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MEASUREMENTS AND CALCULATIONS OF NEUTRON DETECTOR EFFICIENCIES*

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Neutron detector absolute efficiencies measured in our laboratory for several organic scintillators are reported. A substantially revised version of Kurz's neutron detector efficiency computer program has been used to calculate efficiencies for new and previous measurements. Good agreement has been obtained for various scintillators.

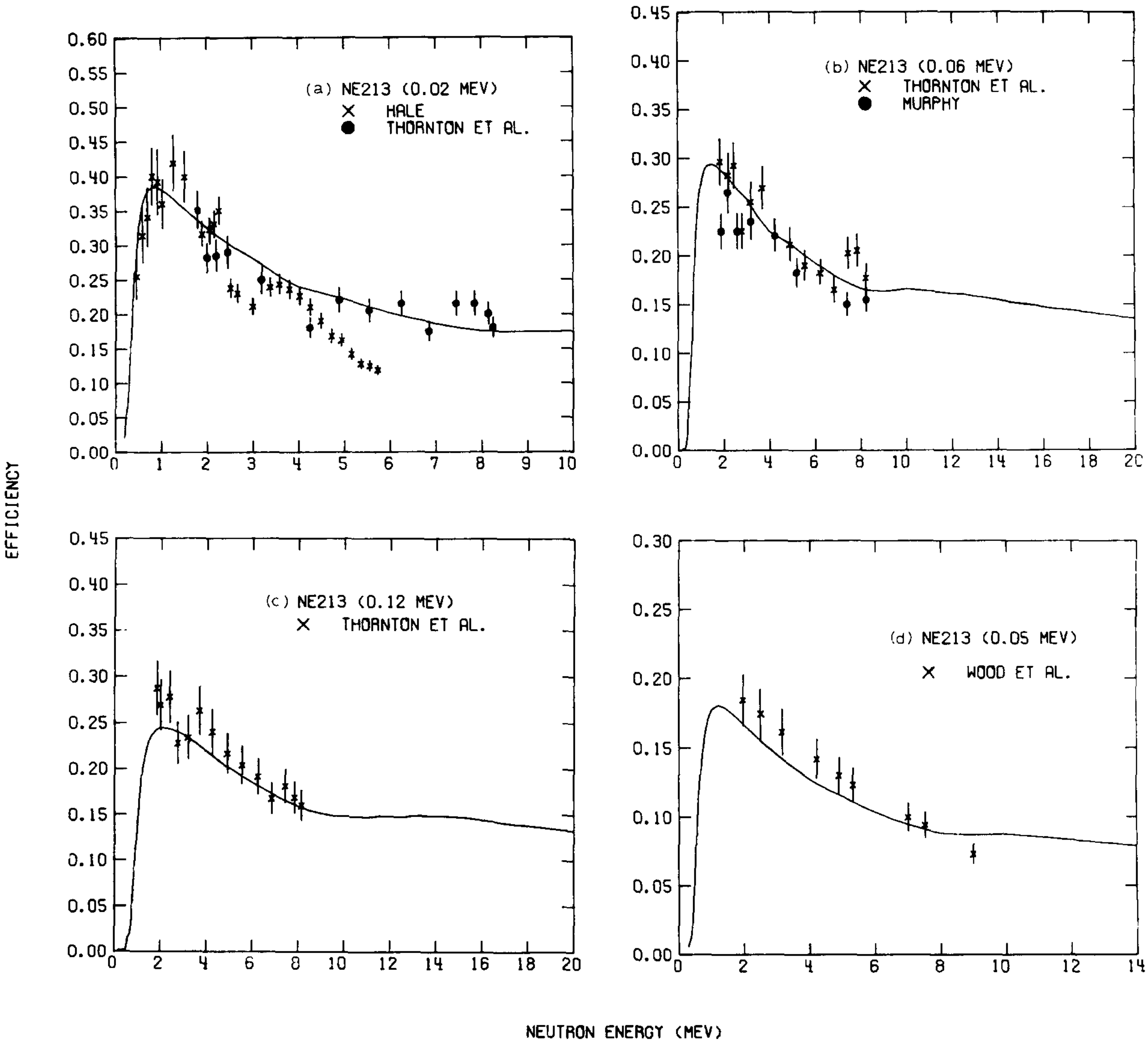

Fig. 1. Comparisons of experimentally measured neutron detector efficiencies and calculations by DETEFF (solid line). The calculations were made for an equivalent electron energy bias as indicated in the parenthesis. The measurements were by (a) Hale[15]) and Thornton et al.[12]), (b) Thornton et al.[12]) and Murphy[13]), (c) Thornton et al.[12]), and (d) Wood et al.[18]).

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1. Introduction

In recent years a number of measured and calculated neutron detector efficiencies have been reported[1-10]. There has been significant disagreement between experiment and calculation in some cases. In addition, most calculations have been for only particular scintillators with unique light output values and hydrogen/carbon ratios. In our laboratory we use various organic scintillators and have needed a computer program to generate absolute efficiencies for any type or size organic scintillator.

We have substantially revised a computer program by Kurz[11] to calculate neutron detector efficiencies for any organic scintillator whose light output, density, and hydrogen/carbon ratio is known. We have compared the results of this revised program, now called DETEFF, to absolute efficiency measurements recently made in our laboratory[12-16] and with previously reported measurements.

2. Experimental measurements

The new efficiencies reported were obtained with the University of Virginia 5.5 MV pulsed Van de Graaff accelerator in conjunction with the Mobley magnet bunching system. The majority of the measurements were made with the $T(p,n)^3He$ and $D(d,n)^3He$ reactions. Comparison with the known absolute differential cross section values produced absolute neutron efficiencies. In some cases relative measurements were made by scattering neutrons from a hydrogenous sample in order to vary the neutron energy. A normalization of the relative efficiency to one of the absolute measurements was then made. The general method of our neutron time-of-flight measurements has been described previously[17].

The new measurements are shown in figs. 1 and 2 along with a previously unreported measurement from Wisconsin[18]. The scintillators are cylindrical and the neutrons entered one flat side while the photomultiplier tube faced the other side. The NE213* scintillator used in our laboratory was 12.7 cm in dia. and 3.8 cm deep. Measurements by Thornton et al.[12] were obtained for electron energy biases of 0.02, 0.06 and 0.12 MeV. Additional measurements for a bias of 0.02 MeV by Hale[15] and 0.06 MeV by Murphy[13] have also been made. The 60 keV gamma ray from ^{241}Am was used to establish the low energy bias. An RCA 4522 phototube was used in conjunction with the NE213 scintillator.

The measurements at Wisconsin by Wood et al.[18] were with a 10.2 cm dia. and 1.83 cm deep NE213 scintillator in conjunction with a 58 AVP phototube. The low energy bias was set at $\frac{1}{8}$ the pulse height of the Compton edge of the 0.66 MeV ^{137}Cs gamma ray.

The measurements of Halley[14] were obtained with a Pilot B† scintillator 12.7 cm in dia. and 3.8 cm deep in conjunction with a 58 AVP phototube. A bias of $\frac{1}{3}$ the peak pulse height of the 60 keV ^{241}Am gamma ray was used. The measurements of Reber[16], Thornton et al.[12] and Hale[15] were obtained with a NE102 scintillator 12.7 cm in dia. and 2.5 cm deep with a 58 AVP phototube. The bias was set at the peak of the ^{241}Am 60 keV gamma ray pulse height response.

The range of measurements was from 0.3 to 9 MeV neutron energy. Typical uncertainties are $\pm 8\%$.

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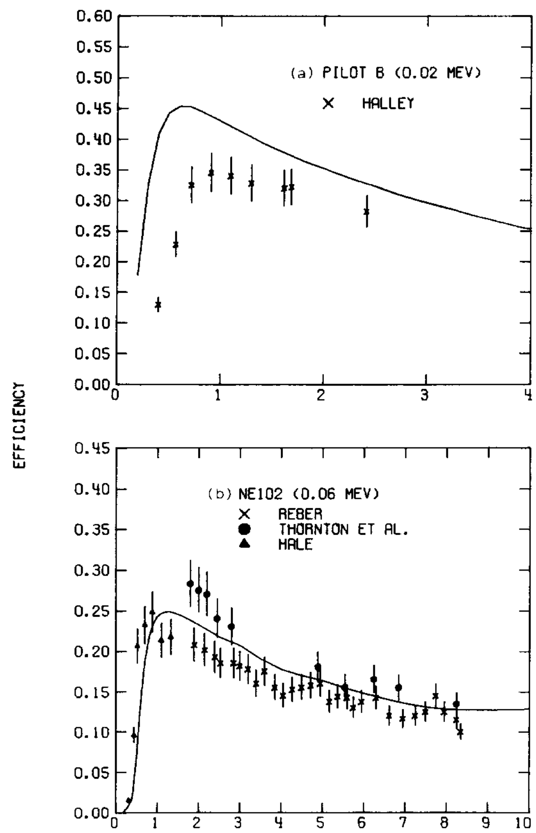

Fig. 2. Comparison of experimentally measured neutron detector efficiencies and calculations by DETEFF (solid line). The calculations were made for an equivalent electron energy bias as indicated in the parenthesis. Measurements were (a) by Halley[14]) and (b) by Reber[16]), Thornton et al.[12]), and Hale[15]).

3. Efficiency calculations

The computer program written by Kurz[11]) was modified in the following ways:

1. Cross sections in the range 0.01 – 1 MeV were included in order to extend the efficiencies to below 1 MeV.
2. Provision was made to vary the hydrogen/carbon ratio rather than having it always equal to unity.
3. The program to calculate the average escape distance was included as a subroutine along with a least mean square fitting subroutine to fit the results. This enables one to make a complete one shot calculation.
4. Provision was made to include light output information for various scintillators rather than only NE102 as was previously done.
5. Other changes such as alphanumeric messages read in and printed out to identify the scintillator, and punched card output for the efficiency were included.
6. The program has been changed to FORTRAN IV.

No basic changes, however, in the calculations were made. The same effects are calculated as before.

The cross section data below 1 MeV was obtained from Gammel[19]) for n–p and from the compilation by Hughes and Schwartz[20]) for n–C. A closed expression for the n–p cross section was used and a least mean square fitting program was used with a power series to fit the n–C data.

At the present time the following scintillators are included: NE102, NE211, NE218 NE213, NE224, Pilot B, anthracene and stilbene. These are the only organic scintillators for which light output values were found. An extensive survey[21]) of the literature was made for the light output of scintillators due to electrons, protons, and alphas. For NE218 the measurements of Masterson[22]) were used. For all the other scintillators the results of Craun and Smith[23]) were used since they were in agreement with many of the other measurements. There is still, however, considerable disagreement between measurements of the light output characteristics and more experiments are needed. The light output for protons and alphas is obtained[23]) from

$$L(E) = S\int_0^E \mathrm{d}\varepsilon[1+kB(\mathrm{d}E/\mathrm{d}x)+C(\mathrm{d}E/\mathrm{d}x)^2]^{-1}. \qquad (1)$$

The form with $C = 0$ was first proposed by Birks[24]). In the computer program the value of S, kB, and C must be known for each scintillator (C may be zero). The light output for electrons[23]) used is

$$L(E) = S(E-0.525)+1000. \qquad (2)$$

The energy losses, $\mathrm{d}E/\mathrm{d}x$, used were from Craun and Smith[23]) for protons. The values for alphas were obtained from the method described by Whaling[25]) with low energy alpha effective charges obtained from Knop and Paul[26]). The light output of NE211 was assumed to be the same as NE213[6]). The hydrogen/carbon ratios and densities were obtained from the manufacturers specifications.

The average escape distance was calculated using the program of Kurz[11]). At the present time the only geometry available is cylindrical with neutrons entering the flat side. Other geometries could easily be incorporated.

4. Results and discussion

The results of the measured detector efficiencies and calculations using DETEFF are displayed in figs. 1–4 along with previously reported measurements. Due to the method of Kurz's calculations there are occasional small discontinuities in the efficiencies, e.g. at 2.9 and 14 MeV. The results near these energies have been smoothed in the figures as they in reality should be.

The overall agreement between experiment and calculation is good. The disagreement in most every case appears to be an error in the determination of the lower level bias. This is clearly evident for the measurement of Pilot B by Halley[14]) in fig. 2. In fig. 4 an extra calculation at 0.60 MeV bias for the measurement by Hunt et al.[7]) indicates better agreement is obtainable for lower bias energies. The occasional disagreement in

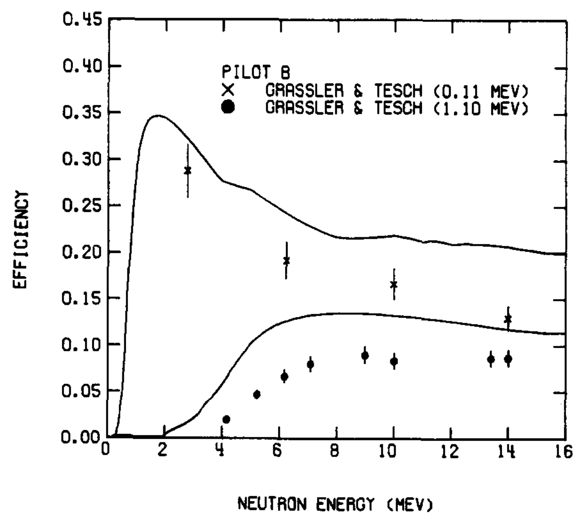

Fig. 3. Comparison of experimentally measured neutron detector efficiencies of Grassler and Tesch[2]) and calculations by DETEFF (solid line). The calculations were made for an equivalent electron energy bias as indicated in the parenthesis.

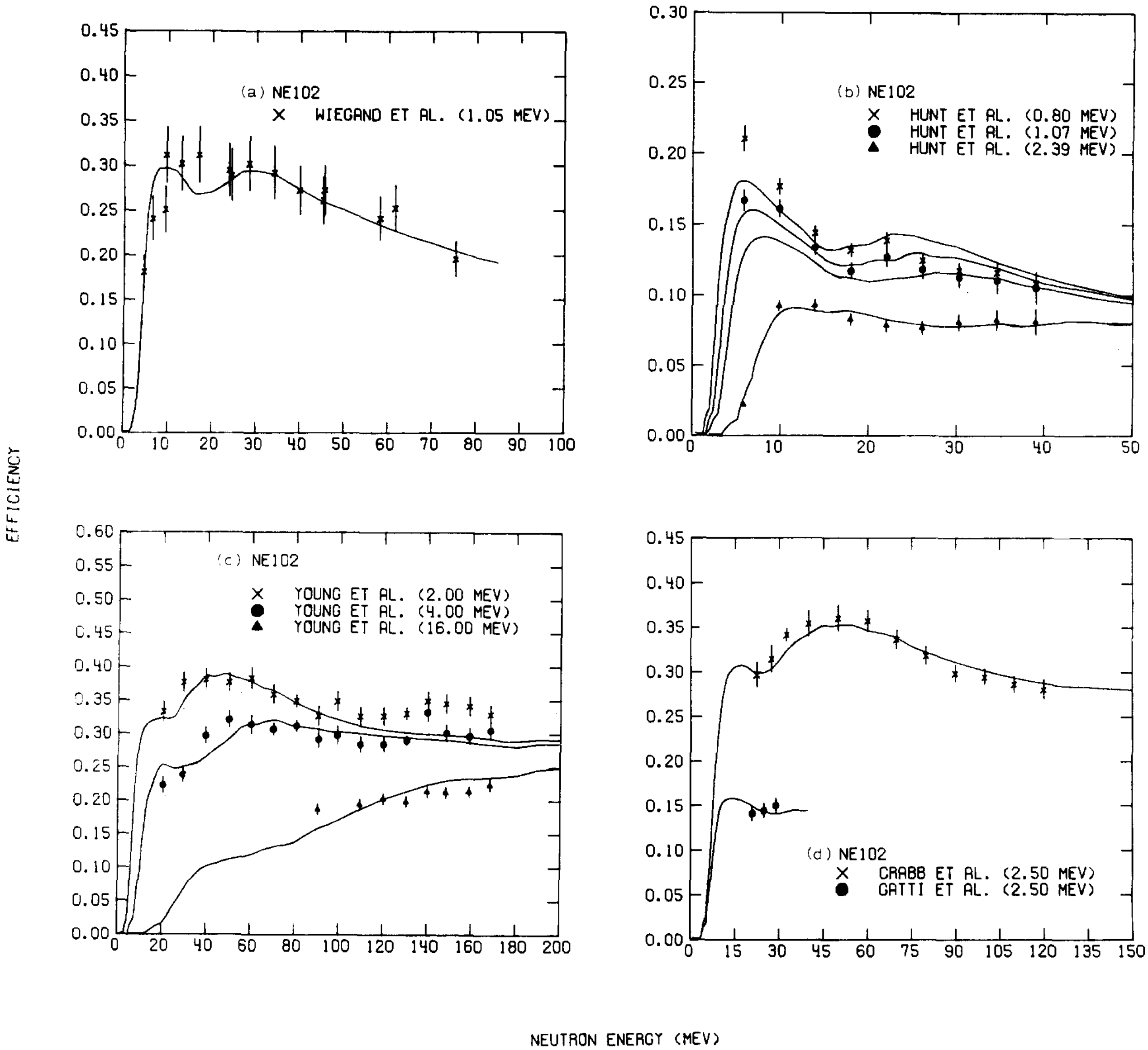

Fig. 4. Comparison of experimentally measured neutron detector efficiencies and calculations by DETEFF (solid line). The calculations were made for an equivalent electron energy bias as shown in the parenthesis. In (b) an extra calculation was made for a bias of 0.60 MeV to indicate the effect of the bias. The measurements were by (a) Wiegand et al.[9]), (b) Hunt et al.[7]), (c) Young et al.[8]), and (d) Crabb et al.[5]) and Gatti et al.[10]).

equivalent electron energy bias is understandable in terms of the large experimental differences in light output values by various authors.

When better light output values are obtained for any organic scintillator they may easily be incorporated into the program. At present the program appears to be accurate in calculating detector efficiencies to at least as good as $\pm 10\%$ which is what Kurz[11]) originally estimated. The program DETEFF is now routinely used for neutron detector efficiencies for various scintillators and bias levels in our laboratory.

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