B-10 ANALYSIS

By W. E. Holland

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Final Report
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B-10 ANALYSIS

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Prepared by W. E. Holland

A method was developed to determine if boron-loaded polymeric material contained enriched boron or natural boron. A prototype analyzer was constructed, and initial planning was done for an actual analysis facility.

DC/drb

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SUMMARY

To assist in reclaiming boron from parts of boron-loaded polymers, a means of determining whether the boron was enriched boron (approximately 90 weight percent ^{10}B) or natural boron was needed. The two can be distinguished in liquid samples by neutron absorption;¹ however, having to liquify the samples would have created additional administrative problems. It is also known that enriched boron can be distinguished in parts much larger than the required size.

The staff at the University of Missouri Research Reactor Facility (MURR) was contacted by the project team from Bendix, and a consultation contract was initiated. The staff at MURR agreed to brainstorm methods of distinguishing enriched or natural boron loading. The MURR report listed nine methods; however, because of the unique Bendix requirements, only two of the methods were suitable. These two methods were studied in greater detail before one was dropped from consideration because suitable research instrumentation was not available. The remaining method, neutron absorption with epithermal neutrons, was studied further.

Known absorption properties of boron were used to calculate the neutron transmission of various thicknesses of boron-loaded polymer. It was determined that neutrons in the energy range of 10 to 1000 eV gave the best discrimination for the thicker samples. Neutrons in the energy range of 1 to 100 eV gave the best results for thinner samples. Laboratory experiments were performed to design a collimator which could produce a beam of neutrons with the correct energy range. A prototype gauge was constructed, but the sources available were not sufficiently intense. The beam size and time requirements could not be met. However, MURR personnel made recommendations which could produce a gauge with suitable performance. A ^{252}Cf source would be required.

Initial design sketches were produced by the project team at Bendix. The electronic components were purchased. However, because of manpower restraints and changing program priorities, it was decided to terminate the project. The boron analysis facility never progressed beyond the planning stage.

DISCUSSION

SCOPE AND PURPOSE

Because of the high cost of natural and enriched boron, it is economically advantageous to reclaim these materials from scrap parts of boron-loaded elastomers. Enriched boron is more expensive than natural boron, and, if some of the natural boron is mixed with the enriched boron during reprocessing, disastrous economic consequences will result. The cost of a single error would be approximately \$50,000.

The possibility of a considerable cost savings was evident if a way of checking loaded parts could be developed. This would determine if the part was loaded with enriched or natural boron and would bypass the effect of errors in records or procedures.

This project was initiated to develop such a part-checking method. The requirements of the method were the following.

1. The test method should clearly differentiate between enriched and natural loaded VCE.
2. Samples would be of uniform thickness up to 7 mm and be at least 10 by 10 mm.
3. Each piece of scrap would be tested intact.
4. The time required to test each piece would be less than two minutes.
5. The final test equipment would be set up at Bendix Kansas City.

PRIOR WORK

Previous experimental work¹ has shown that neutron absorption can be used to differentiate between natural boron and enriched boron liquid samples. From the outset of the development work, neutron absorption techniques were assumed to be the mainstay of the project. However, other techniques were to be investigated.

In previous experimental studies, the boron-loaded material had been dissolved in water. Because of requirement three listed above, the boron-loaded VCE binder could not be dissolved in a liquid for the measurements.

Preliminary studies to determine the feasibility of checking parts intact were conducted by a member of the project team during a visit to LASL where measurements conducted on the "blue"

unit were observed. A trip report which describes the experiment is included as Appendix A. The experimental apparatus is shown in Figures 1 through 5. Samples of boron-loaded polymer were supplied by Bendix. It was shown that parts loaded with enriched boron (89.6 weight percent ^{10}B) had a counting rate of less than 1000 counts/minimum, while parts loaded with natural boron (19.8 weight percent ^{10}B) had a counting rate greater than 2000 counts/minimum. Although the unit had good discrimination for large samples, it had poor beam collimation and was not suitable for small samples.

ACTIVITY

The University of Missouri Research Reactor (MURR) Facility at Columbia, Missouri, was known through previous contacts to have expertise in neutron studies. Dr. Robert M. Brugger and Dr. Don Alger agreed to brainstorm various concepts for the boron determinations and submit a report in approximately two weeks. That report (Appendix B) included nine methods, two of which were considered. However, one of these methods required dissolving the material and was unacceptable. The other method was measuring neutron absorption with epithermal neutrons.

Dr. Brugger said preliminary investigations were performed on determining ^{10}B content by measuring alpha particle emission from a neutron-irradiated sample. The concept of this type gauge is shown in Figure 6. No completely satisfactory alpha particle detector was available. The project team then suggested that Drs. Brugger and Alger abandon surface measurements and concentrate on absorption techniques using smooth surface samples with a well-defined thickness using a gauge similar to that shown in Figure 7.

Drs. Brugger and Alger spent considerable effort aimed at determining the most favorable energy range for the neutron beam. This was accomplished by calculating the transmission of natural and enriched samples bombarded with monoenergetic neutrons. Transmission can be calculated from the following equation.

$$I/I_0 = \text{transmission} = \exp(-n_B \delta d)$$

Where n_B is the atomic density of boron in the elastomer, δ is the nuclear cross-section, and d is the thickness of the sample. These calculations show that the most favorable range for the thicker samples was 10 to 1000 eV, and for the thinner samples it was 1 to 100 eV (Tables 1 and 2).

The desired beam energy can be obtained by surrounding the source with an appropriate amount of moderator. Moderator material is also required around the detectors because they are sensitive only to thermal neutrons. A cadmium shield around the detector

Figure 1. The Blue Unit at LASL

Figure 2. Readout of the Blue Unit

Figure 3. The Source and Storage Container

Figure 4. The Source With its Moderator

Figure 5. The Source in Position on the Blue Unit

filters out the low energy neutrons. Figure 8 shows the approximate energy range of the source and moderated beam.

Figure 9 shows the experimental apparatus. Moderators were constructed of polyethylene. These moderators provided three different thicknesses of material: 13, 25, and 38 mm. Figures 10 and 11 show count rates for various configurations. Figure 10 shows the count rate with a 7-mm-thick sample in the beam, and Figure 11 shows the count rate with no sample in the beam.

Figure 12 shows the experimental transmission of 7 mm natural boron-loaded material. Figure 13 shows the transmission of natural boron material as a function of sample thickness.

Four new samples were supplied to Drs. Brugger and Alger. These were a thick (6 mm) and a thin (1 mm) sample of both the enriched boron material and the natural boron. The samples were larger (100 by 100 mm) than had been supplied previously.

The project team was given a demonstration in the laboratory, and the new samples were tested. Some discrimination between natural samples and enriched samples was achieved, even though the system was not in optimum configuration.

Figure 6. Alpha Particle Emission Method

Figure 7. Initial Concept for the Neutron Absorption (Transmission) Gauge

Although discrimination was achieved for the samples provided, Drs. Brugger and Alger expressed some reservation as to whether the technique would be successful for a 1 cm² sample. The difference in counts in 100 seconds would be reduced to 10 counts, which would be within the statistical error. Either a longer counting time would be required or inspection would have to be limited to the larger parts. A larger source with a more extensive moderator and collimator would be required.

Drs. Brugger and Alger later demonstrated a new gauge which could measure a sample 20 by 20 mm. This was not quite as small a beam size as desired. Moreover, the measurement time was excessive.

The experimental setup that gave best results is shown in Figure 14. The optimum design parameters are also given. The requirement for a small beam size dictated that a long collimator be used.

Table 1. Cross-Section Data (Barns)

	Natural	Enriched
Thermal	760	3800
1 eV	120	600
10 eV	38	190
100 eV	12	60
1000 eV	3.8	19

The neutrons emanating from the collimator at places other than the beam port had to be sufficiently thermalized so that they were absorbed by the boron and cadmium filters and did not add excessively to the background. However, because the collimator was long, the size of the source had to be made larger because of the $1/r^2$ loss. Five $1.0\text{-Ci}^{239}\text{Pu-Be}$ were used instead of the three employed in previous experiments.

Although the setup did not meet the requirements for a finished gauge, Drs. Brugger and Alger stated that the requirements could be met if the source strength, the number of detectors, and the shielding were increased. Their specific recommendations follow.

1. A ^{252}Cf source of about 1 to 2 mg would be needed to have sufficient neutrons.
2. The collimator length would need to be about 1 to 1.5 m for sufficient shielding to reduce the background of neutrons penetrating outside the collimator.
3. The collimator exit should be defined with a thick layer, 10 to 20 mm, of B-10.
4. The source moderator should be about 35 to 40 mm thick and the detector moderator about 10 to 15 mm thick. The system should be designed so that these thicknesses could be adjusted if required.
5. The detector and moderator should be shielded with cadmium to reduce the thermal neutron background.
6. High efficiency thermal neutron detectors with good neutron to gamma ray discrimination should be used.
7. The exit aperture should be designed to ensure that each sample completely covers the exit hole.

Table 2. Neutron Transmission Data ($^{10}\text{B}=0.1 \times 10^{24}$)

	5 mm		1 mm	
	Natural	Enriched	Natural	Enriched
Thermal	10^{-17}	10^{-83}	5×10^{-4}	3×10^{-17}
1 eV	2.5×10^{-3}	10^{-13}	0.3	2.5×10^{-3}
10 eV	0.15	7×10^{-5}	0.68	0.15
100 eV	0.55	0.05	0.89	0.55
1000 eV	0.83	0.39	0.96	0.83

Additional details are provided in the MURR final report (Appendix B).

ACCOMPLISHMENTS

Based on these recommendations, a concept for a completed gauge was prepared (Figure 15). The collimator would be constructed from borated paraffin. The borated paraffin would be prepared by heating paraffin in a steam "kitchen" and mixing in powdered boric acid. A mixture of about 50 weight percent boric acid and 50 weight percent paraffin would be suitable. The mixture would be poured into molds and stirred continuously until it cooled. The collimator would have to be constructed in several sections because of the large size. The collimator would measure about 1.22 m in diameter and about 1.83 m in length, and it would weigh about 2000 Kg (4400 lb.). Because of the weight, some structural support would be required. However, the position and type of support should be designed carefully. Metal placed near the source will be activated by the neutron flux. This would release additional gamma radiation.

The collimator exit area would be defined by a thick layer (10 to 20 mm) of ^{10}B . Additional ^{10}B shielding could be provided on the inner surface of the collimator to reduce the background. A sample slide should be provided at the collimator exit that would hold the sample and allow it to be positioned in the neutron beam without exposing the operator to intense radiation. The sample slide would also assure that the sample was positioned repeatably and that it completely blocked the exit.

Figure 8. Energy Range of the Source and Moderated Beam

MURR recommended a specific type of detector. This was the 40-atmosphere ^3He detector. The advantage of this detector is that it can be made relatively insensitive to gamma radiation by electronic discrimination.

Because of the intense radiation of the ^{252}Cf source, adequate safeguards should be instituted to eliminate hazards to personnel. Particular attention should be given to procedures for handling radioactive material. Safeguards should be instituted in several areas.

1. The adequacy of the proposed shielding should be determined in relation to the expected exposure of personnel.²⁻⁷
2. A means of moving the source from the shipping cask into the collimator should be devised. This is the time when the source would present the most hazard.
3. Shielding should be checked after the source has been installed and periodically thereafter to ensure that damage is not allowing radiation to escape.
4. Protective barriers should be installed to keep the operator from inadvertently putting a hand into the neutron beam.
5. It should be determined if controlled access is necessary for the facility.

Figure 9. Experimental Analysis Apparatus

6. A personnel monitoring system should be instituted. Film badges and pen-type monitors should be used. A hand-held monitor should be available for survey.

Because of the danger of melting in the event of a fire, it would be wise to encase the moderator in a leakproof enclosure. Also, a support or second enclosure would be necessary to keep the source from falling to the bottom of the outer enclosure (Figure 15).

The electronics required to analyze the signal from the detectors are displayed in Figure 16.

Figure 10. Counting Rates for Various Configurations, Natural Boron Sample

Two proposed arrangements for the neutron gauging facility are shown in Figure 17. In one, the collimator is horizontal. In the other, the collimator is vertical.

Because of manpower restraints and changing program priorities, it was decided to terminate the project before the gauge was built.

Figure 11. Counting Rates for Various Configurations, No Sample

Figure 12. Transmission Versus Source Moderator Thickness

Figure 13. Neutron Transmission Versus Sample Thickness

SOURCE	1 TO 2 mg ^{252}Cf
COLLIMATOR LENGTH	1 TO 1.5 m
COLLIMATOR EXIT AREA	10 BY 10 mm
DETECTOR	SEVERAL 40 ATMOSPHERE ^3He , 50 BY 6 mm DIAMETER
SOURCE MODERATOR	35 TO 40 mm tk PARAFFIN
DETECTOR MODERATOR	10 TO 15 mm tk PARAFFIN

Figure 14. Configuration of the Experimental MURR Gauge

SOURCE	5 Ci $^{239}\text{Pu} - \text{Be}$ ($\sim 10^7 \text{n/SECONDS}$)
COLLIMATOR LENGTH	ABOUT 1 m
COLLIMATOR EXIT AREA	20 BY 20 mm
DETECTOR	ONE 40 ATMOSPHERE ^3He , 50 BY 6 mm DIAMETER
SOURCE MODERATOR	35 mm tk. PARAFFIN
DETECTOR MODERATOR	15 mm tk. PARAFFIN

Figure 15. Proposed Gauge Design

Figure 16. Electronics for the Neutron Counter

Figure 17. Proposed Neutron Gauging Facility

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APPENDIX A

TRIP REPORT--BORON ANALYSIS AT LASL

Internal
Memorandum

Date June 16, 1977

Letter No.

Kansas City, Missouri

To J. S. Carson

From D. W. Drayer

Subject TRIP REPORT - BORON ANALYSIS AT LASL

On June 9 and 10, LASL was visited for the purpose of obtaining information regarding the use of neutron absorption to distinguish between filled elastomer material containing natural boron and that containing Boron 10.

For a number of years LASL has had a unit in service incorporating a ^{239}Pu -Be thermal neutron source used for a routine inspection requirement. Recently it was decided this unit probably had the capability for distinguishing between filled elastomer parts made with natural boron and similar parts made with enriched boron. An investigation was conducted in which it was shown on a statistical basis that parts loaded with enriched boron (89.6 wt% ^{10}B) had a counting rate of less than 1000 counts/min. Parts loaded with natural boron (19.8 wt% ^{10}B) had a counting rate greater than 2000 counts/min. Using samples supplied by Bendix a neutron transmission curve was prepared as a function of the ^{10}B areal density. According to LASL the samples used for this evaluation were surplus material of somewhat questionable composition. The neutron source and detection system was designed and has been used for some time for a different application all together. With only very minor alterations it was pressed into service for the boron work and as a result geometry and beam collimation are quite poor. Nevertheless it has been adequate for the required part identification. A curve of neutron absorption based on the Bendix supplied samples is shown in the attached figure.

Using the LASL "Blue" unit a cursory set up was made including demonstration of calibration and technique for checking parts. This unit consists of a neutron source, detector, rate meter, strip chart recorder and fixture for holding parts and quipment.

The source is ^{239}Pu -Be (24,000 yr. half life) whose strength was calibrated as 7.01×10^5 neutrons/second on June 22, 1972. The source is contained in an open-top, right-cylindrical, brass "can" 6" high by 5" in diameter. The outside of the can is covered with a .030" thick cadmium sheet. The total wall thickness of the can is .158". The bottom 4" of the can is filled with a polyethylene plug in which the source is secured and which also serves to thermalize the neutrons.

Internal
Memorandum

Date June 16, 1977

Letter No.

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The detector consists of a bank of four horizontally mounted 1" diameter boron-film counting tubes.

To measure the neutrons detected by the counting tubes a, neutron detector was used. This information was recorded with a strip chart recorder.

In this set up the source to detector distance was 9" and the sample to detector distance was 5". With no neutron absorber other than air in the path of the neutron beam, the source appears essentially as a point and in general obeys the inverse square law. With a sample or calibration absorber in place directly on the source can a broad-beam geometry was generated. Such a poor geometry allows much of the scattered radiation to strike the detector so that the observed cross section of the sample is smaller than the setup geometry would indicate.

The physical characteristics of the original unit does not easily permit a collimated narrow-beam geometry which would eliminate scattering. For the purpose of the tests conducted at LASL, the broad-beam geometry is considered adequate.

For the demonstration run the equipment was initially set up with an electronic calibration. For this the zero of the recorder was set and an internal electrical calibration equivalent to 3600 cpm was adjusted to read 3.6 major divisions. Once the electronics calibration was established the zero was re-checked with the detector energized but with no source for the purpose of checking the background count. With the source in place and air as the only absorber a count rate of 14,000 cpm was indicated. By inserting a Cd plate approximately .020" thick the count rate was decreased to 2,200 cpm.

With the equipment calibrated two sample parts were inserted in the beam. In one case the part contained natural boron which was 19.8% by wt. of ^{10}B in which case the count rate was measured as 3200 cpm. In the second case the sample contained enriched boron, 89.6% by wt. of ^{10}B in which case the count rate was reduced to 900 cpm. This test shows the sample with enriched ^{10}B to transmit only 22.9% of the neutrons as the sample with natural boron. This is an ample difference in count rate to distinguish between parts made with highly enriched boron and parts made with natural boron.

From this information it seems quite feasible that a neutron absorption technique can be used in conjunction with the Bendix scrap reclamation program for differentiation between material made with highly enriched boron and that made with un-enriched material. It also appears feasible that the unit could be made considerably more quantitative than the LASL set up by designing it with consideration to improved geometry beam collimation and neutron detection and read-out.

DWD:rb

APPENDIX B
MURR REPORT

FEASIBILITY STUDY FOR USING NUCLEAR TECHNIQUES TO DETERMINE
B-10 ENRICHMENT

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AUGUST 17, 1978

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I. Introduction

On February 2, 1978 Messrs. William Abel and Don Drayer of Bendix Corporation visited the University of Missouri Research Reactor, MURR. They requested that the staff of the MURR brainstorm possible methods to determine whether the B in highly boron-loaded plastic binder material, VCE, is enriched B-10 or natural boron. On February 28th, a response of brainstorming was sent to Bendix. This letter (Appendix A) outlined ten possible techniques with three methods identified as appearing promising and feasible.

A meeting at Bendix on April 6th resulted in a set of objectives. MURR was asked to conduct a feasibility study of the more promising methods and to make measurements to demonstrate a technique that would meet the objective of identifying the boron isotopes.

This report describes the measurements and results, and shows that a system can be built based upon transmission measurements using epithermal neutrons. The system clearly distinguishes between highly-enriched and natural boron in the scrap plastic binder.

II. Objectives

From a production operation, Bendix Corporation accumulates scrap boron-loaded VCE binder material. Bendix needs to determine if the scrap contains boron of naturally occurring isotopic distribution or boron enriched to about 90 percent B-10. As a result of the meeting at Bendix on April 6, 1978, it was decided that greater than 90 percent of the scrap could be evaluated if the following objectives were met by the test method.

1. The test method should clearly differentiate between B-10 and B-natural loaded VCE.
2. Samples would be of uniform thickness up to 7 mm and be at least 10 mm x 10 mm.
3. Each piece of scrap would be tested intact.
4. The time required to test each piece would be less than two minutes.
5. The final test equipment would be set up at Bendix Corporation.

III. Experiment

Three of the possible techniques for determining the boron enrichment that were considered (Appendix A) were tried. The prompt activation analysis method of measuring the prompt gamma rays or alpha particles both were abandoned when high background interference was encountered in initial measurements. Initial measurements of transmission of the samples using epithermal neutrons showed promise and these were pursued.

Table 1 gives the neutron absorption cross sections for B-10 and B-natural as a function of energy. The energy dependent neutron transmission through 5 mm and 1 mm thick samples of B-10 and B-natural is shown in Table 2. It can be seen from Table 2 that only neutrons between about 1 ev and 1000 ev distinguish samples based upon the boron enrichment. Thus the challenge was to adjust the neutron source and the neutron detector response to maximize the effect of 1 - 1000 ev neutrons and minimize the response to other energy neutrons. Then the transmissions would be sensitive to the boron isotopes.

As shown in Table 3 neutron sources produce energetic neutrons and therefore it is necessary to have a sufficient amount of moderator material around the source to yield neutrons in the desired energy interval of 1 - 1000 ev. In this experiment the best results were obtained with about 35 mm of paraffin on the sample side of the 5 Ci ^{239}Pu -Be source. Also since neutron detectors are much more sensitive for thermal neutrons, it is advantageous to place a moderator material between the sample and the detector of a thickness that optimizes the detection of neutrons below 1000 ev. Using both ^{10}BF and ^3He detectors, the best thickness of paraffin in front of counters was about 15 mm. Better results were obtained with no paraffin behind the counters.

The experimental setup that gave the best results is shown in Figure 1. The following parameters were selected:

Source	5 Ci ^{239}Pu -Be ($\sim 10^7\text{n/sec}$)
Collimator Length	About 1 m

Collimator exit area
Detector

20 mm x 20 mm

One 40 Atm ^3He , 50 mm long x 6 mm
diameter

Source Moderator
Detector Moderator

35 mm tk. paraffin

15 mm tk. paraffin

TABLE 1

<u>NEUTRON ENERGY</u>	<u>ABSORPTION CROSS SECTIONS</u>	
	B-N	B-10
Thermal, 1/40 eV	760	3800
1 eV	120	600
10 eV	38	190
100 eV	12	60
1000 eV	3.8	19

1 eV - 10 KeV

H scattering = 20 barns.

TABLE 2

NEUTRON ENERGY	NEUTRON TRANSMISSION			
	5 mm thickness		1 mm thickness	
	B-N	B-10	B-N	B-10
Thermal	10^{-17}	10^{-83}	5×10^{-4}	3×10^{-17}
1 eV	2.5×10^{-3}	10^{-13}	.3	2.5×10^{-3}
10 eV	0.15	7×10^{-5}	.68	0.15
100 eV	0.55	0.05	.89	0.55
1000 eV	0.83	0.39	.96	0.83

Table 3. Comparison of Isotopic Neutron Sources

Source	Type	Half-Life	Avg. Energy (Mev)	Yield (10^6 n/sec-Ci)	Normalized to 5×10^{10} n/sec			
					Gamma Dose Rate (Rad/hr)	Release (Watts)	Volume (cm ³)	Cost (\$1000)
¹²⁴ Sb-Be	γ, n	60 d	.024	1.6	1.4×10^4	20	200	25
²³⁹ Pu-Be ¹	α, n	24,390 y	4.5	2.0				
²⁴¹ Am-Be	α, n	458 y	4	2.0	2.5	750	2.2×10^4	1,500
²¹⁰ Po-Be	α, n	138 d	4.3	2.5	2.0	640	200	20
²³⁸ Pu-Be	α, n	89 y	4	2.8	0.4	550	350	310
²⁴⁴ Cm-Be	α, n	18.1 y	4	3	0.2	600	70	50
²⁴² Cm-Be	α, n	163 d	4	4	0.3	600	2	10
²²⁶ Ra-Be	α, n	1,620 y	3.6	15				50,000 ²
²⁵² Cf	S.F.	2.65 y	2.3	4,400	2.9	0.8	<1	50

¹A source of sufficient strength would be a critical mass.

²Insufficient radium available for this strength source.

IV. Measurements

The sample materials of B-10 and B-natural provided by Bendix Corporation were tested with the experimental setup as described and illustrated in Section III. The results shown in Figure 2 were developed with samples about 25 mm x 25 mm in cross section and thickness ranging from 0.7 mm to 6.7 mm. The curve, B-10/B-natural, shows that the ratio of the relative transmission of neutrons is nearly independent of sample thickness for samples between 1 mm and 7 mm.

With the parameters listed in Section III, the count rate when using the 6.7 mm thick B-10 sample was about 14.5 counts per minute above background. The backgrounds were about 9.0 counts per minute. The transmission curves of Figure 3 are after background subtraction. The curves of Figure 3 show that the B-natural or B-10 can be clearly identified. These tests show that objectives 1, 3, 5, and part of 2 can be met.

The Pu-Be sources used at MURR were weak and gave too low a counting rate to meet the objective 4 and the 10 mm x 10 mm size requirement of 2. However, a system built at Bendix can increase the source strength, number of detectors and shielding so that objectives 2 and 4 can be met.

If the collimator exit were reduced to 10 mm x 10 mm to accommodate smaller samples, if four or five neutron detectors were used simultaneously to increase the count rate, and if a 1 mg. Californium-252 source were used, then the count rate would be about 4500 counts per minute. At this counting rate and counting for one minute, the uncertainty to three standard deviations based upon counting statistics for such a modified system will be small and is represented by the cross hatched bands of Figure 2. These show that B-natural and B-10 can be distinguished.

V. Recommendations

A system based upon epithermal neutron transmission can be built to meet the objectives outlined in Section II. The following recommendations are made.

1. In order to have sufficient neutrons, a Cf-252 source of about 1-2 mg will be needed.
2. The collimator length will need to be about 1-1.5 m in order to have sufficient shielding to reduce the background of neutrons penetrating outside the collimator.
3. The collimator exit should be defined with a thick layer, 10-20 mm, of B-10.
4. The source moderator should be about 35-40 mm thick and the detector moderator about 10-15 mm thick. The system should be designed so that these thicknesses could be adjusted if required.
5. The detector and moderator should be shielded with cadmium to reduce the thermal neutron background.
6. High efficiency thermal neutron detectors with good neutron to gamma ray discrimination should be used.
7. The exit aperture should be so designed to ensure that each sample completely covers the exit hole.

Figure 1 Experimental Setup

Figure 2

Neutron Transmission vs. Thickness
of Boron Loaded Samples

UNIVERSITY OF MISSOURI

APPENDIX A

Research Reactor Facility

Research Park
Columbia, Missouri 65201
Telephone (314) 832-4211

February 28, 1978

Mr. Don Drayer
Bendix Corporation
Box 1159
Kansas City, MO 64141

Dear Don,

This letter is in response to your request for us to brainstorm possible $^{10}\text{B}/^{11}\text{B}$ detection methods. Attached are notes on methods we have considered. Methods 2 and 4 look quite promising and feasible. Method 3 might have an application. The others have major disadvantages. Don and I would be pleased to join you in Kansas City and discuss these methods in more detail.

Sincerely,

Robert M. Brugger
Director

Don M. Alger
Associate Director

RMB:sb

1. THERMAL NEUTRON TRANSMISSION GAUGING

A piece of boron impregnated polymer (bip) would be placed between a thermal neutron source and a thermal neutron detector. The transmission of the sample would be measured to determine the presence of ^{10}B vs ^{11}B . This method would have good sensitivity for samples of 40-100 μm thickness (See Figure 1). A moderated ^{252}Cf source could be used as the neutron source.

To eliminate the problem of varying sample thicknesses, a known small sample of bip could be dissolved and the solution placed in a standard container for transmission measurements.

2. TRANSMISSION MEASUREMENTS USING EPITHERMAL NEUTRONS

The transmission of a piece of bip would be measured using both neutrons and gamma radiation. The neutron flux would be tailored such that it would be sensitive to ^{10}B vs ^{11}B . This might require an americium flux or harder. The gamma flux would be selected to be sensitive to the thickness of the bip. The ratio of the neutron to gamma rate for the estimated thickness would be compared to a chart (See Figure 2). If the bip is 60-80% boron loaded, this ratio should select < 90% ^{10}B loaded bip from natural boron bip.

Figure 2 looks very promising for separating natural from 90% ^{10}B of 60-80% loading for sample from 1 mm to 1 cm thick. A ^{252}Cf source should probably be used. Its flux would be moderated and then hardened so that the maximum would be ~ 400 eV. The gammas from the source would also be detected as a source monitor and as a density gauge.

Fig. 2

3. MASS AND % LOADING BY WEIGHING

The piece of boron impregnated polymer (bip) would be weighed with a spring balance with the bip in a solution having the same density as the polymer. This should weight the boron in the piece. The amount of liquid displaced will be the volume of piece. From these two measurements one should be able to calculate the % load of boron in the piece to $\sim 10\%$.

If one knew the loading and there were no voids in the polymer, these measurements should be able to determine the density of boron and distinguish between natural and $> 90\%$ ^{10}B .

4. NEUTRON MODERATION GAUGING

The known amount of bip would be dissolved and the solution put around a neutron source and detector. The solution would moderate some of the neutrons which the ^{10}B would then capture. The counting rate in the detector would be sensitive to the amount of ^{10}B in the solution.

5. PROMPT NEUTRON ACTIVATION ANALYSIS

A sample of bip would be placed in a thermal neutron beam. The prompt gamma rays produced by neutron capture in ^{10}B and ^{11}B would be detected. The weighed ratio would tell the ratio of ^{10}B to ^{11}B . The reactions are

The disadvantages of this method are 1) that a strong thermal beam would be needed, probably from a reactor, 2) that while the gammas from the $^{10}\text{B}(n\alpha)$ would be plentiful, those from the $^{11}\text{B}(n\gamma)$ would not be.

6. TRACK-ETCH DETECTION

A thin (about 10-30 μm) strongly colored film of cellulose nitrate would be placed in close contact with a sample of bip. The cellulose nitrate film would be supported by an ethyleneglycol polyterephthalate film. A neutron beam directed at the sample through the film results in α particle tracks. The tracks would be made visible by chemical etching.

In this method, linear response provides a wide latitude. Lack of sensitivity to X- and gamma radiation and beta particles eliminates background problems. The film can be processed and viewed immediately. This method measures only ^{10}B content near the sample surface (5 μm); it is sample thickness independent. Good contact between film and sample is necessary. A low strength isotopic neutron source can be used.

7. MASS SPECTROMETRY

A volatile compound could be made with the boron and then mass spectrometry analysis would yield the ^{10}B and ^{11}B fractions.

A spark source mass spectrometer or secondary ion mass spectrometer could be used.

8. MOLECULAR SPECTROSCOPY

Isotope shifts occur in atomic and molecular spectra to a varying degree determined by the mass difference of the isotopes.

$^{11}\text{BCl}_3$ and $^{10}\text{BCl}_3$ have well resolved absorption lines ($^{11}\text{BCl}_3$ at 956 nm and $^{10}\text{BCl}_3$ at 995 nm).

9. PROTON BACKSCATTERING

Protons could be scattered from the surface of a bip, and the scattered protons magnetically analyzed. Such protons would distinguish between ^{10}B and ^{11}B and the ratio obtained. The disadvantages of this method are that a proton accelerator is needed and the bip's must be put in a vacuum.

10. ALPHA PARTICLES FROM SURFACE

As in method 6, α particles from the surface could be produced by thermal neutron irradiations. These α 's would be detected with a solid state detector. Only ^{10}B would be measured.