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DEVELOPMENT OF A
BORON CONCENTRATION METER
TECHNICAL PROGRESS REPORT
FOR THE PERIOD ENDING

March 31, 1968

MASTER

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Prepared for the New York Operations Office
U. S. Atomic Energy Commission
Under AEC Contract AT(30-1)-3690

April 1968

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PROGRAM DESCRIPTION

The increasing application of Chemical Shim Control to Pressurized Water Reactors (PWR's) has emphasized the need for a means to monitor accurately and automatically the concentration of boric acid in aqueous solution.

The overall objective of this program is to develop, design, test and evaluate the performance of two prototype boron concentration meters. One meter under investigation is based on conductivity measurements of a boric acid solution with mannitol added. The second is based on the neutron absorption principle.

The program can be divided into the following tasks:

A. Laboratory Studies

Experimental and analytical work was conducted to determine whether the design objectives can be attained for meters based on these principles. This task has been completed.

B. Meter Design

Prototype meters will be designed using, where possible, standard commercially available components.

C. Prototype Construction

Prototype meters will be constructed. Laboratory tests of the meters' sensitivity and reliability will be conducted. Following appraisal, modifications will be made, if necessary, to provide acceptable requirements. Further testing will determine the final characteristics of the prototype instruments.

D. In-Plant Evaluation

The final prototype boron meters will be installed and tested in a typical closed-cycle chemical-shim water reactor. The meters will be evaluated side-by-side for a comparison of the meters' sensitivity, reliability, accuracy, maintainability, etc.

E. Design, Operation and Evaluation

A final review and evaluation of the two separate boron meter designs will be prepared. This will compare the performance of the two separate designs and identify any modifications found necessary as a result of in-plant tests. A final report will be prepared documenting all the information developed during the program.

In addition, a review was conducted of the boron concentration meter presently in use at the SENA reactor. Available data was reviewed as to the meter's reliability, maintenance requirements, accuracy and precision, chemicals makeup requirements, operating costs, time delay, waste disposal requirements and other particulars. A topical report was prepared summarizing this evaluation. (WCAP-3690-4)

EUBM-100 - Program Management (Summary of Progress)

J. L. O'Brien, Jr., Project Engineer

This is the fourth technical progress report on a USAEC-EURATOM joint program for the development of a boron concentration meter. The previous reports were:

EURAEC-1722 WCAP-3690-1	"Development of a Boron Concentration Meter, Technical Progress Report for the Period Ending September 30, 1966".
EURAEC-1778 WCAP-3690-2	"Development of a Boron Concentration Meter, Technical Progress Report for the Period Ending January 31, 1967".
EURAEC-1827 WCAP-3690-3	"Development of a Boron Concentration Meter Technical Progress Report for the Period Ending December 31, 1967".

In addition, the following topical report was published under this contract.

EURAEC-1972 WCAP-3690-4	"Description and Evaluation of the Boron Concentration Meter Utilized at the SENA (Franco-Belge) Reactor Plant".
----------------------------	--

Program management is not discussed in this technical progress report, since separate reports emphasizing the administrative aspects of the project are published monthly for limited distribution.

Progress for the period January 1968 through March 31, 1968 may be summarized as follows:

1. Final design of the prototype meter based on the mannitol-conductance technique was completed.
2. The final evaluation of commercially available components was completed, along with the designs for the degasser and mixer for this meter.
3. Physics studies for the meter based on the neutron absorption principle have been completed and have yielded the following conclusions:

- a) Three sample annuli surrounding the detector will be required to adequately cover the range of boron concentrations considered. These thicknesses are as follows:

<u>Concentration Range</u>	<u>Annulus Thickness</u>	<u>Anticipated Uncertainty in Concentration</u>
0 - 1000 ppm	2.05 inches	± 2 ppm
0 - 2500 ppm	0.82 inches	± 5 ppm
0 - 5000 ppm	0.41 inches	± 10 ppm

- b) A light water moderated tank 30 inches in diameter will provide adequate shielding for the expected plutonium-beryllium neutron source of 10 curies.

EUBM-200 - Laboratory Studies - Mannitol Meter

W. D. Fletcher, Manager, Chemistry

This task has been completed. The results have been reported in EURAEC-1722 - WCAP-3690-1, "Development of a Boron Concentration Meter - Technical Progress Report for the Period Ending September 30, 1966" and EURAEC-1778 WCAP-3690-2 "Development of a Boron Concentration Meter - Technical Progress Report for the Period Ending January 31, 1967".

EUBM-300 - Boron Concentration Meter - Design and Construction of Prototype Mannitol Meter

W. D. Fletcher - Manager, Chemistry
J. E. Bulkowski

I. Introduction

A. Previous Work

Previous work accomplished during the EUBM-300 sub-task of the boron meter development program included the preliminary design of a meter, the construction of a first working model, laboratory testing and evaluation of data from the first working model, and evaluation of certain components for the final design. Results of this work were presented in the technical progress report for the period ending December 31, 1967.^{/1}

A summary of conclusions derived from this previous work is:

1. A boron concentration meter operating with an unsaturated mannitol-boron solution is feasible and of simpler design than a saturated mannitol system.
2. The conductivity is not greatly dependent on the flow mixing ratio in the range of 0.6 - 0.8 cc of boric acid/cc of mannitol solution.
3. For a flow of 25 cc/min of reactor coolant sample through the meter, a flow of 36 cc/min of 14.5 w/o mannitol solution is required, or about 5.2 g/min of mannitol is consumed.
4. The expense of operating the boron meter is proportional to the quantity of mannitol consumed. For the above flows, the cost would be approximately \$4,500 for one year of continuous operation (based on a mannitol cost of \$0.75/lb).
5. The sensitivity of the conductivity measurement for the unsaturated boron-mannitol system is only reduced by a factor of approximately two, compared to the saturated mannitol system.

^{/1} EURAEC-1827 (WCAP-3690-3), "Development of a Boron Concentration Meter - Technical Progress Report for the Period Ending December 31, 1967".

6. The first working model indicated that conductivity readings were very stable using the flow technique and that instrument response is rapid (about one minute for this model).

B. Recent Work

The design and construction of the prototype continued during this period with emphasis being placed on modification of the original meter design using the results obtained from the first working model and evaluation of components. Work accomplished during this report period included the final design of a meter, evaluation of the effect of temperature on the conductivity for the unsaturated mannitol system, the design and construction of a degasser and mixer, and a final evaluation of commercially available components.

II. Design of the Meter

The revised design of the boron meter is presented by a flow diagram in Figure 1.

Revisions of the system to that presented in the previous progress report are:

1. The addition of a flow control valve at the degasser inlet.
2. Provisions are added for standardizing the instrument using a solution of known boron concentration.
3. Elimination of the jacketed resin column for temperature control of the pump influent solutions. A heat exchanger employing site cooling water will reduce the primary coolant sample stream temperature at the resin exchange column inlet. A heat exchanger coil immersed in the constant temperature bath will provide exact control of the boric acid temperature entering the first conductivity cell and the pump inlet. Mannitol solution temperature is controlled by an additional heat exchanger receiving cooling water from the constant temperature bath.

Figure 1. Boron Meter System

4. Relief protection is added at the duplex precision metering pump outlet.
5. Provisions are added for continuous monitoring of the solution temperatures by means of thermocouples.
6. The elimination of automatic temperature compensation. (Effect of temperature on conductivity is negligible as will be shown subsequently.)

A list of the major components making up the boron meter system along with a description of each is as follows:

<u>Component</u>	<u>Description</u>
Pressure Regulator	Material - stainless steel Inlet pressure - up to 200 psi Outlet pressure - 1 - 20 psi Spring operated
Flow Control Valve	Material - stainless steel Capacity - 25 - 500 cc/min
Degasser	Material - Plexiglass Capacity - 10 - 50 cc/min
3-way Solenoid Valve	Material - stainless steel with resilient seat Electrical - 115 volts, 60 cycles Orifice - 3/32 in.
Ion Exchange (Cation) Resin Column	Capacity - 80 cc Life - 11.2 days continuous operation Dimensions - 3/4 in. I.D. x 12 in. L
Constant Temperature Bath	Material - stainless steel Reservoir capacity - 7.5 gals. Circulation flow - 9 gal/min Temperature range - -15°C to +70°C Sensitivity - $\pm 0.02^{\circ}\text{C}$ Heat removal capacity - 1100 BTU/hr at 32°F

<u>Component</u>	<u>Description</u>
Mixing Chamber	Material - Plexiglass
Conductivity Meter	AC Wheatstone Bridge Direct reading Solid state electronics Output signal: 0 - 1.0 VDC Accuracy: better than 0.5% of output signal Automatic temperature compensation (optional)
Mannitol Mixing and Storage Tank	Material - stainless steel Capacity - 50 gals. Level indication Provisions for mixing
Cabinet	Standard instrument cabinet Dimensions - 48" H x 30" W x 18" D

III. Evaluation of Temperature Effect

The effect of temperature on the conductivity of boric acid-mannitol solutions was investigated using Atlas Chemical, Reagent Grade, D-Mannitol, A.C.S. grade boric acid, and high quality demineralized water. Conductivity was measured with a Leeds and Northrup electrolytic conductivity bridge (Catalog No. 4866) with an error limit of $\pm 0.3\%$ of its 1 - 12 range, and a conductivity cell with platinized platinum electrodes and a cell constant of 1.030. Temperature was controlled to $\pm 0.1^\circ\text{C}$ by a constant temperature bath.

It was previously determined that maximum conductivity values were obtained for a flow mixing ratio of 0.7 cc boric acid solution/cc of 14.5 w/o mannitol solution. Conductivity measurements were made for these boric acid-mannitol solutions as a function of temperature. The results are presented in Figure 2 and Table 1. It is seen that the effect of temperature on the conductivity is negligible in the range of 15 - 20°C. This information indicates that automatic temperature

* CONDUCTIVITY READINGS ARE AT THE TEMPERATURE SPECIFIED. PREVIOUS VALUES ARE REFERRED TO THE CONDUCTIVITY AT 25°C.

Figure 2. The Effect of Temperature on Conductivity of Boric Acid-Mannitol Solutions with 0.7 cc B Solution/cc 14.5 w/o Mannitol Solution

Table 1

The Effect of Temperature on Conductivity for Boric Acid-Mannitol Solutions

Temperature °C	Original Boron Concentration (ppm B)					
	3085	2055	1030	515	103	58
9.6	404 ^{/1}	333	242	172	75.8	52.5
14.9	407	335	243	172	76.4	53.2
25.0	401	332	241	171	76.3	53.1
35.0	389	322	234	167	75.3	52.8
45.0	370	307	222	159	72.1	50.7

^{/1} Conductivity readings are in micromho/cm at the temperature stated.

NOTE: Previous conductivity values reported in EURAEC-1827 are referred to 25°C.

compensation is not required for an accurate measurement of the conductivity. The temperature bath will be more than adequate for temperature control (control sensitivity is $\pm 0.02^{\circ}\text{C}$).

IV. Discussion

A detailed design of the boron meter prototype has been completed. The meter design is such that 25 cc/min of reactor coolant enters the instrument, combines with 36 cc/min of 14.5 w/o mannitol, and a flow of 61 cc/min of mannitol-boric acid solution is discharged to waste. The instrument is designed to operate at 20°C . The delay time involved from the meter inlet to a corresponding conductivity reading is about two minutes for this design. The resin column exchange capacity is estimated to be 11 days with continuous operation, based on a Li^{+} concentration of 3.0×10^{-4} molar (2.2 ppm). The mannitol mixing tank will require filling every four days for continuous operation or every thirty days if the meter is used intermittently for three hours per day.

The mixing chamber and degasser have been fabricated. Final evaluation and selection of the commercially available components is being completed.

EUBM-400 - Evaluation of Prototype Mannitol Meter

W. D. Fletcher, Manager, Chemistry

Effort under this task has not yet been initiated.

EUBM-500 - Evaluation of the SENA Boron Meter

W. D. Fletcher - Manager, Chemistry

This effort has been completed and was reported in EURAEC-1972 WCAP-3690-4 "Description and Evaluation of the Boron Concentration Meter Utilized at the SENA (Franco-Belge) Reactor Plant".

EUBM-600 - Development of a Neutron Absorptiometer

V. Rajagopal - Manager, Instrumentation and Control Development

I. SUMMARY

This review summarizes preliminary information to be used in designing the boron concentration analyzer based on the neutron absorption principle. Estimates are made of thickness requirements for the annulus containing the boronated water. In addition, an estimate is made of the radial thickness of light water required to reduce the radiation doses to personnel to a permissible level of 1 mrem/hr.

The conclusions reached are: that three annulus thicknesses are required to cover the range 0-5000 ppm boron; that a light water moderator tank 30 inches in diameter will provide adequate shielding; and that experimental measurements of the neutron counting rate as a function of annulus thickness and boron concentration are required to complete the analyzer design. The estimated properties of a 3-annuli instrument are as follows:

<u>Concentration Range</u>	<u>Annulus Thickness</u>	<u>Anticipated Uncertainty in Concentration</u>
0 - 1000 ppm	2.05 inches	$\pm$ 2 ppm
0 - 2500 ppm	0.82 inches	$\pm$ 5 ppm
0-5000 ppm	0.41 inches	$\pm$ 10 ppm

II. SPECIFICATIONS

The specifications for the boron meter based on the neutron absorption principle that influence the analysis presented herein are given below.

1. The desired concentration ranges and the accuracy required in each range:

<u>Concentration Range (ppm)</u>	<u>Permissible Uncertainty (ppm)</u>
25 - 500	$\pm$ 2
250 - 1250	$\pm$ 5
1000 - 2500	$\pm$ 5
2500 - 5000	$\pm$ 25

2. The maximum time interval between concentration determinations: five minutes.
3. Permissible radiation dose rate near the analyzer: less than 1 mrem/hr.

III. GENERAL DESCRIPTION

A conceptual design of the boron concentration analyzer is shown in Figure 3.

A neutron source is fixed in the center of a water-filled tank. The neutron source is comprised of a mixture of beryllium with a radioactive material that emits alpha particles. After an alpha particle is absorbed by a beryllium nucleus, a neutron is emitted. The emitted neutrons have energies that range up to 11 MeV, with correspondingly high velocities.

The water serves two purposes. First, fast neutrons undergo collisions with the hydrogen nuclei in the water and thereby lose energy. This process is called neutron moderation, and is important because the neutron interaction with boron is inversely proportional to the velocity of the neutron. Second, the water serves as a radiation shielding material.

The water whose boron content is to be measured flows through an annular region around the neutron detector. The annulus is located as close as possible to the neutron source to maximize the neutron counting rate.

The neutron detector is connected to an impulse counter. Activation of the counter starts a clock and turns it off when a preset number of counts is reached. The greater the boron content of the water, the longer it will take the counter to arrive at the preset number of counts. Thus, there will be a functional relationship between the time to reach preset counts and the boron content of the water.

IV. ANALYSIS OF PRIOR DATA

Figure 4 shows counting rate data obtained with a 1/2-inch thick annulus.

Figure 3. Conceptual Design of Boron Concentration Analyzer

Figure 4. Counting Rate as a Function of Boron Concentration for a
1/2 -Inch Thick Annulus *

Figure 5 shows counting rate data obtained with a 7/8-inch thick annulus. Three source-to-annulus separations, 5/8", 1-1/2", and 3" were used. A curve is presented for each separation distance.

Figure 6 presents the data from Figures 4 and 5 normalized to show percent change in counting rate as a function of boron concentration.

Two points are clear from a cursory examination of Figure 6. First, the thicker the annulus, the more sensitive the analyzer is to changes in boron concentration. Second, the source-to-annulus separation has little effect on the curve relating boron concentration to percentage change in counting rate.

Comparison of Data with Simple Model

The shape of the concentration vs. counting rate curve is of great interest in designing a workable boron meter. It is of interest to compare the experimental data with what would be expected for transmission of a thermal neutron beam through a slab of boronated water. In the latter case, the counting rate can be predicted to be

$$R = R_0 e^{-\alpha C} = R_0 e^{-n_B \sigma_B T}$$

where R_0 is the counting rate with no boron in the slab, C is the concentration of boron in the slab, α is a constant that is characteristic of the annulus thickness, n_B is the concentration of boron atoms in the solution whose concentration is C , σ_B is the neutron absorption cross section of natural boron, $759 \times 10^{-24} \text{ cm}^2$, and T is the thickness of the slab. For $C = 5000 \text{ ppm}$ natural boron,

$$n_B \sigma_B = 0.210 \text{ cm}^{-1}$$

$$\alpha = 0.534 \times 10^{-4}$$

For the 7/8-inch slab:

$$\alpha = 0.933 \times 10^{-4}$$

Figure 5. Counting Rate as a Function of Boron Concentration for a $7/8$ -Inch Thick Annulus, Three Source-To-Annulus Separations.*

Figure 6. Percentage Change in Counting Rate as a Function of Boron Concentration *

Predicted counting rate curves for transmission of a neutron beam through slabs of thickness $T = 1/2$ -inch and $T = 7/8$ -inch are shown as the upper solid curves in Figure 7.

Two conclusions can be drawn from comparing the experimental data with the predictions for slab attenuation of a thermal neutron beam. First, the experimental data do not follow the simple exponential relationship $R = R_0 e^{-\alpha C}$. Second, the experimentally determined counting rates are lower than predicted by the simple model.

Relationship Between Annulus Thickness and α

Figure 7 can be used to generate information that is useful in extrapolating to new analyzer designs. The dashed curves that pass through data points at 2000 ppm correspond to curves of the form $R = R_0 e^{-\alpha C}$. For the upper curve, corresponding to the $1/2$ -inch annulus, $\alpha C = 0.693$ where $C = 4300$ ppm. Thus $\alpha = 1.61 \times 10^{-4} \text{ (ppm)}^{-1}$. For the lower curve, corresponding to the $7/8$ -inch annulus, $\alpha = 2.88 \times 10^{-4} \text{ (ppm)}^{-1}$. These two points are plotted as a function of annulus thickness in Figure 8. A third point would occur at the origin. These points fall close enough to a straight line to suggest that the linear relationship $T = k \alpha$ may exist in this complicated experiment. For the curve as shown

$$k = \frac{1.2 \text{ inches}}{4 \times 10^{-4} \text{ (ppm)}^{-1}}$$

This constant is used later in the report to determine annulus thickness for a desired value of α .

Counting Rate as a Function of Source-to-Annulus Separation Distance

The effect of neutron source position on counting rate is of interest in the design of an analyzer. Figure 9 shows a plot of counting rate versus the distance of the source from the centerline of the neutron detector. These data were obtained from the zero boron concentration points in Figure 5. Figure 9 is used later in the report to predict counting rates.

Figure 7. Comparison of Existing Data with Predictions of Counting Rate Based on Attenuation of a Thermal Neutron Beam by a Slab

Figure 8, Annulus Thickness as a Function of α

Figure 9. Neutron Counting Rate as a Function of Source Position

V. CALCULATIONS TO ESTIMATE THICKNESSES OF ANNULI

The existing experimental data, as analyzed in Section IV, can be combined with the specifications on accuracy to estimate annuli thicknesses.

A. Assumptions

The assumptions made in the calculation are as follows:

1. The analyzer geometry is that shown in Figure 3.
2. The neutron source is a 10 Curie PuBe unit (calculated source strength 2.2×10^7 neutrons sec^{-1}).
3. The neutron detector is a B^{10} lined proportional counter which has $R_0 = 2.4 \times 10^4$ counts sec^{-1} when the source is adjacent to the counter. This is an experimentally determined value for a Westinghouse 22792 counter.
4. The analyzer operates as described in Section III, i.e., concentration is determined by measuring the time, t , required to accumulate a predetermined number of counts, N .
5. The fractional uncertainty in the time measurement, $\Delta t/t$, is arbitrarily assigned a value equal to the standard deviation in the number of counts, $\Delta N/N = \sqrt{N}/N$.
6. $R + R_0 e^{-\alpha C}$. This relationship of counting rate, R , to boron concentration is useful for estimating purposes, even though it is not likely to be exactly correct as shown in Figure 7.
7. α is proportional to the annulus thickness, T , as per Figure 8.

The initial estimates of annuli thickness required for each concentration range are tabulated in Table 2.

Table 2: Calculation of Thicknesses of Annuli

Concentration Range (ppm)	Permissible Uncertainty in Concentration ΔC (ppm)	α (ppm) ⁻¹	Top of Range αC	R/R ₀ at Top of Range	Annulus Thickness (inches)
25 - 500	± 2	6.85×10^{-4}	0.3425	0.710	2.05
250 - 1250	± 5	2.74×10^{-4}	0.685	0.710	0.823
1000 - 2500	± 5	2.74×10^{-4}	0.685	0.504	0.823
2500 - 5000	± 25	0.548×10^{-4}	0.274	0.760	0.1645

Readjustment of Ranges

From Table 2 it can be seen that R/R_0 is not the same at the top of each of the ranges. There may be some virtue, however, to having R the same at the top of each range. For example, curves of R vs. $C/C_{\max}$ may be the same for each range. R can be made the same at the top of each range by making $\alpha C_{\max}$ the same at the top of each range.

Table 3 shows the logical set of ranges developed with this criterion, together with the corresponding annuli thicknesses and expected uncertainties in concentration determination. Only three ranges are needed. The anticipated accuracies are better than required by the specifications in Section II.

Table 3: Logical Ranges and Corresponding Annuli Thicknesses

Concentration Range (ppm)	Anticipated Uncertainty in Concentration (ppm)	Annulus Thickness (inches)
0 - 1000	± 2	2.05
0 - 2500	± 5	0.82
0 - 5000	± 10	0.41

VI. CALCULATIONS TO DETERMINE RADIATION SHIELDING REQUIREMENTS

A. Assumptions

It is assumed that:

1. The neutron source emits 2.2×10^7 neutrons sec^{-1} .
2. The neutrons all have a single energy, 4 MeV. This is the median energy of the PuBe neutron spectrum.
3. The shielding material is light water.

B. Dose as a Function of Water Shield Thickness

Table 4 shows calculated values of fast neutron dose from a 10 Curie PuBe source (2.2×10^7 n sec^{-1}). These data are plotted in Figure 10 which shows that the radius of water shielding required to reduce the fast neutron dose to 1 mrem/hr is 38 centimeters (15 inches).

The dose rate from thermal neutrons is negligible for a spherical water shield having $r = 38$ cm.

VII. POTENTIAL GEOMETRIES FOR NON-ELECTRONIC PORTIONS OF THE NEUTRON ABSORPTIOMETER

From the preceding discussion it can be concluded that three annuli are needed with thicknesses of 2.05 inches, 0.82-inch, and 0.41-inch and that the distance from the neutron source to the surface of the water tank should be 15 inches. Three possible geometries for changing the annulus thickness were considered:

1. Sliding tubes with thick walls to change the annulus size.
2. Stepping the outside diameter of the annular tube through which the boronated water flows.
3. Using three concentric annuli and by the use of a valving arrangement, either boronated water or pure water can flow through each annulus. This concept is depicted in Figure 11. When boronated water flows through X, Y, and Z, the effective annulus thickness is 2.05 inches. When pure water flows through X and boronated water flows through Y and Z, the annulus thickness is 0.82-inch. When pure water flows through Z, the annulus thickness is 0.41-inch.

Table 4: Fast Neutron Dose Rates from a 4MeV Neutron
Source (2.2×10^7 n sec⁻¹) with Water Shielding

Water Radius r	$4\pi r^2$ D(r)	D(r)	Physical Dose Rate D(r) x 2.2×10^7 n sec ⁻¹	Biological Dose Rate
(cm)	(m rep cm ² hr ⁻¹ sec)	(m rep hr ⁻¹ n ⁻¹ sec)	(m rep hr ⁻¹)	(m rem hr ⁻¹)
10	9.5×10^{-3}	7.5×10^{-6}	165	1650
20	3.3×10^{-3}	6.5×10^{-7}	14.3	143
30	8.2×10^{-4}	7.2×10^{-8}	1.58	15.8
40	2.2×10^{-5}	1.04×10^{-9}	0.023	0.23

Figure 10. Fast Neutron Dose Rates from 4 MeV Neutron Source ($2.2 \times 10^7\text{ n sec}^{-1}$) As a Function of Thickness of Water Shielding

Figure 11. Boron Analyzer with Concentric Annuli

Each of the three concepts has the potential for being developed into a workable boron analyzer. However, the third arrangement is more compact and requires no mechanical movement of materials within the meter.

VIII. DISCUSSION

A. Reliability of Basic Assumptions

Two assumptions made in calculating the annuli thicknesses are questionable.

First, the assumption that $R/R_0 = e^{-\alpha C}$ is known not to be exactly true. This was demonstrated by the data shown in Figure 7. To complete the design of the boron analyzer, the relationship between C and t , the time to reach N counts, must be determined for a geometry close to that which will be used in the analyzer. Experiments will be performed to measure t over the concentration range of interest for each annulus thickness. The source-to-detector centerline distance should be close to that which will be used in the final analyzer design. The preselected number of counts should be consistent with the accuracy ultimately desired in the concentration measurement. As shown in Section IV, N should be at least as large as 2.14×10^6 counts.

Second, the assumption that α is proportional to the annulus thickness, T , needs verification. More points are needed on Figure 8, particularly for annuli with thicknesses greater than the thickest (7/8-inch) annulus used in prior experiments. Experiments will be performed to obtain good values of α for 0.5-inch, 1.0-inch, 1.5-inches, and 2.0-inches thick annuli.

Third, no allowance has been made for the temperature dependence of α . A few measurements will be made to assess the consequence of temperature effects.

IX. CONCLUSIONS

The analyses presented herein assume a 10 Curie PuBe neutron source and a single D^{10} lined proportional counter, Westinghouse 22792.

Three conclusions can be drawn:

1. A promising candidate analyzer would have three annuli with a corresponding boron concentration range for each annulus. A scheme utilizing three concentric annuli appears most promising.
2. The appropriate thicknesses of annuli, concentration ranges and concentration accuracies are as follows:

<u>Annulus Thickness</u> (inch)	<u>Boron Concentration Range</u> (ppm)	<u>Anticipated Uncertainty in Concentration</u> (ppm)
2.05	0 - 1000	$\pm$ 2
0.82	0 - 2500	$\pm$ 5
0.41	0 - 5000	$\pm$ 10

3. The radius of water shielding needed is 15 inches.

EUBM-700 - Evaluation of Prototype Neutron Absorptiometer

V. Rajagopal, Manager, Instrumentation and Control Development

Effort under this task has not yet been initiated.

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