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FUEL ELEMENT HOLE LOCATION SURVEY

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15 June 1965

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Westinghouse Astronuclear Laboratory

FUEL ELEMENT

HOLE LOCATION SURVEY

(*Title Unclassified*)

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ABSTRACT

The purpose of this survey was to determine variations in hole locations in fuel elements manufactured by the Westinghouse Astrofuel Facility, Cheswick, Pennsylvania. The major objectives were the variation in hole location along the length of the element, the extent of mismatch across the cemented joint of the non-fueled tip, and the deviation in location of the outside holes relative to the outer surface of the element.

The survey consisted of a total of 2,856 hole location measurements. Samples were taken from 38 elements; 29 of these from the NRX-A2 and NRX-A3 production runs and nine from the NRX-A4 production runs. The NRX-A2 and NRX-A3 samples were taken from coated elements previously selected as the one percent destructively-tested core candidate elements per PDS 30021. The NRX-A4 samples were uncoated elements checked for mismatch across the non-fueled tip.

Of the 29 final coated elements surveyed for variation in hole location with length, 94.4 percent of the displaced holes were within 6 mils. One third of the displacements which exceeded 6 mils involved outer holes.

Of the nine in-process elements surveyed for hole mismatch, 97 percent of the mismatches across the glued joint of non-fueled tips were within 4 mils (171 hole pairs studied). There was no significant difference between corner, middle-of-face, and inner location holes.

Of the 30* elements surveyed for variation in location of the outside holes, 70 percent of the corner holes and 90 percent of the middle-of-face holes did not exhibit outward excursions. None of the corner holes which did exhibit outward excursions (greater than 6 mils) had a normal vector exceeding 5 mils. Out of the 29 corner holes in the 4 to 6 mil excursion range, 25 involved holes on the right side of the element.

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* Of these 30 elements, 29 were NRX-A2, NRX-A3 final coated elements and one was an NRX-A4 element.

SECTION 1

INTRODUCTION

The fuel element coolant hole location survey reported herein covers three types of hole parameters. The first type of parameter considered is the variation in hole location with length of finished (coated) elements manufactured for NRX-A2 and NRX-A3. In this part of the survey, hole location in each of three wafers, taken at designated intervals measured from the serial numbered end, is referred to the corresponding hole location in a fourth wafer taken from the hot end.

The second area of investigation was hole mismatch across the cemented joint of the unfueled tip for in-process elements manufactured for NRX-A4. The extent of this mismatch was determined from measurements taken immediately adjacent to and on both sides of the cemented joint. The elements examined were in-process elements checked prior to the application of the niobium carbide coating.

The last part of the survey consisted of the determination of variation in location of the outer holes. As in the first series of tests, these were coated elements manufactured for NRX-A2 and NRX-A3.

The test procedures are based on the requirements of figure 1, which illustrates the concept of relative hole displacement. As used in this report, relative hole displacement (RHD) is measured in mills across the plane of the cross section of the element through its longitudinal axis. It is the distance from the centerline of a given hole in one wafer to a corresponding hole in a second wafer, which is taken from the same element and is designated as the reference wafer. This relationship is graphically presented in figure 1. It should be noted that the RHD measurement takes into account both the linear extent (mils) and the angular direction (degrees) of the deviation of the holes from their nominal location.

SCALE: 1/4 INCH = 1 MIL

AC	-	DEVIATION FROM TRUE LOCATION - FIRST WAFER	$HVTR_1$	= AB	=	HORIZONTAL VECTOR - FIRST WAFER
AF	-	DEVIATION FROM TRUE LOCATION - SECOND WAFER	$HVTR_2$	= GF	=	HORIZONTAL VECTOR - SECOND WAFER
$\varnothing_1$	-	ANGLE OF DEVIATION - FIRST WAFER *				
$\varnothing_2$	-	ANGLE OF DEVIATION - SECOND WAFER *				

* - ANGLE OF DEVIATION IS TAKEN COUNTER-CLOCKWISE FROM THAT POINT AT TOP OF CIRCUMFERENCE OF HOLE WHICH IS TANGENT TO A LINE PARALLEL WITH FACE "A" - FACE "A" UP.

TO DETERMINE RHD (IN MILS) = CF: DRAW $HVTR_1 = AB = AC \times \sin \varnothing_1$. ERECT ORDINATE AT B. DRAW AC = MEASURED DEVIATION FOR FIRST WAFER, LOCATING POINT C AS POINT OF INTERSECTION WITH ORDINATE. REPEAT FOR SECOND WAFER, NOTING THAT $HVTR_2 = GF = AF \times \cos(\varnothing_2 - 90^\circ)$. LOCATE POINT F IN SAME MANNER AS POINT C. MEASURE CF IN MILS AND REPORT AS "RHD".

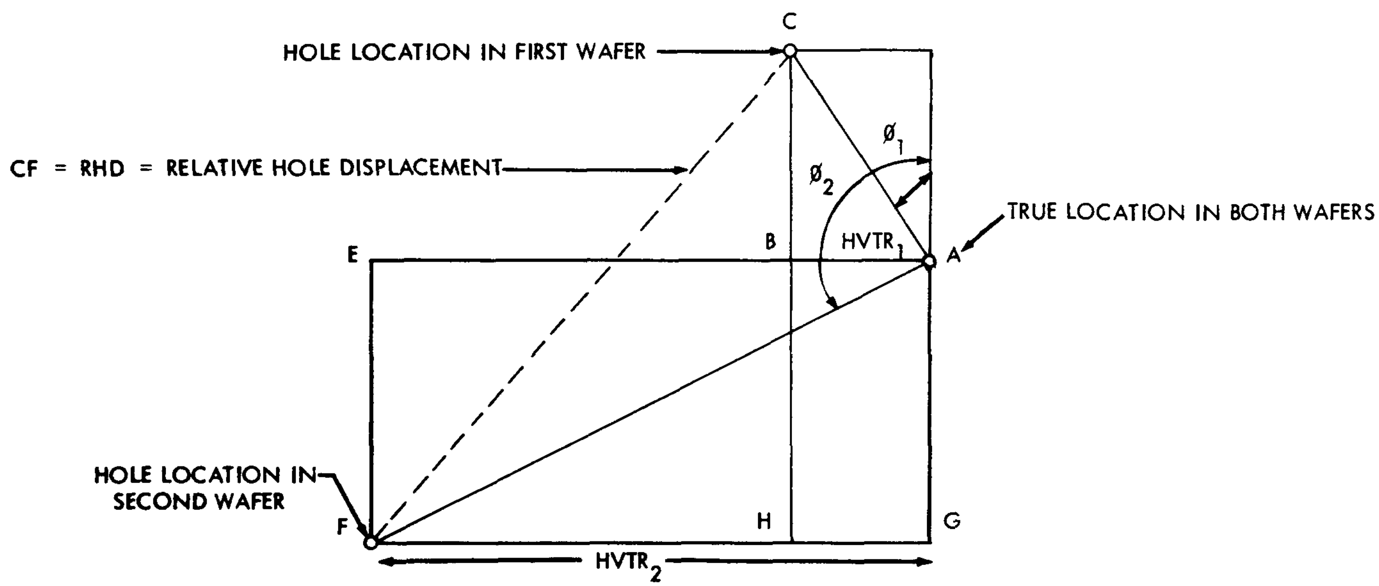

Figure 1 Relative Hole Displacement Geometry

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The test results are reported in the individual sections. Section 2 covers variations in hole location along the length of destructively test coated elements from NRX-A2 and NRX-A3 and Section 3 discusses hole mismatch across cemented joint and hole wander along the length of in-process NRX-A4 unfueled tip elements.

In general, the conclusion may be drawn that the fuel elements currently being produced at Astrofuel are satisfactory, and meet the requirements of Westinghouse drawing 937J492.

SECTION 2

VARIATION IN HOLE LOCATION WITH LENGTH OF DESTRUCTIVELY TESTED COATED ELEMENTS FROM NRX-A2 AND NRX-A3

There were three major objectives in this part of the survey. First, there was the determination of the frequencies and extents to which the holes in the three comparison wafers taken along the element length deviate linearly from the location of the same channel hole in a "reference" wafer taken near the opposite (non-serialed number) end.

Second, there was the determination as to whether the hole location found in the reference wafer could be detrimentally misleading with respect to the risk that holes along the length of the element might unexpectedly approach the peripheral surface if only the reference wafer were inspected.

Third, for those outer hole-wafer locations whose reported deviations exceeded 6 mils outward, or 12 mils inward, the nature of the indications provided by the reported locations of their respective reference wafers was desired.

The data derived in this survey is given in table 1. In this table are listed the serial numbers and parent batch numbers of the 29 destructively-tested elements whose hole location data were listed in this section of the survey.

ARRANGEMENT OF DATA

Table 1 lists the serial numbers and batch numbers of the 29 destructively-tested elements whose hole location data were studied in this section of the survey. The data obtained from these 29 elements are used in both Sections 3 and 4 of this report.

In figure 2 note that hole location wafer specimens No. 5, 11, 17, and 22, numbered from the S/N end of the element, were taken at designated positions. The RHD value for each of Wafers No. 5, 11, and 17 was determined with Wafer No. 22 being taken as the reference wafer. Wafers No. 5, 11, and 17 are later designated as comparison wafers.

TABLE 1

SERIAL NUMBERS AND PARENT BATCH NUMBERS
OF THE 29 DESTRUCTIVELY TESTED ELEMENTS

NRX - A - 2				NRX - A - 3			
S/N	Listing No. *	Batch No.	Date Extruded	S/N	Listing No. *	Batch No.	Date Extruded
99 - 09367	13	884	10/04/63	39 - 13440	18	1348	5/12/64
99 - 09442	1	891	10/10/63	99 - 13542	19	1337	5/13/64
99 - 09458	11	895	10/10/63	99 - 13943	20	1372	6/10/64
99 - 09657	12	918	10/15/63	99 - 14218	21	1381	6/17/64
99 - 09700	2	924	10/17/63	59 - 14790	22	1441	7/09/64
99 - 09798	10	934	10/18/63	49 - 14902	23	1470	7/11/64
99 - 09826	4	938	10/18/63	69 - 15140	24	1498	7/15/64
99 - 10129	9	973	10/31/63	79 - 15402	26	1515	7/18/64
99 - 11079	3	1058	2/19/64	99 - 15805	25	1559	7/28/64
39 - 11660	6	1126	3/07/64	99 - 15998	27	1580	7/30/64
39 - 11713	5	1130	3/09/64 **	99 - 16049	28	1585	7/31/64
39 - 11785	8	1135	3/10/64 **	99 - 16449	29	1630	8/21/64
39 - 11791	7	1136	3/10/64 **	89 - 16738	30	1659	8/31/64
99 - 12431	15	1193	3/23/64 **				
99 - 12590	16	1213	4/01/64				
99 - 12605	14	1215	4/01/64				
99 - 12835	17	1241	4/07/64				

* - "Listing No." - A number in the range, 1 through 30, assigned to each of the F/E surveyed solely for the purpose of simplifying identification of the F/E during tabulation.

Listing Nos. 1 through 17 represent NRX - A - 2; Nos. 18 through 30 represent NRX - A - 3.

** - Approximate

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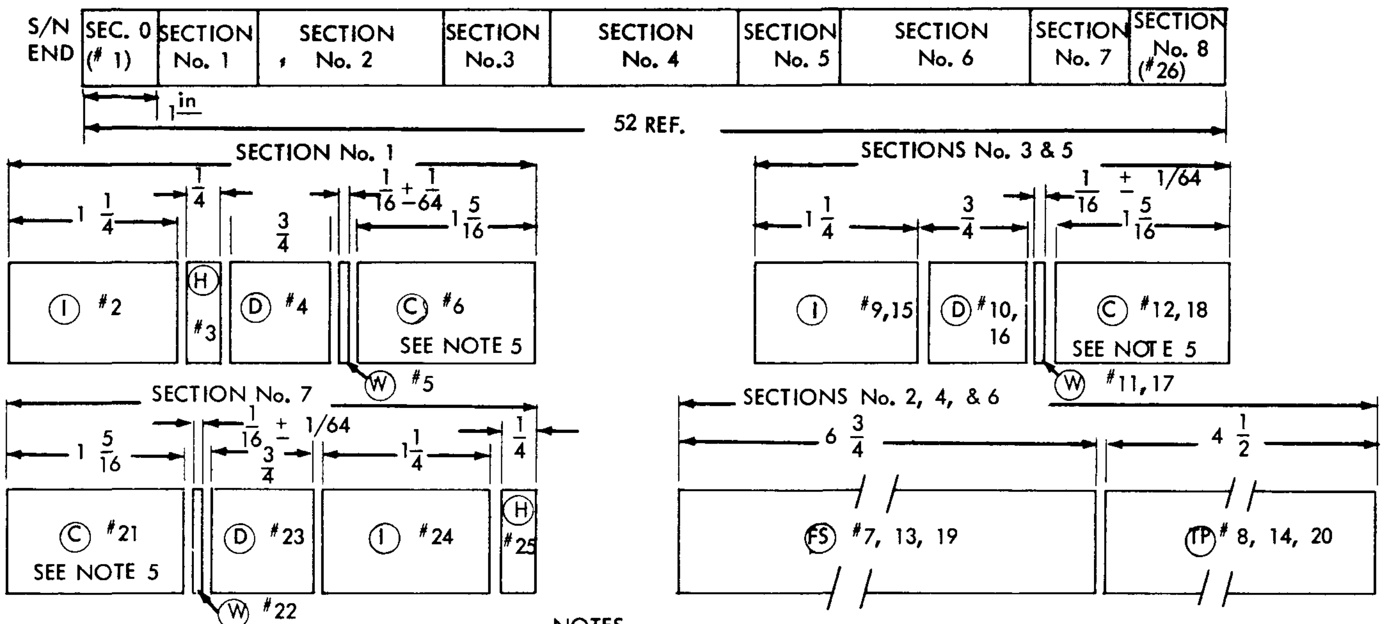

SYM.	SPECIMEN PURPOSE		SEND TO
(C)	CHEMICAL ANALYSIS		WMS
(D)	DENSITY		AFF OP
(FS)	FLEXURAL STRENGTH		LARGE
(H)	HYDROGEN		WMS
(I)	IMPURITIES		WMS
(TP)	THERMAL PROPERTIES		LARGE
(W)	WAFER	HOLE LOCATION	AFF QC
		NbC	LARGE

NOTES:

1 - # = SPECIMEN NO.
2 - SECTION NO. 0 IS IDENTICAL TO SPECIMEN #1
3 - SECTION NO. 8 INCLUDES MATERIAL LOSS; IS IDENTICAL TO #26
4 - TOL. ± 1/16 UNLESS OTHERWISE SPECIFIED. ALL DIM. IN INCHES.
5 - ENDS TO BE FLAT WITHIN .001 & PERPENDICULAR TO ELEMENT AXIS WITHIN .001 on #6, 12, 18 &21
6 - BEFORE SECTIONING, NOTCH EACH (W) WAFER, # 5, 11, 17, & 22, AT NO. 1 HOLE

Figure 2 Sectioning of Destructively Tested Fuel Element

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Table 2 is arranged by hole wafer combination. The holes are grouped as follows: outer corner, outer middle-of-face, and inner. For each combination, the frequency by count is listed within each of the four ranges: exceeding 9 mils, from 7 to 9 mils, from 4 to 6 mils, and from 0 to 3 mils. For example, in the first line of the table Hole No. 1 in Wafer No. 5 showed two RHD values in the range 7 to 9 mils, four RHD values in the range 4 to 6 mils, and twenty-three RHD values in the 0 to 3 mil range.

Table 3 concerns only the 30 outer-hole cases where the RHD value exceeded 6 mils. It compares the linear/angular deviation from true location, as found in each of the comparison Wafers No. 5, 11, and 17, with that found in the No. 22 wafer of the same element. Table 3 meets the second objective of this section, as presented under results, below.

RESULTS

Returning to table 2, note that out of the 12 outer-corner RHD values in the 7 to 9 mil range, ten of these values were found in Wafer No. 5, which is nearest the S/N end. A similar situation is seen in the case of outer-middle-of-face holes. RHD values exceeding 6 mils occurred with a frequency of only 3 percent for outer holes as compared with 10 percent for inner holes. A similar difference in lesser degree (15 percent versus 21 percent respectively) was found in the 4 to 6 mil RHD range. It is evident that inner holes tend more often to be widely displaced from their reference wafer holes than do outer holes.

Referring to table 3, which concerns outer holes only, 15 cases each were found for corner and middle-of-face holes in which the RHD value exceeded 6 mils. The table lists, for both the comparison wafer and its reference wafer, the extent and angle of the reported deviation. The deviation angle is taken with reference to a zero degree - 12 o' clock position which is defined as the point of tangency of the top of the hole circumference with a line parallel to Face "A" when Face "A" is up. In this survey, all angles, expressed in degrees, are taken as counter-clockwise from this 12 o' clock position, unless indicated otherwise.

TABLE 2

RELATIVE HOLE DISPLACEMENTS IN VARIOUS RANGES FOR EACH HOLE WAFER COMBINATION

Hole: Group	Hole: Face Position	Hole: No.	9**: 5*	9**: 11	9**: 17	9**: All	7/9**: 5	7/9**: 11	7/9**: 17	7/9**: All	4/6**: 5	4/6**: 11	4/6**: 17	4/6**: All	0/3**: 5	0/3**: 11	0/3**: 17	0/3**: All	Total
Outer	Corner	1					2			2	4	4	4	12	23	25	24	72	86
		3					1			1	2	1	2	5	26	28	26	80	86
		8					1			1	5	3	3	11	23	26	25	74	86
		12	1	1	1	3	1			1	4	4	3	11	23	24	24	71	86
		17					2	1		3	7	7	6	20	20	21	21	62	85
		19					3		1	4	7	3	3	13	19	26	24	69	86
	Corner	All	1	1	1	3	10	1	1	12	29	22	21	72	134	150	144	428	515
	Middle	2					1			1	5	4	3	12	23	25	25	73	86
		4					2		1	3	4	4	3	11	23	25	24	72	86
		7					1			1	7	4	4	15	21	25	24	70	86
		13					1			1	8	6	4	18	20	23	24	67	86
		16					1	1		2	3	3	1	7	25	25	27	77	86
		18	1			1	3	1	2	6	6	5	5	16	19	23	21	63	86
	Middle	All	1			1	9	2	3	14	33	26	20	79	131	146	145	422	516
Inner		5					4	3	3	10	10	5	5	20	15	21	20	56	86
		6	1	1		2	4	2	3	9	7	4	5	16	17	22	20	59	86
		9	1		1	2		2	2	4	8	8	6	22	20	19	19	58	86
		10					3	1	2	6	4	2	4	10	21	26	22	69	85
		11	1			1	3	2	1	6	7	5	7	19	18	22	20	60	86
		14	1	1		2	2		1	3	10	7	10	27	16	21	17	54	86
		15	2	2	1	5	5	2	4	11	4	5	5	14	18	20	18	56	86
		All	6	4	2	12	21	12	16	49	50	36	42	128	125	151	136	412	601
All	All	All	8	5	3	16	40	15	20	75	112	84	83	279	390	447	425	1262	1632

Note: Data not available:

(1) All holes in Wafer No. 17 - from F/E S/N - 39 - 11791

(2) All holes in Wafer No. 17 - from F/E S/N - 99 - 10129

(3) Hole No. 10 in Wafer No. 5 from F/E S/N - 89 - 16738

(4) Hole No. 17 in Wafer No. 17 from F/E S/N - 99 - 13943

* Wafer Number

** Relative Hole Displacement (RHD) in mils

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TABLE 3

RELATIVE HOLE DISPLACEMENTS FOR OUTER HOLES WITH RHD VALUES GREATER THAN 6 MILS

Hole			Comp.*		Reported Deviation from True Location						Direction of Deviation			F/E
					Comparison		Reference**		Degrees Counterclockwise					
Group	Face Position	Channel No.	Wafer No.	(mils) RHD	Mils	Clock Hour	Mils	Clock Hour	Comp.	Refer.	Comp.	Refer.	Reactor	Listing No.
Outer	Corner	1	5	8	8	4	0	12	250	360	In	TP	A-2	12
		1	5	7	4	5	5	8	210	110	In	Out	A-2	15
		3	5	7	7	4	2	8	250	130	Out	In	A-2	12
		8	5	7	10	2	7	3	315	270	In	In	A-3	18
		12	5	7	5	9	3	7	270	145	Out	In	A-2	12
		12	5	12	3	10	14	11	60	30	In	In	A-2	3
		12	11	11	3	11	14	11	30	30	In	In	A-2	3
		12	17	10	4	11	14	11	30	30	In	In	A-2	3
		17	5	9	5	3	4	10	270	60	Para.	Para.	A-2	12
		17	11	8	4	3	4	10	280	60	Para.	Para.	A-2	12
		17	5	9	3	11	7	3	30	270	In	Out	A-3	24
		19	5	7	6	4	1	9	250	90	Out	Para.	A-2	12
		19	5	7	5	10	5	1	60	335	In	Out	A-3	23
		19	17	7	5	10	5	1	70	335	In	Out	A-3	23
		19	5	8	3	10	5	3	60	270	In	Out	A-3	24
	Middle	2	5	8	8	4	1	8	250	135	In	In	A-2	12
		4	5	8	7	4	1	9	255	100	In	Out	A-2	12
		4	5	7	1	7	6	3	165	270	Para.	In	A-3	23
		4	17	7	2	7	6	3	165	270	Para.	In	A-3	23
		7	5	7	5	4	3	8	255	130	Out	In	A-2	12
		13	5	9	8	4	1	10	255	50	In	Out	A-2	12
		16	5	9	5	3	4	8	270	105	Out	In	A-2	12
		16	11	8	4	3	4	8	270	105	Out	In	A-2	12
		18	5	9	10	1	6	11	330	30	In	In	A-2	6
		18	17	7	5	2	6	11	315	30	In	In	A-2	6
		18	5	10	6	3	4	10	270	60	Para.	In	A-2	12
		18	11	7	3	3	4	10	280	60	Para.	In	A-2	12
		18	5	9	6	11	7	2	40	315	In	In	A-3	23
		18	17	8	4	11	7	2	40	315	In	In	A-3	23
		18	5	9	5	10	7	2	45	310	In	In	A-3	24

* - Comparison Wafers (No. 5, 11, 17)

** - Reference Wafer (No. 22)

TP - True Position

Para. - Parallel to Surface

Note that at the right, table 3 lists the Direction of Deviation with respect to the adjacent peripheral surface(s), as exhibited by the comparison and reference wafers, respectively. As listed, each wafer-hole location could deviate in one of four directions: Inward, Outward, Parallel to Surface, or True Position (Zero Deviation). Out of the 16 possible pairings, seven are found in the following tabulation:

	Direction of Deviation	
Pairing No.	Comparison Wafer	Reference Wafer
1	Inward	Inward
2	Inward	True Position
3	Inward	Outward
4	Parallel	Parallel
5	Parallel	Inward
6	Outward	Parallel
7	Outward	Inward

Notice that, with respect to the risk of unexpected approach to the peripheral surface, only the pairings Nos. 6 and 7, above, would be detrimentally misleading if the reference wafer (No. 22) were used as the predictor of hole locations for the comparison wafers (Nos. 5, 11, and 17).

Six cases of the No. 6 and No. 7 pairings are found in the following tabulation:

			Direction of Deviation	
Case No.	Hole No.	Comparison Wafer No.	Comparison Wafer	Reference Wafer
1	3	5	Outward	Inward
2	12	5	Outward	Inward

			Direction of Deviation	
Case No.	Hole No.	Comparison Wafer No.	Comparison Wafer	Reference Wafer
3	19	5	Outward	Parallel
4	7	5	Outward	Inward
5	16	5	Outward	Inward
6	16	11	Outward	Inward

The above listing shows that Wafer No. 5 (nearest S/N end) is involved in five of the six cases. It should further be noted that all of the five holes involved lie on the right side of the element, as viewed from the S/N end with Face "A" up.

We consider the significant portion of hole location data to be that component (vector) of the reported linear deviation which is normal to the peripheral surface. In Case No. 1, above, the significant portion of the deviation would be 4.5 mils. See the third line from the top in table 3 and figure 3.

Treating each of the six cases in the same manner, we have for the comparison wafers:

Case No.	Significant Portion of Outward Deviation (mils)	Case No.	Significant Portion of Outward Deviation (mils)
1	4.5	4	3.5
2	4.3	5	4.3
3	5.9	6	3.5

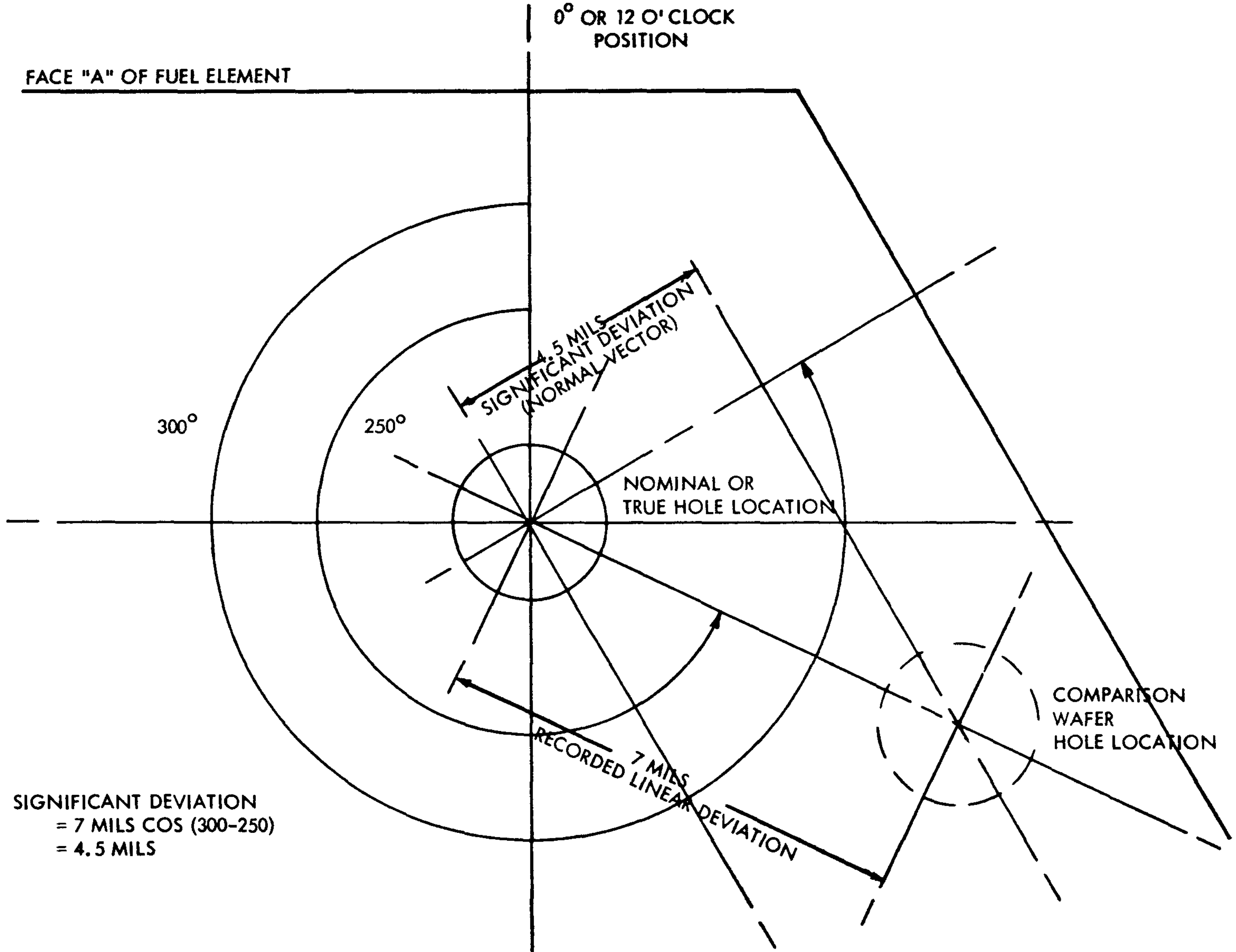

Figure 3. Significant Deviation of Outer Holes

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It can be seen from the listing above that, in each of the six cases where the hole in the comparison wafer deviated outward while its reference wafer hole deviated inward or moved parallel, the comparison hole moved less than 6 mils along a line normal to the peripheral surface.

In the remaining 24 cases listed in the table, the comparison holes moved either inward or parallel to the peripheral surface.

Table 4 below presents pertinent data for the five outer - hole/wafer combinations whose locations were reported as deviating more than 6 mils outward or 12 mils inward. (Note: An additional case, Hole No. 19, Wafer No. 5 from F/E Listing No. 12, has been included because its 6 - mil outward deviation is nearly normal to the peripheral surface.)

TABLE 4

DEVIATION FROM TRUE LOCATION

			Comparison Wafer			Reference Wafer (No. 22)			
F/E Listing No.	Hole No.	Comparison Wafer No.	Linear (mils)	Angle to Normal* (deg.)	Direction	Linear (mils)	Angle to Normal* (deg.)	Direction	RHD (mils)
18	19	11	8	75	Outward	4	125	Inward	6
12	3	5	7	50	Outward	2	130	Inward	7
12	19	5	6	10	Outward	1	150	Inward	7
1	13	5	13	170	Inward	5	180	Inward	6
3	12	22	14	90	Parallel**	--	--	--	--
24	17	22	7	90	Parallel**	--	--	--	--

* Normal to peripheral surface
** Parallel to peripheral surface
(Total Number Surveyed - 1415)

In each of the first three cases listed above, the reference wafer deviated inward while its associated comparison hole wafer deviated outward. In each of these three cases, however, the deviation vector of the comparison hole, normal to the peripheral surface, did not exceed six mils. In the fourth case, the reference hole did deviate inward, as did the comparison hole, but only by 5 mils instead of 13 mils.

SECTION 3

VARIATIONS IN IN-PROCESS NON-FUELED TIP ELEMENTS FROM NRX-A4

HOLE MISMATCH ACROSS CEMENTED JOINT

A pair of hole location wafers, each 0.058-inch thick, were taken from nine as-first machined (reamed and broached) elements immediately adjacent to the opposite sides of the cemented joint, see figure 4. The relative hole displacement (mismatch) between corresponding holes in opposing wafers was distributed as follows:

RHD (Mils)	Frequency Percent	Frequency Count
0 to 2	75	129
3	15	26
4	7	12
5	1	2
6	0.5	1
< 6	0.5	1
	Total	171

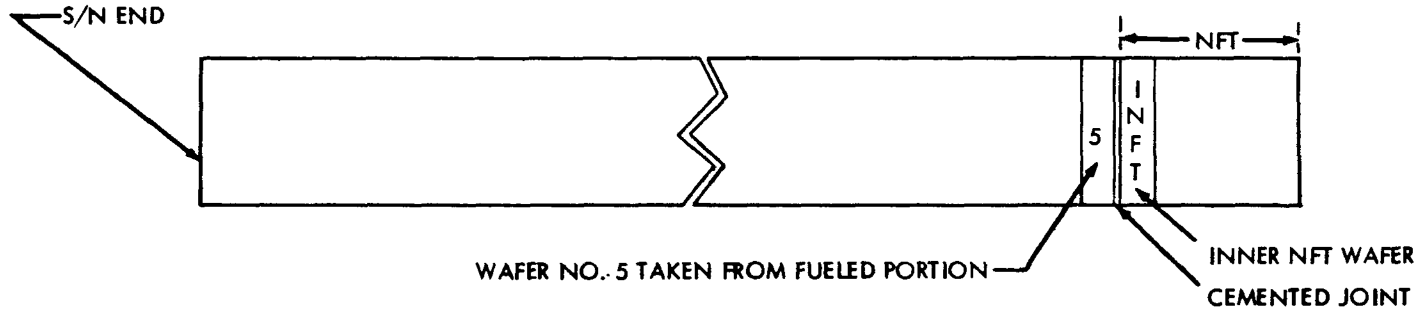
The 42 RHD values exceeding 2 mils are listed below by hole number.

Hole No.	Relative Hole Displacement - mils					Hole No.	Relative Hole Displacement - mils				
	3	4	5	6	7		3	4	5	6	7
1	1					11	3	1	1		
2		2				12	2				
3	2					13	2				
4	1	1				14	2				
5	2					15		2			
6	3	2				16	1				
7	3	1				17	1		1		1*
8						18		1		1	
9		1				19	1	1			
10	2										
* - 8.8 mils						All	26	12	2	1	1

Note: Review of the above table does not indicate any significant difference among (1) Corner, (2) Middle-of-Face, and (3) Inner Hole.

NFT - NON-FUELED TIP

INFT - WAFER TAKEN FROM INNER END OF NON-FUELED TIP



NOTES:
(1) WAFERS NO. 5 AND "INFT" TAKEN ADJACENT TO CEMENTED JOINT.
(2) THICKNESS OF EACH WAFER: 0.058-INCH
(3) WAFERS NO. 1 THROUGH 4 AND WAFER "A", SHOWN IN FIGURE 5, WERE NOT TAKEN FROM THESE EIGHT ELEMENTS.

ELEMENTS REPRESENTED:	-	S/N - 17339	S/N - 17347	S/N - 17355	* - ALL ARE CODE 89 EXCEPT
	-	S/N - 17343	S/N - 17353	S/N - 17356	S/N - 39 - 19648
	-	S/N - 17344	S/N - 17354	S/N - 19648*	

Figure 4. Cemented Joint Wafers from Non-Fueled Tip Elements

HOLE WANDER ALONG LENGTH OF ELEMENT WITH RESPECT TO NON-FUELED TIP

A total of seven hole location wafers were taken from one of the nine elements previously mentioned. Six of the wafers were comparison wafers taken at various positions along the length of the element. A quantity of 114 comparison holes were referenced to Wafer "A". See figure 5 for the location of the wafers.

Wafer "A" - Taken from the non-fuel tip stock immediately beyond the subsequently machined end of the non-fuel tip.

Wafer "INFT" - Taken from the inner end of the non-fuel tip immediately adjacent to the cemented joint.

Wafer No. 5 - Taken from the end of the fueled portion of the element immediately adjacent to the cemented joint.

Wafers No. 1 through 4 - Taken from the fueled portion of the element at 12 inch increments with respect to Wafer No. 5.

Using the location of each hole at the extreme end of the non-fueled tip in Wafer "A" as the zero reference, the wander of each hole along the length of the element was determined by comparing the hole location in each of the other six wafers described above with that found in Wafer "A".

The six Relative Hole Displacements (RHD) for each channel ranged along the element length, as follows:

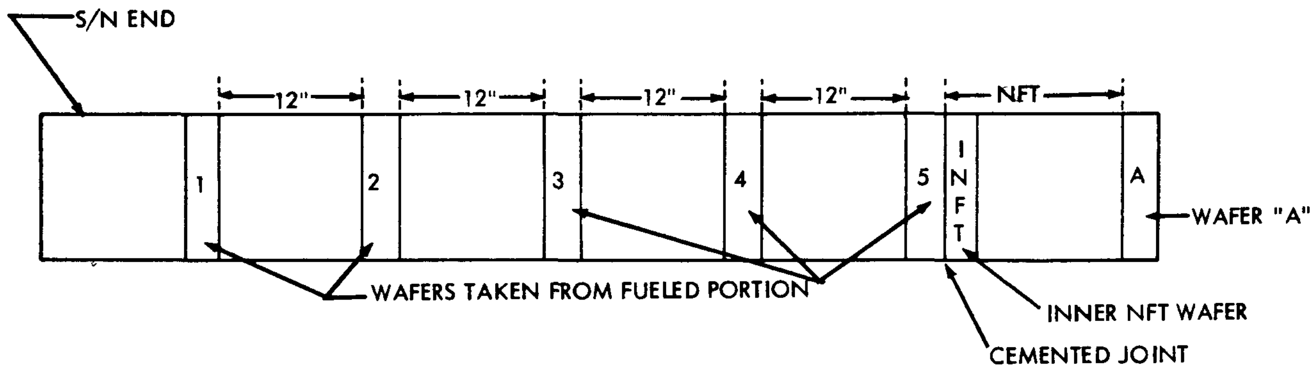
Hole	RHD - mils		Hole	RHD - mils		Hole	RHD - mils	
No.	Min.	Max.	No.	Min.	Max.	No.	Min.	Max.
1	3	4	8	1	3	14	3	7
2	1	4	9	1	8	15	1	5
3	0	6	10	1	5	16	0	6
4	1	3	11	1	5	17	3	7
5	2	5	12	1	4	18	1	8
6	1	5	13	2	3	19	1	4
7	2	5						

POSITIONS OF WAFERS

SN-39-19648

NFT - NON-FUELED TIP

INFT - WAFER TAKEN FROM INNER END OF NON-FUELED TIP



NOTES:
(1) WAFER "A" TAKEN ADJACENT TO OUTER END OF NON-FUELED TIP AS-FIRST MACHINED.
(2) WAFERS NO. 5 AND "INFT" TAKEN FROM OPPOSITE SIDES AND ADJACENT TO CEMENTED JOINT.
(3) WAFERS NO. 4 THROUGH 1 TAKEN AT 12-INCH INTERVALS AS MEASURED FROM WAFER NO. 5.
(4) THICKNESS OF EACH WAFER: 0.058-INCH.
(5) "RELATIVE HOLE DISPLACEMENT" (RHD) IN EACH OF THE SIX WAFERS DETERMINED AS REFERRED TO WAFER "A".
(6) WAFERS NO. 5 AND "INFT" ALSO USED IN SECTION 3 TO DETERMINE EXTENT OF MIS-MATCH ACROSS CEMENTED JOINT.
(7) NOT DRAWN TO SCALE.

Figure 5. Hole Location Wafers from Non-Fueled Tip Elements

Considering the individual RHD values for all channels as a pooled group, the values are distributed as follows:

Relative Hole Displacement (mils)	Frequency Count	%	Relative Hole Displacement (mils)	Frequency Count	%
0/2	40	35	6	4	4
3	26	23	7	2	2
4	28	25	8	2	2
5	12	11	Total	114	

Note from the above table that 93 percent of the RHD values do not exceed 5 mils.

SECTION 4

HOLE LOCATION WITH RESPECT TO SURFACE OF DESTRUCTIVELY TESTED NRX-A2 AND NRX-A3 ELEMENTS

The objective of this portion of the survey was to determine whether some of the outer holes in the element tended to deviate from their nominal location to a greater degree or with greater frequency than the other outer holes. Inner holes were not examined in this portion of the survey.

DESCRIPTION OF DATA

Table 5 lists the percent frequencies of angular/linear excursions of outer holes toward, or receding from, their adjacent peripheral surface(s). This table separates corner holes from middle-of-face holes. Each of these groups in turn is separated into two sub-groups, the NRX A-2 elements and the NRX A-3 elements. These sub-groups are further divided into four listings representing the four hole location wafer positions taken along the length of the element. The wafer positions are numbered from the serial numbered end of the element as 5, 11, 17, and 22.

The hole location excursion data in table 4-1 is of two types; angular and linear; they are defined as follows:

Angular - The angular directions of the excursions, with respect to the pertinent peripheral surfaces, are of five types: 1) direct $\pm$ 30 degrees, 2) semi-oblique $\pm 30^{\circ}$ / 60°, 3) $\pm 60^{\circ}$ / 90°, 4) parallel and receding (inward), and 5) true position (zero excursion).

Linear - Each of the five angular excursion groups described above has been separated into four ranges of linear excursion, as expressed in mils (0.001 inch). These ranges are: greater than 9 mils, from 7 to 9 mils, from 4 to 6 mils, and from 1 to 3 mils.

RESULTS OF CHECK

The entries listed in table 4 are the percent frequencies with which the captioned ex-

TABLE 5

ANGULAR/LINEAR EXCURSIONS OF OUTER HOLES TOWARD, OR RECEDING FROM, ADJACENT PERIPHERAL SURFACES

Hole Group	Reactor	Wafer No.	** Direct		Semi - Oblique			Full Oblique				Parallel and Receding					True Position	Total Count
			*4/6	1/3	7/9	4/6	1/3	9	7/9	4/6	1/3	9	7/9	4/6	1/3	All		
Corner	A - 2	5	4	5	1		6			12	5	1	12	32	22	67	1	102
		11	1	8		1	3			8	6		3	32	33	68	5	102
		17		4		3	3			4	6		7	28	33	64	10	96
		22	2	3		2	3	1		7	7		9	28	25	62	11	96
		All	1.8	5.0	0.2	1.5	3.8	0.2		7.8	6.0	0.2	7.8	30.0	28.0	66.0	6.8	396
	A - 3	5	3	13		1	3			5	12	1	8	10	27	46	18	78
		11	4	12		3	8		1	3	9	3	3	8	29	43	19	78
		17	4	10		1	4			5	14	1	5	6	26	38	22	77
		22	4	9			8		1		8		3	14	20	37	33	78
		All	3.5	10.9		1.3	5.4		0.6	3.2	10.6	1.3	4.5	9.6	25.6	41.0	23.0	311
Middle	A - 2	5	1	2		3	4			3	2	4	16	38	27	85	0	102
		11	2	1			2			2	2		9	40	37	86	5	102
		17		1		1	1			1	4		8	39	35	82	9	96
		22		1			1			1	3		9	43	36	83	5	96
		All	0.8	1.2		1.0	2.0			1.8	2.8	1.0	10.6	40.0	34.2	85.8	4.8	396
	A - 3	5		4			3			1	5		8	29	46	83	4	78
		11		3			5			3	6	3	3	28	42	76	8	78
		17		1		1	5				4		8	28	44	80	9	78
		22		4			5				3		4	32	44	80	9	78
		All		2.9		0.3	4.5			1.0	4.5	0.6	5.4	29.4	43.8	79.4	7.4	312
Corner	A - 2 & A - 3	5	3	8	1	1	4			9	8	1	10	23	24	58	8	180
		11	2	10		2	5		1	6	7	1	3	22	32	58	11	180
		17	2	7		2	3			5	10	1	6	19	30	56	16	173
		22	3	6		1	5	1	1	4	8		6	22	23	51	21	174
		All	2.5	7.6	0.1	1.4	4.5	0.1	0.3	5.7	8.0	0.7	6.3	21.0	26.9	54.9	13.9	707
Middle	A - 2 & A - 3	5	1	3		2	3			2	3	2	12	35	36	85	2	180
		11	1	2			3			2	4	1	6	35	40	82	6	180
		17		1		1	3			1	4		8	34	39	82	9	174
		22		2			3			1	3		7	38	40	82	7	174
		All	0.4	2.0		0.7	3.1			1.4	3.5	0.8	8.3	35.0	38.1	82.2	5.9	708

* Deviation in Mils

** Angle of Approach to Peripheral Surface
- Direct ———— ± ≥30 degrees
- Semi-Oblique ——— ± 30/60 degrees
- Full-Oblique ——— ± 60/90 degrees

cursions occurred. Referring to the last two sections at the bottom of the table, NRX A-2 and NRX A-3 combined, the following points should be noted:

1) 69 percent of the corner holes either moved parallel to or receded from the peripheral surface or maintained true position. For the middle-of-face holes, this frequency increases to 88 percent.

2) 21 percent of the corner holes deviated toward the surface by less than 4 mils as compared with only 9 percent of the middle-of-face holes.

3) 10 percent of the corner holes showed outward excursions in the range of 4 to 6 mils while middle-of-face holes showed only 2.5 percent in this range.

4) None of the four corner hole outward excursions had a vector, normal to the surface, exceeding 5 mils. Only 0.5 percent of the corner holes deviated outward by more than 6 mils while no outward deviations exceeding 6 mils were found for middle-of-face holes.

The tabulation below lists frequencies by count of direct ($\pm$ 0° / 30°) and semi-oblique ($\pm$ 30° / 60°) deviations in the 4 to 6 mil range for two groups of corner holes from all destructively tested elements. Note that these two groups represent, respectively, the left and right side of the element viewed from the serial numbered end (Face "A" upwards):

		Angle of Approach	
Corner Hole Group	Wafer No.	Direct ($\pm$ 0° / 30°)	Semi-Oblique ($\pm$ 30° / 60°)
1-8-17	5		1
	11		
	17	2	
	22		1
TOTAL		2	2
3-12-19	5	6	1
	11	4	2
	17	1	4
	22	5	2
TOTAL		16	9

Note that 25 of the 29 outward excursions found in the range of 4 to 6 mils were contributed by the right side group comprising corner holes No. 3, No. 12, and No. 19. A similar relationship, also involving the right side of the element, was found in Section 2, which concerned relative hole displacement. In that case however, only one element was involved. In this case, however, seven elements are involved with two elements each from NRX A-2 and NRX A-3 contributing 11 and 10 of the 25 cases, respectively.

It appears, therefore, that this marked tendency of right-side corner holes to deviate in the 4 to 6 mil range with greater frequency than left-side corner holes cannot readily be attributed to some special condition which might affect only a single element.