BAW-307

CONTROL BLADE WORTH BY PARTIAL WATER HEIGHT AND SOLUBLE BORON METHODS

JULY 1960

By
Arland L. MacKinney
Russell M. Ball
Critical Experiment Laboratory
Development Department

This report was presented orally as Paper 20-7 of the summer 1959 meeting of the American Nuclear Society in Gatlinburg, Tennessee.

Approved by: D. V. P. Williams
D. V. P. Williams
Critical Experiment
Laboratory

THE BABCOCK & WILCOX COMPANY
ATOMIC ENERGY DIVISION
LYNCHBURG, VIRGINIA

AT(30-3)-274

ACKNOWLEDGMENTS

Appreciation is expressed to Mr. J. Harry Mortenson for his assistance in performing the boric acid analyses and to Mr. Donald A. Ross for his help in reactor operations.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Evaluations of fully inserted patterns of cruciform control blades have been made in slightly enriched, ordinary-water moderated cores. A curve of differential reactivity with water height, $\frac{d\rho}{dh}$ versus h, has been measured. This curve is integrated to develop a plot of reactivity as a function of water height. Using the integral curve and the measured water height for the various blade patterns, the reactivity associated with fully inserted blades may be determined. For single zone cores, the experiments have shown that the value of $\frac{d\rho}{dh}$ is the same for a particular water height, independent of the pattern of blades which was chosen to give that reactivity. In an assembly of 4% enriched UO_2 pins clad with stainless steel and arranged in can lattices, the measurements indicated that the function $\frac{d\rho}{dh}$ versus h was also insensitive to the thickness of the stainless steel or aluminum can walls.

Soluble boron experiments were performed by inserting a small amount of boric acid into the water moderator-reflector, and by measuring its associated reactivity change. These measurements, repeated at various concentrations, yielded a curve of the reactivity coefficient of boric acid as a function of concentration and integral curve of boric acid reactivity. All boric acid measurements were made at full water height.

The boric acid concentrations were determined by a potentiometric titration method. Measurements of accurately prepared solutions yielded a standard deviation of 0.7% with an average different from the prepared solution of 0.6%.

Table I shows some parameters of the core in which these experiments were made, and Table II summarizes some typical results.

INTRODUCTION

The series of experiments described in this paper was performed to determine reactivity values of various patterns of fully inserted cruciform control blades. The experiments yielded the worth of fully inserted blade patterns in terms of their holddown characteristics.[1]

DESCRIPTION OF FACILITIES AND EQUIPMENT

The general description of the facility has been given in paper 14-5 of the 1958 ANS winter meeting at Detroit.[2] Figure 1 shows a photograph of the critical assembly core. This figure shows the can-type construction, and three of the movable control blades are seen suspended by the cable-driven rod drives. The movable control blades, of which six are available, serve a dual purpose as control and fast safety. A cross section of the control blade is shown in Figure 2. The blades are constructed of 1/4 inch boral in the shape of a cruciform, 8 in. tip to tip. The meat is nominally 0.168 in. of boral, 35% by weight of boron carbide, and the surface density is 0.366 gm/cm^2 of boron carbide, or 0.054 gm/cm^2 of boron -10. The boral is intended as a mock-up for B^{10} - stainless steel, which is being used in the NS Savannah core.

PARTIAL WATER HEIGHT METHOD

Measurements of the differential reactivity as a function of water height have been common in the field of experimental reactor physics for several years. It has been shown in this series of experiments using can cores that the value of $\frac{d\rho}{dh}$ determined for a particular water height is primarily a function of infinite medium properties of a cell and is not appreciable modified either by the nature of can walls enclosing the cells or by insertion of slabs of nuclear poisons between cells. The experimental results are shown in Figure 3, which is a curve of $\frac{d\rho}{dh}$ as a function of water height, constructed for three cores with the same properties of the cell. Many of the points were obtained by reaching the same water height with different blade patterns. Graphical integrations, performed independently on each set of data pertinent to a particular core, agree within the experimental uncertainties. A total of 56 points have been measured in two different can lattices with three different sets of can walls. Each lattice yields a consistent curve of differential reactivity versus water height irrespective of the can wall material, within experimental uncertainties.

The integral reactivity versus water height is shown in Figure 4. This curve serves as a calibration curve for blade patterns; that is, the critical water height may be related to the holddown power for a particular blade configuration. Table III shows some typical patterns measured by this method.

The asymptote of the integral reactivity curve represents the excess reactivity in the core when the constant of integration is chosen as zero for the critical water height with no blades inserted.

The measurements of blade worths interpreted by this method represent measurements with different lengths of blades in the active core, since the length of the active core varies with water height. Theoretically, however, the worth of a fully inserted, thermally black control blade is directly proportional to the radial buckling, B_r^2, with a slight dependence on total buckling.[3] The theoretical dependence on total buckling for the range of measurements reported here is less than 0.5%. Table IV demonstrates the radial dependence of a central blade measurement. In routine blade pattern measurements, of course, the core radius is held constant.

SOLUBLE BORON TECHNIQUE

A series of full water height measurements has been made by balancing the reactivity worth of the control blades by the reactivity of boric acid in the water moderator-reflector. The reactivity worth of the boric acid in the water is determined by inserting small amounts of boric acid in the water and measuring the associated reactivity change. The reactivity coefficient measurements involve changes of concentration of order of 0.15 to 0.7 gm boric acid per liter and reactivity changes of 16¢ to 66¢. The concentrations are measured by a potentiometric titration method[4] to an accuracy of ± 1%. The reactivities are measured by comparing the reactor periods corresponding to given control blade settings before and after the change in boric acid concentration. This method in essence is a continuous calibration technique in order to minimize overall interaction effects between control blades and the boron in the moderator. Figure 5 shows the results of these measurements.

Using the reactivity worth of the boric acid and knowing the boric acid concentration in the water for a particular blade pattern, one may obtain the reactivity of the blade pattern. Table II shows a comparison between measurements made with partial water height and with the boric acid method.

REFERENCES

1. A. F. Henry, "The Application of Reactor Kinetics to the Analysis of Experiments", Nuclear Science and Engineering, 3, 52-70 (1958).

2. R. M. Ball, A. L. MacKinney, J. H. Mortenson, D. A. Ross, D. V. P. Williams, "Critical Experiments for the NS Savannah Core", Paper 14-5 of 1958 winter meeting of the American Nuclear Society.

3. W. H. Arnold, Jr., "Worths of Black Control Rods", Nuclear Science and Engineering 3, 296-299 (1958).

4. L. Silverman and W. Bradshaw, "Potentiometric Titrations of Low Concentrations of Boric Acid Anahydride in Deuterium Oxide and in Ordinary Water", Analylica Chenuca Acta, 12, No. 2 (1955).

TABLE I

SUMMARY OF CORE DATA

Fuel: UO_2, 87% theoretical density, 4% $\frac{U^{235}}{U}$

Fuel Pins: 0.5 in. diameter, 0.028 in. stainless steel clad, 66 in. active fuel length (Total Number of Pins: 5280)

Water/Uranium Ratio: 3.5 to 1 (Pin Pitch: 0.663 in.)

Water Gap for Control Blades: 0.830 in.

Control Blade Pitch: 9.76 in.

Can Walls: 0.1565 in. thick - 304 stainless steel

TABLE II

TYPICAL BLADE WORTH RESULTS

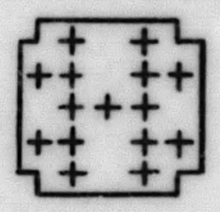
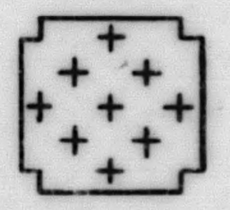
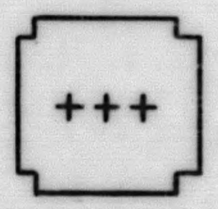
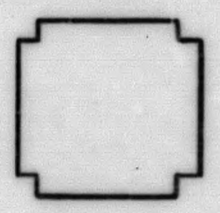
Blade Pattern	Equivalent Concentration gm/H_3BO_3/liter	Excess Reactivity Dollars: Water Height Method	Excess Reactivity Dollars: Boric Acid Method	Holddown Power Dollars: Water Height Method	Holddown Power Dollars: Boric Acid Method
	0.28 ± 0.05	1.23 ± 0.1	1.06 ± 0.2	9.97	10.5 ± 0.2
	1.13 ± 0.05	4.30 ± 0.1	4.3 ± 0.2	6.9	7.3 ± 0.2
	2.34 ± 0.05	8.52 ± 0.25	8.9 ± 0.2	2.68	2.7 ± 0.2
	3.053 ± 0.008	11.20 ± 0.5	11.57 ± 0.2	0	0

TABLE III: TYPICAL ROD PATTERNS IN CORE I

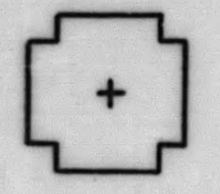
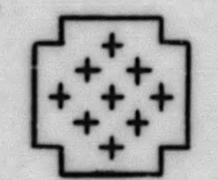
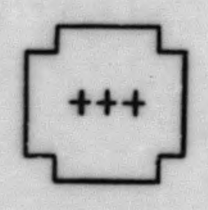
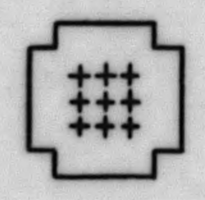
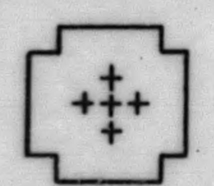
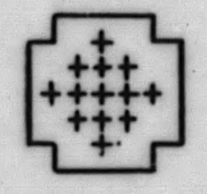
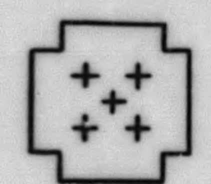
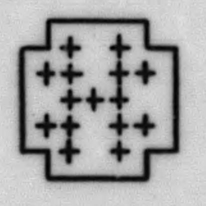
Pattern	Excess Reactivity	Holddown Power	Pattern	Excess Reactivity	Holddown Power
	\$10.1±0.5	\$1.1		\$4.3±0.1	\$6.9
	\$8.5±0.25	\$2.7		\$4.0±0.1	\$7.2
	\$7.0±0.1	\$4.2		\$1.2±0.1	\$10.0
	\$6.8±0.1	\$4.4		\$1.2±0.1	\$10.0

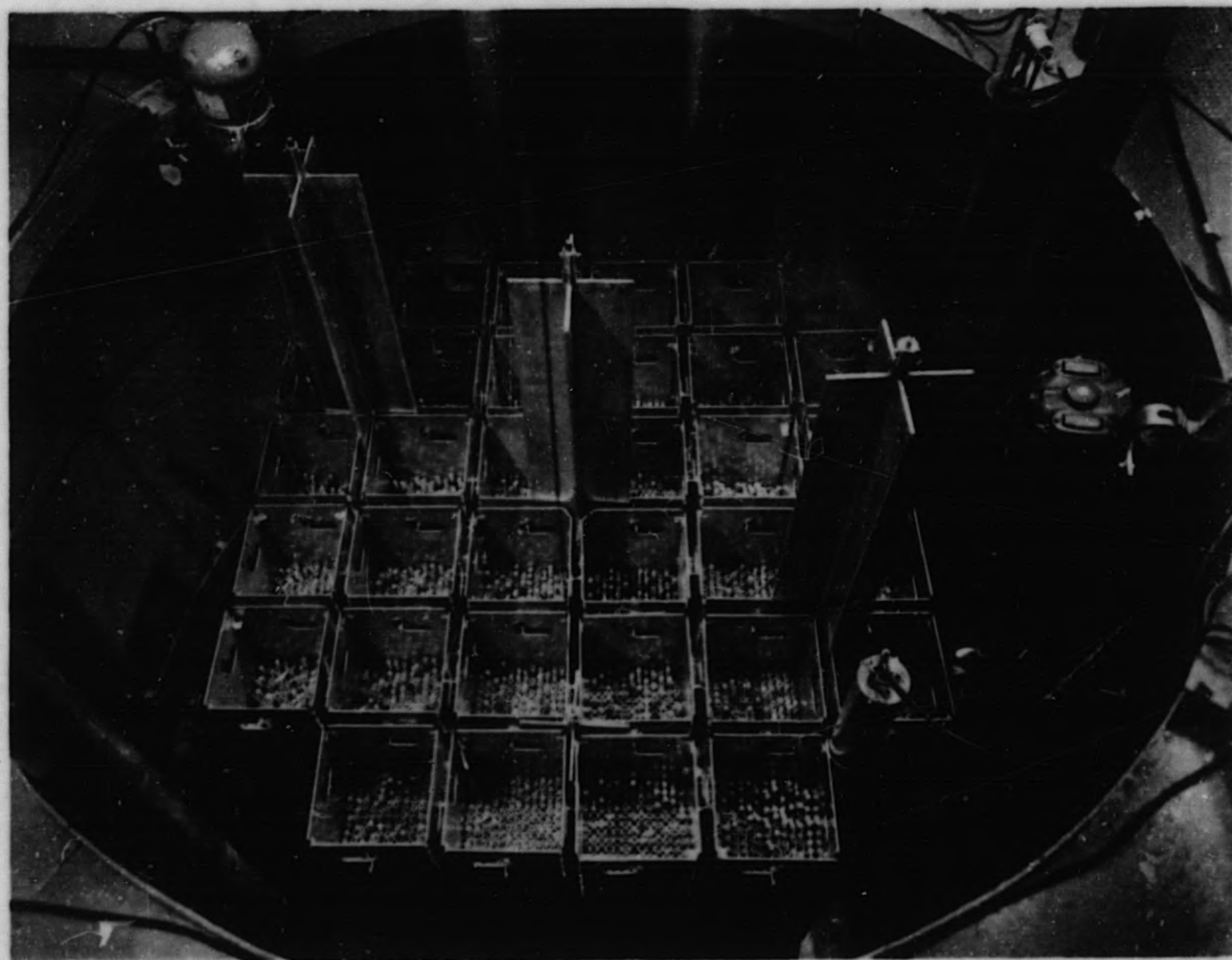
TABLE IV

WORTH OF CENTRAL BLADE

(CORE III)

No. of Pins	Effective Radius	Central Blade Worth	$\frac{\text{Radius}^2 \times \text{Worth}}{1000}$
2384	47.1 cm	\$3.82 ± 0.20	8.47
1944	42.8 cm	\$4.59 ± 0.30	8.41
1344	36.0 cm	\$6.66 ± 0.5	8.57

FIG. 1: VIEW OF CRITICAL ASSEMBLY CORE



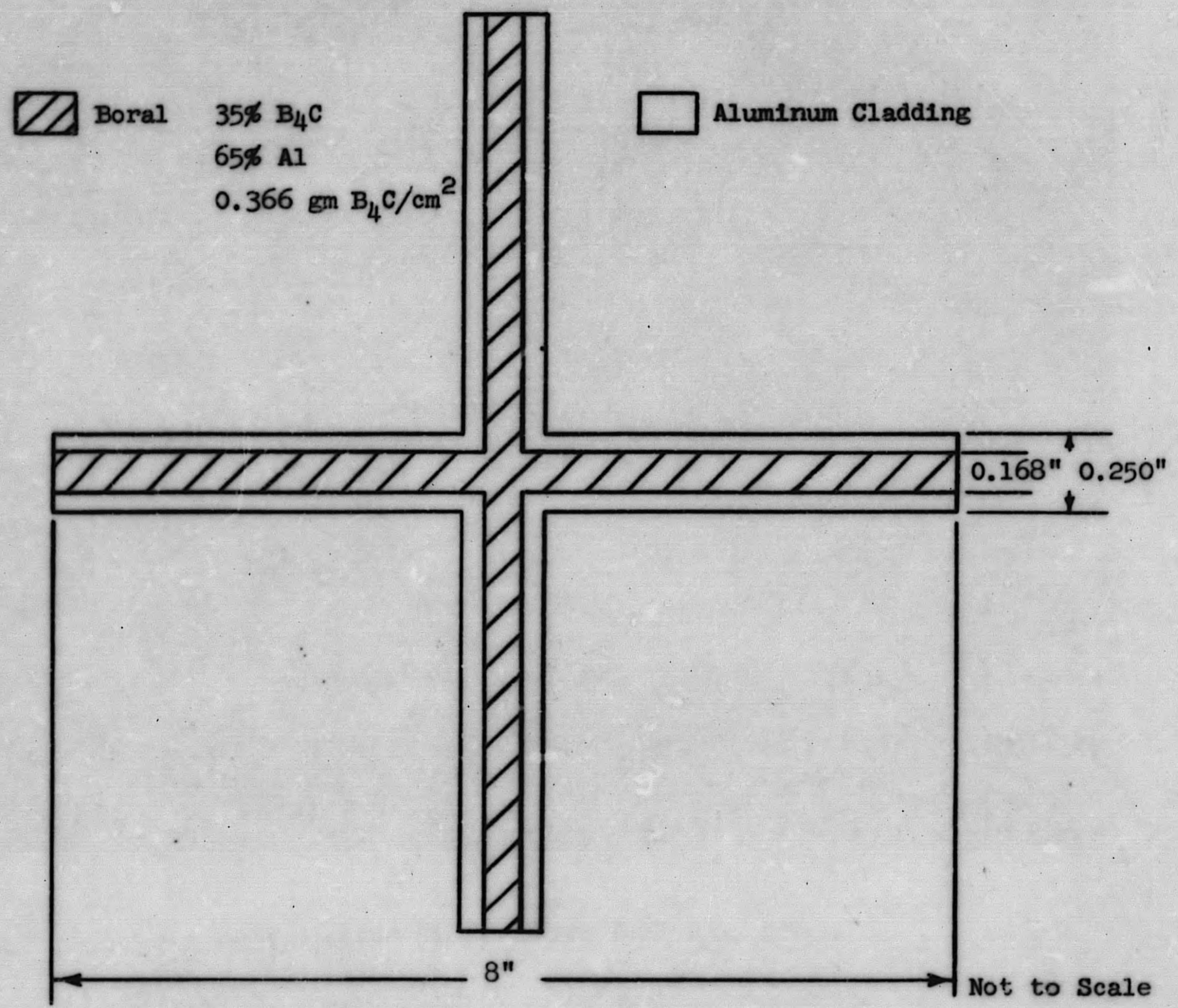


FIG. 2: CROSS SECTION OF BORAL CONTROL BLADE

FIG. 3: DIFFERENTIAL REACTIVITY VS WATER HEIGHT

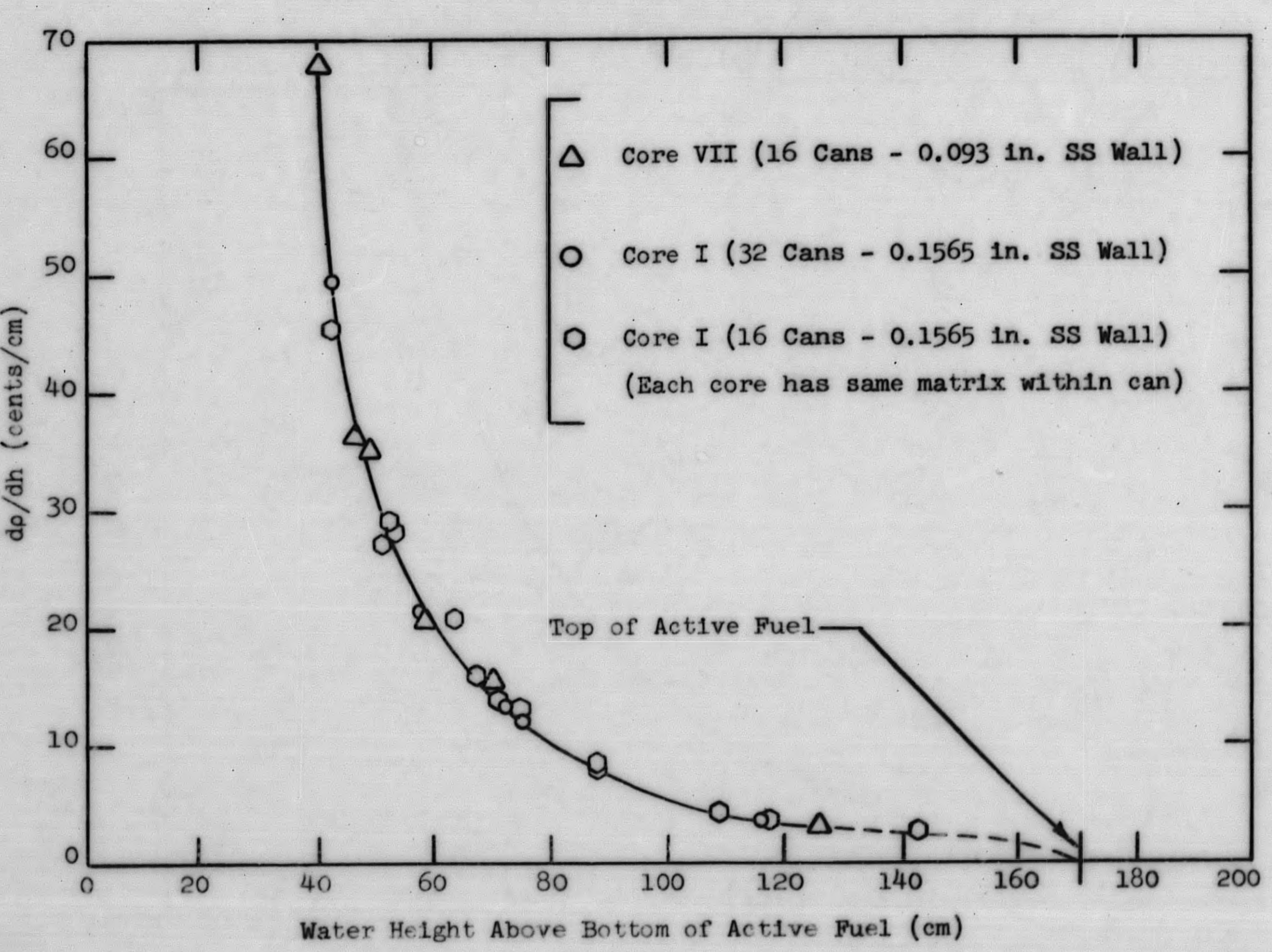


FIG. 4: INTEGRAL REACTIVITY VS WATER HEIGHT

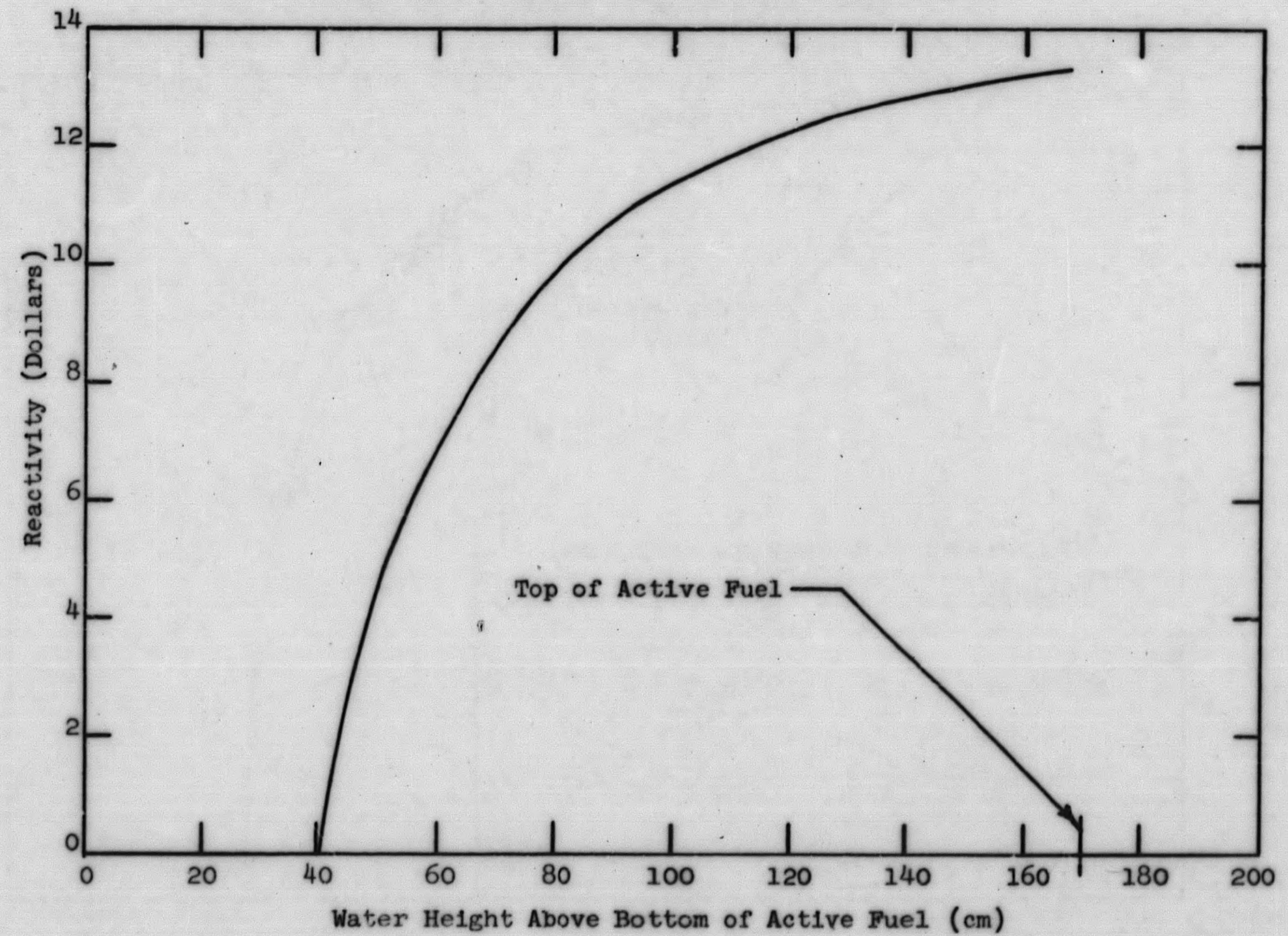
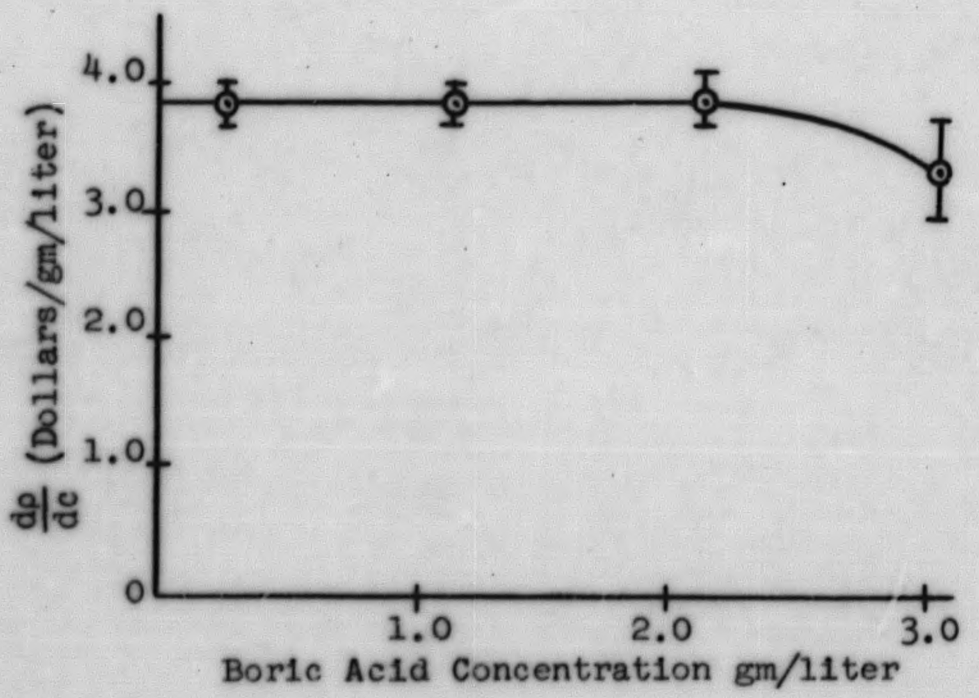
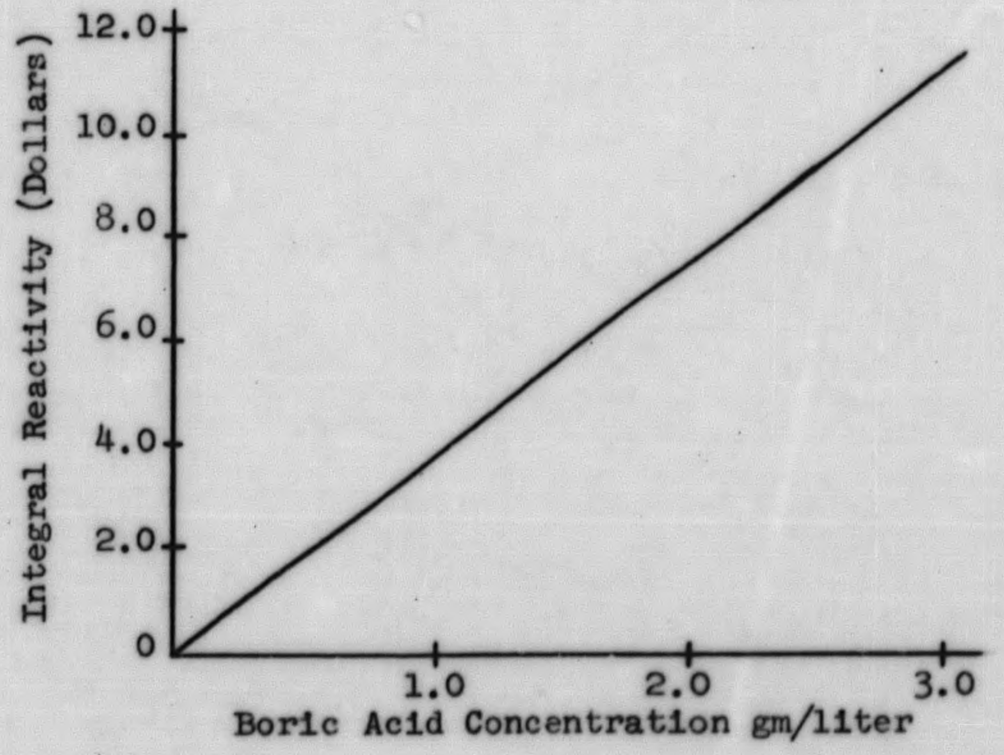


FIG. 5: BORIC ACID REACTIVITY IN MARTY CORE I MODERATOR





END