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(n, 2n) STUDY OF Be^9

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(n, 2n) STUDY OF Be^9

by

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ABSTRACT

The (n,2n) reaction in beryllium has been studied by means of different thicknesses of beryllium around neutron sources, and different thicknesses of paraffin around a boron-lined detecting chamber. Changes in counting rate with these different thicknesses of beryllium and paraffin are attributed to elastic scattering, absorption, and the (n,2n) reaction. Absorption is almost certainly negligible. The effect of elastic scattering was mocked up by means of different thicknesses of graphite, so that the (n,2n) residue could be determined.

Sources of error in this and other measurements of the reaction are discussed. It is found that if fission neutrons are permitted to collide with beryllium before they are degraded below the threshold of the reaction by collisions with other materials, the (n,2n) reaction can make a significant contribution to the neutron economy of a reactor.

INTRODUCTION

During a study of the effect of various materials at the center of Jezebel,$^{(1)}$ it was found that of all the non-fissionable isotopes studied, only protium and beryllium gave positive reactivity contributions. Even such excellent moderators as deuterium and carbon gave negative contributions, and among the fissionable isotopes, thorium-232 was negative. The case of protium is understood. A single collision with a proton can reduce a neutron of any energy to one of thermal energy. For beryllium also to give a positive reactivity contribution, (a) in some manner more neutrons come out of the beryllium than go in, or (b) the neutrons which come out are of very much lower energy than those which go in. The (n,2n) reaction can satisfy both of these criteria. The binding energy of the odd neutron in the beryllium nucleus has been determined by the (γ,n) reaction to be 1.662 Mev,$^{(2)}$ which for a neutron in the laboratory system becomes 1.85 Mev. The incident neutron loses this energy immediately, and the daughter neutrons share, not necessarily equally, the energy which remains. For incident neutrons only a little above the (n,2n) threshold, this can result in very low energy daughter neutrons.

The (n,2n) reaction has been studied by a number of observers. Agnew has tabulated the results of previous workers, as well as making measurements of his own.(3) The published values range from 40 millibarns to 4.1 barns. A large part of this spread results from the different methods of detection. Since the daughter neutrons can be of very low energy, any method of detection which favors high energy neutrons will give results which are too low, and a method which favors the low energy neutrons will give results which are too high. The measurements of Agnew are uncertain in this regard. The long counter which he used has been carefully studied in regard to energy response.(4) It is essentially flat in response from a few hundred kev to several Mev, except for some dips which are attributed to resonance scattering in the carbon of the paraffin. At 25 kev the efficiency has dropped 10 per cent, and it may drop still further at lower energies. That this has occurred is indicated by Agnew's results with a mock-fission source. With each thickness of beryllium, the number of counts observed was less than with the bare source. The absorption of beryllium in the epithermal and higher energies is almost certainly negligible. That fewer neutrons were seen with the beryllium around the source can well indicate that the daughter neutrons were born with such low energy that they were not seen by the counter. Further work seemed desirable.

During a study of several sources with different thicknesses of paraffin around a boron-lined chamber,(5) it was noticed that when a mock-fission source was surrounded by beryllium shells, higher counting rates were obtained than with the bare source. It is obvious that a boron counter surrounded by thin paraffin sees slow neutrons better than the same counter surrounded by thick paraffin sees fast neutrons. On the other hand, moderation is a spreading out of neutron energies, rather than a bodily transfer from one energy to another, and no one thickness of paraffin is optimum for all of the neutrons. It was not obvious which of these effects is predominant. An approximate method of determining this is to degrade the neutrons with some other material which does not have the (n,2n) reaction in the same region as beryllium. Any excess then can be attributed to the (n,2n) reaction.

APPARATUS

The boron counter and paraffin shells have been previously described.(5) A general view of the apparatus is shown in Fig. 1. In the previous work, where neutron energy was the important factor, corrections for room scattering were made. In the present work, where the number of neutrons was considered the important factor and it was not important to know the path by which they reached the counter, whether direct or scattered from the walls, floor, and ceiling, a fixed distance of 1 meter between source and counter was routine.

Beryllium shells used had thicknesses of 1.11, 2.12, 4.24, and 6.36 centimeters. Graphite was selected as the comparison moderator. Its atomic number is similar, its total cross section is also similar, and the absorption somewhat less. Inspection of the curves(6) indicated a cross section for carbon of 2.5 and for beryllium of 2 barns, a ratio of 1.25 in the region of interest. The atomic numbers are 12 and 9, a ratio of 1.33. With the specific gravity of beryllium taken as 1.85 and that of graphite as 1.67, a ratio of atoms per unit volume of 1.48 is obtained. The product of these three ratios is 2.45, and it therefore seemed that graphite two and a half times the thickness of beryllium should give about the same moderating effect. Therefore, graphite shells of 15.4, 10.1, 5.3, and 2.7 centimeters thickness were obtained. The outside diameters of each pair of graphite and beryllium shells were the same.

Two neutron sources were available whose energy spectra were known approximately; one was a mock fission, and the other a plutonium-beryllium. Richards has compared the spectrum of a mock-fission source with the fission spectrum,(7) and a more recent comparison has been made by Lindsey.(8) They agree in that although the average energies of the mock-fission and the fission spectra are similar, in the mock-fission spectrum there is an excess of neutrons in the region from 1 to 1.7 Mev, and a deficiency from 2 Mev up. This means that more of the mock-fission neutrons lie below the threshold of the (n,2n) reaction in beryllium than in the true fission spectrum. The plutonium-beryllium source was similar to one measured by Stewart,(9) who found an average energy of 4.2 Mev, with about 80 per cent of the neutrons above the (n,2n) threshold in beryllium.

RESULTS

For each source configuration, counting rate was measured as a function of thickness of paraffin about the detector. Figure 2 shows the results of the series of counts made with a mock-fission source: bare, inside 6.36 cm of beryllium, and inside 15.4 cm of graphite. In addition to shifting the position of maximum counting rate, the graphite does increase the effectiveness of the source. The increase due to thinner paraffin is greater than the decrease due to the spreading out of the neutron energies. With the beryllium the shift in maximum counting rate is about the same as with the graphite, as was calculated, but the number of counts at maximum is almost 6 per cent greater than with the graphite.

Figure 3 shows the results of a similar series of counts using the plutonium-beryllium source. The shift in the position of the maximum counting rate between the bare source and the source enclosed in graphite is almost the same as with the mock-fission source, and the increase in the number of counts is only slightly greater. The results with the source enclosed in beryllium are markedly different. Not only are the numbers of counts greatly increased, but the position of the maximum is shifted almost to that with the mock-fission source. A considerable number of low energy neutrons evidently have been added to the spectrum. The fact that the neutrons consist of two groups introduces an error which is difficult to evaluate. The resolution of the method is not sufficient to separate the two groups, and it is perhaps safest simply to recognize that the percentage increase shown by the difference between beryllium and graphite is low by an undetermined amount.

The other thicknesses of beryllium and graphite gave smaller but similar results. A summary of these results is plotted in Fig. 4. The abscissa is the thickness of beryllium in centimeters, and the ordinate the percentage increase of counting rate with beryllium around the sources, over that with the sources surrounded by graphite two and one-half times the thickness of the Be. The probable errors plotted are the statistical probable errors. Within experimental error, the points with the mock-fission source can be fitted by a straight line, that is, the effect may be a simple exponential. This does not seem to be true of the plutonium-beryllium source. Although the experimental accuracy does not entirely exclude the fitting of the points by a straight line, it seems very improbable. What does seem to be happening is that the effect increases as the average energy of the neutrons is brought down into the 2 to 3 Mev region (i.e., about 3 cm thick Be), and then falls off as more neutrons drop below the threshold energy. It is interesting that both the total cross section and the (n,α) cross section show peaks in the 2 to 3 Mev region.(6) One is tempted to think that the peak in the total cross section may be due in part to the formation of a compound nucleus, which may break up by the (n,2n) reaction, by the ejection of a neutron leaving the nucleus with insufficient energy to emit the second neutron, or by the (n,α) reaction. It is certain, however, that even with the mock-fission source the (n,2n) reaction is not negligible, and for reasons already given, the effect with newborn fission neutrons will lie between that with the mock-fission source and that with the plutonium-beryllium.

The neutron economy of a reactor is dependent not only on the total number of neutrons generated in the assembly, but also on their energy. The low energy neutrons generated by the (n,2n) reaction are more effective in causing fission than the newly generated fission neutrons. A crude method of determining this was by the response of the bare boron-lined chamber, corrected for the room-scattered neutrons. This correction was made by assuming that the room-scattered neutrons were uniform over a small region in the center of the room, whereas the direct neutrons varied as the inverse square of the distance between the source and the counter. By taking counts at two different distances, the neutrons following each path could be computed. A test of the assumption, made by taking counts at three different distances, showed that the assumption was valid within the statistical probable error, which was less than half of one per cent.

All of the locally-scattered neutrons will follow the inverse square law, and will appear as direct, rather than room-scattered. In the case of the plutonium-beryllium source, bare, and with a bare chamber, about 5 counts per minute appeared to follow the direct path. With graphite around the source, enough more were slowed down by the graphite to give 13 counts per minute. With the 6.36 cm of beryllium around the source this was raised to 83. With the mock-fission source, which was a stronger source and of lower energy to begin with, these numbers were 17, 44, and 175, respectively.

CONCLUSIONS

In contrast to Agnew's findings, this study showed that there is an appreciable amount of (n,2n) reaction in the neutrons from a mock-fission source with beryllium. It appears from the results with a plutonium-beryllium source that it is a resonance effect. The lower energy of the daughter neutrons gives them an effectiveness in a reactor greater than their absolute numbers would indicate. Unfortunately, our knowledge of the energies of the neutrons from the sources and of the resonance, if there is a resonance, does not seem to justify a statement as to the absolute value of the cross section.

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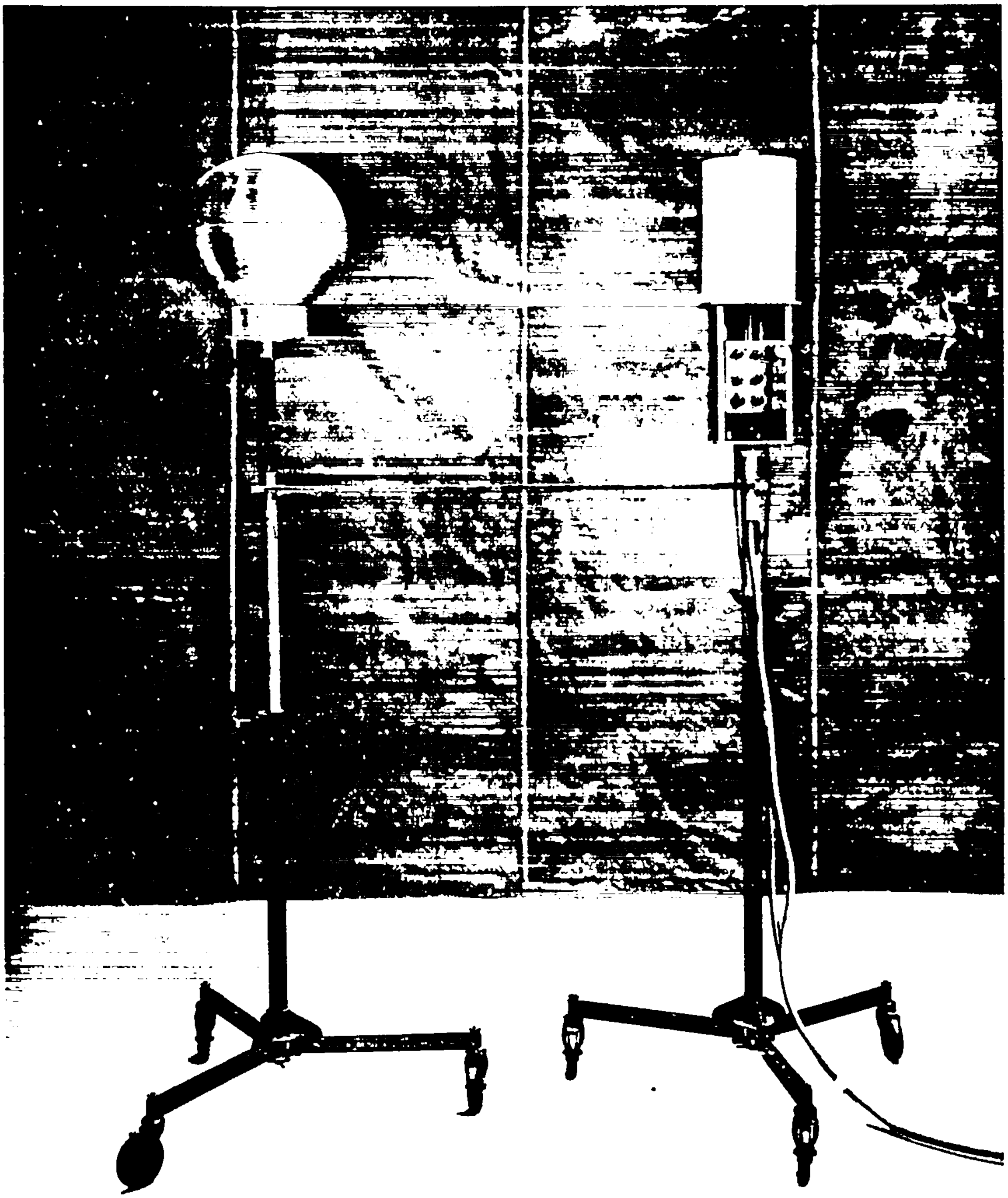

Fig. 1 General view of apparatus.

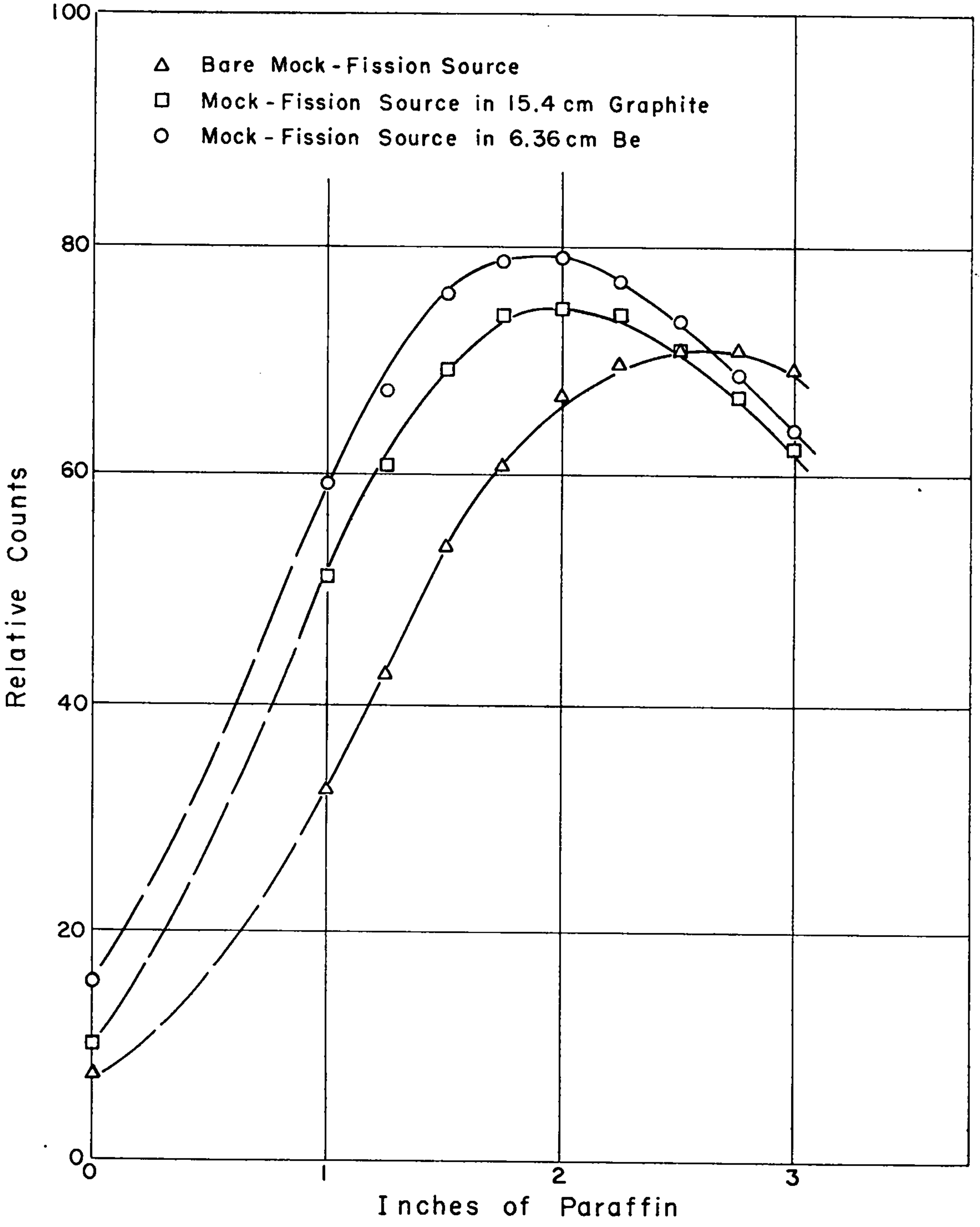

Fig. 2 Relative counting rates with a mock-fission source, bare, in 15.4 cm of graphite and 6.36 cm of Be, as a function of paraffin thickness.

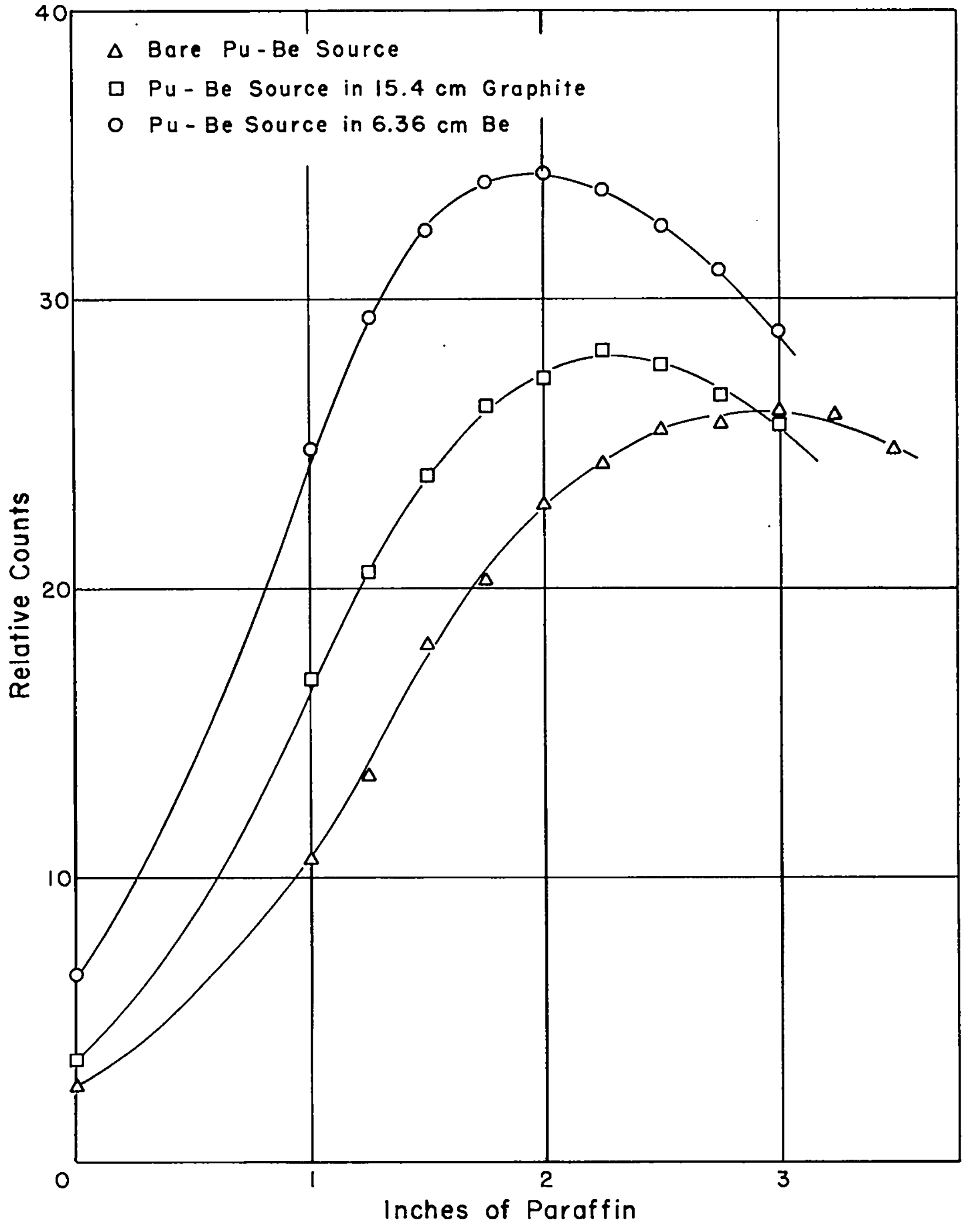

Fig. 3 Relative counting rates with a Pu-Be source, bare, in 15.4 cm of graphite, and 6.36 cm of Be, as a function of paraffin thickness.

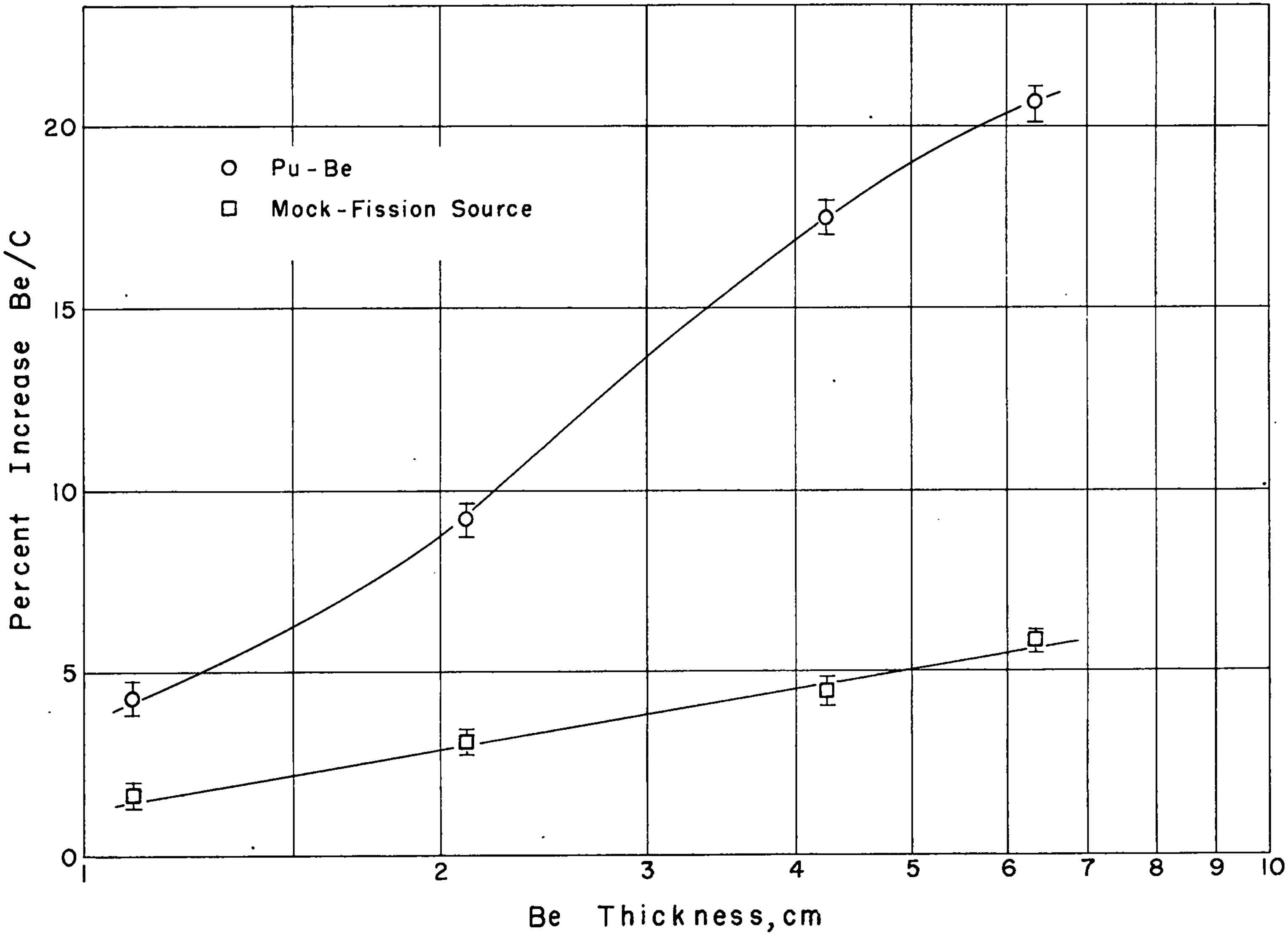

Fig. 4 Increase in counting rate with different thicknesses of Be over that with graphite 2.5 times the Be thickness.