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NOTES ON THE COST OF ENRICHED BORON IN TON LOTS

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Contract No. W-7405, eng. 26*

ORNL SUMMER SHIELDING SESSION

Gale Young, Leader

NOTES ON THE COST OF ENRICHED BORON IN TON LOTS

E. P. Blizard

Date Issued: JAN 4 1950

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*Explanation on page 3.

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This report is one of a series on shielding and represents part of the work of a summer group working principally at Oak Ridge National Laboratory. Participants are drawn from Nuclear Development Associates (Navy contract), NEPA, Bureau of Ships and Bureau of Aeronautics (Navy Department), AEC, RAND, General Electric, Argonne and Oak Ridge National Laboratory.

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NOTES ON THE COST OF ENRICHED BORON IN TON LOTS

E. P. Blizard

The purpose of this report is to clarify certain notions* which have been prevalent to date concerning the availability of separated B^{10} for shielding of mobile reactors.

Conclusions:

The cost of boron highly enriched in the absorbing component is not excessive, being comparable to that of other materials under serious consideration. The weight-saving to be gained from its use could be great but is not known at present. The accurate evaluation of this material should be a prominent part of any shielding program. A pilot plant could serve to improve the cost estimate and at the same time supply a large enough sample for attenuation experiments.

Cost of B^{10} in Ton Lots:

Three estimates have been obtained of the cost of enriched boron, as follows:

1) Dr. Karl Cohen, of the H. K. Ferguson Company, was contracted to make a preliminary cost estimate for quantity preparation of boron-10. A few copies of this report** are available from Oak Ridge National Laboratory or from its author.

Considering fractional distillation at reduced temperature of the methyl complex ($BF_3 \cdot (CH_3)_2O$), Cohen concludes as follows:

"Of the three items in producing B^{10}, (feed cost, separation plant cost, and product finishing) it is found that per pound of B^{10} produced, the feed and

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* H. A. Bethe, "Report on the Status of Shielding Information for the NEPA Project", June 10, 1949, Oak Ridge Central Files No. 49-6-149, page 4, §2.

** Karl Cohen, "Preliminary Cost Estimate for Quantity Preparation of Boron-10", October 14, 1949, HKF-AED-100, or Oak Ridge Central Files No. 49-10-106.

"and raw materials will cost about $15 (assuming return of waste BF_3 to manufacturer), the isotope separation will cost about $32, and the production of amorphous boron from BF_3, $10. Of these items the last is the most uncertain. The over-all price per pound of B^{10}, is about $57. These figures are the results of preliminary estimates, containing some allowance for unknown factors. However a firm figure cannot be expected without some deeper study."

2) Dr. Lorne A. Matheson, of Dow Chemical Company, was asked his opinion concerning the cost of separated boron, and his reply*, also based on distillation processes, while not nearly as complete as that above, did not disagree with Cohen's conclusions significantly. He also suggests the alternate method of thermal diffusion.

3) Dr. George Garrett, of the K-25 gaseous diffusion project estimated that gaseous diffusion costs would be very much higher than the distillation method.

Desirability of B^{10} as Shield Component

Evaluation of separated boron-10 requires considerable work, probably including neutron and gamma attenuation measurements, all of which are beyond the scope of the effort represented by this report. An attempt is made, however, to indicate the desirability of doing this work, in the light of conceivable savings in shield weight. There are several indications that the separated isotope would be desirable, all of them depending on the absorption (n,α) cross-sections.

The cross-sections of the two isotopes have been collected by H. Feshbach in another Summer Session report** and the curves are here reproduced for convenience as Figures 1 and 2.

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*Private communication.

** Herman Feshbach, "Fast Neutron Data", ORNL-433.

R. Zirkind* has made some preliminary estimates of the relative effectiveness of natural boron and boron enriched in the absorbing isotope. Being conservative, he used only the relatively well-measured cross-sections, and thus was confined to consideration of relatively low energy neutrons -- that is, below 2 Mev. Most of his comparisons are for neutrons of 1.5 Mev, where the transport relaxation lengths are identical for B^{10} and natural boron. A computed relaxation length of the type to be expected in a shield, however, was 3.26 for B^{10} and 4.05 for natural boron. This calculation is probably oversimplified, and in the energy region to which it is applied, water is probably a better neutron shield in any case.

Goertzel, in an appendix to one of his Summer Session reports, ORNL-423, reports a stochastic attenuation problem of penetration through a slab 16 mean free paths thick as a function of the probability of survival on a collision. The comparison of boron enrichments must be quite similar, and it is unfortunate that Goertzel's work does not cover the range desired. His results are shown on Figure 3 with the relevant survival probabilities inserted. The curve obviously cannot be extrapolated with assurance, firstly because of its nature and uncertainties, and secondly because Goertzel did not include any moderation, and in natural boron with these attenuations this effect will be of major importance. Nevertheless it is evident that some improvement is to be expected.

One reason for using boron in a shield is that the gamma rays accompanying capture are of about 1/2 Mev, and are consequently easily absorbed. Since boron has a high cross-section for absorption it is not difficult to introduce

* R. Zirkind, "Shielding Properties of Boron Isotopes", ORNL Memo to Blizard, August 23, 1949.

enough to insure that it accounts for a very large fraction of absorptions. Isotopic enrichment would not enhance this advantage appreciably.

Bethe calculates shield weights for different relaxation lengths in the light component. For the case in which boron is chosen, a weight-saving of 30 tons in approximately 120 is demonstrated for a relaxation length reduction from 7.5 to 6.0 cms.

Value of Savings in Shield Weight:

It is, of course, difficult to put a realistic price on weight-saving in a mobile reactor, since any such saving would probably be utilized to improve the performance of the vehicle. We can, however, make a lower limit estimate for the case of the nuclear powered submarine. The cost per pound of a modern warship is about $10. Reduction in shield weight would enable a consequent reduction in overall vessel weight of at least three times as great. Thus we can place a minimum value on a shield weight-saving at $30 per pound.

For the airplane case, the increased performance is difficult to evaluate. The Lexington Report* gives 5 tons for the bomb load, and Bethe** gives about 100 tons for the shield weight. Thus, perhaps a saving in 10% of the latter would enable a doubling of the payload and its appurtenances. Of course, the added saving in weight might be applied to the operational ceiling of the craft, its speed, etc., but these do not lend themselves to price estimates.

If each aircraft is worth on the order of 10^7 dollars,***and the 10% weight-saving raises this to 1.5×10^7 dollars, then the premium for a lighter shield

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* LexP-1, page V-6.

** H. A. Bethe, loc. cit.

*** B-36 bombers cost 4.5×10^6 each when ordered in lots of 90.

could be placed at $\$5x10^6/10$ tons, or about $\$250/lb.

10% saving in weight could be effected by reducing shield thickness by 5% or less. Bethe* estimates the weight of light shield component to be about 20 tons. Thus, if a reduction of 5% in weight could be accomplished by replacing the light component by B^{10}** , we would be willing to pay a differential in cost of $\$5x10^6/20$ tons or $\$125/lb.

The writer wishes to emphasize that he does not speak with authority on any estimates of airplane cost, but it is hard to believe that the above figures are not conservative, and some sort of estimate is required to evaluate the cost of separated boron.

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* loc. cit.

** The light component determines the <u>location</u> of heavy material, hence its mean radius and weight.

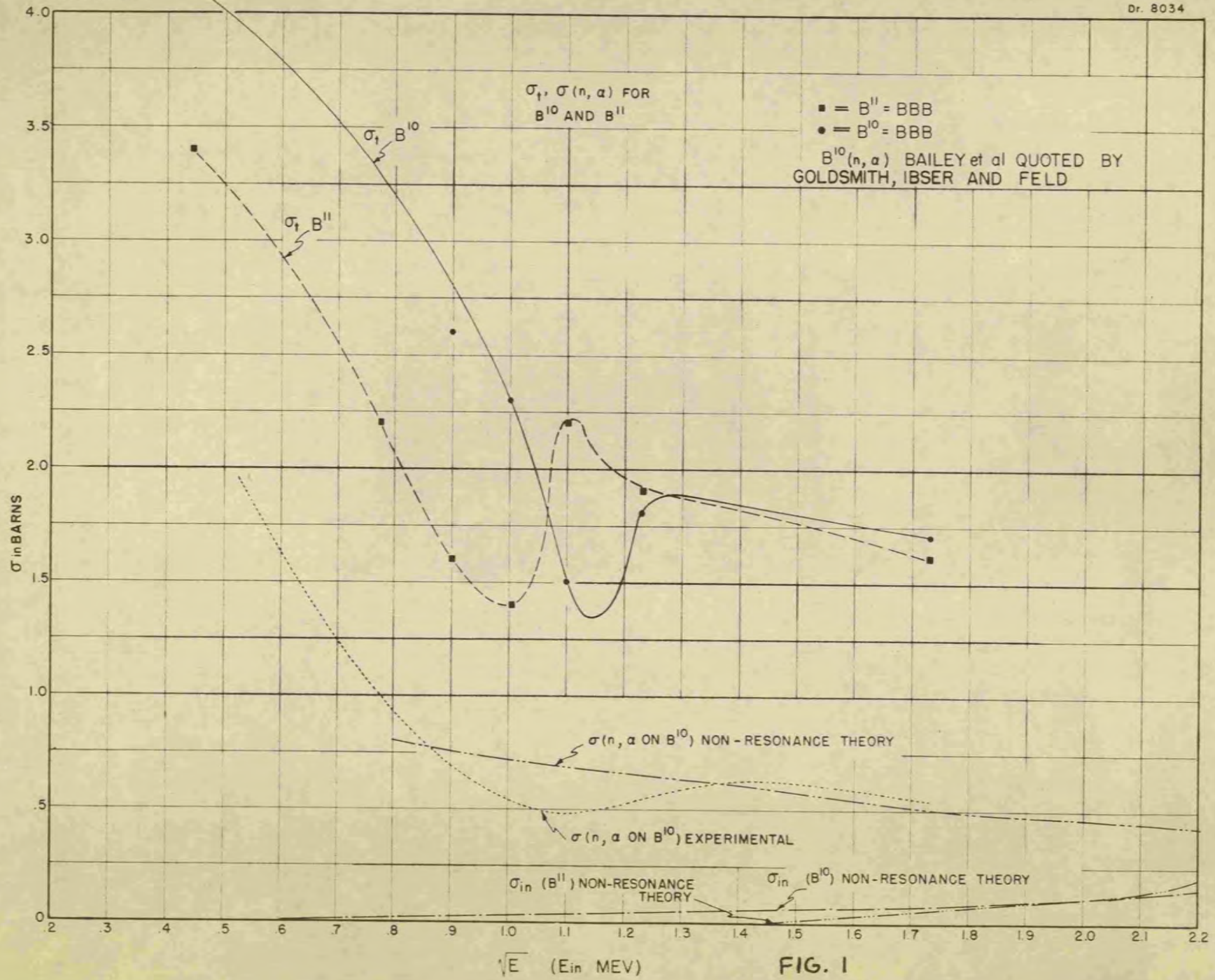
σt, σ(n, α) FOR B10 AND B11
■ = B11 = BBB
● = B10 = BBB
B10(n, α) BAILEY et al QUOTED BY GOLDSMITH, IBSER AND FELD
σt B10
σt B11
σ(n, α ON B10) NON-RESONANCE THEORY
σ(n, α ON B10) EXPERIMENTAL
σin (B11) NON-RESONANCE THEORY
σin (B10) NON-RESONANCE THEORY
σ in BARNS
√E (Ein MEV)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2

FIG. 1

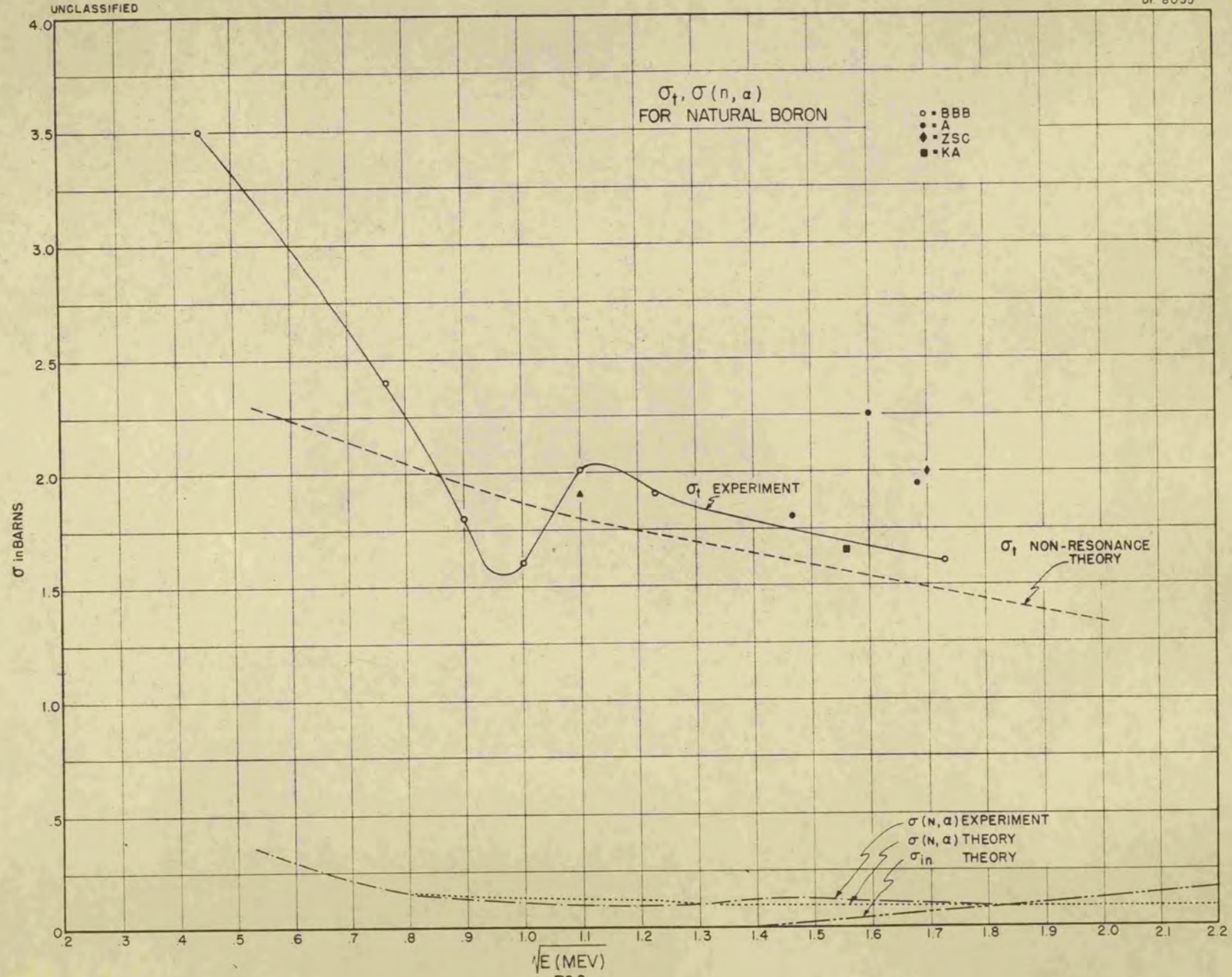
σ_t, σ (n, α)
FOR NATURAL BORON
○ = BBB
● = A
♦ = ZSC
■ = KA
σ_t EXPERIMENT
σ_t NON-RESONANCE THEORY
σ (N, α) EXPERIMENT
σ (N, α) THEORY
σ_{in} THEORY
σ in BARNS
$\sqrt{E}$ (MEV)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
.5
0
.2
.3
.4
.5
.6
.7
.8
.9
1.0
1.1
1.2
1.3
1.4
1.5
1.6
1.7
1.8
1.9
2.0
2.1
2.2

FIG. 2

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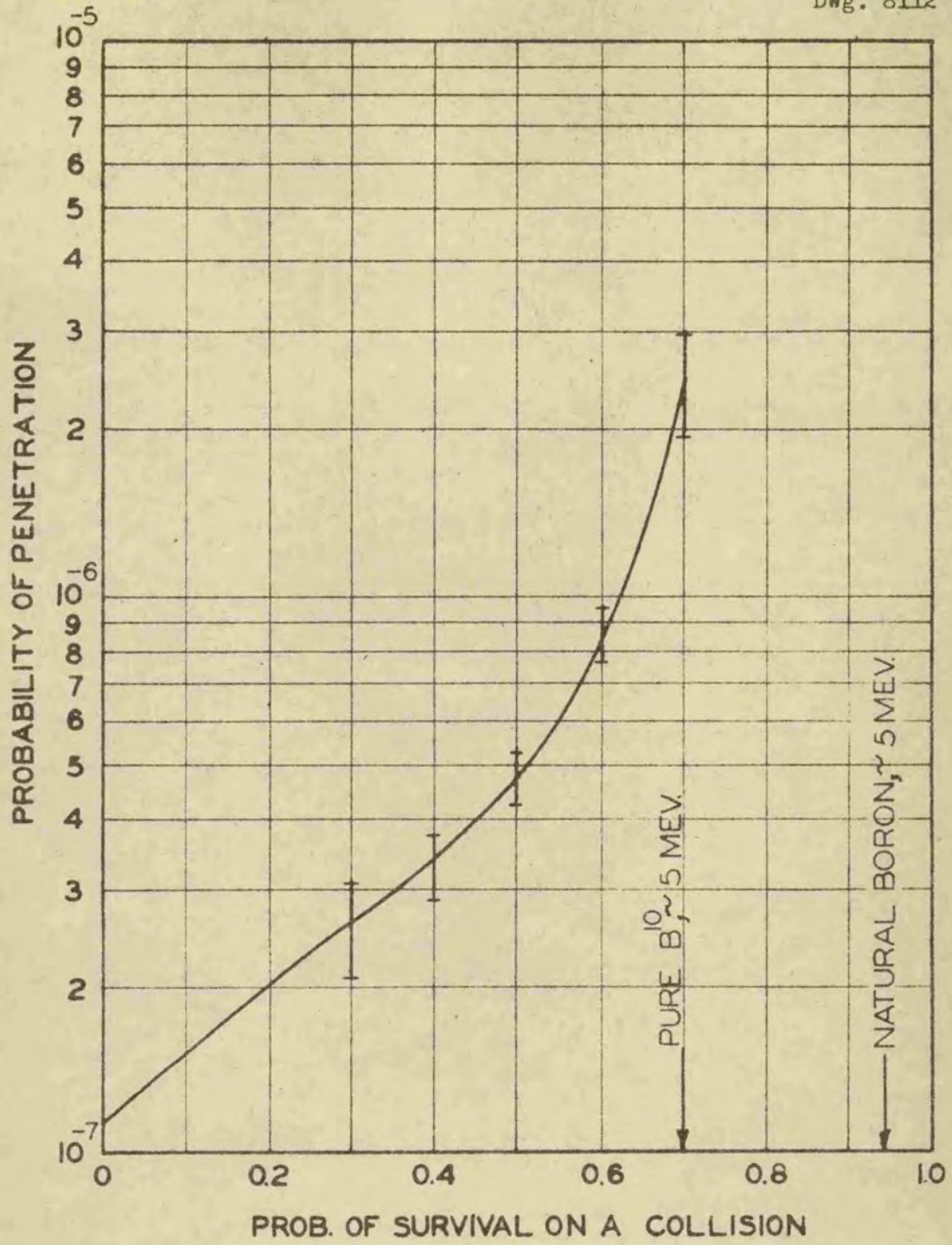

FIG. 3

STOCHASTIC ESTIMATE BY G. GOERTZEL
PROBABILITY OF PENETRATION OF A SLAB, 16 MEAN FREE PATHS, NO SLOWING DOWN, AS A FUNCTION OF PROBABILITY OF SURVIVAL ON COLLISION.