MEASUREMENTS OF PARTICULE EMISSION SPECTRA IN PROTON INDUCED REACTIONS OF INTEREST FOR THE DEVELOPMENT OF ACCELERATOR DRIVEN SYSTEMS

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Abstract

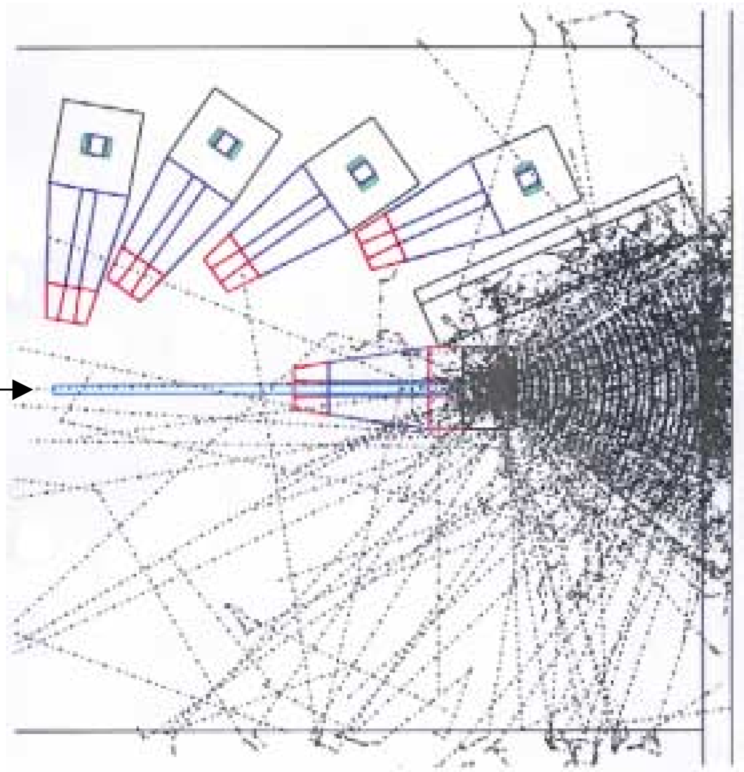
In the framework of the concerted action "Lead for ADS" program, we have measured the double differential cross-sections of neutrons produced in reactions induced by a proton beam on a lead target at 62.5 MeV. The experiment was performed on the S-line of the CYCLONE facility in Louvain-la-Neuve. The neutrons were detected using DEMON counters and their energy was derived from the time-of-flight technique.

1. Introduction

For many accelerator driven system projects [1,2], lead has been chosen as a representative spallation target material. Therefore, Pb (p, X n), Pb (p, X p), Pb (p, X lcp) double differential cross-sections (DDCS) are required with high priority for the development of simulation codes. These codes are used for feasibility studies and optimisation of such hybrid systems in which complex combinations of nuclear processes are involved. Combined with complementary Pb (n, X n), Pb (n, X p), Pb (n, X lcp) DDCS, these data represent the best test for evaluating the global capabilities of the models. In addition, such data provide important constraints which allow the predictive power of the codes to be improved in the 20-150 MeV energy range.

In this context and in the framework of the Concerted Action "Lead for ADS" programme, we measure the DDCS of neutrons and light charged particles (p, d, t, ^{3}He, ^{4}He) produced in reactions induced by a proton beam, impinging on a lead target at 62.5 MeV. In this contribution we present results concerning only the neutrons.

Figure 1. **Simulation with GEANT of the experimental set-up geometry (see text)**



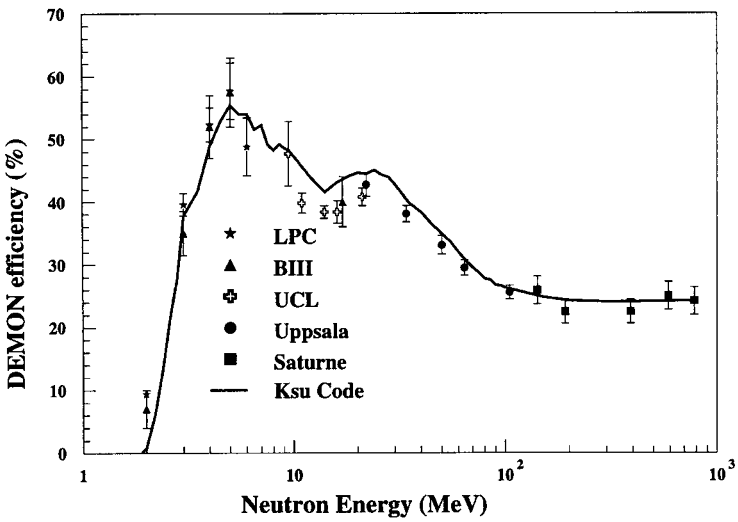
2. Experimental set-up

The experiment was performed on the S-line of the CYCLONE facility in Louvain-la-Neuve. The lead target is 10.7 mg/cm^2 thick and the neutrons are detected using five DEMON large volume NE213 liquid scintillator counters [3]. The following table gives, for each counter, its angle theta relative to the beam and the distance between the target and its entrance window.

DEMON counter	theta (°)	d (mm)
1	120	2 960
2	80	2 507
3	55	3 039
4	35	3 887
5	24	5 347

Each detector is surrounded by a lead cylinder installed inside a “BOMBARDE” barrel filled with paraffin and boron - materials that are efficient shields against background neutrons.

Figure 2. **Compilation of the measured DEMON detector efficiencies (symbols) compared to the predictions of the KSU code (black line)**



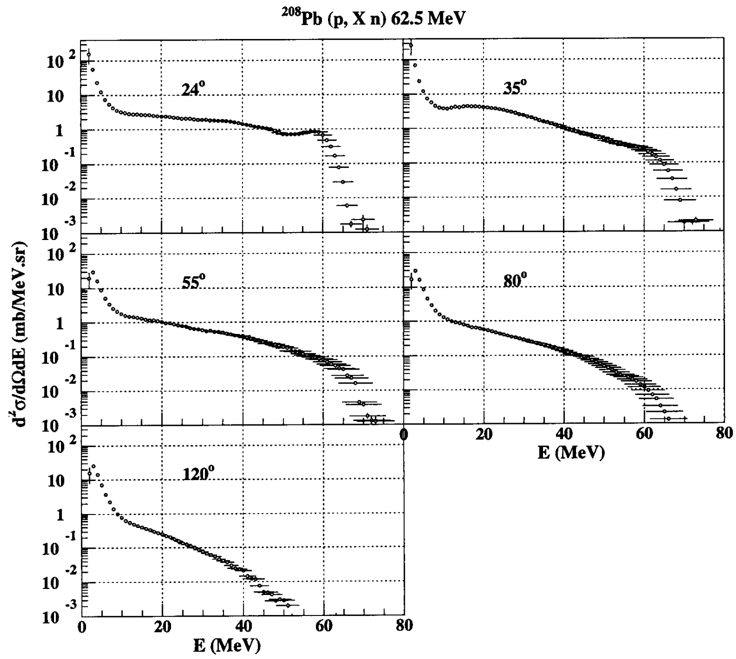
Due to the necessity of shielding the DEMON counters from the very high radiation background resulting from the proton beam dump, a wall made of concrete and paraffin is also built in the experimental area. Taking into account the experiment configuration (various materials and dimensions), the floor-space and the weight of concrete blocks, the wall dimensions is optimised performing GEANT simulations. The final wall geometry divides by a factor of twenty the background of the most exposed DEMON counter to the parasite neutron flux, resulting in a signal-to-noise ratio of 2.1. The Figure 1 illustrates the efficiency of the shielding wall. It presents part of the geometry of the experimental set-up: the faraday cup placed at the end of the beam line and four DEMON counters imbedded in BOMBARDE barrels, and the shielding wall built between the forward DEMON counter and the beam dump. Dashed lines symbolise neutrons escaping from the beam dump. We observe that the majority of the neutrons emitted in the direction of the counters are stopped by the wall or deviated in their trajectories.

3. Data analysis

We discriminate neutrons from gammas by pulse shape analysis of the photomultiplier output. For each neutron, the time-of-flight is derived from the start given by the DEMON counter, and the stop given by the following beam high frequency signal (period = 54 ns). The same procedure is employed for gammas so that the time-of-flight spectra are calibrated with the reference peaks associated to gammas. In order to detect without ambiguity the lowest energy neutrons, nine beam bursts out of ten are suppressed. Neutron energies are derived from their time-of-flight, taking into account the depth at which the particle interacts inside the detector. This depth is estimated using an iterative procedure since it depends on the detection efficiency, which is itself a function of the neutron energy. The DEMON detector efficiency can be found in [4] and it is shown in Figure 2.

During the experiment, attention was paid to alternatively collect data with Pb targets and with blank-targets in order to be able to subtract the background noise. The acquisition dead time is also kept under twenty percent and a correction for this effect is applied to the data. For the cross-section calculation, the number of incident protons is derived from the intensity of the beam measured using the faraday cup. The detector efficiency and solid angle, as well as the orientation of the target are also taken into account in deriving the absolute normalisation factor.

Figure 3. **Double differential cross-section of neutrons produced in reactions induced by a proton beam impinging on a lead target at 62.5 MeV**



4. Results

Figure 3 presents neutron energy spectra obtained at five different angles. The energy uncertainty is derived from the length uncertainty of the time-of-flight path (±1 mm), combined with the uncertainty on the depth at which the neutron interacts inside the scintillator (±1 cm) and the electronic chain resolution. The resulting energy uncertainty increases smoothly with the neutron energy from 0.03 MeV to 4.2 MeV at 62.0 MeV. In order to calculate the cross-section uncertainty, we take into account the detector efficiency uncertainty which is lower than 5.8% over the entire energy range. The contribution of the statistical uncertainty to the relative total uncertainty is estimated to be lower than 2% for energies smaller than 30 MeV, it increases up to 4.4% for an energy value of 60 MeV at a detection angle of 80°, and it reaches a maximum value of 16% at the most backward angle, for the larger energy. Those values result in a total relative uncertainty of the cross-section lower than 5.6% for energies smaller than 30 MeV, it increases up to 6.5% for an energy value of 60 MeV at a detection angle of 80°, and it reaches a maximum value of 17% at the most backward angle and for the larger energy. Due to the logarithmic representation the associated error bars are not visible on the figure.

5. Conclusion

We present neutron double differential cross-sections measured at five different angles for the Pb(p, X n) reaction, at 62.5 MeV. These results will contribute to the extension up to 150 MeV of evaluated nuclear data libraries, which are a combination of experimental and calculated data. Such a database is planned to be implemented in different simulation codes which are used for the conception of the future hybrid systems.

REFERENCES

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