UCRL-8617

MASTER

UNIVERSITY OF CALIFORNIA

Lawrence Radiation Laboratory
Berkeley, California

Contract No. W-7405-eng-48

MEASUREMENT OF AVERAGE NEUTRON ENERGIES FOR (α, n) NEUTRON SOURCES

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April 1, 1959

Printed for the U. S. Atomic Energy Commission

254 001

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Abstract

A method is presented for measuring the average energy of the neutrons from a source. The attenuation of the neutrons by polyethylene is measured by the use of a long counter in good geometry. The attenuation length is a sensitive function of the neutron energy. The average neutron energies from several (α, n) sources have been measured and agree well with values obtained by other techniques.

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The problem of measuring the energy spectrum of neutron sources in the Mev range is not an easy one. Many experiments have been performed, especially with various (α, n) neutron sources, but the results are not too good. In order to get more information about the energy of neutrons from such sources, we have measured the attenuation of the neutrons in polyethylene (CH_2). The neutron detector used was a Hansen and McKibben long counter,[1] and the measurements were made in good geometry.

The counting rate of the long counter was measured for various thicknesses of CH_2 and also for a thick (8-inch) copper absorber; this latter measurement supplied the required "room background" correction for all other data. The measurements were carried out in a thin-walled building (about 1 gm/cm^2 thick) to minimize scattering. The voltage and bias plateaus of the long counter were measured accurately and were quite flat over a considerable range. The source counting rate with no CH_2 absorber was checked several times to assure that the electronics system characteristics were stable. Variations observed here were less than 0.25%. The background counting rate was also checked to see that no significant changes took place.

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[1] A. O. Hansen and J. L. McKibben, Phys. Rev. 72, 673 (1947).

From the total cross sections[2] the attenuation curves for various monoenergetic neutrons have been calculated and are shown in Fig. 1. The energy of a monoenergetic neutron source can be determined to about 10% from the slope of the att nuation curve for the range of energies shown. The problem is more complicated for a source that has a spread of neutron energies. The attenuation curve is not straight as in Fig. 1 but is curved because the spectrum hardens as it passes through the attenuator. The data from Po-Be is shown in Fig. 1 to demonstrate this point.

If good enough data were taken, the neutron-energy spectrum of a source could be obtained from the curvature of the attenuation curve. We tried this for a Po-Be source and found that the calculations were too sensitive to the measured counting rates for different absorber thicknesses to give good results. Our measurements had an accuracy of ± 0.5% and were not good enough to give the spectrum. We estimate that measurements ten times as accurate as ours might give reasonable energy spectra.

From a measured or calculated neutron-energy spectra, we can calculate the CH_2 attenuation curve. We do this by using the total neutron cross section for CH_2 and decreasing the height of the neutron energy spectrum by the proper attenuation factor at several different energies for several different thicknesses of CH_2 absorber. The areas under these different curves are determined and plotted versus absorber thickness to make the attenuation curve. Such a curve for Po-Be is shown in Fig. 2, also shown are the measured points for Po-Be.

[2]D. J. Hughes and J. A. Harvey, Neutron Cross Sections, BNL-325, July 1, 1955.

In order to compare the calculated and measured attenuation curves, we must know that our detector does not distort the energy spectrum, that is, the detector must have the same sensitivity for neutrons of all energies. Otherwise, we would have to weight the energy spectrum by the energy sensitivity of the detector. The energy sensitivity of the Hansen and McKibben counter is known to be constant to ± 10% from E = 25 kev to 9 Mev.[3] No correction has been made for the small variation in energy sensitivity of the detector.

Measurements of the attenuation in CH_2 have been made for sources of polonium-beryllium, polonium-lithium, plutonium-beryllium, and radium-beryllium. The results are shown in Figs. 2—5. The curves calculated from various energy spectra are also shown.[4—9] Determination of the attenuation curves for Po-Be and Ra-Be were repeated for thin absorbers to compare the yield of low-energy neutrons from these sources. From Fig. 6 we see that there are more low-energy neutrons from Ra-Be than from Po-Be, because the Ra-Be curve falls faster.

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[3] W. D. Allen and A. T. G. Ferguson, The Measurement of Fast Neutron Flux over the Neutron Energy Range 0.030 Mev to 3 Mev, AERE-NP/R-2096, October 1956; and J. E. Perry, Los Alamo Scientific Laboratory, private communication, 1957.

[4] David M. Barton, Measurement of the Neutron Spectrum from a $Po-Li^7$ Low-Energy Neutron Source, LA 1609, July 1953.

[5] B. G. Whitmore and W. B. Baker, Phys. Rev. 78, 799 (1950).

[6] Leona Stewart, Phys. Rev. 98, 740 (1955).

[7] D. L. Hill, Studies with the Ranger, AECD 1945 (rev.), April 1947.

[8] Wilmot N. Hess, Annals of Physics, 6, 115 (1959).

[9] Pierre Demers, Energy Distribution of Neutrons from a Ra-Be Mixed Source, MP-204, November 1945.

Curve A of Fig. 6 is the Po-Be calculated attenuation curve from the calculated neutron-energy spectrum of Hess for excitation of the 0; 4.43-, and 7.65-Mev levels in C^{12} with no three-body breakup. Curve B is calculated for Po-Be from three-body breakup instead of excitation of the 7.65-Mev level. From comparison with the experimental data, it is obvious that the attenuation curve calculated from the energy spectrum shown in reference 8, Fig. 3, Curve A (no three-body breakup) is the best fit for Po-Be.

The neutron energy spectrum of Ra-Be[7] used in calculating Curve C of Fig. 6 is shown in Fig. 7. This has considerably more low-energy neutrons than Curve B for Po-Be. These low-energy neutrons are due to three-body breakup of the C^{13} compound nucleus. In other experiments to measure the neutron-energy spectrum of Ra-Be, this group of low-energy neutrons has not been detected, but there are other data that tend to confirm the existence of the low-energy group. First, the average neutron energy from Ra-Be is lower experimentally than the average neutron energy from Po-Be.[10] The Ra-Be spectrum extends to higher energies than Po-Be, so it must have an appreciable low-energy yield to make the average energy less. The fact that the age to indium resonance for Ra-Be neutrons in H_2O is less than for Po-Be in H_2O agrees with this. Secondly, the age measurements for a Ra-Be neutron source in graphite indicate three neutron groups of ages 130, 340 and 815 cm^2.[11] The yield of the 130 cm^2 group is 15% of the total. Calculating the age from the expression[12]

$$\tau = \int \frac{D}{\xi \Sigma_s} \frac{dE}{E} ,$$

[10] Alan R. Smith, University of California Radiation Laboratory, private communication, Jan. 1959.

[11] V. G. Beckerley, Neutron Physics, AECD-2664, 1949.

[12] S. Glasstone and M. C. Edlund, The Elements of Nuclear Reactor Theory (Van Nostrand, New York, 1952).

we get $\tau = 130\ cm^2$, which corresponds to an energy of about 5 kev. This is a lower energy than is allowed by our measurements. The Ra-Be spectrum shown in Fig. 7 shows the low-energy group from three-body breakup centered around 0.5 Mev. The energy of this group could be lowered to about 100 kev and still give agreement with the measured CH_2 attenuation curve. Below 100 kev there would start to be disagreement, and it is hard to see how a large number of such low-energy neutrons would be produced physically. Even though the age seems too small, the existence of this low-energy neutron group ($\tau = 130\ cm^2$) tends to confirm our measurements on Ra-α-Be. Measurements by De Pangher at Hanford also indicate the presence of a low-energy neutron group in Ra-Be.[13]

In Table I are shown several energies associated with the various neutron sources. Column I gives the average energies of various measured neutron-energy spectra. Column II gives the average energies of the neutron-energy spectra calculated by Hess.[8] Column III gives the "average" energy obtained from the attenuation curves. This is obtained from the average slope of the attenuation curves for the first factor-of-ten decrease in counting rate. Column IV gives the average energy of several neutron spectra measured by using a proton-recoil energy-flux proportional counter.[14]

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[13] John De Pangher, Hanford Works, Richland, Washington, private communication, 1958.

[14] Burton J. Moyer, Survey Methods for Neutron Fields, UCRL-1635, Jan. 1952.

Table I

Average energies for various α, n neutron sources

Source	Energy (Mev)			
	I	II	III	IV
Po-Li	0.336[4]	0.460	0.480	
Po-Be	3.9[5]	4.08	4.2	4.5
Pu-Be	4.43[6]	4.05	4.1	4.2
Ra-Be	4.17[7]	3.50	3.7	4.1
	3.6[13]			

CONCLUSIONS

This technique of measuring average neutron energies is quite foolproof and has the advantage of simplicity. It should be useful in studying new neutron sources. The ability to distinguish between spectra that are quite similar has been demonstrated by the work presented here on usual laboratory neutron sources. The fact that the new low-energy neutron group in a Ra-α-Be source has been found by the use of this technique shows its merits.

Figure Legends

Fig. 1. Attenuation curves for various monoenergetic neutrons in CH_2. Shown for comparison is the experimental attenuation curve of a Po-Be source.

Fig. 2. Attenuation curve for Po-Be neutrons in CH_2. Calculated curves from the spectra of Hess[8] and from Whitmore and Baker[5] are shown for comparison.

Fig. 3. Attenuation curve for Po-Li neutrons in CH_2. The calculated curves from Hess[8] and Barton[4] are shown for comparison.

Fig. 4. Attenuation curve for Pu-Be neutrons in CH_2. Calculated durves from the spectra of Hess[8] and Stewart[6] are shown for comparison.

Fig. 5. Attenuation curves for Ra-α-Be neutrons in CH_2. Calculated curves from the spectra of Hess[8] Hill[7] and Demers[9] are shown for comparison.

Fig. 6. Attenuation curve for Po-Be and Ra-Be for thin CH_2 absorbers. Calculated curves from Hess[8] are shown. Curve A is for Po-Be calculated considering excitation of the 0-, 4.43- and 7.65-Mev energy levels in C^{12}. Curve B is for Po-Be considering excitation of the 0- and 4.43-Mev energy levels and three-body breakup instead of excitation of the 7.65-Mev level. Curve C is for Ra-Be from the energy spectrum shown in Fig. 7.

Fig. 7. The neutrons energy spectrum for Ra-Be calculated by Hess.[8]

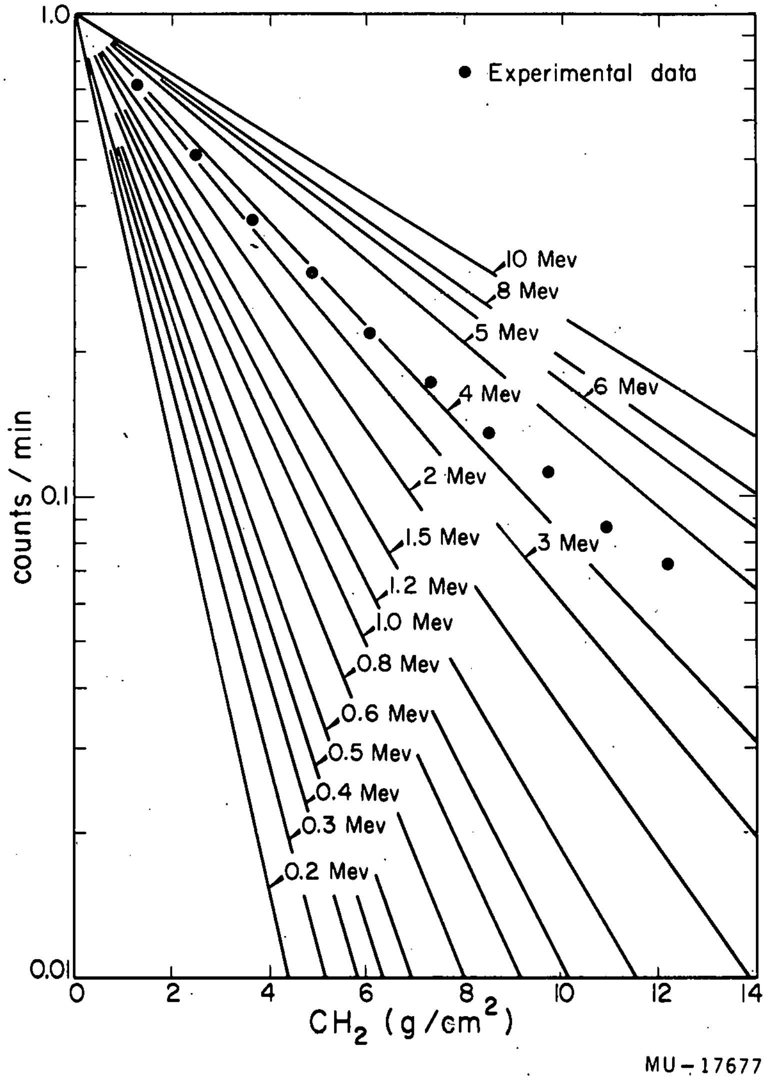
Experimental data
10 Mev
8 Mev
5 Mev
6 Mev
4 Mev
2 Mev
1.5 Mev
3 Mev
1.2 Mev
1.0 Mev
0.8 Mev
0.6 Mev
0.5 Mev
0.4 Mev
0.3 Mev
0.2 Mev
1.0
0.1
0.01
counts / min
0
2
4
6
8
10
12
14
CH_2 (g/cm^2)
MU-17677

Fig. 1

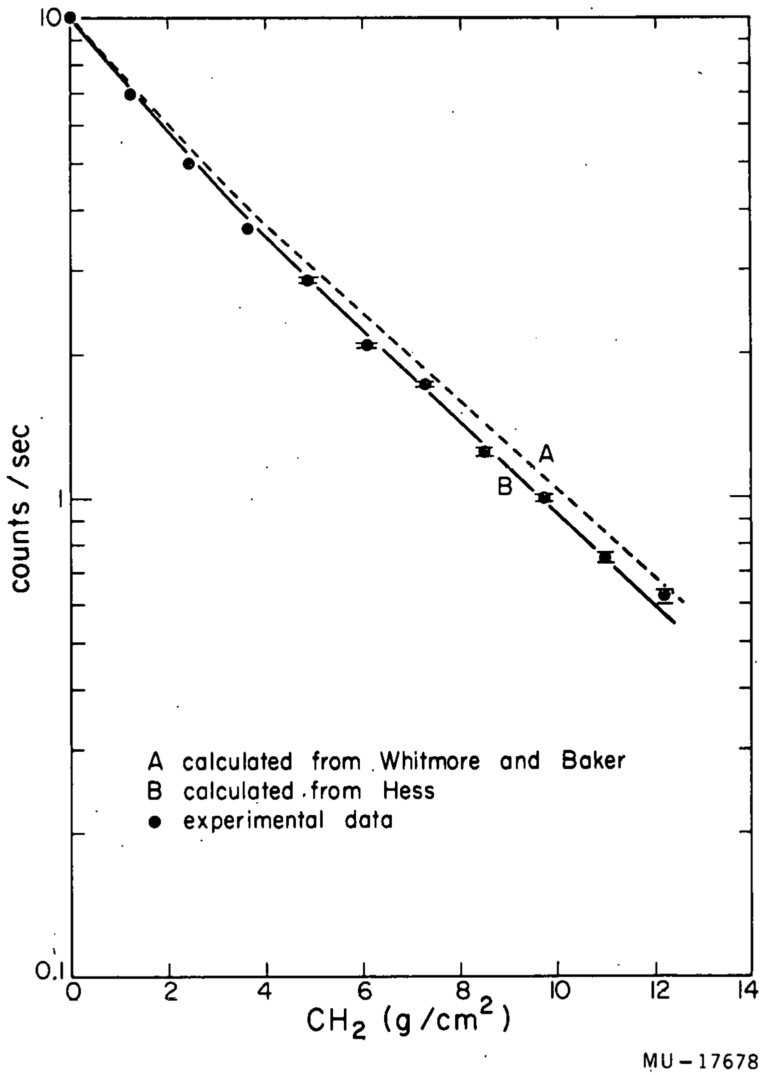
10
1
0.1
counts / sec
0
2
4
6
8
10
12
14
CH2 (g/cm2)
A
B
A calculated from Whitmore and Baker
B calculated from Hess
● experimental data
MU-17678

Fig. 2

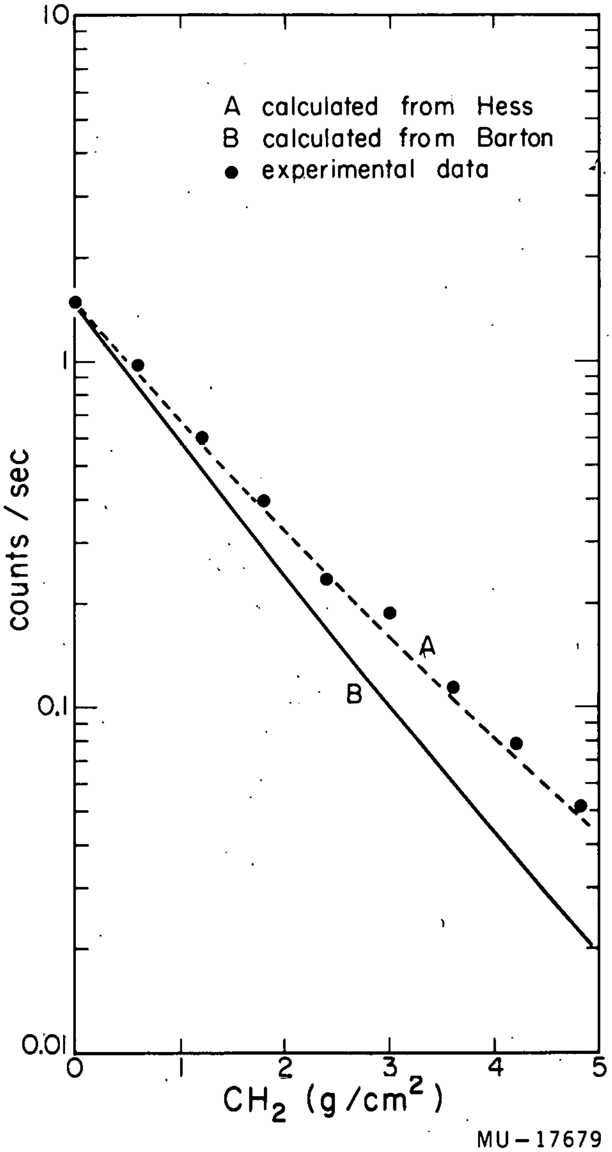
A calculated from Hess
B calculated from Barton
experimental data
counts / sec
10
1
0.1
0.01
0
1
2
3
4
5
CH_2 (g/cm^2)
A
B
MU-17679

Fig. 3

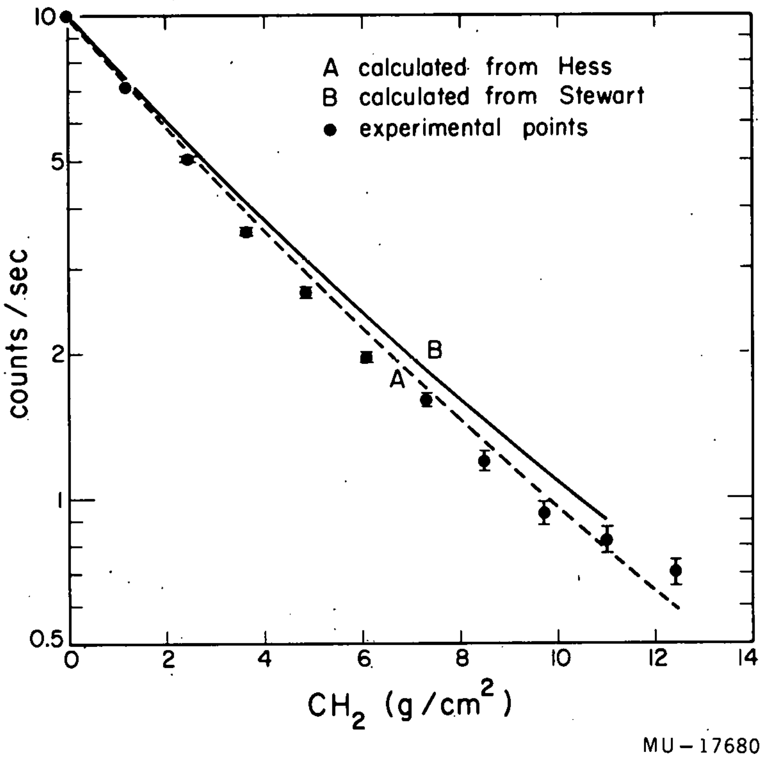
A calculated from Hess
B calculated from Stewart
● experimental points
counts / sec
CH2 (g / cm2)
10
5
2
1
0.5
0
2
4
6
8
10
12
14
A
B
MU-17680

Fig. 4

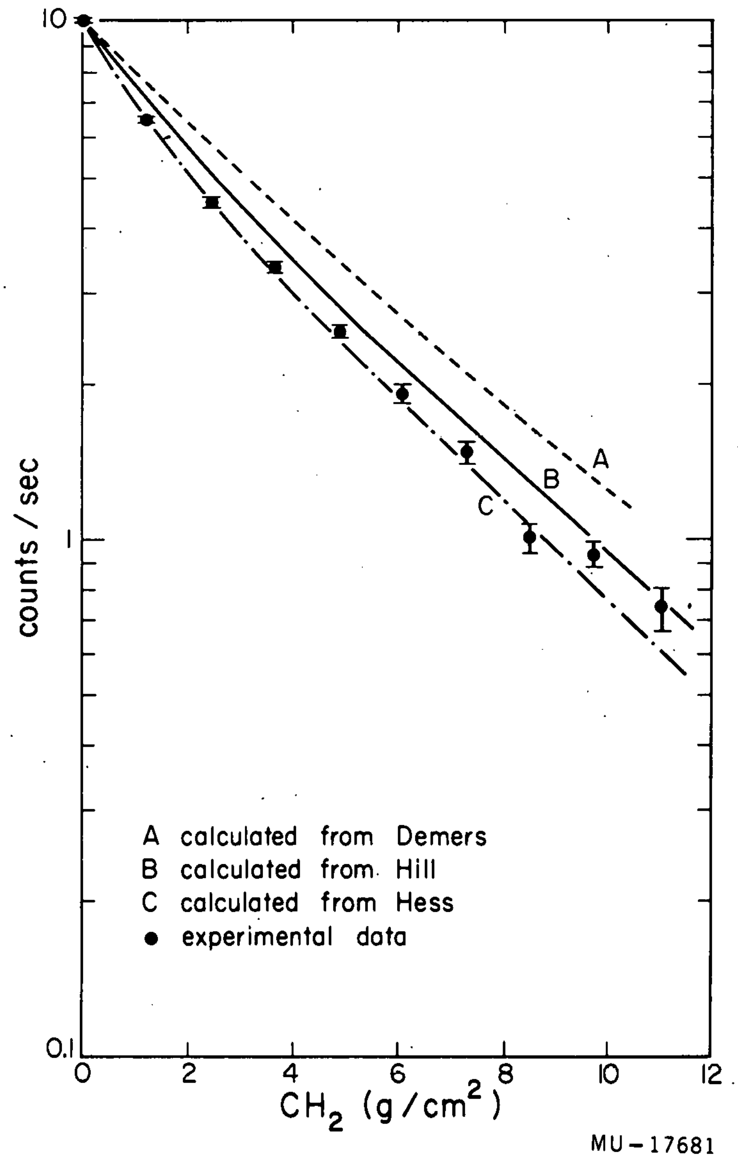
10
1
0.1
counts / sec
0
2
4
6
8
10
12
CH2 (g/cm2)
A
B
C
A calculated from Demers
B calculated from Hill
C calculated from Hess
● experimental data
MU-17681

Fig. 5

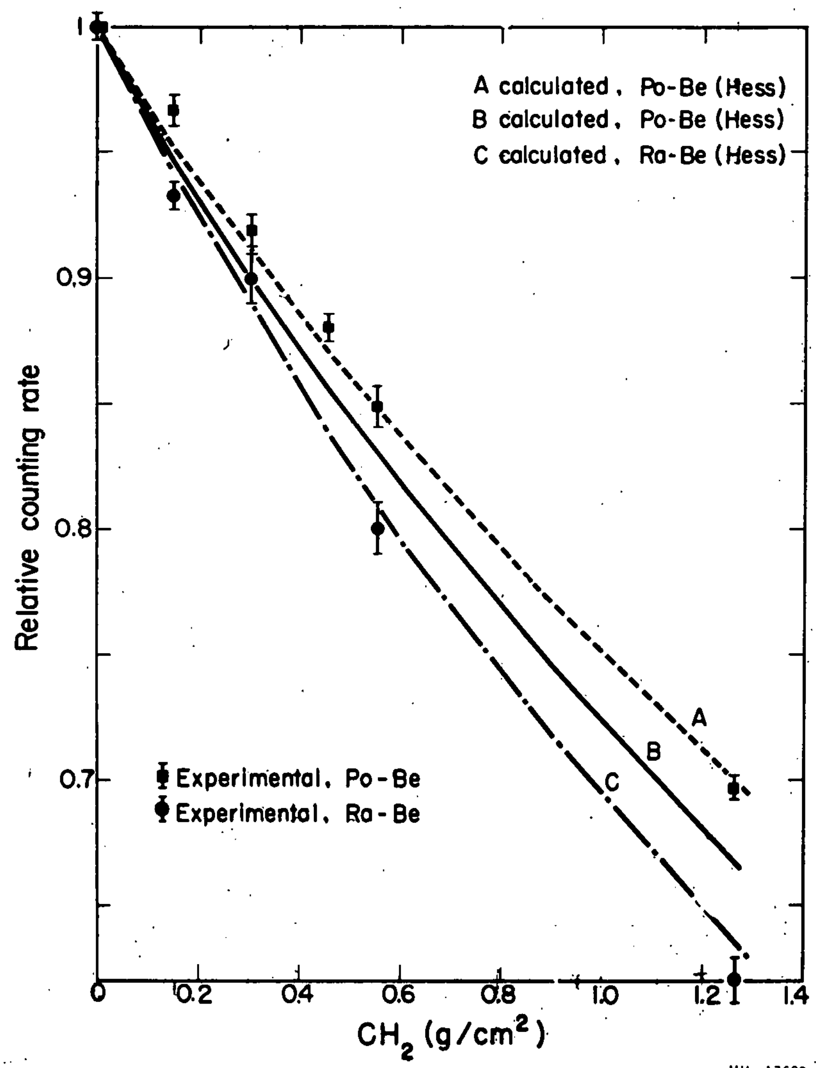
A calculated, Po-Be (Hess)
B calculated, Po-Be (Hess)
C calculated, Ra-Be (Hess)
Experimental, Po-Be
Experimental, Ra-Be
Relative counting rate
CH2 (g/cm2)
1
0.9
0.8
0.7
0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
A
B
C
MU-17682

Fig. 6

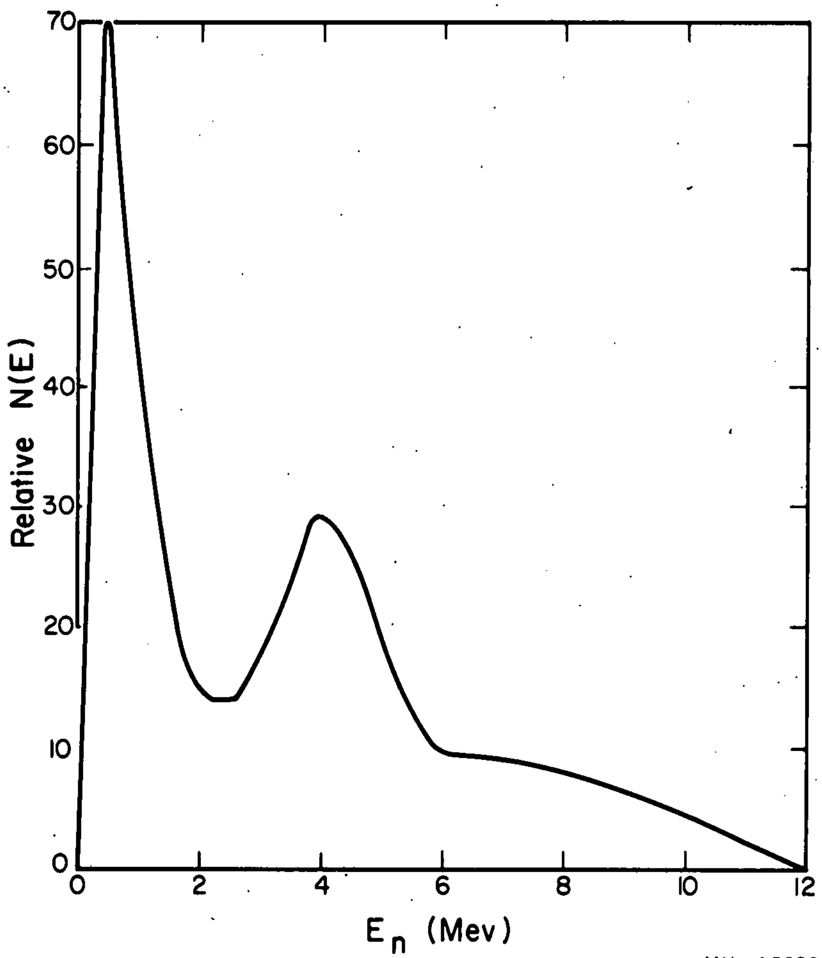

Fig. 7