Intercomparison of Codes for Intermediate Energy Nuclear Data : The first step

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Abstract

Several weak points of the intermediate energy nuclear data calculated in this exercise are described as introduction to some of the areas needing discussion at this meeting. These include nuclear structure effects on precompound spectra, large variations between codes in predicted total reaction cross sections, and in total neutron and proton multiplicities. INC codes don't reflect correct experimental Q values, and may have difficulties at very low angles due to overestimation of the quasi-elastic peak. We raise questions as to additional reaction properties (beyond n and p spectra) which may need benchmarking.

Introduction

We have taken a first step in benchmarking codes to reproduce and predict nuclear data for incident energies up to 1 GeV.[1] This specialists meeting is designed to critique results of this exercise by comparing code results with what we believe are results of very careful experimental measurement. We acknowledge that there were a very large number of calculated results which were in impressive agreement with the experimental data. But we largely will try to focus attention on the cases of poor agreement, in order to consider how these results might be improved, and to reach some consensus on the limits of accuracy we might expect from a-priori code modeled nuclear data.

Comments on Results

One of the first points noted was the large variation in total reaction cross sections used. These are shown for p + ^{90}Zr in Fig. 1; similar variations were present for the ^{208}Pb target (see Table 3 of Ref. [1]). These variations approach 30% with a few extreme values even further from the average results. Reaction cross sections should be known quite well, so some of the values predicted by codes of this intercomparison are in need of improvement; which is perhaps an open question!

The influence of reaction cross sections upon results is removed if we look at neutron and proton multiplicities, as these are the emission numbers per projectile-target interaction. These may be seen in Figure 2 (taken from Figure 1 of Ref. [1]) to differ by up to factors of 3 for neutrons, and of 3 to 5 for protons. This shows clear and significant differences in the treatment of the nuclear physics of the de-excitation processes. These differences may be in the early non-equilibrium phases of the reaction, in the later equilibrium stages, or both. But the discrepancies are clearly larger than we would like if the modeled data are to provide a basis for design of a commercial ATW facility. Discrepancies between sets of calculated results are particularly large at low energies, e.g. Figures 3 and 4 (Figures 19 and I-12 of Reference 1). Unfortunately, much of the (p,xn) experimental data are not good to very low energies due to detector bias settings and/or wraparound problems in time-of-flight measurements. Similarly for (p,xp) measurements; detector cutoffs may limit low energy proton measurements, although review of the literature would be worthwhile. These aspects of differences between codes might yield to some benchmarking if good experimental data can be found (some of the Jülich-LANL (p,xn) data do extend to quite low neutron energies).

There are other points worthy of attention. One of these is that INC results don't conserve energy, in that particle emission may take place beyond the thermodynamic end point, e.g., Figure 5 (Figure 31 from [1]). This is probably due to the use of constant neutron and proton binding energies (often 7 MeV) which do not reproduce experimental Q-values. Is it possible to improve results by replacing Fermi distributions by nucleon level sequences based on experimental nucleon binding energies, or to make the constant binding energy an input variable that can be adjusted according to the average number of nucleons expected to be removed for the incident projectile energy? The latter might require either a good guess, or an iteration.

Another problem for the INC codes is a difficulty in calculating spectra at 0° or very small angles. This includes problems in overestimating the quasi-elastic scattering peak-giving a fairly sharp peak not realized in experimental measurement, and generally not reproducing the inelastic spectra very well. Examples of this may be seen in Fig. 6. Historically, INC codes under-predicted spectra at back angles. While this remains the case for some codes, others in this exercise did extremely well, e.g., Fig. 7. For deterministic codes such as ALICE and GNASH, these yields at very small and very large angles are treated well by begging the question of the physics, and instead using empirical systematic expressions.[2] When the ALICE code is used exercising nucleon-nucleon in Fermi gas scattering physics[3]—similar to that used in INC codes, its does poorly on predicting angular distributions. Perhaps we will learn whether any of the INC codes has also incorporated systematics into the precompound phase, and if not, the reason for improvement at back angles over earlier INC codes.

Concluding Comments

We have tried to highlight a few of the areas needing further discussion and progress. We have concentrated on problem areas, rather than emphasizing the many positive aspects of the intercomparisons. There are other aspects of intermediate energy codes that may need benchmarking, and some discussion of these would be valuable. For example, activation will be a serious consideration for a high beam current accelerator, such as those proposed for ATW. Do we need to be able to calculate (benchmark) isomer yields, product recoil spectra, cluster spectra (d, t, ^{3}He, α)? Do we need to benchmark the low energy portions of the n and p emission spectra? This has been done only to a small degree in this exercise. We need to see what published experimental data exist, or encourage measurement of adequate data if they are not available. Above 800 MeV we have not found high quality published (p, x) double differential cross sections. It would surely be valuable to have such results, as well as (p,xp) results for incident energies above 200 MeV and (p, cluster) spectra above 60 MeV. And at all energies there is the question of contributions from fission.

All this is a way of concluding that, in addition to critiquing the codes in this exercise, deciding on their limitations and possible improvements, we should also ask what other aspects need testing and suggest the type, and, if possible source, of experimental data with which to do this. This meeting is a challenge, and we have outstanding participants here to address these questions.

References

1) M. Blann, H. Gruppelaar, P. Nagel and J. Rodens, OECD/NSC/DOC (93) 8

2) C. Kalbach, Phys. Rev. C **37** (1988) 2350

3) M. L. Goldberger, Phys. Rev. **74** (1948) 1269

p + ^{90}Zr Total Reaction Cross Sections

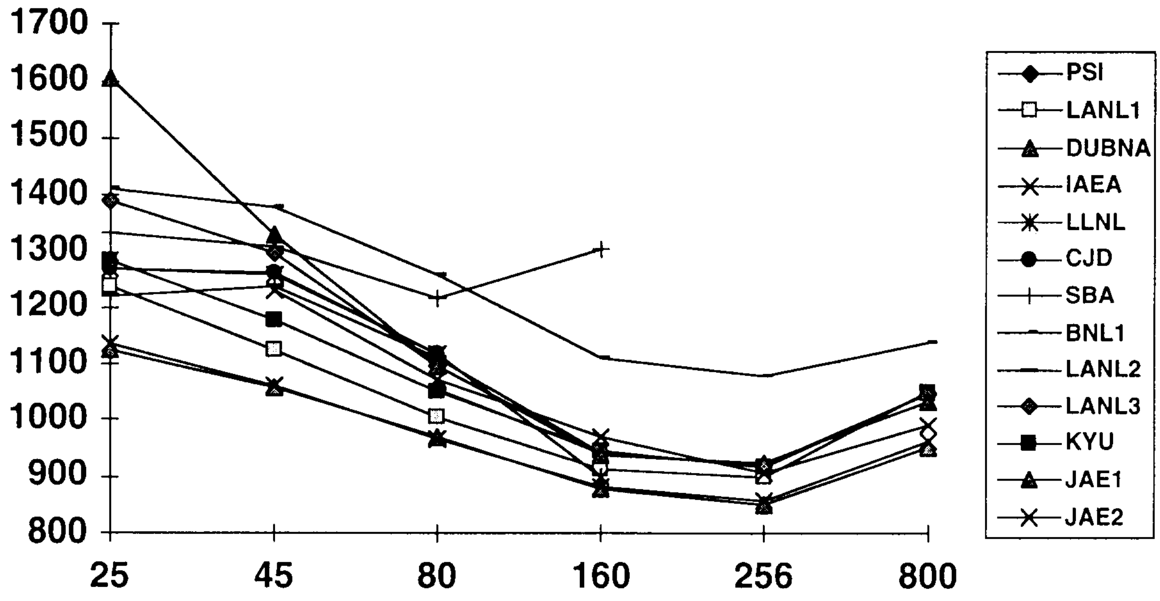

Fig. 1 Calculated total reaction cross sections for protons on ^{90}Zr targets for incident energies of 25, 45, 80, 160, 256 and 800 MeV. Results are identified according to Table 1 of Ref. 1.

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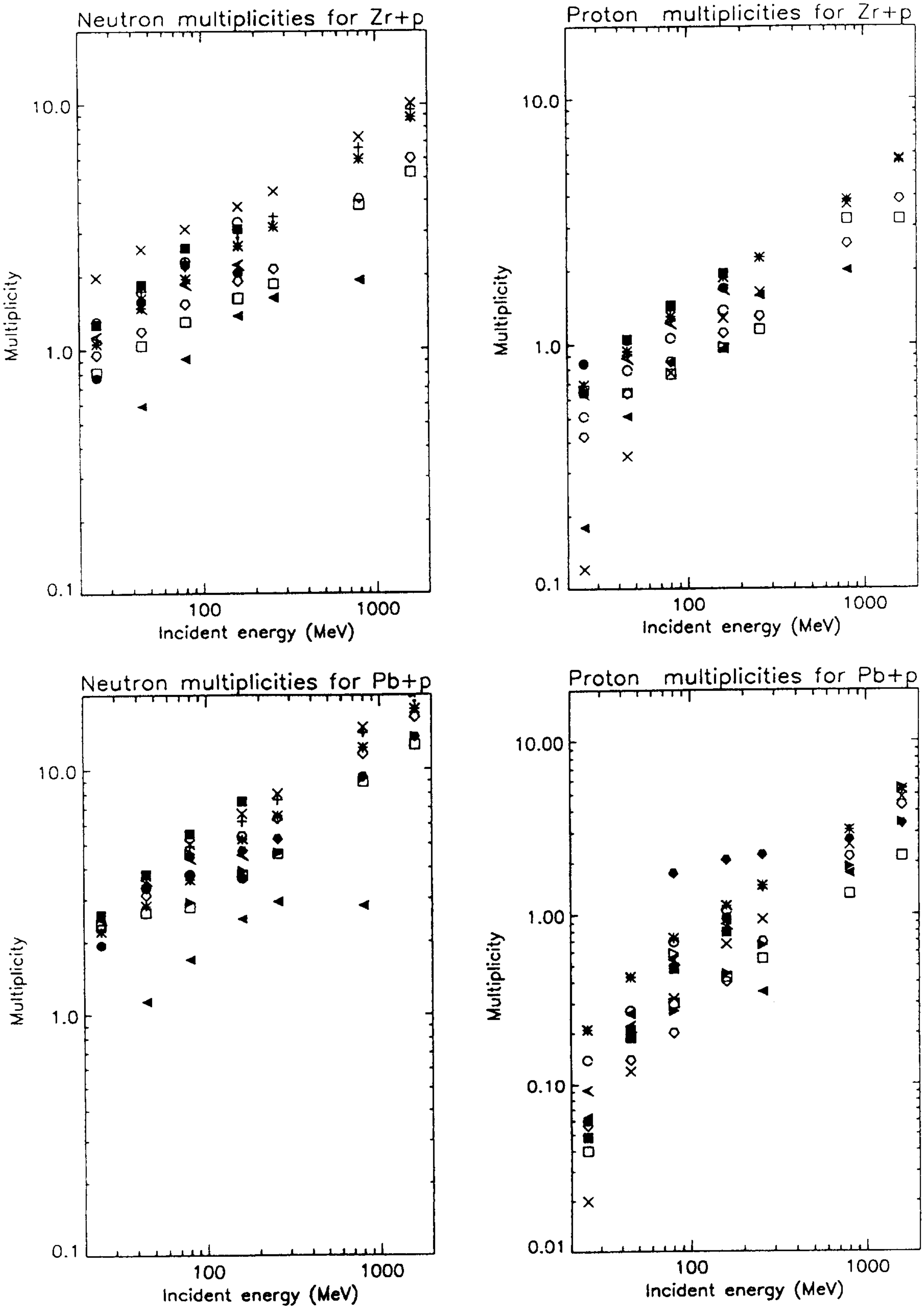

Neutron multiplicities for Zr+p

Proton multiplicities for Zr+p

Neutron multiplicities for Pb+p

Proton multiplicities for Pb+p

Fig. 2 Neutron and proton multiplicities calculated by different codes for protons incident on ^{90}Zr and ^{208}Pb targets. This is reproduced from Fig. 1, Ref. 1.

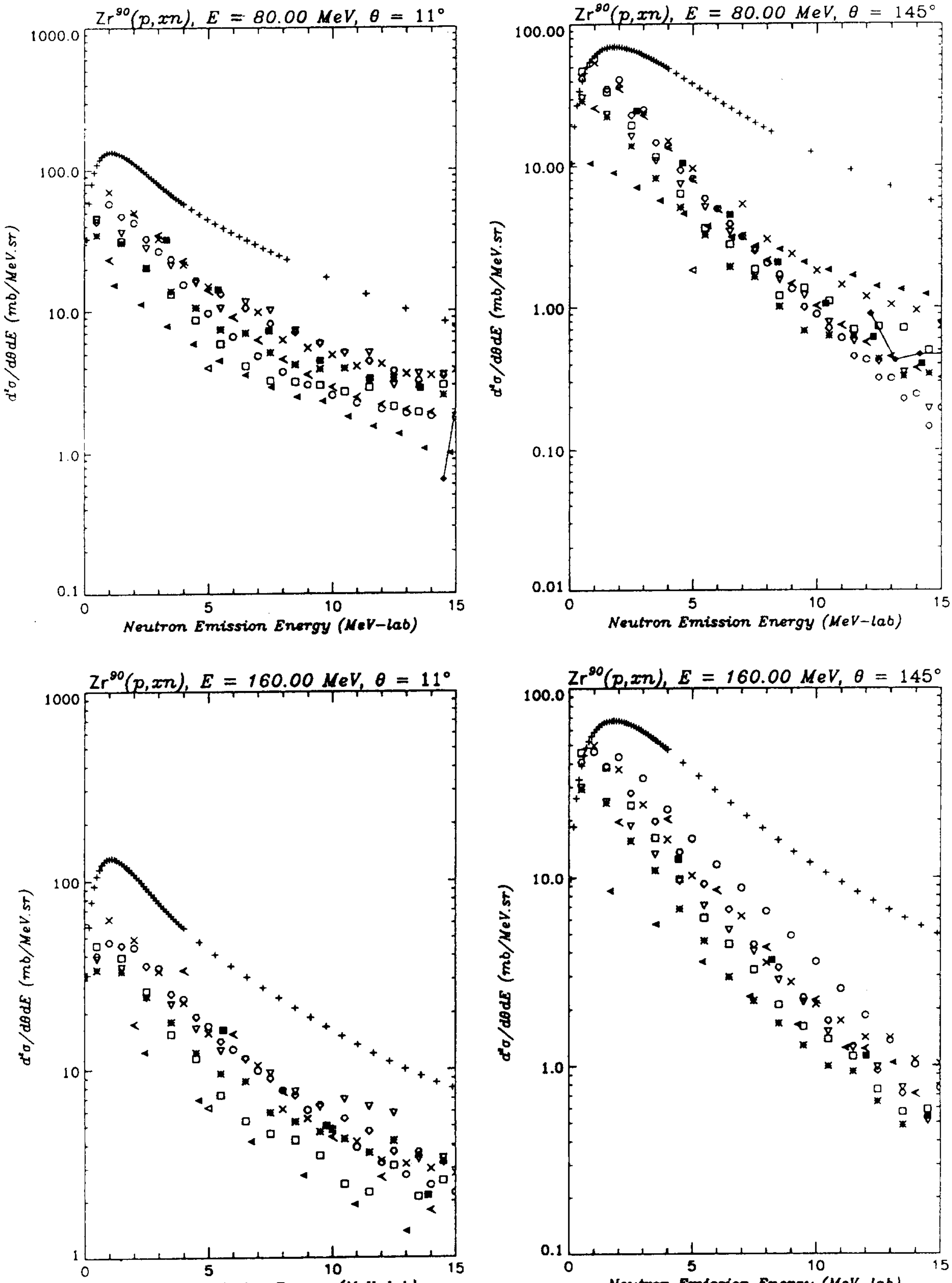


Fig. 3 Low energy region of ^{90}Zr(p,xn) spectra for incident energies of 80 and 160 MeV. Reproduced from Fig. 19, Ref. 1; symbols are referenced in Table 1 of Ref. 1.

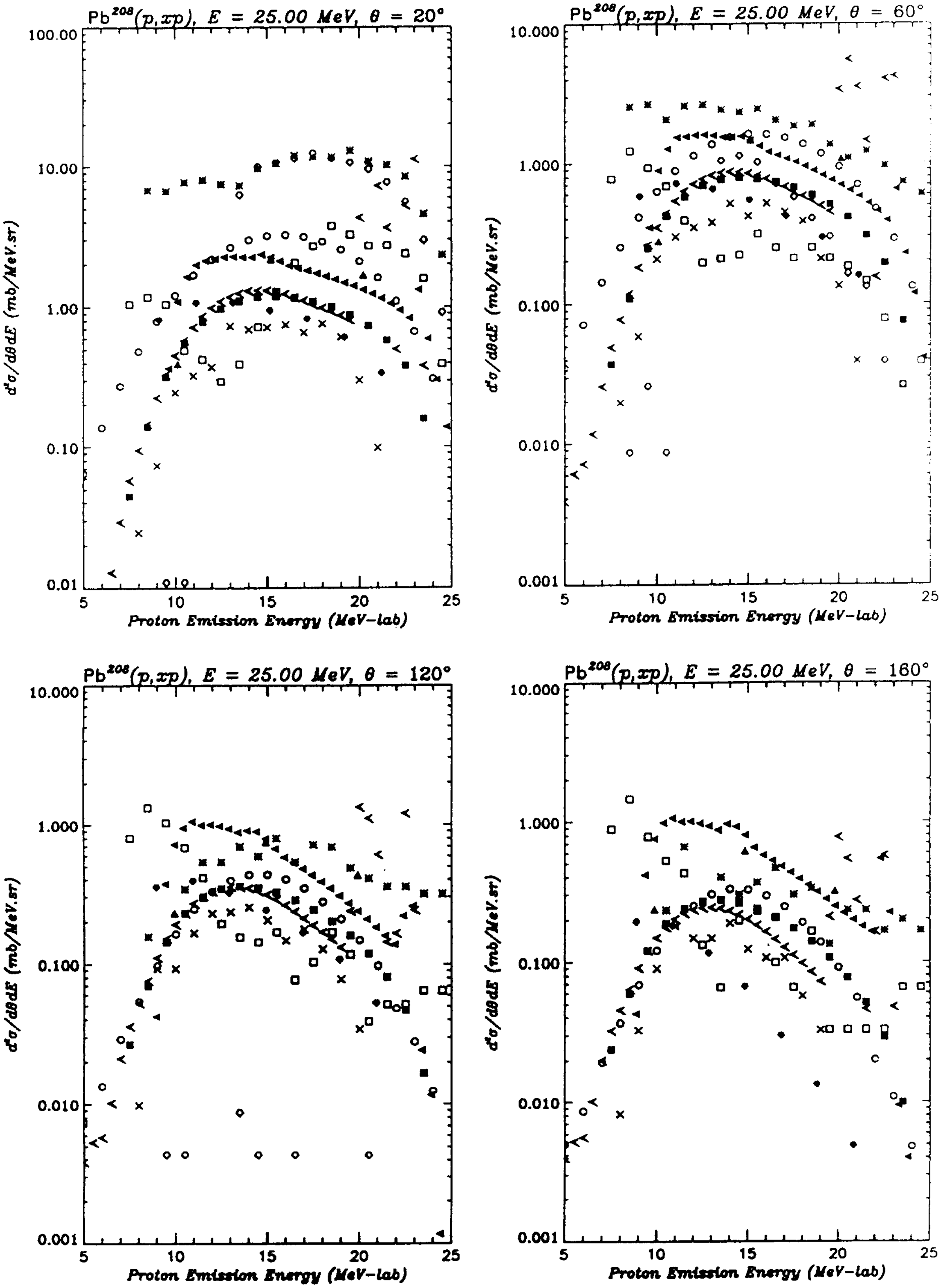
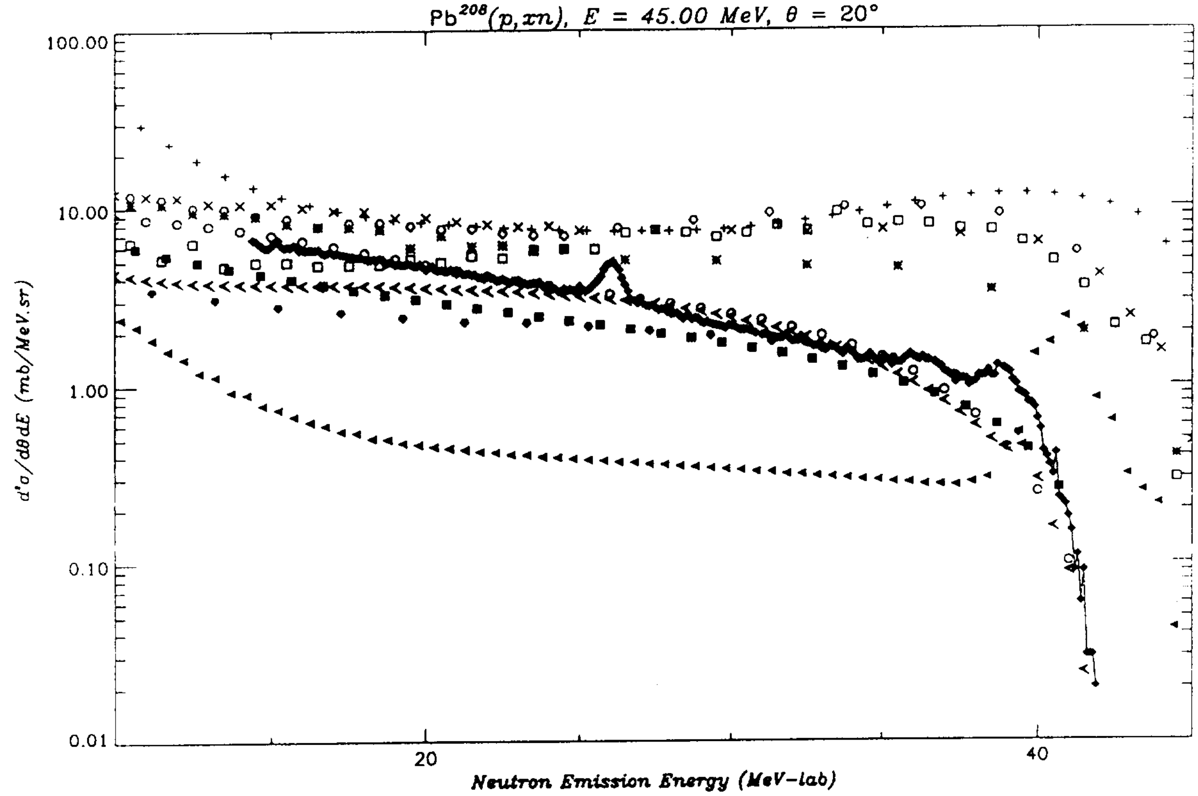


Fig. 4 ^{208}Pb (p,xp) evaporation spectra for 25 MeV incident proton energy, from Fig. I-12 of Ref. 1.



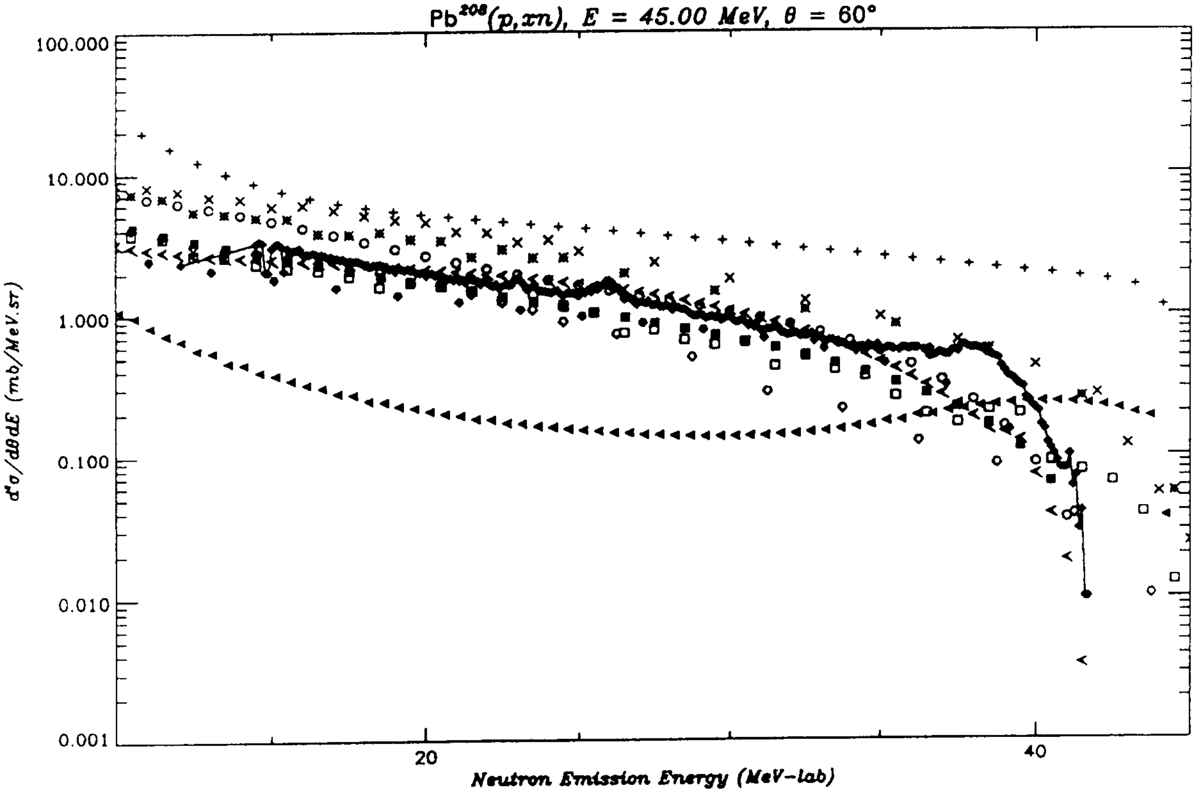


Fig. 5 ^{208}Pb (p,xn) DDCS at 20 and 60° for 80 MeV incident protons. Taken from Fig. 31, Ref. 1

See Tables 1 and 4 for an explanation of symbols

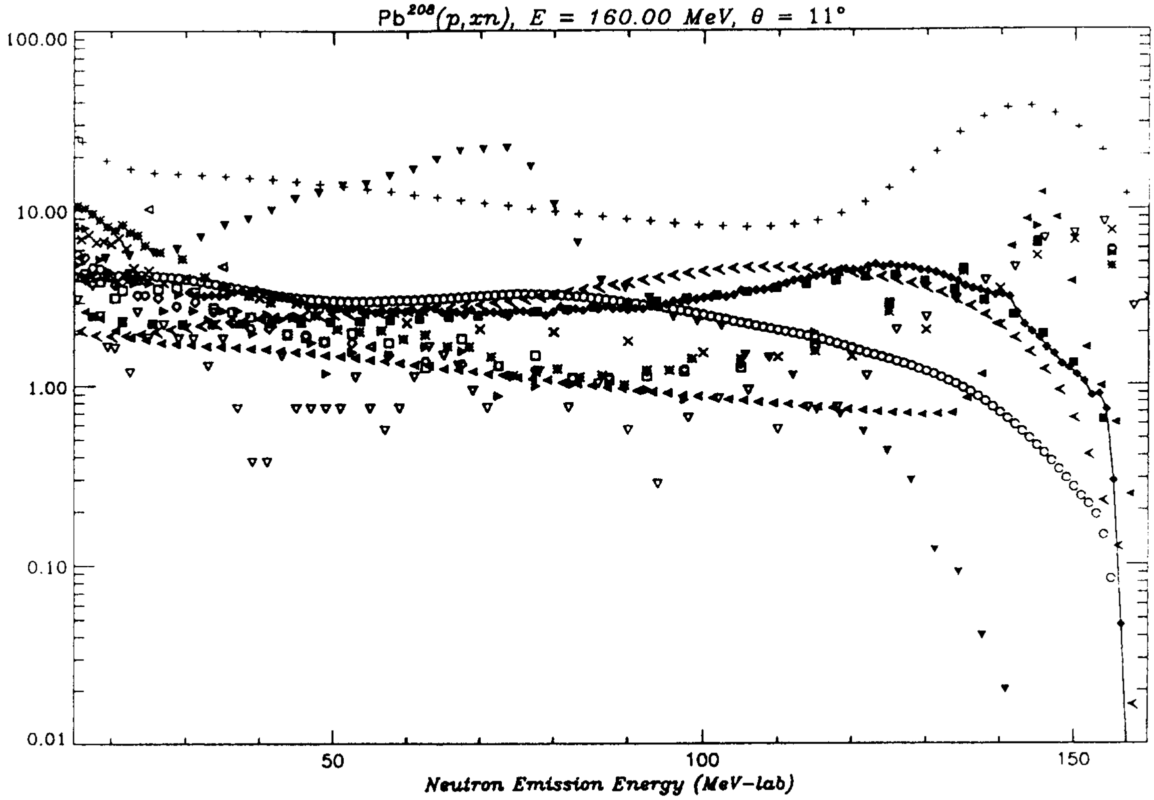


Fig. 6 ^{208}Pb (p,xn) DDCS at 11° taken from Fig. 27; Ref. 1. The calculated quasielastic peak is not seen in the data.