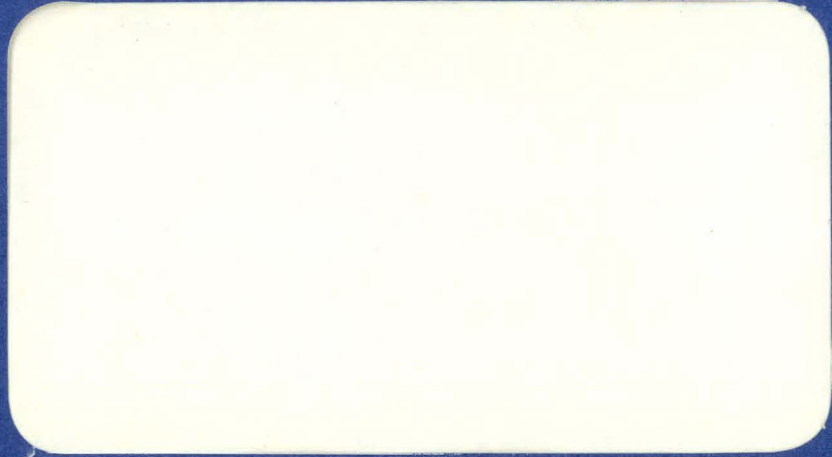




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SAXTON PLUTONIUM PROGRAM  
SEMIANNUAL PROGRESS REPORT  
FOR THE PERIOD  
ENDING DECEMBER 31, 1966

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Project Manager

Prepared for the New York Operations Office  
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## SUMMARY

This semi-annual report replaces the ninth and tenth quarterly reports previously planned and covers the work done during the first half of fiscal 1967.

### Objectives

The purpose of the Saxton Plutonium Project is to develop information concerning the utilization of plutonium enriched fuel in pressurized water reactor systems, through design, fabrication and operation of a partial core of  $\text{PuO}_2\text{-UO}_2$  in the Saxton reactor. Inpile performance of this fuel will be evaluated and post-irradiation examination of fuel samples will be made. Performance will be analyzed and compared with analytical predictions.

### Project Administration

Core II has been operated at or near full power during most of this period with two major shutdowns to carry out routine plant maintenance and to install the inpile supercritical loop.

### Nuclear Analyses of Operating Performance

During the reporting period, the first and second scheduled intermediate shutdowns took place and an abbreviated program of physics measurements

was carried out. At the close of the period the core had operated for 5450 MWD and had achieved an estimated burnup of 6530 MWD/MTM\* average for the core, 10,740 MWD/MTM average for the plutonium enriched region, 14,920 MWD/MTM average for the peak power plutonium rod, and 21,180 MWD/MTM for the peak pellet. This average burnup in the plutonium fuel exceeds the initial burnup objective of 10,000 MWD/MTM in the plutonium region. Core burnup and reactivity characteristics were followed and compared with analysis. The comparisons were generally in agreement.

#### Post-Irradiation Examination and Materials Evaluation

Post-irradiation evaluation of two vipac and two pellet fuel rods, which were removed at an intermediate average exposure level of 4500 MWD/MTM, was started during this report period. Visual and dimensional examinations were performed on each fuel rod. The visual examinations performed with a stereomicroscope, revealed no anomalies or evidence of fretting corrosion at the area of contact with the stainless steel spring clip fingers. Fission gas samples were taken from all rods and the samples were analyzed. Gamma scans were performed along the length of all rods. Measurements made during this report period on spare plutonium rods indicate that the as-fabricated rod diameter variation, which is within specifications, is as large as the post-irradiation diameter

---

\*MWD/MTM = Megawatt days per metric ton of metal (U+Pu)

variations determined with the remote profilometer. It is therefore not possible to determine whether a significant diameter change occurred during irradiation. Comparison of post-irradiation length measurements with pre-irradiation inspection values show that both pellet and vipac fuel rods increased slightly in length during irradiation.

SAX-100 Project Administration

R. S. Miller

The remaining program objectives are: 1) to continue operating the plutonium fuel for a minimum of one equivalent full-power year in the Saxton reactor, following operation periodically and analyzing the nuclear performance of the partial plutonium core; 2) to conduct post-irradiation examination of selected fuel samples; 3) to compare nuclear and materials performance with predicted performance; and 4) to analyze any discrepancies found.

Management responsibility for the Saxton Plutonium Project was transferred from the Advanced Reactors Division to the Nuclear Fuel Division during October, 1966. At that time the status of this program, was reviewed with personnel from the Division of Reactor Development and Technology, USAEC Headquarters.

A preliminary Safeguards Report for a proposed increase in Saxton power level from 23.5 MWt to 35 MWt was prepared and reviewed by the Saxton Safety Committee in September. The Committee recommended additional studies to be incorporated in the Safeguards Report. These studies were completed and incorporated in the Safeguards Report. At the end of the report period, Westinghouse and Saxton Nuclear Experimental Corporation were continuing the final preparation of the Safeguards Report for submittal to the AEC. (This work is not funded by this program. However, it is reported here because of its relevance to this program.)

Several meetings were held with cognizant Westinghouse personnel to review the overall Saxton experimental program with respect to schedule. With the schedule as adopted, operation with the plutonium core will be completed about December, 1967.

At the end of this report period, estimated burnup was 6530 MWD/MTM average for the core, 10,740 MWD/MTM average for the plutonium enriched region, 14,920 MWD/MTM average for the peak power plutonium rod, and 21,180 MWD/MTM for the peak pellet. During this period, the plutonium fuel achieved a burnup increment of 4570 MWD/MTM average for the plutonium region, 5760 MWD/MTM average for the peak power plutonium rod, and 8780 MWD/MTM for the peak pellet.

Routine operation of the reactor at full power (23.5 MWt) was accomplished during this period with the exception of two major outages. The reactor was shut down from July 22 to August 23 to perform a vapor containment leak rate test, to change subassembly experiments and to perform routine plant maintenance. During the major portion of November the reactor was shut down for installation of the in-pile supercritical loop experiment.

## SAX-510 Nuclear Analyses of Operating Performance

F. L. Langford, Jr., R. L. Thompson, W. L. Orr

### A. Introduction

The objectives of this task are: 1) to compare the expected performance of the plutonium fuel in the Saxton reactor with experimental results and to evaluate the differences between analysis and experiment; 2) to provide supporting analyses during the irradiation period.

As part of this program two shutdowns were scheduled to carry out zero power physics tests. Data obtained in these tests, at core startup and at end of core life, will be utilized to evaluate the performance of the partial plutonium core as a function of depletion.

### B. Operation Follow Program

The operating performance of the Saxton Core II is being followed by measurements made with flux wires and in-core detectors used with the appropriate analysis. Figures 510.1 through 510.6 summarize the operating history during June, July, August September, October and November. Supporting calculations were made to follow the reactivity of the core and to determine the appropriate nuclear factors relating experimental measurements to local power. These

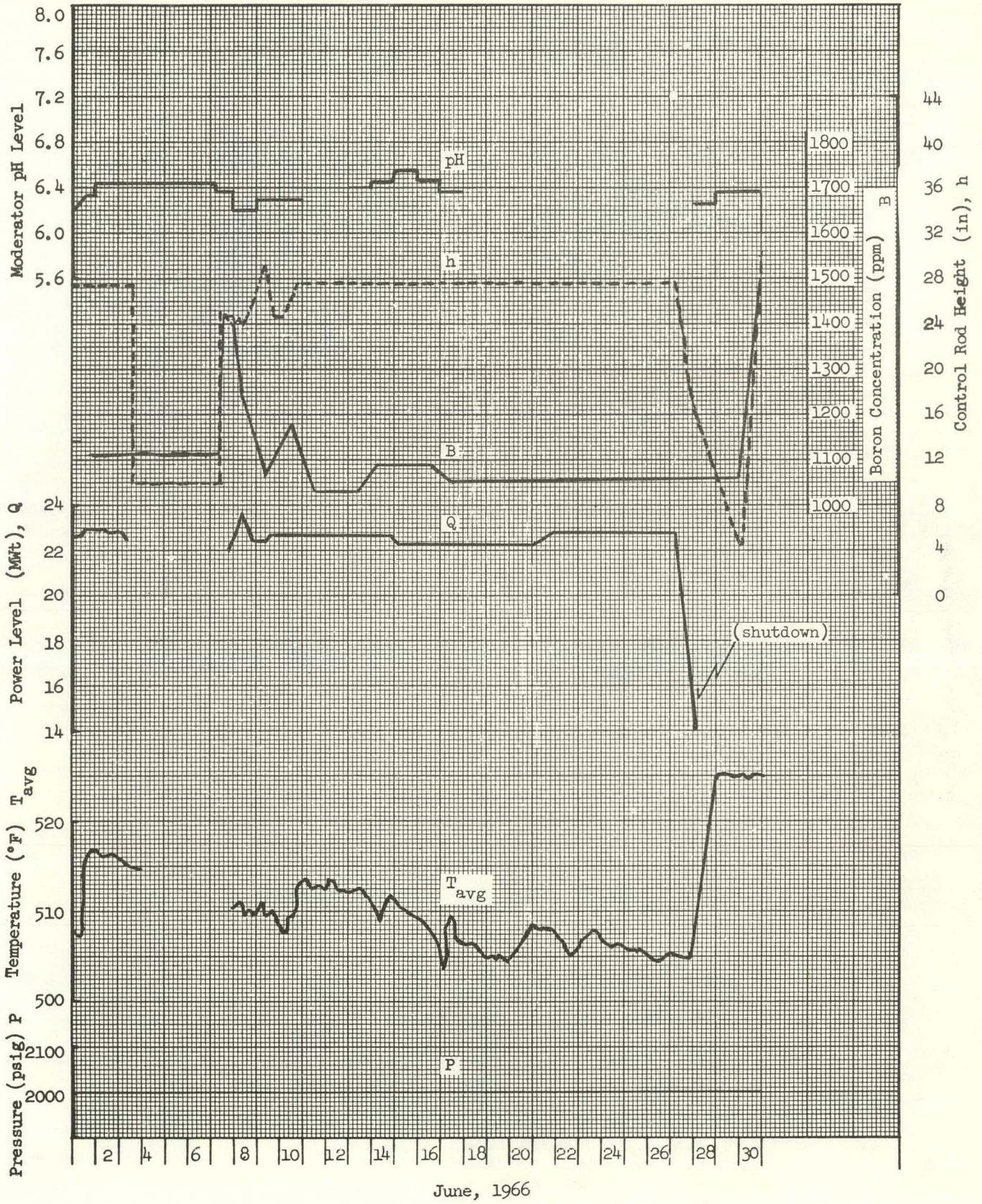


Figure 510.1 : Saxton Core II Operating History for June

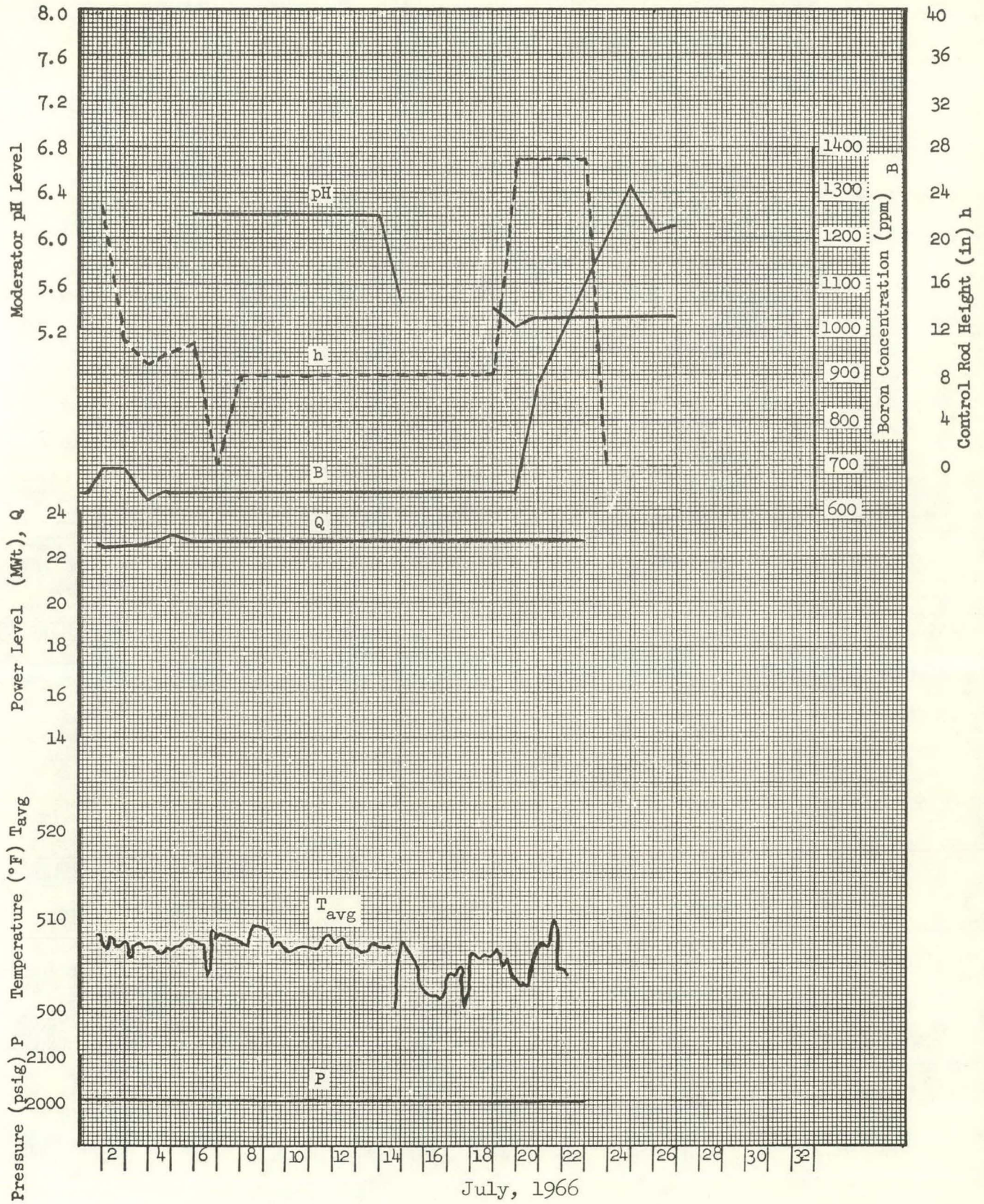


Figure 510.2 : Saxton Core II Operating History for July

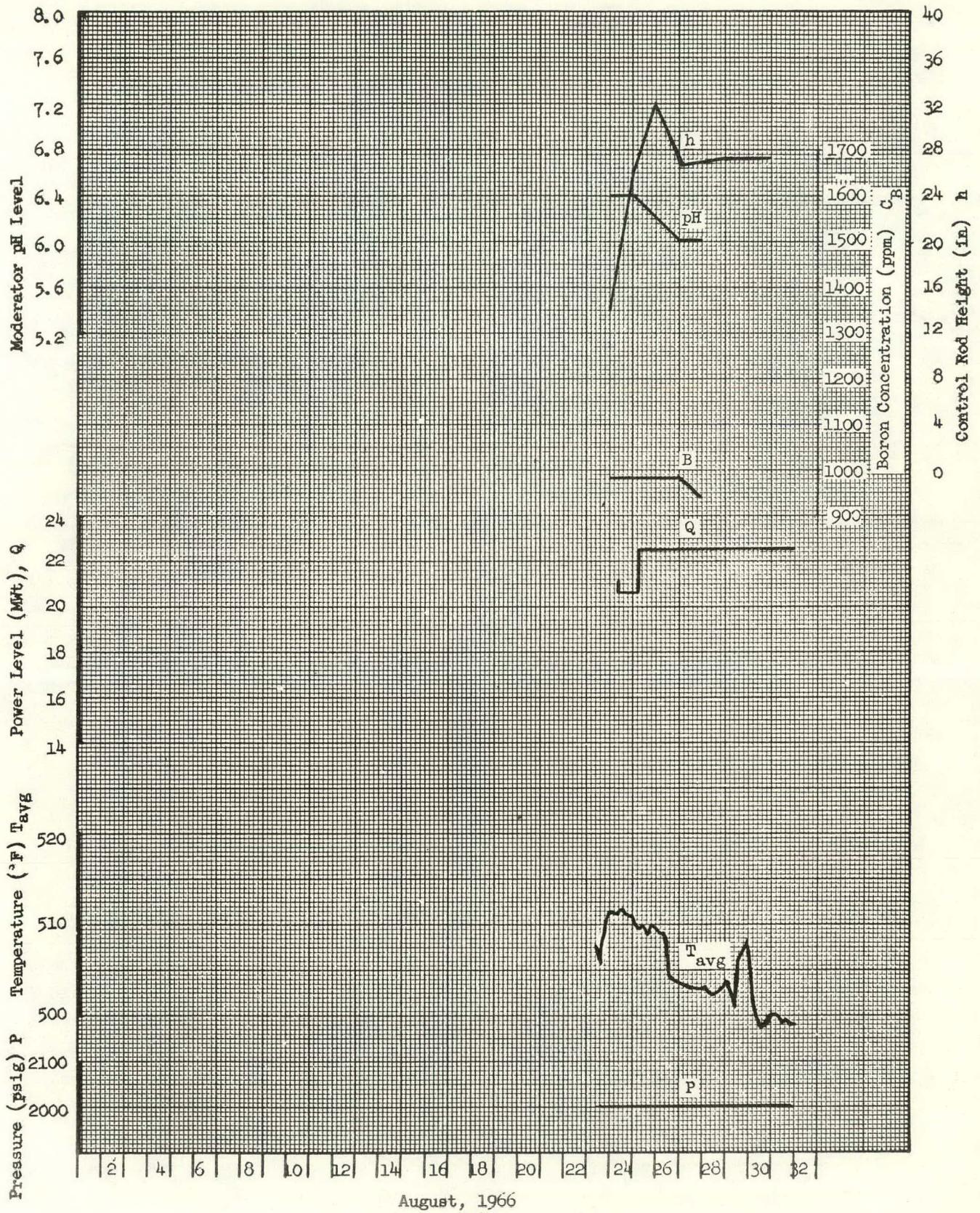
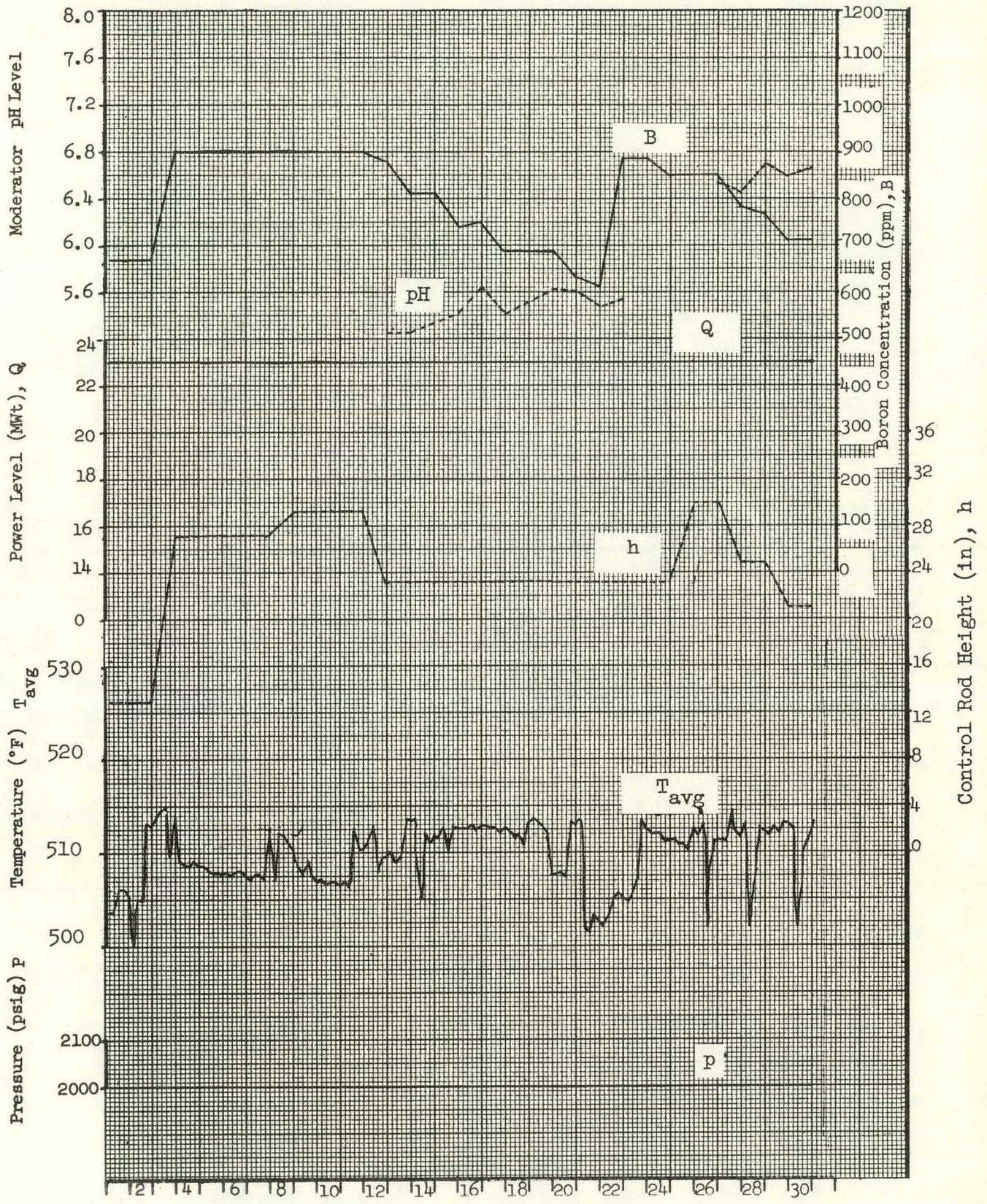


Figure 510.3 : Saxton Core II Operating History for August



September 1966

Figure 510.4.: Saxton Core II Operating History for September

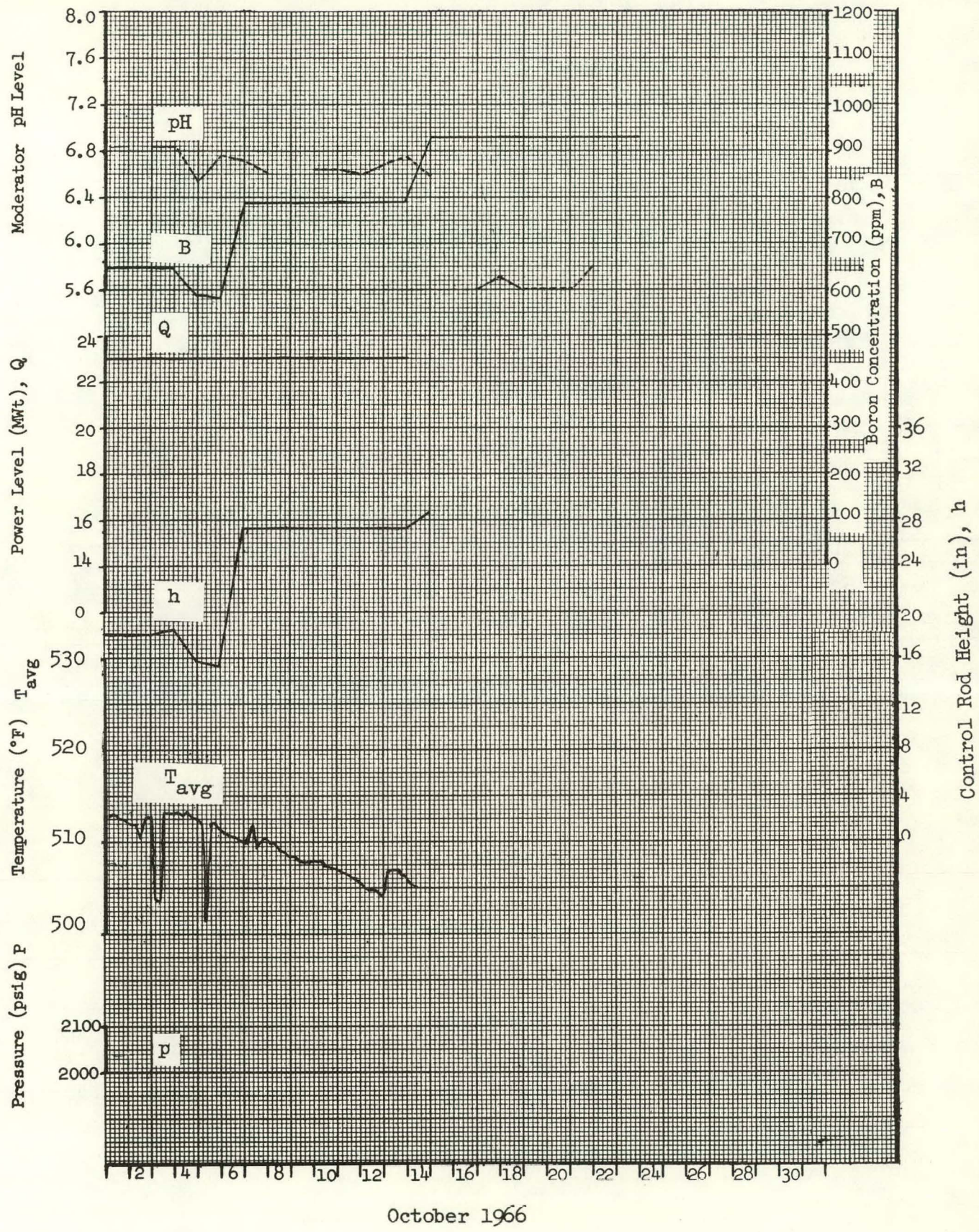


Figure 510.5 . Saxton Core II Operating History for October

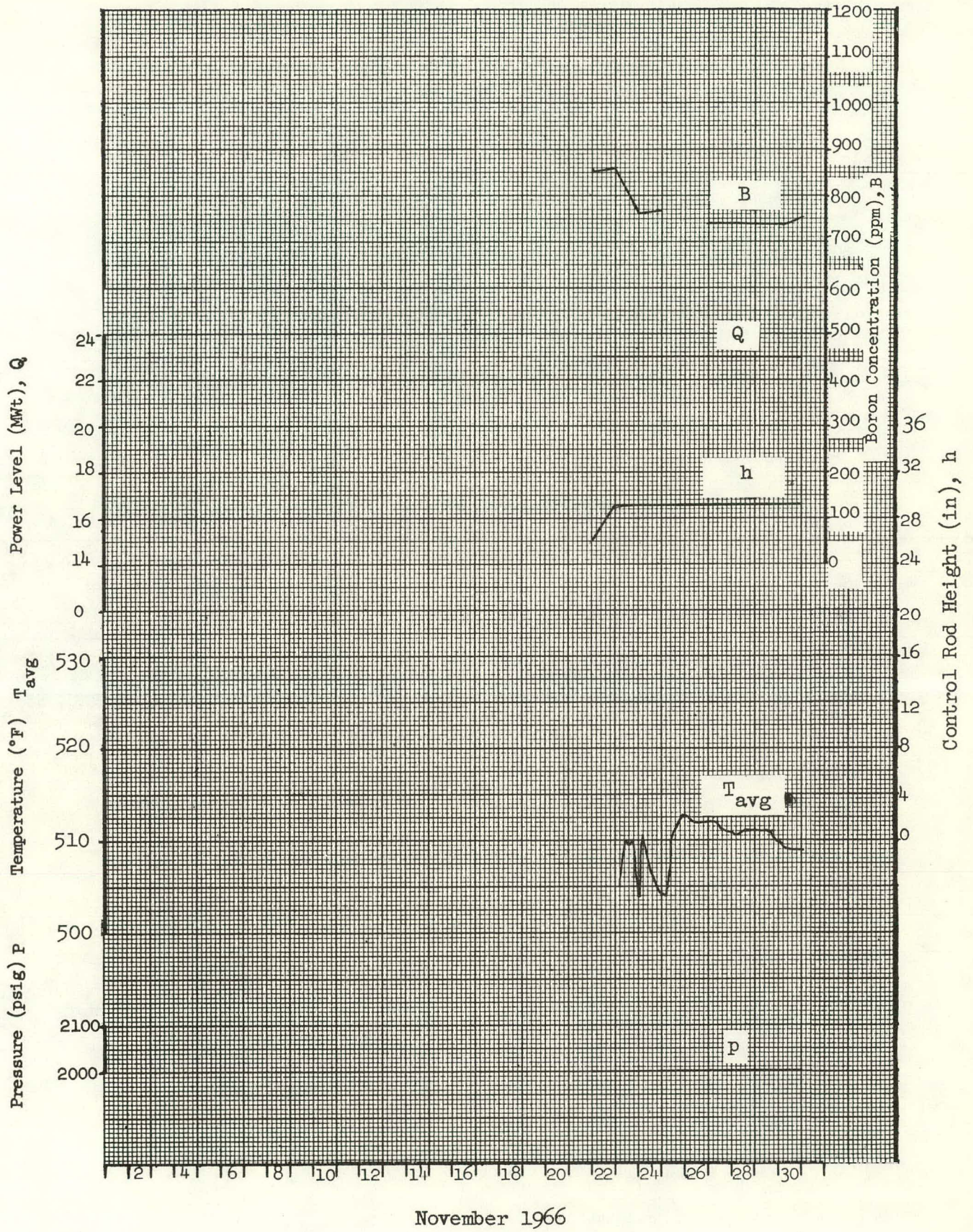


Figure 510.6 : Saxton Core II Operating History for November

calculations were carried out at core average exposure levels of 2963 MWD/MTM, 4262 MWD/MTM and 5670 MWD/MTM, using the LEOPARD-BUBBLE-PDQ sequence. Figure 510.7 shows the calculated and experimentally determined just-critical boron concentration as a function of core life. Also shown are the experimentally determined hot, zero-power, xenon-free, just-critical boron concentrations at the beginning-of-life and at core average burnups of 3716 MWD/MTM and 5670 MWD/MTM.

Numerous flux maps were made with the Saxton flux wire and miniature detector systems to determine the power distribution and relative depletion characteristics of the core. The power distribution measurements showed a reduction in power peaking which made it possible to remove previous restrictions on the position of control rod 2. Figure 510.8 shows the experimentally determined all rods out power and burnup distribution at core average burnup of 5670 MWD/MTM. Also shown is the assembly-wise power distribution determined using the LEOPARD-BUBBLE-PDQ analysis sequence.

The non-symmetrical burnup and power distribution is attributed to operation with control rod 2 partially inserted over most of the core life. The measured relative power in the center assembly is higher than calculated because of a special test subassembly in the

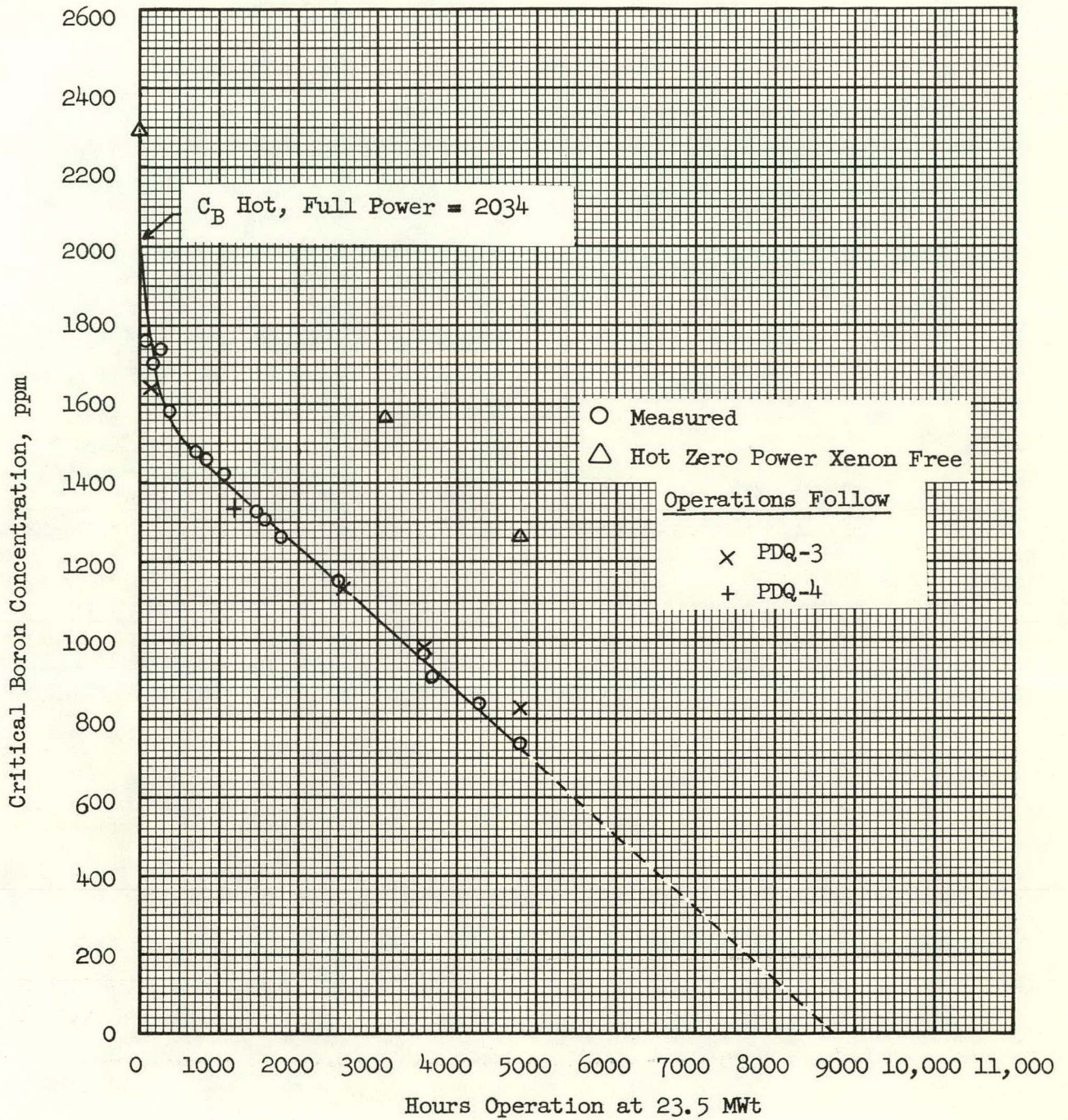
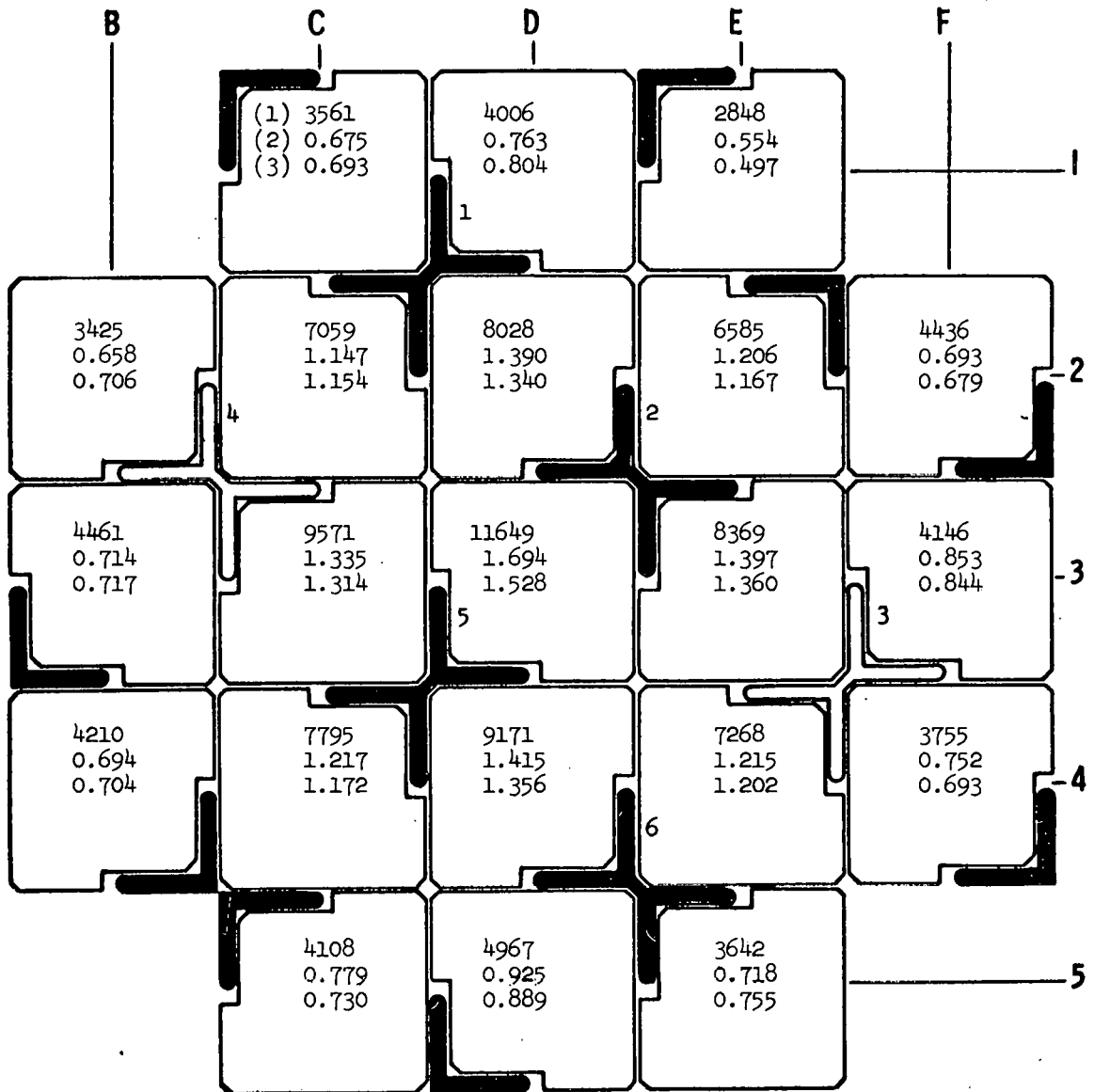


Figure 510.7 : A Comparison of the Calculated and Measured Critical Boron Concentration as a Function of Hours Operation for Saxton Core II.

- (1) Assembly Average Burnup (MWD/MTM)
- (2) Measured Relative Assembly Power
- (3) Calculated Relative Assembly Power (LEOPARD-BUBBLE-PDQ)



\* Hot Rod,  $F_{\Delta H}^N$

1.85 BUBBLE-PDQ

1.94 Measured

All Rods Out Power and Burnup Distribution at Core Average Burnup of 5670 MWD/MTM

Figure 510.8

central 3 x 3 subassembly which contains increased moderation. The peak rod power has not been reduced as much as predicted in the initial design. This is also attributed to the presence of this special test subassembly.

In November an extensive review and evaluation of the Saxton in-core flux measuring system (wires and detectors) was made and procedural changes to improve the data were recommended. This work was not performed with project funds but is reported because it will improve the prediction of power peaking and the basis for the comparison of analysis with experiment.

#### C. Zero Power Physics Measurements

As part of the continuing evaluation of the partial plutonium core, a brief series of reactor physics tests were carried out in the hot zero power, xenon-free condition after core average burnup levels of 3716 and 5670 MWD/MTM had been achieved. These burnups are equivalent to average burnups of 6112 MWD/MTM and 9364 MWD/MTM in the plutonium region.

##### 1. Boron Endpoints

The just critical boron concentrations with all rods out, and with rod 2 inserted and all other rods out, were established.

The measured boron concentrations were adjusted for deviation in temperature and pressure from reference conditions. Table 510.1 shows the endpoint boron concentrations for these two cases at three different burnups at 530°F and 2000 psi.

## 2. Control Rod 2 Worth

The direct differential worth of control rod 2 was measured at 5715 MWD/MTM during continuous boron dilution by inserting the control rod in a series of prescribed steps and observing the change in reactivity as determined by an on-line reactivity computer. The resulting differential and integral rod worth plots are shown in Figures 510.9 and 510.10. The solid lines represent best fits to the data. The broken lines are curves constructed from the start of life measurements.

## 3. Substitution Experiments

A series of reactor physics tests were carried out in the Saxton reactor during which substitutional exchanges among moderator temperature, control rod position, and reactor coolant boron concentration were made. At the start of these measurements the reactor had accrued a core average burnup of 4709 MWD/MTM corresponding to an average burnup of 7779 MWD/MTM in the plutonium region. The measurements were conducted at power (23.5 MWt), at a core average temperature of 507°F, and over a boron range of 906 ppm to 574 ppm.

TABLE 510.1

Endpoint Boron Concentrations and Boron Equivalents  
of Control Rod 2

---

<u>Burnup MWD/MTM</u>	<u>Control Rod Configuration</u>	<u>Endpoint Boron Concentration, ppm</u>	<u>Boron Equivalent of Rod 2, ppm</u>
0	All rods out	2296	
0	2 inserted All others out	1702	594
3716	All rods out	1565	
3716	2 inserted All others out	1037	528
5670	All rods out	1265	
5670	2 inserted All others out	874	491

Figure 510.9

Saxton Core II  
 $\beta_{eff} = 0.004582$   
 $\Delta h)_{step} = 43.0 \text{ mils/step}$   
Control Rod 2  
Differential Worth  
5715 MWD/MTM Burnup  
Hot, Zero Power  
Rods 1, 3, 4, 5 and 6 at 40"

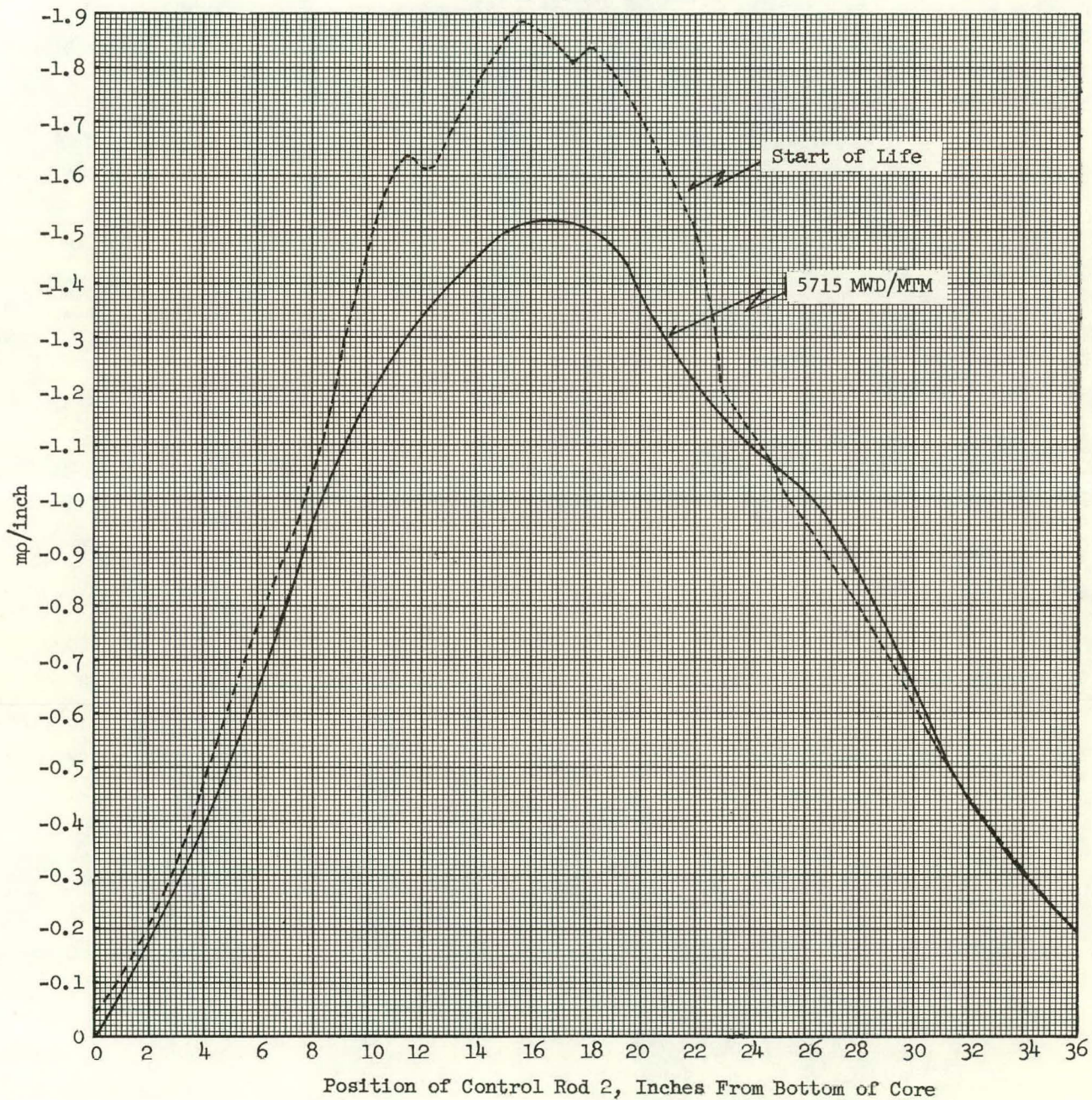
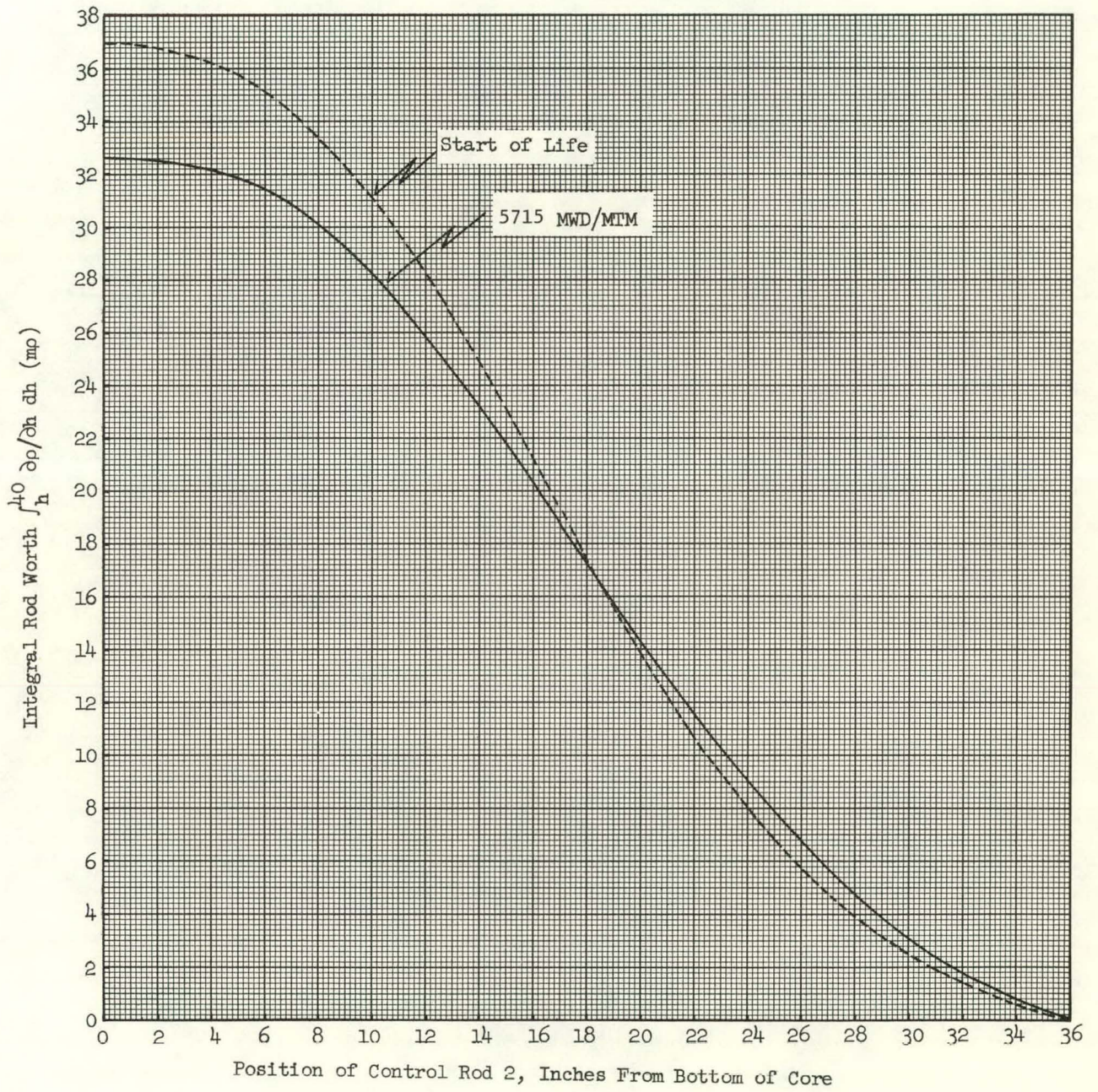


Figure 510.10

Saxton Core II  
 $\beta_{eff} = 0.004582$   
 $\Delta h)_{step} = 43.0 \text{ mils/step}$

Control Rod 2  
Integral Worth  
5715 MWD/MTM Burnup  
Hot, Zero Power  
Rods 1, 3, 4, 5 and 6 at 40"



The measurement consisted of a series of control rod/temperature exchanges, deducing the equivalence ratio ( $\Delta T/\Delta h$ ) corresponding to the given set of core conditions and relating the temperature equivalence of rod motion to absolute temperature coefficient ( $\partial p/\partial T$ ) through the use of the previously established differential rod worth ( $\partial p/\partial h$ ). Then, while the controlling rod was being moved to a new position by a compensating adjustment of boron concentration, the equivalence ratios ( $\Delta T/\Delta B$ ) and ( $\Delta h/\Delta B$ ) were measured; and subsequently, the absolute boron worth ( $\partial p/\partial B$ ) was established by reference to the previously measured rod worth. The values of moderator temperature coefficient and boron worth as a function of boron concentration deduced by this measurement are shown in Figures 510.11 and 510.12. The measured ( $\Delta T/\Delta B$ ) was used as a cross check on the moderator coefficient and boron worth deduced from the differential control rod worth.

#### SAX-630 Post-Irradiation Examination Hot Cells

D. T. Galm

The two pellet (D,E) and two vipac (XI, X5) fuel rods, removed from the plutonium 3 x 3 subassembly were inserted in another 3 x 3 subassembly and shipped from the Saxton Reactor to the Westinghouse Post-Irradiation Facility. The subassembly was removed from the shipping cask in the Transfer Building and subsequently transferred to the Hot Cells, where the individual fuel rods were removed. The following non-destructive examinations were completed.

Figure 510.11

Moderator Temperature Coefficient vs Boron Concentration at 507°F

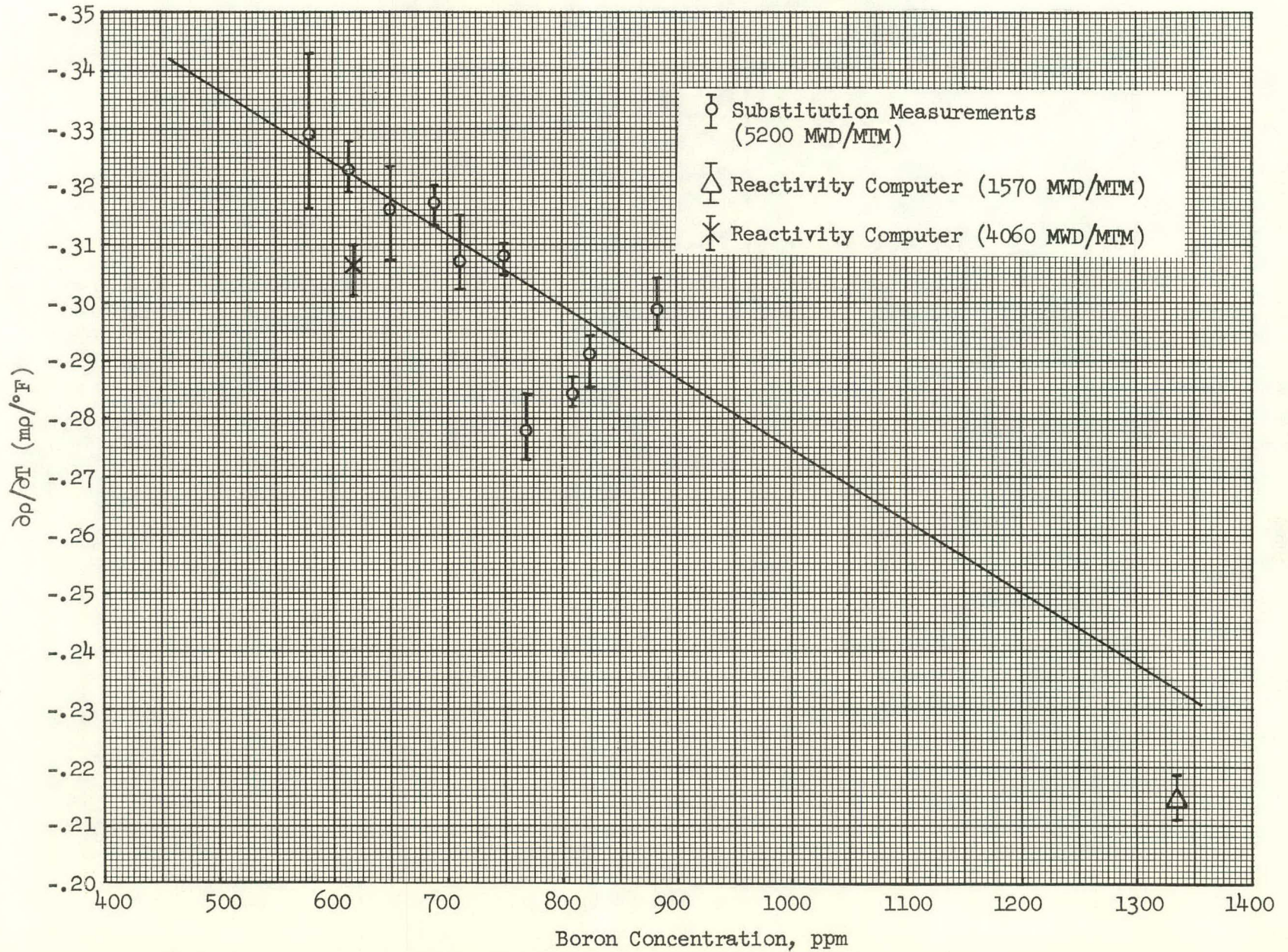
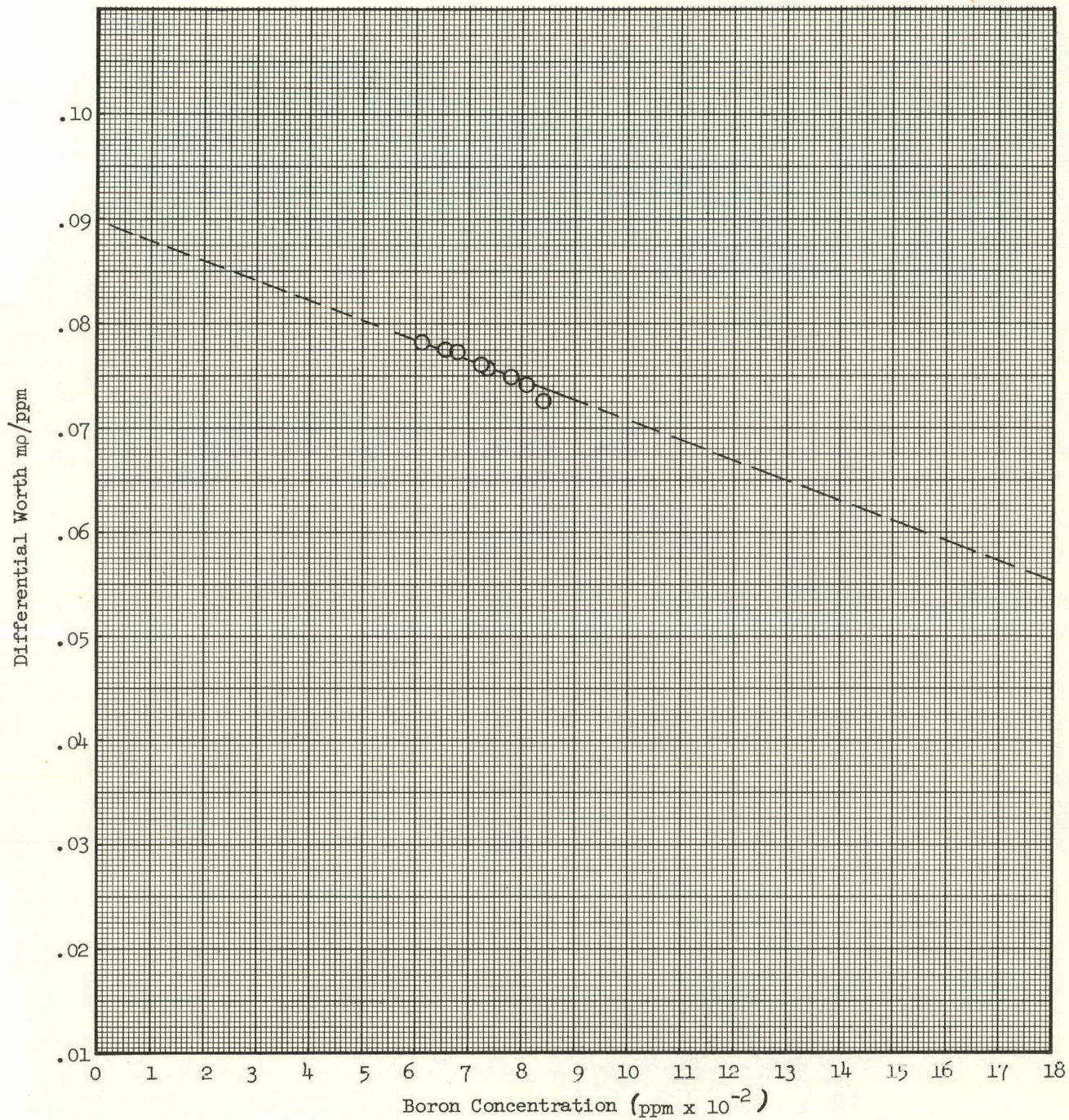


Figure 510.12

Saxton Core II Differential Boron Worth



1. Visual Examinations: Visual examinations and photographs showed no defects or other abnormalities of the four fuel rods. Some crud deposits were visible but were not considered to be excessive. There were also some longitudinal scratches caused by removal of these fuel rods from the 3 x 3 subassembly.
  
2. Dimensional Measurements: Dimensional measurements of the four fuel rods were made with a remotely-operated profilometer. No swelling, distortion, or other anomalies in the rod diameters were detected. An apparent increase in length of about 25 mils was noted for both pellet and vipac fuel rods. All data were reported to the cognizant technical personnel for evaluation and comparison with fabrication records.
  
3. Gamma Scanning: All four fuel rods were gamma scanned using a single and multi-channel gamma spectrometer in conjunction with a miniature ionization chamber. The resultant data were plotted and submitted for evaluation.
  
4. Fission Gas Sampling and Analysis: All four rods were punctured and the volume of gas released from each rod was measured. Gas samples were collected from each fuel rod and forwarded to Westinghouse Research Laboratories for mass spectrometer analyses. The analyses confirmed earlier indications that no significant leakage occurred during the puncturing operations.

No significant problems were encountered with either the handling or the non-destructive examination of the four fuel rods.

Approval of the broad by-product license application was granted by the AEC, and modifications to the hot cell ventilation system were completed. Work was also initiated on the preparation of a hot cell for installation of the alpha containment box required for the destructive examination of these fuel rods.

#### SAX-660 Materials Evaluation

K. R. Jordan, D. R. McClintock, J. L. Rolin

The purpose of this task is to evaluate the in-pile performance of fuel and cladding materials comprising the Saxton Plutonium Core.

The scope of the task includes post-irradiation evaluation of 19 fuel rods selected from two assemblies and one subassembly. The initial portion of this program will be performed in Fiscal 1967 and consists of the evaluation of two vipac and two pellet-type Zircaloy clad fuel rods removed from the 3 x 3 subassembly. These rods have achieved a calculated peak burn-up of 6100 MWD/MTM, and will provide interim materials performance information.

Post-irradiation evaluation of the vipac (XI, X5) and the pellet (D,E) fuel rods was started during this report period. Visual and dimensional examinations were performed on each of the fuel rods.

The visual examinations were performed with a stereomicroscope over a range of magnification from 1 to 30X and no anomalies or evidence of fretting corrosion at the area of contact with the stainless steel spring clip fingers was observed. Figure 660.1 illustrates the typical appearance of the rods at the location of contact with the spring clip. Dimensional measurements were made along the length of each rod with a remote profilometer to determine whether swelling or other deformation of the clad had occurred during irradiation. Figures 660.2 and 660.3 illustrate the dimensional profiles of the irradiated rods. Analyses of the remote profilometer diameter measurements revealed no increase in the diameter of the rods; however, overall length measurements made with a vernier caliper have revealed an apparent increase in the length of the fuel rods.

A gamma scan was made of each fuel rod to determine the thermal neutron flux profile during irradiation. As illustrated by the exposure profiles of each rod, Figures 660.4-660.7, the region of peak exposure was located approximately one-half inch below the middle of the fuel pellet stack. These curves will be used to assure selection of burnup and metallographic samples from the regions of maximum exposure.

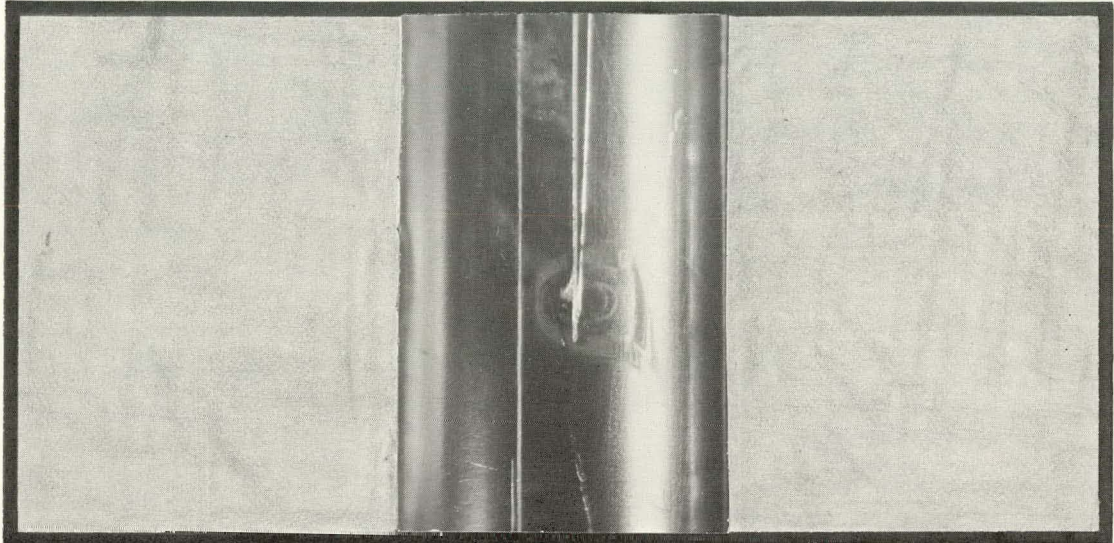
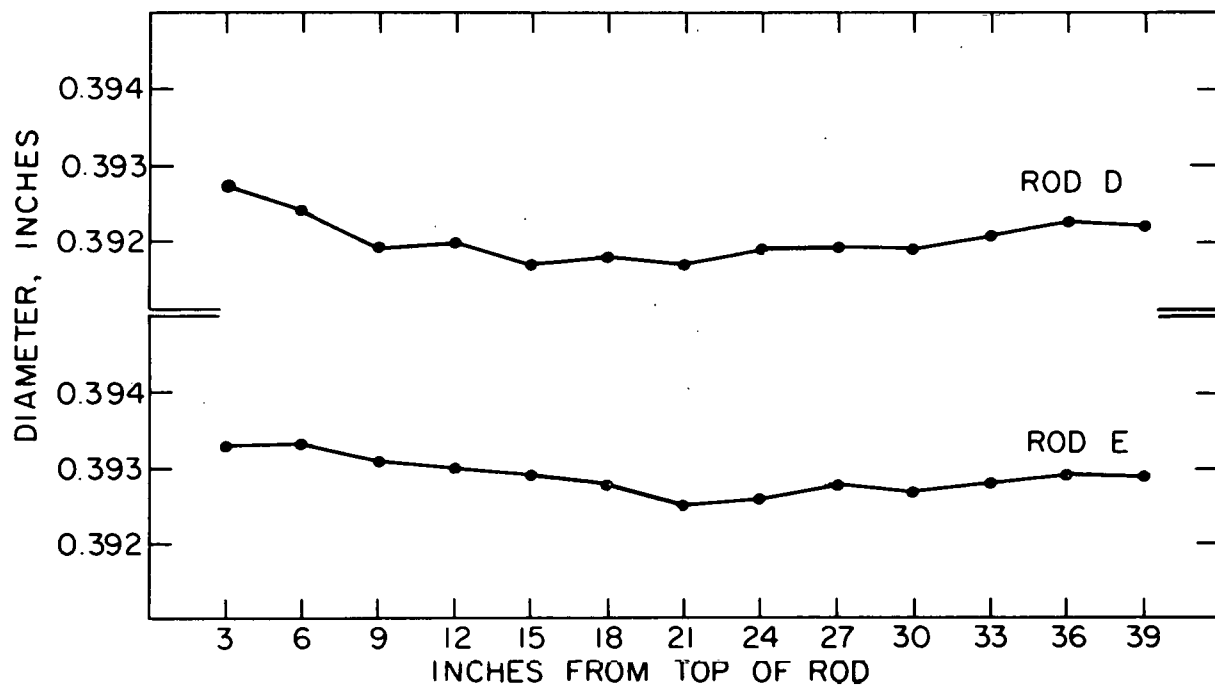
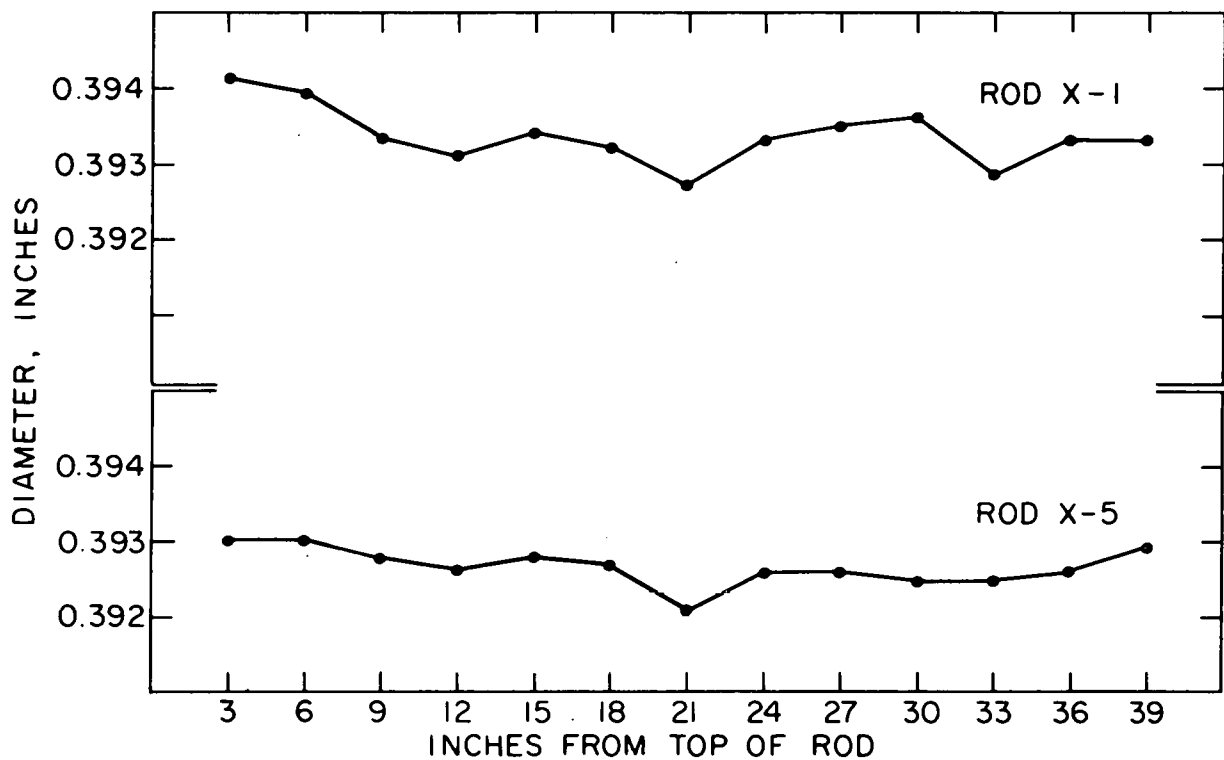


Figure 660.1: TYPICAL APPEARANCE OF CLAD AT LOCATION OF  
SPRING CLIP.



PROFILOMETER DATA OF PELLETTED RODS D AND E.

Figure 660.2



PROFILOMETER DATA OF VIPAC RODS X-1 AND X-5

Figure 660.3

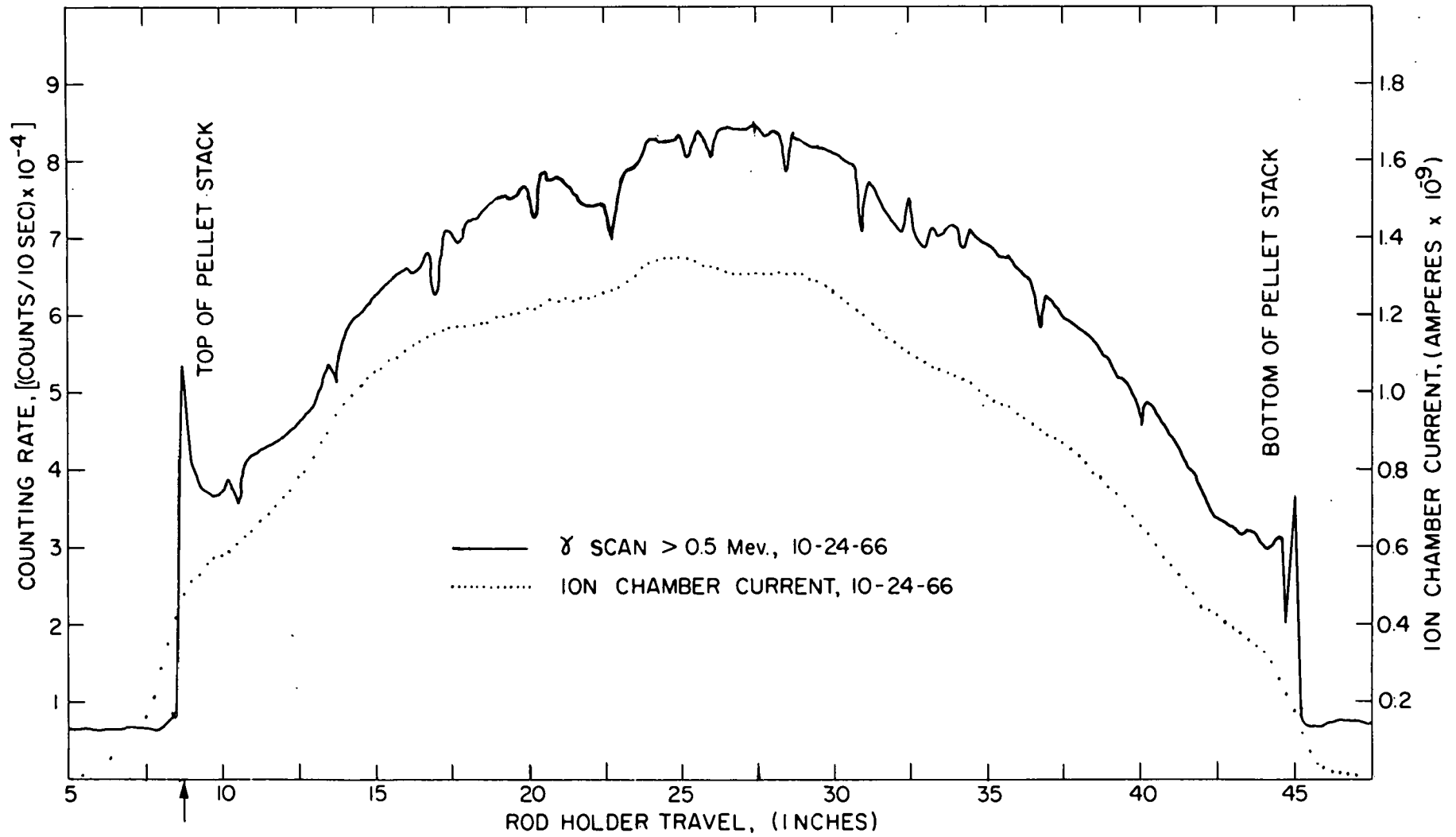


Figure 660.4 : GAMMA SCAN OF SAXTON ROD D.

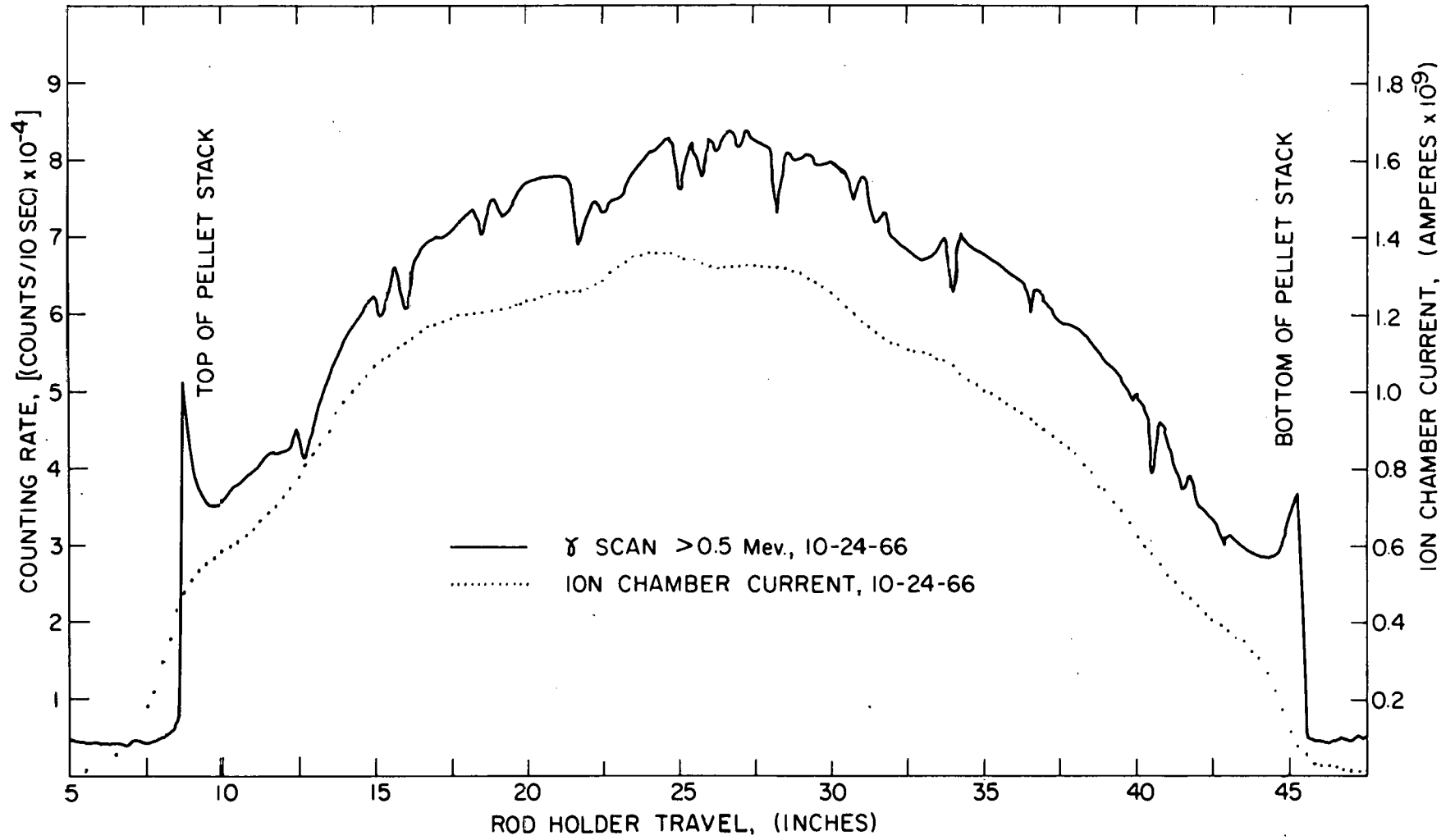


Figure 660.5 : GAMMA SCAN OF SAXTON ROD E.

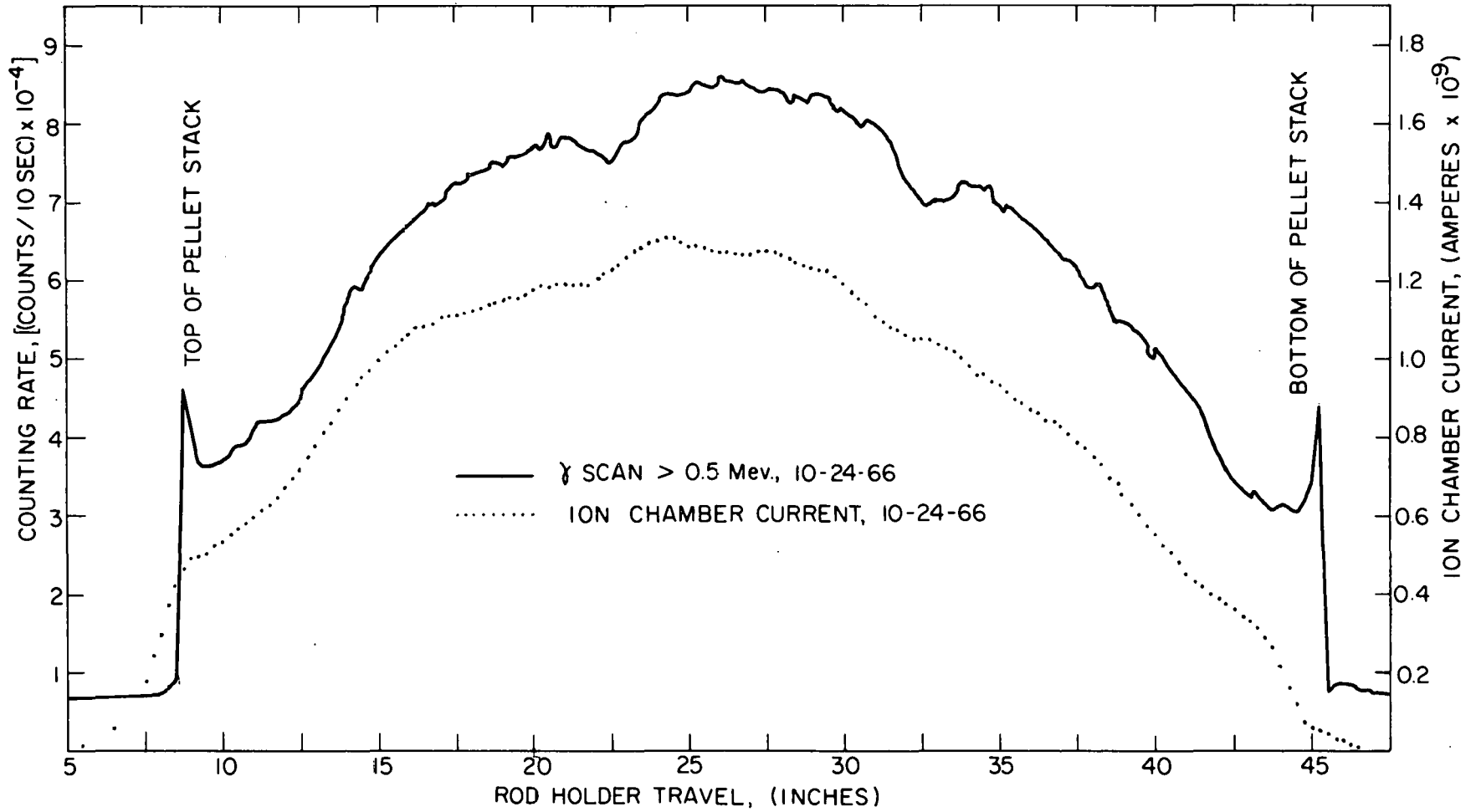


Figure 660.6 : GAMMA SCAN OF SAXTON ROD X-1.

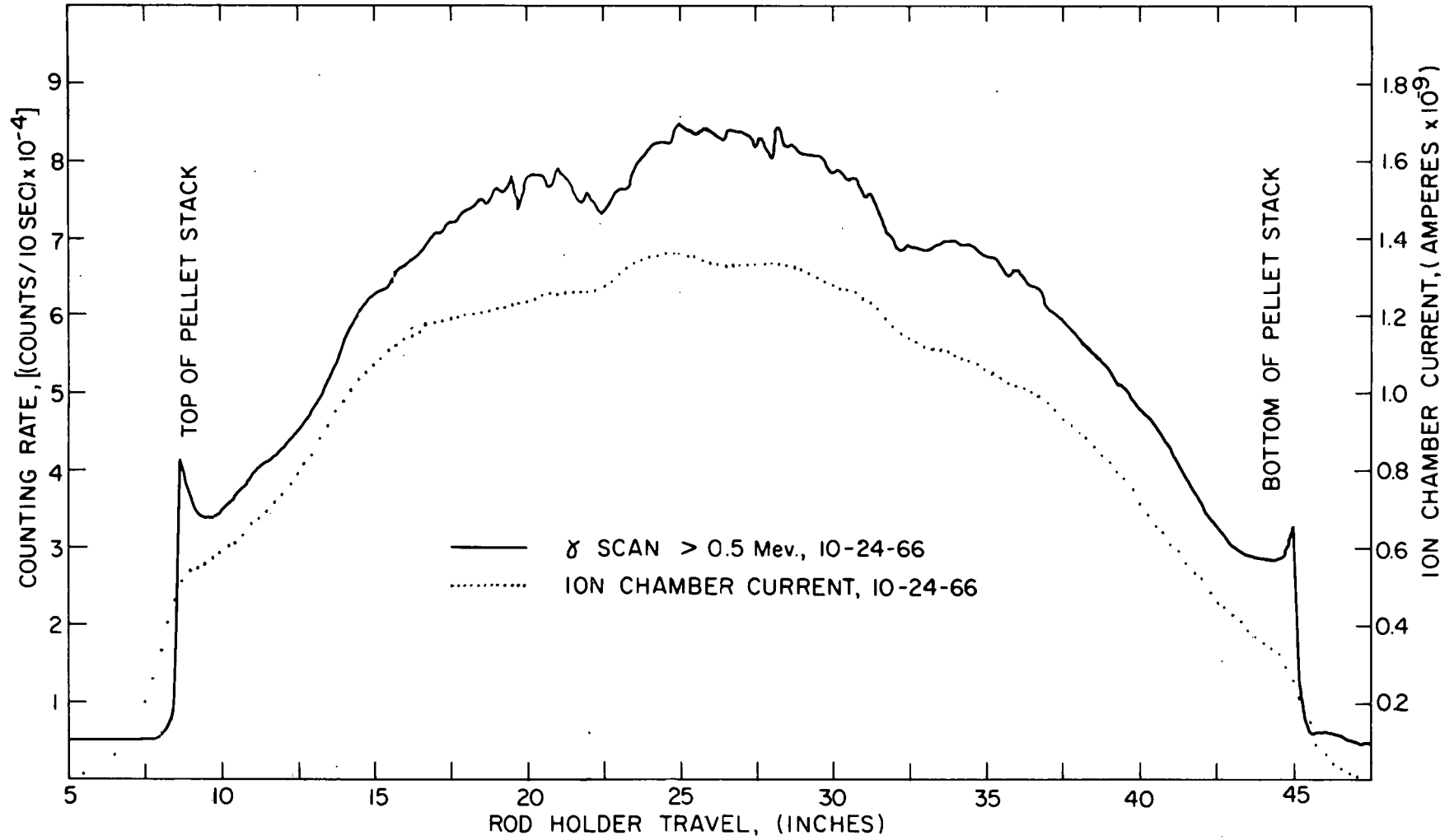


Figure 660.7 : GAMMA SCAN OF SAXTON ROD X-5.

To determine the volume of fission gases released from the  $\text{PuO}_2\text{-UO}_2$  fuel, the rods were punctured after irradiation and the contained gases collected for mass spectrometer analyses. The total volume of gas contained within each fuel rod was determined to within  $\pm 10\%$ . The gases collected from these rods were analyzed for He,  $\text{H}_2$ ,  $\text{CH}_4$ ,  $\text{N}_2$ ,  $\text{O}_2$ , Ar, Kr and Xe. The isotopic distributions of the xenon and krypton fission gas were also determined. A summary of the collected gases is given in Table 660.1. Preliminary evaluation of these results shows that rods of the same kind yielded similar gas samples. The Xe/Kr ratios were similar for all rods. Differences in the composition of the vipac and pellet rod gas samples can be partly explained by the different gas atmosphere used in welding the rods.

Sectioning of the fuel rods to obtain samples for metallography, integrated fast flux and burnup determinations, and hydrogen analyses awaits the availability of the in-cell alpha facility.

Table 660.1

SUMMARY OF MASS SPECTROMETER FISSION GAS SAMPLE ANALYSESSample Composition, cc @S.T.P.

Fuel Rod Identification	<u>D</u>	<u>E</u>	<u>X-1</u>	<u>X-5</u>
<u>Gas</u>				
H <sub>2</sub>	0.004	-----*	-----	-----
He	4.445	4.897	4.555	2.677
N <sub>2</sub>	0.047	0.018	7.770	9.881
O <sub>2</sub>	0.022	0.007	0.057	0.143
Ar	0.287	0.303	0.004	0.010
Kr	0.080	0.087	0.490	0.494
Xe	1.185	1.445	5.886	7.507
CH <sub>4</sub>	-----	0.001	-----	0.037
<u>Total Volume, cc @S.T.P.</u>	6.07	6.77	18.86	20.75

Isotopic Composition, Atom Percent

Kr 82	---*	--	--	--
Kr 83	17.67	17.40	17.39	17.60
Kr 84	28.64	28.77	28.60	28.55
Kr 85	7.16	7.08	7.21	6.93
Kr 86	46.53	46.75	46.80	46.86
Xe 128	--	--	--	--
Xe 130	0.04	--	0.04	0.02
Xe 131	13.31	13.43	13.34	13.41
Xe 132	20.66	20.98	20.21	20.07
Xe 134	28.91	28.84	29.15	28.98
Xe 136	37.08	36.75	37.26	37.52

\*-- Indicates concentration below sensitivity of mass spectrometer