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Westinghouse
Astronuclear
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WANL-TME-1909
JANUARY 1970

DATA ITEM T-119

PAX-GO APPROACH TO CRITICAL (U)

FINAL TEST REPORT

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Mr. J. L. Dooling
Manager, Prime & Subcontract Administration
Nuclear Rocket Operations
Aerojet-General Corporation
P. O. Box 15847
Sacramento, California 95813

Attention: Mr. P. P. Ventura

Subject: Transmittal of Data Item T-119, PAX-GO Approach to Critical

Dear Mr. Dooling:

Enclosed are ten (10) copies of WANL-TME-1909, Data Item T-119, PAX-GO Approach to Critical.

This test report is required by the Statement of Work for Subcontract NP-1, Project 712.

Respectfully,

[illegible]
A. C. [illegible]

A. C. Sanderson, Manager
Program Management
NERVA Nuclear Subsystem

GRR:jc

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Subcontract NP-1

CODE IDENT NO. 14683

WANL-TME-1909
JANUARY 1970

Classification cancelled (~~or changed to~~ ________)
by authority of ________
by H. T. C., TIC, date SEP 12 1973

DATA ITEM T-119

PAX-GO APPROACH TO CRITICAL (U)

FINAL TEST REPORT

SPECIAL REREVIEW FINAL DETERMINATION	Reviewers	Class.	Date
Class: U	JRP	U	4-29-82

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ABSTRACT

An experiment was performed to assist in development of an approach-to-critical procedure to determine accurate criticality estimates from subcritical multiplication measurements during the shipping poison wire removal operation. This experiment will also be useful in selecting most suitable detector/source locations for startup operation. The experimental procedure consisted of subcritical inverse count rate measurements at several detector positions taken during one, two and three drum roll-out conditions.

Utilization of centrally located sources (at the reactor midplane in the central cluster) resulted in an essentially linear inverse count rate versus number of poison wires remaining during the approach-to-critical experiment.

A clear dependence of the apparent multiplication (detector response) to the source/detector and test drum configuration was demonstrated. A detector placed at 90° from the test drum with a central source appears to give the single, most accurate estimate of the actual change in multiplication.

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LIST OF TABLES

1.0 INTRODUCTION

1.1 TEST IDENTIFICATION

1.1.1 Type of Report

This report is a complete Final Report.

1.1.2 Scope of Test Document

The applicable Scope of Test Document is Number M58DW-216-1.

1.1.3 Functional Category of Test

This is a Development test.

1.1.4 Contractor

The Westinghouse Astronuclear Laboratory (WANL/14683), under Subcontract NP-1, CY'69, is the contractor.

1.1.5 Test Facility

These tests were performed at the Westinghouse Astronuclear Experimental Facility, located at the Westinghouse Waltz Mill Site, during January 1969.

1.2 PURPOSE

The procedure for the PAX-G0 approach-to-critical experiment was specified to assist in the development of a standardized method for subsequent NERVA reactors. The purpose of developing a standard approach-to-critical procedure is to permit accurate criticality estimates from the subcritical multiplication measurements during the poison wire removal operation. Ultimately, this procedure may permit accurate estimates to be made of shimming requirements, drum uniformity, drum span and shutdown estimates. The approach-to-critical experiments are also useful in selecting detector/source locations for startup and operation.

2.0 REFERENCES AND ASSUMPTIONS

2.1 REFERENCES

2.1.1 Specification

EC 677559 - Part I. Performance/Design and Qualification Requirements Reflector, Control Drums & Axial Support for 677555A NERVA Nuclear Subsystem, 1/23/69

EC 677566 - Part I. Performance/Design and Qualification Requirements Fuel Element for 677555A NERVA Nuclear Subsystem, 1/23/69

2.1.2 Data Item Description

Form 9, Data Item Description, T-119, dated 4/2/69

2.1.3 Scope of Test Document

M58DW-216-1 - PAX-G0 Approach to Critical

2.1.4 Data Release Memorandum

51151B - Initial Criticality Measurements in the PAX-G0 Reactor
51150 - Parts Inventory in the PAX-G0 Reactor
51504 - Relation of Detector Response to Multiplication
51057 - Nuclear Predictions for the PAX/R-1 Experimental Program
51186 - Chemical Analysis of WANEF Reactivity Materials

2.1.5 Drawing

711J496 - Reactor/Vessel Assembly, R-1 PAX
944C979 - Rod, Poison Shipping

2.1.6 TME

WANL-TME-267, Revision H - Westinghouse Astronuclear Experimental Facility Reactor Operations Manual

2.2 ASSUMPTIONS

2.2.1 Source of Background

The background measurements (using BF_3 detectors) are true measurements of the test cell neutron background and are not measurements of system electronic noise or gamma background. The source of this background is attributed to the various neutron sources stored in the test cell as well as resulting from subcritical multiplication in the nearby FCX reactor.

2.2.2 Effect of Background

As the background is a neutron source, it will be multiplied by the subcritical multiplication factor of the PAX-G0 reactor. Thus, the background will be considered as arising from the neutron loading source.

3.0 TEST ARTICLE CONFIGURATION

3.1 TEST SETUP

Figure 3-1 shows the detector locations relative to the PAX-G0 reactor and the test cell. Figure 3-2 presents a schematic diagram of the electronic equipment used in the test setup. A description of the components used in this experiment are as follows:

3.1.1 PAX-G0 Reactor

The PAX-G0 reactor is basically an NRX type assembly which was modified to be an early nuclear mockup of the R-1 Reference Design. Basically, it is a beryllium reflected reactor with a core consisting of a highly enriched uranium dicarbide fuel contained in a graphite matrix. Control is obtained through the rotation of 12 beryllium control drums which contain neutron absorbing plates on one side. These control drums are contained in the reflector. Further details of the reactor components may be found in Appendix A of this document.

3.1.2 Electronic Equipment

A block diagram of the electronic equipment used in the test setup is given in Figure 3-2. Table 3-1 identifies most of the components in the system.

3.1.2.1 Detectors

The neutron detectors are Westinghouse 6998 BF_3 chambers in polyethylene moderating blocks. The dimensions of the polyethylene blocks are:

DAS-1: 4" O.D. cylinder, 30-5/8" long, 2" diameter hole.

DAS-2: 6" square, 29-1/2" long, 2-1/8" diameter hole.

DAS-3: 6" square, 30-1/4" long, 1-1/8" diameter hole.

Startup (SU): 6" square, 30-1/4" long, 1-1/8" diameter hole.

All of the blocks are longer than the active lengths of the detectors.

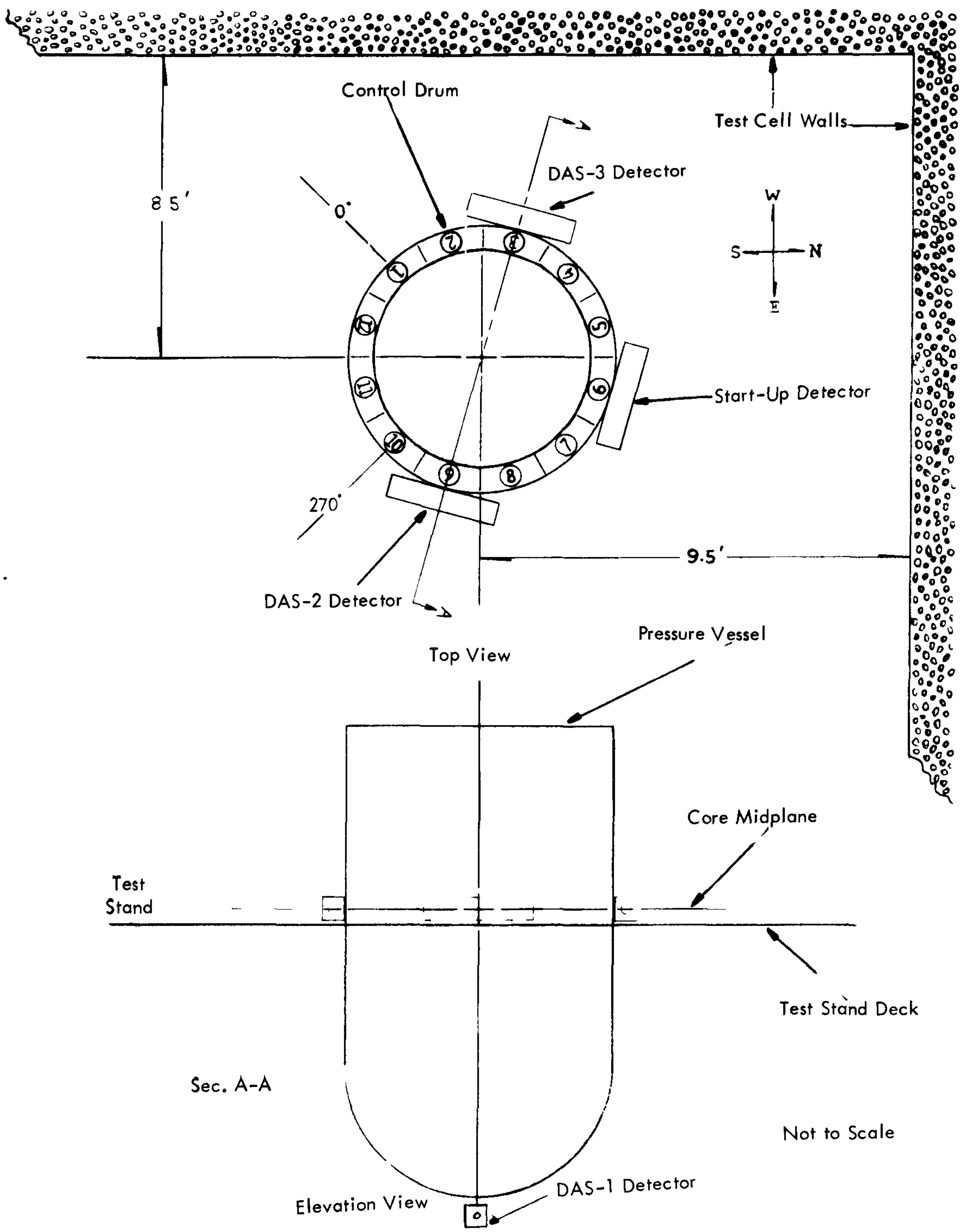

Figure 3-1. Orientation of Detectors With Respect to the PAX-G0 Reactor

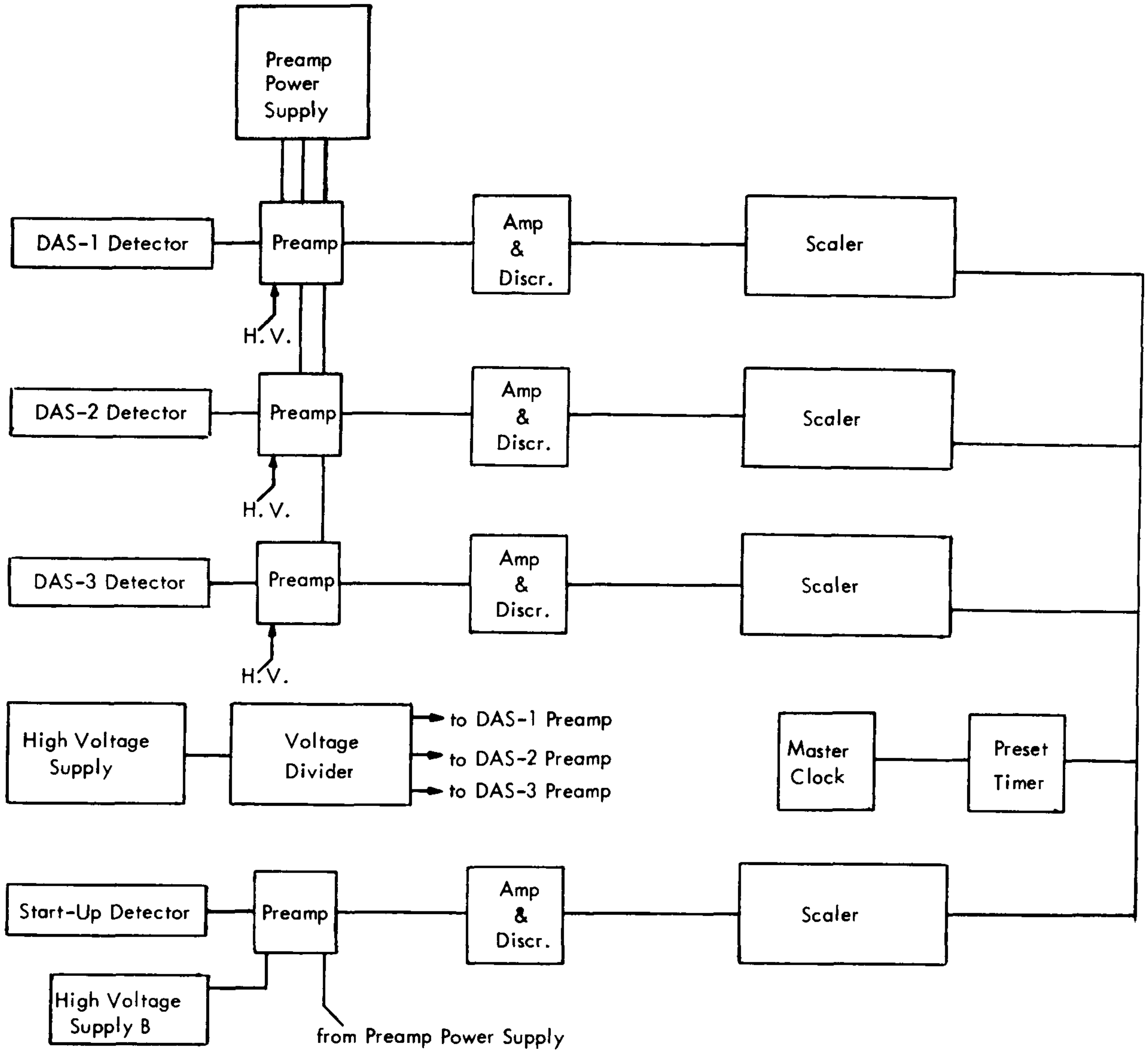

Figure 3-2. Block Diagram of the Data Acquisition and Startup Channels

TABLE 3-1

PRINCIPAL COMPONENTS OF THE THREE DATA ACQUISITION SYSTEM CHANNELS AND THE STARTUP CHANNELS

Component Function	Data Acquisition System Channel 1	2	3	Start-Up Channel
Detector	Ⓦ* 6998 Serial 672625	Ⓦ 6998 Serial 672630	Ⓦ 6998 Serial 672627	Ⓦ 6998 Serial 672645
Preamplifier	Hamner N 361 Serial 65	Hamner N 361 WANL 20-3-876	Hamner N 361 MA 101530	Hamner N 361 MA 101529
Amplifier & Discriminator	Hamner N 338 Serial 97	Hamner N 338 Serial 103	Hamner N 338 Serial 100	RIDL** 30-19 Serial 50T6435
Scaler	CMC*** 308 B-2602 Serial 38135	CMC 308 B-2602 Serial 38134	CMC 308 B-2602 Serial 38136	CMC 305 BI-2602 Serial 3

* Westinghouse

** Radiation Instrument Development Laboratory

*** Computer Measurements Corporation

3.1.2.2 Preamplifiers

All four preamplifiers are Hamner Model N-361.

3.1.2.3 Amplifier-Discriminators

The amplifier-discriminators in the three DAS channels are Hamner Model N-338. The start-up channel uses a Radiation Instrument Development Laboratory Model 30-19.

3.1.2.4 Scalers

The scalers in the three DAS channels are Computer Measurements Corporation (CMC) Model 308 B-2602. A CMC 305 B1-2602 scaler is used in the startup channel.

3.1.2.5 Preamp Power Supply

A Lambda Model 28, Serial D-16983 provides filament and regulated B^+ power to all four Hamner N-361 preamplifiers.

3.1.2.6 High Voltage Supply (A)

A Hamner Model N-4035, Serial 224, provides regulated high voltage for the three DAS channels.

3.1.2.7 Voltage Divider

A Hamner three channel voltage divider, Number AI-21667, distributes the output of the N-4035 high voltage supply to the three DAS channel preamplifiers.

3.1.2.8 High Voltage Supply (B)

A Radiation Instrument Development Laboratory (RIDL) Model 40-9, Serial 50D1311 provides high voltage to the startup channel preamplifier.

3.1.2.9 Master Clock

A Computer Measurements Corporation (CMC) Master Clock Model 2602A, Serial 1, provides accurate timing pulses for the counting system.

3.1.2.10 Preset Timer

After a start command is given, a CMC Preset Timer Model 313A 2602, Serial 1, delays the start of the four scalers until the arrival of the next pulse from the Master Clock. This accurately determines the start of each counting interval. It then turns off the scalers at the end of the desired elapsed time interval.

3.1.3 Neutron Sources

A one millicurie U.S. Nuclear Corp. Ra-Be loading source, Serial Number J-405, was in the center element of cluster 000 at the midplane. Six 10 millicurie NUMEC Am-Be sources (Serial Numbers 3AM239 - 3AM244, inclusive) were at the core midplane in the centers of Elements B through G in cluster 000.

3.1.4 Shipping Poison Wires

The poison wires (Drawing Number 944C979) consist of Type 304 stainless steel tubes filled with boron carbide and coated with a thin layer of polyethylene.

4.0 SUMMARY OF TESTS

4.1 NARRATIVE

The measurements presented in this document were performed during, and in addition to, the standard set of measurements taken during the initial approach to critical and the attainment of clean criticality on the PAX-G0 reactor. Thus, although other data was taken during the approach to clean critical, only that data pertinent to the previously referenced Test Scope document are contained in this report.

4.2 TEST CONDITIONS

Prior to the removal of the shipping poison wires from the PAX-G0 reactor, four polyethylene covered BF_3 neutron detectors were placed next to the pressure vessel as shown in the previous section of this report. The shipping poison wires were then removed in certain specified increments in accordance with the procedures set forth in Appendix B. At selected intervals during this removal procedure, data were taken with all four detectors under the following conditions:

1. With all 12 control drums at 0°.
2. With control drum number 9 at 115°; all remaining control drums at 0°.
3. With control drum numbers 8 and 9 at 115°; all remaining control drums at 0°.
4. With control drum numbers 8, 9, and 10 at 115°; all remaining control drums at 0°.

The data are presented in Section 4.3 of this report.

4.3 TEST RESULTS

Table 4-1 presents the total counts obtained on each of the four detectors for each of the four different control drum configurations given earlier. Table 4-2 presents the corresponding inverse multiplication (1/M) data together with the associated uncertainties. The calculated 1σ uncertainties listed in the tables and presented in the figures are those due to counting statistics alone and were obtained from the formula for the standard deviation σ_f as follows:

TABLE 4-1

PAX-G0 DETECTOR COUNTS DURING SHIPPING POISON WIRE REMOVAL

Run No. PAX-G0-	Drum Positions*			Total Counts				Counting Time (min.)
	Drum 8	Drum 9	Drum 10	SU Detector	DAS-1 Detector	DAS-2 Detector	DAS-3 Detector	
11	0	0	0	34832	2780	14108	20362	8
	0	115°	0	35387	2824	14984	20670	8
	115°	115°	0	35988	2993	15937	21285	8
	115°	115°	115°	37339	2982	16576	22187	8
13	0	0	0	47982	3899	18901	28753	8
	0	115°	0	49422	3996	20206	29636	8
	115°	115°	0	51876	4080	21616	30614	8
	115°	115°	115°	53399	4206	22367	31632	8
15	0	0	0	39761	3294	14865	24398	5
	0	115°	0	49834	4074	18958	29951	6
	115°	115°	0	53178	4208	21329	31872	6
	115°	115°	115°	47027	3665	18744	27878	5
30	0	0	0	96407	14284	35152	57171	5
	0	115°	0	106785	21176	40904	64553	5
	115°	115°	0	125357	24853	48449	73163	5
	115°	115°	115°	150543	30172	59562	84831	5

*See Figure 3-1 for drum locations in reflector. All other drums are at 0°.

[redacted]

TABLE 4-2

PAX-G0 INVERSE MULTIPLICATION DATA (U)

Run Number (PAX-G0-)	Date	Total Wires Left in Core	Wires Removed from Cluster(s)	Drum Position* Drum 8	Drum 9	Drum 10	Inverse Multiplication (1/M) SU	DAS-1	DAS-2	DAS-3
11	1/3/69	2016	--	0	0	0	1.00 ± .008	** 1.00 ± 0.27	**1.00 ± .012	**1.00 ± .010
				0	115	0	0.984 ± .007	0.984 ± .026	0.942 ± .011	0.985 ± .010
				115	115	0	0.968 ± .007	0.929 ± .024	0.894 ± .010	0.957 ± .009
				115	115	115	0.933 ± .007	0.932 ± .025	0.851 ± .010	0.918 ± .009
13	1/6/69	1260	(1-6)D(2-3) (1-6) C1	0	0	0	0.726 ± .005	0.713 ± .018	0.746 ± .008	0.708 ± .006
				0	115	0	0.712 ± .005	0.696 ± .017	0.698 ± .008	0.687 ± .006
				115	115	0	0.671 ± .005	0.681 ± .017	0.653 ± .007	0.665 ± .005
				115	115	115	0.652 ± .005	0.661 ± .016	0.631 ± .007	0.644 ± .006
15	1/7/69	852	(1-6) C2 26 wires each from (1-6)C3	0	0	0	0.548 ± .004	0.527 ± .014	0.593 ± .007	0.522 ± .006
				0	115	0	0.524 ± .004	0.512 ± .013	0.558 ± .006	0.510 ± .005
				115	115	0	0.491 ± .003	0.496 ± .012	0.496 ± .005	0.479 ± .004
				115	115	115	0.463 ± . 003	0.474 ± .012	0.470 ± .005	0.457 ± .004
30	1/13/69	276	16 wires each from (1-6)C3 40 wires each from (1-6)B(1-2)	0	0	0	0.226 ± .001	***0.201 ± .007	0.251 ± .003	0.223 ± .002
				0	115	0	0.204 ± .001	***0.135 ± .005	0.216 ± .002	0.197 ± .002
				115	115	0	0.174 ± .001	***0.115 ± .004	0.182 ± .002	0.174 ± .001
				115	115	115	0.145 ± .001	***0.095 ± .004	0.148 ± .001	0.150 ± .001

* See Figure 3-1 for these drum locations in the reflector.
** 1σ uncertainty due to statistical variation in count rate.
*** Normalized by 1.65 to account for a sudden change in system efficiency.

[redacted]

$$\sigma_f = \sqrt{\left(\frac{\partial f}{\partial C_o}\right)^2 \sigma_{C_o}^2 + \left(\frac{\partial f}{\partial C_i}\right)^2 \sigma_{C_i}^2}$$

$$= \frac{C_o t_i}{C_i t_o} \sqrt{1/C_o + 1/C_i}$$

where: $f = \dfrac{C_o/t_o}{C_i/t_i}$

C_o = total initial counts

C_i = total counts at i^{th} step

t_o = counting time to obtain C_o counts

t_i = counting time to obtain C_i counts

$\sigma_{C_o} = \sqrt{C_o}$

$\sigma_{C_i} = \sqrt{C_i}$

The data presented in Table 4-2 are graphically displayed in Figures 4-1 through 4-4. It should be noted that for the last series of measurements made on DAS-1, there was a sudden change in system efficiency. There is no known reason for this change at the present time. Since the change was quite abrupt, a correction factor of 1.65 was obtained through the simple expedient of taking the ratio of the count rate after the efficiency change to the count rate before the efficiency change. Since the efficiency change occurred during a series of counts, it is felt that this type of correction is reasonable.

As may be seen upon inspection of Figures 4-1 through 4-4, initial criticality was reached with approximately 680 wires left in the core and with a delayed critical drum bank angle of 167.17^{o}.

All of the data presented in this report were taken on the PAX-G0 reactor before it was reshimmed to the PAX-G0A configuration.

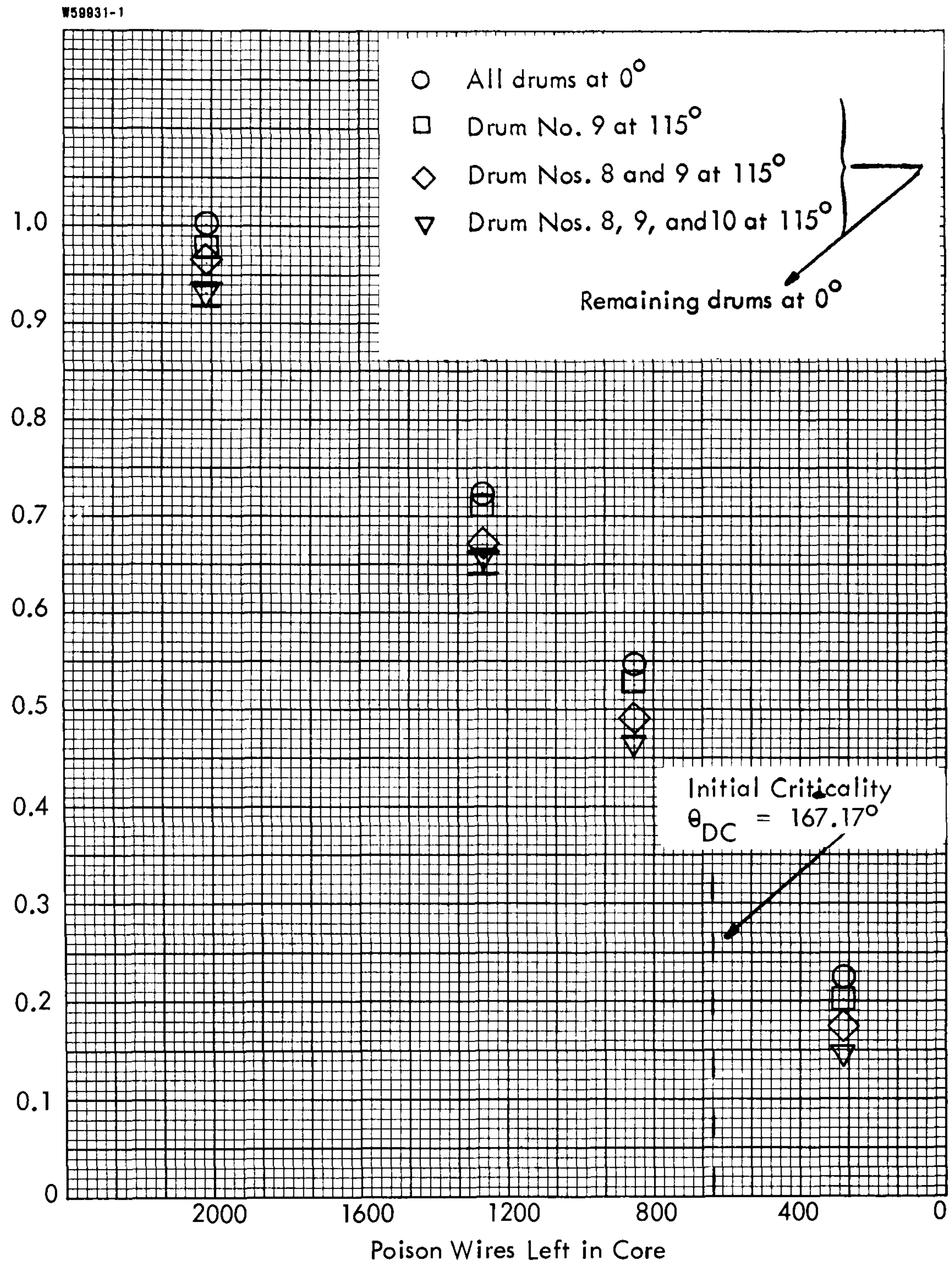

Figure 4-1. 1/M Versus Shipping Poison Wires Left in PAX-G0 for SU Detector

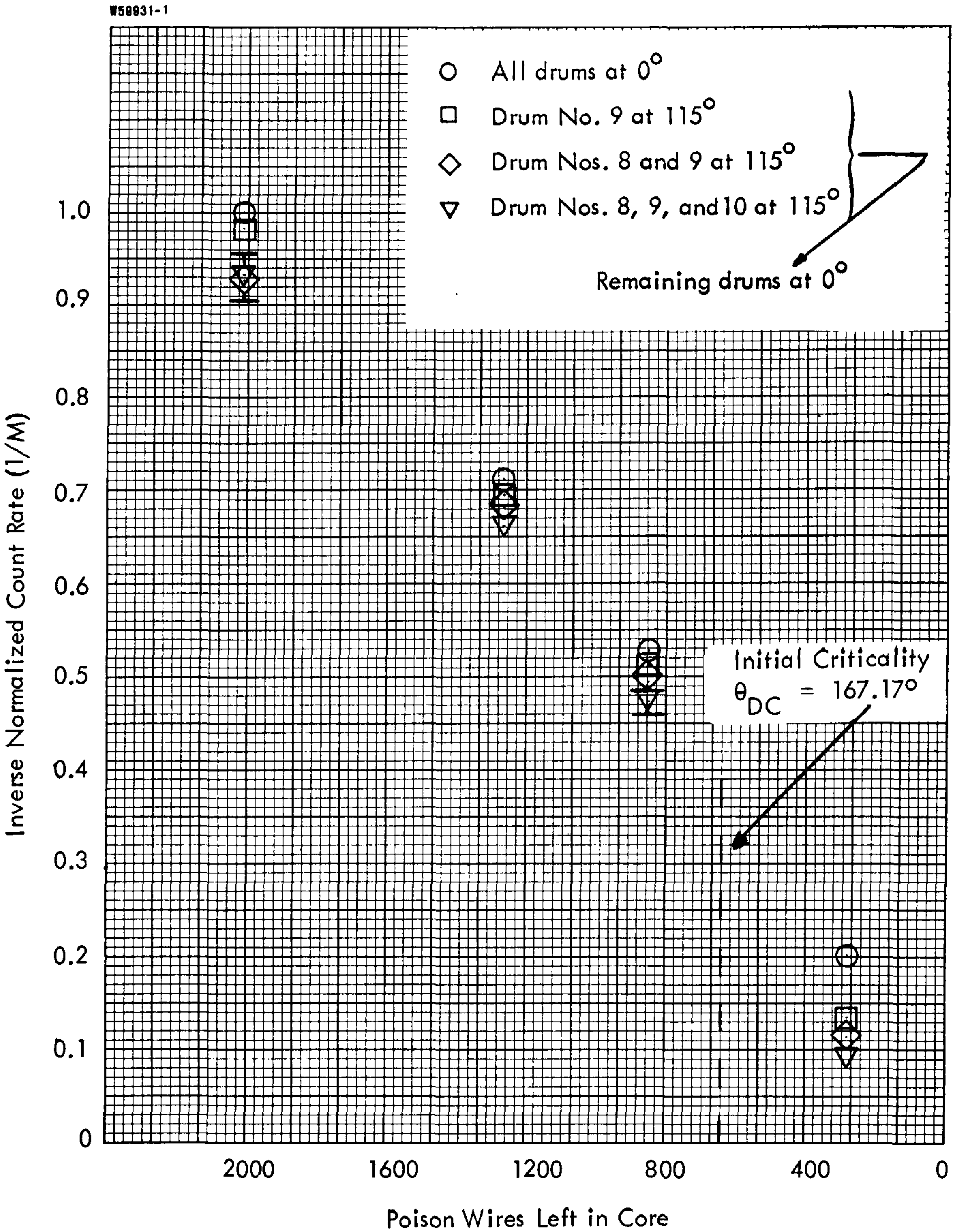

Figure 4-2. 1/M Versus Shipping Poison Wires Left in PAX-G0 for DAS-1 Detector

W59831-1

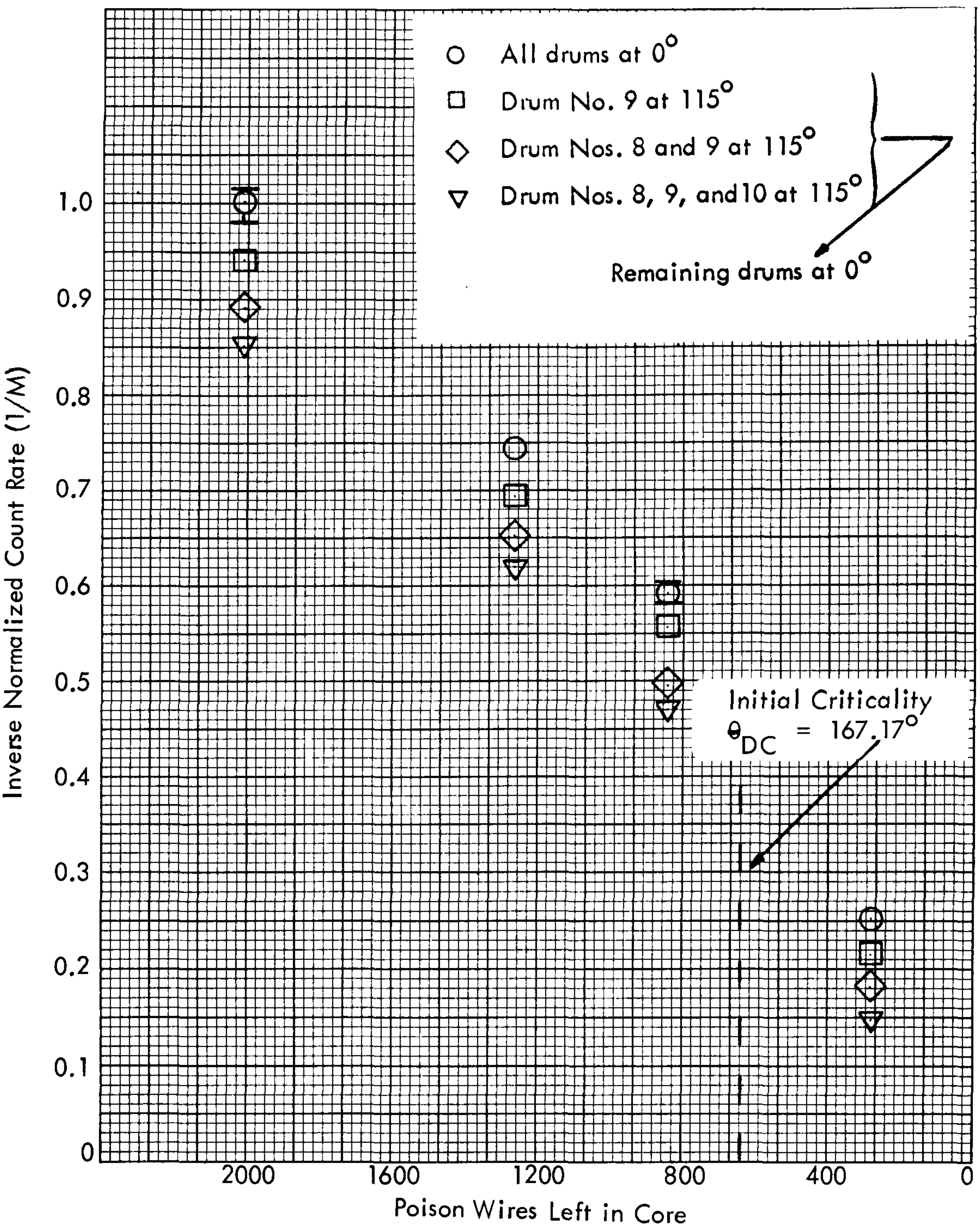

Figure 4-3. 1/M Versus Shipping Poison Wires Left in PAX-G0 for DAS-2 Detector

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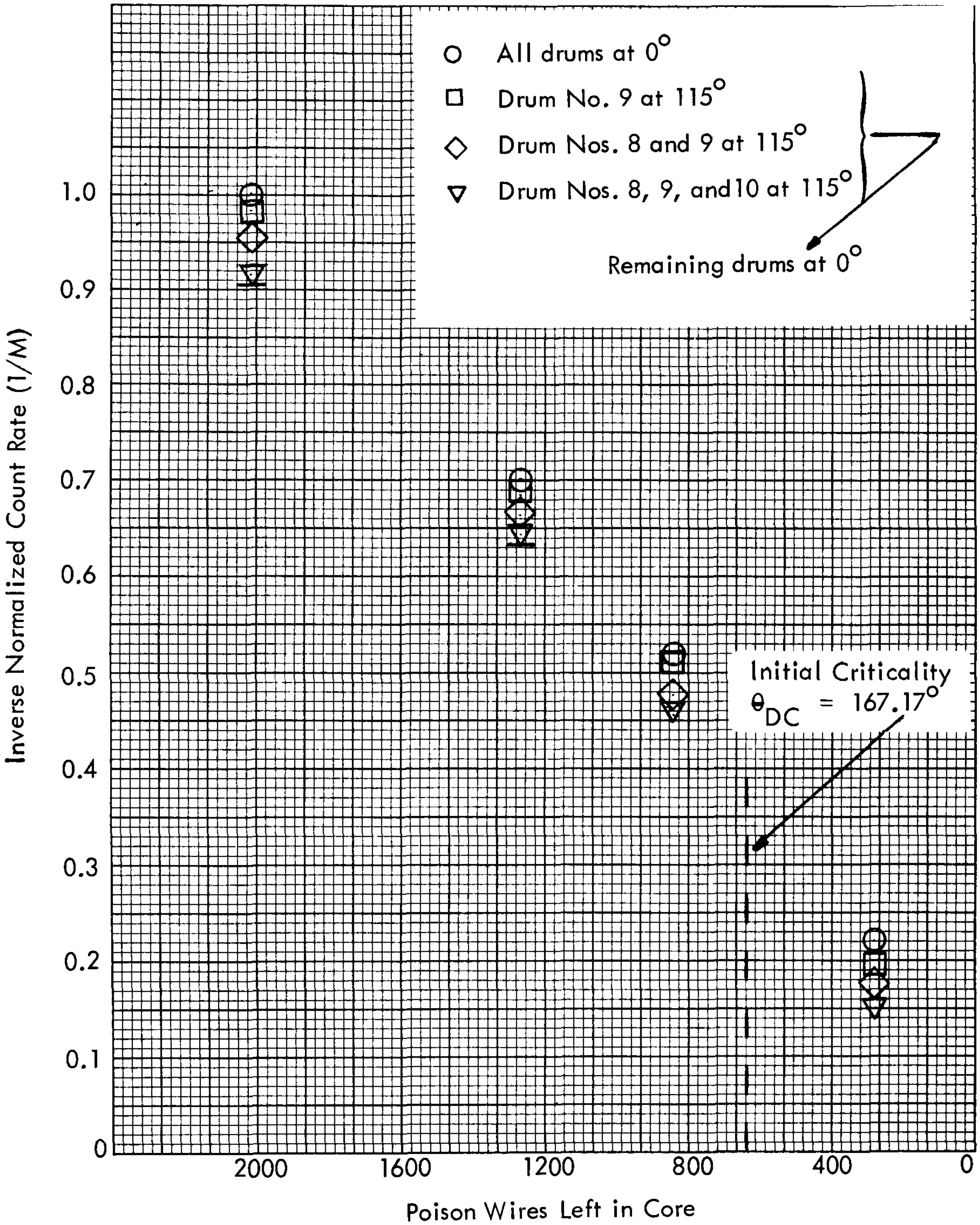


Figure 4-4. 1/M Versus Shipping Poison Wires Left in PAX-G0 for DAS-3 Detector

4.4 VALIDITY OF DATA

The reciprocal count rate* taken with 276 wires left in the core are lower for all four detectors than would be expected based on a linear extrapolation of the other measurements. This is attributed to the increased background caused by the reactor runs made after attainment of initial criticality with 678 wires left in the core and because of the increasing worth of the poison wires. However, this effect is only significant for the last few hundred poison wires. It should be noted that after initial criticality was attained, and before the last reported data point was taken, several watt-hours of operation were performed. This caused a considerable increase in the apparent neutron source as evidenced by the more detailed 0 and 90^{o} data required by the Standard Operating Procedure** but not reported here. Because of the lack of appropriate normalization data, count rates beyond 276 wires removed are difficult to compare with the earlier data.

* 1/M is the designation for the inverse normalized count rate.

** For further information see Section 5.5 in WANL-TME-267, Revision H, "Westinghouse Astronuclear Experimental Facility Reactor Operations Manual".

5.0 ANALYSIS

5.1 INTRODUCTION

The drum rotation method of calibrating the reactor shutdown from subcritical multiplication measurements has been employed since NRX-A5. This method appeared to have substantial utility in predicting shutdown, but certain anomalies were observed between the data from the NRX-A5, A6 and XE-Prime approach-to-critical experiments. Consequently, the PAX-G0 initial critical experiment was designed to resolve, as far as possible, the previously observed discrepancies. Once understood, subsequent experiments would employ a standardized approach-to-critical procedure so that a history of information could be developed to permit accurate subcritical predictions.

The first change was to locate the neutron source in the center of the core. All prior experiments used an external source. The purpose of this modification was twofold:

1. Better reproducibility of data.
2. Simplification of analytical analysis.

Reproducibility is, of course, important in any data gathering and especially important in subcritical multiplication. Location of the neutron sources within the fuel assures good reproducibility of source position. Further, the central source gives excellent linearity of the approach-to-critical inverse count rate versus shutdown. This is necessary to insure safety in the initial critical experiment and expedite the experimental position.

Another facet of the experimental design was to determine the relation between the apparent change in multiplication (detector response) to the actual change in multiplication. The three detectors were positioned to determine the effect of azimuthal location on their response to individual drum reactivity.

5.2 VARIATION OF AZIMUTHAL DETECTOR RESPONSE

At several of the poison wire removal increments, a drum calibration experiment was performed by rotating one, then two, then three drums to the expected critical angle of 115°. The increase in count rate detected should correlate to the shutdown at the poison wire inventory. To correlate these data, the relation between the increase count rate and increase in actual multiplication must be determined.

To assist in defining this relationship, three detectors were positioned about the reactor midplane on the pressure vessel. One (DAS-2) was placed behind Drum 9 (centrally located in the R-1 test sector), detector SU was placed 90° away and DAS-3 was at 180° or opposite the R-1 test sector. The response of these detectors for the various experimental configurations is shown in Table 5-1. In each case, count rates with all the drums at zero were used to normalize the subsequent drum rollout data.

A plot of these count rate data versus number of drums inserted shows consistently small deviations from linearity. This is due to the interaction effects of the drums. To eliminate this interaction, a straight line fit to each set of data was employed. These fits show that DAS-2 data (at the drum No. 9 location) were consistently high relative to the curve fit, DAS-3 (opposite drum No. 9) was low, and SU was intermediate. To better display this azimuthal variation, the average of the detector responses weighted by their relative geometric reactor perimeter coverages was assumed to be proportional to the actual change in multiplication. The individual detector count rate changes were divided into this average multiplication to determine an azimuthal correction factor. These correction factors are shown in Table 5-1 and Figure 5-1.

As the accuracy of the data, the azimuthal correction factor does not show a dependence on the number of poison wires remaining in the core. It does show a large error for a detector either adjacent to the test drum or opposite the test drum and relatively small error at 90° to the test drum. This small error at 90° and the linearity of the azimuthal variation indicates that this location will provide the single, most accurate indication of multiplication.

TABLE 5-1

DEVELOPMENT OF AZIMUTHAL DETECTOR RESPONSE CORRECTION FACTORS

Reactor Drum Configuration (Bank at 0°) No. 8	No. 9	No. 10	Number of Central Poison Wires	Normalized Count Rates: Count Rate (all drums 0°) / Count Rate SU[1]	DAS-2[2]	DAS-3[3]	Azimuthal Detector Correction Factors: (Actual Multiplication / Detector Response) SU	DAS-2	DAS-3
0°	0°	0°	276	1.00	1.00	1.00	0.986	0.910	1.145
0°	115°	0°		0.876	0.859	0.886			
115°	115°	0°		0.747	0.726	0.781			
115°	115°	115°		0.622	0.590	0.674			
0°	0°	0°	852	1.00	1.00	1.00	1.032	0.821	1.182
0°	115°	0°		0.946	0.941	0.957			
115°	115°	0°		0.886	0.836	0.898			
115°	115°	115°		0.835	0.793	0.856			
0°	0°	0°	1260	1.00	1.00	1.00	1.020	0.852	1.150
0°	115°	0°		0.981	0.936	0.970			
115°	115°	0°		0.924	0.875	0.939			
115°	115°	115°		0.898	0.846	0.910			

1. Located at 90° to the R-1 test sector (see Figure 3-1 for further information).
2. Adjacent to R-1 test sector.
3. Opposite R-1 test sector

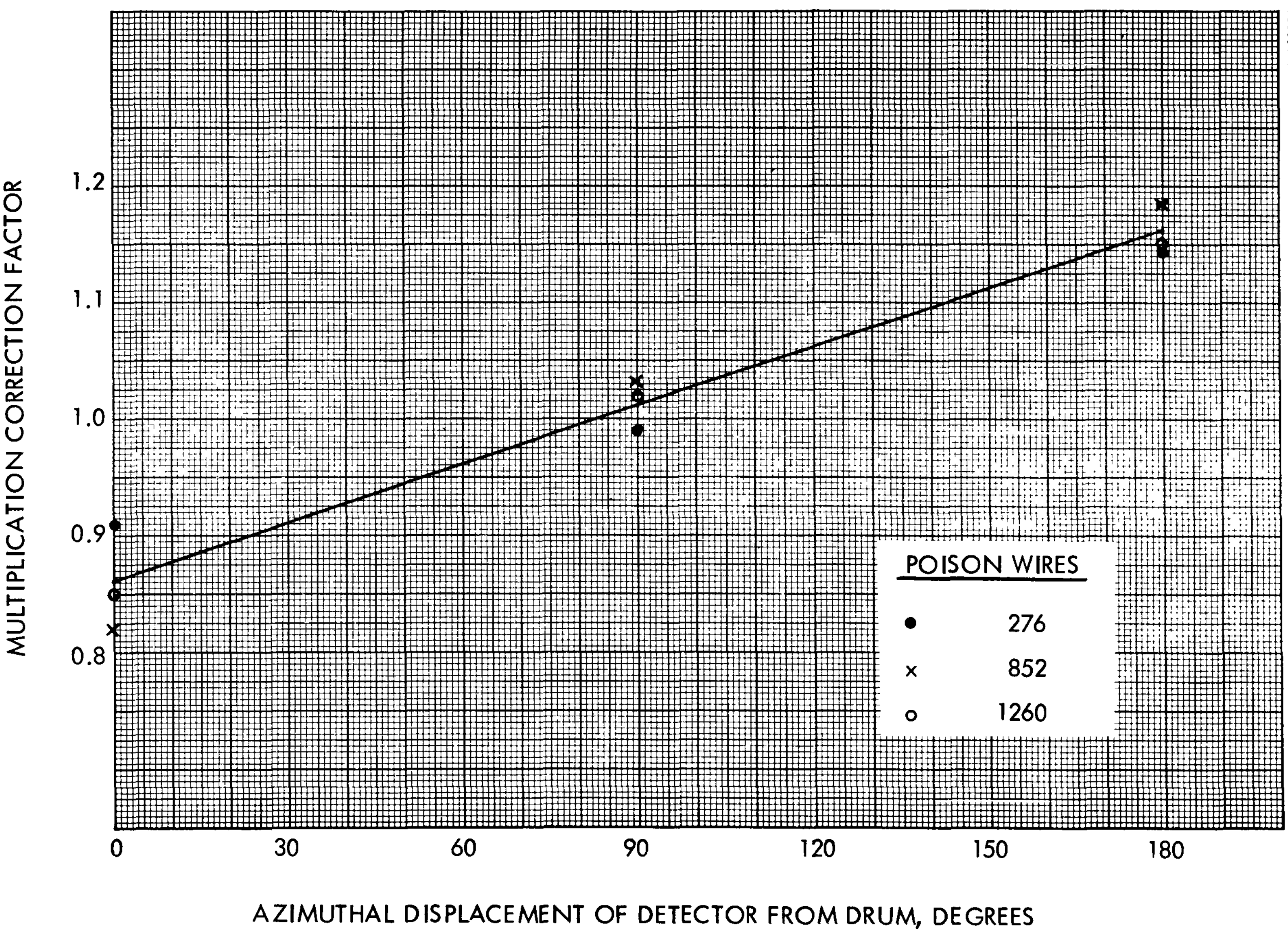


Figure 5-1. Azimuthal Detector Response Correction Factor

5.3 FUTURE USE OF DATA

Prior to the NCX approach-to-critical, the anomalies in NRX-A5, A6 and XE-Prime will be re-investigated in light of the information gained from this experiment. The NCX approach-to-critical will be designed to discover the accuracy of the subcritical predictions of the critical bank angle as a function of the level of shutdown. This will determine the utility of subcritical predictions with respect to accuracy requirements.

6.0 CONCLUSIONS

Utilization of centrally-located sources (at the reactor midplane in the central cluster) resulted in an essentially linear inverse count rate versus poison wire during the approach-to-critical experiment.

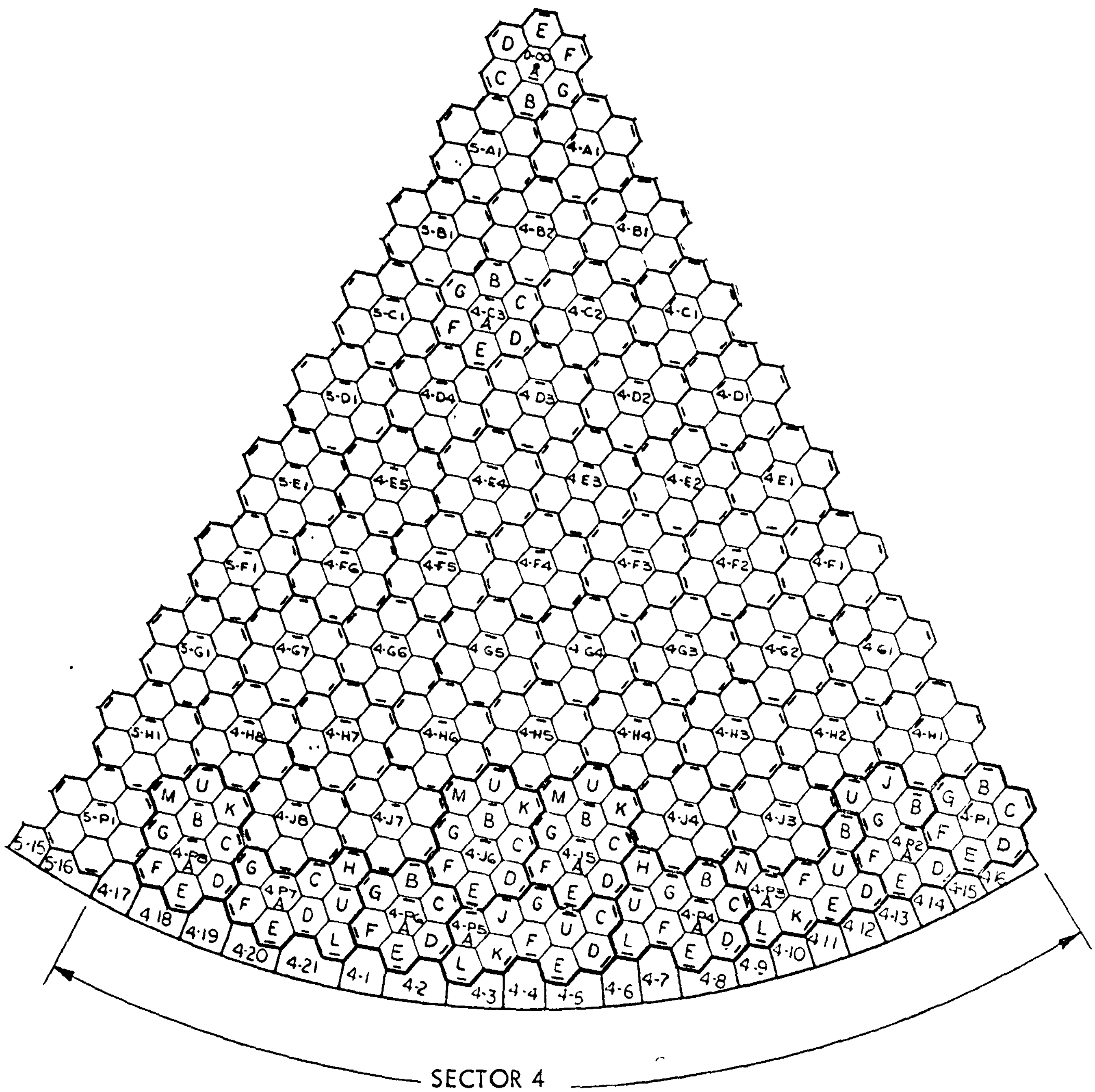
The asymmetry of the apparent multiplication with detector azimuthal position in the drum roll-out experiments was clearly demonstrated. A detector placed at 90° from the test drum appears to give the single, most accurate estimate of the actual change in multiplication. This information should be factored into the NRX-A5, A6 and XE-Prime critical predictions from drum roll-out to determine whether detector location was responsible for the observed errors.

These results will be incorporated into the development of the test procedure for the NCX approach-to-critical experiment which will lead to the standardized approach-to-critical procedure.

APPENDIX A
THE PAX-G0 REACTOR DESCRIPTION

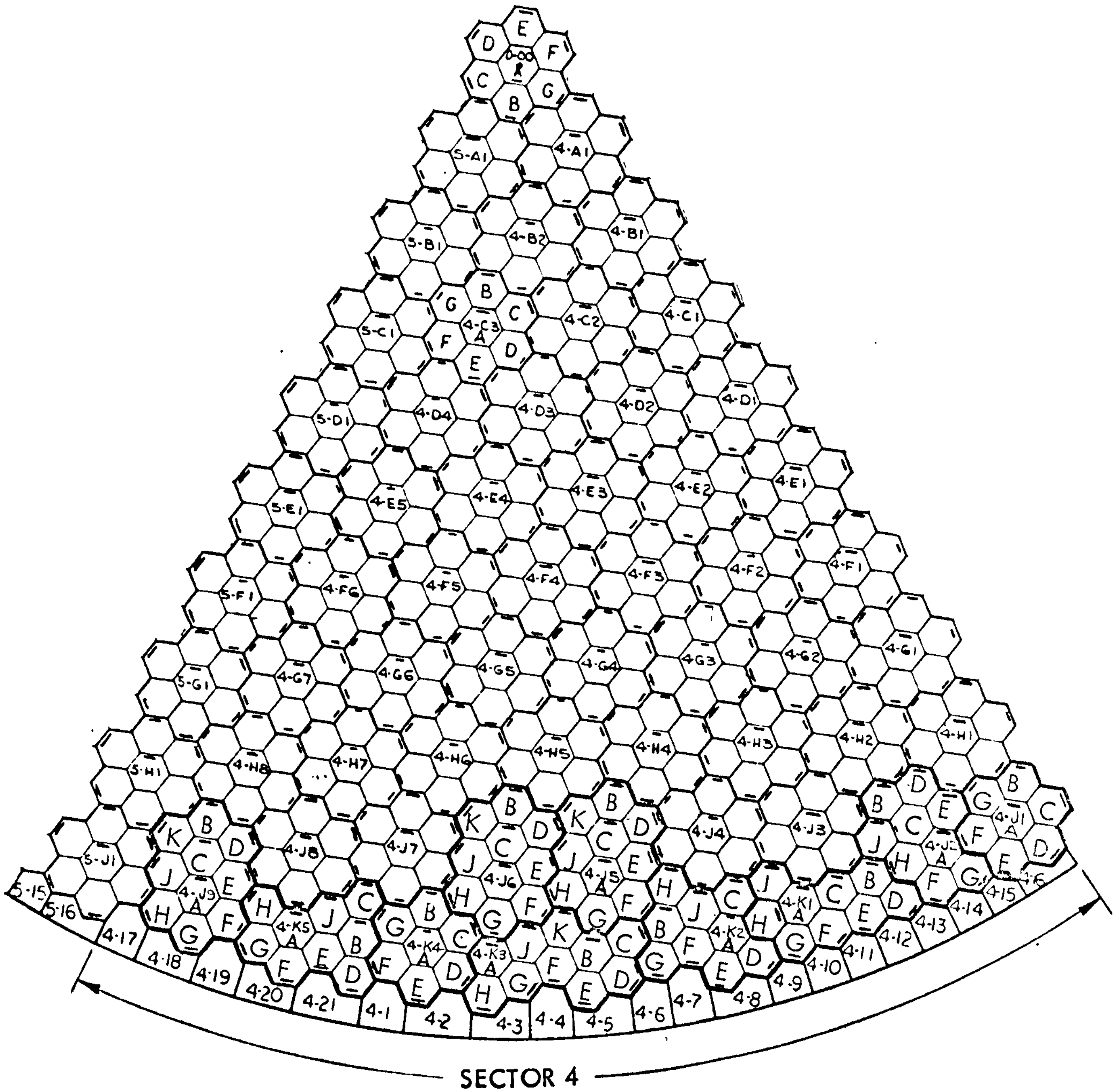
The PAX-G0 reactor is described in Drawing 711J496.

DRM 51150 contains a listing of the actual fuel elements and the actual and/or representative as-built weights for the reactor components. Also contained in this DRM is a listing of the shim wire locations. Chemical analyses of the different shim wires may be found in DRM 51186. It should be noted that all element position listings are in the PAX/R-1 notation and not in the R-1 notation. The only difference between the two notations is in the peripheral region of the core. In the former, the clusters are given J and K designations. In the latter, J and P notations are used. The former notations, however, correspond to the actual as-built conditions while the latter correspond to an R-1 Reference Design. Figures A-1 and A-2 contain a one sector representation of the two different notations.



LOOKING FORWARD
R-1 NOTATION

Figure A. 1. PAX/R-1 Core Notation (U)



LOOKING FORWARD
PAX R-1 NOTATION

Figure A. 2. R-1 Core Notation (U)

TABLE A-1

CHEMICAL ANALYSIS FOR SHIM WIRES

Copies of actual or representative chemical analyses, as supplied by the vendor, for the different shim wires used in the PAX-G0 reactor are contained in Sections 1 through 4 of this Table, on the following pages.

1. TYPICAL CHEMICAL ANALYSIS FOR 0.031" OD "X" MATERIAL SHIM WIRE

FANSTEEL
METALLURGICAL CORPORATION
NUMBER ONE TANTALUM PLACE
NORTH CHICAGO, ILLINOIS • 60064
Phone 312/336-4900 TWX 312/244-4530

CERTIFICATE OF ANALYSIS

Date May 25, 1966

Customer Westinghouse Electric Corp.

Purchase Order No. 39NYB5776

Material Molybdenum Wire 0.031" x coil

Production No. 434-W24318-1 Lot No. 589-B-2 Quantity 6.565 kgs

TYPICAL CHEMICAL ANALYSIS

C	20 PPM
N	10 PPM
O	40 PPM
Ca	10 PPM
Cr	10 PPM
Cu	10 PPM
Fe	30 PPM
Mg	10 PPM
Ni	30 PPM
Si	50 PPM
W	80 PPM
Ag	Less than 10 PPM
Al	Less than 10 PPM
Co	Less than 10 PPM
Mn	Less than 10 PPM
Sn	Less than 10 PPM
Ti	Less than 100 PPM
Zr	Less than 100 PPM

Molybdenum 99.95% Min.

FANSTEEL METALLURGICAL CORPORATION

2. TYPICAL CHEMICAL ANALYSIS FOR 0.040" OD "X" MATERIAL SHIM WIRE

FANSTEEL
METALLURGICAL CORPORATION
NUMBER ONE TANTALUM PLACE
NORTH CHICAGO, ILLINOIS • 60064
Phone 312/336 4900 TWX 312/244 4530

CERTIFICATE OF ANALYSIS

Date May 9, 1966

Customer Westinghouse Electric Company

Purchase Order No. 59NYB85778

Material Molybdenum Wire 0.040" x Coil

Production No. 434-024318-2 Lot No. 585C-2 Quantity 15.600 Kgs.

TYPICAL CHEMICAL ANALYSIS

C	20 PPM
N	10 PPM
O	40 PPM
Ca	10 PPM
Cr	10 PPM
Cu	10 PPM
Fe	30 PPM
Mg	10 PPM
Ni	30 PPM
Si	50 PPM
W	80 PPM
Ag	Less than 10 PPM
Al	Less than 10 PPM
Co	Less than 10 PPM
Mn	Less than 10 PPM
Sn	Less than 10 PPM
Ti	Less than 100 PPM
Zr	Less than 100 PPM

Molybdenum 99.95% Min.

Quality Control Representative

FANSTEEL METALLURGICAL CORPORATION

3. CHEMICAL ANALYSIS FOR 0.068" OD NIOBIUM SHIM WIRE

FANSTEEL
[redacted]
NUMBER ONE TANTALUM PLACE
NORTH CHICAGO, ILLINOIS • 60064
Phone 312/689 4900 TWX 312/244 4530

CERTIFICATE OF ANALYSIS

Date Dec. 22, 1967

Customer Westinghouse Electric Corp.
Astro-Nuclear Laboratory

Purchase Order No. 59MXB94156

Material Columbium Ingot As Forged - 2.375" diameter x RL

Production No. 896-033794-1 Lot No. 89B2149 89B2153 Quantity 500 Kgs.

CHEMICAL ANALYSIS

LOT ANALYSIS

89B2149			89B2153		
C	23	ppm	C	30	ppm
O	42	ppm	O	75	ppm
N	20	ppm	N	19	ppm
H	5-	ppm	H	5-	ppm
Ta	450	ppm	Ta	360	ppm
W	100-	ppm	W	100-	ppm
Zr.	50-	ppm	Zr	50-	ppm
Mo	100-	ppm	Mo	100-	ppm
Ti	20-	ppm	Ti	20-	ppm
Fe	50-	ppm	Fe	50-	ppm
Ni	20-	ppm	Ni	20-	ppm
Si	50-	ppm	Si	50-	ppm
Mn	20-	ppm	Mn	20-	ppm
Ca	20-	ppm	Ca	20-	ppm
Al	20-	ppm	Al	20-	ppm
Cu	20-	ppm	Cu	20-	ppm
Sn	20-	ppm	Sn	20-	ppm
Cr	20-	ppm	Cr	20-	ppm
V	20-	ppm	V	20-	ppm
Co	20-	ppm	Co	20-	ppm
B	2-	ppm	B	2-	ppm
Cd	5-	ppm	Mg	20-	ppm
Mg	20-	ppm	Cd	5-	ppm
Hf	100-	ppm	Pb	20-	ppm
Pb	20-	ppm	Hf	100-	ppm
Cb	Balance		Cb	Balance	

Quality Control Representative
mb

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OF PROGRESS

801-41

Astronuclear Laboratory

4. A CHEMICAL ANALYSIS FOR THE 0.077" OD NIOBIUM SHIM WIRE

KAWECKI CHEMICAL COMPANY

CERTIFICATE OF COMPLIANCE

Date June 7, 1966

To Westinghouse Electric Co.
Astronuclear Laboratory
P. O. Box 10864
Pittsburgh, Penna. 15236
Attn: G. R. Bock

Ship To Same
Route 51
Largo, Pennsylvania

Specification No. --

Customer P. O. No. 59NZD76195

Drawing No. --

K.C.C. O. No. 36220

ITEMS AND/OR MATERIALS

(1) 6,000 Ft. Niobium Wire, Metallurgical Grade, Annealed,

99.8% Minimum:

.078" ± .003" Diameter (4780)

CHEMICAL ANALYSIS

Ingot#2661-C

C	30ppm	O_2	115ppm
H_2	13.1	N_2	10
Ta	550	Ti	<10
Fe	60	Mn	10
Si	20	Sn	ND<10
Ni	<10	Cr	<10
Ca	<10	Na	ND
Al	30	Mo	ND<10
Zr	ND<100	Co	ND<10
Mg	<10	B	ND<10
W	ND<100		

1. *Raw Materials*
 X We certify that the raw materials used for the items listed conform to accepted commercial specifications.
 ____ We certify that the raw materials used for the items listed conform to your specifications.
2. *Product*
 X We certify that the items listed conform to commercial specifications and to your order.
 ____ We certify that the items listed conform to your specifications.
3. Suitable evidence of compliance to your requirements is available in our files.

Witnesses:
1. ____________
2. ____________

Sworn to before me this ________
day of ____________, 19____
____________ *Notary Public*

John M. Muir Authorized Signature
Chief Inspector

Attachment(s)

APPENDIX B

THE PAX-G0 INITIAL CRITICALITY EXPERIMENTAL PROCEDURE

In accordance with WANEF procedures,* an Experimental Details Checklist (EDC) was written to set forth the details of assembling the PAX-G0 reactor and bringing it to clean criticality as well as evaluating any nuclear hazards resulting from such an operation. Those portions of the experimental procedure applicable to this TME may be found in Parts 2 and 3 of the EXPERIMENTAL DETAILS section of EDC 66.** The body of EDC 66 is contained in this appendix.

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* For further details, see WANL-TME-267, Revision H. "Westinghouse Astronuclear Experimental Facility Reactor Operations Manual".

** In order to conform to the test scope requirements, Part 2b of the EXPERIMENTAL DETAILS section should be revised to read: After each poison removal step, the data taken in Part 2a will be repeated in the same sequence as given above except that the 115° data need only be taken a total of three times during the entire wire removal process.

WANEF EXPERIMENTAL DETAILS CHECKLIST

No. 66

Date 12/19/68

TITLE OF EXPERIMENT: PAX/R-1 (KIWI) (PAX-G0) Fuel Loading, Poison Wire Removal, Criticality, and Control Drum Worths*

OBJECTIVES:

1. To load the PAX-G0 fuel clusters.

2. To perform 1/M measurements during initial approach to criticality, including 1-, 2-, and 3-drum roll-out information.

3. To remove poison wires and attain clean criticality with a predicted drum bank angle of approximately 115 degrees.

4. To shim the core through the use of niobium wires (and beryllium shim rods in the reflector, if required) to attain a delayed critical drum bank angle of 115 degrees.

5. To perform drum worth measurements in preparation for PAX/R-1 (Build 1)(PAX-G1).

EQUIPMENT REQUIREMENTS:

1. A full core of fuel clustered and poisoned, as given in Appendix I. The fuel will contain an initial loading of Nb wires as indicated in Appendix II.
2. A special cluster for position 000 complete with the loading source.
3. Additional niobium wires and beryllium rods, as required for shimming to the final delayed critical drum bank position.
4. An assembled reflector consisting of 12 KIWI sectors with PAX drums and graphite liner plates installed. The control drum system will have been checked out to assure compliance with operational limits.
5. Fuel support assembly and miscellaneous hardware needed for a reactor assembly.
6. Four data channels for the 1/M measurements, of which a minimum of three are required.
7. The WANEF reactivity computer and recorder.

HAZARDS CONSIDERATIONS:

Since the PAX-G0 reactor has not been previously assembled, the fuel will be poisoned before insertion into the reactor to assure that the reactor will be shut down by 20$ per S.O.P. 5.5.1.2.1. Based upon past data**, credit for the poison wires will be taken at the rate of 1.1¢ per wire for the first 350 wires, and 0.9¢ per wire for the remaining wires. A credit of 3.25$ will also be taken for the shutdown in the 12 drums. Using the standard loading of 42 poison wires per cluster cup, 43 full cluster cups are

* In response to Scope of Test Document M 58 DW-216-0, 12/20/68

** A differential poison wire worth obtained in the PAX-E reactor is shown in Figure 1. Since the PAX-G0 neutron spectra near the center of the core would be very close to that in the PAX-E reactors, it is felt that this wire worth curve can be used with a reasonable degree of confidence.

required to provide the necessary 20$ shutdown. For purposes of symmetry, we will actually employ 48 cluster cups full of the poison wires. These cluster cups will be positioned in every cluster in Rows A, B, and C, and in two clusters in each sector for Row D.

Three data channels and their associated polyethylene moderator will be positioned in a horizontal attitude next to the pressure vessel supported by the test stand deck before loading begins. Since they are at the position of maximum worth (core midplane), any reasonable displacement of these polyethylene-wrapped detectors will result in a negative reactivity insertion of only a few cents. After the removal of all of the poison wires, these detectors will be removed from the test stand deck. Thus, the presence of these detectors next to the reflector presents no nuclear safety hazard. The fourth channel (polyethylene-wrapped detector) will be placed underneath the dome end of the reactor. Any failure of its support would cause only a negative reactivity insertion. Thus, no nuclear safety hazards are presented by the new position of this detector.

Assembly of the core and removal of the poison wires to attain initial criticality, and clean criticality will be done according to S.O.P.'s 5.5.1, 5.5.2, and 5.5.3, respectively. To obtain all of the requested information during the approach to initial criticality, however, 1/M data in addition to the standard 1/M data required during the approach to critical will be required. Since these additional measurements will only entail running a maximum of 3 drums to 115 degrees, with the remaining 9 drums at 0 degrees, this additional data will present no unevaluated safety hazard.

The interchange of the special clusters containing the loading source and the cluster specified for 000 will present no unevaluated safety hazard since the reactivity change will be of the order of a few cents.

Drum worth measurements, when performed within the limitations described herein and in the WANEF OLD, present no unevaluated hazards.

All operations will be performed within the limitations set forth in the OLD and in the framework of the SAR as amended for the PAX/R-1 experiment.

XPERIMENTAL DETAILS:

1. The reactor will be loaded with poisoned fuel in accordance with the loading sheets provided in Appendices I and II. In accordance with S.O.P. 5.5.1, the following steps will be taken:

   a. A loading source will be installed in cluster 000 before any fuel is loaded in the core.

   b. At least 3 pulse channels having adequate detector response to the loading source and core, will be used to obtain 1/M data. One detector (associated with the "flux-up" interlock) shall have a minimum count rate of 120 cpm.

c. The fuel will be added to the reactor in an incremental manner from the center outwards using the core assembly frame.

d. The initial fuel increment will not exceed 10% of the total fuel complement in the assembled reactor. Each succeeding increment will be no more than 20% of the total fuel complement or 1/2 of the extrapolated additional fuel loading required for criticality, whichever is the smaller. The count rate data upon which to base this extrapolation will be obtained after each increment with the control drums at zero degrees and a plot of the inverse count rate vs. the number of fuel clusters in the reactor will be constructed. Count rate data will be taken as a series of five one-minute counts which will be individually examined for spurious response.

e. After the core and filler strips have been completely assembled, the core will be bundled using the core bundling device and the PASS cans will be inserted. The bundling devices will be torqued alternately in sequence in 5-inch-lb. increments until a total of 30-inch-lb. is applied to each bundling device. A final count rate will then be taken.

2. In order to obtain initial criticality, the poison wires will be removed in an incremental manner in accordance with S.O.P. 5.2.2. The following steps will be taken:

a. Before any poison wires are removed, count rate data will be obtained with at least three pulse channels for a drum bank position of zero degrees. Drum 9 will then be driven to 115° and additional count rate data obtained. Drum 8 will then be driven to 115° and a second set of count rate data obtained. Drum 10 will then be driven to 115° and a third set of count rate data taken. Drums 8, 9, and 10 will then be driven back to 90° and the remaining 9 drums will be driven to 90° in order to take additional count rate data. Finally, the whole bank will be driven to 180° and the final set of count rate data will be taken. After each step, a plot will be made of the inverse count rate vs. the amount of poison in the reactor. Finally, the drum bank will be scrammed to 0° in preparation for removing the next poison wire increment. The initial increment of poison removed would be no more than 20% of the initial content. Each succeeding increment removed would be no more than the smaller of 20% of the initial poison content or 1/2 of the extrapolated additional poison removal required for criticality with the drums full out. Data obtained with the control drums full out will be utilized for the prediction of criticality.

b. After each poison removal step, the data taken in Part 2a, will be repeated in the same sequence as given above.

c. The final poison increment to be removed will be specified by the Experimentalist such that the 50¢ excess reactivity limit is not exceeded. After initial criticality, a measurement of the shutdown will be performed by the standard "rod drop" method.

3. Clean criticality will be obtained by removal of the remaining poison wires in accordance with S.O.P. 5.5.3, in the following manner:

a. The remaining poison wires will be removed in increments such that the positive reactivity insertions are not greater than 50¢.

b. The bank position for delayed critical and period measurements will be determined after each increment until all of the poison wires have been removed. From this, one will obtain a calibration of the drum bank position as well as a differential wire worth curve.

c. The core shutdown reactivity will be monitored at each step by 1) a delayed critical bank position vs. poison wire content, 2) rod drop shutdown measurements, or 3) by integrating differential bank worth measurements.

d. In the event that poison wires remain in the core and shutdown measurements indicate the minimum shutdown limit of $3.40 would be violated by further removals, Nb wires will be inserted into the core in accordance with Appendix III in order that the minimum shutdown is not compromised. Nb wires will thus be traded for the poison wires until all of the poison wires are removed.

e. In the event that all poison wires are removed and the delayed critical drum bank position is less than 115°, Nb wires will be added in accordance with Appendix III in order to bring the delayed critical drum bank position to 115°.

f. In the event that the clean critical drum bank position is between 115° and 180°, a decision will be made whether to remove Nb wires or insert Be shims. Otherwise, Be shims will be inserted into the reflector in accordance with Appendix IV to bring the delayed critical drum bank position to 115°. If the decision is made to remove Nb wires, they will be removed according to Appendix III.

g. After all poison wires have been removed, the special cluster in 000 containing the loading source will be removed and the specified central cluster (see Appendix I) will be inserted in its place.

4. Individual control drum worth measurements will be performed within the limits set forth in the OLD and will be done in the following manner:

   a. The reactor will be brought critical with Drum No. 1 at 180° with approximately a 20¢ period. The positioning of the remaining drums should agree with each other within ± 1/2 degree. At a power level between 5 and 10 watts (as determined by the input requirements of the reactivity computer), Drum 1 will then be driven full in* and the output of the reactivity computer recorded on a recorder. The computer operator will record the positions on the curve as the drum passes through 10° increments as determined by the drum position readout on the console.

   b. The procedure designated in part a, will then be followed for the remaining drums until all the drum worths have been obtained.

DATA REQUIRED:

1. A complete description of the PAX-G0 reactor including but not limited to a parts list, a clustering assignment list and weights (actual or representative) of all core and reflector components.

2. Location, size, and weights (actual and representative) of all Nb wire placed in the core.

3. Standard 1/M measurements during the core loading procedure.

4. 1/M measurements during poison wire removal with all drums at 0°, 90°, and 180°. Also, 1/M measurements with Drums, 9, 8, + 9, and 8 + 9 + 10 at 115° with the remaining drums at 0° for a minimum of three wire pulls. The latter shall be taken with (1) a full load of poison wires, (2) approximately 1000 wires, and (3) no wires in the core. A minimum total of 10^4 counts in each data channel is desirable.

5. θ_{DC} and number of remaining poison wires at initial criticality.

6. θ_{DC}, incremental wire worth curve, and shutdown measurements vs. number of wires remaining in core during attainment of clean criticality.

7. Integral and differential drum bank worth.

8. Integral individual drum worth measurements.

9. Be worths or Nb worths of shimming (as required).

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* The estimated worth of the PAX-G0 drums are $.60 each. Based on past experience, the initial + 20¢ reactivity is necessary in order that meaningful data may be obtained when the drum is full in and the power level has decreased considerably.

WRITTEN BY J. W. Rowland Date 12/23/68
J. W. Rowland

SIC F. S. Frantz Date 12-20-68
F. S. Frantz

MANAGER, NRD W. P. Kovacik Date 12-20-68
W. P. Kovacik

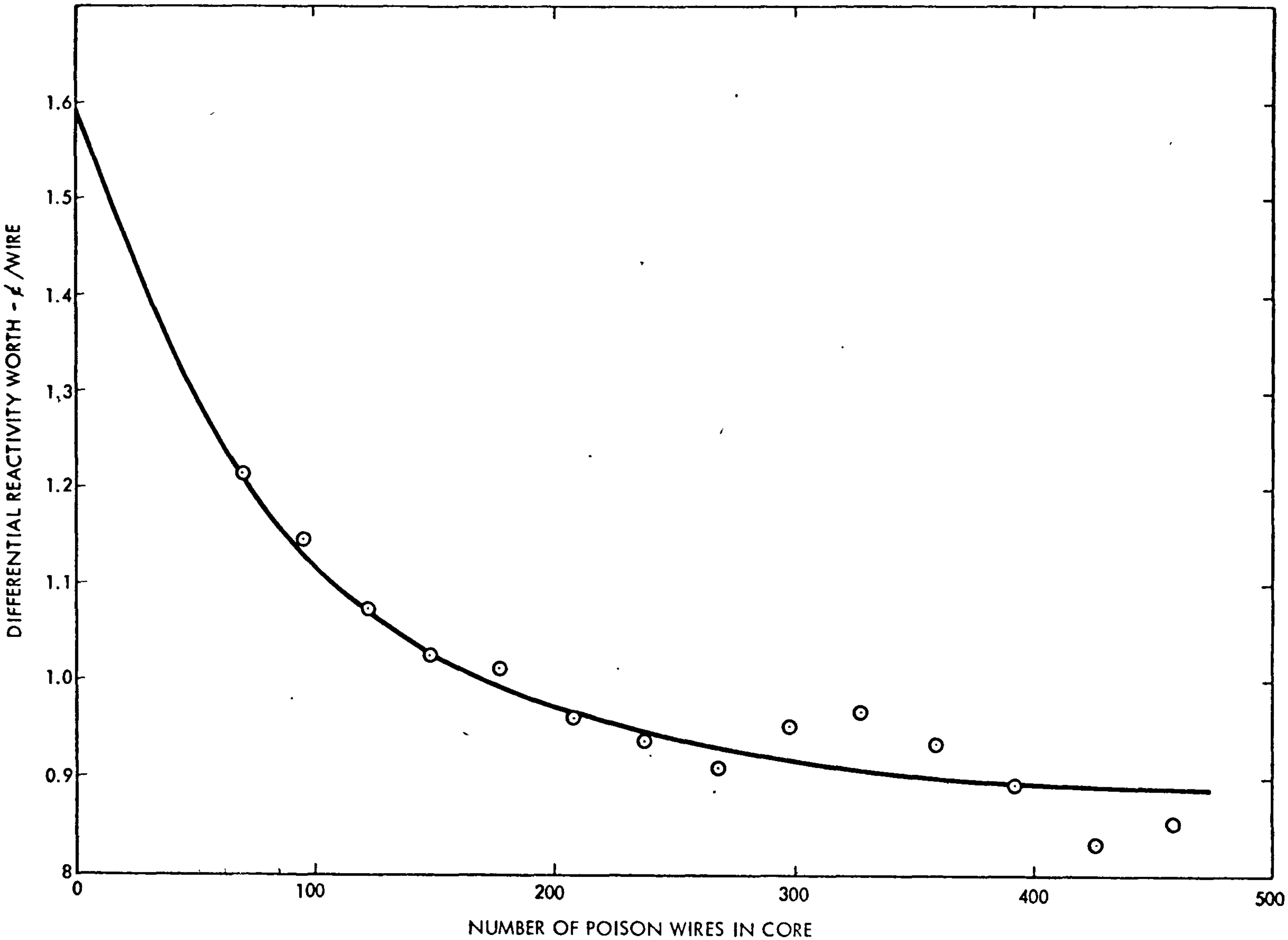

Figure 1. Differential Poison Wire Worth

Astronuclear Laboratory

TITLE

PAX-G0 Approach to Critical

DOCUMENT NO. WANL-TME-1909

DATE October, 1969

ABSTRACT

An experiment was performed to assist in development of an approach-to-critical procedure to determine accurate criticality estimates from subcritical multiplication measurements during the shipping poison wire removal operation.

A clear dependence of the apparent multiplication to the source/detector and test control drum configuration was demonstrated. A detector placed at 90° from the test drum with a centrally located neutron source appears to give the single, most accurate estimate of the actual change in multiplication.

Fold or Cut

Fold or Cut

DATA ITEM NO. T-119

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