DOUBLE DIFFERENTIAL CROSS-SECTION FOR PROTONS EMITTED IN REACTIONS OF 96.5 MeV NEUTRONS ON ENRICHED ^{208}Pb TARGETS.

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Abstract

Transmutation techniques involve high-energy neutrons created by the proton-induced spallation of a heavy target nucleus. The existing nuclear data libraries developed for the present reactors go up to about 20 MeV, which covers all available energies for that application; but with a spallator coupled to a core, neutrons with energies up to 1-2 GeV will be present. Although a majority of the neutrons will have energies below 20 MeV, a small fraction at higher energies has still to be characterised. Above 200 MeV, direct reaction models work reasonably well, while at lower energies nuclear distortion plays a non-trivial role. This makes the 20-200 MeV region the most important for new experimental cross-section data.

Very little high-quality neutron-induced data exist in this energy domain. For (n,xp) reactions, different experimental programmes have been run at Los Alamos [7] and TRIUMF [1] facilities but with limited coverage in particle energy and angle. Better coverage has been obtain by the Louvain-la-Neuve Group up to 70 MeV [9].

Due to this particular lack of data above 70 MeV and in the framework of the European concerted action “Lead for ATD” and the HINDAS project (see J.P. Meulders contribution in these proceedings), in March’99 we performed an experiment in order to measure double differential cross-sections for protons and other light charged particles emitted in reactions of 96.5 MeV neutrons on enriched ^{208}Pb targets, at the neutron facility of The Svedberg Laboratory (TSL), Uppsala, Sweden [2].

1. Experimental set-up

The charged particles (p, d, t, ^{3}He and alpha) were detected using the MEDLEY device [4] which allows to measure continuous energy distributions in the forward direction (10°-80°). At larger angles, due to the relatively low intensity of the neutron beam and due to the weak estimated cross-sections, only the low-energy part of the spectra could be measured (E_p < 40 MeV at θ = 160°). In order to improve the counting rate at backward angles and to measure the high-energy part of the proton spectra, we used a multi-target box together with the two arms of SCANDAL [5]. This set-up covered the angular range 10°-140°.

The MEDLEY detector set-up is installed inside a cylindrical scattering chamber of 100 cm diameter. It consists of eight detector telescopes which are mounted inside the vacuum chamber and placed every 20 degrees. They cover scattering angles ranging from 20 up to 160 degrees. In order to obtain a good separation between the different particles (p, d, t, ^{3}He and alpha) over a large dynamic range, i.e. from a few MeV alpha particles up to 100 MeV protons, each telescope is composed of three detectors: two silicon surface barrier detectors and one CsI(Tl) crystal. The front detectors (dE_1) are either 50 or 60 mm thick, while the second ones (dE_2) are 400 or 500 •m. The CsI(Tl) crystal, used as E detectors, are long enough to stop 100 MeV protons. Using the well-known dE1-dE2-E method, we are able to identify with no ambiguities light charged particles.

SCANDAL, SCAttered Nucleon Detection AssembLy, is a CsI hodoscope with auxiliary detectors: drift chambers used to determine the proton trajectory and plastic scintillators used to trigger the acquisition. SCANDAL is designed for protons and neutrons in the 30-130 MeV interval.

While the proton energy threshold is around 10 MeV for MEDLEY, for SCANDAL this threshold is above 30 MeV because particles have to go through different materials before reaching the CsI(Tl) detectors.

2. Preliminary results and comparison with theoretical prediction

The Double Differential Cross-Section (DDCS) for protons emitted in reactions of 96.5 MeV neutrons on lead targets are presented in Figure 1.

We observe that in the energy region covered by both set-up there is a good agreement between MEDLEY and SCANDAL measurements despite a small underestimation of high energy proton production with MEDLEY at forward angles. This experimental effect is associated to the relative low thickness of the second detector which induces detection efficiency lower than 100% for the high part of the proton spectrum.

Comparisons with theoretical predictions are shown in Figures 1 and 2. A good agreement is obtained either with the GNASH-CEA [8] or the MINGUS [6] or the CUGNON [3] calculations, but there are still several problems (see Figure 3 for example with a linear y-axis) which are listed below:

- With the MINGUS calculation, the low energy part of the spectra is underestimated at forward angles and overestimated above 60 degrees.
- The GNASH-CEA calculation always underestimates the DDCS at low energies.
- The CUGNON calculation which is based on intra-nuclear cascade and optimised for incident energy above 200 MeV, works reasonably, except at low energies for the evaporative component.

3. Conclusion

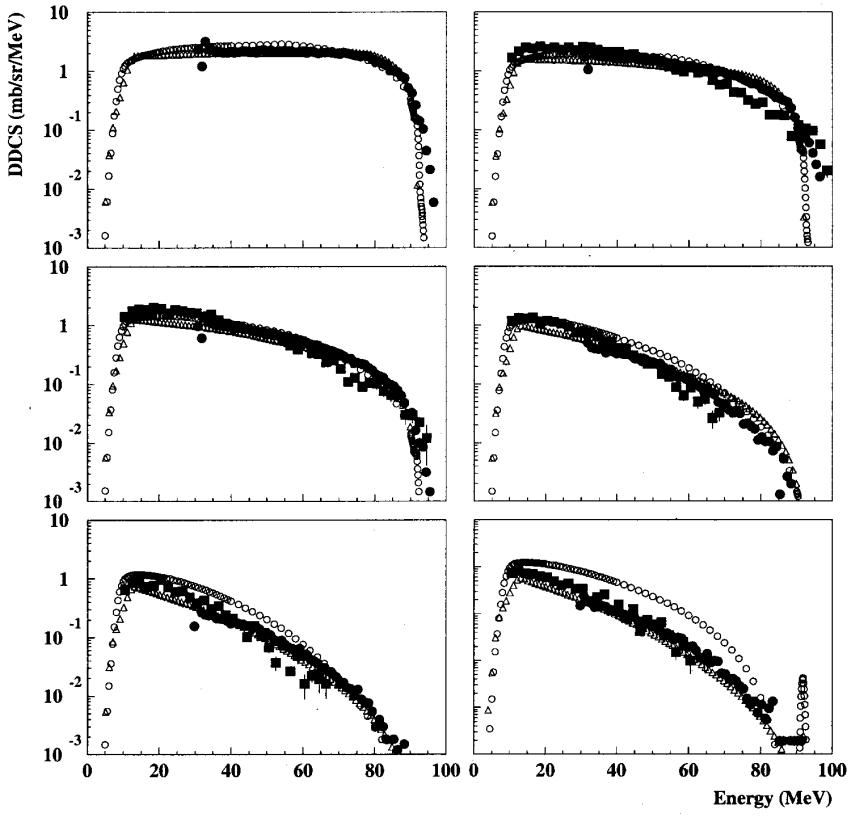
Double differential cross-section measurements for protons emitted in reactions of 96.5 MeV neutrons on enriched lead targets were performed using the TSL facilities.

Preliminary results were compared with different theoretical calculations: they have reasonable predictions nevertheless they have to be improved in order in particular to reproduce the low energy part of the proton spectra.

This conclusion will be reinforced or cancelled

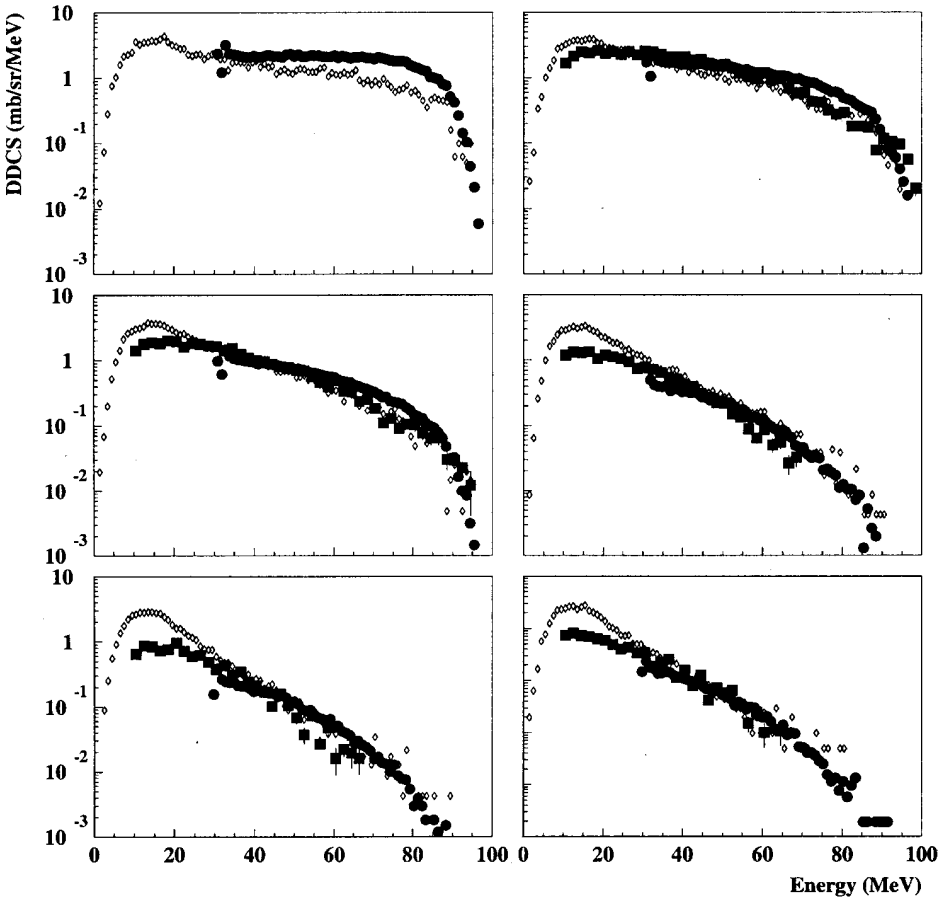
- By doing the same analysis on lead target for the other light charged particles (d, t, ^{3}He and alpha) measured with the MEDLEY set-up.
- By studying DDCS with iron target (the dedicated experiment has been performed in May 2000 at TSL) and an uranium one (the experiment is planned in autumn 2001 at TSL).

Figure 1. **Preliminary results of double differential cross-sections for protons emitted in reactions of 96.5 MeV neutrons on enriched ^{208}Pb**



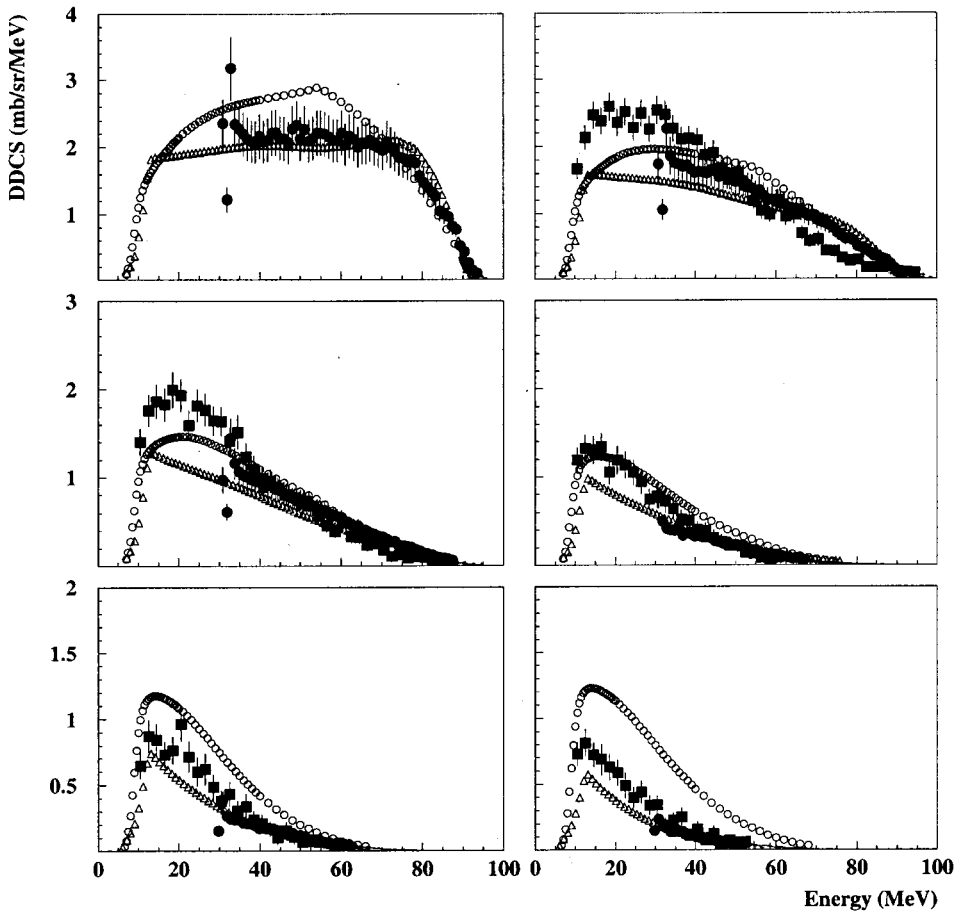
- Experimental Data : SCANDAL (black circle) and MEDLEY (black square).
- Theoretical Prediction : MINGUS (open circle) and GNASH-CEA (open triangle).
- From left to right and top to bottom, angles are ranging from 20 up to 120 degrees with 20 degrees interval.

Figure 2. **Preliminary results of double differential cross-sections for protons emitted in reactions of 96.5 MeV neutrons on enriched ^{208}Pb**



- Same as Figure 1.
- Theoretical Prediction: CUGNON (open star).

Figure 3. **Preliminary results of double differential cross-sections for protons emitted in reactions of 96.5 MeV neutrons on enriched ^{208}Pb**



Same as Figure 1 with linear y-axis.

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