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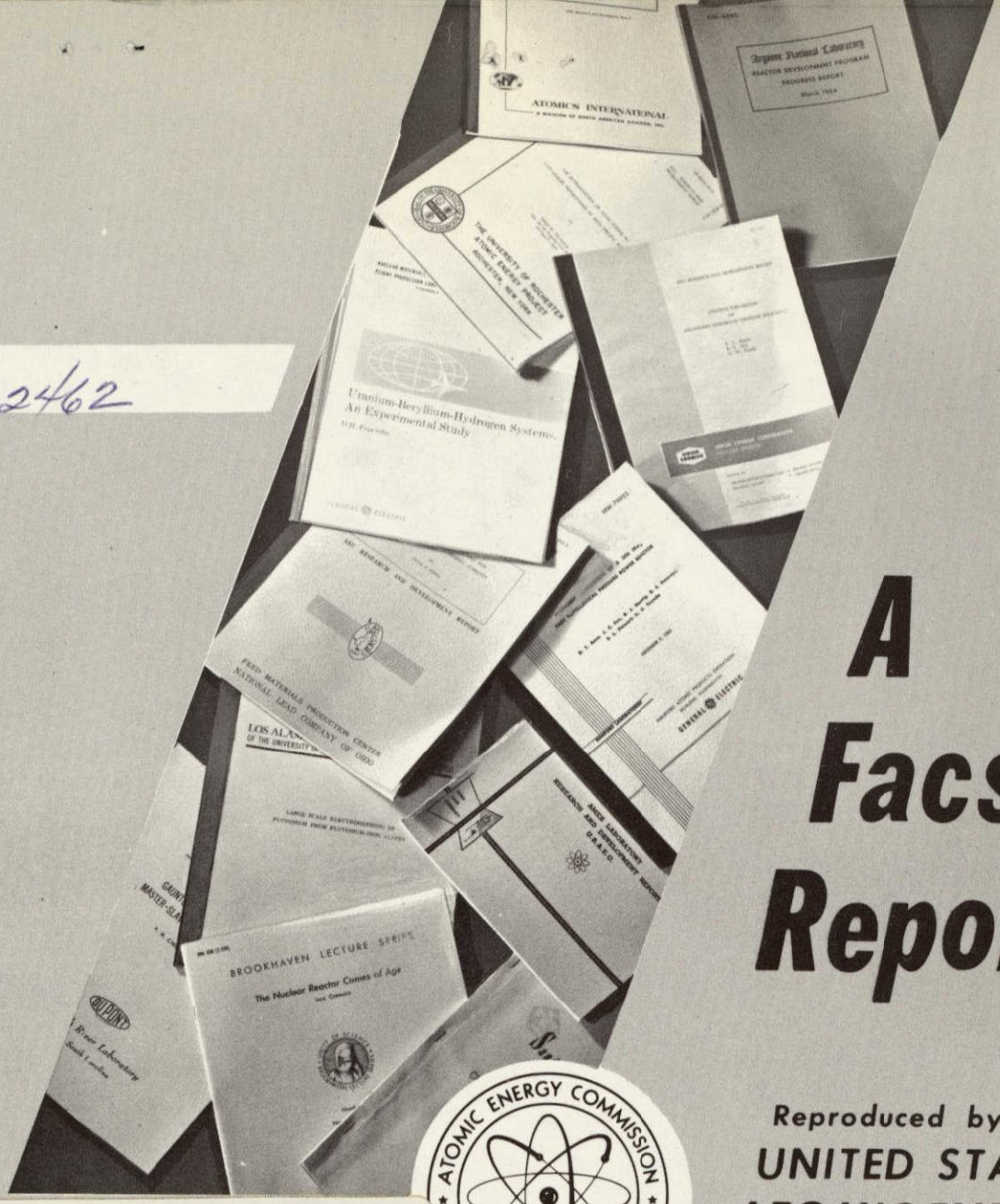

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Neutron Physics Division

CALCULATION OF THE NEUTRON AND PROTON SPECTRA FROM THICK TARGETS BOMBARDED BY 450-MeV PROTONS AND COMPARISON WITH EXPERIMENT*

R G. Alsmiller, Jr , J W. Wachter, and H S Moran

Abstract

Nucleon-meson cascade calculations have been carried out for 450-MeV protons incident on a variety of thick targets The energy spectra of emitted neutrons and protons at specific angles are compared with experimental measurements

NOTE
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
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*Submitted for journal publication

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I INTRODUCTION

Wachter, Gibson, and Burrus (1) have recently published experimental data on the high-energy neutron and proton spectra from thin and thick targets bombarded by 450-MeV protons These thick-target data cover a wide variety of angles and target materials and are therefore very suitable for testing the validity of high-energy nucleon transport calculations In this paper, comparisons between calculations carried out with the nucleon-meson transport code written by Coleman[b] (2,3) and the thick-target experimental data are presented

In Section II the calculational details are described, and in Section III the results are presented and discussed

II CALCULATIONAL DETAILS

The calculations presented here were obtained using the nucleon-meson transport code written by Coleman (2,3) The physical processes incorporated into the code and the data used have been described in detail by Coleman and will therefore not be discussed here

In the experiment, a narrow beam of 450-MeV protons was incident on the face of a cylindrical target 20 cm in diameter, and the neutron or proton current per unit energy which crossed a specified area A (see Fig 1) was measured Area A is at right angles to the line R The results given in Ref 1 are expressed as the number of particles per MeV per steradian about a "midpoint" c in the target The radius R_c is different for each target

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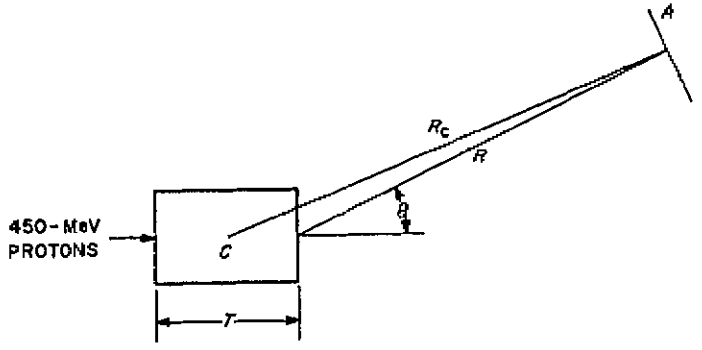

Fig 1 Schematic of Experimental Geometry

The calculations were carried out to correspond very nearly to the experimental geometry The lateral dimensions of the target in the calculations were taken to be infinite, but this should have no appreciable effect on the comparisons In the calculations, the target thickness and the distances R and R_c in all cases were taken to have the values given in Ref 1. The area A used in the calculations is only approximately that used in the experiment, but, since the comparisons are presented on the basis of an average over A, this should have no appreciable effect on the comparisons Finally, to make the comparison between the experimental values and the calculations as meaningful as possible, the calculations have been performed using a Gaussian energy resolution corresponding to the resolution of the experimental spectrometer

III RESULTS AND DISCUSSION

Calculations have been carried out and compared with all of the thick-target neutron data given in Ref 1 and with a representative portion of the thick-target proton data The comparisons are shown in Figs 2 through 7 All of the results for a given type of emergent particle and a given element are shown in a single figure Thus, Figs 2-4 show the neutron yields from the elements C, Al, and Co, respectively, and Figs 5-7 show the proton yields from the elements C, Al, and Cu, respectively In the figures, the two solid curves with each set of data represent the 67% confidence limits of the experimental data The calculated results are shown as plotted points with error bars that represent one standard deviation Each point represents a 15-MeV histogram interval in the calculation and is plotted at the center of the interval The calculations, of course, predict the

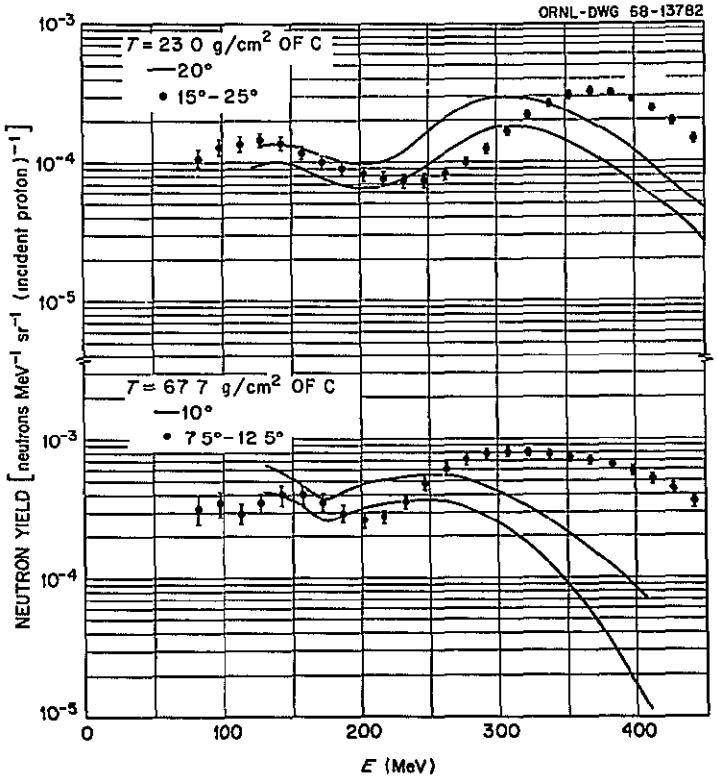

Fig 2. Neutron Yields from 450-MeV Protons on Carbon Targets

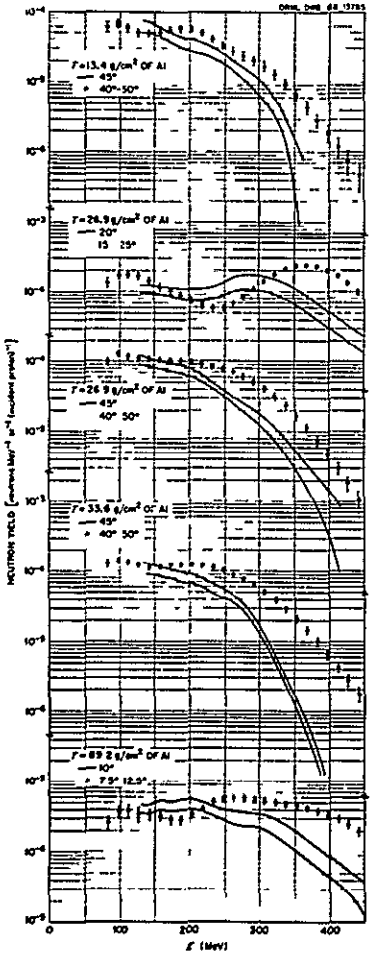

Fig 3 Neutron Yields from 450-MeV Protons on Aluminum Targets.

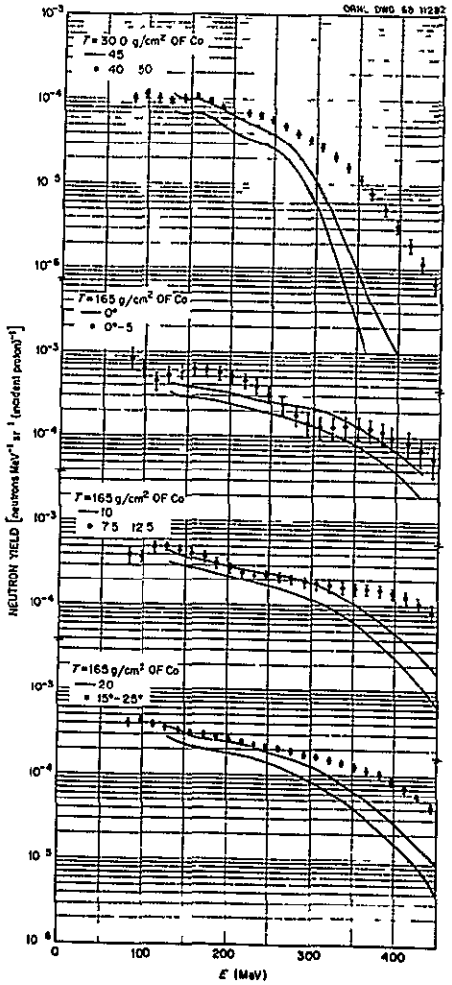

Fig 4. Neutron Yields from 450-MeV Protons on Cobalt Targets

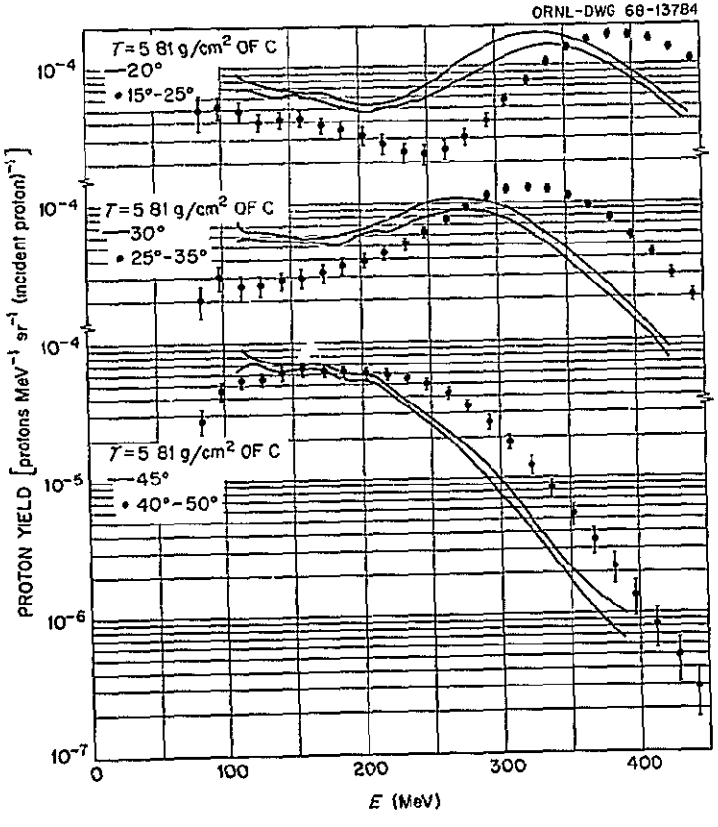

Fig. 5 Proton Yields from 450-MeV Protons on Carbon Targets

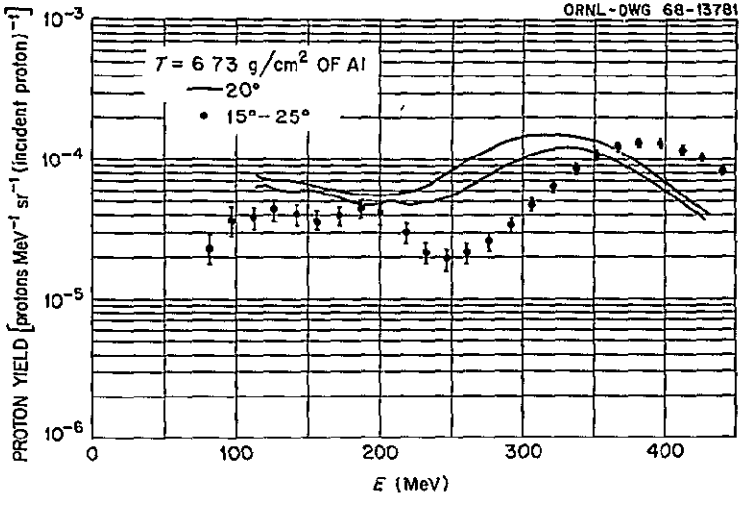

Fig 6 Proton Yields from 450-MeV Protons on Aluminum Targets

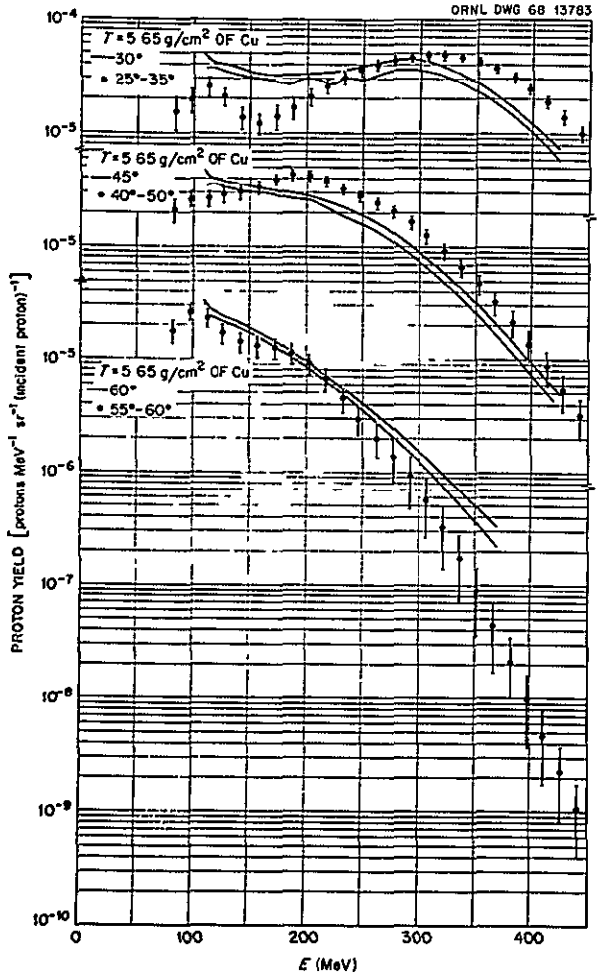

Fig 7 Proton Yields from 450-MeV Protons on Copper Targets

particle-emission spectra at all energies, but only the higher energy spectra are shown in the figures The target thickness, the experimental angle θ (see Fig 1), and the angular interval over which the calculations have been averaged are given in the figures for each comparison

In considering the results, it should be noted that all comparisons are made on an absolute basis In all of the neutron comparisons, Figs 2-4, the calculated values are larger than the experimental values at high energy In most cases, the discrepancy becomes progressively larger as the neutron energy increases In the one case of a measurement at 0° (Fig 4), the agreement at the higher energies is somewhat better than at the larger angles At the lower measured energies, the calculated values tend to be slightly larger than the experimental values at large angles and slightly less than the experimental values at the small angles Roughly speaking, the degree of agreement between the calculated and experimental results is independent of target thickness and material Qualitatively, the disagreement between the thick-target calculated and the experimental values seems to be consistent with the disagreement between the thin-target calculated and the experimental values (4)

In all of the proton comparisons, the target thicknesses considered are small and therefore the comparisons test primarily the differential cross section for proton production [c] That is, for such thin targets neither the incident protons nor the secondary protons lose appreciable energy in the target, so the measured and calculated results are representative of the energy and angular distribution of protons from a 450-MeV proton-nucleus collision In the case of carbon and aluminum, Figs 5 and 6, and the 30° and 45° data in Fig 7, the proton comparisons are similar to those obtained

with neutrons At all angles the calculated values are larger than the experimental values at high energies, and at small angles the calculated values are smaller than the experimental values at the lower energies Figure 7 also contains proton data measured at 60° This comparison seems noteworthy because this is the largest angle considered here and because it is the only case in which the calculated values are smaller than the measured values at the higher energies

In general, the agreement between the calculated and experimental results is rather poor, particularly at the higher energies If one assumes that the experimental data are correct, then the discrepancies shown in the figures must be taken to represent the state of the calculational art at this time The comparisons presented here are very detailed, that is, absolute comparisons of energy spectra at specific angles, and it is very difficult to determine how much effect discrepancies such as those shown in the figures will have on space-vehicle and high-energy-accelerator shielding calculations where one is primarily concerned with integral quantities such as dose In this regard, it should be noted that calculations carried out with the nucleon-meson transport code are in reasonable agreement with several different kinds of experimental data (3,5,6)

FOOTNOTES

a This work partially funded by the National Aeronautics and Space Administration, Order H-38280A, under Union Carbide Corporation's contract with the U S Atomic Energy Commission

b A paper comparing the particle-production cross sections used in the transport calculations with the thin-target data of Wachter et al and with the thin-target data at other energies is in preparation by Bertini A few of the thin-target comparisons with the Wachter et al. data are given in Ref 4

c The proton spectrum at 0° from a very thick (165 g/cm^2) cobalt target is given in Ref 1 It has not been possible to obtain sufficient statistical accuracy in the calculations to obtain a meaningful comparison with these data

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