AN ON-LINE CHEMISTRY MONITOR FOR BORON CONCENTRATION

by

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(ABSTRACT)

This paper discusses the development of a microprocessor-based instrument to measure boron concentration in the cooling water of a pressurized water reactor. The technique used to develop the boronimeter is neutron transmission entailing the use of a neutron source and a bank of detectors to measure the absorbed neutrons in a sample of borated water. A unique feature of the boronimeter is the inclusion of a servo-operated absorber sleeve which is automatically positioned to compensate for changes in boron concentration. The sleeve is positioned to keep the count rate constant and the position of the sleeve is then used to determine the concentration of the sample. The null operation feature makes the boronimeter particularly adaptable to on-line operations owing to the improved counting statistics. Tests completed on the boronimeter demonstrate its usefulness for accurate, rapid analysis of boron concentration. The system was calibrated over the concentration range 0-2500 ppm boron. At a concentration of 1000 ppm the standard deviation was $\pm$ 2% for an analysis time of $<$ 4 minutes.

This work is dedicated to my parents,

Jerome W. Jaeger and Clara A. Jaeger,

whose faith in God and in me has been

the foundation for all I do.

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First and foremost thanks go to my advisor Dr. Thomas F. Parkinson, without whose help, knowledge and appreciation of Tom Lehrer and other good humor, this work could have bordered on tedium. Also thanks to Eric Ellis whose knowledge, ability and practicality were my saving grace. Thanks also to my committee members, Dr. Leonard and Dr. Robertshaw for their suggestions and advice both in and out of school.

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To my family, thank you for your encouragement, and moral and financial support these last 25 years. I hope I can do justice to the faith that you have instilled in me, I hope I can do half the job my parents have done, and I hope I can know a love as deep as theirs. Thanks, mom, for always knowing the right verse; Phil 4:6 got me through more things than you could ever know. Thanks, dad, for always having the answers; there are now two constants in the universe.

To Sue, Ann, and Jenny, thanks; what is life without a Mall?

And finally to Robert, thanks for being what I never thought I would find, and for making my dearest dream come true.

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Nomenclature

A	surface area, (cm^2)
B	boron (isotopic)
B-10	boron ten isotope
B-11	boron eleven isotope
B-12	boron twelve isotope
BC	boron concentration (parts per million)
Be	berylium
BF_3	neutron proportional counter(s)
C	a constant (see local text)
Ci	curie
$\overline{D}$	diffusion constant
I	count rate (counts per second)
I_0	count rate with zero boron concentration
Ke	kinetic energy after collision
Ke_0	initial kinetic energy of particle
L_T	thermal diffusion length
L_T^2	thermal diffusion area
No	Avagadro's Number (= 6.023 x 10-23)
Pu	plutonium
S	source strength (neutrons per second)
eV	electron volt

r radius (inches if not otherwise specified)

x sample thickness (inches)

Greek Letters

Δt elapsed time (seconds)

Θ angle of collision (radians)

Φ_1 theoretical fast neutron flux

Φ_T theoretical thermal neutron flux

Σ_a macroscopic absorption cross-section (cm^{-1})

ρ density (g/cm^3)

σ_a microscopic absorption cross-section (barns)

τ time constant

τ_T $\frac{D_1}{\Sigma_1}$

Subscripts

1 fast

T thermal

0 zero boron concentration

Chapter 1

Introduction and Literature Review

1.1 Background

Many chemical measurements must be made during the operation of nuclear power plants; one of the critical measurements is the determination of boron concentration in the reactor coolant system (RCS) of pressurized water reactors (PWR's). Presently the standard industry method employs batch sampling and titration to determine this important parameter, a process that is very time consuming. While this procedure provides accurate results, disadvantages to such a cumbersome and slow process are obvious. Plant operators are required to boronate or dilute the RCS ("bleed and feed") on what they assume the concentrations are until they receive the results, and then make the corrections as necessary. An on-line continuous system could provide data more quickly, thus eliminating the need for estimation of concentration while reducing the chance for human errors. Automation of the process would enhance plant efficiency. With automated boron analysis the turn-around time for boronation / deboronation would be faster, and start-up time for physics testing would be reduced. Elimination of the batch-mode sampling would lower personnel exposure times. Thus an instrument that could perform the boron measurement would improve plant operation, cycle speed, and worker conditions.

The industry is considering a switch from natural boric acid to enriched boric acid [Rodill,1987]. Although Virginia Power has decided to continue with natural boric acid owing to the expense of conversion, Electric Power Research Institute (EPRI) recommends the switch to B-10 as more economically sound [Roesmer,1986], [Rodill,1987]. Natural boric acid contains approximately 20 % B-10 and 80 % B-11; see Table 1. B-10 has an extremely high neutron absorption cross-section (3837 barns) and is the dominant neutron absorber in natural boron; B-11 has a low absorption cross-section ($5x10^{-3}$ barns) and is basically ineffectual in reactivity control (a barn is a unit of absorption cross-section and is more fully discussed in the next chapter, barn = $10^{-24} cm^2$). Titration, the standard analytical method, measures how much total boron is present, but does not differentiate between the two isotopes. The boronimeter will determine the absorption of B-10, the more direct and useful measurement. Thus the instrument would be particularly useful for those utilities that switch to enriched boric acid.

Table 1. Isotopes of Boron

Element or Isotope	Abundance (%) (Atomic)	Half-life (seconds)	Atomic Mass (u)	σ_{abs} @ 0.025 eV (barns)
B	-	-	10.811	755
^{10}B	19.8	-	10.013	3813
^{11}B	80.2	-	11.009	$5x10^{-3}$
^{12}B	-	0.0193	-	-

While the boronimeter is designed to measure boron concentration in water, the neutron absorption method, on which the boronimeter is based, has many other applications. In general it is applicable to the determination of any element having a high absorption cross-section disbursed in a low cross-section matrix. For example, an instrument was developed at Savannah River Laboratory (SRL) for assaying the lithium content in lithium-aluminum alloy rods [Dexter,1955]. Another possible application is the analysis of boron fiber content in composites. To determine other applications, it is useful to compile a list of elements with "high" thermal absorption cross-sections (greater than 50 barns); see Table 2. The elements found enumerated in the table have a high cross-section and a technique like the one used in the boronimeter could detect their presence. An important feature of this technique is that it is a non-destructive analysis. It uses an intrinsic property of an element to determine its presence and concentration within other substances

Table 2. Absorption Cross-sections of Selected Elements

Element	σ_a(0.025)barns
B	755
Rh	149
Ag	63
Cd	2450
In	191
Pm	60
Li	71
Sm	5600
Eu	4300
Gd	46000
Dy	950
Ho	65
Er	173
Tm	127
Lu	112
Hf	105
Re	86
Ir	440
Au	99
Hg	380
Ac	510
Pa	300
Np	170
Pu	1026
Bk	500
Cf	900
E	160

1.2 Literature Review

Although the technology and science that surrounds this project is old and accepted, little literature exists documenting its use. Both Babcock and Wilcox (B&W) and Westinghouse have developed boronimeter devices, but little has been published because much of the information is considered proprietary. Much trouble has been reported with the Westinghouse Mark I instrument installed at Surry [Parkinson,1985], to the extent that Virginia Power has forgone its use altogether. The B&W Random Walk Boronimeter detects changes in boron in less than five minutes with an accuracy of $\pm$ 1% or less for normal boron levels [Pitka & Ball,1986]. Dexter used the same principle to develop a method for measurement of the lithium content in target slugs by neutron transmission. "The target slug is interposed between a source of thermalized neutrons and a neutron detector, and the neutron transmission of the slug is measured." He was able to determine the lithium content of the slugs to $\pm$ 500 parts per million [Dexter,1955]. The operation of the boronimeter will follow similarly: boronated water will be contained between a source of thermalized neutrons and a bank of neutron detectors.

The objectives of this project were to develop, test and demonstrate an on-line boronimeter chemistry monitor. A unique feature of the boronimeter is the application of a servo-system that enables the instrument to function in a null-mode and facilitates on-line operation [Parkinson,1985]. Following successful demonstration, the instrument is to be transferred to a Virginia Power nuclear station for evaluation.

Chapter 2

Operational Basis

The design premise of the boronimeter is neutron absorption. Boron has a high thermal absorption cross-section (755 barns) so that when boron is present in a thermal neutron flux, absorption of neutrons will occur. The amount of absorption can be correlated to the boron atom density. This correlation will be the means by which the boronimeter will determine the concentration of boron present in a sample.

The cross-section for a reaction can be defined as the probability that a particle (neutron) will interact with a nucleus, or more loosely the cross-section can be viewed as the target area through which the particles pass if an interaction is to occur [Foster & Wright, 1980]. Cross-sections are expressed in barns where 1 barn = $10^{-24} cm^2$. When boron is present in a thermal neutron flux, absorption of neutrons will occur proportionally (although not linearly proportionally) to the boron population density [Foster & Wright, 1980]. The boronimeter is based on the neutron transmission equation of a point source:

$$\frac{I}{I_0} = e^{-(\Sigma_a X)}. \quad [2..1]$$

The value of Σ_a is given to a good approximation by

$$\Sigma_a = \left[\Sigma_a^B + \Sigma_a^{H_2O}\right]. \quad [2.2]$$

A compilation of cross-sections versus boron concentration is given in Table 3. In terms of the boron concentration (BC) in ppm, for low values of (BC)

$$\Sigma_a X \simeq (BC)\ \text{Constant}. \quad [2.3]$$

Since the sample distance is fixed and the other terms are constant if the sample temperature is regulated, the basic equation for the boronimeter can be written:

$$\frac{CR}{CR_0} = e^{-(BC)\ \text{Constant}} \quad [2.4]$$

or

$$CR = C_1 e^{-(BC)C_2}. \quad [2.5]$$

It is convenient to have a fixed count (e.g. 10^6) and measure the elapsed time (Δt), so that the fractional error owing to counting statistics is constant. Thus

$$\frac{10^6}{\Delta t} = C_1 e^{-(BC)C_2} \quad [2.6]$$

or

Table 3. **Cross-section vs. Boron Concentration**

Boron Conc. (ppm)	Cross-Section (cm^{-1})
1×10^5	.9290
5×10^4	.4742
1×10^4	.1104
9000	.1014
8000	.0923
7000	.0832
6000	.0741
5000	.0650
4000	.0559
3000	.0468
2000	.0377
1000	.0286
500	.0240
100	.0204
0	.0195

or

$$\ln\Delta t = (C_3(BC)) + C_4 \qquad [2.7]$$

A calculated plot of Equation [2.7] is given in Figure 1. The values of C_3 and C_4 will depend on the neutron source strength and the counting efficiency.

In order to determine the boron concentration (BC), the count rate from the neutron detectors can be measured and related to boron concentration using Equation [2.5]. An alternative method is to use a preset count, measure the elapsed time, Δt, and utilize Equation [2.6]. A third method which may offer an advantage for continuous on-line boron indication was investigated. This method utilizes an electro-mechanical annular absorber that moves vertically between the source and detectors (Figure 2). A feedback circuit continuously adjusts the vertical position with the boron concentration changes to maintain a constant neutron count rate. Then the vertical position of the absorber is an indication of the neutron count rate. A patent disclosure has been filed for this concept [Parkinson, 1986].

Preliminary measurements were made in an eighty gallon water-filled drum. The neutron flux was mapped as a function of the distance between a BF_3 detector and 1 Ci PuBe source. The radial thermal flux can be represented by Equation [2.8]

$$\Phi_T = \frac{SL_T^2}{4\pi r\overline{D}}\left(L_T^2 - \tau_T\right)\left[e^{\frac{-r}{L_T}} - e^{\frac{-r}{\sqrt{\tau_T}}}\right] \qquad [2.8]$$

and the radial fast flux can be represented by Equation [2.9]

$$\Phi_1 = \frac{Se^{\frac{-r}{\sqrt{\tau_T}}}}{4\pi rD_1} \qquad [2.9]$$

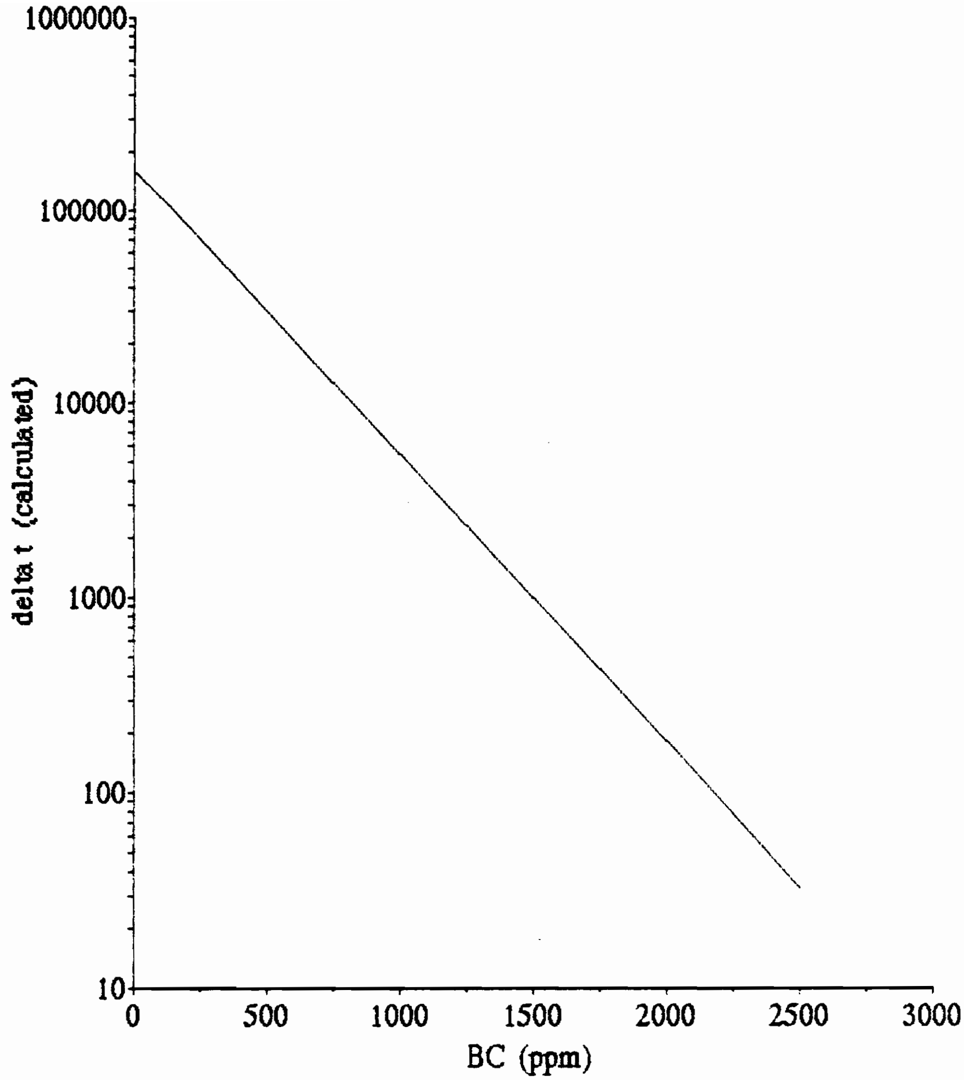

Figure 1. Elapsed Time vs. Concentration (Calculated)

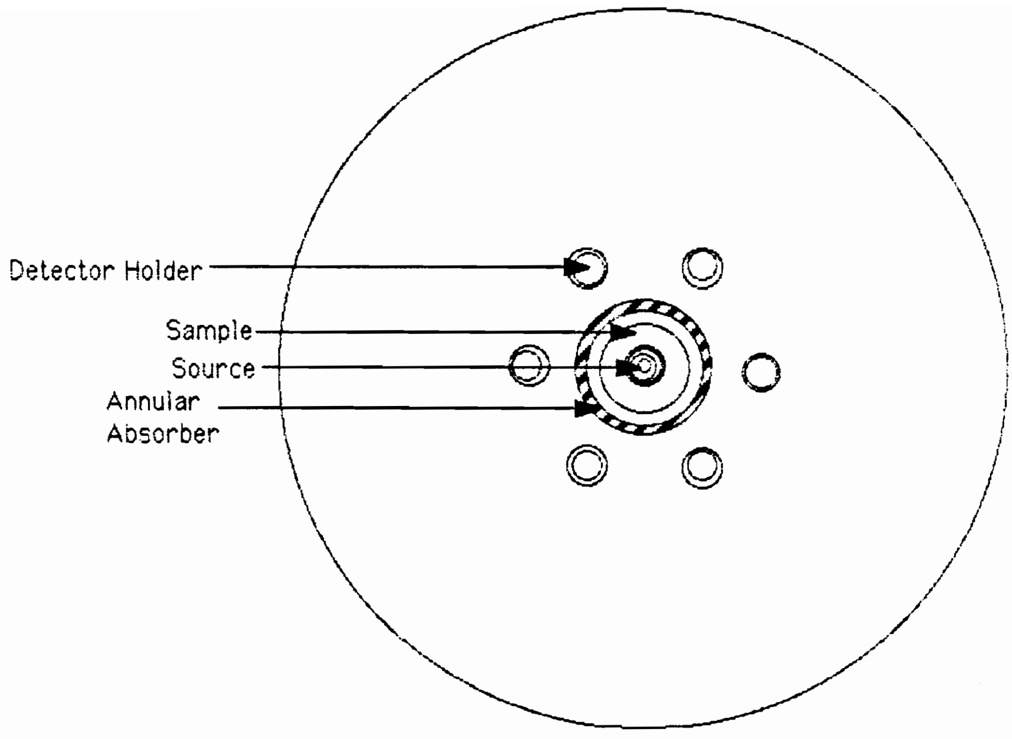

Figure 2. Annular Absorber Position

where for H_2O :

$$\tau_T = 27\text{cm}^2$$

$$D_1 = 1.13 \text{ cm}$$

$$L_T^2 = 81\text{cm}^2$$

$$\overline{D} = 16 \text{ cm}$$

$$S = 10^6 \frac{\text{neutrons}}{\text{second}} .$$

The units for Φ_T and Φ_1 are $\frac{\text{neutrons}}{\text{second cm}^2}$. Tabulated values of the theoretical fast and thermal fluxes are given in Table 4. Graphs of these theoretical values are given in Figure 3 and Figure 4. Measured count rates of thermal flux versus radial and axial measurements can be found in Figure 5 and Figure 6. A graph of the measured fast flux made with a covered detector given in Figure 7. As expected, the inverse slope of the thermal neutron flux is $\simeq \sqrt{27cm^2}$ since the thermal source dies out rapidly a few mean paths from the PuBe source.

From the preliminary experiments, the optimum locations for the sample annulus and the detector bank were determined.

Table 4. Calculated Flux Values vs. Radius

Radius (cm)	Φ_T $\frac{n}{\text{sec cm}^2}$	Φ_1 $\frac{n}{\text{sec cm}^2}$
1	25,836	58,094
2	19,747	23,962
3	15,125	13,178
4	11,609	8,153
5	8,929	5,381
6	6,881	3,699
7	5,314	2,615
8	4,112	1.888
9	3,188	1,384
10	2,476	1,028
11	1,927	771
12	1,502	583
13	1,173	444
14	918	340
15	719	262
16	565	202
17	444	157
18	349	122
19	276	96
20	218	75
21	172	59
22	136	46
23	108	37
24	86	29
25	68	23

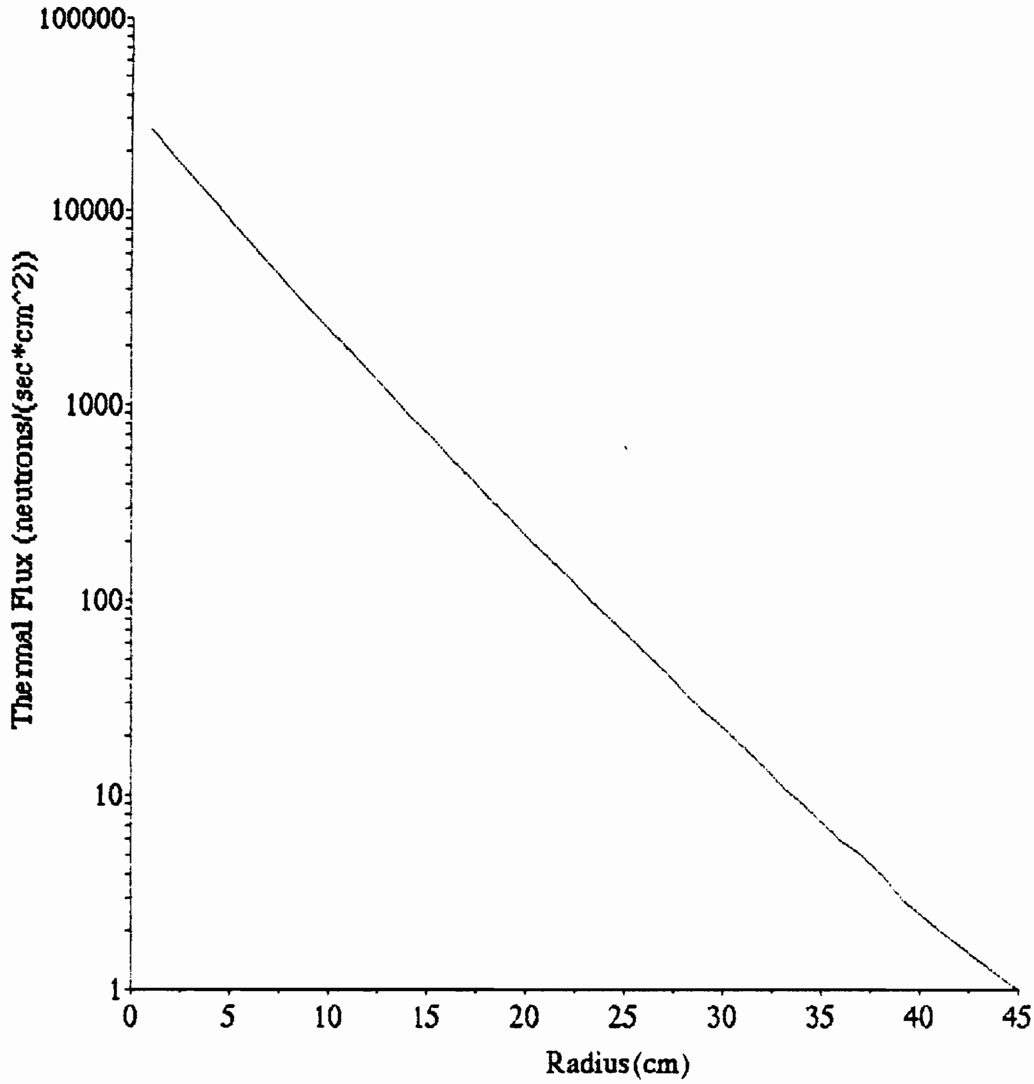

Figure 3. Theoretical Thermal Flux vs. Radius

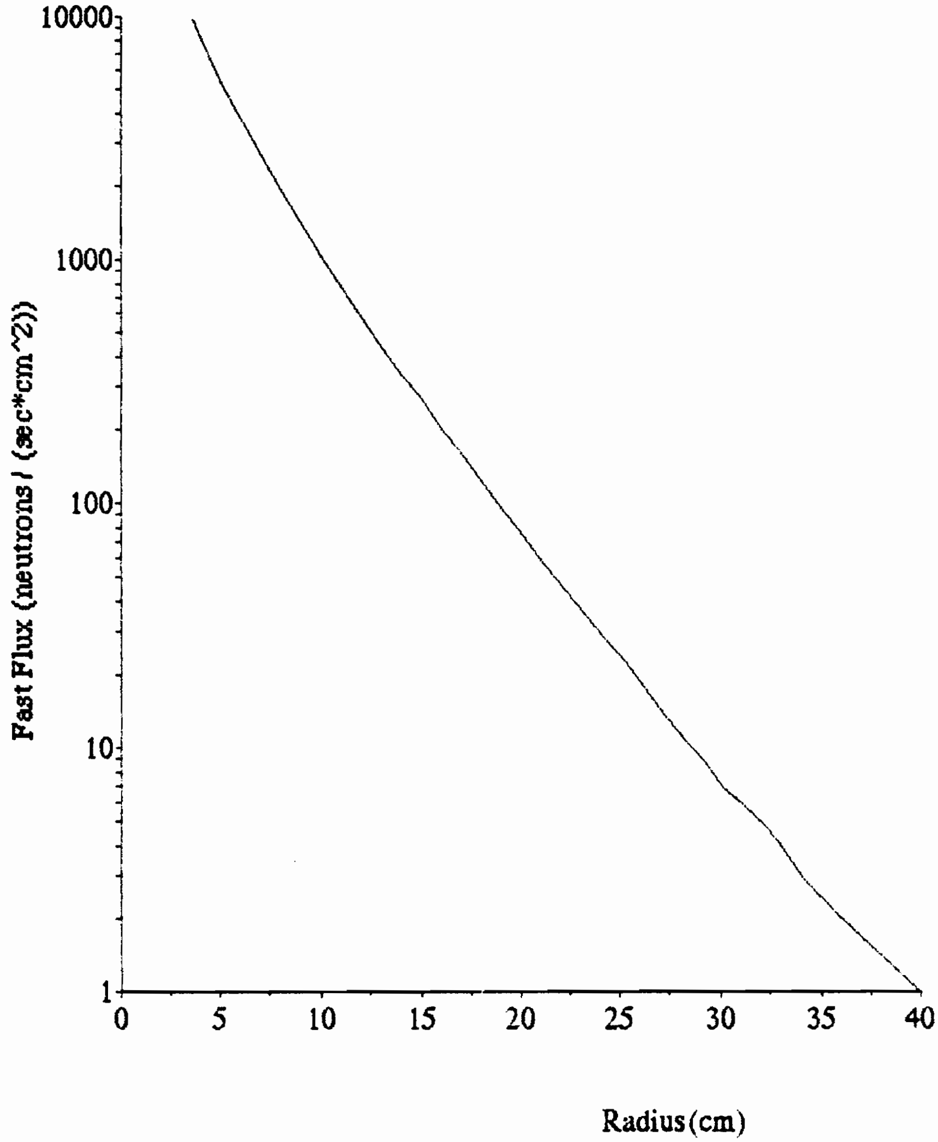

Figure 4. Theoretical Fast Flux vs. Radius

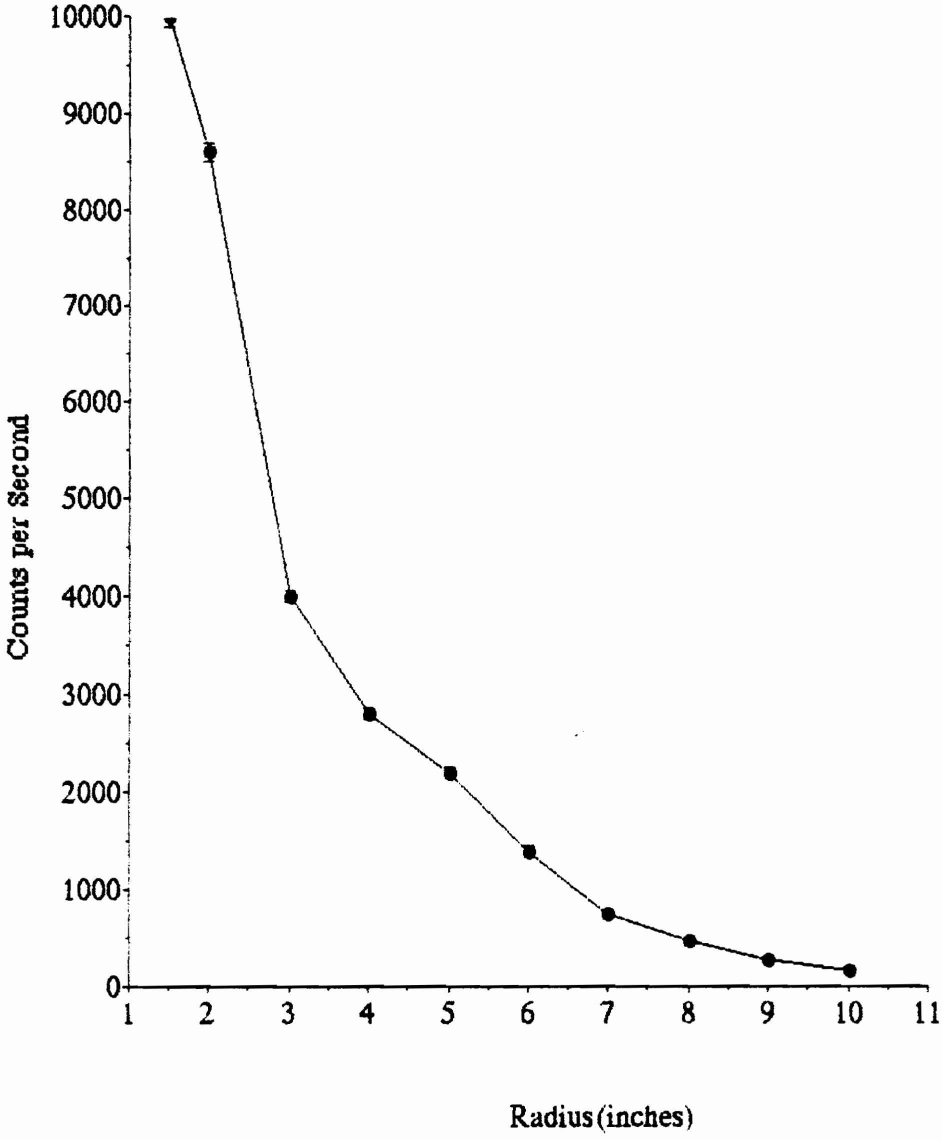

Figure 5. Measured Flux vs. Radius (Thermal)

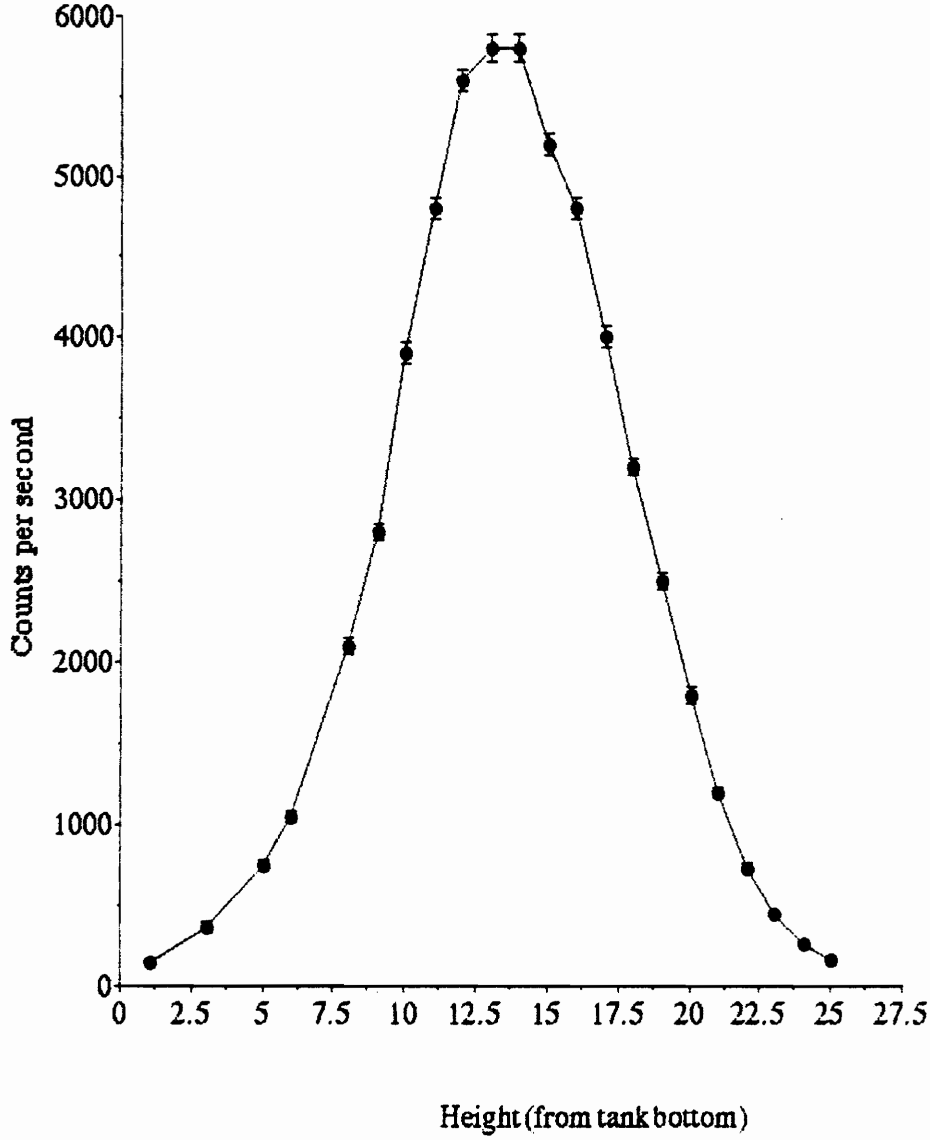

Figure 6. Measured Flux vs. Axial Position (Thermal)

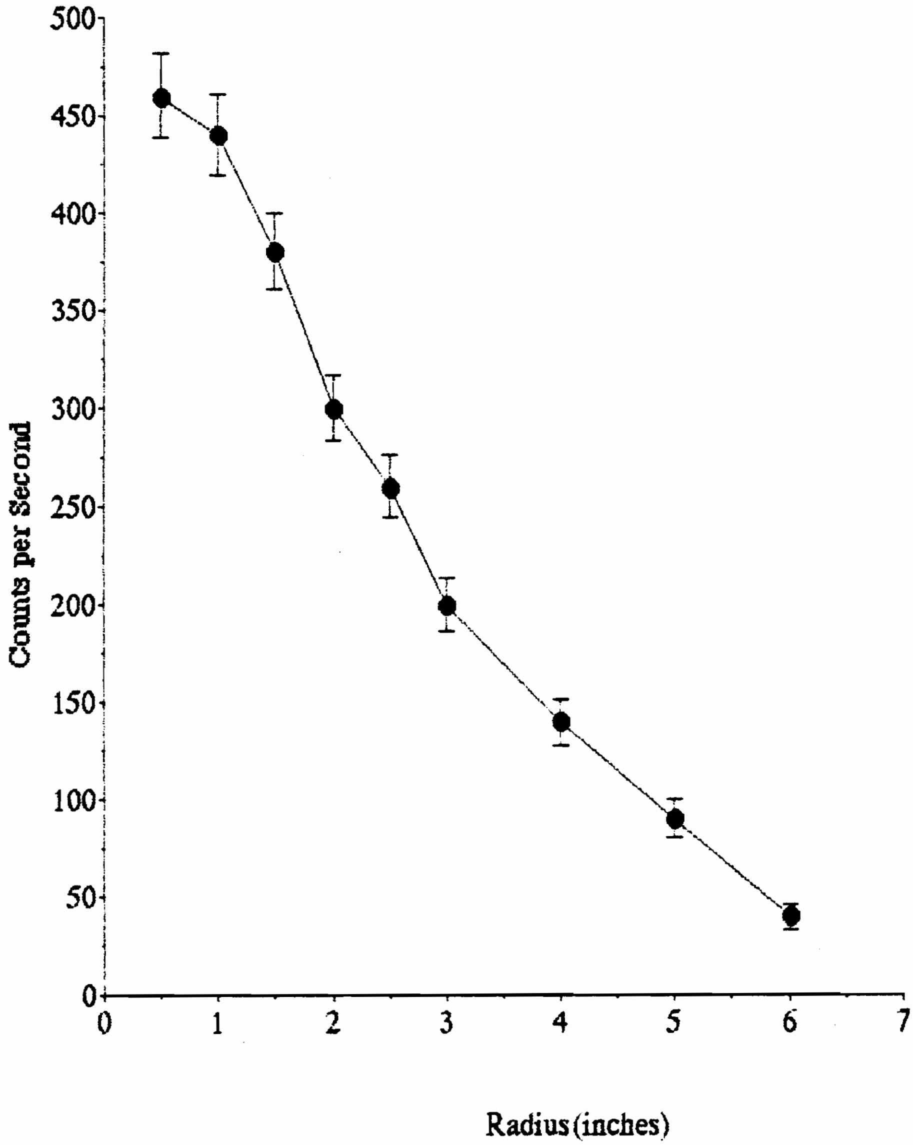

Figure 7. Measured Flux with Cd covered Detector vs. Radius (Fast)

Chapter 3

System Description

The boronimeter is comprised of four subsystems: the tank, the nuclear instrumentation, the computer with data acquisition board and the position-demand servo system. The subsystems must act as a collective unit that measures the B-10 concentration of the sample. The algorithm of operation can be seen in Figure 8. A sample enters into the sample container surrounding the source; see Figure 9. The boron present in the sample affects the flux measured by the detectors. The pulse rate from the detectors through the nuclear instrumentation increases / decreases accordingly. The counter sends the pulse rate as a voltage to the computer through the D/A board. The computer algorithm adjusts the absorber sleeve until it receives its preset "null" reading. From the position of the sleeve and other parameters, the computer software determines the boron concentration of the liquid in the container; see Figure 8. Each part of the system must fit into the overall purpose.

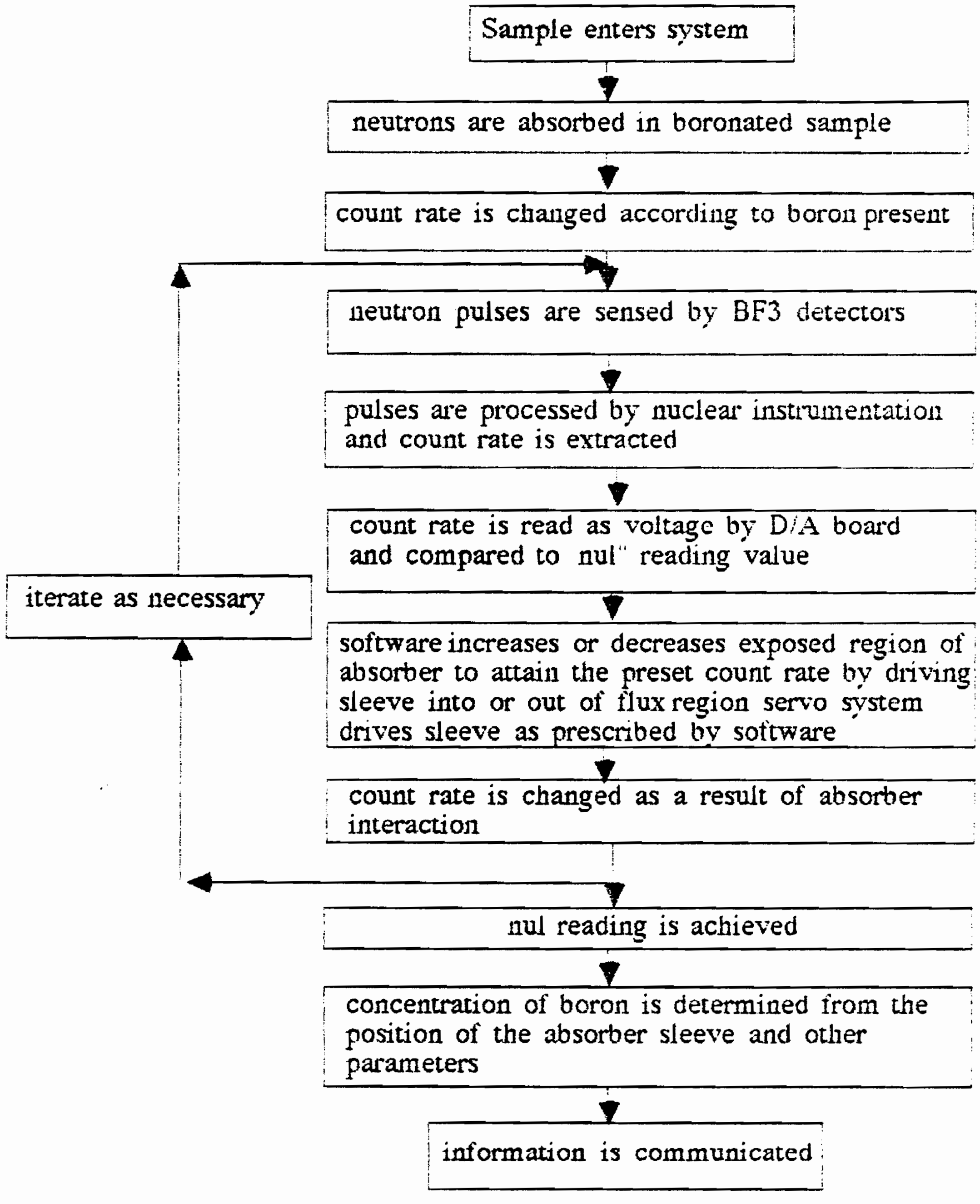

Figure 8. Boronimeter Algorithm

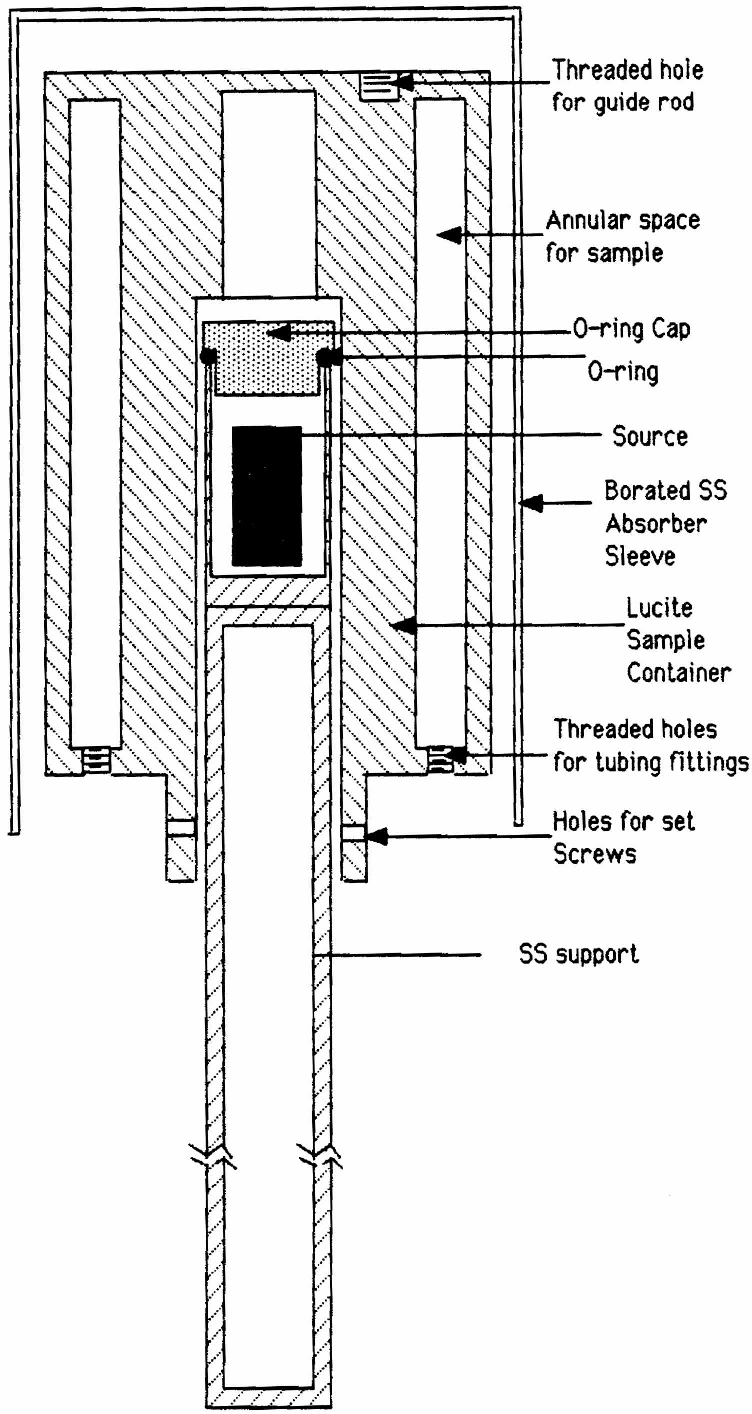

Figure 9. Sample Container

3.1 The Tank

The tank provides two functions to the system, that of housing and neutron moderation / shielding. The tank is the housing of the source and everything in the tank is designed relative to the location of the source. The 1 curie PuBe source is contained in a waterproof, stainless steel container in the center of the tank. The source comes in a waterproof housing of its own and then is sealed in the tanks' source holder having a threaded o-ring seal. The redundant mounting protects the integrity of the $\simeq$ 80 gallons of water that the tank contains against contamination from the PuBe source. Water is an effective neutron shield and by isolating the source in the center of a large water mass, the external radiation levels can be minimized. It is therefore imperative that the liquid cannot be contaminated by the PuBe source. Fitted over the source holder is the lucite sample container. It is annular, distributing $\simeq$ 600 ml of coolant around the source thus placing boronated water between the source and the detectors. The inlet line is a few inches higher than the outlet so that when in continuous, on-line operation, gravity propels the flow. The inlet and outlet lines are of 1/4" OD stainless steel tubing and tube fittings. The resistance temperature detector (RTD) is mounted on the sample container with a tube fitting so that the active length is inside the sample container. The RTD allows the temperature of the sample to be determined so that corrections can be made for the sample density changes owing to temperature changes. Finally, there is a vent to allow air to escape for the initial filling of the sample container. The lucite sample container is held in place by four set screws in the base of the container; the lucite also serves to moderate the source neutrons, since the lucite has about the same hydrogen density as water. The tank thus supplies a means for the sample to be introduced.

A collar is attached about the central pipe and to that collar is a brace for mounting the limit switch. The limit switch sends a signal to the computer upon the absorber sleeve reaching full-down position . The absorber sleeve is just slightly larger than the sample container and when lowered completely, it covers the sample container. It is made of boronated stainless steel with the composition listed in Table 5. There is a guide rod that leads off the top of the sample container to match a hole in the sleeve; this is to keep the absorber sleeve from free spinning about the lead screw. The absorber sleeve is attached to a screw collar and mounted. The screw is driven by the stepper motor mounted on the tank top. The lead screw goes through a clearance hole in the center top of the tank. See Figure 10 through Figure 12.

The boron within the material of the absorber sleeve is also between the source and the detectors with the maximum boron within the active length when the absorber sleeve is in the down position. As it is raised it has less and less effect on the flux for less and less boron is in the path between source and detector. With the combination of boron from the sample and the absorber sleeve, it is possible to acquire the same reading count rate at the detectors by inserting more of the absorber sleeve for weaker samples. This will be the operating basis of the "null" reading boronimeter.

The water in the tank serves a dual purpose. The water first thermalizes the neutrons and then absorbs them. Source neutrons slow from an average energy of 2 MeV to the 0.025 eV average energy of thermal neutrons. Elastic scatter is the means by

Table 5. **Composition of Absorber Sleeve**

Element	Weight %	σ_a, barns	Atomic Mass
C	00.026	0.003	12.01
Mn	1.64	13.2	54.94
Si	0.68	0.13	28.09
P	0.021	0.20	30.975
S	0.005	0.49	32.066
Cr	18.33	2.9	52.01
Ni	12.88	4.6	58.71
Mo	0.31	2.5	95.95
Cu	0.17	3.69	63.54
Co	0.23	37.0	58.94
B	1.11	755.0	10.82
Fe	49.603	2.53	55.85

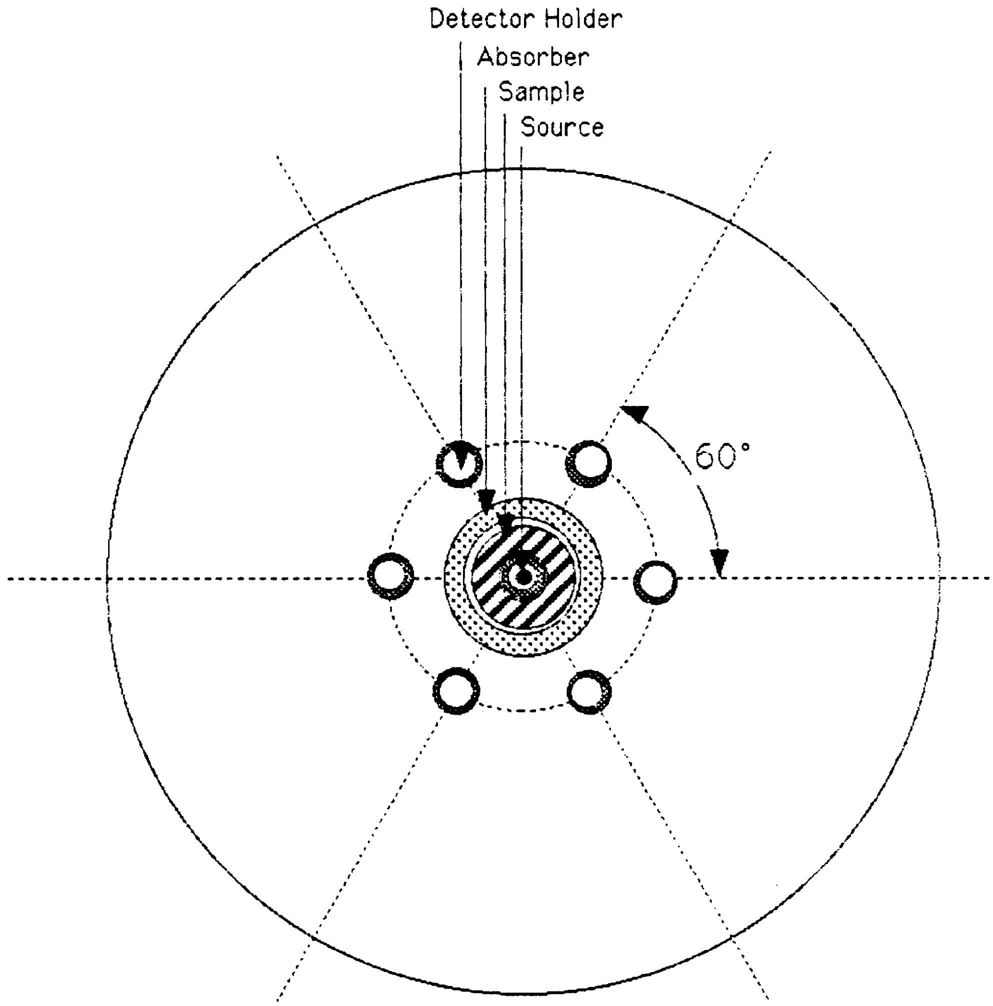

Figure 10. Tank (Top View)

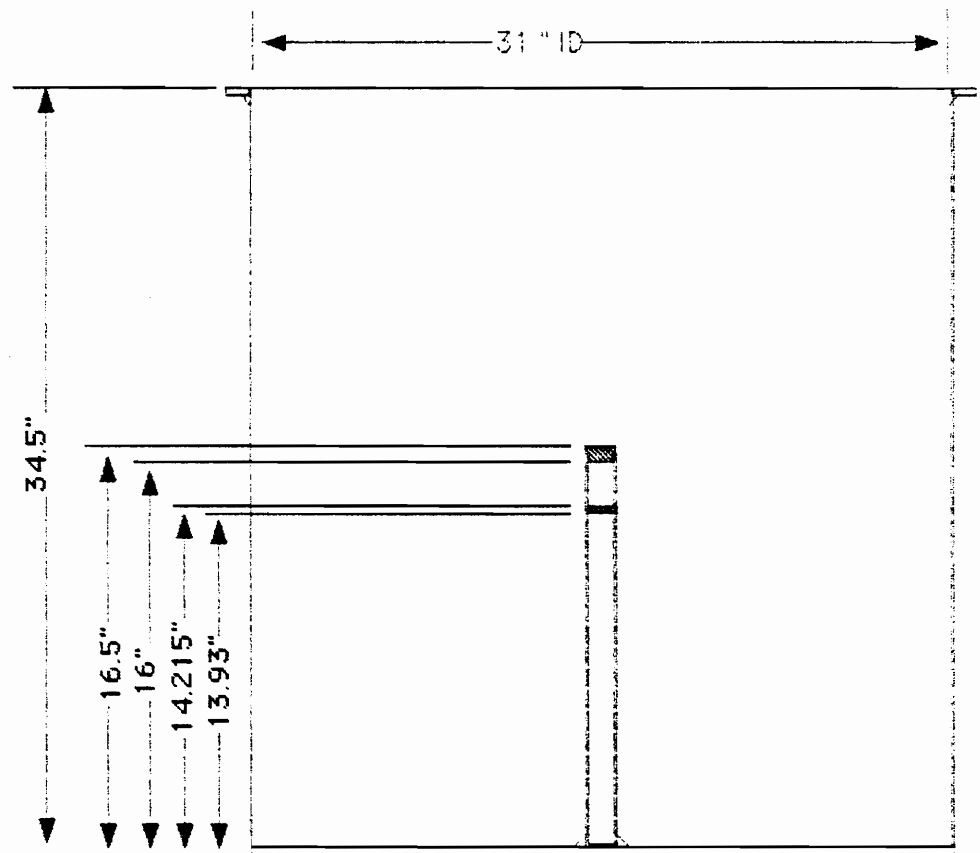

Figure 11. Tank (Cut View)

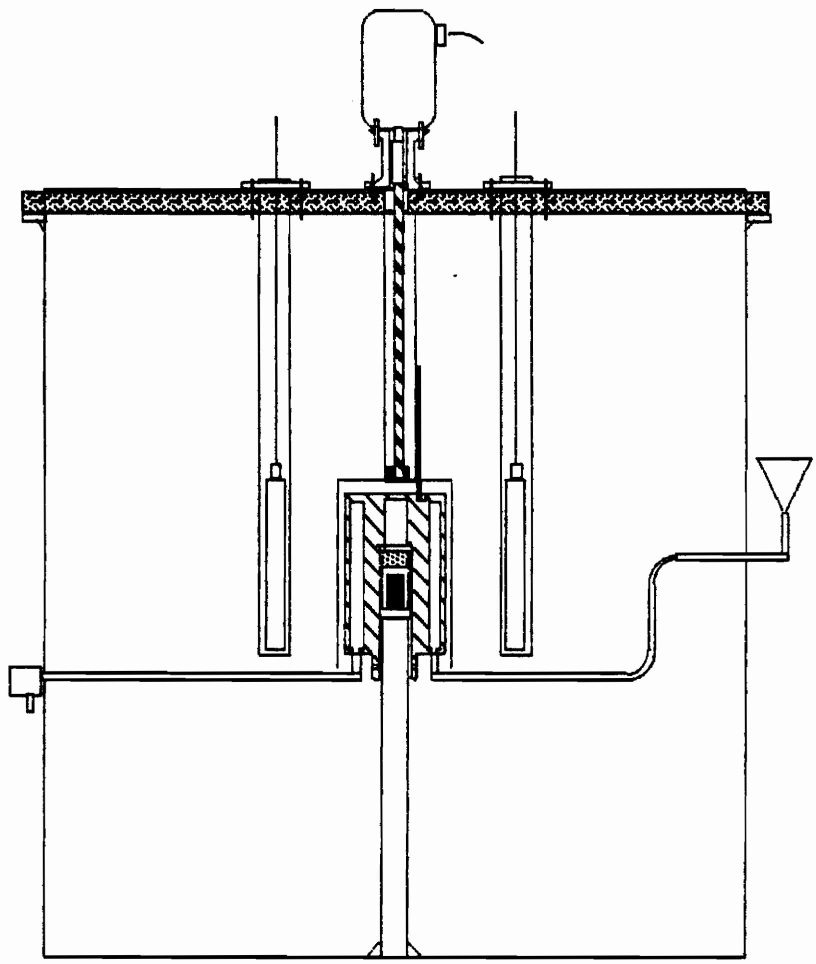

Figure 12. Tank Composite

which this slowing from source energy to thermal state occurs, where kinetic energy and momentum are conserved. Since more energy is dissipated in scattering with light nuclei, water makes an effective moderator. The loss of energy in a collision is contingent upon the angle of the collision as in the following equation:

$$\frac{Ke}{Ke_0} = \frac{A^2 + 2A\cos\theta + 1}{(1 + A)^2} \qquad [3.1]$$

3.2 Nuclear Instrumentation

The purpose of the nuclear instrumentation is to determine the neutron flux and provide that information to the instrumentation in a useful manner. The nuclear instruments are connected as shown in Figure 13. In the tank, six BF_3 detectors are evenly spaced around the source at a radius of four inches. The detectors send pulses as they absorb incident thermal neutrons. The BF_3 detectors send an electronic pulse (spike) for each absorbed neutron -- for further operational details of the detectors, see Appendix A. The signals from the detectors are grouped together into two groups (of three detectors each); the signals from the preamplifiers are then summed and fed into the amplifier. The shaping function adjustment allows the pulses to be "shaped" to match the "shape" detection parameters of the counter. The shaping preset in the Ortec 570 linear amplifier has a good signal to noise ratio and is easy to measure, yet keeps the electronics to a minimum. Pulse shaping is gaussian with peak time equal 2.2 τ and pulse width at 1%. The shaping time can

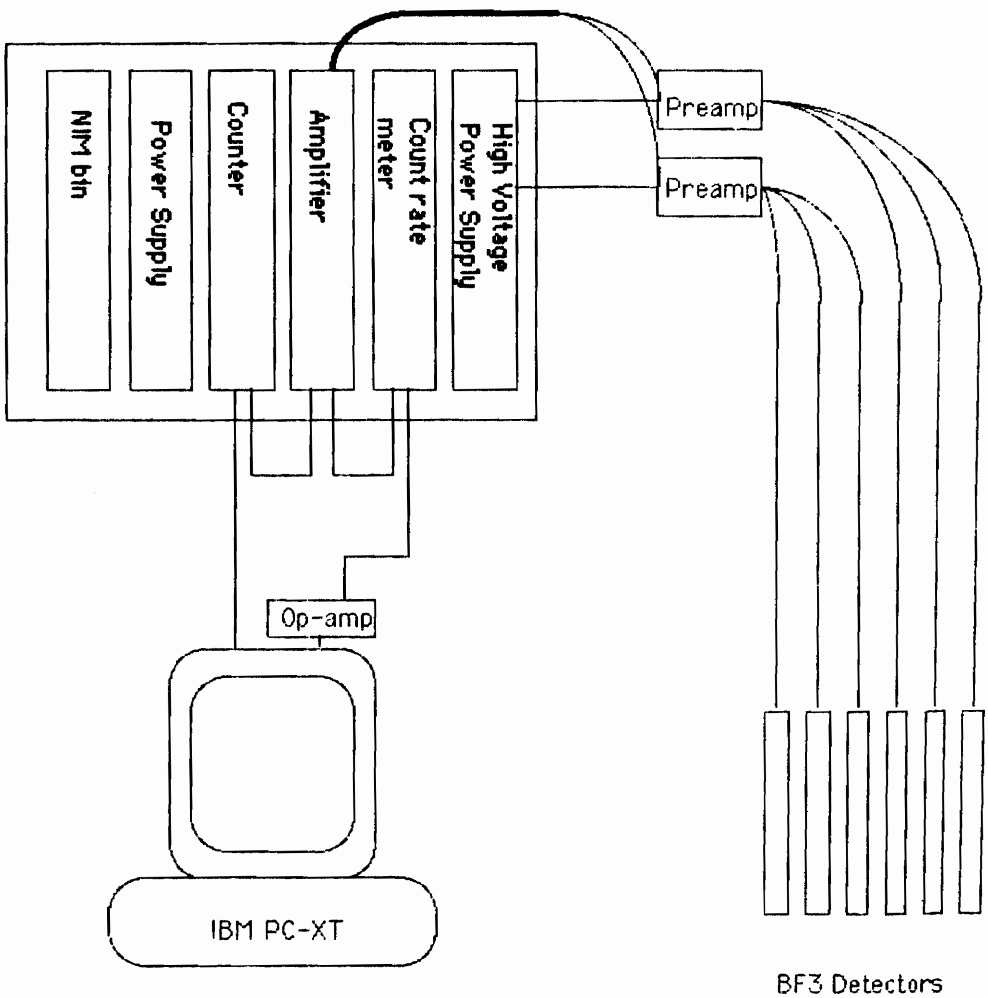

Figure 13. Nuclear Instrumentation

be chosen and is generally an optimization between having a shorter time constant for high count rates and a longer time constant for better noise elimination.

Another adjustment is the amplifier gain which is used to set the pulse amplitude to between 8 to 10 V. The final adjustment is the discriminator; the discriminator eliminates all signals below a certain voltage -- those considered to be noise. There is an automatic discriminator that analyzes the signal noise level by an interval signal and determines and sets the optimal thresholding level. The pulses are thus processed and sent to one of two counting devices. The counter / timer counts the total number of pulses received in a certain time period or it times the period required to receive a certain number of counts. The most useful aspect of the counter timer is that it has an RS-232C connection that allows remote control by interfacing to a computer. Remote mode allows the user to program a function or set of functions for the counter / timer to perform. A computer code can set up acquisition of data from the counter / timer, analyze the data, and function remotely. (See Appendix A for a list of commands.) The linear count ratemeter accepts a wide range of input count rates with statistical accuracy selectability. For the theory of the ratemeter's operation see Appendix A. The ratemeter also has an instrumentation recorder output that outputs a voltage of 0 - 100 mV corresponding to 0 - full scale. This output can be read via the D/A board and used to determine "instantaneous" rates as opposed to counts / time interval calculations necessary for analysis in the counter / timer. All the equipment (except the detectors) is mounted in the Ortec Nim Bin powered by common line current through the Ortec power supply. Specifications and fuller details of each instrument are given in appendix A.

3.3 The Position-Demand Servo System

The position demand servo system has 4 major parts: stepper motor, motor drive, the lead screw and nut, and the software. The purpose of the position-demand servo system is to place the absorber sleeve as prescribed by the boronimeter algorithm. The boronimeter algorithm is the software that uses the count rate and position information to determine B-10 concentration.

The software is the intelligent part of the servo system. It keeps track of where the absorber is and also determines and controls its movements. At set-up, the software drives the absorber sleeve to the down position. A limit switch mounted off the center column in the tank closes to signal the full-down vertical positioning of the sleeve. The software then initializes the location tracker. The stepper motor has a coarse resolution of 200 steps / revolution. The lead screw has a resolution of 2 threads / inch; therefore each 400 steps of the motor corresponds to one inch of travel for an overall resolution of 0.0025 inches / step:

$$\frac{\text{inch}}{\text{2 threads}} \; \frac{\text{thread}}{\text{revolution}} \; \frac{\text{revolution}}{\text{200 steps}} = .0025\,\frac{\text{inches}}{\text{steps}} \quad . \qquad [3.2]$$

The stepper motor has four coils and by activating / deactivating the coils in a set sequence, the motor is stepped through revolutions. The motor also has a fine setting of 400 steps / revolution yielding a resolution of 0.00125 inches per step, but no need for such resolution was found. Activation of the coils can be achieved through the A/D board and the motor drive circuitry (see Figure 14).

The sequences for coarse and fine operation can be found in Table 6 and Table 7 respectively. Four digital I/O ports are used to generate the currents to

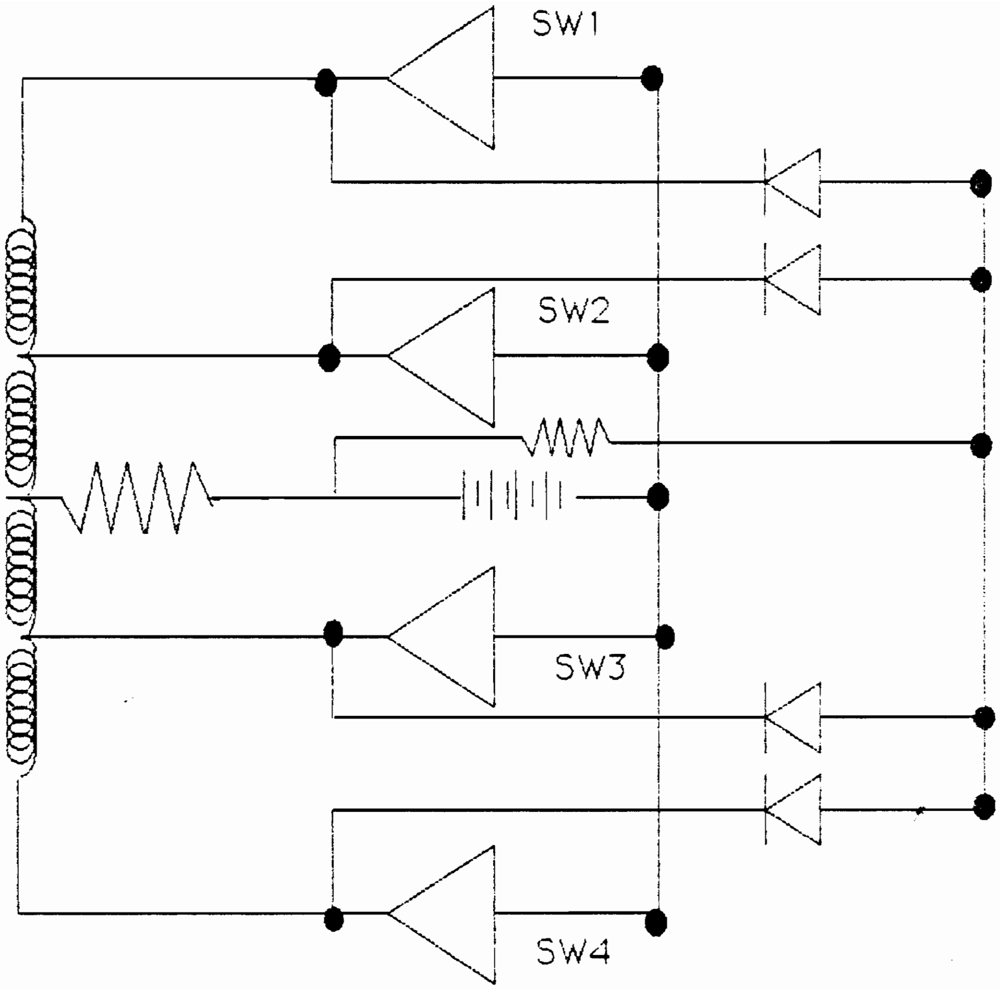

Figure 14. Motor Drive Circuitry

Table 6. Coarse Step Sequence

Step	SW1	SW2	SW3	SW4	BCD
1	+5V	0	+5V	0	10
2	+5V	0	0	+5V	9
3	0	+5V	0	+5V	5
4	0	+5V	+5V	0	6

Table 7. Fine Step Sequence

Step	SW1	SW2	SW3	SW4	BCD
1	+5V	0	+5V	0	10
2	+5V	0	0	0	8
3	+5V	0	0	+5V	9
4	0	0	0	+5V	1
5	0	+5V	0	+5V	5
6	0	+5V	0	0	4
7	0	+5V	+5V	0	6
8	0	0	+5V	0	2

activate the coils. The I/O ports are "read" by the motor drive (see schematic in Figure 14.) The positive (true logic) of the digital I/O's is converted to a 12 volt signal the activates the corresponding coil of the motor. For example to move the motor forward one step when the motor is in position one (a digital I/O value of 5) the motor needs to receive a digital I/O value of 6. It must change from activating coils 3 and 1 {0101} to coils 3 and 2 {0110}. The coils magnetically rotate the shaft of the motor one step (1/200 th of a revolution). The software keeps track of the last active setting and for each step increments through the coil settings. The software counts the numbers of steps moved from the home position and translates that count into a height. In this way the software monitors and directs the positioning of the absorber sleeve.

3.4 The Computer and Data Acquisition Board

The computer is an IBM PC-XT with a Dascon-1 D/A board mounted in one of the expansion ports. The D/A board is the computer's interface to the rest of the boronimeter and it allows the computer to determine and act upon the status of the rest of the system. The D/A board allows the computer to communicate with the stepper motor drive, the limit switch, the rate meter, and the RTD. For communications with the stepper motor drive, the digital I/O ports are used to output coil settings to turn the motor. The limit switch uses a digital I/O port to input the status of the limit switch for positioning of the absorber sleeve. The ratemeter and

RTD signals are read on separate D/A channels from the board and the information can be used in the software analysis.

Chapter 4

Calibration

4.1 Standards

Calibration of the system was made against known standards. The system parameters-- boron concentration and absorber position -- were varied and their effects on the system reading were determined.

Final calibration of the system was done using two sets of standards. Concentrations of 0, 25, 50, 100, 400, and 1000 ppm were made from boron stock from the National Bureau of Standards (SRM 3107). A 5000 ppm solution of 200 ml was diluted by the following schedule to make the standards, see Table 8. Initial experiments were run with secondary standards, made from laboratory boric acid dissolved in distilled water and then diluted to the needed concentrations. Five different nominal

Table 8. NBS Standards Dilution Schedule

Original Sol'n		Diluted w/	Resulting Sol'n		Kept	Rediluted
conc (ppm)	amt (ml)	amt (ml)	conc (ppm)	amt (ml)	amt (ml)	amt (ml)
5000	200	800	1000	1000	600	400
1000	400	600	400	1000	600	400
400	400	1200	100	1600	850	750
100	500	500	50	1000	1000	--
100	250	750	25	1000	1000	--

concentrations were made of 0, 100, 400, 1000, and 2500 ppm, by diluting down an originally, highly concentrated solution. The original solution was 40g of H_3BO_3 in 1 liter of H_2O. The original solution had a concentration of 6729 ppm.

Molecular weight of Boric Acid:

H: 1.008 x 3 = 3.024

B: 10.82 x 1 = 48.00

O: 16.00 x 3 = 48.00

= 61.84 g/mole

Weight of Boron in 40 g Boric Acid:

$$40\,x\ \frac{10.82 \text{ grams Boron}}{61.84 \text{ grams} H_3BO_3} = 6.9987\ \frac{\text{g of Boron}}{\text{g Boric Acid}}$$

$$\frac{6.9887}{40gH_3BO_{3.} + 1000H_20} = 6{,}729 \text{ ppm.}$$

To make, for example, 2 liters of the 1000 ppm solution the calculation was made

$$\frac{x \text{ (solution)}}{2000}\ \frac{6729}{1000000} = \frac{1000}{1000000}$$

$x = 298.5$ ml.

Table 9. Concentrations of Secondary Standards

Nominal (ppm)	Tech A	Tech B
100	104	98
395	381	395
1000	1034	1034
2500	2561	2557

The other solutions were determined in a similar manner. Portions of these solutions were sent to Virginia Power for titration analysis and actual concentrations are given in Table 9.

4.2 Calibration

4.2.1 Varying Concentration

The final calibration data was taken with a data acquisition routine written in Turbo Basic; see Appendix C. The sample container was filled with a concentration (starting with 0 ppm and going to 2500 ppm) and 1000 point averages from the rate meter were taken in half inch increments of absorber position (starting at full down (0 inches) and going to full up (6.5 inches)). The settling time of the Dascon-1 is 0.25 seconds so 1000 point averages require 250 seconds to collect. A histogram of one such set of data can be found in Figure 15. The standard deviation for this set of data was 0.0177 and the mean was 0.9038 . This histogram shows that the data appears to be gaussian in its distribution and shows that the boronimeter displays the random nature expected with counting statistics. The standards were used to determine the correlation among count rate, absorber position and concentration. The theoretical relationship between concentration and count rate is given by equation [2.4] This equation can be written in the logarithmic form

$$\ln\left(\frac{CR}{CR_0}\right) = C_1(BC) + C_2. \qquad [4.1]$$

By fitting the data to Equation [4.1], the following equation, giving the empirical relationship of the data, was obtained. The average deviation and maximum deviations from the curve fit for the NBS data are 0.57% and 0.99% respectively. The equation for NBS data is:

$$\ln\left(\frac{CR}{CR_0}\right) = -5.213E - 05(BC) + 0.2599. \qquad [4.2]$$

This curve can be seen in Figure 16.

4.2.2 Varying Absorber Position

The effect of the absorber sleeve on the count rate is of the same shape as a curve for the reactivity of a partially inserted control rod on a reactor [Foster & Wright,1980]. The equation is of the form:

$$Y\left(\frac{z}{H}\right) = \frac{z}{H} - \frac{\sin(2\pi \frac{z}{H})}{2\pi} \qquad [4.3]$$

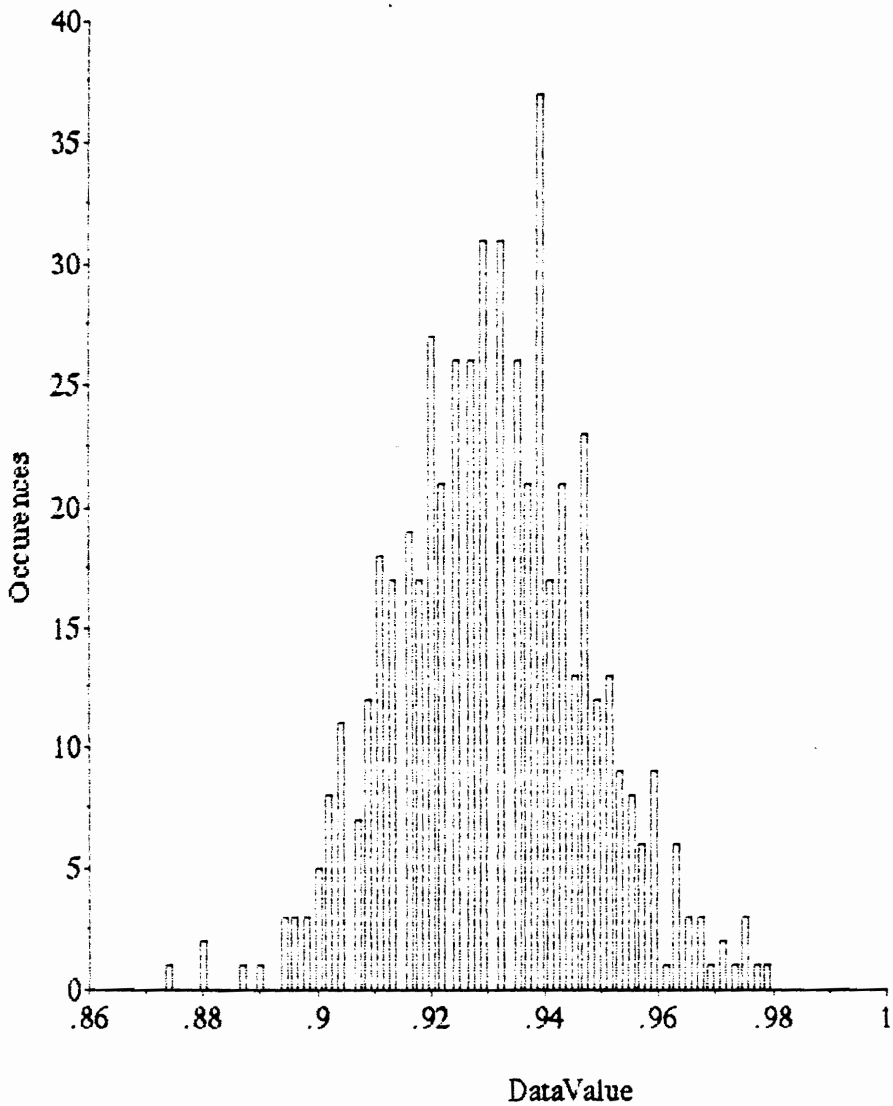

Figure 15. Histogram of a Set of Data Used in 1000 Point Averaging

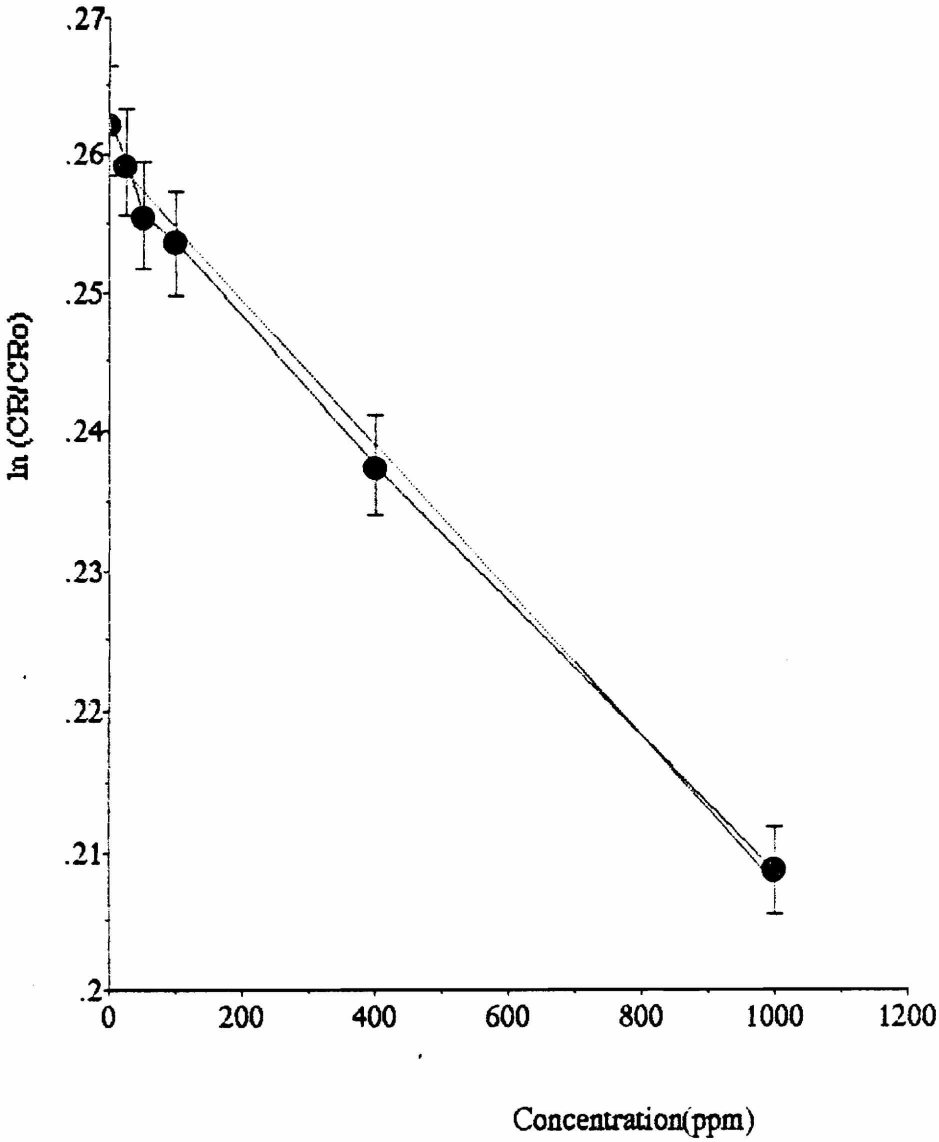

Figure 16. CR vs BC for NBS Standards

for $y(0)=0$ and $y(1)=1$. But to fit the boundaries of the system the equation is rewritten in the form:

$$g\left(\frac{z}{H}\right)=(1-k_1)Y\left(\frac{z}{H}\right)+k_1. \qquad [4.4]$$

Fitting the data to the curve a good approximation is with k_1 = 0.77; see Figure 17.

4.2.3 Integrated

A combined affect of the two parameters can be seen in Figure 18 and Figure 19. The former shows count rate versus concentration at constant absorber positions; the latter shows count rate versus absorber positions at constant concentrations. The operating line for the boronimeter is shown on both graphs.

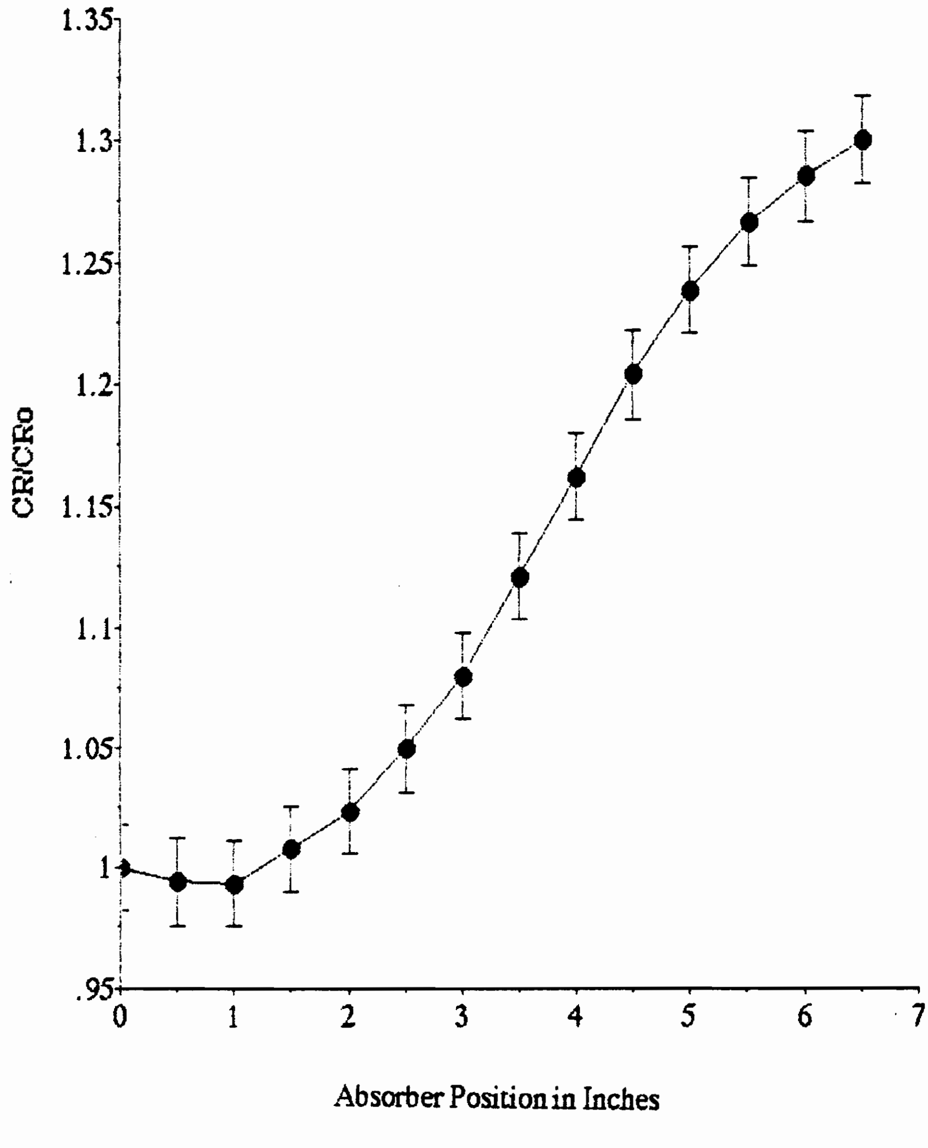

Figure 17. Count Rate vs Absorber Position

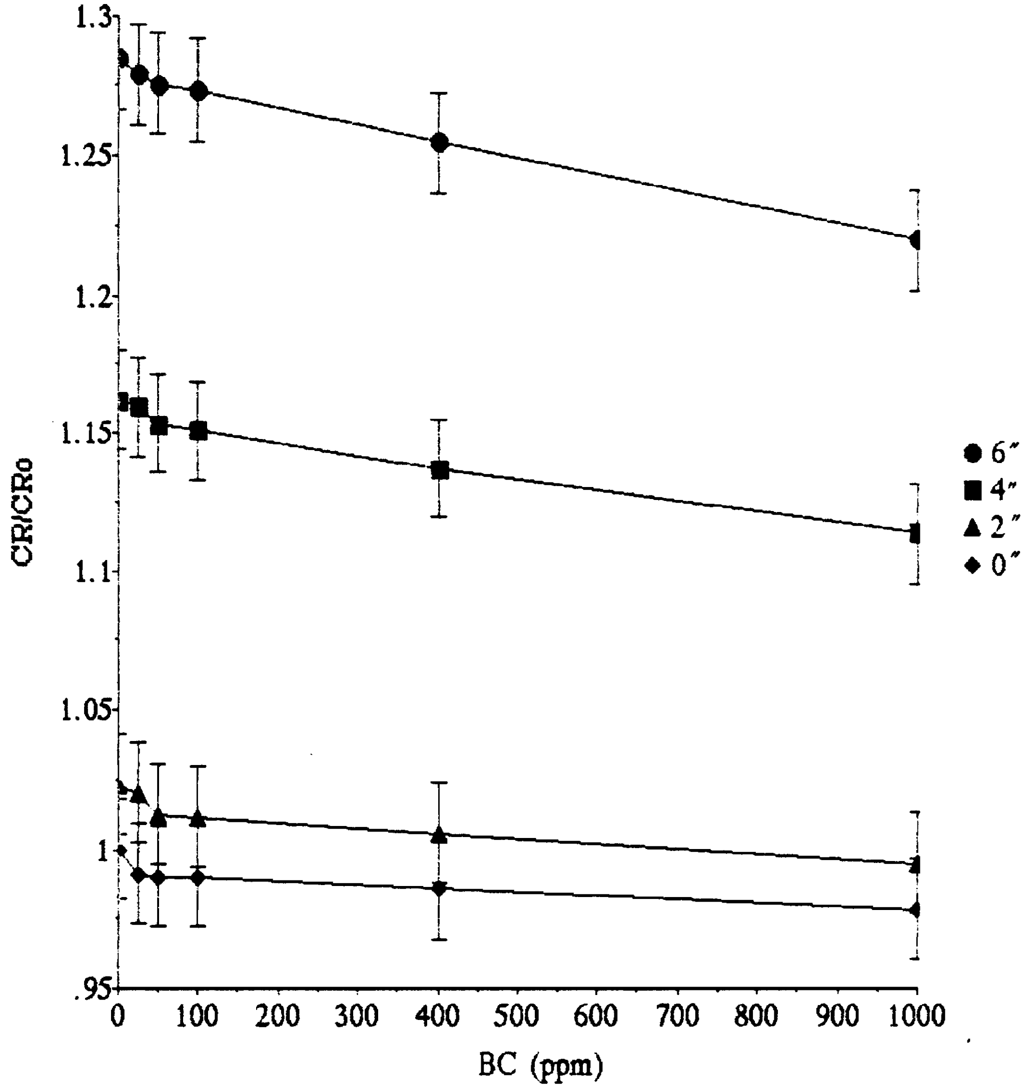

Figure 18. Count Rate vs BC with constant Absorber Positions

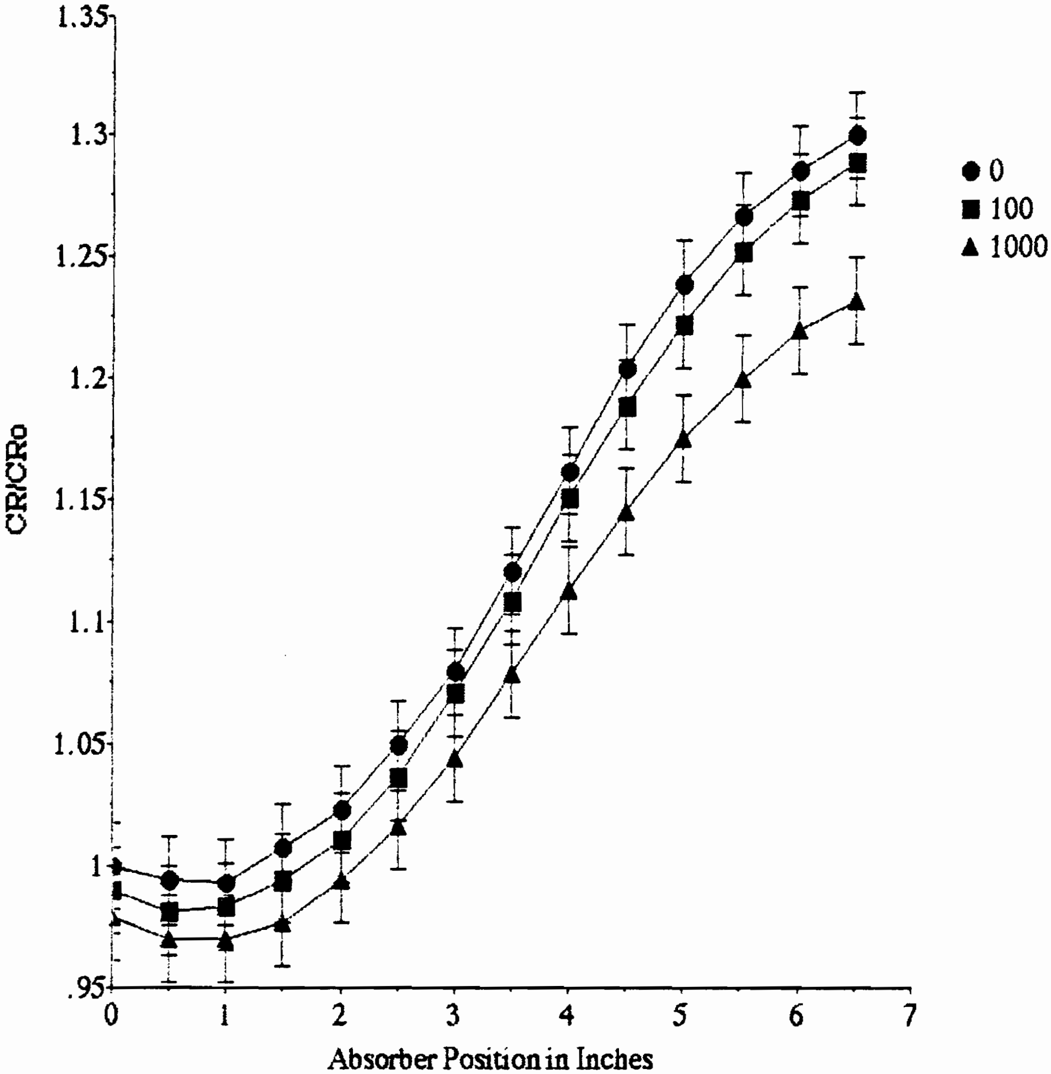

Figure 19. Count Rate vs Absorber Position with constant BC

Chapter 5

Results, Conclusions and Recommendations

The boronimeter has been developed to operate in two modes -- the first for batch sampling, the second for on-line analysis. Batch sampling is a simpler mode of operation for it can be done without use of the servo-system. The boronimeter can be used should the servo system fail, or if batch sampling is preferred to on-line analysis. On-line operation includes the servo system, and is advantageous because of its constant counting statistics. When the two parameters are combined the characteristics of both or either are evident and can be used. Both modes are theoretically sound, and the boronimeter has shown its adaptability to either method.

Batch sampling relies on the CR/CRo vs BC curve to determine the boron concentration. Figure 16 shows that the boronimeter behaves according to the theoretically prescribed pattern of Equation [4.1]. On-line operation relies on the CR/CRo vs absorber position curves of Figure 17. It follows the curve prescribed by Equation [4.5]. The data match these theoretical curves and show the boronimeter

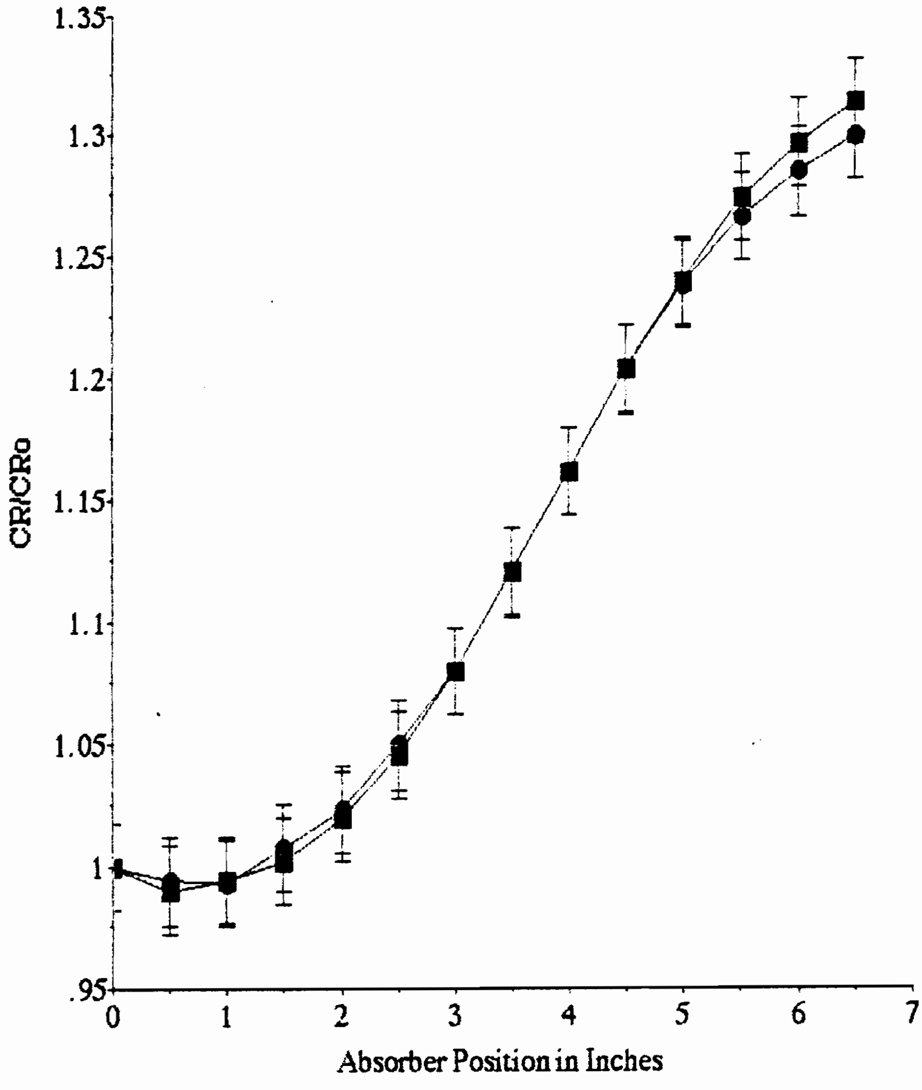

Figure 20. Repeatability Data

to be a well behaved system. The histogram of Figure 15 shows that the data seem to follow a gaussian distribution of counting statistics, behaving as expected. Further, the repeatability of the data is reasonable. Figure 20 shows two sets of data taken (with BC = 0) at separate times. The two curves follow one another and match almost exactly at the operating point of the boronimeter. In short, the boronimeter behaves as expected, repeatedly and reliably.

Further experiments need to be done to more fully determine the accuracy of the boronimeter over a greater variation of conditions. Temperature compensation needs to be added to the system once a waterproof Resistance Temperature Device can be found. Parametric studies are needed to determine how the boronimeter can be improved or produced more inexpensively, e.g., how would three less detectors affect the system performance? What effects can be seen if the data is taken more quickly or less quickly. A schedule of calibrations and maintenance needs to be performed to keep the instrument accurate. There were many hardware problems encountered in the creation of this device and these need to be addressed to make continued use plausible. The nut mate for the lead screw has a small section that corrodes; there is trouble keeping the water of the tank aesthetically pleasant, and so on. While these are not major operational problems, they have to be considered. Two limit switch failures have been encountered in the last month and a new more durable switch needs to be found for a replacement.

The boronimeter requires further attention but it is near to being an industry quality instrument.

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Appendix A

Nuclear Instrumentation Specifications

A.1 Spectroscopy amplifier

The Ortec 570 Spectroscopy Amplifier is a single-width NIM which has a variety of switch-selectable shaping characteristics. It accepts input from proportional counters, such as the BF_3 detectors, as well as other detectors. The input impedance of the amplifier is approximately 1000 Ω. Input pulses can be either positive or negative with rise times <650 ns and fall times of >40 μ s. The amplifier has six differentiating and integrating time constants available to allow for optimum resolution and count rate through pulse shaping. The amplifier has a filter shaping system that actively optimizes the signal-to-noise ratio and minimizes the overall resolving time. The output is unipolar and a BLR (baseline restorer) circuit is incorporated in the amplifier to be applied during intervals between input pulses. The 570 has the capabilities to operate with any Ortec preamplifier, to properly match the

Table 10. Amplifier Specifications

Option	Specification(s)
Gain	Ten turn precision potentiometer for continuously variable gains from x0.5 to x1.5.
Coarse Gain	Six position selector switch selects gain factors of 20, 50, 100, 200, 500, and 1000.
Input Attenuator	Jumper on printed circuit board selects an input attenuation factor of 1 or 10.
Positive / Negative	Locking toggle switch selects input polarity of pulses.
Shaping Time	Six-position switch selects time constant for the active filter network for pulse shaping of the input trigger pulses, selections for time constants are 0.5, 1, 2, 3, 5, amd 10 μs.
PZ Adjustment	Potentiometer to adjust pole zero cancelation for decay times from 40 μs to ∞.
Base Line Restorer	Locking toggle switch selects a source for the gated baseline restorer discriminator setting from one of three positions.
Threshold	A potentiometer that allows the BLR to be set manually. The range of adjustment is 0 to 300 mV.

input signal. The specifications for the 570 are given in Table 10. The controls and adjustments are enumerated in Table 11.

A.2 Dual Counter and Timer

The Model 994 Dual Counter and Timer is comprised of two eight decade counters and a blind preset counter. It has high functional flexibility allowing many configurations for a variety of measurement tasks. Flexibility in setting the preset value is offered by the $MNx10^{P}$ selection, allowing presets in the ranges of 0.01 to 990,000 seconds, 0.01 to 990,000 minutes, or 0.01 to 990,000 counts. The counter

Table 11. Amplifier Controls and Adjustments

Option	Specification(s)
Gain Range	Adjustable from x1 to x1500 continuously
Pulse Shaping Integral Nonlinearity	Gaussian on all ranges with peaking time at 2.2 τ and having a pulse width at 0.1% level equal to 2.9 times the peaking time. $<0.05\%$ (0.025% typically) using 2 μs shaping
Noise	<8 μV referred to input (5 μ V typically) using 2 μs shaping and gain $\geq$ 100
Temperature Instability	Gain: $\leq$ 0.0075%/ ° C, 0 to 50 ° C DC level:$<$ $\pm$ 50 μ V / ° C, 0 to 50 ° C
Walk	$\leq$ $\pm$ 3 ns for 50:1 dynamic range, including contribution of Ortec 551 or 552 Constant fraction timing single channel analyzer using 50% fraction and 0.5 μ s shaping
Count Rate Stability	The 1.33 MeV gamma ray peak from a Cobalt-60 source positioned at 85% of analyzer range, typically shifts $<$ 0.024% and its FWHM broadens $<$ 16% when its incoming count rate changes from 0 to 100,000 counts per second using 2 μs shaping and external pileup rejection. The amplifier will hold the baseline reference up to count rates in excess of 150,000 counts per second.
Overload Recovery	Recovers to within 2% of rated output from x300 overload in 2.5 nonoverloaded unipolar pulse widths, using maximum gain; same recovery from x1000 overload for bipolar pulses.

timer has two separate counters, counters A and B. Each could be used to perform as a counter or a timer. The Model 994 includes an 8-decade LED display offering instantaneous visual readout of the full contents of the registers. A full list of specifications can be found in Table 12. The computer controlled option is available through the IEEE-488 or RS-232-C interfaces. The RS-232-C option has been added to the boronimeter system allowing simple remote operation through IBM PC-XT, operating as a terminal. The computer-controllable remote functions include start and stop count, readout, reset, setting the preset value, and selecting the desired time base. For a list of commands and their formats see Table 13.

Table 12. Counter Timer Specifications

Option	Specification(s)
Count Capacity	8 decades for counts ranging from 0 to 99,999,999 in each of two counters.
Maximum Counting Rate	100 MHz for negatice inputs, 25 Mhz for positive inputs
Time Base	10-MHz clock with minimum preset or displayed intervals of 0.01 seconds or 0.01 minutes. Synchronising error is nominally 100 ns. Also accepts an external input from the counter A input (In A) when the external mode is selected.
Time Base Accuracy	≤ ± 0.0025% over the 0 to 50 ° C operating temperature range
Preset Time and Counts	The Module stop counting when it has reached the preset value MN x 10^P. M and N are digits (ranging from 0 to 9) and P is a digit ranging from 0 to 6. Preset times from 0.01 to 990,000 seconds or minutes can be achieved by using the 0.01 second and and minute time bases respectively. In the external mode preset counts can range from 1 to 99,000,000
Positive Input Discriminator	Threshold variable from +100mV to +9.5V with a 25-turn trimpot.
Pulse Pair Resolution	< 10ns for negative inputs; <40ns for positive inputs

A.3 Power Supply

The Ortec Model 402D Power Supply is designed to be mounted in the rear of the 4001A Modular System BIN. The supply furnishes six standard dc voltages ±24 volts at 1 amp, ±12 volts at 2 amps and ±8 volts at 6 amps with a maximum power capability of 132 watts at 50 °. The dc outputs are regulated, short circuit protected current limited and thermal protected. Input voltages of 117 volts ac or 230 volts ac, 47-63 hertz, may be used. See Table 14 for specifications.

Table 13. Commands for Remote Operations

Command	Short	Meaning
CLEAR_ALL	CL_ALL	Clears counters, count preset, event counter, and event preset.
CLEAR_COUNTERS	CL_COU	Clears all counters in the 994. module
CLEAR_COUNT_PRESET	CL_COU_PR	Clears the M, N and P values.
CLEAR_EVENT_PRESET	CL_EV_PR	Resets the event preset register to zero.
COMPUTER	COMP	Sets the 994 to the computer mode, the complement to the terminal command.
DISABLE_ALARM	DI_ALA	Disables the alarm function (see enable alarm).
DISABLE_EVENT	DIS_EV	Disables the event counter.
DISABLE_EVENT_PRESET_	DIS_EV_PR	Disables the event preset function.
DISABLE_TRIGGER_START	DIS_TRI_STAR	(IEE-488 operation only).
DISABLE_TRIGGER_STOP	DIS_TRI_STOP	(IEE-488 operation only).
ENABLE_ALARM	EN_ALA	Causes the 994 to transfer the contents of the counters to the host at the end of a preset interval without a direct command.
ENABLE_EVENT_AUTO	EN_EV_AU	Causes the event counter to be advanced, by one count each time the preset value is reached.
ENABLE_EVENT_PRESET	EN_EV_PR	Causes the event counter to stop after a preset number of counting cycles have occurred.
ENABLE_LOCAL	EN_LOC	Places the 994 under local control (i.e., the front panel controls). The 994 will still respond to the communications interfaces and to commands from a host.
ENABLE_REMOTE	EN_REM	Places the 994 totally under the control of a host computer. All front panel controls except for display select are disabled

Table 13. Commands for Remote Operations (cont.).

Command	Short	Meaning
ENABLE_TRIGGER_START	EN_TRI_STA	Enables the 994 to start a counting cycle on a "group execute trigger" command from the IEEE-488 bus. This enables a number of counters to start simultaneously from a single trigger command.
ENABLE_TRIGGER_STOP	EN_TRI_STO	Enables the 994 to stop a counting cycle on a "group execute trigger" command from the IEEE-488 bus. This is the complement to the above command.
INIT	INIT	Causes the 994 to restart /initialize. Same as reset or power up.
SET_COUNT_PRESET<MN,P>	SET_COU_PR	Sets the preset value to the value of the MN,P parameter.
SET_EVENT_PRESET<MN,P>	SET_EV_PR	Loads the value to the event preset register. Counting will be stopped when the event counter reaches that value.
SET_MODE_EXTERNAL	SET_MOD_EXT	Selects the external input to the preset counter.
SET_MODE_MINUTES	SET_MOD_MIN	Selects the minutes time base as the input to the preset counter.
SET_MODE_SECONDS	SET_MOD_SEC	Selects the seconds time base as the input to the preset counter.
SET_DISPLAY_<VALUE>	SET_DISP	Selects the counter whose contents will be displayed on the front panel, 7-segment LEDs. The value will be either 0 or 1 respectively.
SHOW_ALARM	SH_ALA	Returns a $1 response record showing the status of the alarm. The answer is in the form of a "T" for true and "F" for false.
SHOW_COUNTS	SH_COU	Shows the contents of Counters A and B. Example 00000000:00000000;
SHOW_COUNT_PRESET	SH_COU_PRE	Causes the 994 to transmit a $D response record which includes the MN and P values selected.

Table 13. Commands for Remote Operations (cont.).

Command	Short	Meaning
SHOW_DISPLAY	SH_DISP	Causes the 994 to send a response record showing the number of the counter whose contents are being displayed in the digits on the front panel. 0 = A, 1 = B.
SHOW_EVENT	SH_EV	Causes the 994 to send the contents of the event counter. This is an 8-digit number.
SHOW_EVENT_PRESET	SH_EV_PRE	Causes the 994 to send the contents of the event preset register. This will be an 8-digit number.
SHOW_MODE	SH_MOD	Causes the 994 to send a record showing which input is selected for the preset counter. 0 = seconds, 1 = minutes, 2 = external.
SHOW_VERSION	SH_VER	Causes the 994 to send a record which shows the firmware version included in the 994.
START	STA	Starts a counting cycle.
STOP	STO	Stops the counting.
TERMINAL	TER	Places the 994 in the terminal mode so that every character is echoed to and displayed on the terminal.
TEST	TEST	Causes the 994 to perform certain self-test routines. Only the ROM and RAM self-tests are implemented.

Table 14. Power Supply Specifications

Option	Specification(s)
Regulation	±0.1%(typically ±0.05%)for 12 and 24 V ±0.2%(typically ±0.1%)for 6 V
Stability	long term (6-mo) better than ±0.5% after hour warmup at constant load, line adn ambient temperature
Output Impedance	< 0.15 &Omec. for ± 6V < 0.3 &Omec. for others
Temperture Coefficient	< 0.02%/° C over 0 to 60 *deg. C
Noise and Ripple	< 3 mV peak to peak

A.4 High Voltage Power Supply

The Ortec 556 High Voltage power supply is a dual polarity NIM module that provides output voltages from 50 to 3000 volts at 0 to 10 milliamps. The power levels are used to supply the necessary power to the detectors since the approximate operating voltage is 1800 volts. The power supply supplies output voltage through SHV connections in the rear of the power supply. For a list of performance specifications see Table 15 for specifications.

A.5 Preamplifier

The Ortec 142PC Preamplifier is a charge-sensitive unit to be used with proportional counters in applications such as soft x-ray of low energy gammas for spectroscopy

Table 15. High Voltage Supply Specifications

Option	Specification(s)
Output Polarity	Positive or Negative, switch selectable
Output Range	50 to 3000V
Regulation	≤0.0025% varaition in output V for combined load & line variations within operating range @ ambient temp.
Temperature Instability	≤±500ppm/° C after 30 minute warmup operating range 0 - 50 ° C
Long Term Drift	< 0.01%/hour & < 0.03%/day variation in output voltage at constant input line voltage
Output Ripple	< 10mV peak to peak 20 Hz to 20 MHz
Overload Protection	Internal Circuitry protects against overlads including short circuits. Max overload current is ≃ 20 mA
Ressetability	Output Voltage can be reset within 0.1%

where resolution approaching the theoretical limit is likely or desirable. The preamplifier has been designed to provide the best combination of energy and timing resolution. It is also designed to help the counters operate more effectively by the gain provided with the preamplifier. The gain in the preamplifier allows the counter to be operated at substantially lower voltages and thus lowering or eliminating peak position shifts and peak broadening owing to space charge effects in the tube and simultaneously extending the tube life.

An input protection circuit is built into the preamplifier to safeguard its FET from transient voltages that would otherwise damage the transistor. This also provides a damping resistance on the input so that relatively long cables can be used without disrupting the system stability.

A test pulse connector with a built-in charge terminator is provided for use with a pulse generator to simulate the signal of the counter. This allows the user to run a check of the system performance while an experiment is in progress.

The 142PC preamplifier will accommodate up to ± 3000 V bias for the proportional counter. The output pulse polarity is the same as the applied bias polarity. This preamplifier is designed to connect to existing Ortec spectroscopy amplifiers. See Table 16 for a list of specifications.

A.6 Modular System Bin

The EG&G Ortec 4001A Modular System Bin conforms to the recommended standards of Atomic Energy Commission (AEC) Report TID-20893 "Standard Nuclear Instrument Modules." This report, the work of a committee of equipment users from AEC-related institutions, provides standards for a module mounted interchangeability. The standards currently specify power supply voltages of ± 6, 12, 24 volts dc and of 117 volts ac delivered to assigned module connectors

Modules may be of single or multiple widths of the standard module width (1.35 inches). Twelve basic module widths are provided in a standard bin. All twelve module connectors are provided in the standard bin, allowing any combination of module location. Two module bin heights are available under the standard, 8 ¾ and 5 ¼ and are standard rack mounting heights allowing the modular bin to be mounted in standard relay racks along with other rack-mounted equipment.

Table 16. Preamplifier Specifications

Option	Specification(s)
Noise	2.9KeV @ 0 pF and 4.1 KeV at 100 pF typical slope is 20 eV /pF
Risetime	25 ns @ 0 pF and 150 ns @ 100 pF
Sensitivity	Nominal, 300 mV/MeV Si
Energy Range	0 to 20 MeV Si
Energy Rate	3 E+04 MeV /S
Dynamic Input Impedance	1000pF
Integral Nonlinearity	≤0.05% for 0 to 7 V open circuit or ± 3.5 V terminated
Temperature Stability	≤ ± 50 ppm/° for 0 to 50 ° C
Detector Bias Isolation	± 3000V
Open Loop Gain	&GE.40,000
Connectors	SHV

Along with the standards if TID-20893, the 4001A bin also provides two compatibility features:

1. Where applicable, the standard linear and logical signal parameters of the Preferred Practices of TID-20893 are used, providing compatible interconnections between instruments.
2. The power supply demand of any given EG&G Ortec module is generally limited to no more than its proportional share of the occupancy of the bin space. In this way the user need not computed the loads on the power supply.

A.7 Ratemeter

The 541 Ratemeter is a stable linear ratemeter that is contained in a single width NIM module. It accepts a wide range of input counting rates and has great statistical flexibility. It allows the user to choose a standard deviation instead of time constant to allow the user the fastest time with the desired accuracy. The input requirements are easily mated to extant equipment. For a list of specifications of the ratemeter see Table 17.

A.8 Proportional Counters

The LND 20232 is a 1.0 inch diameter Stainless Steel BF_3 (boron trifluoride) filled neutron detector specifically designed to detect thermal neutrons; see Figure 21 for a plateau curve of the detector. Specifications for the detector are given in Table 18.

Table 17. Ratemeter Specifications

Option	Specification(s)
Nonlinearity	< ± 0.5% full scale
Instability	< ± 0.05% of full scale per day at constant temperature
Temperature Coefficient	< ± 0.05% of full scale/° C
Pulse Input Requirements	
Rise Time	< 1 ms/V at +2V level
Amplitude	+2 V to operate ± 100 V maximum pulse amplitude ± 30 V maximum average
Width	no maximum minimum of 200 ns

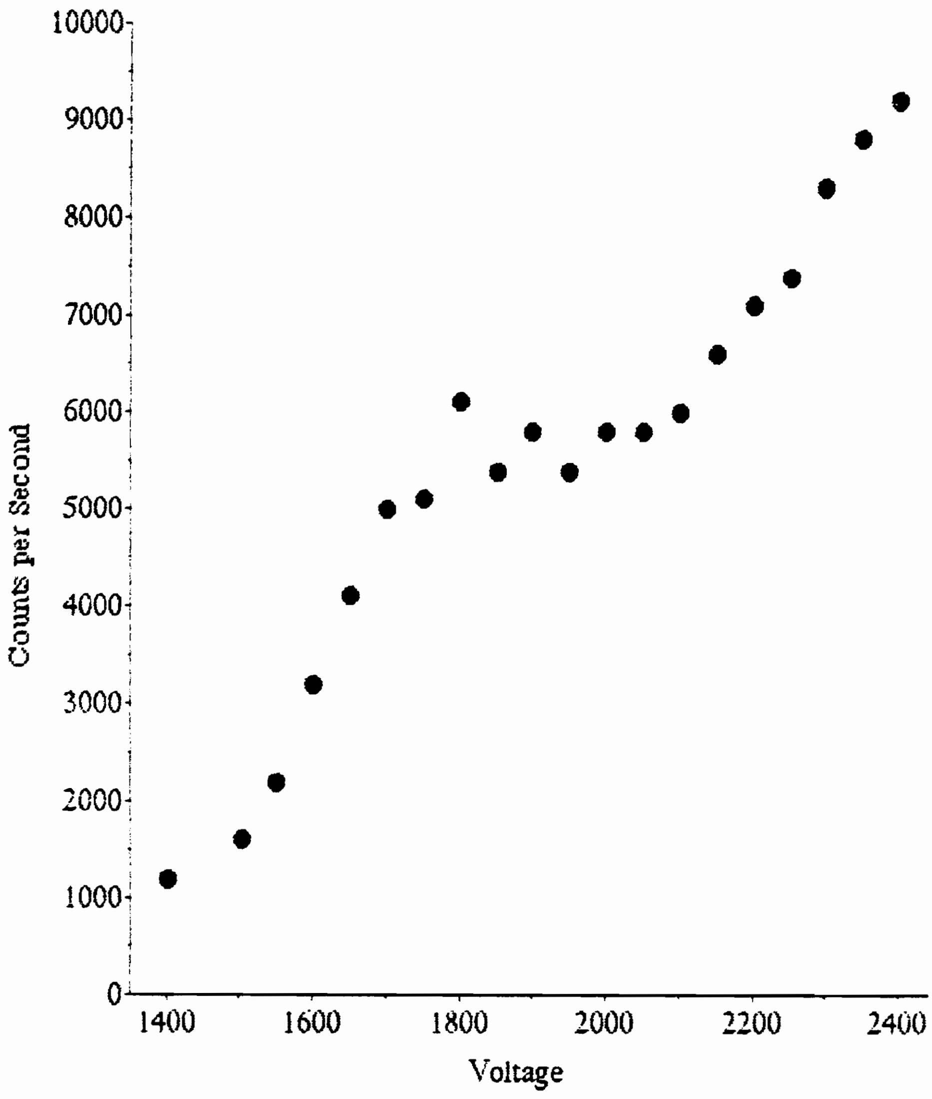

Figure 21. Single Detector Count Rate vs. Voltage Plateau Curve

Table 18. BF_3 Specifications

Option	Specification(s)
CathodeMaterial	304 Stainless Steel
Gas Filling	boron trifloride
Gas pressure	650 Torr
Length.	7.9in / 200.7 mm (maximum) 4.7 in / 120 mm (effective)
Diameter	1.0 in /25.4 mm (maximum) 0.96 in / 25.4 mm (effective)
Operating Temperature Range	-40 ° C to +100 ° C
Connector	HN
Recommended Operating Voltage	1900 V
Operating Voltage Range	1800-2500 V
Maximum Plateau Slope	1% per 100 V
Resolution (%FWHM)	15
Tube Capacitance	4 pf

Appendix B

DASCON-1 Specifications

B.1 Capabilities

Metrabyte's DASCON-1 is a multifunction analog/digital I/O board for the IBM personal computer. It fits into one of the expansion ports in the back of the IBM PC-XT. It is designed to operate high precision, low speed data acquisition and control using the I/O ports and communications set up on the board. The following operations and functions are available on the DASCON-1.

1) A 4 channel, 12 bit plus sign dual slope converter. The full scale input of each channel is ± 2.0475 V with a resolution of 0.0005 volts (500 μV) and the input configuration is differential with a common mode range of ± 2 volts. Each channel is provided with a switch selectable 30 dB (@60Hz) input noise

filter that can further enhance the inherently excellent noise rejection characteristics of the dual slope A/D. Throughput is 30 channels per second.

2) A battery backed up clock calendar. On power up in conjunction with the CLKPWRUP program and an AUTOEXEC.BAT file the clock performs and automatic update of the IBM PC time and date functions eliminating DOS entry. The clock also provides reference pulses at 1 second, 1 minute, and 1 hour intervals or a frequency of 1024 Hz. which can be used as a source of processor interrupts or to initialize external timing actions.

3) 12 bits of digitial I/O on the main connector composed of one port of 8 bits and another of 4 bits. Each port may be independently programmed as an input or output and is TTL/CMOS compatible. An additional 8 bits of output are provided through an on-board header from the D/A latches.

4) Two precision adjustable reference voltage outputs derived from A/D converter reference. Each output can be adjusted between ± 6.8 V and can source/sink 5mA. Typical uses would be offsetting zero in 4-20mA current loops and exciting bridges and use supply input circuits.

5) Two precision general purpose 1.000 mA current sources. Each source has a compliance of +2.5 to - 10 V. These can be used to excite RTD's (resistance thermometers) for other purposes.

6) Two built in RTD interfaces that can be switched into Channels 2 and 3. These provide built in temperature measurement capabilities from -200 °C to

+650 °C with .2 ° C resolution using industry standard 100 Ω platinum RTD probes (alpha = 0.00385). Lead wire resistance compensation is included for 3 and 4 wire probes.

7) Two channels of 12 bit D/A output. The industry standard DAC-80Z-CBI-V converters are a user option, and are easily installed by plugging into the sockets provided. Output ranges of ± 10, ± 5, ± 2.5, +5, +10 v are D.I.P. switch selectable and digital inputs are double buffered to provide instantaneous single step update.

8) Channels 0 and 1 of the A/D converter may be equipped with optional LM363D instumentation operational amplifiers by plugging into the sockets provided and selecting the apppropriate gains of 10, 100, or 1000 by switches. The instrumentation amplifiers provide gain scaling for thermocouples and all types of resistance bridge transducers. System noise at this level is approximately ± 1 μvolt and drift typically 1 μvolt/°C.

9) An external interrupt input is provided that can select any of the IBM PC interrupt levels 2-5 and allow use programmed interrupt routines to provide background data acquisition or interrupt driven control.

B.2 Software

The following utility software for DASCON-1 is provided on disk.

Real time clock. Setting reading and transfer to system clock

A machine language driver (Dascon1.bin) for control of A/D, D/A and digital I/O channel functions via BASIC CALL.

Transducer and RTD linearization

Graphical display and storage of data versus time and x/y mode.

Calibration and test programs

Example and demonstration programs.

Table 19. Dascon Pin Connections

Pin	Connection	Meaning
1	$\overline{\text{IRQ IN}}$	A high to low logic transition initiates interrupt 2-7 as selected on jumper block J3
2	$\overline{\text{CONV COMP}}$	Output goes low for 10 μs when valid data has been transferred by A/D to on-board RAM.
3 4 5 6 7 8 9 10	PB7 PB6 PB5 PB4 PB3 PB2 PB1 PB0	Digital lines corresponding to Port B of the P.I.A. They may be programmed as a group of inputs or outputs.
11	DIG. COM.	Digital Common. Return for all logic signals and power supply currents. Connected to computer frame.
12	D/A #1 OUT	D/A converter #1 output.
13	REF #1 OUT	A stable adjustable reference voltage between ±6.8 volts. Adjusted by R24 on the DASCON-1 board.
14	CH3 LO.IN.	Channel #3 analog low input.
15	Iexc 3	1.000 mA precision current source.
16	CH2 LO.IN.	Channel #2 analog low input.
17	CH1 LO.IN.	Channel #1 analog low input.
18	CH0 LO.IN.	Channel #0 analog low input.
19	LOW LEVEL GND.	Analog signal return for analog input channels, D/A and reference voltage outputs.

Table 19. Dascon Pin Connections

Pin	Connection	Meaning
20	+5V	Computer +5V supply, fused at 1A on DASCON-1.
21	$\overline{\textit{RUN}}$/HOLD	When high, A/D performs continuous conversion. When momentarily pulsed high initiates new conversion.
22	$\overline{\text{LD. CH. ADDR.}}$	Load channel address. low - enables channel address. Active data inputs on pins 23 & 24.
23	CH. ADDR. 1	Most significant channel address input.
24	CH. ADDR. 0	Least significant channel address input.
25	BUSY	When high, signifies A/D conversion in process.
26 - 30	PC3 - PC0	Digital lines corresponding to Port C lower of the P.I.A. They may be programmed as a group of inputs or outputs.
30	$\overline{\text{CLOCK}}$	A 122 μs negative pulse is output on this pin as set by jumper J2 and programming of the clock/calendar.
31	D/A #0 OUT	D/A converter #0 output.
32	REF. #0 OUT	Adjustable reference voltage similar to REF>#1 OUT. Adjust by R23 on DASCON-1.
33	CH.3 HI. IN.	Channel #3 andalog high input.
34	Iexc 2	1.000mA precision current source.
35	CH.2 HI. IN.	Channel #2 analog high input.
36	CH.1 HI. IN.	Channel #1 analog high input.
37	CH.0 HI. IN.	Channel #0 analog high input.

Appendix C

Computer Code

C.1 Data Acquisition Routine

(Turbo Basic)

```
cls
call initio
'goto cont
call checkswitch(x%)
print x%
call down
call checkswitch(x%)
print x%
end
cont :
dim x(1000,15),dist(20),sum(20)
open "Data.dat" for output as #1
j=0
for k=0 to 6.0 step 0.5
  j=j+1
  dist(j)=k
  for i=1 to 100
    call adin(value,overflow)
    if overflow=1 then
      value=99
    end if
```

```
    if i< =100 then
      x(i,j)=value
      print value
    end if
    sum(j)=sum(j)+value
  next i
  beep
  call up
  print j,dist(j)
  print
next k
j=j+1
dist(j)=dist(j-1)+0.5
for i=1 to 100
  call adin(value,overflow)
  if overflow=1 then
    value=99
  end if
  if i< =100 then
    x(i,j)=value
    print value
  end if
  sum(j)=sum(j)+value
next i
print j,dist(j)
for k=1 to j
  print#1,using "###.#### ";dist(k);
  print#1,using "###.#### ";sum(k)/100
next k
print#1,
print#1,
for i=1 to 100
  for k=1 to j
    print#1,using "###.#### ";x(i,k);
  next k
print#1,
next i
end
sub adin(value,overflow)
   low%=inp(&H300)                    ' get low byte
   high%=inp(&H301)                   ' get low byte
   value%=low%+256*(high% and &HF)           ' produce value
   if (high% and &H80)=0 then  value%=-value%    ' check sign
   if (high% and &H40)=1 then
     overflow=1
   else
     overflow=0
   end if
   value=value%*0.0005                        ' convert to actual voltage
end sub
sub initio   ' intalize digital I/O
  out &H300+11,&H8A     ' output PC  input PB
end sub
sub down
for i=1 to 50
  out &H300+10,6
```

```
  for j=1 to 10 : next j
  out &H300+10,5
  for j=1 to 10 : next j
  out &H300+10,9
  for j=1 to 10 : next j
  out &H300+10,10
  for j=1 to 10 : next j
next i
end sub
sub smdown
      out &h300+10,6
      for j = 1 to 30 : next j
      out &h300+10,5
      for j = 1 to 30 : next j
      out &h300+10,9
      for j = 1 to 30 : next j
      out &h300+10,10
      for j = 1 to 30 : next j
end sub
sub up
for i=1 to 50
  out &H300+10,10
  for j=1 to 10 : next j
  out &H300+10,9
  for j=1 to 10 : next j
  out &H300+10,5
  for j=1 to 10 : next j
  out &H300+10,6
  for j=1 to 10 : next j
  next i
end sub
sub checkswitch(switch%) ' check PB to see it micro-switch is closed
  switch%=inp(&H300+9)
  switch%=switch% and 3
end sub
sub home
      call checkswitch(switch%)
       while switch%=2

          call smdown
         call checkswitch(switch%)
       wend
end sub
```

Vita

Carol A. Jaeger was born in Fort Belvoir, Virginia on June 24, 1963. She moved to Brookfield, Wisconsin in 1965 when her father finished the service. In 1973 she moved to Boca Raton, Florida, where she lived for two years until her family moved to Midlothian, Viriginia. She graduated from Midlothian High School in June, 1981. She attended Virginia Tech and worked for Blue Cross and Blue Shield writing and adapting software. She received her Bachelor of Science in Mechanical Engineering in June, 1985. In July,1985 she began work at Norfolk Naval Shipyard in Portsmouth, Virginia and left in October, 1986 to begin her graduate studies at Virginia Polytechnic Institute and State University. In May, 1988 she graduated from Virginia Tech with the degree of Master of Science in Mechanical Engineering. She will stay at Virginia Tech for Doctoral work, and will marry Robert H. Wynn Jr. on December 17, 1988.

Carol A Jaeger