REACTOR TEST PROGRAM

KEWAUNEE NUCLEAR POWER PLANT

Wisconsin Public Service Corporation
Wisconsin Power & Light Company
Madison Gas & Electric Company

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1.0 Introduction

This report describes the Reactor Test Program at the Kewaunee Nuclear Power Plant for the Start-up of a reload core. Included are the test objectives, descriptions, review and acceptance criteria.

The objective of the reactor test program is to verify that the reload core, and hence the reactor, is safe and can be operated in a safe manner. Furthermore, the test program verifies the reliability and accuracy of the computer codes used to analyze the reload core.

Appendix A contains the necessary information for approval of the rod swap method of measuring rod bank worths. This includes a comparison of the cycle IV results obtained independently by WPS and Westinghouse, and cycle V predictions from WPS and Exxon Nuclear Corporation.

This report describes the test program as a minimum. The program is not limited to the tests or test methods described in this report, and is not intended to detail specifications for use in a compliance inspection. Procedures and techniques may be upgraded as state-of-the-art equipment and techniques become available.

2.0 Low Power Tests

The tests described in this section are to be performed at "low power". For the purposes of this report, low power is defined as the power range below the point of adding nuclear heat.

All measurements taken during these tests and all predictions include corrections for uncertainties, such as measurement and prediction accuracy. Extreme care is taken to maintain steady state conditions wherever practical in the tests, to assure that the parameter under surveillance can be measured as accurately as practical.

2.1 Rod Drop Time

The objective of the rod drop time test is to verify the mobility and minimum reaction time of the rods, thus assuring the capability to safely shutdown the reactor, if necessary.

The test is performed at normal operating temperature with both reactor coolant pumps running. This test will be conducted prior to initial criticality.

The stationary gripper coil signal, the RPI produced rod drop signal and the 60 Hz reference time base are monitored and recorded on a five point brush recorder for each rod drop.

The desired bank is withdrawin to the full out position. Selected rods are then dropped by first removing the fuse in the moveable gripper coil, and then removing the fuse in the stationary gripper coil. This test is repeated until all rods have been tested.

Rod drop times are then determined from the strip chart indications. For conservatism, the initiation of the event is assumed to be that point in time when the signal from the stationary gripper coil first starts to decay. The end of the event is chosen as the point when the rod enters the dashpot. Figure 2.1-1 shows a typical strip chart trace for this test.

The acceptance criterion for this test is Technical Specification 3.10.h. If this specification is not met, the rod shall be declared inoperable.

2.2 Initial Criticality

The purpose of this test procedure is to provide a safe and controlled method of achieving initial criticality.

The initial conditions are: The reactor coolant system temperature and pressure is nominally 547F and 2235 psig. Both Reactor coolant pumps are operating, all full length rods are inserted, and rod drop tests for all rods have been completed satisfactorily. The power range trip setpoint is set at 85% of full power.

The approach to criticality will be performed by boron dilution with the rods in the nearly full out position. Initial ten minute counts are taken on the source range instrumentation to establish a base for the Inverse Count Rate Ratio (ICRR). An initial boron concentration is also determined from a reactor coolant system sample.

The rods are then pulled out of the reactor in specified increments, until they are in the nearly full out position. After each increment the count rate is recorded and a plot of ICRR vs Rod Position is maintained.

The reactor coolant is sampled every 15 minutes to determine the boron concentration. The pressurizer is sampled every 30 minutes to assure homogeneous distribution of boron in the reactor coolant. Boron dilution begins after rod withdrawal stops. Plots of ICCR vs dilution time, gallons of reactor makeup water added and boron concentration are maintained.

When criticality is achieved boron dilution is secured, and the neutron flux is stabilized about two decades above the initial critical level. The neutron flux is stabilized using RCC group D. With the reactor just critical, reactor coolant temperature and pressure, RCC positions, boron concentration, nuclear instrumentation readings and the date and time of initial criticality are recorded.

There are no specific acceptance or review criteria for this test, as the following tests include boron concentration acceptance criteria.

2.3 Determination of the Maximum Flux Level for Low Power Tests

The purpose of this procedure is to establish an upper limit and the operating level of the zero power neutron flux level.

The reactor coolant system is at normal operating pressure and temperature. The reactor is critical with bank D withdrawn to the near full out position. Both reactor coolant pumps are operating.

A nominal start-up rate of .25 Decades per Minute (DPM) is established by rod withdrawal, and the neutron flux level is allowed to increase until nuclear heating is observed. The reactor is then brought to a steady state critical condition just before the point of nuclear heat addition. A plot of reactivity vs. flux is obtained by alternately withdrawing and inserting bank D in small amounts. The range of this plot is two to three decades of flux, with the point of nuclear heat addition as the maximum.

The low power physics tests will be performed at flux levels below the point of nuclear heat. The maximum level will be about one decade below the first indication of reactivity feedback.

2.4 Reactivity Computer Checkout

The purpose of this procedure is to prepare and check out the reactivity computer for low power physics tests.

The reactor is just critical and the 20 reactivity constants have been entered into the reactivity program. Approximately 75 pcm of rod worth is inserted into the reactor core.

The computer is then calibrated at three reactivity values, approximately 25, 50 and 75 pcm; these positive reactivity insertions are obtained by rod withdrawal and measured via doubling time.

A review of the results is initiated if the agreement between the computer and actual values is not within 2% (nominally).

2.5 Isothermal Temperature Coefficient Measurement

The purpose of this test is to determine the temperature coefficient of reactivity for the reactor core due to moderator and doppler contributions.

The initial conditions are stable plant conditions with the boron concentration of the pressurizer, reactor coolant loops and volume control tank as near to the same concentration as is practical. The reactor is just critical with bank D in the near full out position.

The reactor coolant system temperature is increased or decreased at a rate of approximately 20F per hour by manually adjusting the steam dump. Normally the heatup is performed first, and both a heatup and a cool down are desired.

A plot of reactivity vs T_{ave} is maintained during the heatup and cool down. The isothermal temperature coefficient is the slope of the trace on this plot. See Figure 2.5-1.

The acceptance criterion for this test is Technical Specification 3.1.f. A review of the analytical data is performed if the measured isothermal temperature coefficient differs by $\pm$ 3pcm/F from the predicted value.

2.6 Zero Power Flux Distribution Measurement

The purpose of taking a zero-power flux map is to verify that the flux profile agrees with predictions, to assure that the core is symmetric and that no loading errors have occurred.

The flux map is obtained via the moveable in-core instrumentation system, which utilizes 36 locations throughout the core (See Figure 2.6-1). At least 75% of the locations must be available to have a valid map. Fission chambers are used to obtain 61 data points along the axial length of each of the 36 channels. The data is then reduced through the use of the INCORE computer program.

Because of the low flux levels and consequent absence of feedback in the core, it is difficult to predict actual flux distributions at this level. Therefore, there is no acceptance criterion applicable, however, a review is initiated if the flux tilt exceeds 5%.

2.7 Rod Bank Worth Verification

The purpose of this test is to determine the differential boron worth over the range of RCC bank insertion, to determine the endpoint boron concentration and to infer the differential and integral worths of the RCC banks.

The initial conditions are normal operating temperature and pressure of the RCS, both reactor coolant pumps running, and the reactor is critical with the rods at the fully withdrawn position.

2.7.1 Boron Differential Worth Measurement

The reactor coolant system is sampled at 15 minute intervals and the pressurizer is sampled at 30 minute intervals to determine the boron concentration. After dilution is initiated the RCC banks are inserted a specified number of steps as necessary to compensate for the reactivity change due to boron concentration changes, and to maintain the flux level within the prescribed zero power limits.

During this phase of the test a record is kept of rod position, boron concentration and reactivity scale on the reactivity meter. This information is then used with the traces on the strip chart to compute the differential boron worth over the range of RCC bank insertion. The dilution is terminated when the moving RCCA bank is near the full in position (i.e. within 100 pcm of the endpoint bank position).

2.7.2 Boron Endpoint Measurement

After the system has stabilized, the endpoint concentration is determined by insertion of the RCC bank to the full in position. The incremental worth of the RCC bank is estimated by monitoring the flux and reactivity response via the reactivity computer. This last measurement is performed approximately three times, with the incremental worth taken as the average of the three measurements. The endpoint boron concentration is measured at the specified statepoint, with slight differences in system parameters accounted for.

The boron endpoint data for the all rods out configuration is acceptable if the measured worth differs by less than 100 ppm from predicted. A review will be performed if the worth differs by more than $\pm$ 50 ppm from the predicted value.

2.7.3 Rod Worth Measurement by Boron Dilution

The RCC bank predicted to have the greatest worth is measured by boron dilution and the reactivity computer.

The procedure is identical to the differential boron worth determination, and can be performed concurrently with it (See section 2.7.2 for test description). After the integral and differential worths are determined, the worths of the remaining banks are inferred from the rod swap method.

Utilization of the rod swap method requires that the worth of the reference bank be measured by boron dilution. The reference bank is defined as the bank predicted to have the highest worth. Although this is the only bank worth requiring measurement by dilution, the remaining bank worths may be verified by dilution in the event that the results of the rod swap method fail to meet the acceptance criteria.

2.7.4 Rod Worth Verification By Rod Swap

Rod worth verification via rod swap techniques involves the measurement of several different statepoints of the reactor. These measurements are then compared to computer predictions of the same statepoints. Good agreement between the measured and predicted statepoint values indicates that the computer model can accurately predict parameters, such as shutdown margin and bank worths.

The remaining bank worths are inferred in the following manner. The measured reference bank is initially in a full in, or almost full in, position with the reactor just critical. The bank to be measured (bank "X") is then inserted to the full in position, while the reference bank is withdrawn to the critical position. The worth of bank X can now be inferred from the worth of the reference bank. Corrections are made to account for the spatial effects of bank X on the worth of the reference bank, and to account for the varying initial position of the reference bank.

The acceptance criterion for the rod worth measurements is that the calculated shutdown margin on the sum of all rods is within 10% of the predicted value. A review will be initiated if any individual bank worth differs by more than ± 15% from its predicted value, or if the total worth of all rods measured differs by more than 10% from the predicted value.

3.0 Power Escalation Tests

The purpose of the power escalation tests is to obtain reactor characteristics to verify physics design parameters. The tests shall include as a minimum incore flux maps at 75% and 100% full power, Nuclear instrumentation calibration, and critical boron concentration measurement at equilibrium xenon.

3.1 Power Profile Determination

The power profile is determined by in-core flux maps as described in section 2.6. These maps verify that the flux profile is within acceptable limits at the specific power level.

The acceptance criteria for power profile determination are Technical Specifications 3.10.b and 3.10.c.

3.2 Nuclear Instrumentation Calibration

The nuclear instrumentation calibration is performed by correlations of primary system delta-T measurements with secondary system calorimetrics.

The full power delta-T is measured by directly measuring the loop temperatures in each channel of each loop. This requires four measurements for each T_{hot} and T_{cold}.

These four delta-T measurements are then normalized to full power by using secondary side calorimeter data.

Finally, the four "full-power" delta-T's are averaged to determine the core-average full power delta-T.

No acceptance criterion is necessary for this test, however, it is reviewed with a historical perspective. If the delta-T is not consistent with past results, a reanalysis of the data is initiated.

The secondary plant calorimetrics are performed to check the results of primary ΔT measurements and to assure that the nuclear instrumentation is operating properly.

The thermal power output of the steam generators is obtained using a mass and energy balance from data obtained using secondary system instrumentation. Steam Generator pressure, feedwater temperature and feedwater flow data are used to determine power by the relation

$$\text{Power} = \frac{\text{(flow rate) LB/HR X (Ho-Hi) BTU/LB}}{3.412 \text{ X } 10^{6} \text{ BTU/MW-HR}}$$

where Ho and Hi are the outlet and inlet enthalpies of the steam and feedwater.

3.3 Critical Boron Concentration at Equilibrium Xenon

The critical boron concentration is determined at hot-full-power at equilibrium Xenon, steady-state conditions. The concentration is determined by chemical analysis of a reactor coolant system sample.

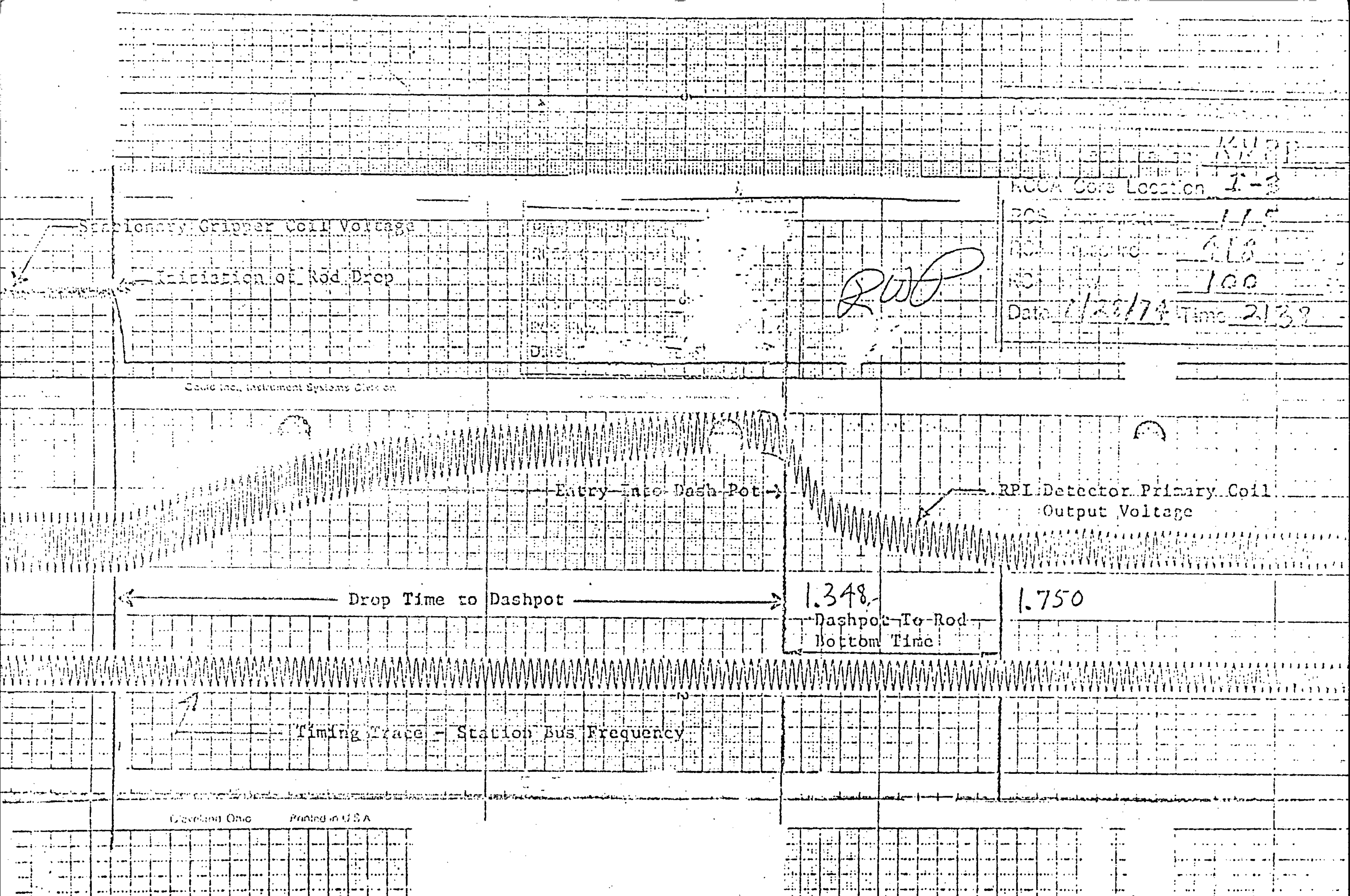
The review criterion for critical boron concentration at hot full power is that the measured worth is ± 50 ppm of the predicted worth. The acceptance criterion is ± 100 ppm agreement.

4.0 Review and Remedial Action

The results of each reactor test shall be reviewed by the test engineer and shift supervisor. This review will consider historical performance and design objectives as applicable for each parameter.

In the event of discrepancies or anomalies, the results of the affected test will be reported to the Plant Operations Review Committee (PORC), which will review any safety related questions.

If any acceptance criteria are not met, PORC shall review the results of the test and any action taken. All data and predictions will be reanalyzed in an effort to find errors in data reduction or logic. If no errors or explanations can be found, each problem will be addressed specifically on its own merits.


Stationary Gripper Coil Voltage
Initiation of Rod Drop
Entry Into Dash Pot
RPI Detector Primary Coil
Output Voltage
Drop Time to Dashpot
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1.750
Dashpot To Rod
Bottom Time
Timing Trace - Station Bus Frequency
RCCA Core Location
Date
Time
Cleveland Ohio
Printed in U.S.A

Figure 2.1-1

ISOTHERMAL TEMPERATURE COEFFICIENT

T_{ave} Start	546^{o}F
T_{ave} End	540.5^{o}F
Bank D	200 steps
Boron Conc.	1513 ppm

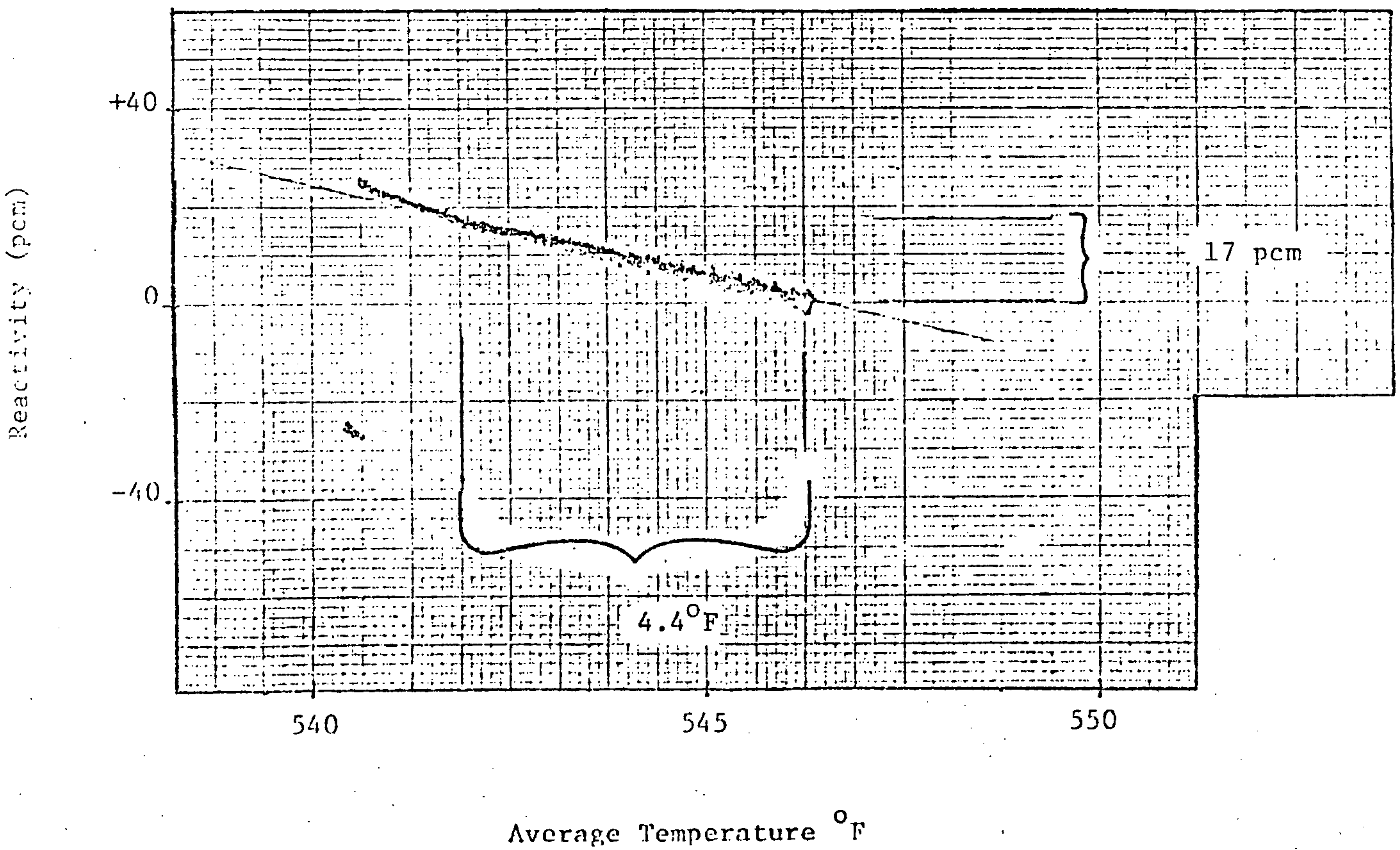

Figure 2.5-1

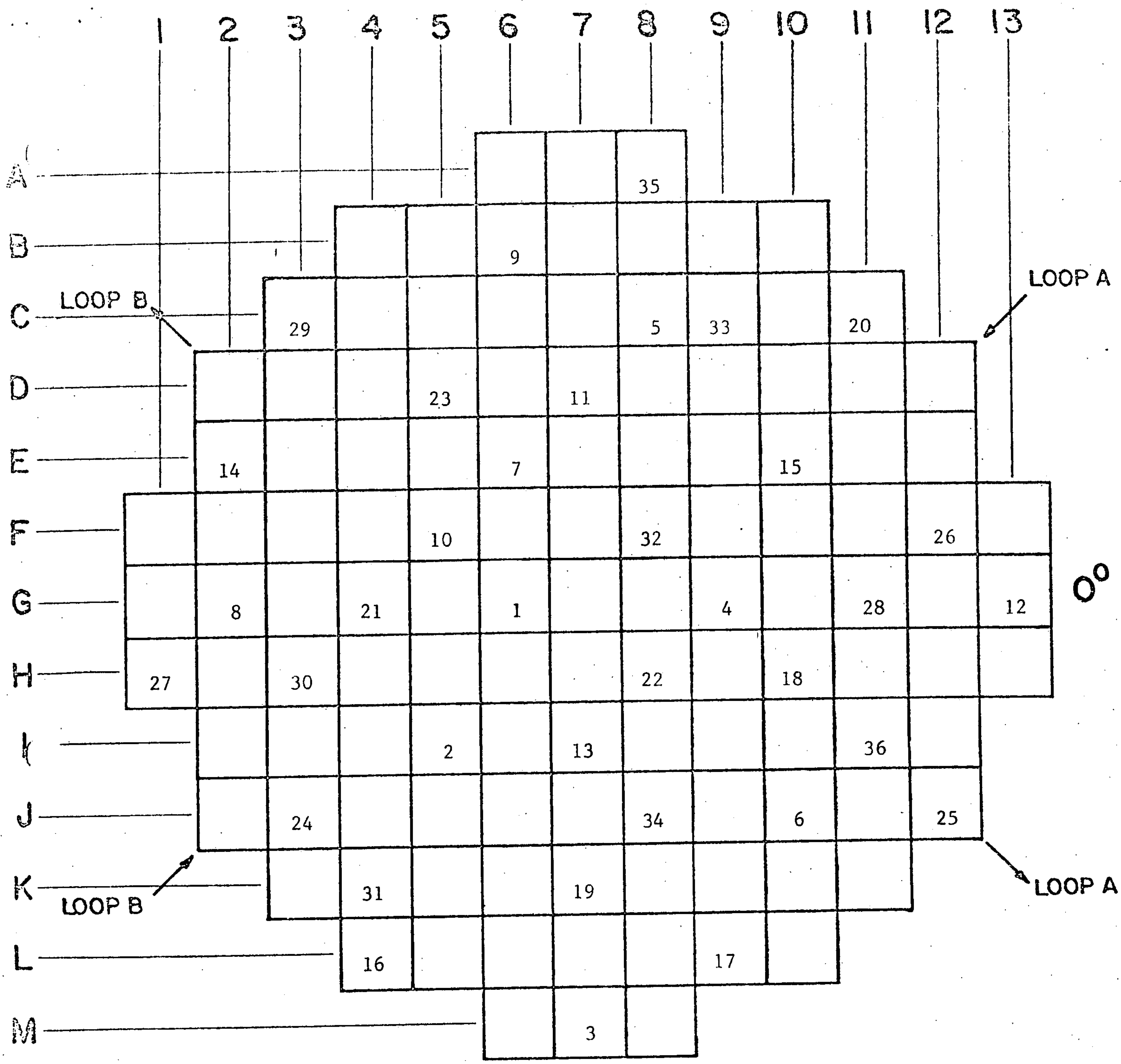

FIGURE 2.6-1 Location and I.D. Number of Moveable In-Core Fission Chambers

TABLE 1 ACCEPTANCE AND REVIEW CRITERIA FOR REACTOR TESTS

REACTOR TEST	REVIEW CRITERIA	ACCEPTANCE CRITERIA
Rod Drop Time	Consistency with past results	T.S. 3.10.h.: Rod Drop Time 1.8 seconds
Initial Criticality	Not Applicable	Not Applicable
Max. Low Power Flux Level	Not Applicable	Not Applicable
Reactivity Computer Checkout	2% Accuracy	Not Applicable
Isothermal Temperature Coefficient Determination	Measured ITC within $\pm$ 3 pcm of predicted ITC	T.S.3.1.f.: ITC is negative in operating range
Flux Map at Zero Power	Less than 5% tilt	None
Rod Bank Worth Measurements	ARO C_B is $\pm$ 50 ppm of predicted value difference between measured and predicted integral worth for sum of all banks is <10% difference between measured and predicted worth of reference bank is <10% difference between inferred and predicted integral worth for all other banks is $\pm$ 15%	Calculated SDM is greater than predicted by less than 10% ARO C_B is $\pm$ 100 ppm of predicted value
Power Profile Measurement	Correlation with predictions	T.S.3.10.b.1: Power Distribution Limits T.S.3.10.b.8: Axial Flux Diff. Limits T.S.3.10.c : Quadrant Power Tilt Limits
Nuclear Instrumentation Calibration	Not Applicable	Not Applicable
Equilibrium Xenon Boron Concentration	C_B $\pm$ 50 ppm of predicted value	ARO C_B is $\pm$ 100 ppm of predicted value

APPENDIX A

VERIFICATION OF ROD SWAP METHODS

A.1 History

Wisconsin Public Service Corporation utilized the Rod Swap Technique for measuring rod bank worths for cycle IV startup tests in May, 1978. The measurements were done concurrently and independently of Westinghouse Electric Corporation.

Although the WPS predictions agreed well with the measurements, and, in fact, did meet the acceptance criteria, the Westinghouse predictions were not as accurate. During the subsequent re-analysis by Westinghouse, an error was found in their work. This eventually led to a new submittal to the NRC, via Westinghouse transmittal letter NS-TMA-1973, November 1, 1978.

The Westinghouse submittal referenced above includes a description of the test methods and data reduction methodology. The Technical justification for rod swap, including comparison to the boron dilution method of rod worth measurement, is included in the above referenced submittal and the submittal to the NRC entitled "Rod Exchange Techniques for Rod Worth Measurement." This was submitted on docket 50-305 in a letter from Mr. E. W. James (Wisconsin Public Service Corporation) to Mr. A. Schwencer (NRC) dated May 12, 1978.

The WPS staff has recalculated all of the 1978 cycle IV rod swap data following the procedure outlined in the referenced Westinghouse submittal of November 1, 1978. The results of these calculations are included within this appendix.

To further demonstrate the reliability of the WPS calculational methods, section 3.0 of this appendix includes comparisons of predictions of rod worth for cycle V with the predictions of Exxon Nuclear Company. Although this comparison does not directly indicate the reliability of the WPS calculational models, the agreement in theory with ENC and Westinghouse, and the agreement with the measurements of Cycle IV, together demonstrate the reliability of the WPS calculational methods and models.

A.2 Cycle IV Results

Due to the proprietary nature of the calculational methods, WPS references the Westinghouse submittal to the NRC via transmittal letter NS-TMA-1973, November 1978, for the details of the rod swap calculational methods.

Table A.1 includes the Westinghouse results and the WPS results for Kewaunee, BOC IV rod swap bank worth measurements. As can be seen by the table, the agreement between WPS and Westinghouse is very good.

A.3 Cycle V Predictions

Exxon Nuclear Company, the fuel supplier for KNPP Cycle V, has performed physics calculations on the KNPP reactor core independently of WPS calculations. To demonstrate the correlation of WPS methods, this section includes a table of comparisons between WPS and Exxon predictions concerning RCC Bank worths and reactivity requirements for cycle V.

Table A.2 compares predictions of total rod worth, total reactivity requirements and excess reactivity. Also included are the individual RCC bank worths determined by computer simulation of boron dilution measurements by both ENC and WPS.

The good agreement of these predictions (as shown by table A.2) indicates that the WPS calculational model can accurately predict rod worths.

The values used in this table are from Kewaunee Nuclear Plant Cycle 5 Safety Analysis Report, by Exxon Nuclear Company, Inc., April 1979 (XN-NF-79-27).

Table A.1 Rod Worth Measurements, BOC IV

	WPS RESULTS BOC IV			WESTINGHOUSE RESULTS BOC IV		
	Predicted	Inferred Worths		Predicted	Inferred Worths	
RCC BANK	Worth	Differential	Integral	Worth	Differential	Integral
CA	929	972	966	[(1)]	974	976
SA	660	720	705		712	717
SB	660	716	710		716	722
CB	796	677	694		694	699
CD	683	702	678		702	696
CC(2)	1043	1025	1025		1025	1025
Σ	4771	4812	4778		4822	4834

1. Westinghouse proprietary information. Refer to submittal of November 1, 1978 Westinghouse Transmittal letter NS-TMA-1973, from T. M. Anderson to Paul S. Check. Information referenced is on "Summary Table (Revised)". No page number is given.

2. Control bank C was chosen as reference bank, therefore, its worth was measured directly by boron dilution.

TABLE A.2

Comparisons of Predictions for Cycle V (WPS vs ENC)

RCC BANK	ENC Predicted Worth (1)	WPS Predicted Worth (1)		
D	731	695		
C	1386	1301		
B	1012	941		
A	1684	1588		
Shutdown	1512	1480		
	BOC		EOC	
	ENC (2)	WPS (2)	ENC (3)	WPS (3)
Total Rod Worth	6375	6005	6658	6528
Total Reactivity Requirements	2514	2010	2795	2533
Excess Reactivity	1555	1740	574	533

1. All worths in PCM

2. Calculated with no Xenon

3. Calculated at equilibrium Xenon

REFERENCES

Westinghouse Electric Corporation, "Rod Exchange Technique for Rod Worth Measurement" and "Rod Worth Verification Tests Utilizing RCC Bank Interchange", submitted on Docket 50-305 via letter from Mr. E. W. James (WPSC) to Mr. A. Schwencer (NRC), May 12, 1978.

Westinghouse Electric Corporation, "Proprietary Version of Overhead Slides Used for Rod Exchange Techniques Presentation to NRC 9/29/78", via letter NS-TMA-1973 from T. M. Anderson (Westinghouse) to P. S. Check (NRC), November 1, 1978.

Exxon Nuclear Company, Inc., "Kewaunee Nuclear Plant Cycle 5 Safety Analysis Report", XN-NF-79-27, April, 1979.