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REACTOR PHYSICS RESULTS FROM LOW-POWER
MEASUREMENTS IN THE ADVANCED TEST REACTOR

IDAHO NUCLEAR CORPORATION
NATIONAL REACTOR TESTING STATION
IDAHO FALLS, IDAHO

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REACTOR PHYSICS RESULTS FROM LOW-POWER MEASUREMENTS IN THE ADVANCED TEST REACTOR

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ABSTRACT

Power distribution and outer shim calibration data show that the outer shim modifications following the initial ATR startup did not change the previously demonstrated ATR-ATRC nuclear correspondence. The outer shim calibration data also indicate that the small difference in excess reactivity, $\approx 0.3\%$, between ATR and ATRC is the same as observed previously.

Increasing the reactor coolant temperature caused only slight changes ($\approx$ two percent) in safety rod and shim worths. Increasing the loop coolant temperatures caused a nine percent decrease in the No. 1 neck shim set worth, a 12 percent increase in outer shim S34 worth, and only slight changes in regulating rod and safety rod worths.

Fast (>1 MeV) neutron flux and gamma heating measurements produced data with the expected axial cosine distributions. Comparison of these data with ATRC data indicates that ATR fast neutron flux and gamma heating (for positions near the fuel) can be predicted from low power ATRC measurements with 5 and 20 percent uncertainties, respectively.

Noise measurements produced a value of 25.2 ± 0.3 Hz for β/Λ , as expected. The power spectral density from zero-power measurements shows prominent resonances resulting from vibration of the in-pile experiment tubes.

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REACTOR PHYSICS RESULTS FROM LOW-POWER MEASUREMENTS IN THE ADVANCED TEST REACTOR

I. INTRODUCTION

The startup program for the Advanced Test Reactor (ATR) is an organized series of experiments or proof tests which, in conjunction with the experiment program in the ATR Critical Facility (ATRC), will demonstrate that the reactor is completely capable of operating according to the design specifications set forth in the Safety Analysis Report^[1]. The post-neutron testing program is divided into three parts -- Part IIA, Initial Fuel Loading and Zero-Power Experiments; Part IIB, Approach-to-Power Program; and Part IIC, High Power Demonstration. Part IIA of the startup program was completed in July 1967 and indicated good agreement between ATR and its nuclear duplicate, the ATRC^[2]. This report describes the results of the low power reactor physics measurements of Part IIB. The remaining tests during Part IIB (ie, lobe power monitoring system calibration, reactor stability measurements, and comprehensive thermal hydraulic tests) will be reported later.

The reactor physics experiments performed in Part IIB of the startup program were designed to strengthen the nuclear correlations established between ATR and ATRC in Part IIA and to obtain those data which are not readily obtained in the nominally zero-power experiments conducted in ATRC. Initial zero-power experiments were conducted in Part IIB to ascertain that reversal of the outer shim withdrawal direction had been properly accomplished and had produced the desired effects. (As a result of ATRC studies that indicated possible reductions in hot-spot fission rates^[3], the direction of rotation of the ATR outer shim cylinders was reversed between Parts IIA and IIB of the startup program.) Additional tests performed at zero power were investigations of the reactivity effects induced by changes in the coolant water temperature, performed in order to extrapolate the data from the ATRC measurements at ambient to those characterizing operating temperatures in ATR. During subsequent elevations of reactor power, fast neutron flux and gamma heating were measured in representative experiment positions; and a comprehensive study of reactor stability measurements was initiated using reactor noise techniques.

II. INITIAL CORE COMPOSITION AND CRITICALITY

Except where indicated, the composition of the ATR during the reactor physics measurements of Part IIB of the startup program was as listed in Table I. For orientation of the listed positions, a core diagram is shown in Figure 1. This composition differs from that of Part IIA of the startup program in two ways:

- (1) The standard pressure tube formerly in the NE flux trap has been replaced with a dummy pressure tube
- (2) The solid aluminum filler plugs in the B-holes have been replaced with standard ATR B-hole flow restrictors.

In addition to these compositional differences, the withdrawal direction of the ATR outer shim cylinders was reversed between Parts IIA and IIB. Accompanying this reversal was a 35-degree displacement of the inboard shim cylinders (eg, N2 and N3) toward the center of the core. This latter change now places all fully inserted outer shims at positions of reactivity null such that movement in either direction results in a positive reactivity change.

TABLE I

CORE COMPOSITION FOR ATR DURING REACTOR PHYSICS MEASUREMENTS OF PART II B

<u>Core Position</u>	<u>Composition</u>
NW and SE flux traps	Flow tube, standard pressure tube, and safety rod guide tube.
N, SW, and S flux traps	Flow tube, standard pressure tube, and safety rod guide tube with flux trap fillers.
NE and E flux traps	Dummy pressure tube and dummy flux trap filler.
W flux trap	Dummy gas loop (dummy flux trap filler, sleeve, and center tube).
C flux trap	Standard pressure tube and flow tube.
H-holes	All are water-filled (contain short flow restrictors), except H-3 and H-11 which contain N-16 monitor tubes and H-1, H-5, H-9, and H-13 which contain fixed hafnium shims.
A-holes	All contain standard flow restrictors, except A-10 and A-11 which contain standard flux monitor holders.
B-holes	All contain standard flow restrictors.
I-holes	All contain specimen filler plugs.

The loading of the forty 975-g U-235 fuel elements was conducted stepwise, replacing dummy fuel elements containing U-238. To predict the critical mass, the multiplication change for each step was determined from a detector in an air-filled thimble in the center flux trap pressure tube. (This thimble and detector system were subsequently used to record reactor periods during all zero-power

shim calibrations.) As shown in Table II, the shim positions at criticality for the fully loaded core were in good agreement with those obtained in ATRC for the same core. On the average, the differences between the shim positions obtained in ATR and ATRC indicate approximately 0.3\$ more excess reactivity in the ATRC. This difference is essentially the same as that noted in Part II A and is primarily due to a small difference in the hafnium plates on the outer shim cylinders^[4].

TABLE II

ATR AND ATRC SHIM POSITIONS FOR INITIAL CRITICALITY
WITH FULLY LOADED CORE

ATR Shims		ATRC Shims		Shim Position Difference	Reactivity Difference ^[a]
Outers	Necks	Outers	Necks		
79.48°	All at L.L.	75.25	All at L.L.	4.23°	+0.50\$
All at L.L.	29.02 in. ^[b]	All at L.L.	29.44 in.	0.42 in.	-0.18\$

[a] Plus (+) indicates that ATRC has more reactivity than ATR.

[b] The indicated ATR neck shim positions have been corrected to account for the fact that the ATR neck shim position indicators move from 0 to 49 when the shims move from 0 to 48 inches.

III. ZERO-POWER TEMPERATURE-INDUCED REACTIVITY EFFECTS

Several of the static reactivity effects induced in ATR by changes in water temperature were measured during the zero-power portion of the startup program. These measurements were made in order to provide estimates of the algebraic signs and magnitudes of the static temperature reactivity effects that will be encountered during routine reactor operation and to identify, insofar as possible, the mechanisms responsible for the observed behavior. These measurements are a necessary complement to computer calculations and to studies performed in the ATRC, since in both cases it has been difficult to estimate the effects of small differences existing in the models or mock-ups used.

Particular reactivity effects studied at equilibrium temperature conditions and zero power were (a) the net effect of increasing the reactor coolant water temperature and (b) the net effect of increasing the temperature of each of five water-filled experiment loops. In particular, the effect of these temperature changes on the hafnium control elements (safety rods, regulating rods, neck shims, and outer shims) was studied. Additionally, a reactivity calibration for an outer shim pair was obtained to investigate the reactivity effects of reversing the withdrawal direction of the outer shims. The results and techniques used for each of these measurements are discussed below, and whenever possible the results are compared with calculational or experimental results obtained previously.

1. REACTIVITY EFFECTS DUE TO CHANGES IN REACTOR WATER TEMPERATURE

The static reactivity effects due to increasing the ATR reactor water temperature from 80 to 150°F were measured at nominally zero power with the reactor in a nominally 5-5-5 power division^[a]. For these measurements, the water temperature in six of the experiment loops (NW, N, C, SW, S, SE)^[b] was maintained at 95°F while the inlet temperature of the reactor was increased step-wise to 101, 130, and 150°F using the heat input of the primary coolant system pumps and adjusting temperature with secondary coolant flow. At each step sufficient time was allowed to permit the components of the nearly critical reactor to reach thermal equilibrium. A regulating rod was then withdrawn to a predetermined position, and the resulting stable reactor period was recorded. The reactivity effects induced by the temperature changes were then calculated from the differences in the reactivity equivalents of these positive periods. The results of these measurements are graphically presented in Figure 2.

The reactivity values shown in Figure 2 represent the algebraic sum at each temperature of the many local positive and negative reactivity effects in the reactor, excluding those of the six loops whose temperatures were unchanged.

[a] In a 5-5-5 power division, equal power is generated in all five lobes. A lobe is defined as the eight fuel elements surrounding an inner flux trap.

[b] The water temperature in the NE, E, and W loop positions was the same as that of the reactor water, since they contain dummy in-pile tubes.

Fig. 2 Reactivity changes due to increasing the ATR reactor water temperature while maintaining the temperature in experiment loops NW, N, C, SE, S, and SW constant. All outer shims are at 78 degrees, both regulating rods are fully withdrawn, the No. 1 neck shims are at 14.75 inches, and all other neck shims are fully inserted.

As expected, the reactivity changes are small and positive. The results of these measurements may be used to adjust excess reactivity values measured in the cold ATRC to those characterizing zero-power, beginning-of-cycle conditions in ATR, where the inlet coolant temperature is typically 125°F. However, these results do not characterize reactivity changes associated with increased reactor power, where the temperature will be relatively greater in the fuel annulus (which has a strong net negative reactivity effect) than in other regions (which generally have positive reactivity effects).

The ATR reactor water temperature results are generally in good agreement with isothermal temperature measurements in ATRC. A comparison with the ATRC measurements may be obtained from these ATR data by adding an estimated reactivity effect for heating the six ATR loops that were held at constant temperature (see next section)[a]. For heating from 80 to 130°F, the ATR isothermal temperature effect is estimated to be +0.23\$ compared to 0.20\$ measured in ATRC[5].

[a] For this comparison, the C loop was assumed to respond the same as the SE loop.

2. REACTIVITY EFFECTS DUE TO CHANGES IN LOOP TEMPERATURES

The reactivity effects produced by increasing the water temperature from 95 to 450°F in each of five water-filled experiment loops were measured at nominally zero power with the reactor in a nominally 5-5-5 power division. With the reactor water temperature maintained at 150°F (which is characteristic of the mean reactor coolant temperature near full power), the water temperatures in the SW, N, S, NW, and SE loops were increased sequentially in that order. The reactivity effect for each loop was then calculated from the resultant change in the positions of the No. 1 neck shims at critical. The results of these measurements, listed in the order of measurement, are presented in Table III.

Table III

REACTIVITY EFFECTS DUE TO INCREASING EXPERIMENT LOOP TEMPERATURES [a]

Experiment Loop	Reactivity Effect of Increasing Loop Water Temperature From 95 to 450°F [b]
SW	0.190 ± 0.011\$
N	0.191 ± 0.011\$
S	0.184 ± 0.010\$
NW	0.144 ± 0.009\$
SE	0.125 ± 0.009\$

[a] All outer shims at approximately 65 degrees, both regulating rods withdrawn, No. 1 neck shims partially withdrawn, and all other neck shims inserted.

[b] The indicated errors are estimates of one standard deviation.

As expected from earlier measurements made in the ATRC [6], all of the reactivity effects in Table III are positive. As also expected from the ATRC studies, the average of the values obtained for the SW, N, and S loops is greater than that obtained for the NW and SE loops, due to the absence of flux trap fillers in the latter and the consequent decrease of neutron importance at the center of these flux traps. However, the single-loop studies performed in ATRC could not have been expected to predict the progressively decreasing values among the values pertaining to either the loops with fillers or loops without fillers. The progressive reactivity decrease with the sequential increase in loop temperatures suggests a progressively increasing second-order flux shift with an associated negative reactivity effect. As described in the next section, such a flux shift appears probable, as evidenced by shim worth changes which also resulted from the increased temperatures of the five loops.

The reactivity effects shown in Table III should be considered to be maximum effects and will be larger in every case than those actually observed during routine ATR operation. During such operation a loop will not be operated at these high temperatures unless it contains an experiment train. Since the observed effects are primarily due to water density changes, the reactivity effect due to water temperature will be reduced approximately in proportion to the amount of water displaced by the experiment. Additionally, since the loop in the C flux trap (whose temperature was not raised during this experiment) will usually also be in operation, the observed flux shifts will probably be reduced. Thus, the values pertaining to a loop during routine operation will be best predicted by use of the measured value for the SW loop when flux trap fillers are used and the NW loop when flux trap fillers are not used. These values should then be reduced to account for the volume of the experiment added.

The reactivity effect measured in ATR for the SW loop, $+0.190 \pm 0.011\%$, agrees well with a value of $+0.189 \pm 0.008\%$ obtained for the ATRC Hot Loop^[7] in the NE flux trap with flux trap fillers and adjusted by the ratios of squares of the measured flux values in both loop positions. Both values were obtained for a 95 to 450°F temperature increase. The agreement is sufficient to expect that the relative functional temperature behavior measured in the ATRC Hot Loop over the range of 80 to 500°F will, when normalized to account for differences in flux trap composition, be applicable to all ATR loops.

3. SHIM AND ROD REACTIVITY EFFECTS

Temperature-induced changes in the reactivity worths of the safety rods, regulating rods, neck shims, and outer shims were measured at nominally zero power. These changes were determined from shim and rod reactivity worths measured while the reactor was in thermal equilibrium with one of three water temperature states^[a]: (a) all water in the reactor at ambient, ie 75°F, (b) reactor water at 150°F, five water-filled experiment loops at 95°F, and (c) reactor water at 150°F, five water-filled experiment loops at 450°F. Although these measurements will be individually discussed below, the results obtained, as summarized in Table IV, were similar, as expected, since all shims and rods utilize hafnium absorbers.

The results shown in Table IV indicate that increasing the temperature of the reactor water from ambient to 150°F resulted in a small (approximately two percent) increase in the reactivity worths of all shims and rods. This result suggests that the effect of an increase in the neutron temperature has tended, if only slightly, to dominate the effect of the concurrent decrease in hafnium density. However, when the water temperatures of the five experiment loops (NW, N, S, SW, SE) were increased to 450°F, changes in the reactivity worths of the shims and rods of up to 12 percent were measured. These reactivity changes suggest an apparently general shift in the relative neutron distribution.

[a] Throughout, the C loop was at 80°F and the NE, E, and W loops were at the same temperature as the reactor water.

TABLE IV

REACTIVITY WORTHS FOR THE ATR SAFETY RODS, REGULATING RODS,
NECK SHIMS, AND OUTER SHIMS WITH DIFFERENT REACTOR
AND LOOP TEMPERATURE CONDITIONS

Rods or Shims	Reactivity Worth (Dollars) ^[a]		
	Reactor at 70°F Loops ^[b] at 80°F	Reactor at 150°F Loops ^[b] at 95°F	Reactor at 150°F Loops ^[b] at 450°F
Safety Rods ^[c]	12.9 ± 0.1 12.9 ± 0.1 ^[d]	---	13.1 ± 0.1 13.2 ± 0.1 ^[d]
Regulating Rods ^[e]			
SW	0.515 ± 0.010	0.520 ± 0.009	0.505 ± 0.009
NE	0.555 ± 0.010	0.572 ± 0.009	0.507 ± 0.009
No. 1 Neck Shims ^[f]	1.67 ± 0.03	1.70 ± 0.03	1.55 ± 0.03
Outer Shim S34 ^[f]	1.66 ± 0.03	1.71 ± 0.03	1.92 ± 0.03

[a] The indicated errors represent estimates for one standard deviation of the measured values.

[b] The loops at temperature were NW, N, SW, SE, S. The C loop remained at 80°F. The NE, E, and W loops were always at the same temperature as the reactor water.

[c] All neck shims inserted; both regulating rods withdrawn; all outer shims at 76 degrees.

[d] To obtain an estimate of reproducibility, the measurement at each temperature was performed twice. Additionally, this value, obtained for shutdown worth using the rod drop technique, is sensitive to detector position. A shutdown worth of $10.0 \pm 0.4\%$ was previously obtained using the pulsed-neutron technique.

[e] All outer shims inserted; neck shim sets Nos. 2, 3, 5, and 6 fully withdrawn; regulating rods and No. 1 neck shim set partially withdrawn; NW4 and SE4 shims inserted.

[f] All outer shims at 55 degrees; No. 2 neck shim set fully withdrawn; neck shim sets Nos. 6 and 5 and NW4 and SE4 fully inserted; regulating rods fully withdrawn; neck shim sets No. 1 and 3 partially withdrawn.

This shift resulted from the reduced neutron absorption in the loops caused by increased loop temperatures and apparently overshadowed any reactivity effects that might have resulted from density or neutron temperature changes. When compared with the neutron distribution persisting prior to increasing the loop temperatures, the neutron density appears to have been depressed in the NE and C lobes (which contain no loops at high temperature), unchanged within the flux traps of the NW, SW, and SE lobes, and enhanced in the reflector surrounding these same three lobes. However, such a shift will be reduced during routine ATR operation. That is, (a) the C loop will usually also be at high temperature, tending to increase the neutron density in the C lobe and thus reduce the

shift toward the reflector and (b) all loops at high temperature will contain experiments and will thereby reduce the loop reactivity effects responsible for the shift.

3.1 Safety Rod Reactivity

The shutdown reactivity of the five safety rods was measured with ambient water temperature and again with the reactor water at 150°F and five water-filled experiment loops (NW, N, S, SW, SE) at 450°F. Both of these reactivity measurements were performed twice using the modified rod drop technique[8] in order to obtain an estimate of the reproducibility of the measurements. The results of these four measurements are presented in Table IV.

The excellent reproducibility of the safety rod shutdown reactivity measurements, as indicated in Table IV, suggests that the small (approximately two percent) reactivity difference between the measurements made at the two temperature conditions is indeed real, although not significant for ATR operation. The measured difference may be totally due to either the temperature increase of the reactor water or to the loop water, or it may represent the net effect of changes caused by both temperature increases. However, since the reactivity differences obtained for the neck shims, regulating rods, and outer shims following increased reactor water temperature are on this same order, it might be reasonable to speculate that this two percent safety rod increase is due only to the increased reactor water temperature.

3.2 Regulating Rod Reactivity Effects

The reactivity worths of the regulating rods were measured with ambient water temperature, with the reactor water temperature increased to 150°F, and with the temperatures of five water-filled experiment loops (SW, N, S, SE, NW) increased to 450°F. These worths were calculated from measured reactivities corresponding to incremental rod position changes and an extrapolation to total worth using a normalized position-worth curve obtained in an earlier phase of the ATR startup program[9]. The resultant total worth values for each rod for each of the three temperature conditions are summarized in Table IV.

As shown in Table IV, an increase in the reactor temperature to 150°F increased the regulating rod worths by approximately two percent. Even though the estimated experimental errors are on this same order, the consistency of the results and the agreement with similar results from other shims suggest that the observed changes are real.

When the temperatures of the five loops were increased to 450°F, the worths of both regulating rods decreased, NE4 decreasing more than SW4. Assuming that the reactivity change observed is proportional to the change in the square of the surrounding flux, the measured reactivity changes suggest a decrease of six percent in the flux about NE4 and of two percent in the flux about SW4. However, these reduced reactivity worths are not sufficient to alter the effectiveness of the rods for reactor control.

3.3 Neck Shim Reactivity Effects

The reactivity worth of the No. 1 neck shim was measured with ambient water temperature, with the reactor water temperature increased to 150°F, and with the temperatures of five water-filled experiment loops (SW, N, S, SE, NW) increased to 450°F. These total worths were obtained by summing

measured reactivity changes associated with incremental rod motions, which included the full range of travel of the neck shim set. The results of these measurements are summarized in Table IV.

As shown in Table IV, raising the reactor water temperature to 150°F apparently increased the worth of this neck shim set by about two percent. The direction and magnitude of this change are more certain than would be inferred from the errors indicated for the reactivity values in Table IV. That is, this small increase in worth was noted in all of the incremental measurements obtained for this shim set whereas the error associated with the total worth is the cumulative error.

The decrease of nine percent of the total worth which was associated with increasing the five loop temperatures to 450°F suggests an average decrease of about five percent in the flux surrounding these shims. The results of the regulating rod measurements suggest that the decrease for NE1 was probably greater than the decrease for the other No. 1 neck shims.

3.4 Outer Shim Reactivity Effects

The reactivity worth of outer shim S34 was measured with ambient water temperature, with the reactor water temperature increased to 150°F, and with the temperatures of five water-filled experiment loops (SW, N, S, SE, NW) increased to 450°F. The total worth in each case was obtained by summing measured reactivity changes associated with incremental rod motions over the full range of travel of the shim. The worths obtained are presented in Table IV; and measured integral calibration curves, normalized to the same total worth, are shown in Figure 3.

Fig. 3 Outer shim S34 calibration curves for three reactor water temperature conditions.

As shown in Table IV, the worth of outer shim S34 increased by approximately three percent when the reactor water temperature was increased to 150°F. Again, as in the case of the neck shims, this change is more certain than the cumulative total error indicated in Table IV would suggest in that it was observed in all the measured increments. When the temperatures of the five

loops (one of which was the adjacent SW loop) were increased to 450°F, the total worth of S34 increased by 12 percent, suggesting a five percent increase in the surrounding neutron flux. This increase is most probably due to the local effect of increasing the temperature of the SW loop. As such, it is also probable that the reactivity worths of outer shim pairs W12, W34, N12, S12, and E34 were similarly increased, since they too are in geometrically similar positions with respect to experiment loops at 450°F.

Because the outer shims are located within the reflector, they would be sensitive to any significant temperature-induced change in the neutron distribution within the reflector. Consequently, detailed calibration curves were obtained at each of the three temperature conditions examined. As shown in Figure 3, there were no detectable temperature-induced changes in the shape of these curves, indicating no significant changes in the surrounding neutron distribution.

4. EFFECT OF OUTER SHIM REVERSAL

Between Parts IIA and IIB of the ATR startup program, the withdrawal direction of the ATR outer shims was reversed. In addition to this change, the positions of the inboard shims (eg, N2 and N3) were rotated to a position such that a reactivity null would occur at zero degrees. ATRC measurements of the effect of these changes indicated that a slight change in the shape of the outer shim calibration curves would occur and that the total worths would remain unchanged^[10]. During Part IIA small differences between the curves obtained in ATRC and ATR were detected and were hypothesized to be due to small hafnium extensions present only on the ATR outer shims^[11]. If these extensions are indeed responsible, it was predicted that the shim reversal would be accompanied by better ATR-ATRC agreement in the shape of the calibration curves but that a three percent difference in total worth would remain.

In order to compare the effects of the outer shim reversal with those effects predicted, outer shim S34 was calibrated in detail with the same ambient temperature conditions characterizing Part II A of the startup program. Figure 4 shows comparisons of the curves obtained in both ATR and ATRC before and after the withdrawal reversal^[a], and indicates that the expected changes in shape occurred and that there were no detectable changes in total worth. A comparison of the curves obtained in ATR and ATRC after reversal is shown in Figure 5. These curves indicate, as also predicted, that there is now better agreement in the shape of the calibration curves and that a three percent difference in magnitude remains, as observed in Part II A.

[a] During Part IIA, and in ATRC, outer shim N34 was calibrated in detail and a total worth was obtained for S34. The N34 curve, normalized to the S34 total worth, has been used for the comparisons described.

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Fig. 4 Outer shim S34 calibration curves in ATR and in ATRC before and after reversal of the outer shim withdrawal direction.

Fig. 5 Comparison of the ATR and ATRC outer shim S34 calibration curves after reversal of the outer shim withdrawal direction.

IV. POWER DISTRIBUTION COMPARISONS

Detailed power distribution data were obtained in ATR for comparison with similar ATRC data. An earlier comparison obtained from Part II A startup data shows that the ATR-ATRC nuclear correspondence is good^[2]. However, because of the repositioning of the outer shims and the reversal of the withdrawal direction, the power distribution comparison was repeated. These data, obtained after the outer shim reversal, show that the ATR-ATRC nuclear correspondence is still good.

The power distribution measurements in ATR and ATRC were obtained with essentially identical core compositions, power levels (nominally 300 W), and temperatures (ambient). With the exception of the fuel elements, the ATR core composition for the measurement was as shown in Table I. Because of a modification of the upper end box of the fuel elements for Part II B that restricts access to the water channels, these elements were not used in the measurement. Instead, a core having essentially the same boron distribution was selected from fuel elements not yet modified. The boron content of each fuel element in this interim core, which was used in the initial fuel loading and the power distribution measurements (in both ATR and ATRC), is shown in Table V.

Comparison of the ATR and ATRC power distributions normalized to 250 W in Figure 6 shows that, on the average, element powers agree within about one percent, with the largest difference being only four percent. With the exception of fuel positions 5, 6, 7, and 8, those positions where differences are greater than the estimated standard deviation of 1.5 percent are generally scattered and the differences are probably not real. The differences greater than 1.5 percent in the NE lobe (fuel positions 5 through 8) appear to be due to a slight difference in shim positions between the ATR and ATRC irradiations. Near the beginning of the ATR irradiation, there was an inadvertent regulating rod insertion and consequent outer shim movement which were difficult to duplicate in the ATRC irradiation. ATRC irradiations indicate that at least part of the difference in the NE lobe is caused by this difficulty. It is believed that any remaining difference is not large enough to be significant.

Point-wise power distribution comparisons at 17 locations in the horizontal midplane of each fuel element are available from the data obtained to calculate the power distributions. However, additional fission-rate monitors were included in fuel positions 26 through 35 (an arbitrarily selected quarter core) to obtain data at the 23 points shown in Figure 7. These detailed ATR-ATRC data normalized to 250 W of total core power are compared in Figures 8 through 17 in approximate cross-sectional fuel element outlines. The agreement in the point-wise power distribution between ATR and ATRC is very good with only a few exceptions. (The standard deviation of these measurements is about three percent near the fuel element center and about six percent near the sideplate except in water channel 19 where poor monitor positioning results in four and seven percent differences.) The comparisons for fuel positions 33 and 35 (Figures 15 and 17) show slightly more difference than the other positions. However, renormalization of these data by element power improves the comparison considerably. This apparent bias also occurs in the point-wise comparisons for fuel positions 5, 6, 23, and 24 (not shown here). No cause has been found as yet for this slight anomaly.

TABLE V

FUEL ELEMENT BORON CONTENTS FOR INTERIM CORE LOADING

<u>Fuel Position</u>	<u>Element Number</u>	<u>Boron Content (g)</u>	<u>Fuel Position</u>	<u>Element Number</u>	<u>Boron Content (g)</u>
1	A59C	4.20	21	A96C	4.27
2	A83C	4.24	22	A81C	4.22
3	A154C	4.08	23	A212C	4.07
4	A47C	4.16	24	A180C	4.24
5	A122C	4.18	25	A143C	4.16
6	A125C	4.28	26	A183C	4.17
7	A78C	4.17	27	A126C	4.11
8	A51C	4.16	28	A49C	4.15
9	A84C	4.26	29	A198C	4.08
10	A97C	4.24	30	A50C	4.09
11	A99C	4.27	31	A77C	4.20
12	A57C	4.30	32	A165C	4.16
13	A54C	4.19	33	A209C	4.08
14	A182C	4.19	34	A145C	4.16
15	A171C	4.23	35	A179C	4.15
16	A73C	4.22	36	A52C	4.05
17	A89C	4.23	37	A112C	4.10
18	A91C	4.22	38	A210C	4.08
19	A204C	4.36	39	A141C	4.15
20	A76C	4.22	40	A119C	4.15

Fig. 6 Core power distribution in watts normalized to 250 W for ATRC (top numbers) and ATR (middle numbers). Also shown are the percent differences from ATR to ATRC powers (bottom numbers). Lobe powers shown in the fluxtraps have the same order. Both regulating rods were withdrawn, all neck shims were inserted, and all outer shims were withdrawn to 77.7 degrees in ATRC and 80.8 degrees in ATR.

<u>Monitor No.</u>	<u>Inches From C</u>	<u>Monitor No.</u>	<u>Inches From C</u>
1	1.73	13	0.08
2	0.93	14	0.69
3	0.12	15	1.29
4	0.93	16	1.10
5	1.73	17	0.59
6	1.57	18	0.08
7	0.83	19	0.59
8	0.08	20	1.10
9	0.83	21	0.85
10	1.57	22	0.08
11	1.29	23	0.85
12	0.69		

Fig. 7 Cross-sectional diagram of an ATR-ATRC fuel element showing positions of monitors used to determine the specific power distribution.

0.1395E-01 0.1428E-01 =2.	0.1087E-01 0.1074E-01 1.	0.9459E-02 0.9479E-02 =0.	0.8347E-02 0.8076E-02 3.	0.1170E-01 0.1128E-01 4.
0.1184E-01 0.1192E-01 =1.	0.6839E-02 0.6923E-02 =1.	0.6453E-02 0.6515E-02 =1.	0.6613E-02 0.6571E-02 1.	0.1098E-01 0.1058E-01 4.
0.8685E-02 0.9204E-02 =6.	0.6231E-02 0.6519E-02 =4.	0.6087E-02 0.6223E-02 =2.	0.6438E-02 0.6376E-02 1.	0.9622E-02 0.9169E-02 5.
0.1105E-01 0.1171E-01 =6.	0.7571E-02 0.7690E-02 =2.	0.6992E-02 0.7255E-02 =4.	0.7491E-02 0.7580E-02 =1.	0.1120E-01 0.1133E-01 =1.
0.1331E-01 0.1373E-01 =3.	0.1089E-01 0.1069E-01 2.	0.1401E-01 0.1365E-01 3.		

Fig. 8 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 26.

0,1215E-01 0,1180E-01 3.	0,1083E-01 0,1027E-01 5.	0,1145E-01 0,1076E-01 6.	0,1253E-01 0,1241E-01 1.	0,1825E-01 0,1708E-01 7.
0,1062E-01 0,1041E-01 2.	0,7098E-02 0,7312E-02 -3.	0,7233E-02 0,7324E-02 -1.	0,8130E-02 0,8212E-02 -1.	0,1436E-01 0,1415E-01 2.
0,8800E-02 0,8792E-02 0.	0,6752E-02	0,6637E-02 0,6734E-02 -1.	0,7472E-02 0,7583E-02 -1.	0,1161E-01
0,1139E-01 0,1149E-01 -1.	0,7876E-02 0,7937E-02 -1.	0,7754E-02 0,7504E-02 3.	0,8402E-02 0,8263E-02 2.	0,1373E-01 0,1297E-01 6.
0,1533E-01 0,1418E-01 8.		0,1147E-01 0,1077E-01 6.	0,1519E-01 0,1459E-01 4.	

Fig. 9 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 27.

0.1766E-01	0.1380E-01	0.1344E-01	0.1367E-01	0.1637E-01
0.1785E-01	0.1349E-01	0.1357E-01	0.1321E-01	0.1601E-01
=1.	2.	=1.	4.	2.
★				
0.1426E-01	0.8636E-02	0.8444E-02	0.8933E-02	0.1410E-01
0.1424E-01	0.8647E-02	0.8484E-02	0.8940E-02	0.1463E-01
0.	=0.	=0.	=0.	=4.
★				
0.1049E-01	0.7895E-02	0.7721E-02	0.8242E-02	0.1085E-01
0.1058E-01	0.7951E-02	0.7824E-02	0.8270E-02	0.1126E-01
=1.	=1.	=1.	=0.	=4.
★				
0.1290E-01	0.8771E-02	0.8602E-02	0.9208E-02	0.1364E-01
0.1264E-01	0.8767E-02	0.8719E-02	0.9135E-02	0.1380E-01
2.	0.	=1.	1.	=1.
★				
0.1587E-01	0.1195E-01	0.1608E-01	★	
0.1490E-01	0.1163E-01	0.1490E-01	★	
7.	3.	8.	★	

Fig. 10 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 28.

0.1062E-01 0.1141E-01 7.	0.8625E-02 0.8952E-02 4.	0.1019E-01 0.1052E-01 3.	0.1218E-01 0.1206E-01 1.	0.1629E-01 0.1644E-01 1.
0.1200E-01 0.1204E-01 0.	0.7701E-02 0.8303E-02 7.	0.8121E-02 0.8383E-02 3.	0.8857E-02 0.8923E-02 1.	0.1363E-01 0.1386E-01 2.
0.1142E-01 0.1117E-01 2.	0.7809E-02 0.8128E-02 4.	0.7586E-02 0.8013E-02 5.	0.8265E-02 0.8409E-02 2.	0.1158E-01 0.1194E-01 3.
0.1477E-01 0.1454E-01 2.	0.9621E-02 0.9688E-02 1.	0.9055E-02 0.9219E-02 2.	0.9549E-02 0.9573E-02 0.	0.1399E-01 0.1388E-01 1.
0.1706E-01 0.1676E-01 2.		0.1295E-01 0.1307E-01 1.	0.1678E-01 0.1711E-01 2.	

Fig. 11 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 29.

0.1447E-01	0.1081E-01 0.1092E-01 =1.	0.9315E-02	0.7578E-02 0.7881E-02 =4.	0.1072E-01 0.1175E-01 =9.
0.1318E-01 0.1284E-01 3.	0.8641E-02 0.8530E-02 1.	0.7815E-02 0.7944E-02 =2.	0.7649E-02 0.7746E-02 =1.	0.1194E-01 0.1193E-01 0.
0.1125E-01 0.1132E-01 =1.	0.8346E-02 0.8228E-02 1.	0.7756E-02 0.7888E-02 =2.	0.8085E-02 0.8140E-02 =1.	0.1131E-01 0.1121E-01 1.
0.1480E-01 0.1434E-01 3.	0.9639E-02 0.9561E-02 1.	0.8790E-02 0.8985E-02 =2.	0.9354E-02 0.9220E-02 1.	0.1288E-01 0.1271E-01 1.
0.1675E-01 0.1655E-01 1.		0.1250E-01 0.1296E-01 =4.	0.1701E-01 0.1664E-01 2.	

Fig. 12 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 30.

0,8448E-02 0,8213E-02 3.	0,5998E-02 0,7286E-02 4.	0,8393E-02 0,8516E-02 1.	0,1084E-01 0,1066E-01 2.	0,1428E-01 0,1399E-01 2.
0,1087E-01 0,1097E-01 1.	0,7239E-02 0,7313E-02 1.	0,7457E-02 0,7527E-02 1.	0,8266E-02 0,8327E-02 1.	0,1274E-01 0,1269E-01 0.
0,1028E-01 0,1051E-01 2.	0,7957E-02 0,7935E-02 0.	0,7603E-02 0,7772E-02 2.	0,8113E-02 0,8158E-02 1.	0,1115E-01 0,1091E-01 2.
0,1375E-01 0,1391E-01 1.	0,9245E-02 0,9409E-02 2.	0,8871E-02 0,8799E-02 1.	0,9284E-02 0,9224E-02 1.	0,1384E-01 0,1358E-01 2.
0,1604E-01 0,1618E-01 1.		0,1270E-01 0,1290E-01 2.		0,1548E-01 0,1567E-01 1.

Fig. 13 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 31.

0,1709E-01 0,1690E-01 1.	0,1252E-01 0,1302E-01 -4.	0,1073E-01 0,1101E-01 -3.	0,7964E-02 0,8104E-02 -2.	0,9203E-02 0,9456E-02 -3.
0,1397E-01 0,1432E-01 -2.	0,8444E-02 0,8465E-02 -0.	0,7693E-02 0,7808E-02 -1.	0,7336E-02 0,7481E-02 -2.	0,1097E-01 0,1093E-01 0.
0,1053E-01 0,1078E-01 -2.	0,7766E-02 0,7984E-02 -3.	0,7497E-02 0,7678E-02 -2.	0,7707E-02 0,7751E-02 -1.	0,1074E-01 0,1071E-01 0.
0,1345E-01 0,1326E-01 1.	0,8899E-02 0,8916E-02 -0.	0,8409E-02 0,8357E-02 1.	0,9085E-02 0,9103E-02 -0.	0,1328E-01 0,1387E-01 -4.
0,1693E-01 0,1651E-01 3.		0,1218E-01 0,1229E-01 -1.	0,1684E-01 0,1647E-01 2.	

Fig. 14 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 32.

0.1627E-01 0.1702E-01 -4,	0.1297E-01 0.1313E-01 -1,	0.1268E-01 0.1275E-01 -1,	0.1244E-01 0.1270E-01 -2,	0.1491E-01 0.1585E-01 -6,
0.1402E-01 0.1450E-01 -3,	0.8243E-02 0.8398E-02 -2,	0.7834E-02 0.8003E-02 -2,	0.7646E-02 0.7862E-02 -3,	0.1237E-01 0.1267E-01 -2,
0.1068E-01 0.1109E-01 -4,	0.7488E-02 0.7753E-02 -3,	0.6959E-02 0.7213E-02 -4,	0.6850E-02 0.7459E-02 -8,	0.9332E-02 0.1018E-01 -8,
0.1385E-01 0.1410E-01 -2,	0.8548E-02 0.8888E-02 -4,	0.7769E-02 0.8303E-02 -6,	0.7953E-02 0.8263E-02 -4,	0.1245E-01 0.1277E-01 -3,
0.1776E-01 0.1746E-01 2,		0.1268E-01 0.1313E-01 -3,		0.1597E-01 0.1665E-01 -4,

Fig. 15 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 33.

0,1531E+01 0,1453E+01 5,	0,1082E+01 0,1106E+01 2,	0,1023E+01 0,1000E+01 2,	0,9182E-02 0,8925E-02 3,	0,1022E+01 0,1006E+01 2,
0,1216E+01 0,1274E+01 5,	0,7010E-02 0,7072E-02 -1,	0,6288E-02 0,6452E-02 -3,	0,6116E-02 0,6193E-02 -1,	0,9463E-02 0,9185E-02 3,
0,9589E+02 0,9982E+02 -4,	0,6454E-02 0,6667E-02 -3,	0,5937E-02 0,5989E-02 -1,	0,5978E-02 0,6122E-02 -2,	0,8715E-02 0,8620E-02 1,
0,1218E+01 0,1290E+01 -6,	0,7726E-02 0,7823E-02 -1,	0,6954E-02 0,7036E-02 -1,	0,7220E-02 0,7255E-02 -0,	0,1073E+01 0,1088E+01 -1,
0,1562E+01 0,1544E+01 1,		0,1135E+01 0,1143E+01 -1,	0,1498E+01 0,1444E+01 4,	

Fig. 16 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 34.

0,9485E-02 0,8876E-02 7,	0,6885E-02 0,7139E-02 -4,	0,7559E-02 0,7742E-02 -2,	0,9123E-02 0,9406E-02 -3,	0,1302E-01 0,1330E-01 -2,
0,9134E-02 0,9024E-02 1,	0,5381E-02 0,5515E-02 -2,	0,5236E-02 0,5504E-02 -5,	0,5983E-02 0,6078E-02 -2,	0,1033E-01 0,1091E-01 -5,
0,7662E-02 0,7758E-02 -1,	0,5396E-02 0,5599E-02 -4,	0,5293E-02 0,5263E-02 1,	0,5476E-02 0,5802E-02 -6,	0,8559E-02 0,9021E-02 -5,
0,1143E-01 0,1111E-01 3,	0,7020E-02 0,6930E-02 1,	0,6356E-02 0,6450E-02 -1,	0,6650E-02 0,7142E-02 -7,	0,1002E-01 0,1094E-01 -8,
0,1464E-01 0,1439E-01 2,		0,1049E-01 0,1075E-01 -2,		0,1377E-01 0,1419E-01 -3,

Fig. 17 ATRC (top number) and ATR (middle number) specific powers in watts per gram and the percent difference from ATR to ATRC for position 35.

A more graphic comparison of the fission-rate distributions in water channel 19 of fuel positions 26 through 35 is shown in Figures 18 through 27. These figures (obtained from data in addition to that from Figures 8 through 17) readily show that with only minor deviations the water channel 19 distributions in any one position are essentially the same in ATR and ATRC. Most apparent differences are accounted for by considering the ± 0.06 -inch positioning uncertainty. (The uncertainty is not in the relative position of each data point shown in Figures 18 through 27, but in the location of the left-hand group of five data points and in the right-hand group of four data points.) The radial fission-rate distributions near the fuel element center have been included in Figures 28 through 37 for these same fuel positions. Only minor differences are indicated by these figures.

Fig. 18 Azimuthal specific power distributions in water channel 19 of fuel position 26.

Fig. 19 Azimuthal specific power distributions in water channel 19 of fuel position 27.

Fig. 20 Azimuthal specific power distributions in water channel 19 of fuel position 28.

Fig. 21 Azimuthal specific power distributions in water channel 19 of fuel position 29.

Fig. 22 Azimuthal specific power distributions in water channel 19 of fuel position 30.

Fig. 23 Azimuthal specific power distributions in water channel 19 of fuel position 31.

Fig. 24 Azimuthal specific power distributions in water channel 19 of fuel position 32.

Fig. 25 Azimuthal specific power distributions in water channel 19 of fuel position 33.

Fig. 26 Azimuthal specific power distributions in water channel 19 of fuel position 34.

Fig. 27 Azimuthal specific power distributions in water channel 19 of fuel position 35.

Fig. 28 Radial specific power distributions through the fuel element at core midplane in fuel position 26.

Fig. 29 Radial specific power distributions through the fuel element at core midplane in fuel position 27.

Fig. 30 Radial specific power distributions through the fuel element at core midplane in fuel position 28.

Fig. 31 Radial specific power distributions through the fuel element at core midplane in fuel position 29.

Fig. 32 Radial specific power distributions through the fuel element at core midplane in fuel position 30.

Fig. 33 Radial specific power distributions through the fuel element at core midplane in fuel position 31.

Fig. 34 Radial specific power distributions through the fuel element at core midplane in fuel position 32.

Fig. 35 Radial specific power distributions through the fuel element at core midplane in fuel position 33.

Fig. 36 Radial specific power distributions through the fuel element at core midplane in fuel position 34.

Fig. 37 Radial specific power distributions through the fuel element at core midplane in fuel position 35.

V. FAST (>1 MeV) NEUTRON FLUX

Fast (>1 MeV) neutron flux data were obtained in a number of positions in the ATR which are representative of the different types of experiment irradiation positions available. These data were subsequently compared with data from the ATRC to determine how well the ATRC measurements can be expected to predict the results of fast flux measurements in ATR. The comparison of the ATR and ATRC fast flux data at the horizontal midplane in six experiment loop positions and selected A-, B-, and H-holes is shown in Table VI. In general, the agreement between ATR and ATRC data is good and indicates that the results of an ATR fast flux measurement can be predicted from ATRC data with an estimated standard deviation of five percent. However, to obtain the uncertainty in absolute fast flux, this number must be combined with an estimated standard deviation of 10 percent to account for the uncertainty in ATR fast flux obtained from nickel activation.

TABLE VI

FAST (>1 MeV) NEUTRON FLUX AT CORE MIDPLANE NORMALIZED TO 250 MW

Position	ATR (10^{14} n/cm ² sec)	ATRC (10^{14} n/cm ² sec)	ATRC/ATR
Capsule Positions:			
A-10	3.55	3.61	1.017
A-11	3.77	3.81	1.011
B-4	1.77	1.71	0.966
B-5	1.84	1.84	1.000
H-6	2.84	2.97	1.046
H-8	2.77	2.91	1.051
H-10	2.85	2.87	1.007
H-12	2.80	2.93	1.046
Flux Traps:			
N	1.67	1.66	0.994
S	1.62	1.61	0.994
NW	1.63	1.57	0.963
SW	1.89	1.86	0.984
C	1.96	1.96	1.000
SE	1.61	1.60	0.994

The midplane values shown in Table VI were obtained from axial distribution measurements in ATR and from axial distribution and core midplane measurements in ATRC. The available axial distribution comparisons and least-squares computer fits to the data are shown in Figures 38 through 41. The curve drawn in each figure is the least-squares fit to the ATR data. The asymmetries in these data may be real or simply the result of a small error ($\approx \pm 0.5$ inch) in the axial position of the monitor wires. Since the error in positioning is estimated to be ± 0.25 inch, any real asymmetry is assumed to be small.

The core composition for the measurement is shown in Table I, the power division was approximately 5-5-5, and the reactor coolant was at ambient temperature. The ATR data were obtained primarily from nickel activation; however, several zinc detectors were included to provide a normalization of ATR data to ATRC data. (Zinc detectors are routinely used to obtain fast flux data in ATRC instead of the less sensitive nickel detectors.)

The cross sections used in the calculation of fast flux are 95 mb for Ni-58 (n, p) Co-58 and 29 mb for Zn-64 (n, p) Cu-64. These cross sections were obtained by averaging the energy-dependent cross sections over a fission spectrum. However, since the energy-dependent values may be updated as new information is obtained, these average cross sections may be revised, resulting in changes in the fast flux values reported here.

Fig. 38 Axial fast neutron flux distribution in the center flux trap in ATR and ATRC.

Fig. 39 Axial fast neutron flux distribution in H-6 in ATR and ATRC.

Fig. 40 Axial fast neutron flux distribution in A-10 in ATR and ATRC.

Fig. 41 Axial fast neutron flux distribution in B-4 in ATR and ATRC.

VI. GAMMA HEAT MEASUREMENTS IN EXPERIMENT POSITIONS

Gamma heat measurements were obtained in a number of typical experiment irradiation positions. The purpose of these measurements was (a) to obtain axial distributions of gamma heat or peak gamma heat values in representative experiment positions throughout the reactor in a nominally 5-5-5 power division and (b) to obtain a comparison with gamma heat values obtained at nominally zero-power in the ATRC using thermoluminescent phosphors. This comparison will show the feasibility of using thermoluminescent phosphors in the ATRC for predicting gamma heat in the ATR.

The measurements in the ATR were made at a power level of about 2.5 MW using both graphite-wall and aluminum-wall ionization chambers. The graphite-wall chambers, utilizing dry tubes for placement and water protection, provided axial gamma heat distributions in most experiment positions; whereas the water-tight aluminum-wall chambers were used in smaller diameter positions to obtain only peak gamma heat values. The data obtained using these chambers are all reported as gamma heat in graphite and are extrapolated to a reactor power level of 250 MW.

The axial gamma heat profiles obtained using the graphite-wall ion chambers were fit by a nonlinear least squares program to the function $P \cos C(x-x_0)$ where P is the peak gamma heat value, x_0 is the displacement of the gamma heat peak from core midplane in inches, and x is the number of inches from core midplane for which a gamma heat value is to be computed. The values for the parameters of this function for representative irradiation positions are given in Table VII for irradiation position locations in and around the core shown in Figure 42. Where only peak gamma heat values were obtained, the parameters of this function were estimated from those obtained for the axial profiles in nearby positions.

A comparison of the ATR and ATRC gamma heating is shown in Table VIII. The ATRC data were obtained in an ATR mock-up using the thermoluminescent properties of $\text{CaF}_2\text{:Mn}$ and LiF (TLD-700) phosphors[12]. These phosphors, homogeneously imbedded in extruded teflon rods (1 by 6 mm long), were irradiated in positions typical of those measured in the ATR. On comparing data from the two types of phosphors, it is apparent that the gamma heat values obtained from $\text{CaF}_2\text{:Mn}$ agree more favorably with those obtained in the ATR using ion chambers. On the basis of these comparisons, it is reasonable to expect $\text{CaF}_2\text{:Mn}$ measurements in the ATRC (for positions near the fuel) to predict gamma heat values in the ATR within 20 percent of those found using ion chambers.

TABLE VII

VALUES FOR THE PARAMETERS OF THE FUNCTION $P \cos C(x-x_0)$
 DESCRIBING THE AXIAL GAMMA HEAT DISTRIBUTION
 IN REPRESENTATIVE EXPERIMENT POSITIONS AT 250 MW

<u>Irradiation Position</u>	<u>P</u> (W/g of graphite)	<u>C</u> (inches ⁻¹)	<u>x₀</u> (inches)
NW Flux Trap	11.8	0.056	-0.5
N Flux Trap	13.9	0.059	-0.3
C Flux Trap	16.5	0.058	-0.6
E Flux Trap	16.6	0.055	-0.6
SW Flux Trap	13.5	0.057	-0.2
S Flux Trap	14.2	0.057	0.3
SE Flux Trap	14.5	0.057	-0.9
A-10[a]	20.0	0.057	0.0
B-3[a]	15.0	0.057	0.0
B-4[a]	14.0	0.057	0.0
H-6, -7, and -8	19.0	0.057	0.0
I-6	1.4	0.053	-1.0
I-7	1.4	0.053	-1.7
I-8	1.5	0.056	-0.2
I-9	1.5	0.054	-1.4
I-10	1.4	0.051	1.5
I-11	1.4	0.053	-1.0
OS-2	0.45	0.052	1.2
OS-3	0.28	0.051	0.2
OS-4	0.32	0.051	0.1
OS-5	0.33	0.053	0.1
OS-6	0.30	0.048	1.1
OS-7	0.26	0.050	0.3
OS-8	0.10	0.048	-2.5
OS-9	0.11	0.048	0.6
OS-10[a]	0.12	0.047	0.0
OS-11	0.11	0.046	-0.2
OS-12	0.097	0.048	0.9
OS-13	0.045	0.039	0.6
OS-14[a]	0.043	0.040	0.0
OS-16	0.045	0.040	0.1
OS-17	0.041	0.037	-1.2
OS-18[a]	0.023	0.038	0.0
OS-20[a]	0.024	0.038	0.0
OS-21	0.024	0.038	0.0
OS-22	0.021	0.039	0.1

[a] The parameters, C and x₀, for these positions were estimated on the basis of those determined in nearby positions.

Fig. 42 Cross-sectional diagram of ATR core.

TABLE VIII

COMPARISON OF PEAK GAMMA HEAT VALUES IN THE ATR AND ATRC

Position	Gamma Heat (W/g of graphite) ^[a]		
	ATR	ATRC	
	(Ion Chamber)	(CaF ₂ :Mn)	(LiF)
N Flux Trap	13.9	16.3	26.6
SW Flux Trap	13.5	15.7	28.2
C Flux Trap	16.5	18.0	31.5
I-6	1.4	2.13	1.7
I-7	1.4	-----	1.7
B-3	15.0	14.8	22.8
A-10	20.0	21.8	27.5
H-7	19.0	20.7	26.2

[a] All data are extrapolated to 250 MW reactor power.

VII. REACTOR NOISE MEASUREMENTS

Noise measurements were made in ATR at nominally zero power with variable primary coolant flow (up to full flow) to obtain the zero-power neutron spectral-density for the ATR. Since full-power spectral-density effects are, to first order, superposed on the zero-power, full-flow spectral density, these zero-power noise measurements establish a reference which can be used as a diagnostic during the approach to power.

The reactor noise was detected with a pair of Texas Nuclear He-3 chambers, amplified with a current amplifier system^[13], and recorded with an Ampex FR-1300 tape recorder operating in the FM mode. In the zero-power low-flow measurement the chambers were centered about the reactor midplane in an air-filled tube in the center flux trap. However, in the zero-power measurements with variable flow the chambers were moved to the T3 instrument thimble exterior to the core and centered at the reactor midplane.

The data from the zero-power, low-flow measurement were analyzed using a cross-correlation technique to determine the break-frequency, β/Λ . A value of 25.2 ± 0.3 Hz was determined from this analysis. This value compares favorably with the value, 24.9 ± 0.5 Hz, determined from similar measurements in the ATRC.

The power spectral-density obtained from the zero-power measurements with variable primary coolant flow is shown in Figure 43. Except for the resonance at 11.0 Hz, the resonances that appear with increased flow were caused by vibration of the experiment in-pile tubes. This correspondence was established from individual accelerometer measurements of the in-pile tubes. Using the results of the accelerometer measurements it may be shown that the resonances at 4.2 Hz and 7.0 Hz were caused respectively by vibration of the center and corner in-pile tubes. The cause of the resonance at 11.0 Hz is presently unknown but it is not believed to be due to in-pile tube vibration. The resonant frequencies of the in-pile tubes were so prominent in these zero-power measurements that, in comparison, the power spectral density without flow-noise sources was negligible except for the usual white noise associated with the detection process at high frequencies.

Fig. 43 ATR zero-power spectral density as a function of primary coolant system flow showing effects of in-pile tube vibration.

VIII. REFERENCES

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