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HALLAM NUCLEAR POWER FACILITY
PREOPERATIONAL TEST INTERIM REPORT
DRY EXCESS LOADING

AI-P-1163

ATOMICS INTERNATIONAL

A DIVISION OF NORTH AMERICAN AVIATION, INC.

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PREOPERATIONAL TEST INTERIM REPORT
DRY EXCESS LOADING
AI-P-1163

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P. O. Box 309 Canoga Park, California

CONTRACT: AT(11-1)-GEN-8

February 24, 1962

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PREOPERATIONAL TEST INTERIM REPORT

DRY EXCESS LOADING, AI-P-1163

I. TEST PURPOSE

The purpose of this test was to obtain data to be used in determining the reactivity worth of the sodium in the reactor core, to obtain information on the dry temperature coefficient of reactivity and to train operators in reactor operation with a core loading of slightly greater than dry criticality.

II. TEST PERFORMANCE

The Dry Criticality Test, AI-P-1155, was completed prior to starting this test. The fuel was loaded in a specified sequence to maintain an approximate right cylinder core shape. A total of eleven fuel elements was loaded during the Dry Excess Loading. Table I shows the number and core positions of the individual loadings. Not more than 1% reactivity was loaded in one step. A plot of k_{eff} vs fuel loading, Fig. 1163-1, was maintained to assure this criterion. The excess reactivity worth of each fuel loading was determined from period measurements. The total excess reactivity loaded was determined by summing the incremental worths of each loading. Fuel loading was continued as long as adequate shutdown margin was assured. The minimum shutdown margin must be equal in magnitude to the core excess reactivity. A simple way to assure meeting this requirement was to not allow more fuel than that required to make

the reactor critical with all control rods withdrawn 50 percent.

TABLE I
FUEL LOADING SEQUENCE

Fuel Loading Increment	Number of Fuel Elements Loaded	Total Fuel Elements Loaded	Core Positions Loaded
1	1	32	C-41
2	2	34	C-51, C-63
3	2	36	C-39, C-55
4	2	38	C-67, C-43
5	2	40	C-52, C-64
6	2	42	C-40, C-54

Another precaution was that the core could not be loaded so that criticality could be achieved by full withdrawal of any one control rod with all other rods inserted. Since the central control rod has the greatest reactivity worth, it was fully withdrawn with all other control rods fully inserted after each incremental fuel loading to enforce this precaution. Inverse average multiplication vs functions of fuel loading were plotted (Fig. 1163-2, -3, -4) for this control rod configuration. By extrapolating these plots to $1/M = 0$, the fuel loading at which criticality would occur for this control rod configuration, could be determined.

The addition, inverse average multiplication vs number of fuel elements (N), Fig. 1163-2; vs square root of the number of fuel elements ($\sqrt{N}$), Fig. 1163-3; vs a factor proportional to radial buckling (B_r^2), Fig. 1163-4, was plotted after each

incremental fuel loading with all control rods fully inserted and with all control rods withdrawn 50%. From these plots, expected criticality was extrapolated for these control rod configurations.

A typical example of how the reactivity worth of each fuel increment was determined follows. With 34 fuel elements in the core, the control rod positions at criticality were gangs 1, 2, 3, and 4 fully withdrawn and gang 5 at 73.4 in. (X_1). With 36 fuel elements, the control rod positions at criticality were gangs 1, 2, 3, and 4 fully withdrawn and gang 5 at 57.75 in. (X_2). Thus, the reactivity change resulting from the addition of the 35th and 36th fuel elements was equivalent to the reactivity worth of gang 5 from X_2 to X_1 (ΔX). To find the reactivity associated with these two fuel elements it was only necessary to calibrate ΔX .

The aforementioned critical positions were with the source in its normal location (full). As pointed out in the report for the HNPF Dry Criticality Test, AI-P-1155, it was necessary to separate the source in order to minimize nuclear heating and reduce the critical flux level, thereby, giving enough range on the incore fission chambers to perform precise period measurements. With the source withdrawn 29 in. the desired range was obtained. In this particular example, 36 fuel elements, the critical rod positions with the source at 29 in. were gangs 1, 2, 3 and 4 fully withdrawn, and gang 5 at 57.45 in. Moving the source from full in to 29 inches resulted in a positive change equivalent to about 0.3 of an inch on gang 5 at this particular time. With the neutron flux at equilibrium or below point B (Point B is the minimum flux level at which the effect of the source neutrons is negligible), gang 5 was withdrawn to 57.75 in. and a long period, approximately 701 sec obtained. Next, gang 5 was inserted and the flux level dropped below point B again. Then gang 5 was withdrawn to 60.2 in. which produced a period

of approximately 48 sec. The reactivity associated with a 701 sec period is approximately 1.7 cents and with a 48 sec period 16.4 cents.

Thus from these two period measurements the reactivity worth of gang 5 from 57.75 to 60.2 in. was determined to be 14.7 cents (16.4 cents minus 1.7 cents). Now the flux level was brought to approximately point B again with gang 5 about one half in. below its last position or about 59.7 in. To accomplish this, gang 4 had to be inserted to 131 in. Now gang 5 was withdrawn to 60.2 in. again and a long period obtained. After this long period was measured the flux was dropped below point B again, and a short period obtained by pulling gang 5 to approximately 62.7 in. This technique was continued until the desired amount of gang 5 (ΔX) was calibrated and thus, the reactivity worth of the fuel increment determined. This is the differential period technique of determining reactivity. For a detailed explanation of how period data was reduced to reactivities by the "Ratio Method," see HNPF Operations Manual NAA-SR-6500 Vol. IV, section D.

After the reactivity of each fuel increment was determined, rod drop measurements were performed to estimate the total worth of the control rods. The reactor was run at a constant power level at criticality for a short time. Equilibrium was assured by watching the printouts for equal counts per unit counting interval. Total counts for a 15-sec interval were obtained at this power level. Right after a count had been printed, all rods were scrammed manually. The counter recycled (this was approximately the same time as was required for rods to drop) and counted again for 15 sec. The ratio of total counts before scramming, N_0 , and total counts after scramming, N_1 , is defined as R.

$$R = \frac{N_0}{N_1}$$

The change in k_{eff} (Δk) is obtained by using:

$$\frac{\Delta k}{\beta_{\text{eff}}} = C(R-1); \text{ or } \Delta k = \beta_{\text{eff}} (R-1)C$$

Where C is the Schulz constant, and

$$\beta_{\text{eff}} = 0.0069 \text{ for the } 3.6 \text{ } ^W/_0 \text{ U235} - 10 \text{ } ^W/_0 \text{ Mo fuel.}$$

The Schulz constant (C) was determined experimentally to be 0.673. The "book value" of C is from 0.367 to 0.417.

After 42 fuel elements were loaded and criticality attained, the loading of fuel was halted. The reactivity worth of the 41st and 42nd fuel elements was determined. Then seven (7) fuel elements were unloaded and the reactor heaters installed. To date the core has been preheated with 35 fuel elements from an ambient temperature of 71 F to 313 F. The reactor was brought critical approximately once each day and the core temperature recorded.

III. ANALYSIS AND PRESENTATION OF TEST RESULTS

The excess reactivity data taken during the Dry Excess Loading Test are summarized in Table II. A plot of the experimental data is presented in Fig. 1163-5. Also plotted are calculated $k_{\text{eff},s}$, (a) accounting for the source and, (b) not accounting for the source.

The total worth of the central control rod was 488.983 cents or 3.389 percent. A calibration plot of the central control rod is presented in Fig. 1163-6. After 42 fuel elements were loaded, criticality occurred with gangs 1, 2, 3, and 4 at 78 in. and gang 5 at 72.1 in. Since this compromised the minimum shutdown margin, the loading of fuel was halted after determining the reactivity worth of the 41st and 42nd fuel elements. Then seven fuel elements were unloaded

and the reactor heaters installed. With these heaters in place in the 35 element core, the excess reactivity was approximately 124 cents or $0.86\% \frac{\Delta k}{k}$.

TABLE II
SUMMARY OF EXCESS REACTIVITY DATA

Number of Fuel Elements (N)	Critical Rod Position (Gangs)	Incremental Worth (Cents)	Total Worth (Cents)	Reactivity (Percent)	K _{eff}
31	1,2,3,4 out, 5 at 123.9	29.062	29.062	.201	1.002
32	1,2,3,4 out, 5 at 95.4	69.391	98.423	.682	1.0068
34	1,2,3,4 out, 5 at 73.4	100.277	198.700	1.377	1.0139
36	1,2,3,4 out, 5 at 57.75	91.827	290.527	2.013	1.0205
38	1,2,3,4 out, 5 at 39.0	107.381	397.908	2.758	1.0283
40	1,2,3 out, 4 at 140.0, 5 at 23.1	69.435	467.343	3.239	1.0334
42	1,2,3,out,4 at 118.2, 5 at 1.9	74.668	542.011	3.756	1.0390

From Fig. 1163-6 it can be seen that the worth of the central control rod is asymmetrical. The first 50% of rod withdrawal is approximately 65% of the reactivity worth of the central control rod. When withdrawn 50%, only 35% of the reactivity worth of this rod remains in the core. The excess associated with 42 fuel elements is approximately 3.8%

and criticality occurred with the control rods withdrawn approximately 50%. If one assumes that all control rods had the same asymmetrical worth curve as the central control rod and, that only 35% of the reactivity worth of the control rods remained in the core upon 50% withdrawal, then it can be concluded that 35% of the reactivity worth of the rods equals $3.8\% \frac{\Delta k}{k}$ or the total worth of all control rods is $10.9\% \frac{\Delta k}{k}$.

The worth of gang 4 was calibrated from 118.2 to 156.0 inches and found to be 53¢. The same portion of gang 5 was found to be 37¢. If it is assumed that this ratio holds true over the entire length of gang 4, then gang 4 was worth 1.43 times gang 5. If it is also assumed that gang 3 equals gang 4 and that gangs 1 and 2 are worth nothing, then the total worth of the control rods is approximately $13.1\% \frac{\Delta k}{k}$.

From rod drop measurements and using the book value^k of 0.417 for Schulz's constant, the total reactivity worth of the control rods is approximately $14.5\% \frac{\Delta k}{k}$. If the experimental value of 0.673 for Schulz constant^k is used, the worth of the rods is approximately $20\% \frac{\Delta k}{k}$.

Very little can be concluded from these rod drop measurements. The outer 12 control rods of gangs 1 and 2 have little reactivity worth in the active, small, dry core but have a large effect on the number of neutrons which leak to the fission chambers. The control rods of gangs 1 and 2 shadow the detecting chambers so that a larger reduction in neutron flux occurs at the chambers than occurs in the active core. This in turn indicates that the apparent reactivity worth of the control rods is greater than is the case. The fission chambers are so located, radially, that a "representative sampling of the flux" can not be obtained when all control rods are dropped in the small core. Period data taken during this test are tabulated in Appendix A. As already mentioned

two periods (short and long) were required to calibrate each increment (ΔX) of the control rod. All other control rods were fully withdrawn (156.0 in.) during the period measurements except those where a position is specified (Appendix A). To date the core has been preheated (with 35 fuel elements) from an ambient temperature of 71 F to 313 F. A plot of reactivity change vs core temperature is presented in Fig. 1163-7.

The isothermal temperature coefficient was found to be positive throughout the range from 71 F to 313 F. In the dry core, only the fuel and moderator temperature coefficient can be considered. Apparently, the positive effect of the moderator is greater than the negative effect of the fuel in this temperature range. Table III lists the reactivity changes as a function of temperature increase.

TABLE III
REACTIVITY CHANGE VS TEMPERATURE

Average Core Temperature	Change in Temperature from Ambient (F)	Total Reactivity Change (Cents)
71	0	0
120	49	23
161	90	39
222	151	59
248	177	65
273	202	72
296	225	79
313	242	86

With 35 fuel elements in the core and at approximately 320 F, the 6 control rods of gangs 3 and 4 and gangs 1 and 2 have been intercalibrated against gang 5, the central rod. With the source separated 29 in., the control rod or gang to be intercalibrated fully inserted, and the remaining control rods except gang 5 fully withdrawn, the core was made critical with gang 5. This was done for each of the control rods of gangs 3 and 4 and for gang 1 and gang 2. With all rods fully withdrawn, criticality occurred with gang 5 at 75.025 in. Thus, when the rod, or gang, to be calibrated was fully inserted, criticality occurred with gang 5 at a new position. The reactivity worth of gang 5 from 75.025 in. to the new position is equal to the worth of the rod or gang to be calibrated as determined from data plotted in Fig. 1163-6. A summary of the intercalibration data follows in Table IV.

The ratio of reactivity worth of control rod 6 to gang 5 is .376. The first 38 in. of control rod 6 have been calibrated independently by period measurements and are worth 31.68 cents. The same 38 in. of gang 5 from the integral worth curve were worth 86.08 cents. This ratio of control rod 6 to gang 5 is .368, which indicates that the total reactivity worths listed are accurate to about 2%, not to be confused with 2% Δk over k .

Rod drop measurements have been performed on control rod 6 and gang 5. From these measurements the ratio of the reactivity worth of control rod 6 to gang 5 is .4015. This compares favorably with previously stated ratios. Assuming that gang 5 is worth 3.389% Δk over k , then Schultz constant is .4523 and the worth of all rods at the 35 fuel element loading is 12.1% Δk over k .

TABLE IV

CONTROL ROD REACTIVITY WORTHS

Control Rod or Gang Number	Core Position	Gang 5 Critical Position (Inches withdrawn)	Total Worth Cents	Total Worth Percent Delta k over k
CR6	C16	145.00	184	1.275
CR9	C24	141.10	182	1.261
CR12	C32	125.70	166	1.151
CR2	C20	139.50	181	1.254
CR3	C28	128.60	170	1.178
CR4	C36	127.70	169	1.171
Gang 2	C38, C44, C50, C56, C62, C68	105.10	124	.859
Gang 1	C78, C86, C94, C102, C110, C118	81.95	36	.249
Gang 5	C1	-----	489	3.389
Total worth of all rods		-----	1701	11.787

IV. TEST COMPLETION CRITERIA

The criteria as listed in NAA-SR-5700, Supplement 4 of the HNPF Safeguards Supplement Report are as follows:

- a) Fuel is loaded into the dry core as limited by Precaution "k". Precaution "k" states that the minimum shutdown margin is equal in magnitude to the core excess reactivity. A simple way to assure meeting this requirement is to not allow more fuel than that required to make the reactor critical with all control rods 50 percent withdrawn. Due to the slight asymmetry in control rod worth vs position, the lower 50 percent of rod travel is worth more than 50 percent of total rod worth. This asymmetry will be experimentally verified. In any event, not more than 75 fuel elements are loaded.
- b) From period measurements the total excess reactivity in the dry core is known.
- c) A plot of fuel loading vs excess reactivity for the dry core has been completed.
- d) The dry temperature coefficient of reactivity has been determined with the reactor core loaded to one fuel element above dry criticality, over the temperature range from ambient to 350 F. The data necessary to make this determination is obtained during the primary system helium purge and pre-heat. These operations afford valuable operator training in starting up and shutting down the reactor.

The above criteria a through c have been satisfied by the following:

- a) Forty two elements were loaded and criticality achieved with gangs 1, 2, 3 and 4 withdrawn 50% (78.0 inches) and gang 5 withdrawn 72.1 inches.
- b) The total excess reactivity in the dry core is known and is presented in Table II.
- c) A plot of fuel loading vs excess reactivity for the dry core has been completed (Figures 1163-1 and 1163-5).

Criterion "d" quoted above was modified by Technical Specifications allowing approximately 1% excess reactivity instead of one fuel element excess. Criterion "d" (as modified) has been partially met to date, since the core temperature has been raised to only 313 F. (Figures 1163-7 and Table III present data obtained to date).

V. EVALUATION

This report of the dry excess loading test is an interim report; and, as such, the evaluation can cover only the partial presentation of results which is contained in the previous section.

Thus far the dry excess loading test has been conducted in a very safe manner. Each of the loading increments added less than one percent reactivity to the core. The excess reactivity with the maximum loading of forty two elements was approximately 35% of the reactivity worth of the control rods.

Some of the expected results of this test have not been achieved. First a fuel loading equal to, or greater than, the expected wet critical loading of fifty elements was not achieved. Secondly, with the dry excess loading limited to forty two fuel elements it is impractical to

extrapolate the plot of inverse average multiplication, with rods down, to zero. Failure to obtain these expected results will require further reliance on theoretical calculations for determination of sodium worth.

However, the excess reactivity data obtained during the dry excess loading test correlate closely with previous calculations, thereby increasing confidence in method and assumption adopted for calculating this core.

The control rod worth measurements made during this test indicate the shut-down margins during the test were always within the limitations as specified in the technical specifications. No conclusions can be drawn at this time as to the adequacy of these control rods in an operationally loaded core.

The resolution of this question must await further testing in a more fully loaded core.

The isothermal temperature coefficient of the dry core was positive from 71 F to 313 F as anticipated. The data, as presented, do not indicate how control rod worth may have varied during rise in temperature. An indication of control rod worth variation will be made before this test is terminated.

FIG. 1163-4
HNPF DRY ZERO
POWER EXPERIMENTS

PLOT OF INVERSE AVERAGE
MULTIPLICATION
VS
FACTOR PROPORTIONAL TO
RADIAL BUCKLING (B_r^2)

WHERE $B_r^2 = \frac{K \cdot 10^5}{(R+S)^2}$

$S = 22 \text{ CM}$

$R = 16.64 \sqrt{N}$

INVERSE AVERAGE MULTIPLICATION ($\frac{1}{k_{eff}}$)

○ ALL RODS IN

□ GANG 5 FULLY WITHDRAWN; GANGS 1,2,3,4 IN

△ ALL RODS AT 50%

FIG. 1163-4
HNPF DRY ZERO
POWER EXPERIMENTS

PLOT OF INVERSE AVERAGE
MULTIPLICATION
VS
FACTOR PROPORTIONAL TO
RADIAL BUCKLING (B_r^2)

WHERE $B_r^2 = \frac{K \cdot 10^5}{(R+S)^2}$

$S = 22 \text{ CM}$

$R = 16.64 \sqrt{N}$

INVERSE AVERAGE MULTIPLICATION ($\frac{1}{k_{eff}}$)

○ ALL RODS IN

□ GANG 5 FULLY WITHDRAWN; GANGS 1,2,3,4 IN

△ ALL RODS AT 50%

FIG. 163-5 HNDP DRY ZERO POWER EXPERIMENTS

PLOT OF K_{eff}
VS
NUMBER OF FUEL
ELEMENTS

FIG. 1163-6
 HNPF DRY ZERO POWER
 EXPERIMENTS
 INTEGRAL REACTIVITY WORTH
 OF CENTRAL ROD
 CENTS VS ROD POSITION

VI. A P P E N D I X A

PERIOD DATA
(Gang 5 Movement)

Number of Fuel Elements	Gang 5 (Inches)*	Gang 4 (Inches)	Period T (Sec)	ρ ** (Cents)	$\Delta \rho$ *** (Cents)	Total $\Delta \rho$ (Cents)
31	156.0	124.4	271.78	4.139	1.477	489.017
31	148.0	124.4	440.76	2.662		
31	148.0	126.0	172.71	6.123	3.007	487.540
31	141.0	126.0	370.16	3.116		
31	141.0	129.0	108.71	8.994	4.594	484.533
31	135.0	129.0	253.68	4.400		
31	135.0	133.5	78.43	11.551	7.318	479.939
31	129.0	133.5	264.96	4.233		
31	129.0	137.1	113.21	8.709	4.685	472.621
31	126.0	137.1	280.48	4.024		
31	126.0	156.0	61.86	13.757	13.757	467.936
31	119.3	156.0	∞	00.000		
32	119.3	107.0	105.74	9.176	6.246	454.179
32	115.2	107.0	397.39	2.930		
32	115.2	110.7	55.05	14.928	11.091	447.933
32	109.7	110.7	294.83	3.827		
32	109.7	115.0	52.82	15.364	10.146	436.842
32	105.7	115.0	208.87	5.218		
32	105.7	121.5	39.26	18.698	12.182	426.696
32	101.7	121.5	161.16	6.516		
32	101.7	128.9	43.92	17.396	12.686	414.514
32	98.2	128.9	234.81	4.760		
32	98.2	137.7	66.26	13.080	8.621	401.828

* Denotes inches withdrawn

** Reactivity

*** Change in reactivity

610 620

PERIOD DATA

(Gang 5 Movement Cont'd)

Number of Fuel Elements	Gang 5 (Inches)*	Gang 4 (Inches)	Period T (Sec)	ρ ** (Cents)	$\Delta \rho$ *** (Cents)	Total $\Delta \rho$ (Cents)
32	96.0	137.7	249.92	4.459		
32	96.0	156.0	82.40	11.146	2.569	393.207
32	95.4	156.0	115.17	8.577		
34	95.4	98.3	57.25	14.525	11.323	390.638
34	92.0	98.3	360.78	3.202		
34	92.0	101.0	68.84	12.726	8.224	379.315
34	90.0	101.0	247.58	4.502		
34	90.0	103.0	75.43	11.896	5.824	371.091
34	88.6	103.0	174.28	6.072		
34	88.6	106.0	56.31	14.694	10.637	365.267
34	86.0	106.0	277.76	4.057		
34	86.0	110.5	53.87	15.154	11.113	354.630
34	83.5	110.5	279.02	4.041		
34	83.5	116.1	51.57	15.608	12.007	343.517
34	81.1	116.1	317.31	3.601		
34	81.1	123.0	55.49	14.835	10.696	331.510
34	79.0	123.0	271.08	4.139		
34	79.0	133.2	51.21	15.691	13.365	320.814
34	76.5	133.2	509.22	2.326		
34	76.5	156.0	71.42	12.401	12.401	307.449
34	74.3	156.0	∞	0.000		
36	74.3	96.4	89.36	10.477	8.602	295.048
36	72.7	96.4	639.71	1.875		

* Denotes inches withdrawn

** Reactivity

*** Change in Reactivity

PERIOD DATA
(Gang 5 Movement Cont'd)

Number of Fuel Elements	Gang 5 (Inches)*	Gang 4 (Inches)	Period T (Sec)	ρ ** (Cents)	$\Delta\rho$ *** (Cents)	Total $\Delta\rho$ (Cents)
36	72.7	102.0	36.11	19.735	13.859	286.446
36	70.2	102.0	182.15	5.876		
36	70.2	107.0	37.46	19.266	14.273	272.587
36	67.7	107.0	219.74	4.993		
36	67.7	112.3	44.17	17.311	14.985	258.314
36	65.2	112.3	508.23	2.326		
36	65.2	121.5	37.20	19.369	14.925	243.329
36	62.7	121.5	250.32	4.444		
36	62.7	131.0	44.25	17.311	15.177	228.404
36	60.2	131.0	558.00	2.134		
36	60.2	156.0	48.03	16.411	14.693	213.221
36	57.8	156.0	701.31	1.718		
38	57.8	101.0	46.44	16.763	10.943	198.534
38	56.0	101.0	183.87	5.820		
38	56.0	104.7	43.49	17.501	11.852	187.591
38	54.2	104.7	189.52	5.649		
38	54.2	108.7	47.52	16.510	13.642	175.739
38	52.0	108.7	406.30	3.868		
38	52.0	114.6	44.17	17.324	14.438	162.097
38	49.6	114.6	403.29	2.886		
38	49.6	121.2	46.22	16.816	13.593	147.659
38	47.3	121.2	358.10	3.223		
38	47.3	129.5	44.52	17.242	14.236	134.066
38	44.7	129.5	386.37	3.006		

* Denotes inches withdrawn

** Reactivity

*** Change in reactivity

PERIOD DATA

(Gang 5 Movement Cont'd)

Number of Fuel Elements	Gang 5 (Inches)*	Gang 4 (Inches)	Period T (Sec)	ρ ** (Cents)	$\Delta\rho$ *** (Cents)	Total $\Delta\rho$ (Cents)
38	44.7	140.0	52.03	15.524	11.260	119.830
38	42.5	140.0	262.73	4.264		
38	42.5	156.0	71.88	12.336	12.336	108.570
38	40.0	156.0	∞	00.000		
40	40.0	115.7	37.63	19.232	16.094	96.234
40	36.8	115.7	367.35	3.138		
40	36.8	122.5	36.50	19.604	16.620	80.140
40	33.0	122.5	389.54	2.984		
40	33.0	130.5	38.90	18.843	15.926	63.520
40	28.6	130.5	399.12	2.917		
40	28.6	140.0	46.27	16.798	15.562	47.594
40	23.1	140.0	988.55	1.236		
42	23.1	115.6	30.87	21.754	16.570	32.032
42	16.0	115.6	210.74	5.184		
42	16.0	118.1	66.76	13.020	9.992	15.462
42	9.0	118.1	383.28	3.028		
42	9.0	119.9	111.35	8.837	5.470	5.470
42	0.0	119.9	340.29	3.367		

* Denotes inches withdrawn

** Reactivity

*** Change in reactivity

PERIOD DATA

(Gang 4 Movement)

Number of Fuel Elements	Gang 4 (Inches)*	Gang 3 (Inches)	Gang 5 (Inches)	Period T (Sec)	ρ ** (Cents)	$\Delta\rho$ *** (Cents)
40	156.0	156.0	20.0	215.81	5.078	3.394
40	148.0	156.0	20.0	713.96	1.684	
40	148.0	156.0	24.6	71.01	12.433	6.920
40	140.0	156.0	24.6	195.83	5.513	
42	140.0	123.0	0.0	98.34	9.716	4.699
42	135.5	123.0	0.0	218.52	5.017	
42	135.5	125.5	0.0	88.78	10.518	8.904
42	129.5	125.5	0.0	750.17	1.614	
42	129.5	132.5	0.0	66.34	13.080	9.517
42	125.0	132.5	0.0	320.81	3.563	
42	125.0	149.0	0.0	49.88	15.977	10.495
42	121.2	149.0	0.0	197.11	5.482	
42	121.2	156.0	12.0	49.10	16.124	9.021
42	118.2	156.0	12.0	145.85	7.103	

* Denotes inches withdrawn

** Reactivity

*** Change in reactivity

NOTE: To convert reactivity in cents (ρ_{ϕ}) to reactivity in terms of % $\frac{\Delta k}{k}$ ($\rho_{\Delta k}$) use the following relationship:

$$\rho_{\phi} \times (0.00693) = \rho_{\Delta k}$$