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Study of Spallation Neutrons for the Transmutation of Long-lived Nuclear Waste

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1 Motivations

With the renewed interest in accelerator-driven systems to transmute long-lived nuclear waste or to produce energy, new requirements for intermediate-energy nuclear data are now emerging. In all these systems, neutrons are produced by spallation reactions induced by around 1 GeV protons on a heavy target. These neutrons then drive a sub-critical blanket in which wastes are burned or energy is produced. A good knowledge of the spallation process (energy and angular distribution of the neutrons) is necessary to design and optimize the target-blanket system: for instance, to determine the best choices of beam energy, of composition and geometry of the target, in order to have the maximum neutron yield at the lowest cost, or to minimize the back-scattering of neutrons to the accelerator. Calculation codes to fully simulate the system are available but are far from being totally reliable [1] and, at least, need to be validated on experimental data. Recently, several papers [2, 3] have addressed the question of the missing data for accelerator-based transmutation applications. They all emphasize that there are no data concerning spallation neutron production at energies higher than 800 MeV or with projectiles other than protons. Even below 800 MeV, there are still discrepancies between different groups of existing data, as is shown in fig. 1.

SATURNE is one of the very few accelerators that provides GeV beams of protons and deuterons. A new programme, aimed at measuring the double differential cross-sections for the production of spallation neutrons induced by protons and deuterons on different targets, is just beginning at SATURNE. It is a collaboration between PTN (Bruyères-le-Châtel), LNS (Saclay), DAPNIA (Saclay), Collège de France (Paris) and Uppsala University.

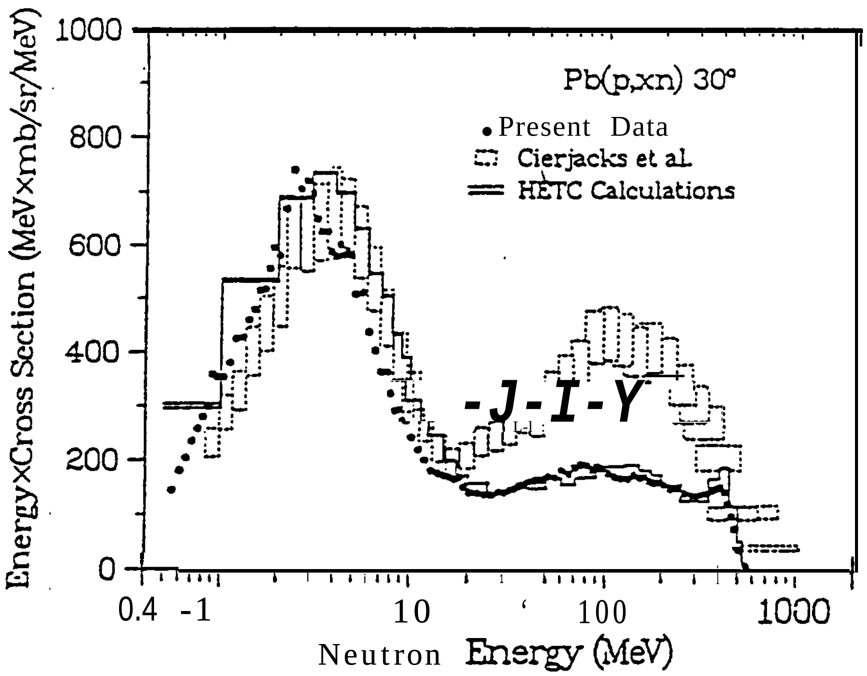

Figure 1: *Comparison of neutron production cross-sections (multiplied by the energy) for 585 and 597 MeV protons on lead obtained by two different groups. From Ref.[2].*

2 Experimental set-up

The beam structure of SATURNE and the little space available for time-of-flight (tof) paths do not allow conventional time-of-flight measurements. Two different experiment al techniques will thus be used for these measurements and both set-ups are sketched in fig.2. For the low energy part of the neutron spectrum, time-of-fright between the incident tagged proton and a liquid NE213-scintillator detecting the neutron will be employed. Gammas will be rejected by a pulse shape discrimination. The expected precision of the tof is around 1.5 ns. This will allow the detection of neutrons with energies between 1 MeV and 400 MeV. At higher energies the tof length is too small to permit good resolution, so the neutron energy spectrum will be obtained through the detection of recoil protons in a magnetic spectrometer, after (n, *p)* reaction in a liquid hydrogen target. Three wire chambers will give trajectory reconstruction, and a time-of-flight measurement between a plastic scintillator close to the hydrogen target and a plastic wall will allow separation between protons and other charged particles. A precision of 50 MeV/c on the proton momentum is expected. This technique will be used to measure the high energy part of the spectrum between 200 MeV and the beam energy. In both cases, a cone-shaped collimator made through an 8-meter long, heavy concrete wall will enable us to reduce the noise level which will be measured by the shadow bar technique. A plastic scintillator detector will

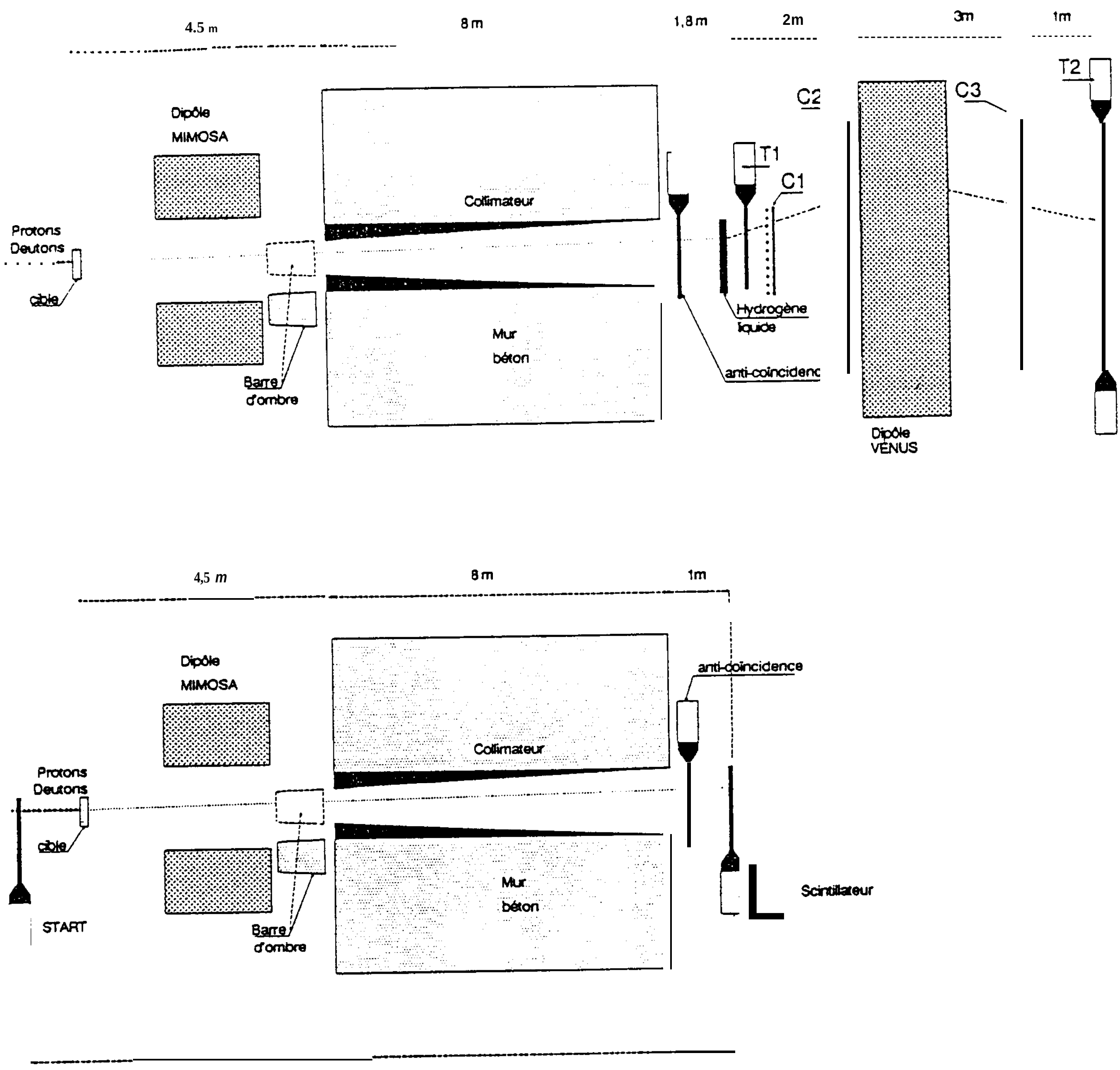

Figure 2: *Experimental set-up. Top: Measurement of the high energy part of the neutron spectrum. Cl, C2 and C3 are the wire chambers; T1 and T2 are plastic scintillators. Bottom: Set-up for the low energy part of the spectrum.*

veto charged particles from the target or from the interaction of neutrons in the collimator.

The first experiments will be performed at 0°, the direct beam and charged particles produced in the reaction being deflected by a sweeping magnet. Subsequently, by varying the angle of the incident beam on the target, we will be able to measure the energy spectrum at angles between O and 25°.

One of the main problems in this type of experiment is the difficulty of determining the detection efficiency of the set-up. This is very likely the reason for the discrepancies observed between different experiments. SATURNE presents the definite advantage that it can accelerate deuteron beams. By deuteron break-up on a *Be* target, it is possible to produce a mono-energetic neutron beam which will then be used to determine experimentally the efficiency response of the detection system.

3 Programme

The programme will begin in November 1994 with the study of the efficiency response of the detectors with mono-energetic neutron beams and with the measurement of neutrons produced at 0° by 800 MeV protons on a lead target, to make a comparison with existing data. Protons of 1.2 GeV on lead will also be studied. Then, during 1995-96, data will be taken with protons and deuterons of incident energies between 800 MeV and 2 GeV, on different targets, between O and 25°. Extensive modifications to the experimental area and the set-up will be required to make measurements at angles larger t han 25° possible. These modifications will be done in 1995, and experiments are planned to begin mid-96. Measurements of (n, xn) reactions, if interest is large enough, could also be considered.

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