NSAC/46

April 1982

An Evaluation of On-Line Boron Analyzers

Prepared by
NUS CORPORATION

The Nuclear Safety Analysis Center is operated for
the electric utility industry by the Electric Power Research Institute

An Evaluation of On-Line Boron Analyzers

NSAC-46

Final Report, April 1982

Prepared by

NUS CORPORATION
Park West Two
Cliff Mine Road
Pittsburgh, Pennsylvania 15275

Principal Investigator
W. Lechnick

Prepared for
Nuclear Safety Analysis Center

Operated by
Electric Power Research Institute
3412 Hillview Avenue
Palo Alto, California 94304

NSAC Project Manager
R. N. Kubik

ORDERING INFORMATION

Copies of this report may be ordered from Research Reports Center (RRC), Box 50490, Palo Alto, CA 94303, (415) 965-4081. There is no charge to NSAC member utilities and certain other nonprofit organizations.

Keywords: Boron Analyzers, Boron Analysis, Postaccident Instrumentation, Qualification

NOTICE

Prepared by
NUS Corporation
Pittsburgh, Pennsylvania

NSAC PERSPECTIVE

PROJECT DESCRIPTION

Boron dissolved in the reactor coolant is a primary means of reactivity control in pressurized water reactors and a backup means of reactivity control in boiling water reactors. Thus, boron concentration is a fundamental safety parameter and must be measured.

Under normal conditions the boron concentration is determined by analyzing a grab sample and in some cases by an on-line boron analyzer. However, under postaccident conditions grab samples may involve unwarranted personnel exposure and not all of the new postaccident sample systems provide rapid measurements. Conventional on-line boron analyzers are overwhelmed by the radiation expected during an accident. To overcome these shortcomings, several new on-line boron analyzers are on the market. These have been especially designed to function during an accident.

In this service, high radioactive fluids will expose components of on-line analyzers to radiation levels which can be as high as 10^6 R/hr. Radiation of this magnitude can damage some types of electronic components and elastomers that are present in the instruments. Photoelectric devices and small solid state components are particularly sensitive to radiation damage. It is also possible that high radiation levels may temporarily affect sensing elements.

The market for on-line analyzers is limited. Because of this, NSAC was concerned that this equipment might not be thoroughly and independently tested. This test program was sponsored as a result of that concern. Three commercially available postaccident boron analyzers were tested in radiation fields up to and exceeding those that would be encountered in an accident.

PROJECT OBJECTIVE

The three boron analyzers were tested under normal conditions and at radiation levels as high as 10^5 to 10^6 R/hr. The tests sought to determine the accuracy of

the analyzers, their reliability under normal conditions, their susceptibility to radiation damage, and their accuracy when exposed to high radiation levels.

PROJECT RESULTS

The Ionics Digichem analyzer as modified by Sentry, the Westinghouse Mark V boron analyzer, and the Combustion Engineering Boronmeter are all suitable for postaccident service if properly installed and maintained. The testing did indicate improvements that could be made to some of this equipment. These suggestions were accepted by the manufacturers and are being incorporated into the product line.

Robert N. Kubik
NSAC Project Manager

ABSTRACT

Testing has been performed to evaluate the performance of three on-line boron analyzers and determine the effect of a high intensity gamma field (10^3 to 10^6 R/hr) on this instrumentation. The main objective of this work was to verify the applicability of the analyzers for boron analyses under post-accident conditions. The on-line analyzers tested included an Ionics model (DigiChem Analyzer) as modified by Sentry, the Westinghouse Mark V Analyzer, and the Combustion Engineering High Radiation Boronometer System. Irradiation testing was also performed on elastomers, solid-state electronics, and pH probes. Results of this work indicate that the three on-line analyzers tested are suitable for boron determinations during accident conditions. Radiation exposure levels involved in determining boron concentration with these systems would be essentially zero.

Results from gamma irradiation tests indicate that teflon will remain serviceable at 10^6 rads exposure. Other elastomers tested were more radiation resistant than is teflon. Solid-state components tested showed radiation damage at between 10^4 and 10^5 rads exposure. A slight but constant bias in readout was noted when pH probes were exposed to high radiation levels. This bias has no significant effect on boron analyses results obtained from titrating the boron-mannitol acid complex.

ACKNOWLEDGMENTS

We wish to note the cooperation of the Sentry Corporation, Ionics Corporation, Westinghouse Electric, and Combustion Engineering. These companies furnished the equipment used in this test program and provided the manpower required for initial startup of the equipment. In particular, we wish to thank Joe Leon of the Sentry Corporation, Dale Lueck of the Ionics Corporation, Rick Pod of Westinghouse Electric, and Joe Kowles of Combustion Engineering.

CONTENTS

ILLUSTRATIONS

TABLES

Tables

Section 1

INTRODUCTION AND SUMMARY

Four vendors of in-line boron analyzers were invited to participate in a program to test the ability of their equipment to withstand postaccident environmental conditions. Three vendors responded to this invitation as follows:

- Sentry and Ionics with the DigiChem Analyzer. This boron analyzer is manufactured by the Ionics Corporation and is modified by Sentry to withstand the high gamma radiation levels encountered in post-accident application. The modified instrument is sold only through Sentry.
- Westinghouse with their Boron Concentration Monitoring System (BCMS) Mark V Analyzer.
- Combustion Engineering with their High Radiation Boronometer System.

The Sentry Modified Digichem Analyzer provides for boron determination by remote titration of the boron-mannitol acid complex. It is assumed that the boron solution contains the normal isotopic concentration of ^{10}B to provide for reactivity control of the system. The procedure followed is identical to the referee method used for normal laboratory determination of boron concentration. The Westinghouse and Combustion Engineering analyzers provide for boron determination by measuring the ^{10}B concentration or the neutron absorption characteristics of the system. Since neutron absorption is determined directly, it provides for an absolute measurement of reactivity control.

Equipment provided by these vendors was tested under normal operating conditions and in the presence of high-level radiation. The high-level radiation testing was performed in a hot cell using ^{60}Co as the radiation source. Energy level of the ^{60}Co gammas are normalized so that the energy absorbed by the materials in test will be comparable to the accident case. Maximum radiation levels were on the order of 10^5 - 10^6 R/hr. Test description and results for each analyzer are described separately in the main body of the report.
For those who are interested in results on irradiation testing of elastomers, solid-state electronics and pH probes, your attention is called to the Sentry-Ionics report.

The general conclusions derived from this overall study and the advantages of using these on-line analyzers are summarized below:

- Sentry Modified DigiChem Analyzer

  --The Sentry modified DigiChem analyzer is acceptable for use to determine boron concentration under post-accident conditions. Concerning its use for normal power operations, the accuracy is probably acceptable.

  --All boron analyses operations can be performed remotely. The exposure involved in determining boron concentration would approach zero.

  --Sample volume requirements are on the order of 1-2 ml per analysis, thus shielding requirements would be minimal.

  --Analyses results can be achieved within 10 minutes after the sample line is purged to obtain a representative sample.

  --Though not sealed gas tight, there would be little tendency for release of gaseous activity to the atmosphere. This would be particularly true if the sample addition sequence is changed to add water prior to addition of the sample.

- Westinghouse BCMS Mark V Analyzer

  --The Westinghouse Mark V boron analyzer is acceptable for use under post-accident conditions. It should be possible to obtain an analysis within 5 or 10 minutes with this system. Concerning its use for normal power operations, the accuracy is probably acceptable.

  --Count rate increases, and thus the ppm boron readout decreases with increasing radiation levels, however, the effect is a predictable one and accuracy is still quite acceptable.

  --For maximum anticipated exposure levels of 5×10^5 R/hr (10 Ci/cc activity level), the fissioning count rate will increase by about

5 percent. This 5 percent increase in count rate will result in a small error relative to the accuracy required for post-accident conditions.

--The increase in count rate from irradiation is essentially a constant (as percent of count rate) for the three conditions tested (pure water, 2570 and 5140 ppm boron). The increased count rate does not linger when the radiation field is removed.

- Combustion Engineering High Radiation Boronometer System

--The CE Borommeter is acceptable for use under post-accident conditions.

--Reproducibility of results is excellent as based on fission count rate, however, conversion of count rate to ppm is somewhat below the accuracy desired for daily operations. CE indicates, however, that the proper curve fit routine in the microcomputer will provide proper ppm indication.

--A 500 second count rate is recommended for determining boron concentrations below 1,000 ppm.

--The use of a strip chart recorder is recommended for use with the borohometer. This will improve statistics and show trending.

--There is some increase in the standard deviation from radiation levels in the range of 10^6 R/Hr at the planned discriminator setting of 50 millivolts. The increase is not significant with respect to post-accident analyses requirements.

Section 2

SUMMARY OF RESULTS - SENTRY DIGICHEM ANALYZER

The Ionics DigiChem Analyzer, as modified by Sentry, performed properly at radiation levels of 8.64×10^4 R/hr. Maximum radiation levels anticipated under credible accident conditions are on the order of 10^4 R/hr.

The analyzer operated at an integrated dose of 2.7×10^7 rads. This corresponds to about three months of operation at maximum dose rates anticipated under accident conditions.

If this system is used, NUS recommends that the analyses to determine boron concentration be performed titrating the boron-mannitol acid complex from a pH of about 5.5 to pH 8.5. Actual pH used for the low and high pH end points should be determined by titrating known boron standards after addition of mannitol to the boron solution. Titrating from a low pH inflection point (pH 4-6) to a high pH inflection point (pH 8-8.5) can also be used, however, results of previous testing performed by NUS indicates better precision can be achieved by titrating to specific pH end points. Either method of titration (pH end point or inflection point) is acceptable for post-accident use.

If the production model DigiChem analyzer is modified as indicated below it should perform properly at radiation levels of $10^4 - 10^5$ R/hr and continue to operate at an integrated dose of 10^7 rads.

- Separate the rotary spin assembly and sample addition module so that only these components are exposed to high radiation fields.
- Replace the photon coupled modules H21AY3 and MCA8 with mechanical switches. Alternately. it would be possible to provide localized shielding for these modules to limit exposure level to about 10^3 rads.
- Move the solid state relay for the solenoid actuated valve on the rotary reaction cell to a location outside the high radiation zone.
- Replace the two nylon pulleys used to drive the rotary reaction cell with metal pulleys.

- Replace the teflon with elastomers that are more resistant to radiation. The teflon does not have to be replaced if the integrated exposure is limited to 10^6 rads.

BACKGROUND INFORMATION

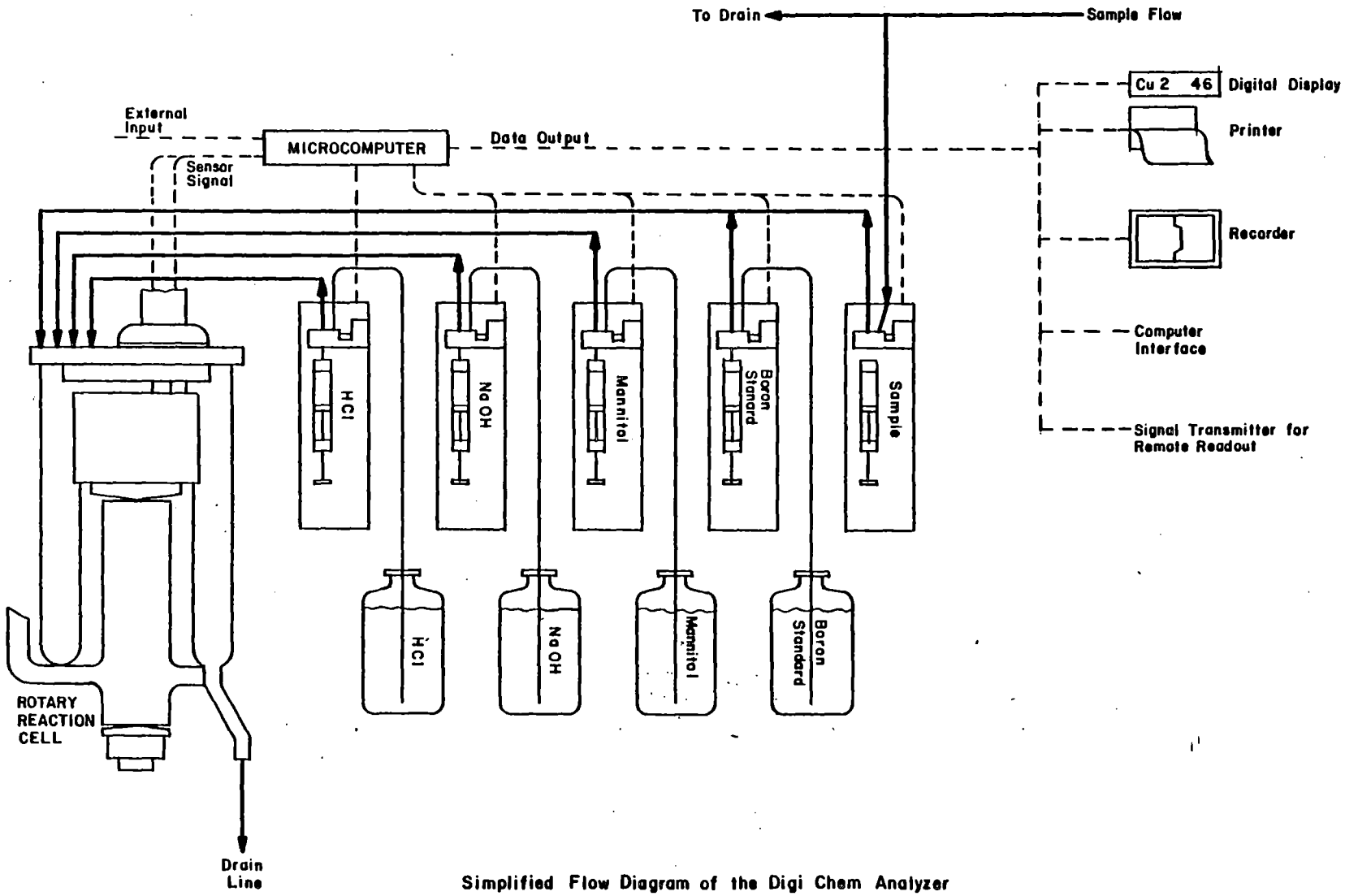
TEST PURPOSE

Testing was performed to determine if the Sentry modified DigiChem analyzer and selected components from an unmodified DigiChem analyzer would suffer radiation damage in analyzing for boron at radiation exposure levels anticipated under post-accident conditions. In addition. testing was performed to determine the accuracy that could be achieved with the DigiChem analyzer for boron determinations during normal operating conditions. Modifications made by Sentry to the DigiChem analyzer include replacement of selected components that would be in a high radiation field with components made of more radiation resistant material. The selected components tested from the unmodified system include all solid state components and elastomers that would be exposed to high radiation fields, the rotary spin assembly, and sample burette assembly. Both the rotary spin and sample burette assemblies would be exposed to relatively high radiation levels if the system is used in post-accident testing.

The system provides for boron determination by remote titration of the boron-mannitol acid complex. It is assumed that the boron solution contains the normal isotopic concentration of ^{10}B to provide for reactivity control of the system. The procedure followed is identical to the standard method used for normal laboratory determination of boron concentration.

SYSTEM DESCRIPTION

The DigiChem analyzer system consists of a microcomputer, a rotary reaction cell assembly, a measurement sensor (pH probe in this application), and up to five sample and reagent addition modules. A simplified flow diagram of the system is shown in Figure 2-1. The microcomputer consists of a series of plug-in circuit boards and the keyboard control panel devices. A motherboard of bus lines and connectors is spread along the inside rear for plugging in the circuit boards as needed. All boards are easily replaced.



Simplified Flow Diagram of the Digi Chem Analyzer
FIGURE 2-1

The rotary spin assembly is of modular construction, located at the lower left side of the DigiChem analyzer enclosure. The reaction cell inside the spin assembly is fabricated from teflon. It forms the heart of the assembly. As programmed, the microcomputer controls a variable speed motor which spins the reaction cell to provide for mixing of the solution as reagents are added. A cover to the spin assembly provides entrances for the sample and reagent addition lines and the pH probe. Reagent addition and sensing occurs below the surface of the sample.

The sample and reagent dispensing modules are located on the bottom right hand side of the DigiChem enclosure. All modules are interchangeable with each other. The sealed plug-in modules provide a dispensing capability for up to five fluids. such as samples, reagents, and buffers. Three reagent (acid, base, and mannitol) addition modules, one boron standard addition module, and one sample addition module are used in this application. The digital controlled module has a stepper-motor which pushes a plunger through a burette to dispense fluids in precise microliter increments.

The DigiChem analyzer was designed for process control applications, providing on-line analyses and control for continuous, semicontinuous, and batch processes. It automatically performs titrimetric, colorimetric or selective-ion analyses. The microcomputer controls the automatic functions of sample and reagent dispensing, solution mixing, and concentration sensing through a programmed sequence of analyses. The instrument as it is normally used takes and measures a sample from an on-line stream and performs the following programmed operations automatically:

- A fixed but programmable volume of sample is forced into the reaction vessel. Sample volume required for boron analyses is on the order of 0.5-2 ml for boron concentrations in the range of 1000 to 6000 ppm. Low boron concentrations require higher sample volumes.

- Next the instrument adds dilution water to flush the sample line and provide sufficient volume to cover the tip of the pH probe. If it is planned to use the instrument for post-accident analyses, the programming sequence should be changed to add water first. This will dilute the sample and thus reduce the potential for release of iodine gas which may be present. After the sample is added, a little more water (2-5 ml) is required to flush the sample addition tip.

- If the solution is basic, as could be the case during an accident. the system can be programmed to add acid to neutralize the base. The manufacturer should be consulted concerning programming requirements.

- A programmed volume of mannitol solution is added to the reaction vessel. Mixing is achieved by rotation of the reaction vessel.

- The solution is titrated with NaOH to an end point pH of 8.5 Alternately, the volume of titrant used can be determined by automatic derivation of the change in slope of the pH line (inflection point), which occurs when the caustic titration of the boron-mannitol complex is complete.

- The microcomputer takes the information concerning sample size and NaOH titrant volume used and computes the boron concentration. Boron concentration is printed out as ppm boron on a computer tape. Digital readout of boron concentration can also be provided locally or at some distant point.

- At the conclusion of each analysis, the rotary speed of the reaction vessel is increased to spin out the solution in the vessel. Water is added at this time to flush the vessel by centrifugal force. Waste solutions are gravity drained to a collection tank.

SYSTEM MODIFICATION FOR OPERATION IN A RADIATION ENVIRONMENT

For operation in a radiation environment, it is necessary to separate the rotary spin assembly and the sample addition module from the microcomputer section to provide for localized shielding of components containing primary coolant. The microcomputer section and other components which are not exposed to the primary coolant probably cannot withstand high radiation exposure levels. Separation poses no serious technical problem since the units are of modular construction. However, this task should not be undertaken lightly since there are many electrical lines which must be lengthened, three solid state components which must be changed or shielded and longer length tubing must be provided for sample and reagent feed. Preamplification of the pH signal is also required.

SENTRY MODIFICATIONS TO THE DIGICHEM ANALYZER

The Sentry approach in providing a system that is suitable for on-line boron analyses under post-accident conditions was to replace all elastomers with more radiation resistant materials where necessary. Specific changes made to the DigiChem analyzer by Sentry prior to this test work are indicated below. Other changes have since been made to correct problems identified in the high level irradiation experiments.

- All teflon and Kel-F parts in the system were replaced with more radiation resistant elastomers.

- O-rings in the radiation zone were replaced with O-rings made of materials known to be more resistant to radiation.

- Solid state controls that will be in the high radiation zone were replaced with mechanical switches.

- The rotary spin assembly, sample addition module and reagent addition modules were separated 25 feet from the control module. Only the rotary spin assembly and sample addition module will be in the high radiation area. Shielding is provided for these components.

- A separate pH preamplifier was added.

TEST DESCRIPTION

DIGICHEM COMPONENTS PROVIDED BY IONICS

The irradiation testing was performed at the hot cell test facilities at Georgia Tech. Components tested were those from the DigiChem Analyzer which would be subjected to moderately high radiation levels during boron analyses under post-accident conditions. In selecting the components that will be exposed to high radiation levels, it was assumed that the rotary spin assembly and sample addition module would be located behind a lead shield to separate other components from the high radiation area. The components tested were in the form provided by the manufacturer in their standard version of the DigiChem Analyzer. These components are as follows:

- Rotary Spin Assembly - This was exposed to 10^7 rads.
- Sample Addition Module - This was exposed to 10^7 rads.
- Separate photo-interrupter cells for the rotary spin assembly and sample addition module were tested at 10^4, 10^5 and 10^6 rads. This additional testing was performed to determine the failure point since the photo-interrupter cells included as part of the rotary spin assembly and sample addition module failed totally after exposure to 10^7 rads.
- O-Rings (Buna, Kalrez and Viton) - These were tested to 10^6 and 10^7 rads exposure.
- Delivery Tips (Kel-F) - These were tested at 10^6 and 10^7 rads exposure.
- Teflon Tubing - Two separate lots of teflon tubing were tested at 10^5, 10^6 and 10^7 rads exposure.
- pH and Reference Electrodes - Testing was performed with two sets of pH probes with external reference cells of the type used by Ionics in their DigiChem analyzer. In addition, testing was performed on a pH probe with an internal reference cell. Four series of tests were performed at maximum radiation levels of 10^6 R/hr, as follows:

  --Testing was performed using the buffer solutions indicated below. Buffer solutions were used to minimize the effect of CO_2 pickup from air on pH of the solutions. It was necessary to leave the solutions exposed to air during the course of this testing.

Organic buffers were not used because these buffers will degrade under irradiation, resulting in a change in pH. This change in pH could be wrongfully attributed to radiation induced degradation of the pH probes.

pH	Compound	Concentration	Comments
4.5	Potassium dihydrogen phosphate	0.2 Molar	Laboratory preparation
7.0	Monobasic potassium phosphate and sodium hydroxide	--	Commercial preparation
10.0	Potassium carbonate, potassium borate and potassium hydroxide	--	Commercial preparation

--One set of buffer solutions was exposed to the radiation field in the hot cell, checking the pH of each solution periodically during the course of the working day. The pH probes and reference cell were exposed to the same radiation field as were the buffer solutions. The pH meter was installed outside the hot cell. A 10 foot lead was required for connection of the probe to the pH meter.

--The temperature of the solution in the hot cell was monitored so that correction could be made for the temperature effect on pH. The hot cell lights were turned off when not in use so that temperature inside the hot cell would remain relatively constant.

--The control buffer solutions were stored outside the hot cell. checking the pH at the same frequency as were the solutions inside the hot cell.

MODIFIED DIGICHEM ANALYZER

The Sentry modified DigiChem analyzer is programmed to determine boron concentration by automatic derivation of the change (inflection point) in slope of the pH line which occurs when the caustic titration of the boron-mannitol complex is complete. After the sample is added to the rotary reaction cell, deionized water and mannitol are added to the sample. A pH determination is made at this point and if the solution is basic, acid is added automatically to reduce the pH to the range of 2 to 2.5. Then a back titration is performed to neutralize the excess acid, indicated by an inflection point at around pH 5-6 in the slope of the pH line. Titration of the boron-mannitol complex begins at this time and is complete at the high pH inflection point.

Analyses performed with the production model DigiChem analyzer followed the pattern indicated above except that a pH of 5.5 was used as a start point for titration of the boron-mannitol complex and a pH of 8.5 was used as the end point.

Initially the equipment was operated outside the hot cell using four standard solutions containing 60, 600, 1200 and 3000 ppm boron to verify operation of the system. The equipment was operated with a 25-foot separation between the control unit and other components as it would be in post-accident conditions. Following the initial testing the rotary spin assembly, with its pH probe, the sample addition module, and the 3000 ppm boron standard were installed inside the hot cell. The other components, the preamplifier for the pH probe, and the 1200 ppm standard remained outside the hot cell.

Testing was performed at radiation levels of 1.75×10^4 R/hr, 8.64×10^4 R/hr and 1.57×10^5 R/hr. The central point for determining the radiation level was adjacent to, and just above the top of the rotary spin assembly. Other areas may have been slightly higher or lower than the reported radiation level. Total radiation exposure for the Sentry modified equipment was approximately 2.7×10^7 rads.

PRODUCTION MODEL DIGICHEM ANALYZER

A series of boron standards and post-accident matrix solutions prepared by NUS were analyzed with the DigiChem analyzer at the Ionics, Inc., plant in Watertown, Massachusetts. The analyses were performed by a NUS representative using a production model analyzer. Titration of the samples were performed with 0.5N and 0.1N NaOH to determine if there is an advantage to using a more dilute titre. No radiation exposure was involved in this testing.

The solutions analyzed are listed below. Concentration of the additives used to make up these solutions are shown on Table 2-1.

- Boron standards based on the weight of boric acid used to prepare the solutions.
- Boron standards containing low concentrations of lithium hydroxide. This was to simulate the buildup of lithium in the primary coolant during normal power operations.
- Post-accident fission product matrices containing known concentrations of boron.
- Simulated solutions that might be expected to develop in the reactor containment sump after a loss-of-coolant-accident and activation of caustic containment spray.
- Solutions containing calcium, this testing was performed to determine if calcium that is leached from the concrete during a loss-of-coolant-accident would affect the boron analysis results.

TABLE 2-1

COMPOSITION* OF MATRIX SOLUTIONS USED IN TESTING THE DIGICHEM ANALYZER

Sample	mg/l B	mg/l Li OH	mg/l $La Cl_3$	mg/l $Ba NO_3$	mg/l KI	mg/l $Cs Cl_3$	mg/l $Ce (NO_3)_6 (NH_4)_2$	mg/l $CaCl_2$
Matrix 1	60	6.9	4.0	15.4	51.0	312.9	20.7	0
Matrix 2	2000	6.9	4.0	15.4	51.0	312.9	20.7	0
Matrix 3	6000	6.9	4.0	15.4	51.0	312.9	20.7	0
Matrix 4	6004	0.7	0.4	1.5	5.1	31.3	2.1	0
Matrix 5	0	0.7	0.4	1.5	5.1	31.3	2.1	0
Matrix 6	0	6.9	4.0	15.4	51.0	312.9	20.7	0
Matrix 7	600	1.4	0	0	0	0	0	2018
Matrix 8	60	6.9	0	0	0	0	0	0

* The ppm concentrations indicated are based on weighed amounts of salts dissolved in one liter of water. The boron is indicatd as mg/l of boron. The other salts are indicated as mg/l of Li OH, $La Cl_3$ and so forth.

TEST RESULTS

IRRADIATION TESTING OF SELECTED COMPONENTS FROM THE DIGICHEM ANALYZER

Prior to reporting results it should be noted that the maximum radiation level expected in the DigiChem analyzer would be 10^6 R/hr to the teflon plunger of the sample addition module. This considers both gamma and beta radiation levels. Radiation levels in the other areas of the analyzer would be in the range of 10^4 - 10^5 R/hr. Radiation exposure for other components would be less than 10^5 rads. Estimated radiation exposures are based on the following assumptions:

- The first boron analysis will be performed in triplicate at one hour after the accident occurs. Approximately 25 minutes will be required to perform the triplicate analyses.
- The primary coolant will contain a maximum activity concentration of 4 curies per ml during the first boron analysis performed.
- Total volume of primary coolant contained within the tubing. the one ml sample addition module and rotary reaction cell will be on the order of 3 ml. This volume is assumed to exist as a point source within an imaginary sphere of one foot diameter.
- The radioactive coolant will be flushed from the system with water when the triplicate analysis is complete. Flushing will require the use of manual commands to the DigiChem analyzer.
- There will be two additional triplicate analyses performed within the next 24 hours. Boron analyses performed on a once per day basis after this time will not add significantly to total radiation exposure.

Limited radiation damage was observed in the testing performed; however, this was to components which have been replaced with radiation resistant components in the Sentry modified system. Solid state components which were damaged were subsequently tested at irradiation levels of 10^4, 10^5, and 10^6 rads to establish the threshold level at which damage occurs.

ROTARY SPIN ASSEMBLY

After irradiation to 10^7 rads, the rotary spin cell assembly was installed in an operational DigiChem analyzer and the system was activated. The teflon reaction

TABLE 2-2

RADIATION TESTING OF VARIOUS ELASTOMERS

Item	Exposure in Rads	Material	Results
O-Ring	10^6	Buna	Control, 75 Durometer[1]; Irradiated, 70-75 Durometer
O-Ring	10^7	Buna	Irradiated, 75-80 Durometer
O-Ring	10^6	Kalrez	Control, 84-85 Durometer[1]; Irradiated, 80-85 Durometer
O-Ring	10^7	Kalrez	Irradiated, 83-89 Durometer
O-Ring	10^6	Viton	Control, 78-80 Durometer[1]; Irradiated, 75-80 Durometer
O-Ring	10^7	Viton	Irradiated, 75-80 Durometer
Delivery Tips	10^6	Kel-F	No visible effect; material would still serve its intended purpose
Delivery Tips	10^7	Kel-F	Slight darkening noted; material would still serve its intended purpose
Tubing (Lot 1)[3]	10^5	Teflon	No irradiation effect
Tubing (Lot 1)	10^6	Teflon	Rupture pressure - 1600 psi[2] for three specimens
Tubing (Lot 1)	10^7	Teflon	Severly embrittled; tubing would break when bent
Tubing (Lot 2)[3]	10^5	Teflon	No irradiation effect
Tubing (Lot 2)	10^6	Teflon	Rupture pressure - 1600 psi[2]
Tubing (Lot 2)	10^7	Teflon	Longitudinal cracking occurred when the tubing was bent
Tubing	10^7	Tygon	Rupture pressure - 300 psi[4] for three irradiated specimens

(1) Evaluation of results was based on change in hardness. There was no visual indication of damage.

(2) Control samples from both lots ruptured at 1600 psi. The failure mode differed in that a bubble developed on the control sample prior to rupture. Pressure failure of the irradiated samples resulted from development of pin-hole cracks.

(3) Two lots of tubing from separate sources were tested.

(4) One control specimen ruptured at 270 psi and the other at 290 psi.

TABLE 2-3

IRRADIATION TESTING OF PHOTO-INTERRUPTER CELL MCA8

Irradiation Level	Milliamp Output	*Comments
0 rads (Control Sample) tested	301 cell	
10^4 rads	24	1 cell tested
10^5 rads	0.1	2 cells tested
10^6 rads	0	2 cells tested

*20 ma source, 5V detector excitation

TABLE 2-4

IRRADIATION TESTING OF PHOTO-INTERRUPTER CELL H21A3

Irradiation Level	Milliamps Output*
0 rads (control Sample)	17.5
0 rads (Control Sample)	14.3
10^4 rads	14.0
10^5 rads	9.8
10^5 rads	10.4
10^6 rads	0.5
10^6 rads	0.9

*60 ma source, 10V detector excitation

cell within the rotary spin cell assembly spun momentarily and stopped. Testing performed indicated that the photon coupled interrupter module had failed. Sentry has replaced this module with a mechanical system which is not sensitive to radiation. The photo interrupter module was replaced and the teflon reaction cell was operational. Also, a solenoid valve would not operate because the solid state relay which activates this valve had failed. Replacement of this relay was required to activate the valve. This relay can be located outside the radiation zone in the computer control system, without making any change other than installing longer connection wires. Output from this relay is 120 VAC.

A visual inspection was then made of the rotary spin assembly with the following results:

- All glass and clear plastics had darkened. This darkening does not detract from the physical properties of the material.
- The two nylon pulleys which provide the driving force to spin the teflon cell had a myriad of cracks, however the pulleys held together when operated. It would be pointless to do any further test work with these nylon pulleys since they are easily replaced with metal pulleys which are not affected by radiation.
- No visual indication of degradation (cracks, loss of elasticity) could be found in the elastomer belt which connects the nylon pulleys.
- The teflon tubing which feeds reagents and sample to the assembly had become very brittle. Other testing performed with teflon tubing indicates the threshold damage indication for teflon tubing is between 10^6 and 10^7 rads. Considering radiation damage alone. the safety factor involved with the use of teflon tubing in this application is several orders of magnitude.
- The teflon reaction cell suffered no apparent visual damage. No cracking occurred when the cup-shaped cell was spread apart and squeezed together with maximum hand pressure.

SAMPLE ADDITION MODULE

The teflon plunger of the sample addition module may see total radiation exposures in the range of 10^6 rads. This component is discussed separately because it is the high exposure item in the overall assembly. Testing performed, as discussed below, indicates that this plunger will be functionally adequate at 10^7 rads exposure. However, the system failed at this exposure level for another reason as identified below.

After irradiation to 10^7 rads exposure, the system was installed in an operational DigiChem analyzer and the system was activated. The module did not operate.

Testing performed indicated that the photon coupled solid state limit switch had failed. (Sentry has replaced this solid state switch with a mechanical limit switch which is not sensitive to radiation.) After the solid state limit switch was replaced, the sample addition module was operated continuously for about 1.5 hours without problem. Around 100 samples could have been processed during this period. The operational test was terminated at this time.

A visual inspection was made of this module with the following results:

- The glass and clear plastics had darkened.
- There was no visual indication of degradation of the teflon plunger or leakage past this plunger as it was operated.
- The teflon tubing was severly embrittled. However, actual irradiation level that will occur under post-accident conditions is on the order of 10^5 rads or less. The tubing is still serviceable at 10^6 rads exposure.

O-RINGS AND OTHER ELASTOMERS

The elastomers were tested at several different radiation levels with results as indicated in Table 2-2.

The result of the testing clearly indicates that all elastomers in the DigiChem analyzer will withstand 10^7 rads exposure except for the teflon tubing. Exposure level for the teflon tubing should be limited to 10^6 rads. This is beyond the exposure levels anticipated under accident conditions. Heavier components, such as the teflon reaction cell and the teflon plunger in the reagent addition module, remained operational at 10^7 rads exposure. However, it would be desirable to limit all teflon components in the system to 10^6 rads of cumulative exposure.

Data from the pressure tests performed on the irradiated and control samples of teflon tubing are somewhat unusual in that all specimens failed at exactly 1600 psi. All specimens were pressure tested with compressed nitrogen in the same manner, slowly increasing the pressure while monitoring a pressure gauge till failure occurred. About one minute was required to increase pressure to the 1600 psi failure level.

Tygon tubing was tested even though none is used in the DigiChem analyzer to develop alternate materials in the event that the teflon tubing failed at some low irradiated exposure level. This material is very resistant to irradiation based on no indication of change or darkening of this material even at 10^7 rads exposure.

Results of the test work with teflon tubing reported here are consistent with results of testing performed by General Electric on their nuclear plane project. In the General Electric work, teflon hose that was maintained under static pressure with a liquid at 1200 psig while under gamma irradiation, started to leak at slightly above 10^6 rads exposure. Five irradiation tests were performed in the temperature range of 100 to 350°F. Temperature had no effect on test results. The hose was pressurized with a liquid identified as MIL-L-7808C.

Observations made indicate that failure of the elastomers tested ultimately occurs because of embrittlement. This failure mode does not present a problem with the DigiChem analyzer since there are no components in the system that are flexed on a constant basis. There may be some very minor flexing of the teflon tubing but this would occur very infrequently.

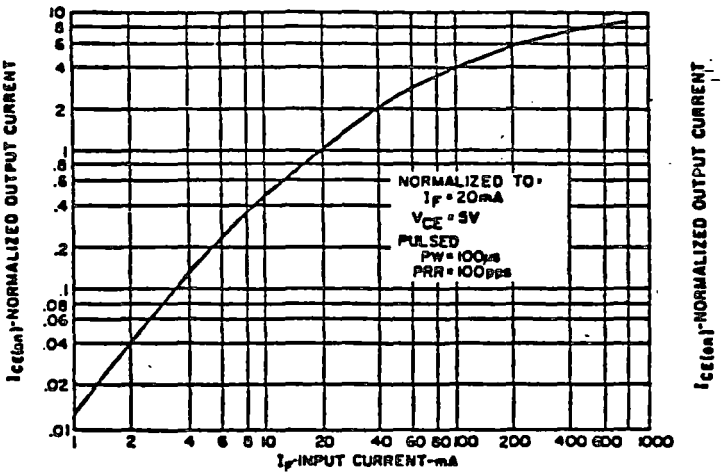
PHOTO-INTERRUPTER CELLS

Evaluation of results for these solid state components is based on typical characteristic curves developed by the manufacturers. Typical curves for the unirradiated cells are shown in Figures 2-2 and 2-3. A comparison was made of output current verses input current for the control samples and for separate samples tested after irradiation. As indicated in Tables 2-3 and 2-4, testing was performed at 10^4, 10^5 and 10^6 rads. Data reported in these tables indicate that threshold damage occurs between 10^4 and 10^5 rads for module H21A3 and about 10^4 rads for module MCA8. It cannot be concluded that the MCA8 module will withstand 10^4 rads on a consistent basis since only one module was tested at this exposure level. Slight damage resulted from the irradiation, however, the module was still operational.

IRRADIATION TESTING OF THE pH PROBES

A separate test was performed to determine the effect of irradiation on pH probes because satisfactory performance on their part while under irradiation is an absolute must to operation of the DigiChem analyzer. This topic is of additional interest because of NRC regulations concerning pH determination requirements for all nuclear systems under post-accident conditions. There is limited data available indicating that pH probes should perform satisfactorily under high level irradiation. However, additional testing was considered necessary to provide direct experience.

TYPICAL CHARACTERISTICS OF MODULE H21A3



OUTPUT CURRENT VS. INPUT CURRENT

FIGURE 2-2

TYPICAL CHARACTERISTICS OF MODULE MCA8

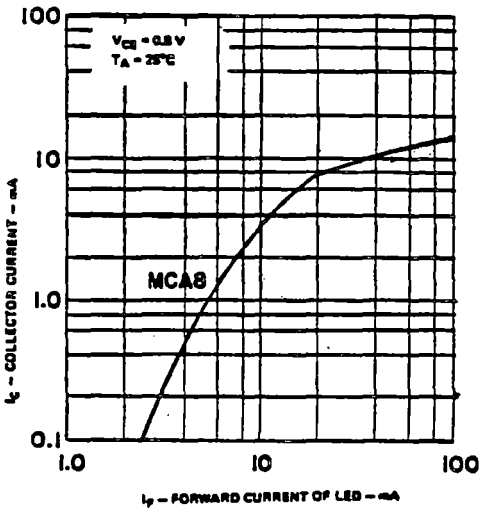


FIGURE 2-3

The results of irradiation testing performed on an internal reference pH probe are presented in Table 2-5. There is no effect on pH indication at a exposure level of 3×10^5 R/hr, however the pH showed a decrease of around 0.1 pH units for the pH 4 and 7 range at a radiation level of 9.77×10^5 R/hr. This differs from external reference probes response which showed a slight increase during irradiation as is later discussed. The high level radiation had no significant effect on the internal reference probes for the pH 10 buffer solution.

Total exposure on the internal reference probe was about 2×10^6 rads at the time it was broken while being moved with the hot cell manipulators. There was no observed change with time in the behavior of the pH electrodes during the two hour period the probe was under test.

The results of irradiation testing performed on an external reference pH probe are presented in Table 2-6. An increase in pH of 0.14 units was observed for the pH range of 4 through 10 at a radiation level of 3×10^5 R/hrs. A further increase of 0.21 pH units was observed when the radiation level was increased to 9.77×10^5 R/hr. The radiation effect is reversible based on data taken when the radiation level was reduced and later eliminated. Note in the subject table that the pH of the neutral buffer increased from 7.06 to 7.20 at a radiation level of 3×10^5 R/hr. This pH increased to 7.28 at a radiation level of 9.77×10^5 R/hr and then dropped to 7.19 when the radiation level was reduced to 3×10^5 R/hr. The final pH reading at the end of the test was 7.10 for both the control and the irradiated sample. The pH of the control sample was taken with the irradiated probe and with a probe that had not been irradiated.

Some radiation degradation of the pH 10 solution was observed after exposure to an integrated dose of 5×10^6 rads. Note that the measured pH of this solution dropped from 10.06 to 9.60, however, the control sample outside the hot cell showed no change in pH level when measured with the irradiated probe. If the reduction in pH of the basic solution had resulted from radiation damage to the probe, the pH of the control sample should also have indicated a lower pH.

The results of irradiation testing performed on an external reference probe with a previous history of 5×10^6 rads exposure are presented in Table 2-7. Note that the effect of irradiation on pH is slightly enhanced over that previously experienced. The increase for exposure at a radiation level of 3×10^5 R/hr and 9.77×10^5 R/hr is 0.15 and 0.3 pH units respectively versus an increase of 0.14 and 0.21 pH units during the initial testing reported in Table 2-6.

TABLE 2-5

EFFECT OF RADIATION[3] ON AN INTERNAL REFERENCE pH PROBE (L & N CAT #117495)

Type Buffer Solution	Initial pH No Radiation	pH at 3×10^5 R/Hr	pH at 9.77×10^5 R/hr
KH_2PO_4	4.60	4.60[1]	4.50[2]
KH_2PO_4 + NaOH	7.05	7.06[91]	6.93
K_2CO_3, K_3BO_3 + KOH	10.10	10.13[1]	10.12

(1) No change in pH from the instantaneous reading was noted over a 5-10 minute exposure period.
(2) After taking the initial readings, the probe was left immersed in this solution. Readout of the pH meter varied between 4.48 and 4.51 during a 90 minute exposure period. The probe was broken at this time when it was moved.
(3) Total exposure = 2×10^6 rads.

TABLE 2-6

EFFECT OF RADIATION ON EXTERNAL REFERENCE PROBES
(FISHER CAT # 13-639-8 and 13-639-63)

Types Buffer Solution	Initial pH No Radiation	pH At 3×10^5 R/Hr	Rads Cum. Ex	pH At 9.77×10^5 R/Hr	Rads Cum. Ex	pH At 3×10^5 R/Hr	Rads Cum. Ex	pH At 3×10^5 R/Hr	Rads Cum. Ex.	Final pH[1] No Radiation
KH_2PO_4	4.39	4.53	1.5×10^5	Spilled buffer solution	-	-	-	-	-	buffer
KH_2PO_4 + NaOH	7.06	7.20	1.5×10^5	7.28	5×10^5	7.19	10^6	7.19	5×10^6	7.10
K_2CO_3, K_3BO_3 + KOH	10.06	10.19	1.5×10^5	10.27	5×10^5	Not[3] determined	10^6	Not[3] determined	5×10^6	9.60[2]

(1) A pH determination was made after all sources were removed from the hot cell.
(2) A control sample that was exposed to the same environmental conditions without radiation exposure had a pH of 10.05.
(3) Readings were not taken because of the extreme difficulty in moving the pH probe with the manipulators.

TABLE 2-7

EFFECT OF RADIATION ON EXTERNAL REFERENCE pH PROBES WITH 5×10^6 RADS PREVIOUS EXPOSURE (FISHER CAT #13-639-8 and 13-639-63)

Type Buffer Solution	Initial pH (1) No Radiation	pH at 3×10^5 R/Hr	pH at 9.77×10^5 R/Hr
KH_2PO_4	4.45	4.60	4.75
$KH_2PO_4 + NaOH$	7.08	7.26	7.37
K_2CO_3, $K_3BO_3 + KOH$	10.08	10.24	10.37

(1) The pH measurements were taken on probes that were previously irradiated as indicated in Table 2-6. No change was noted after about 2 hours exposure in the test indicated above.

The results of long term irradiation testing performed on external reference probes are presented in Table 2-8. Note that there is an increase of 0.1 and 0.15 pH units at a radiation level of 10^3R/hr. Overall results differ somewhat from previous experiments in that there is little effect at the high radiation level exposure (9.1 x 10^5 R/hr). This may be because the high radiation exposure was preceded by 60 hours exposure at 10^3 R/hr. Other experiments did not have this low level exposure preceding the high level test.

IRRADIATION TESTING OF THE SENTRY MODIFIED DIGICHEM ANALYZER

Checkout of the modified equipment was performed outside the hot cell for nominal boron concentrations of 60, 600, 1200 and 3000 mg/l. The boron solutions used were obtained by known dilution of a 6000 mg/l stock solution. The system was set up as it would be under accident conditions with 25 feet of separation between the control module and the components that will be exposed to irradiation. Multiple analyses were were performed at each boron concentration. The end point of the titation was determined by automatic derivation of the change in slope of the pH line which occurs when titration of the boron-mannitol titration is complete. Maximum deviation noted from actual boron concentration was 1.1 percent with an average deviation on the order of 1 percent. Accuracy requirements for boron determination during normal power operation, as specified by many utilities, are on the order of plus or minus 0.5 percent.

When checkout of the equipment was completed, the rotary reaction cell assembly, the 3000 ppm boron standard, and the sample addition module were installed in the hot cell. The 1200 ppm boron standard remained outside the hot cell. The eight ^{60}Co frames (53,000 curies, total) were arranged around the rotary reaction cell assembly and the sample addition module to achieve a radiation level of 1.75 x 10^4 R/hr, as measured near the top center of the rotary reaction cell assembly. This value is comparable to the general radiation level that may be present during a post-accident condition, assuming a 4 Ci/cc activity in the coolant. Boron analyses results with the Sentry modified DigiChem analyzer in a 1.75 x 10^4 R/hr radiation field are presented in Table 2-9. This testing was performed in the hot cell where temperature was on the order of 95°F. Testing performed outside the hot cell to checkout the equipment was performed at a temperature of 72°F. This change in temperature could have had some effect on results because of

TABLE 2-8

EFFECT OF LONG TERM RADIATION EXPOSURE ON pH PROBES

Two Fisher external reference pH probes were irradiated for 60 hours at 10^3 R/Hr while one probe was in a pH 3.98 and the other probe in a pH 7.00 buffer solution. One probe was new and the other probe had 5×10^6 rads previous exposure. The probe with the previous exposure was not identified in the data that was taken. Results from this test are as follows:

pH With No Radiation	pH at 10^3 R/Hr	pH After 60 Hours Exposure at 10^3 R/hrs
3.98	4.09	4.09
7.00	7.15	7.15

The probes were then restandarized with new buffer solutions and the radiation level was increased to 9.1×10^5 R/Hr. One probe was left in a pH 3.98 and the other probe in a pH 7.00 solution. Results from this test are as follows:

Radiation Level = 9.1×10^5 R/Hr

pH With No Radiation	pH At 5 Min	pH At 1 Hr	pH At 2.33 Hrs	pH At 17.33 Hrs	pH At 20 Hrs	Total Exposures*
3.98	4.01	3.98	3.99	4.00	3.98	1.8×10^7 rads
7.00	7.06	7.04	7.05	7.05	7.06	1.8×10^7 rads

* One probe which was not identified prior to performing the test had a previous exposure history of 5×10^6 rads.

evolution of gas bubbles from degasification occurring as the liquids were heated. The boron analyses results had a higher error band and more scatter than was observed in testing performed outside the hot cell or in testing performed at Ionics with a production in model analyzer. However, the results observed were totally acceptable for post-accident use.

Testing was then performed at a radiation level of 8.64×10^4 R/hr (factor of five higher). The higher radiation level was achieved by moving the ^{60}Co frames closer to the test equipment. Results of this test work are presented in Table 2-10. Note that there is little or no change in variability from results shown in the last part of Table 2-9.

The final test phase was performed at a radiation level of 1.75×10^5 R/hr. This was the maximum radiation level achievable at the top center of the rotary reaction cell assembly with the 53,000 curie source. This work was performed over the a weekend. The test was started late Friday afternoon. Reasonable results were achieved for the first few analyses, at which time, the test personnel departed for the weekend. The equipment started behaving erratically soon after the personnel departed and continued this behavior for most of the weekend. Results achieved at the beginning of this weekend run are presented in Table 2-11. Note that the results of the 1200 ppm and 3000 ppm boron standards are unacceptable for post-accident use. However, equipment problems were identified that are responsible for this condition and changes have been made to the equipment design to prevent repeat of this occurrence. This is discussed later in more detail. In any event, it should be noted that the radiation levels anticipated under post-accident conditions will not approach the radiation level used in the final testing of the equipment.

As shown in Table 2-12, results improved near the end of the weekend run. Note, in particular, that all values in the 3000 ppm column, except two, are within plus or minus 5 percent of actual. The two exceptions both indicate a boron concentration of 953 ppm (68.2 percent low). Improving results with increased time under exposure is not consistent with the behavior pattern expected from radiation damage. In particular, radiation damage would not be expected to result in a pattern where both exceptions to general results indicate a boron concentration of 953 ppm.

The test was terminated when a nylon pulley broke on the rotary reaction cell assembly. This nylon pulley is internally stressed with a press fit brass bushing.

TABLE 2-9

BORON ANALYSIS RESULTS WITH THE SENTRY
MODIFIED DIGICHEM ANALYZER IN A 1.75×10^4 R/HR RADIATION FIELD

Nominal 1200 ppm Boron Solution[1]			Nominal 3000 ppm Boron Solution[1]		
Steps[2] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Nominal	Steps[2] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Nominal
524	1258	4.8	1243	2983	-0.57
537	1291	7.6	1263	3031	1.0
546	1310	9.2	1233	2959	-1.4
535	1284	7.0	1198	2875	-4.2
506	1214	1.2	1201	2882	-0.39
503	1207	0.6	1272	3053	1.8
498	1195	-0.4	1250	3000	0
505	1212	1.0	1276	3062	2.1
528	1267	5.6	1236	2966	-1.1
529	1270	5.8	1254	3009	0.3
536	1286	7.2	1187	2849	-5.0
539	1294	7.8	1199	2878	-4.1
538	1291	7.6	1187	2849	-5.0
529	1294	7.8	1199	2878	-4.1
538	1291	7.6	1246	2990	-0.3
529	1270	5.8	1234	2962	-1.3
531	1274	6.2	1271	3050	1.7
529	1270	5.8	-	-	-
538	1291	7.6	-	-	-
$\bar{X}$527	1267	5.6	1232	2957	±2.1
σ±13.9	±34.2	±2.8	±31.1	±74.6	±1.7
2σ±27.8	±68.4	±5.6	±62.2	±149.2	±3.4

(1) The historical samples could not be found at the Georgia Tech. test facility, so boron concentration cannot be verified. The indicated concentrations were obtained by known dilution of a 6000 mg/l boron stock solution.

(2) One step = 2.17×10^{-6} liters.
The analyzer was programmed to alternately analyze the 1200 ppm and 3000 ppm boron standards.

TABLE 2-10

BORON ANALYSIS RESULTS WITH SENTRY
MODIFIED DIGICHEM ANALYZER IN A 8.64×10^4 R/HR RADIATION FIELD

Nominal 1200 ppm Boron Solution			Nominal 3000 ppm Boron Solution		
Steps[1] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Nominal	Steps[1] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Nominal
538	1291	7.6	1250	3000	0
540	1296	8.0	1257	3017	0.6
536	1286	7.2	1256	3014	0.5
544	1306	8.8	1288	3091	3.0
544	1306	8.8	1260	3024	0.8
545	1308	9.0	1258	3019	0.6
-	-	-	1166	2798	-6.7
$\bar{X}$541	1299	8.2	1248	2995	1.7
$\sigma\pm$3.7	$\pm$9.2	$\pm$0.7	$\pm$38.1	$\pm$91.6	$\pm$2.4
$2\sigma\pm$7.4	$\pm$18.4	$\pm$1.4	$\pm$76.2	$\pm$183.1	$\pm$4.8

(1) One step = 2.17×10^{-6} liters
The analyzer was programmed to alternately analyze the 1200 ppm and 3000 ppm boron standards.

TABLE 2-11

BORON ANALYSIS RESULTS WITH THE SENTRY MODIFIED DIGICHEM ANALYZER IN A 1.75×10^5 R/HR RADIATION FIELD BEGINNING OF A WEEK END RUN

Nominal 1200 ppm Boron Solution			Nominal 3000 ppm Boron Solution		
Steps[1] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Nominal	Steps[1] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Nominal
538	1291	7.6	1265	3036	1.2
538	1291	7.6	1260	3024	0.8
364	874	-27.2	633	1519	-49.4
490	1176	-2.0	747	1793	-40.2
457	1097	-8.6	838	2011	-33.0
458	1099	-8.4	1000	2400	-20.0
392	941	-21.6	1213	2911	-3.0
367	881	-26.6	824	1978	-34.1
404	970	-19.2	1452	3485	16.2
440	1056	-12.0	1265	3036	1.2
468	1123	-6.4	1257	3017	0.6
538	1291	7.6	783	1879	-37.4
540	1296	8.0	1257	3017	0.6
528	1267	5.6	902	2165	-27.8
538	1291	7.6	1268	3043	1.4
528	1267	5.6	1246	2990	0.3
482	1157	-3.6	383	919	-69.4
521	1250	4.2	622	1493	-50.2
574	1378	14.8	619	1486	-50.5
561	1346	12.2	331	794	-73.5
542	1301	8.4	759	1822	-39.3
537	1289	7.4	684	1642	-45.3
541	1298	8.2	1209	2902	-3.3
527	1265	5.4	922	2213	-26.2
608	1459	21.6	937	2249	-25.0
481	1154	-3.8	1274	3058	1.9
$\bar{X}$498	1196	10.4	960	2303	25.1
$\sigma\pm$63.8	$\pm$153.0	$\pm$7.1	$\pm$309	$\pm$743	$\pm$22.8
$2\sigma\pm$127.6	$\pm$306.0	$\pm$14.2	$\pm$619	$\pm$1486	$\pm$45.6

(1) One step = 2.17×10^{-6} liters
The analyzer was programmed to alternately analyze the 1200 ppm and 3000 ppm boron standards.

TABLE 2-12

BORON ANALYSIS RESULTS WITH THE SENTRY MODIFIED DIGICHEM ANALYZER IN A 1.75 x 10^{-5} R/HR RADIATION FIELD NEAR END OF A WEEK END RUN

Nominal 1200 ppm Boron Solution			Nominal 3000 ppm Boron Solution		
Steps[1] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Actual	Steps[1] of 0.1105 N NaOH	Indicated ppm Boron	Percent Deviation From Actual
531	1274	6.2	1289	3094	3.1
488	1171	-2.4	1292	3101	3.4
534	1287	7.2	1283	3079	2.6
564	1354	12.8	397	953[2]	-68.2
530	1272	6.0	1269	3046	1.5
471	1130	-5.8	1287	3089	3.0
542	1301	8.4	1277	3065	2.2
473	1135	-5.4	1291	3098	3.3
570	1368	14.0	1269	3046	1.5
534	1282	6.8	1295	3108	3.6
482	1157	-3.6	1284	3082	2.7
537	1289	7.4	1287	3089	3.0
531	1274	6.2	1298	3115	3.8
480	1152	-4.0	1292	3101	3.4
534	1282	6.8	1283	3079	2.0
564	1354	12.8	397	953[2]	-68.2
530	1272	14.3	1269	3046	1.5
471	1130	-5.8	1287	3089	3.0
542	1301	8.4	1277	3065	2.2
473	1135	-5.4	1291	3098	3.3
570	1368	14.0	1269	3046	1.5
534	1282	6.8	1295	3108	3.6
482	1157	-3.6	1284	3082	2.7
537	1289	7.4	1287	3089	3.0
			1293	3103	3.4
$\bar{X}$521	1251	7.6	1285	3083	2.8
σ±34	±82	±3.5	±9.0	±21.5	±0.75
2σ±68	±163	±7.0	±18.0	±43	±1.5

(1) One step = 2.17 x 10^{-6} liters
The analyzer was programmed to alternately analyze the 1200 ppm and 3000 ppm boron standards.

(2) Not within 3 STD Deviations of the mean, thus are not included in the calculations.

There was 2.7 x 10^7 rads exposure on the test equipment at this time. Testing subsequently performed with the Ionics equipment indicates that extensive cracking will develop on this nylon pulley with 10^7 rads exposure. While the pulley on the Ionics supplied equipment did not fail after operation at the 10^7 rads exposure level, its appearence was such that it could have easily failed.

Subsequent examination of the equipment performed by Sentry indicated that the nylon and Kel-F parts that were not replaced had become severely embrittled. This was expected, based on the total exposure levels involved. All metal and electronic components were fully operational.

TEST RESULTS FROM THE PRODUCTION MODEL DIGICHEM ANALYZER

The DigiChem analyses results and laboratory analyses results for standard boron solutions are presented in Table 2-13. There is reasonable agreement between these results, however, there is more variation than was seen in previous testing performed with the DigiChem analyzer (Table 2-15). Results of this other work indicate that it should be possible to obtain a precision of $\pm$ one percent with the DigiChem analyzer. Note in Table 2-13 that part of the titrations were perfomed with 0.5 N NaOH and part with 0.1 N NaOH solutions. A comparison of the data indicate that essentially equivalent results were achieved with either normality.

The analyses results for matrix solutions containing simulated fission product species and caustic solutions are presented in Table 2-14. These data indicate that the concentrations of fission product species expected following an accident will not interfere with boron analyses results. The data also indicate that boron analyses results will not be affected by the caustic added to the primary coolant when the containment sprays are activated during a LOCA event. The limited testing performed concerning the effect of lithium alone on boron analyses results indicates this addition had no apparent effect on accuracy or precision.

TABLE 2-13

STANDARD BORON AND BLANK ANALYSES RESULT
WITH THE PRODUCTION MODEL DIGICHEM ANALYZER

Sample	Nominal Boron mg/l	Number of Analyses	Titrant Normality	Mean Boron[2] mg/l	Laboratory Analyses Results[3]	% Error Mean-Lab / Lab
Standard	6000	4	0.5	6124	6108	1.90
Standard	6000	6	0.5	5962	6108	-2.39
Standard	6000	5	0.1	5914	6108	-3.18
Standard	2000	6	0.5	2082	2017	3.22
Standard	2000	4	0.1	2102	2017	4.21
Standard	1000	6	0.5	1002	1025	2.24
Standard	1000	3	0.5	1048	1025	2.24
Standard	1000	1	0.1	1065	1025	3.90
Standard	60	6	0.5	57.25	61	6.15
Standard	60	6	0.1	59.05	-1.58	
Blank[1]	0	3	0.5	0.40	-	-
Blank[1]	0	5	0.5	-1.12	-	-
Blank[1]	0	7	0.1	-3.57	-	-

(1) Deionized water
(2) Analyses results with the Digichem Analyzer
(3) As determined by caustic titration of the boron-mannitol complex

TABLE 2-14

MATRIX SOLUTION ANALYSES RESULTS
WITH THE PRODUCTION MODEL DIGICHEM ANALYZER

Sample	Nominal Boron mg/l	Number of Analyses	Titrant Normality	Mean Boron mg/l (1)	Laboratory Analyses Results (2)	% Error Mean-Lab Lab
Matrix-1	60	3	0.5	59.92	65	-7.82
Matrix-1	60	3	0.1	58.79	65	-9.55
Matrix-2	2000	3	0.5	2082	2022	2.97
Matrix-2	2000	3	0.1	2079	2022	2.82
Matrix-3	6000	3	0.5	5897	6101	-3.34
Matrix-3	6000	3	0.1	5840	6101	-4.28
Matrix-4	6000	3	0.5	5995	6136	-2.30
Matrix-4	6000	3	0.1	5927	6136	-3.41
Matrix-8	600	3	0.5	608.4	624	-
Matrix-7	60	3	0.5	56.73	66	-14.0
Matrix-7	60	3	0.1	59.76	66	-9.59
Matrix-5	0	3	0.5	-3.61	-	-
Matrix-5	0	5	0.1	-0.61	-	-
Matrix-6	0	7	0.5	-2.92	-	-
Matrix-6	0	3	0.1	-0.46	-	-
Boron + 0.4N NaoH	600	3	0.5	663.8	666	-0.33
Boron + 0.4N NaoH	600	3	0.1	653.8	666	-1.83
Boron + 0.4N NaoH	6000	3	0.5	5916	6056	-2.31
Boron + 0.4N NaoH	600	3	0.5	626.8	666	-5.88
Boron + 0.4N	600	3	0.1	624.4	666	-6.25

(1) Analyses results with the Digichem Analyzer
(2) As determined by caustic titration of the boron-mannitol complex

DISCUSSION OF RESULTS AND CONCLUSIONS

DISCUSSION OF RESULTS

Test results from the irradiation experiments clearly indicate that the critical components in the production model the DigiChem analyzer with respect to radiation damage are as follows:

- Photon coupled interrupter module (H21A3). This is a light activated speed control system for the rotary reaction cell.
- Solid state relay for a solenoid actuated valve on the rotary reaction cell.
- Photon coupled solid state limit switch (MCA8) in the sample addition module.
- Two nylon pulleys used to drive the rotary reaction cell.

Threshold damage level for photon coupled interrupter module H21A3 is between 10^4 and 10^5 rads. For module MCA8 it is about 10^4 rads. Total radiation exposure for H21A3 and MCA8 could be at the 10^4 rad level in a accident condition, dependant on the overall design and operating philosophy of the sampling system. No conclusions can be drawn that MCA8 will withstand 10^4 rads exposure since only one module was tested at this level. The module suffered minor damage with 10^4 rads exposure, however, it remained operational. Threshold level for the solid relay (total failure at 10^7 rads) was not determined since it is easier to locate this relay outside the radiation zone than it would be to determine the threshold damage level. The nylon pulleys would almost certainly remain operational at 10^6 rads exposure, however, should be replaced with metal pulleys since this change can be accomplished with little difficulty.

The solid-state components listed above that can be damaged by radiation have been replaced with mechanical switches in the modifications made to the DigiChem analyzer by Sentry. The nylon pulleys were replaced by Sentry with stainless steel pulleys as a consequence of the irradiation experiments performed at Georgia Tech.

Teflon tubing can withstand 10^6 rads exposure while the heavier teflon components remained operational at 10^7 rads exposure. It is not expected that radiation damage would preclude the use of teflon components in a DigiChem analyzer during a post-accident condition. However, the change made by Sentry to eliminate teflon in favor of more radiation resistant materials will add a higher degree of conservatism to the system, For example, the need for flushing the sample lines of highly radioactive coolant within a specified time period becomes less critical with the Sentry system since the teflon has been replaced with more radiation resistant material.

Concerning pH probes the data indicate that high radiation levels (10^6 R/hr) will decrease the indicated pH by about 0.1 pH units for an internal reference probe. Indicated pH will increase by about 0.1 or 0.2 pH units for external reference probes in a high radiation field. An initial effect is noted at 10^3 R/hr. The increase in pH is immediate. The effect is fully reversible when the radiation source is removed. The DigiChem system has an external reference pH probe.

The shift in pH resulting from radiation should have a slight effect on accuracy of analyses with the DigiChem analyzer, however, the effect will not be significant as concerns post-accident requirements. During normal operating conditions, the system will be titrating from pH 5.5 to 8.5 to determine boron concentration. Under high radiation conditions the system will still titrate from an indicated pH 5.5 to pH 8.5. However, in reality it may be titrating from say a pH of 5.3 to 8.3 because of the radiation induced shift in pH.

The erratic results noted in the high radiation level testing (Table 2-11) occurred because of an electronic "loophole" created by the high radiation field. This resulted in the leakage of current, causing erratic pH electrode behavior. A design change has been made which includes a driven shield concept that will prevent radiation induced leakage in the cable shield to the pH electrode. This driven shield will be a standard feature in all DigiChem analyzers. It should be emphasized, however, that the system tested without the driven shield operated satisfactorily at radiation levels anticipated under post-accident conditions. Increased reliability can be anticipated with the addition of the driven shield.

Results of testing performed with the production model DigiChem analyzer are not equivalent to results previously achieved with this instrument. Compare for example, the data in Table 2-13 with the data from previous testing presented in Table 2-15. The difference between these results is not understood. One posssi-

bility is that there may have been some degassing of the titrant solutions or of the sample itself as system pressure is reduced when the plungers of the sample or titrant burettes are withdrawn to replenish system volumes. Introduction of bubbles adds to the error because these bubbles are measured and computed as liquid volume.

It is apparent from the data presented in Table 2-15 that there is very little scatter to the results. Virtually all the results are low by about the same percentage value. This pattern has appeared again and again, with some results consistently low and others consistently high by some small percentage value. Generally, the analyses results have been computed based on normality of the caustic solution used for titration. From examination of the data, it would appear that some improvment in accuracy can be achieved if results were compared directly to results achieved with a known boron standard. The computer can be programmed to provide for such a comparision.

If the DigiChem analyzer is used for normal operation or post-accident analyses, it should be noted that the primary coolant must be degassed to a low level prior to introduction of the sample to the sample burette. With high concentrations of gas present, as can occur in an accident involving core damage, bubbles will be produced in the sample stream when system pressure is reduced as the plunger in the sample burette is withdrawn. This would result in values which are lower than actual. The error would be proportional to the ratio of gas volume to liquid volume in the sample stream.

Another feature that would be desirable though not mandatory for this system, would be to inject a small volume of water to the rotary reaction assembly prior to injecting the sample itself. The reason for this is to dilute the sample immediately so that there is less tendancy for radioactive iodine to escape from solution during post-accident conditions. It would also be necessary to inject a small volume of water after the sample addition to properly flush the sample tip. The system can be programmed to provide this sample addition sequence.

The overall advantages of using the DigiChem analyzer for the boron determinations during accident conditions are as follows:

- All operations can be performed remotely. The exposure involved in determining boron concentration would approach zero.
- Sample volume requirements are on the order of 1-2 ml per analysis, thus shielding requirements would be minimal.

TABLE 2-15

BORON REPRODUCIBILITY RESULTS
2000 ppm STANDARD

Analysis Results	ppm DEV	% Error	Analysis Results	ppm DEV	% Error
1975	-25	-1.25	1975	-25	-1.25
1977	-23	-1.15	1975	-25	-1.25
1973	-27	-1.35	1975	-25	-1.25
1974	-26	-1.3	1975	-25	-1.25
1074	-26	-1.3	1974	-26	-1.3
1977	-23	-1.15	1975	-25	-1.25
1977	-23	-0.15	1977	-23	-1.15
1975	-25	-1.25	1977	-23	-1.15
1975	-25	-1.25	1998	-2	-0.1
1973	-27	-1.35	2000	0	0
1973	-27	-1.35	1974	-26	-1.3
1973	-27	-1.35	1978	-22	-1.1
1979	-21	-1.05	1981	-19	-0.95
1976	-24	-0.2	1977	-23	-1.15
1973	-27	-1.35	1977	-23	-1.15
1974	-26	-1.3	1977	-23	-1.15
1973	-27	-1.35	1978	-22	-1.1
1973	-27	-1.35	1981	-19	-0.95
1974	-26	-1.3	1982	-18	-0.9
1975	-25	-1.25	1977	-23	-1.15
1974	-26	-1.3	1978	-22	-1.1
1974	-26	-1.3	1978	-22	-1.1
2002	2	0.1	1977	-23	-1.15
1974	-26	-1.3	1981	-19	-0.95
-	-	-	1974	-26	-1.3
$\bar{X}$1975	21.9	1.1	1979	21.2	0.6
$\sigma\pm$5.8	$\pm$8.9	$\pm$0.4	$\pm$6.5	$\pm$6.5	$\pm$0.3
$2\sigma\pm$11.6	$\pm$17.8	$\pm$0.8	$\pm$13.0	$\pm$13.0	$\pm$0.6

Average error = -1.05%
Maximum error = -1.35%

- Analyses results can be achieved within 10 minutes after the sample line is purged to obtain a representative sample.

- Though not sealed gas tight, there would be little tendency for release of gaseous activity to the atomsphere. This would be particularly true if the sample addition sequence is changed to add water prior to addition of the sample.

The disadvantages of using the DigiChem analyzers under post-accident conditions are as follows:

- Waste solutions cannot be pumped back to the primary system since chemicals are added to the system in the analysis procedure.

- A small pumping system must be provided to pump the gravity drain waste solutions from the analyzer to a waste disposal facility if the waste disposal system is above the level of the analyzer. Most plants using this equipment have gravity drain collection tanks.

CONCLUSIONS AND RECOMMENDATIONS

- The Sentry modified DigiChem analyzer is acceptable for use to determine boron concentration under post-accident conditions. Concerning its use for normal operations, the accuracy is probably acceptable.

- If the DigiChem analyzer or Sentry modified system is used for boron determination during normal operations, results should be compared to known boron standards rather than computed solely on normality of the titrant solution. The system can be programmed to provide for such comparison.

- The primary coolant must be degassed to a low lever prior to introduction of the sample to the sample burette. This is to prevent introduction of gas bubbles in the sample stream.

- It would be desirable (but not necessary) to program the system to add a small volume of water to the rotary reaction assembly prior to addition of the sample. This will further reduce an existing low potential for release of radioactive gas to the environment.

Section 3

SUMMARY OF RESULTS - WESTINGHOUSE ANALYZER

The Westinghouse Mark V boron analyzer performed well, both at high radiation levels (3.45×10^5 R/hr) and under steady state conditions in the absence of radiation. There was an increase in fissioning count rate resulting from high level irradiation, however, the effect of this increase on accuracy of the boron analyses is not significant. With operation at radiation levels anticipated under NRC post-accident reference conditions, the accuracy achievable is equal to, or better than other methods of boron analyses available for use during post-accident conditions.

The system can be used to monitor boron concentration during normal power operations. Accuracy expected at intermediate or high level boron concentrations should be suitable for normal requirements. Determination of low-level boron concentrations would probably require a 500 or 1000 second count rate period.

No problems of any kind were experienced in operation during a test period of about 15 days total. This is a relatively short period compared with duty in a power plant, however, we believe the analyzer will work for a long time in a power plant.

BACKGROUND INFORMATION

TEST PURPOSE

Testing was performed to determine if the prototype unit of the Westinghouse Mark V boron analyzer would suffer radiation damage or reduction in accuracy when operated at radiation levels anticipated under post-accident conditions. Testing was also performed to establish reliability of the equipment when operated under normal conditions.

SYSTEM DESCRIPTION

General

The Boron Concentration Monitoring System (BCMS) Mark V is an electronuclear system that continuously measures the boron content in the primary coolant of a pressurized water reactor (PWR) power plant and digitally displays the results in parts total boron per million parts of water (ppm). In a shielded tank, a sample of the primary coolant is positioned between a neutron source and a fission chamber. Neutrons originating at the source are thermalized, then pass through the boron solution (where some are absorbed) and impinge upon the enriched uranium in the fission chamber. Fissioning occurs with the release of charged particles, resulting in voltage spikes in the fission detector that are translated into ppm boron. The charged particle population is directly proportional to the fissioning process, and therefore proportional to the neutron population. This provides a measure of the boron concentration in the water since the fissioning rate and resulting charged particle population varies inversely as does the neutron absorption characteristics of the primary coolant. The charged particle count rate is translated into ppm boron by an algorithm programmed into the system's microcomputer which accounts for non-linear response and for temperature correction. Calibration is performed by determining the count rate for three known concentrations of boron solutions and entering this information into the computer unit. The system is self-calibrating at this point. The microcomputer transmits this boron concentration data to local or remote displays.

The BCMS Mark V is comprised of three major assemblies: the sampler tank, which

detects the charged particle count rate and coolant temperature; the electronic processor enclosure, which contains the processing control and monitoring electronics for most of the system; and the remote display, which enables a remote indication of boron concentration. The sampler tank is shown in Figure 3-1, and the overall system is shown in Figure 3-2. Test equipment evaluated in this work did not include the use of a remote display unit. This equipment is not required for system operation. Also provided are an interrupt line output and serial data output which permit the processor enclosure to transmit data to the plant computer. General descriptions of the three main BCMS Mark V assemblies are given below.

Sampler Tank Assembly

The sampler tank assembly is a stainless steel cyinder, approximately 15.12 inches (38.4 cm) in diameter, 19 inches (48.3 cm) high, and weighing 100 pounds (45.3 kg), which is secured to the mounting platform by four hold-down clips. The cylinder contains polyethylene which functions as a neutron shield and moderator. The unit has two cavities, one neutron source well and one annulus assembly containing the fission detector. The neutron well is 1 inch in diameter by 7 inches deep in a high density polyethylene epoxy resin. The neutron source is provided by one curie of americium/beryllium (Am-Be). The fission detector has 2 grams of enriched uranium. The Am-Be source is in the center of the tank in a vertical cavity which is inserted on the end of a polyethylene rod. Surrounding the fission detector is a one liter stainless steel annulus assembly. Coolant flow to and from this tank is provided by 0.5 inch tubes with Swagelok fittings for connection to the plant piping.

The sampler tank assembly receives reactor coolant solutions from a sampling location such as the letdown heat exchanger or Boron Thermal Regeneration System (BTRS). Reactor coolant samples are routed to the input port of the sampler tank. A thermocouple inserted through the cover plate extends 8 inches into the polyethylene material. Sample flow through the unit is determined by the pressure drop between the inlet and outlet tube connections.

Two electrical signals are derived from the sampler tank assembly: (1) fission count rate from the fissioning detector and (2) thermocouple potential (in millivolts). Detector pulses are applied to the preamplifier in the processor enclosure via a coaxial cable attached to the detector. The thermocouple signal is applied to a digital thermometer in the processor enclosure via thermocouple wire.

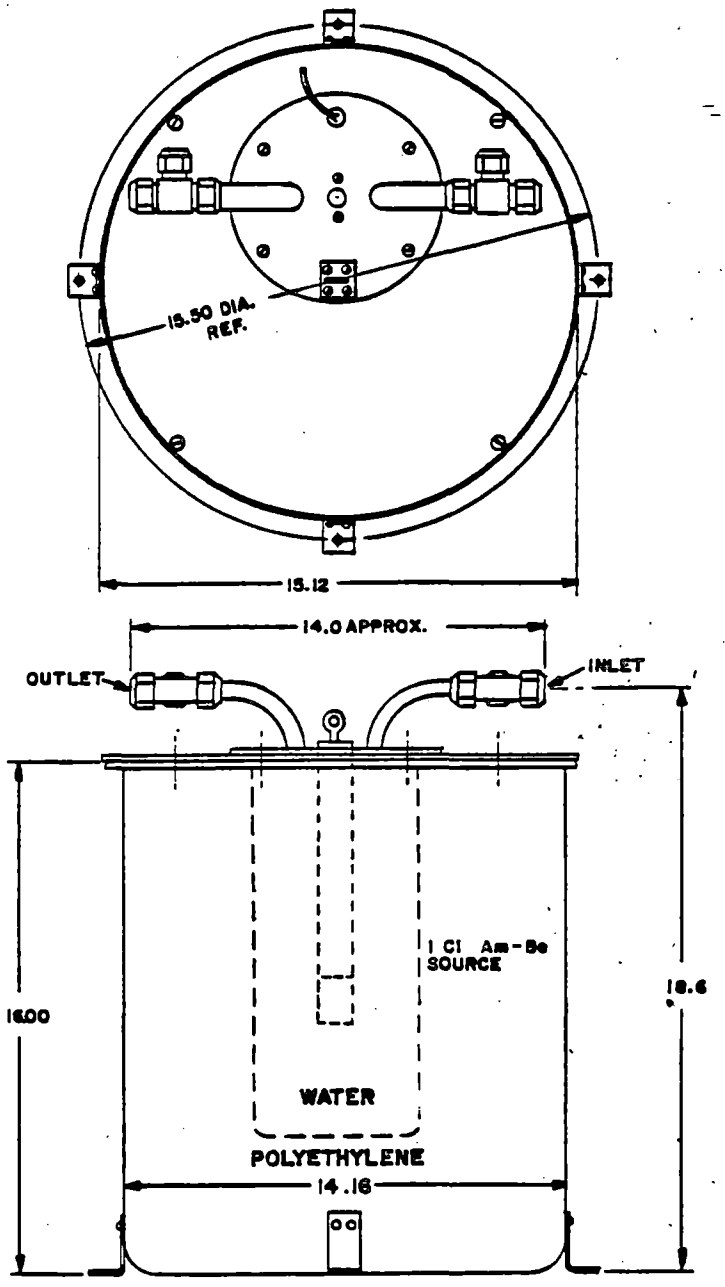


FIGURE 3-1

Ⓦ SAMPLER TANK ASSEMBLY

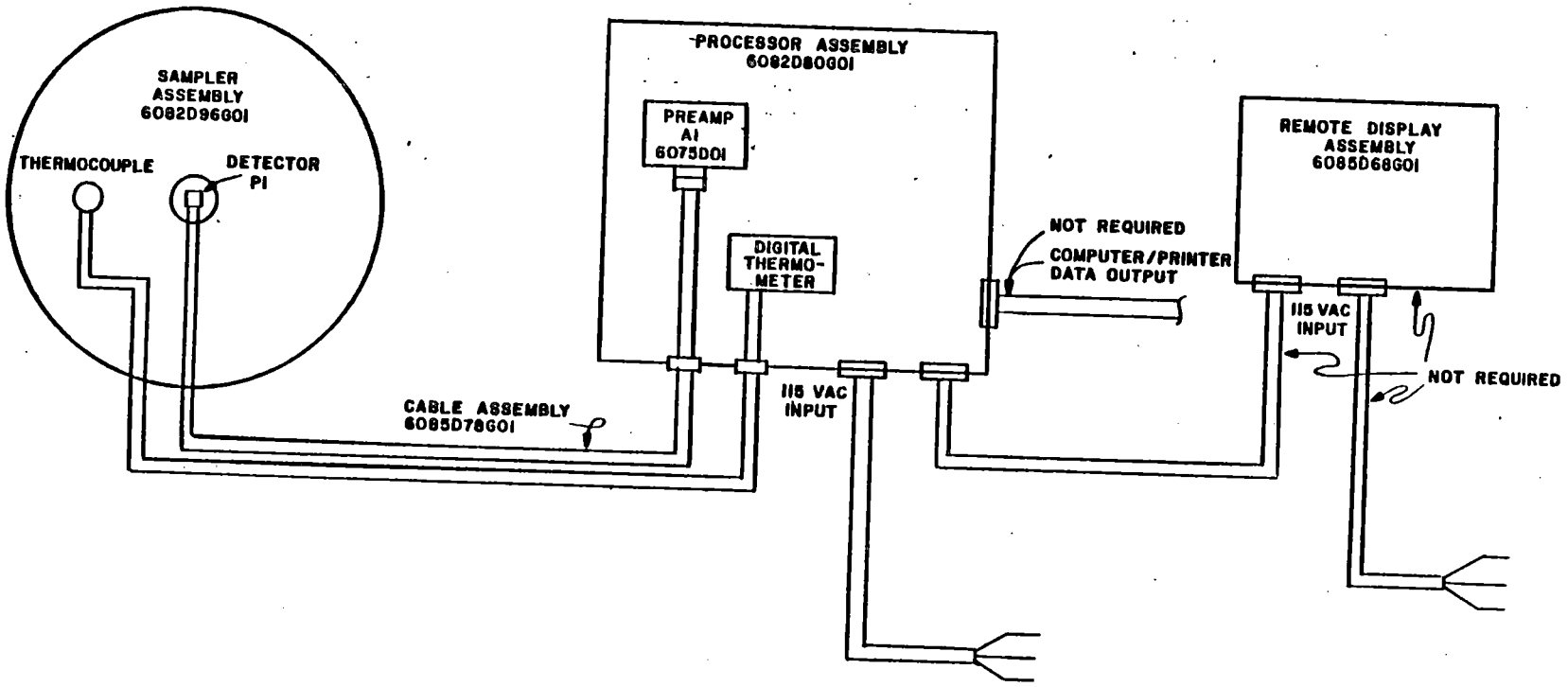


FIGURE 3-2
WESTINGHOUSE MARK V BORON ANALYZER

Processor Enclosure

The processor enclosure is a wall-mounted, louvered, NEMA 12 enclosure containing the components that control operation of the BCMS, Mark V analyzer. Operator controls and indicators are contained on the control panel which is accessed by opening the hinged front door of the cabinet. Also contained in the process enclosure is the preamplifier with bias control to discriminate against detection of noise. For maintenance and troubleshooting purposes, the control panel is hinged to allow access to the microcomputer power supplies, preamplifier, card cage, terminal boards, and test point assemblies.

The electronic processor enclosure may be located hundreds of cable feet away from the sampler tank provided the preamp is removed and located within 20 feet of the tank. It receives the fission count rate and temperature from the sampler tank assembly, processes it, displays the calculated boron concentration (in measure mode) on the local display, and serially transmits the concentration data to the remote display assembly and plant computer. The electronic processor enclosure contains a microcomputer made up of a single-board central processing unit (CPU) board, complementary metal-oxide semiconductor random-access memory (CMOS RAM) board with battery backup, and input/output (I/O) expansion board.

Remote Display Assembly

The remote display assembly displays the boron concentration in ppm at a location (usually in the control room) remote from the processor enclosure. Measuring approximately 7.75 inches wide, 4.5 inches high, 9.62 inches deep, and weighing 10 pounds, the unit can be installed up to 1000 feet from the processor enclosure.

Concentration data calculated by the processor enclosure is transmitted serially over a twisted shielded pair. The remote display assembly contains the circuits that receive, decode, and present the data on a four-digit light-emitting-diode (LED) display.

TEST DESCRIPTION

GENERAL

The irradiation testing was performed at the hot cell test facility at Georgia Tech. Testing to investigate reliability characteristics of the Mark V boron analyzer was performed at this same location. Testing to determine reproducibility of the boron analyzer was also performed at Georgia Tech.

IRRADIATION TESTING

The radiation source was provided by eight, 8 x 13 inch frame assemblies containing a total of 53,000 curies ^{60}Co (6,600 curies per frame). Radiation source from the one liter primary coolant sample tank under accident conditions will be around 40,000 curies for reactor coolant with activity of 4 Ci/cc. Radiation levels were increased or decreased by placing one or more of these frame assemblies around the sampler tank assembly as shown in Figure 3-3. The radiation level for maximum radiation testing was measured by placing a dosimeter at the detector location in a second sampler tank assembly. Geometry was held constant for the second sampler tank and the tested sampler tank assembly in the irradiation testing performed. A second tank was required to determine radiation dosage because the dosimeter was placed in the position that would have been occupied by the detector tube during irradiation testing. Testing was performed at a maximum radiation level of 3.45×10^5 R/hr, determined by dosimetry. The level of 3.45×10^5 R/hr required the use of the eight frame radiation sources that were available. A radiation level with the second sampler was determined for only this one configuration because most of the irradiation experiments were performed at the maximum achievable level. Estimated radiation levels for the Westinghouse boron analyzer for reactor coolant with an activity of 4Ci/cc are around the maximum radiation levels achieved in this test work.

The fission count rate was determined as a function of boron concentration and/or radiation level in the sampler assembly. Count rate was determined in the absence of radiation to determine a base level, followed by testing with exposure to high and intermediate radiation levels. The ^{60}Co frames were added or removed to change

GEOMETRY OF IRRADIATION ASSEMBLY
FOR Ⓦ MARK V SAMPLER TANK ASSEMBLY
53,000 Ci TOTAL RADIATION SOURCE

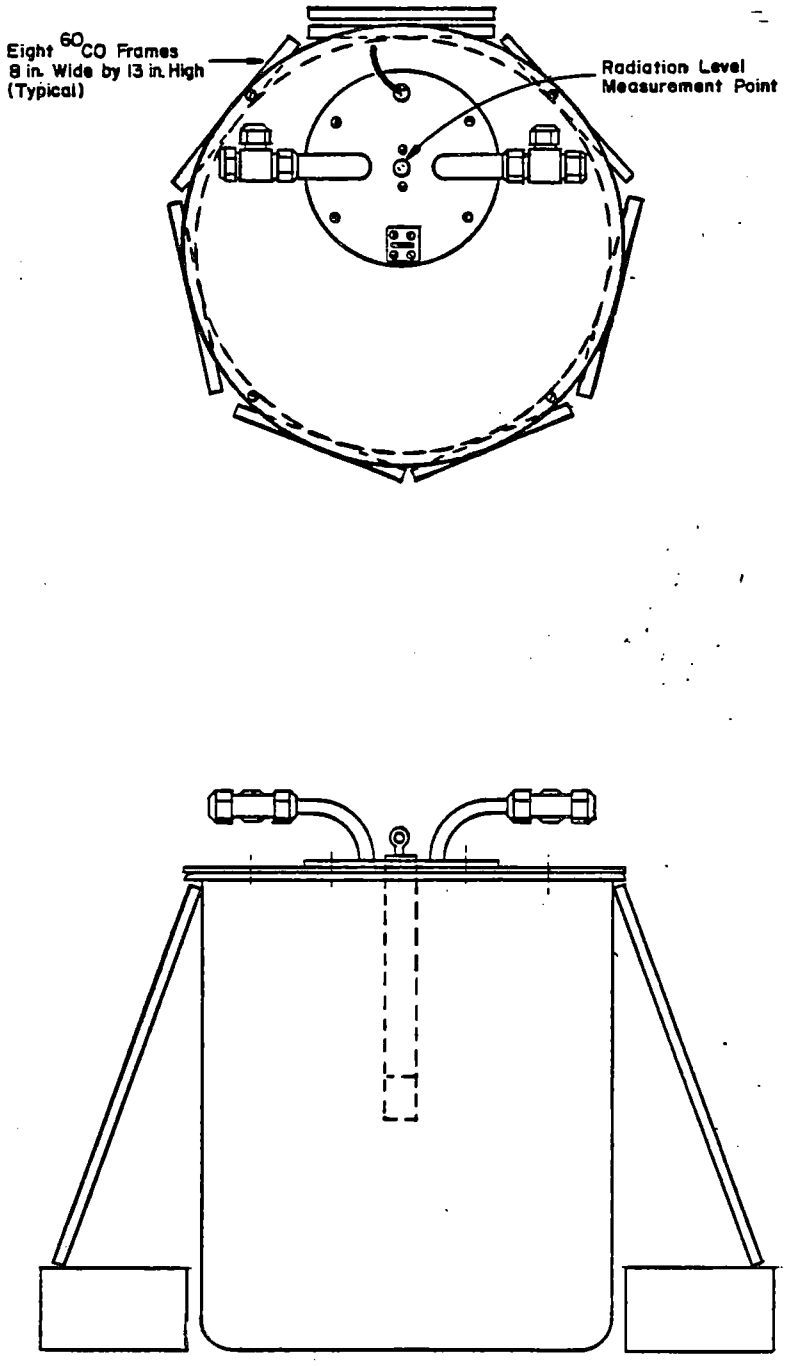


FIGURE 3-3

the radiation levels. Results are based on the fissioning rate rather than ppm readout because the main objective of this test was to determine the effect of high radiation levels on the detector equipment. Evaluation of this equipment can best be performed by monitoring the fission rate during testing under irradiation.

All testing involving radiation exposure was performed in a hot cell under no-flow conditions. The tank sampler tank was rinsed three times with the reference boron solution when concentration was changed.

TEST RESULTS

IRRADIATION TEST RESULTS

Prior to installation of the sampler assembly in the hot cell, the boron analyzer was operated overnight with pure water in the sampler tank. An average fissioning rate frequency of 476.83 counts/second was determined for the 30,000 second overnight run. This compares to an average count rate of 476.16 counts/second for a series of eighteen, 100 second count periods made prior to starting the irradiation tests. This series of 100 second count periods varied from a low of 473.56 to a high of 479.28 counts/second. The data are presented in Table 3-1.

Initial radiation under testing was performed with pure water in the sample tank. The count rate increased by almost 3 percent from an average of 474.96 counts/second to an average of 487.96 counts/second when exposed to a radiation level of 3.45×10^5 R/hr. Moving the connector cable so that is was further removed from the radiation source had no effect on count rate based on the average of 487.44 determined for six, 100 second count periods. The count rate returned to the base level obtained in the preirradiation testing when all radiation sources were removed. Data obtained from the irradiation testing performed with pure water are presented in Table 3-2.

Testing performed with 5140 ppm boron solution in the sampler tank showed the same behavior as was observed with irradiation testing performed with pure water in the tank. In the absence of radiation, the count rate for the 5140 ppm boron solution was 125.98 counts/second for a 100 second count period. This increased by about 3 percent to 129.49 counts/second when exposed to a radiation level of 3.45×10^5 R/hr (eight ^{60}Co frames). Four ^{60}Co frames were removed leaving a total of four ^{60}Co frames around the sampler assembly. This reduced the count rate from 129.49 counts/second to an average of 128.19 counts/second or about 1.5 to 2 percent above the base level obtained in the absence of radiation. The count rate returned to the original base level when all radiation sources were removed. Data obtained with the irradiation testing performed with 5140 ppm boron solution are presented in Table 3-3.

TABLE 3-1

BASE LEVEL FISSIONING COUNT RATE
FOR THE WESTINGHOUSE MARK V BORON ANALYZER
(PURE WATER RESULTS)

Run Time Sec.	Counts Per Sec.
30,000	476.83
100	474.91
100	473.83
100	475.86
100	475.71
100	473.56
100	476.89
100	474.64
100	479.28
100	478.11
100	475.82
100	476.57
100	475.43
100	474.84
100	477.36
100	479.11
100	478.61
100	475.53
100	474.95

$\bar{x}$ = 476.17
σ = ±1.73
2σ = ±3.46

TABLE 3-2

EFFECT OF IRRADIATION WITH PURE WATER
IN THE WESTINGHOUSE MARK V BORON ANALYZER

Zero Radiation			3.45×10^5 R/hr			3.45×10^5 R/hr(1)		
Run Time Sec.	Counts Per Sec.	Temp. °C	Run Time Sec.	Counts Per Sec.	Temp. °C	Run Time Sec.	Counts Per Sec.	Temp. °C
600(2)	475.69							
			100	490.93	25			
			100	491.67	25	100	487.83	26
100	474.20	23	100	486.93	25	100	488.47	26
100	476.45	23	100	487.93	25	100	485.49	26
100	475.02	23	100	487.07	25	100	490.71	26
100	474.04	23	100	485.22	26	100	488.61	26
100	474.87	23	100	485.98	26	100	483.51	27
$\bar{x}$	475			488			487	
σ	$\pm$ 0.95			2.45			2.55	
2σ	$\pm$ 1.90			4.90			5.10	

(1) The cable which connects the sampler tank to the electronic processor enclosure was moved further away from the radiation source for this test sequence. This was to determine if count rate is affected by high radiation level exposure of the cable.

(2) Not included in standard deviation.

Testing was also performed with 2570 ppm boron solution in the sample tank. The same behavior was observed as was noted with the pure water and 2570 ppm boron solutions. The count rate increased about 3 percent from 206.73 to 212.29 counts/second. These data are presented in Table 3-4.

Further testing was performed to determine if exposure of the connector cable to very high radiation levels would affect the count rate. The connector cable was clamped between two ^{60}Co frames (1/2 inch gap) to obtain exposure level estimated to be in the range of 10^6 to 10^7 R/hr. Radiation measurements made in connection with other irradiation experiments performed indicate that radiation levels between the two frames are on the order of 10^6 R/hr with 3 to 4 inches gap between the two frames. Since the actual gap was about 1/2 inch, the radiation level would be well over 10^6 R/hr. No effect on count rate was noted from this radiation level based on count rates of 206.58, 209.35, 206.96 and 206.35 counts/second over four, 100 second count periods. The base level count rate for this system (2570 ppm boron) in the absence of radiation was 206.73 counts/second. These data are consistent with the data presented in Table 3-2.

The testing performed indicates that the increase in count rate noted with the high radiation levels is an instantaneous function of radiation levels. That is, the count rate changes as soon as the radiation level increases or decreases. There is no memory effect, nor is there any indication of permanent damage suffered based on about 2×10^7 rads total exposure to the sampler assembly. This is equivalent to over 25 hours operation with an activity level of 4 Ci/cc in the primary coolant.

RELIABILITY TEST RESULTS

After the irradiation testing was complete, the Mark V boron analyzer was operated under steady state conditions for a period of 13 days. This was done in the absence of radiation with 2570 ppm of boron in the sample tank. Initially, data were taken every half hour during the course of an eight hour day. Later, the data were taken on an hourly basis or sometimes on a daily basis. This data is shown in Table 3-5.

The Westinghouse equipment operated very well during the reliability testing. There were no outages or system malfunctions of any kind during this test period. Unfortunately, the data recorded in Table 3-5 represent 1 second count periods rather than the 100 second or 1000 second data intended. However. since the standard deviation is proportional to $\frac{1}{n}$, n being the number of samples, we can infer a standard deviation for 100 second and 1000 second counting intervals of 1.02 and 0.32 respectively.

TABLE 3-3

EFFECT OF IRRADIATION WITH 5140 ppm
IN THE WESTINGHOUSE MARK V BORON ANALYZER

Zero Radiation			3.45×10^5 R/hr			2×10^5 R/hr(1)		
Run Time Sec.	Counts Per Sec.	Temp. °C	Run Time Sec.	Counts Per Sec.	Temp. °C	Run Time Sec.	Counts Per Sec.	Temp. °C
600(2)	125.97	32						
			100	130.20	29			
			100	127.79	30			
			100	129.87	30	100	128.85	31
100	125.16	32	100	128.90	30	100	127.68	31
100	124.19	32	100	130.51	30	100	129.86	31
100	126.96	32	100	129.38	30	100	127.27	31
100	127.02	32	100	129.19	30	100	127.92	31-32
100	125.63	32	100	128.99	30	100	127.34	32
100	125.68	32	100	129.83	31	100	128.39	32
100	125.58	32	100	130.25	31	100	128.26	32
$\bar{x}$	126			129			128	
σ	$\pm$ 0.99			1.62			1.72	
2σ	$\pm$ 1.98			3.24			3.44	

(1) Estimated radiation level of 2×10^5 R/hr
(2) Not included in standard deviation.

TABLE 3-4

EFFECT OF IRRADIATION WITH 2570 PPM BORON
IN THE WESTINGHOUSE MARK V BORON ANALYZER

Zero Radiation			3.45×10^5 R/hr		
Run Time Sec.	Counts Per Sec.	Temp. °C	Run Time Sec.	Counts Per Sec.	Temp. °C
600(1)	207.02	32	600(1)	213.20	32
			100	212.83	32
			100	212.72	32
100	206.87	32	100	213.28	32
100	205.97	32	100	211.99	32
100	205.61	32	100	213.25	32
$\bar{x}$	206			213	
σ	$\pm$ 0.65			0.49	
2σ	$\pm$ 1.30			0.98	

(1) Not included in standard deviation.

TABLE 3-5

STEADY STATE OPERATION FOR 1 SECOND COUNT PERIODS WITH 2570 PPM BORON IN THE WESTINGHOUSE MARK V ANALYZER (BACKGROUND RADIATION)

8-28-81		(1) 8-31-81		9-1-81		9-2-81		9-3-81		9-4-81	
Counts Per Sec.	Temp. °C	Counts Per Sec.	Temp. °C	Counts Per Sec.	Temp. °C	Counts Per Sec.	Temp. °C	Counts Per Sec.	Temp. °C	Counts Per Sec.	Temp. °C
				211	23						
				200	23						
226	24			221	24						
205	23			206	24						
199	23			204	24	202	23				
204	24	228	23	202	23	197	23	217	23		
197	24	215	23	191	24	190	24	204	24		
214	24	219	23	209	24	213	24	212	24		
226	24	217	23	218	24	222	24	198	24	215	24
213	24	207	23	203	23	198	24	209	24	205	24
200	24	214	23	207	24	206	24	215	24	221	24
196	24	201	23	218	24	211	24	214	24	217	24
195	24	210	23	213	24	202	24	200	24	203	24
210	24	219	24	200	24	199	24	191	24	197	24
199	24	215	24	198	24	189	24	204	24	212	24
233	24	201	23	205	24	207	24	202	24	209	24
187	24	209	24	217	24	217	24	196	24	191	24
193	24	214	24	193	24	190	24	194	24	213	24
212	24	212	24	186	24	206	24	196	24	215	24
208	24	208	24	180	24	211	24	199	24	205	24
206	24	217	24	190	24	209	24	211	24	193	24

Total Counts = 102
$\bar{x}$ = 206.16
σ = 10.16

(1) The system was operated, however, there was no data taken over the weekend.

DISCUSSION OF RESULTS AND CONCLUSIONS

DISCUSSION

Results of the irradiation tests indicate that the Westinghouse Mark V boron analyzer would perform well under post-accident conditions. Count rate increases, and thus the ppm boron readout decreases with increasing radiations levels, however, the effect is a predictable one. For exposure levels in the range of 2 x 10^5 R/hr and 3.45 x 10^5 R/hr (maximum achievable radiation level) the fissioning count rate increases by about 1.5 percent and 3 percent, respectively. Linear extrapolation of this data indicates that the fissioning count rate would increase by about 5 percent for a radiation field of 5 x 10^5 R/hr. Extrapolation is based on results of other irradiation tests which indicate a linear relationship to radiation levels of 7.1 x 10^5 R/hr. A radiation level of 5 x 10^5 R/hr is anticipated in the Westinghouse Mark V analyzer with a primary coolant activity of 10 Ci per cc.

An increase in count rate resulting from high radiation levels will not give an equivalent percent decrease in apparent boron concentration. The change in boron indication will be slightly less than the percent change in count rate. Even assuming a linear relationship between change and count rate and decrease in indicated boron concentration, the accuracy of this instrument is equivalent to, or better than the accuracy that can be achieved with other methods of on-line or wet-chemical analyses available for use during accident conditions. Consequently, no corrective factor would need be applied to results of this analyzer during operation in a high radiation environment.

The temperature correction system was not operated during this work. However, temperature was not a factor in the results since temperature did not vary by more than a few degrees in any one test. The intent was to determine the relative change that may result from high radiation levels rather than measure absolute values. Testing performed with the Combustion Engineering Boronometer indicate that a 5-10 degree change in temperature has no significant effect on count rate.

It is of interest that the increase in count rate resulting from irradiation effects is essentially a constant (as percent of count rate)

It is of interest that the increase in count rate resulting from irradiation effects is essentially a constant (as percent of count rate) for the three conditions tested (pure water, 2570 and 5140 ppm boron).

The data indicate that the standard deviation for boron concentration is acceptable with respect to post-accident or normal conditions. High radiation levels have no significant effect on deviation as indicated below:

Boron Concentration mg/l	Standard Deviation No Radiation 100 Sec Count		1000 Sec Count		Standard Deviation 100 Sec. Count 3.45×10^5 R/hr		2×10^5 R/hr	
	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ	$\bar{x}$	σ
0	476	1.73	-	-	-	-	-	-
0	475	0.95	-	-	488	2.45	-	-
0	-	-	-	-	487	2.55	-	-
2500	206	0.65	-	-	213	0.49	-	-
2500	206	1.02	206	0.32				
5000	126	0.99	-	-	129	0.81	128	0.86

CONCLUSIONS AND RECOMMENDATIONS

- The Westinghouse Mark V boron analyzer is acceptable for use under post-accident conditions. It should be possible to obtain an analysis within 5 or 10 minutes with this system. Concerning its use for normal power operations, the accuracy is probably acceptable.

- Count rate increases, and thus the ppm boron readout decreases with increasing radiation levels, however, the effect is a predictable one and accuracy is still quite acceptable.

- For maximum anticipated exposure levels of 5×10^5 R/hr (10 Ci/cc activity level), the fissioning count rate will increase by about 5 percent. This 5 percent increase in count rate will result in a small error relative to the accuracy required for post-accident conditions.

- The increase in count rate from irradiation is essentially a constant (as percent of count rate) for the three conditions tested (pure water, 2570 and 5140 ppm boron). The increased count rate does not linger when the radiation field is removed.

Section 4

SUMMARY OF RESULTS - CE BORONOMETER

The Combustion Engineering (CE) boronometer performed well, both at radiation levels of 10^6 R/hr and under steady state conditions in the absence of radiation. A 53,000 curie ^{60}Co radiation source was used to achieve the 10^6 R/Hr levels in the high radiation level test work. The boronometer operated at integrated dose of about 2×10^7 rads. This corresponds to 20 hours of operation at maximum radiation levels anticipated under radiation conditions. It is expected that the system would remain operational at higher exposure levels based on known characteristics of the system. However, prudent considerations would dictate that radiation exposure be minimized by flushing the sample vessel when the required boron concentration information has been obtained during post-accident conditions.

The system can also be used to monitor boron concentration during normal power operations. The instrument provides readout of the fission rate of the enriched uranium in the fission chambers. Fission rate is inversely proportional to the boron concentration in the sample tank surrounding the neutron source. The boron concentration is derived from the fission count rate by a mathematical curve fitting routine performed by a microcomputer. Use of the boronometer would not eliminate the need for periodic check analyses performed using the boron-mannitol titration. However, it would provide a continuing check against sudden changes in boron concentration and would reduce exposure to personnel.

BACKGROUND INFORMATION

TEST PURPOSE

Testing was performed to determine if the CE boronometer would suffer radiation damage or reduction in accuracy when operated at radiation levels anticipated under post-accident conditions. Testing was also performed to establish accuracy and reliability of the equipment when operated under conditions as anticipated during normal operations. Testing was performed on a preproduction model in the latter stages of development.

SYSTEM DESCRIPTION

General

The boronometer consists of a sampler, preamplifier and signal processor. The system used in this test included a strip chart recorder. This is not part of the normal equipment package, however, its use is recommended to improve statistics and show trending. Performance specifications for these components are listed in Tables 4-1, 4-2 and 4-3. Schematic design of the sampler which contains the neutron source and fission chambers is shown in Figure 4-1. Only those components shown in this figure are in the high radiation field. Overall schematic system design is shown in Figure 4-2. Predicted delay time due to mixing is shown in Figure 4-3.

Operation of the boronometer is based on the principle of neutron absorption by ^{10}B. A small flow of primary coolant containing boron passes through a tank which holds an americium-beryllium source in the center of the tank. Neutrons from this source are thermalized and pass through the primary coolant to cause fissioning of the 93 percent enriched uranium contained in the four fission chambers. Location of the fission chambers relative to the neutron source is shown in Figure 4-1. The counting rate of the fission chambers is inversely proportional to the ^{10}B concentration in the primary coolant, due to the neutron absorption characteristics of ^{10}B. Signals from the fission chambers (neutron detectors) are accepted by the preamplifier box which amplifies and transmits the signals to the signal processor.

TABLE 4-1

PERFORMANCE SPECIFICATIONS FOR THE BORONOMETER

Neutron Detectors	Four fission chamber neutron detectors
Thermistor	Contains one thermistor for temperature compensation control
Pressure Drop	0.04 psid at 1.0 GPM, 0.01 psid at 0.5 GPM, 0.0004 psid at 0.1 GPM
Construction	Designed to ASME B31.1 power piping code, rated at 200 psig and 250°F. All wetted parts are 300 series austenitic stainless steel. Standard inlet and outlet connection are 1/2 inch, Schedule 40 butt weld.
Volume	0.9 gallon
Dimensions	Approximately 12 inches in diameter and 19 inches high.
Weight	Approximately 35 pounds
Neutron Source	2 curie AmBe, double encapsulated, with source handling tool, DOT approved shipping container and vessel padlock.
Ambient Operating Temperature Range	40 to 250°F
Finish	The sampler is constructed of 300 series stainless steel. No finish is applied.

TABLE 4-2

PERFORMANCE SPECIFICATIONS FOR THE BORONOMETER PREAMPLIFIER

POWER REQURIED	
Low Voltage ± 15 VDC	100 mAmps
High Voltage. maximum	800 Volts
MAXIMUM RATINGS	
Preamplifier Operating Temperature	122°F
Pressure	70 psig
Relative Humidity	95%
High Voltage	+ 800 Volts
Maximum Output Signal Cable Length	500 feet
TYPICAL CHARACTERISTICS	
Conversion Gain Input	800 mV/pC
Rise Time each Input (maximum)	50 nSec
Fall Time each Input	200 nSec
Equivalent Noise Charge	2.5×10^{-15} C (rms)
High Voltage in Leakage Current (maximum)	1.4×10^{-4} Amps
Enclosure	All electronics are contained in a 14 gauge steel 20 X 20 X 8 inch NEMA 4 box. The box is finished in gray enamel over phosphatized surfaces.
Cabling to Signal Processor	1 - RG-59/u 1 - 3 conductor No. 16 AWG 1 - 8 conductor No. 16 AWG consisting of four twisted shielded pairs.

TABLE 4-3

PEFORMANCE SPECIFICATIONS FOR THE BORONOMETER SIGNAL PROCESSOR

Digital Displays	Sample Temperature - °F Detector Count Rate - counts/second Boron Concentration - ppm natural Boron
Analog Outputs	One of the following: 4-20 ma into 0-600 ohms 1-5 ma into 0-2400 ohms 10-50 ma into 0-200 ohms 0 to 10 VDC into 500 ohms Full scale for the above signals can be switched to either 3,000 or 6,000 ppm.
Alarms	High and low alarms, front panel adjustable with indicator lights. Each alarm utilizies a relay with SPDT contacts rated at .1 amp at 120 VAC. Relays deenergized on alarm.
Digital Output	Serial, teletype compatible
Front Panel	The front panel is brushed aluminum with a clear anodized finish.
Ambient Operating	40 to 122°F Temperature
Dimensions	8-3/4" H X 19" W X 16" D, designed for 19" rack mounting
Weight	35 pounds

FIGURE 4-1

SAMPLER FOR THE CE BORONOMETER

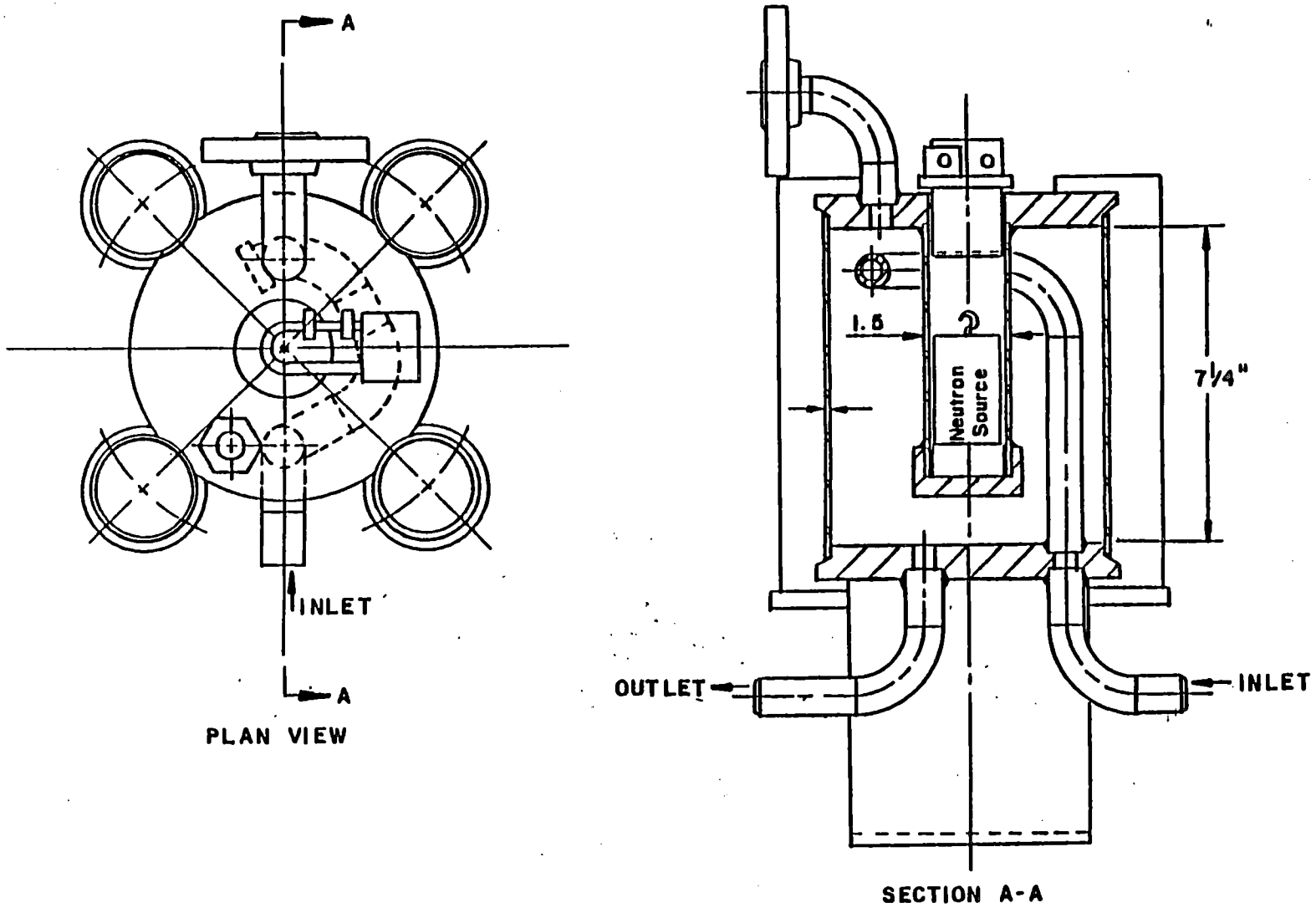


FIGURE 4-2

CE BORONOMETER

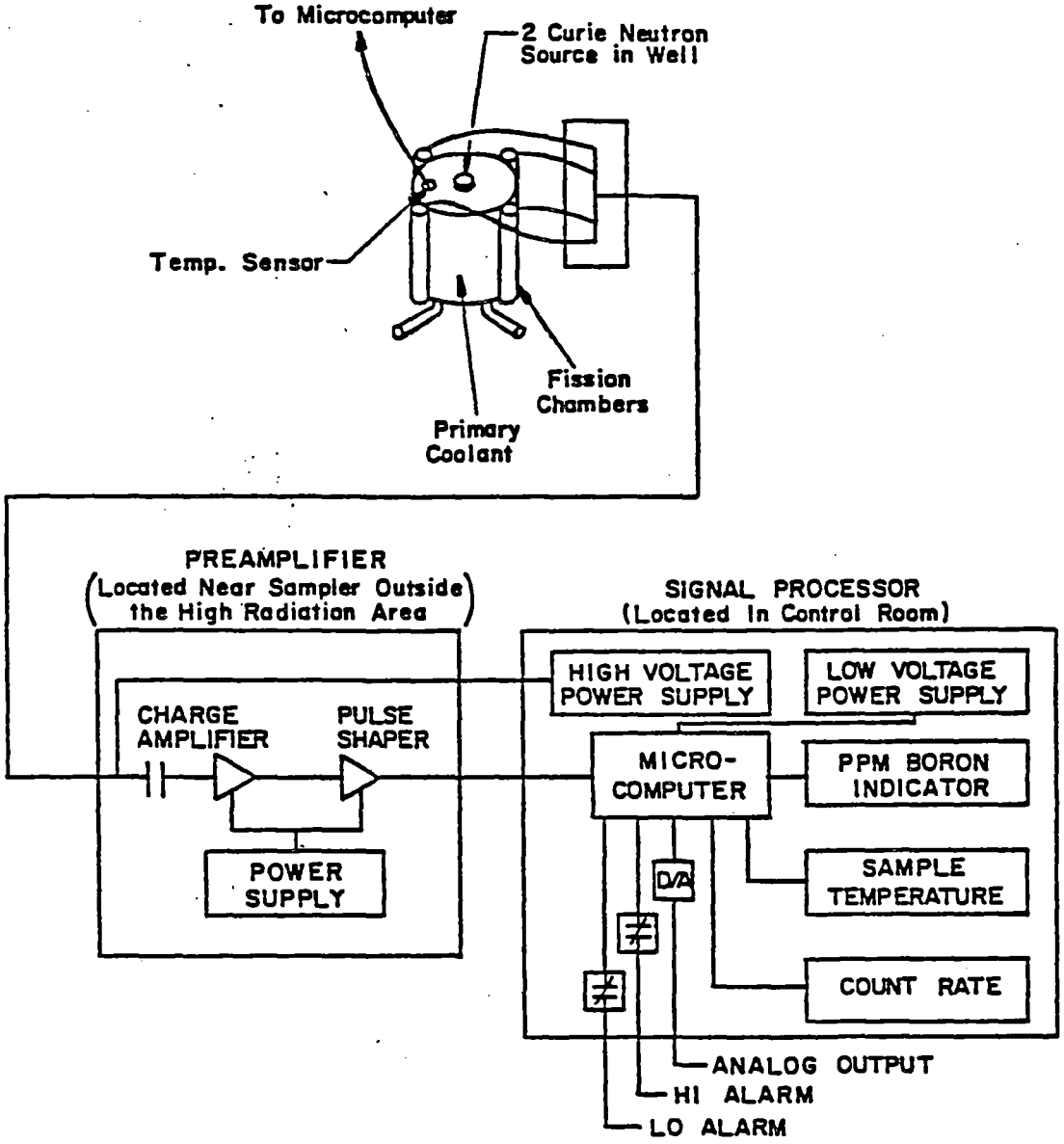
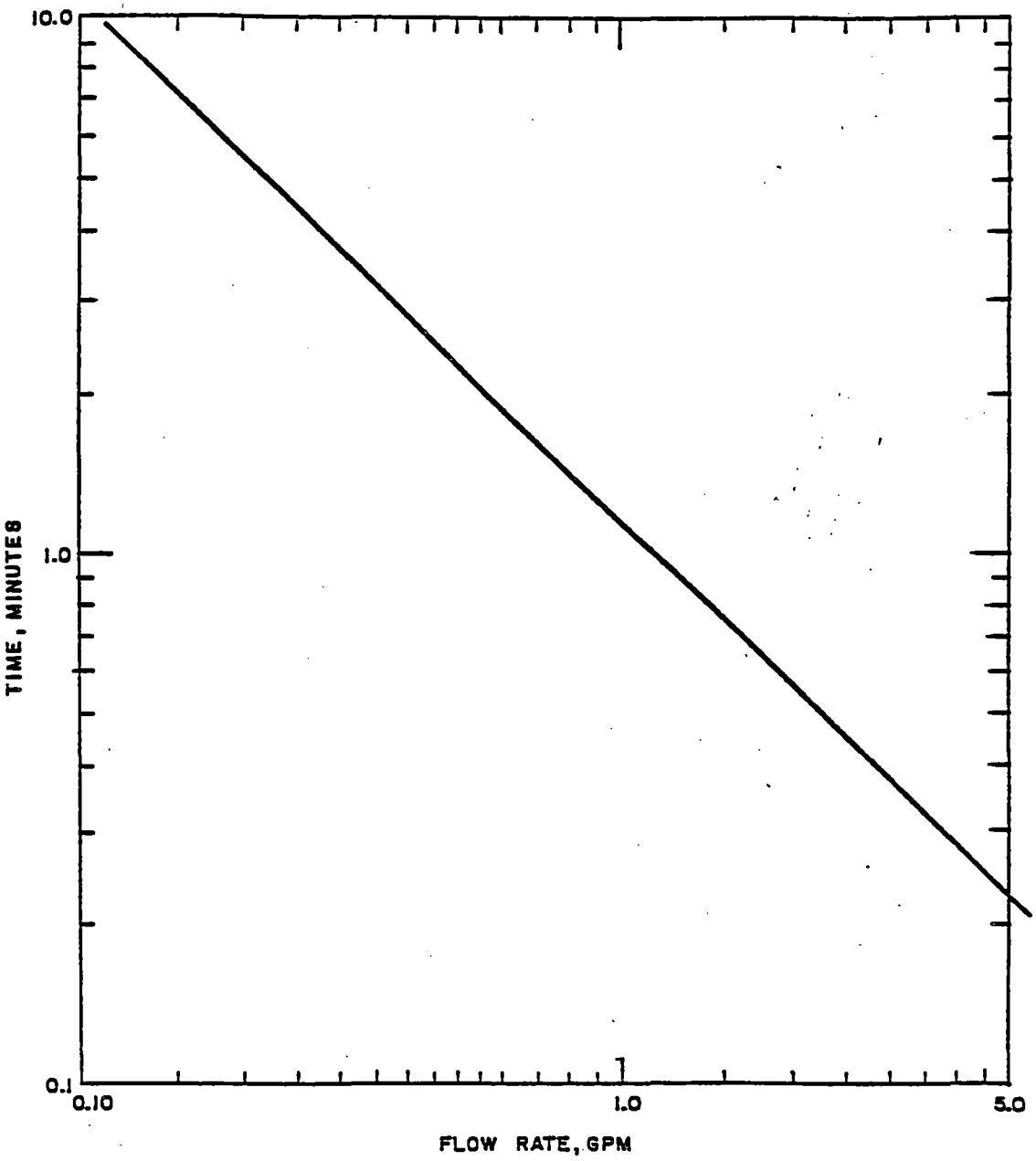


FIGURE 4-3

PREDICTED DELAY TIME DUE TO MIXING
FOR THE CE BORONOMETER



The preamplifier is located remotely outside the high radiation area. The signal processor continuously monitors the signal rate, and through an algorithm stored in a microcomputer in the instrument, converts the count rate to parts per million of boron. Count rates are normally averaged over a time period which can be adjusted over the range of 1 to 999 seconds.

TEST DESCRIPTION

GENERAL

The irradiation testing was performed at the hot cell test facility at Georgia Tech. Testing to investigate reliability characteristics of the boronometer was performed at this same location. No radiation exposure was involved with the reliability testing. Testing to determine accuracy and reproducibility of the boronometer was performed at the CE test facility and witnessed by NUS. Check analyses of the boronometer results was performed by CE and NUS using a boron-mannitol titration to determine boron concentration.

IRRADIATION TESTING

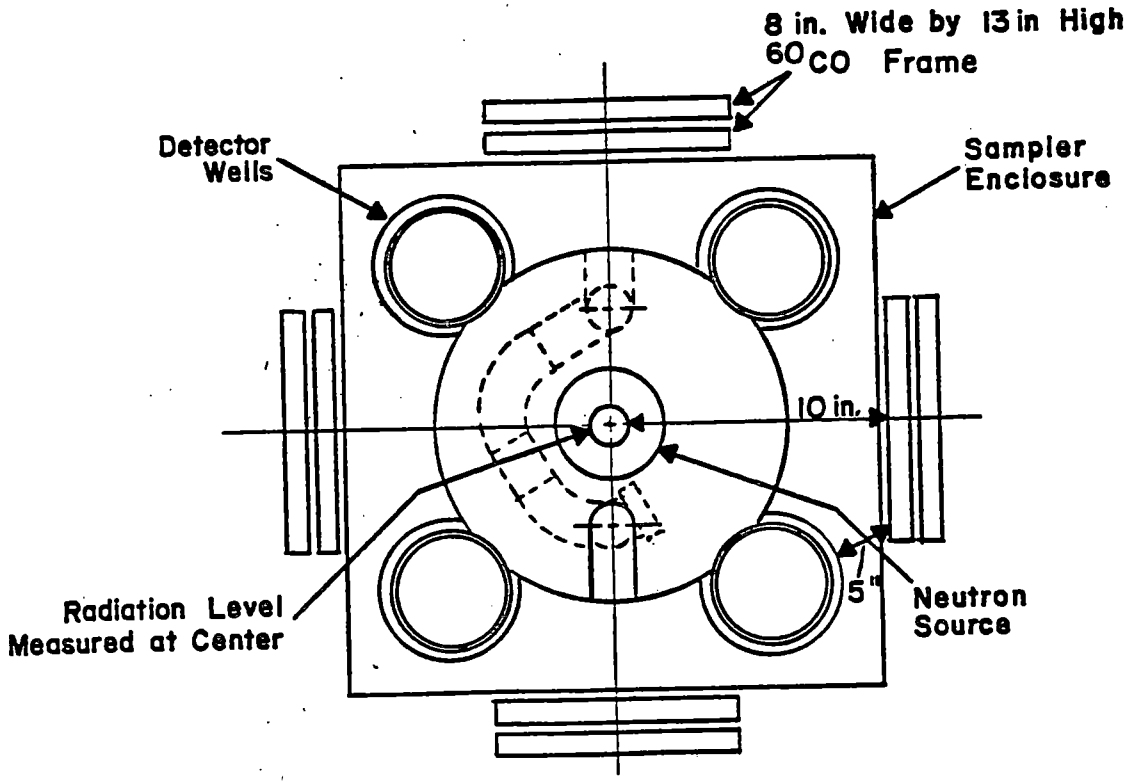
The radiation source was provided by eight, 8 X 13 inch frame assemblies containing a total of 53,000 curies ^{60}Co (6,600 curies per frame). Radiation levels desired were achieved by placing one or more of these frame assemblies around the sampler assembly as shown in Figure 4-4. Radiation levels were measured with dosimetry at the center of the assembly at a point just above the neutron source and estimated elsewhere. Testing was performed at an estimated maximum radiation level of 1×10^6 R/hr at the detector tubes. Maximum radiation levels at the center reference point as determined by dosimetry were 7.1×10^5 R/hr. The detector tubes were several inches closer to the radiation source than the central reference point, therefore are in a higher radiation level area than is the reference point.

The fission count rate was determined as a function of boron concentration and/or radiation level in the sampler assembly. Count rate was determined in the absence of radiation to determine a base level, followed by testing with exposure to low, intermediate and high radiation levels.

All testing involved radiation exposure was performed in a hot cell under loop flow conditions. Only the sampler assembly was exposed to the radiation source. The remainder of the equipment which includes the preamplifier and the signal processor were installed outside the hot cell. This is the manner in which the equipment would be installed for post-accident or normal operation.

FIGURE 4-4

GEOMETRY OF IRRADIATION ASSEMBLY
FOR BORONOMETER SAMPLER
53,000 Ci TOTAL RADIATION SOURCE



RELIABILITY AND ACCURACY TESTING

In the reliability testing, a boron solution was circulated through the boronometer for a period of seven days while monitoring the fission count rate. This work was performed under normal background radiation levels. Accuracy testing under loop flow conditions was performed at CE using boron solutions containing about 100, 600, 1,800, 3,200 and 5,000 ppm boron.

TEST RESULTS

IRRADIATION TEST RESULTS

Note that the radiation levels noted are measured at the center reference point. Actual radiation levels at the detector tubes which were affected by this radiation, were about 25 to 50 percent higher than the reference point measurements.

Typical results for the fission count rate as a function of boron concentration and radiation levels for discriminator settings of 50 and 60 millivolts are presented in Table 4-4. The results indicate that virtually total discrimination against radiation noise can be achieved. There is no memory effect nor is there any indication of permanent damage based on about 2×10^7 rads total exposure to the detector tubes. This is above the exposure levels anticipated under post-accident conditions.

RELIABILITY TEST RESULTS

After the irradiation testing was complete, the boronometer was operated under steady state conditions for a period of seven days. Water containing about 2,960 ppm boron was circulated through the sampler and the fission count rate was recorded on a strip chart recorder. Some noise pickup was evident as is shown in Figure 4-5, demonstrating results of a one day run over this period. However, the system was found to be completely free of noise when the development model preamplifier was replaced with a production model preamplifier.

ACCURACY TEST RESULTS

The boronometer test results for low level boron concentrations are presented in Table 4-5. Note that the data are presented in terms of ppm boron for an approximate curve fit that was used when the data was recorded. This curve has been refined subsequent to the testing reported here to provide the proper ppm indication. Accuracy results for high level boron concentrations are presented in Table 4-6. The deviation from results indicated are acceptable for post-accident analyses.

TABLE 4-4

FISSION COUNT RATE(1) AS A FUNCTION OF RADIATION LEVELS
FOR A 50 AND 60 M.V. DISCRIMINATOR SETTING ON THE
CUSTOM DESIGNED PREAMPLIFIER WL-24038 (2,960 PPM BORON CONCENTRATION)

	50 M.V. Discriminator Setting				60 M.V. Discriminator Setting				
	Background Radiation	2×10^5 R/Hr(2)	4×10^5 R/Hr(2)	7.1×10^5 R/Hr(2)	Background Radiation	2×10^5 R/Hr(2)	4×10^5 R/Hr(2)	6×10^5 R/Hr(2)	7.1×10^5 R/Hr(2)
	208	210	210	204	124	120	120	119	110
	214	214	211	219	121	121	121	121	111
	210	211	214	218	121	124	120	119	114
	209	212	214	225	120	121	119	120	115
	211			205	122	118			118
						120			
Average $\bar{x}$	210	212	212	214	121	121	120	120	114
σ	± 2.3	1.7	2.1	9.3	1.7	2.0	.8	.9	3.2
2σ	± 4.6	3.4	4.2	18.6	3.4	4.0	1.6	1.8	6.4

(1) 100 second time interval
(2) Radiation levels at the detector tubes were higher by an estimated value of 25 to 50 percent than indicated here.

TABLE 4-5

BORONOMETER ACCURACY RESULTS FOR LOW LEVEL BORON CONCENTRATIONS

99 ppm Boron[1]			620 ppm Boron[1]		
Count Period Seconds	Count Rate[2]	PPM Display	Count Period Seconds	Count Rate[2]	PPM Display
			100	278	504
			100	275	603
			100	275	653
100	314	89	100	275	679
100	315	68	100	275	697
100	314	56	100	275	688
100	310	76	100	274	690
100	314	72	100	274	710
100	311	77	100	275	697
100	314	61	500	275	684
100	315	58	500	275	695
100	310	74	500	278	671
500	314	70	500	278	667
500	314	71	$\bar{x}$	275	664
500	315	62	σ ±	1.5	55.2
500	314	65	2σ ±	3.0	110.4
$\bar{x}$	313	69			
σ ±	1.8	9.0			
2σ ±	3.6	18.0			

(1) As determined by chemical analyses
(2) Combined count rate from four fission chambers

At the conclusion of the test, the boronometer was operated briefly while increasing temperature of the solution from 80°F to 117°F. In the half hour testing performed, there was no change in ppm readout beyond the spread noted when temperature was controlled at 80°F. Admittedly, this was a very brief test period, yet it does indicate that minor fluctuation in temperature will have little if any effect on boron readout.

The CE wide range boronometer with BF_3 detectors was also tested by KWU in Germany at GKN for a period of about eight months. They reported that the "measured values, compared to other chemical measurement and evaluation methods were within the specified accuracy of $\pm$ one percent (+5 mg/l)." They further recommended the boronometer for use at the KWU site.

The advantages of operating a boronometer for determining boron concentration during post-accident conditions are as follows:

- All operations can be performed remotely. The exposure involved for determining boron concentration would approach zero.
- No chemicals are added to the sample. Sample flow can be pumped back to the primary system reducing the load on the radwaste system.
- It provides a direct measure of boron-10 or neutron poison concentration in the system.
- The system is sealed, thus preventing release of gaseous activity to the environment.
- Analyses results can probably be achieved within a matter of 15 to 30 minutes dependent on flow rate through the sampler.

The disadvantages of operating a boronometer during post-accident conditions as follows:

- The sampler system would have to be shielded since a relatively large volume of coolant is required. About 15,000 curies of activity would need to be transported outside the primary containment to operate this system.
- The system has not been proven under long-term use. However, there is not reason to assume that it would not be reliable. Individual components within the system are off-the-shelf items. Most of the electronics are identical to those used on CE's wide range boronometer and CE has been shipping these units since 1977.

TABLE 4-6

BORONOMETER ACCURACY RESULTS FOR HIGH LEVEL BORON CONCENTRATIONS

1825 ppm Boron[1]				2904 ppm Boron[1]				4928 ppm			
		Boron (±)									
Period Seconds	Count Rate	PPM	Count Display[2]	Period Seconds	Count Rate	PPM	Count Display[2]	Period Seconds	Count Rate	PPM	Count Display[2]
100	234		1921	100	215		2996	100	191		5309
100	234		1915	100	215		2946	100	191		5317
100	234		1921	100	218		2844	100	190		5394
100	235		1904	100	215		2912	100	195		5004
100	234		1861	100	214		2901	100	194		5001
100	231		1899	100	215		2917	100	194		5005
100	234		1897	100	215		2944	100	191		5033
100	234		1915	100	215		2937	100	195		4968
500	234		1915	100	215		2958	100	194		5217
500	230		1951	100	215		2908	100	194		5101
500	231		1944	100	215		2884	100	190		4954
$\bar{x}$	233		1913	100	211		2981	100	194		4951
σ	± 1.7		24.0	100	214		2934	100	194		4864
2σ	± 3.4		48 0	100	215		2943	100	195		4834
				100	211		3012	100	194		4875
				500	215		2991	100	191		4999
				500	214		3016	100	195		4921
				$\bar{x}$	215		2943	500	194		5077
				σ	± 1 6		46.7	500	194		5045
				2σ	± 3 2		93.4	500	191		
									5046		
								$\bar{x}$	193		5046
								σ	± 1.8		154.1
								2σ	± 3.6		308.2

(1) As determined by chemical analyses (2) Combined count rate from four fission chambers

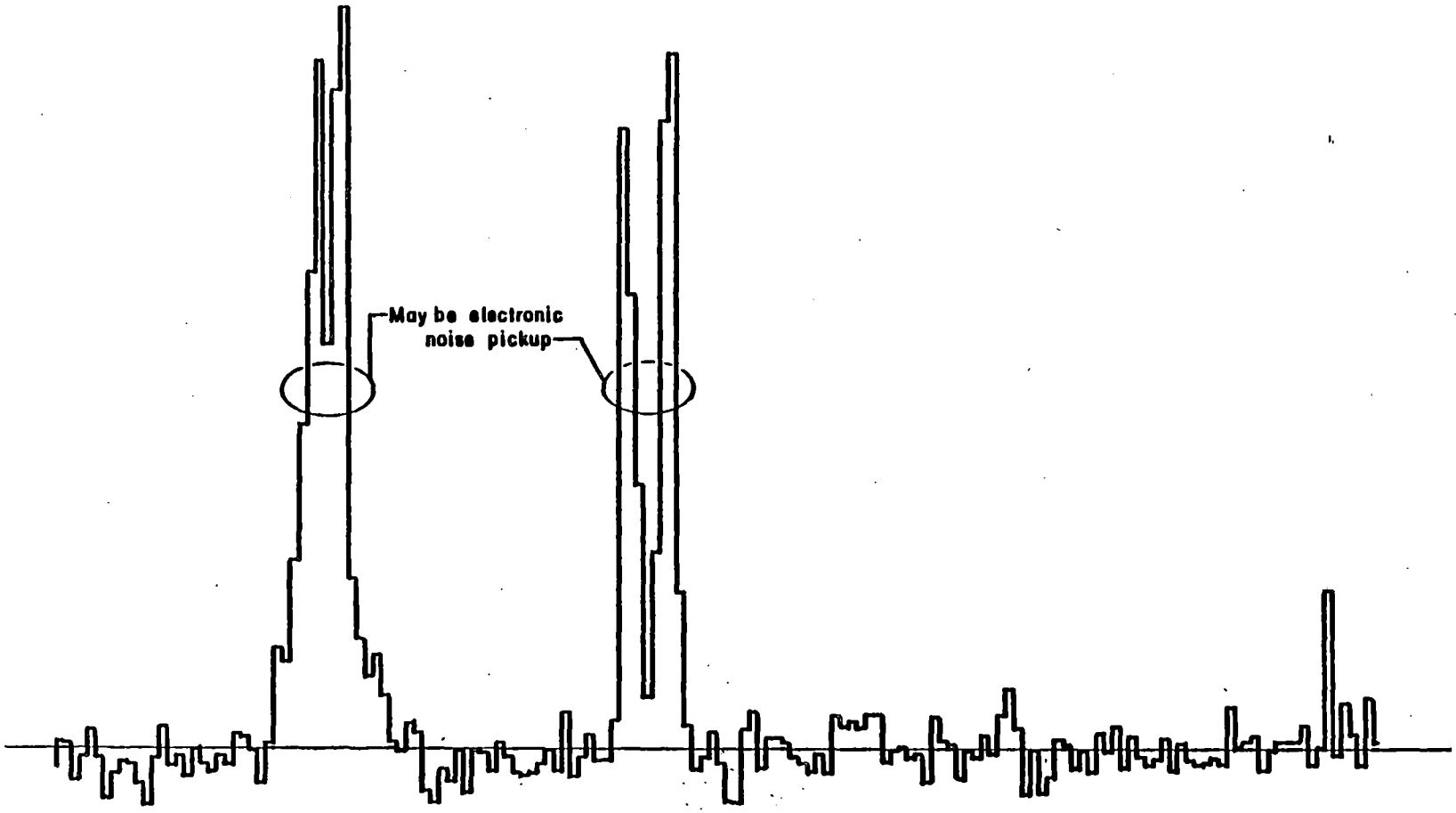


FIGURE 4-5
ONE DAY STRIP CHART RECORDING
OF 2960 ppm BORONOMETER ANALYSES RESULTS
(Background Radiation)

CONCLUSIONS AND RECOMMENDATIONS

- The CE Boronmeter is acceptable for use under post-accident conditons.
- Reproducibility of results is excellent as based on fission count rate, however, conversion of count rate to ppm is somewhat below the accuracy desired for daily operations. CE indicates, however, that the proper curve fit routine in the microcomputer will provide proper ppm indication.
- A 500 second count rate is recommended for determining boron concentrations below 1,000 ppm.
- The use of strip chart recorder is recommended for use with the boronometer. This will improve statistics and show trending.
- There is some increase in the standard deviation (Table 4-4) from radiation levels in the range of 10^6 R/Hr at the planned discriminator setting of 50 millivolts. The increase is not significant with respect to post-accident analyses requirements.