	12.16	38.13	0	H.M.
		4.20	20.69	-1	Spline
11-7-61	2670	3.11	20.96	-1	H.M.
11-8-61	2670	1.07	15.75	-1	Spline
1-16-62	2669	1.39	9.81	-4	H.M.
1-27-62	2666	2.95	9.82	0	Spline
2-9-62	2666	2.50	9.88	-1	Spline
2-16-62	2670	1.08	5.47	-4	H.M.

DECLASSIFIEDHW-77403
Page 31Table 2
(Cont'd)ZONE 3 (Cont'd.)

<u>Date</u>	<u>Tube</u>	<u>RRP</u>	<u>% Peaking</u>	<u>Skewing Units D.S.</u>	<u>Method of Traverse</u>
2-19-62	2670	1.91	9.17	-3	Spline
4-16-62	2669	3.12	14.44	0	H.M.
5-5-62	2670	2.58	11.55	0	H.M.
7-19-62	2671	2.53	14.28	-2	H.M.
8-9-62	2669	3.26	16.06	-2	H.M.
	2670	2.31	13.72	-2	H.M.
9-11-62	2871	7.90	25.85	-2	Spline
9-21-62	2871	3.12	15.70	-2	Spline
9-28-62	2871	2.69	13.24	-1	Spline
11-29-62	2671	1.51	8.34	0	H.M.

ZONE 4

6-12-61	2179	1.70	-2.00	6	Spline
6-26-61	2074	1.48	3.79	1	H.M.
8-19-61	2181	2.10	16.90	-1	Spline
9-16-61	2167	1.32	11.38	-3	Spline
	2181	1.05	8.24	-2	Spline
10-12-61	2074	6.78	33.46	-1	H.M.
		3.87	20.11	-1	Spline
11-7-61	2075	3.14	23.96	-1	H.M.
11-8-61	2075	1.04	21.73	-1	Spline
	2167	1.04	8.52	-4	Spline
12-1-61	2171	1.58	10.56	-3	Spline
12-8-61	2073	1.41	14.02	-1	H.M.
	2167	0.56	-0.08	-4	Spline
1-16-62	2074	0.58	0.35	-5	H.M.
2-9-62	2179	1.53	5.17	-5	Spline
2-16-62	2075	0.50	3.00	-5	H.M.
2-19-62	2075	0.59	4.11	-4	Spline
3-16-62	2073	1.19	-5.57	-1	H.M.
5-5-62	2074	1.21	6.21	-2	H.M.
5-25-62	2082	0.51	5.31	-4	Spline
7-19-62	2075	1.51	8.26	-3	H.M.
8-9-62	1976	1.16	5.88	-3	Spline
	2073	1.36	6.22	-3	H.M.
	2074	1.65	9.53	-2	H.M.
	2075	0.93	5.55	-2	H.M.
11-29-62	2073	1.25	6.19	-3	H.M.

ZONE 5

8-19-61	1463	0.96	-1.27	0	Spline
10-23-61	1562	1.19	-7.47	-1	H.M.
		0.96	4.06	-1	Spline
11-7-61	1462	1.00	4.75	-1	H.M.
11-8-61	1462	1.03	5.74	-2	Spline
1-16-62	1562	0.64	-8.88	5	H.M.
2-16-62	1462	0.49	-2.88	-4	H.M.
2-19-62	1462	0.42	-6.51	-5	Spline
4-16-62	1562	0.91	4.08	-2	H.M.

Table 2
(Cont'd)**DECLASSIFIED**ZONE 5 (Cont'd.)

<u>Date</u>	<u>Tube</u>	<u>RRP</u>	<u>% Peaking</u>	<u>Skewing Units D.S.</u>	<u>Method of Traverse</u>
5-5-62	1462	1.30	5.40	-2	H.M.
5-25-62	1463	0.81	1.69	-2	H.M.
	1562	0.97	3.20	-2	H.M.
8-9-62	1561	1.00	1.44	-1	Spline
	1462	1.04	3.67	-2	H.M.
9-11-62	1561	2.51	11.73	-2	Spline
9-23-62	1562	1.28	5.79	-3	H.M.
	1463	1.08	3.78	-3	H.M.
11-29-62	1462	1.13	4.16	-3	H.M.

ZONE 6

8-1-61	1585	1.20	-6.90	-2	Spline
8-19-61	1487	0.72	-2.87	-4	H.M.
		1.02	-7.14	5	Spline
	1482	0.89	0.74	-4	Spline
10-23-61	1587	1.25	11.73	-2	H.M.
		1.01	16.71	-2	Spline
11-7-61	1487	1.43	9.11	0	H.M.
11-8-61	1482	1.10	16.63	-3	Spline
12-8-61	1489	1.62	9.52	-3	Spline
	1486	0.77	3.44	-1	H.M.
1-16-62	1587	0.78	5.17	-3	H.M.
3-10-62	1486	0.91	5.73	-6	H.M.
	1487	1.15	6.53	-5	H.M.
4-16-62	1587	1.60	10.84	-3	H.M.
5-25-62	1585	0.53	1.58	-3	Spline
	1689	0.91	2.92	-2	Spline
	1587	1.61	7.01	0	H.M.
8-9-62	1689	2.12	13.61	-3	Spline
	1487	1.49	8.24	-3	H.M.
9-23-62	1587	1.65	8.75	-3	H.M.
11-29-62	1587	1.59	8.38	-3	H.M.

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Table 3

Average Flux Distribution Parameters

ZONE 1

<u>Time Period</u>	<u>Avg. RRP</u>	<u>Avg. Peaking</u>	<u>Avg. Skewing</u>	<u>Method of Traverse</u>
10-12-61 to 9-23-62	2.560 2.013	12.157 14.783	-2.3 -2.0	Spline H.M.

ZONE 2

9-16-61 to 9-23-62	1.101 1.126	2.261 5.057	-1.6 -2.8	Spline H.M.
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ZONE 3

8-19-61 to 11-29-62	3.000 3.305	14.567 15.276	-1.6 -1.5	Spline H.M.
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ZONE 4

6-12-61 to 11-29-62	1.389 1.769	8.910 8.844	-2.2 -2.2	Spline H.M.
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ZONE 5

8-19-61 to 11-29-62	1.147 0.987	2.532 1.441	-1.8 -1.7	Spline H.M.
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ZONE 6

8-1-61 to 11-29-62	1.156 1.246	5.297 6.838	-1.9 -2.8	Spline H.M.
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Table 4

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<u>Statistical Parameters</u>					
<u>Zone Number</u>	<u>v_B</u>	<u>v_W</u>	<u>F</u>	<u>n₁, n₂</u>	<u>P(%)</u>
1	1.047	4.553	4.348	12,1	~ 40
2	0.003	0.269	81.900	18,1	~ 10
3	0.441	7.567	17.174	17,1	~ 20
4	0.939	1.726	1.839	24,1	~ 50
5	0.102	0.199	1.945	16,1	~ 50
6	0.042	0.168	4.003	19,1	~ 40

Definition of terms:

$$v_B = \frac{N_S N_M}{N_S + N_M} (\bar{S} - \bar{M})^2 \quad (\text{variation between the methods})$$

$\bar{S}$ is the average RRP by the spline traverse method.

$\bar{M}$ is the average RRP by the uranium traverse method.

N_S is the number of spline traverses.

N_M is the number of uranium traverses.

$$v_W = \frac{\sum_{i=1}^{N_S} (S_i - \bar{S})^2 + \sum_{i=1}^{N_M} (M_i - \bar{M})^2}{N_S + N_M - 2} \quad (\text{variation within the methods})$$

The S_i and M_i are the various values obtained for RRP by spline and uranium traverses, respectively.

$$\text{For } v_W > v_B: F = \frac{v_W}{v_B}, n_1 = N_S + N_M - 2, n_2 = 1$$

$$\text{For } v_B > v_W: F = \frac{v_B}{v_W}, n_1 = 1, n_2 = N_S + N_M - 2$$

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