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Abstract

[The availability of B¹⁰ enriched boron has stimulated a consideration of its use in fabricating boron curtains to replace boral in Circulating Fuel Reactor mockup experiments conducted at the Lid Tank Shielding Facility. In the fabrication of boral, difficulties were encountered in mixing powdered boron carbide with an aluminum melt; consequently, to facilitate fabrication, the particle form of boron carbide has been adopted. However, the neutron absorption efficiency is shown to be less than presupposed as a result of neutron leakage between the particles of boron carbide. Therefore, in order that maximum efficiency of neutron absorption be realized it is recommended that an effort be made to develop a technique to use powdered B¹⁰ enriched boron in the fabrication of boron curtains.]

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~~SECRET~~A PRELIMINARY INVESTIGATION OF B¹⁰ ENRICHED BORON CURTAINSIntroduction

Consideration is given to the use of B¹⁰ enriched boron in the fabrication of boron heat exchanger curtains for Lid Tank Circulating Fuel Reactor mockups. Boral curtains using natural B₄C are in present use. Past assumptions of a homogeneous mixture of boron carbide and aluminum in boral have given an overestimate of the neutron absorption efficiency because neutron leakage between B₄C particles was ignored. The advantages that might be gained from B¹⁰ enriched curtains suggest that additional sodium activation experiments be performed in the CFR mockup.

I. Nuclear Considerations for Boral Curtains

As can be seen from Fig. 1, the specific activation of sodium measured at the Lid Tank in CFR heat exchanger mockups continues to decrease as the boral thickness is increased. An insight into the processes involved in the attenuation of activating neutrons using the present boral is given by consideration of the following factors:

1. Assuming a homogeneous mixture of boron carbide and aluminum, 1 in. of boral should attenuate 2200-m/sec neutrons by a factor of 10^{19} , which is sufficient to remove substantially all thermal neutrons.
2. The B¹¹, C, and Al constituents of boral comprising 97% by volume act as a moderator in slowing down neutrons which are subsequently captured by the distributed B¹⁰. This effect may

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be important for large boral thicknesses and may account for the decrease in Na activations as the boral thickness is increased. Since contemplated boron curtains in reactor design are approximately $\frac{1}{4}$ in. thick, the effect of the extraneous constituents in the boral now available should be considered.¹

3. The B^{10} capture of 3-Kev neutrons at the sodium resonance peak may have an effect as the boral thickness is increased. The estimated microscopic cross section of B^{10} for 3-Kev neutrons is 10 barns, and 3.8×10^{22} B^{10} atoms per cm^2 (3.5 in. of the boral now available) give 3-Kev neutrons an attenuation of 1.5.

4. Last and perhaps most significant is the leakage of neutrons through boral due to the nonhomogeneous mixture of B_4C particles and Al (see Fig. 2). If it is assumed that the B_4C particles are cubes of uniform thickness Δx and the particles are distributed randomly in layers having their thickness equal to the particle size, then the probability of normally incident neutrons encountering a particle is equal to the volume fraction, F , of B_4C in the layer Δx , and the probability that normally incident neutrons will pass through the layer Δx without encountering a particle is $1 - F$, the volume fraction of Al. It follows that the transmission through a single layer is $1 - F + Fe^{-\Sigma\Delta x}$, where Σ is the thermal

¹This effect has been approximated by J. B. Dee and D. R. Otis, "ANP Quar. Prog. Report for Period Ending Dec. 10, 1955," ORNL-2012, Part III, p. 206.

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absorption cross section for $B_{14}C$, taken to be 74 cm^{-1} . The transmission through n layers is²

$$\left(1 - F + Fe^{-\Sigma \Delta x}\right)^n$$

The result of this calculation (Fig. 3) indicates that the effectiveness of boral is largely controlled by $B_{14}C$ particle size. Figure 3 is intended only to indicate the significance of $B_{14}C$ particle size. A more realistic calculation of neutron transmission would consider the Maxwellian distribution of thermal-neutron energies, an angular distribution of neutrons entering the boral, scattering within boral, and perhaps other refinements. Consideration is being given to these factors and a more elaborate treatment of neutron transmission through boral will appear in a forthcoming document.³ This problem also appears worthy of further experimental investigation.⁴

²Derived by R. R. Coveyou and reported by N. M. Smith, Jr., in CNL-21 Revised, "The Absorption and Scattering of Radiation in Random Aggregates of Pebbles" p. 28 (Mar. 3, 1949).

³This investigation is being carried out by W. R. Burrus, loanee from Wright Air Development Center.

⁴A measurement has been made by John Moteff on the transmission of thermal neutrons to the cadmium cut-off through $1/8$ in. of boral. An attenuation factor of 80 was thus obtained by a cadmium difference in gold foil. This information was obtained in conversation with Moteff and the preliminary results are reported in APEX-16, General Electric Aircraft Nuclear Propulsion Dept. Prog. Report No. 16 for the period from April 1, 1955 to June 30, 1955, p. 126.

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II. The Problem of Fabrication

Inquiries were made about the fabrication techniques which might be employed to form 4-ft-sq. sheets of enriched boron mixed with aluminum or copper. Copper is considered because of its contemplated use in reactors.

In conversation with Mead D'Amore^{*}, ORNL Metallurgy Division, the following information was obtained.

1. Attempts to mix boron powder or $B_{14}C$ in a Cu melt would probably be unsuccessful because of the high density of Cu which may preclude mixing it with less dense B or $B_{14}C$.
2. Success has been obtained in combining $B_{14}C$ and Cu using powder metallurgy techniques. However, the process is expensive and difficulties would be encountered in the fabrication of large sheets.
3. Since the contemplated LTSF experiments will be conducted at room temperature, it was suggested that Al be used as the binder and that sheets be fabricated using specifications established for boral. The mixing of boron and aluminum might require that the B^{10} powder be converted to $B_{14}^{10}C$ in particle form.

C. A. Rinderer, Chemical Operations Division, Y-12 Plant, expressed a willingness, subject to AEC approval, to conduct research in mixing the B^{10} and Al. Mr. Rinderer has assisted in establishing specifications for boral and is an adviser to vendors involved in boral fabrication.

*Loan employee from Pratt and Whitney Aircraft.

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Best results have been obtained for $B_{14}C$ particles in size from 20-100 mesh with the coarser mesh size predominating. If the B^{10} is in the form of a fine powder this might preclude its direct use.

III. Combining B^{10} With Heat Exchanger Materials

Sodium activation measurements taken with boral slabs interspaced between the 2-in.-thick heat exchanger mockup tanks indicate that greater rewards are obtained by distributing B^{10} throughout the heat exchanger region. In addition to increased effectiveness in removing activating neutrons originating in the core, the distributed B^{10} would reduce the number of activations due to decay neutrons from fission products circulated through the heat exchanger. These decay neutrons place limits on the extent to which boron curtains can be effectively used to reduce sodium activations (see Table 1).

In view of the above, consideration may be given to mixing B^{10} or $B_{14}^{10}C$ with the sodium flouride in the heat exchanger mockup tank. The data thus obtained would be useful provided that metallurgists are successful in combining boron with heat exchanger materials.

IV. Summary

1. The effect of neutron moderation by the extraneous materials in boral and the effect of the nonhomogeneous mixture of the boral cause uncertainties in applying sodium activation measurements at the LTSF to reactor design.

2. Fabrication of boral using $B_{14}^{10}C$, where the boron is enriched to 90%, would increase the atomic density of B^{10} present by a factor

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of $\frac{90}{18.7} = 4.8$, thereby enabling the curtain thickness to be reduced by the same factor for an equivalent B^{10} density. The effect of the moderation in the boron curtain would then be reduced. The B^{10} density in boral may be further increased by using a melt of about 50 wt. % Al and 50 wt. % B_4C instead of the present 65 wt. % Al and 35 wt. % B_4C .

3. An increased B^{10} density in boral would enable an investigation of further reductions in Na activations which might result from additional attenuation of neutrons at the 3-Kev Na resonance energy.

4. The effect of nonhomogeneity of the boral melt would remain a problem requiring separate investigation.

V. Conclusions

1. The boral now available could be used for the purpose of investigating the effect of nonhomogeneity of the melt.

2. It is believed that B^{10} -enriched boral curtains of reduced thickness, having the same number of B^{10} atoms per cm^2 , would not yield results significantly different from those already obtained. However, the enriched boral curtains would enable investigation of further reductions in Na activations by employing curtains containing B^{10} in amounts greater than 4×10^{22} atoms per cm^2 .

3. An effort should be made to fabricate boral using a fine powder of B^{10} enriched boron. Preliminary calculations indicate that the boron particle size is very important as a result of neutron leakage between particles.

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Note: The above information is extracted from a report by J. B. Dee and D. R. Otis. For a more complete interpretation of the data refer to ORNL 2012, ~~CONF~~ Quar. Prog. Report for Period Ending Dec. 10, 1955,* Part III, p. 205

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Fig. 2. An X-ray Photograph of 1/8 inch thick Boral. IX (Actual size)

In the above contact print of an X-ray photograph the light areas are the distributed B_4C particles and the dark structure is the aluminum binder which is essentially a window to thermal neutrons.

Specifications for B_4C used in the fabrication of Boral:

Boron Carbide (B_4C) metallurgical grade, minus 20 plus 100 mesh.

19% through 20 retained on 25
72% through 25 retained on 70
9% through 70 retained on 100

Minimum B_4C content 98%

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Table 1. Sodium Activation in the Heat Exchangers
of Circulating-Fuel Reactors

	Configuration			(ART)
	1	2	3	
Beryllium thickness (in.)	8	12	16	11
First B ¹⁰ curtain (atoms/cm ²)	3.52x10 ²²	3.52x10 ²²	3.52x10 ²²	---
Heat exchanger thickness (in.)	8	6.5	5	2.1
Second B ¹⁰ curtain (atoms/cm ²)	1.12x10 ²²	1.12x10 ²²	1.12x10 ²²	---
Saturated activity (curies)				
From core neutrons	19,300	3,350	430	470
From delayed neutrons	1,970	1,530	1,250	61
Total	21,270	4,880	1,680	531

Note: The above information is extracted from a table published by J. B. Dee and D. R. Otis in ORNL-2012, "ANP Quar. Prog. Rep. for Period Ending Dec. 10, 1955," Part III, p. 209.

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