Experimental measurement programme at SATURNE

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1 Presentation of SATURNE

SATURNE is a French national facility located in Saclay, near Paris, operated jointly by CNRS/IN2P3 and CEA/DSM. It consists of two synchrotrons, MIMAS, used as injector and accumulator ring, and SATURNE, the main ring. It can accelerate a wide variety of beams from protons to heavy ions (up to krypton), up to 2.9 GeV for protons and 1.15 GeV/u for heavy ions with a charge to mass ratio of 0.5. Maximum final energies and beam intensities are given in table 1. Polarized beams of $p, d, ^6Li$ are also available. An international scientific committee evaluates all the experimental proposals.

Table 1 : Projectiles Accelerated in SATURNE

Projectile	A	Q	Source	Intensity (part/cycle)	Max.Energy (GeV/u)
P	1	1+	AMALTHEE	8.10^{11}	2.95
D	2	1+	AMALTHEE	5.10^{11}	1.15
He	3	2+	AMALTHEE	2.10^{11}	1.69
He	4	2+	AMALTHEE	2.10^{11}	1.15
$\vec{P}$	1	1+	HYPERION	2.10^{11}	2.95
$\vec{D}$	2	1+	HYPERION	3.10^{11}	1.15
$\vec{Li}$	6	3+	DIONE	1.10^{9}	1.15
C	12	6+	DIONE	1.10^{9}	1.15
N	14	7+	DIONE	7.10^{8}	1.15
N	15	7+	DIONE	7.10^{8}	1.02
O	16	8+	DIONE	2.10^{8}	1.15
Ne	20	10+	DIONE	2.10^{8}	1.15
Ar	40	16+	DIONE	1.10^{8}	0.82
Kr	84	30+	DIONE	2.10^{6}	0.69
Kr	84	28+	DIONE	4.10^{6}	0.62
Kr	84	26+	DIONE	2.10^{7}	0.55

Twelve beam lines and four large magnetic spectrometers, the characteritics of which are given in table 2, are at the disposal of physicists working at SATURNE. More details about the machine and the experimental areas can be found in [1].

Table 2 : Characteristics of the Spectrometers					
	Angular range	Solid angle	Momentum resolution	Maximum momentum	$\Delta p/p$
SPES 1	0^0 to 80^0	3.10^{-3} sr	7.10^{-5}	2.00 GeV/c	4 %
SPES 2	0^0	2.10^{-2} sr	3.10^{-4}	0.75 GeV/c	34 %
SPES 3	-5^0 to 65^0	1.10^{-2} sr	5.10^{-4}	1.40 GeV/c	.6 to 1.4 GeV/c
SPES 4	-9^0 to 39^0	4.10^{-4} sr	1.10^{-3}	3.90 GeV/c	7 %

The main scientific purpose of SATURNE is to study strong interactions in its various aspects, in nuclear as well as in particle physics. Up to recently, there was no programme specifically dedicated to the measurement of intermediate energy nuclear data. However, an extensive study of nucleon-nucleon interaction [2] is beeing carried out at SATURNE and $N-N$ cross-sections have been measured. Also, results from the DIOGENE collaboration on proton and pion production in p-nucleus collisions [3] could be usable.

With the recent interest for accelerator-based systems for transmutation of long-lived nuclear waste or energy production, in which high neutron flux are produced in spallation reactions induced by projectiles with energy around 1 GeV, new needs for intermediate energy nuclear data have emerged. Since the energy range of SATURNE just corresponds to this domain, some programmes aiming at measuring nuclear data for accelerator-based neutron source are now starting up. For some of these experiments, this is a side goal of a more fundamental programmes while other ones will be specifically dedicated to this.

2 Neutron multiplicity measurements on thin targets

One of the key problem of spallation neutron sources is to produce the maximum number of neutrons at a reasonable cost. It is thus important to have a good knowledge of the neutron multiplicity distribution on thin targets to be able to model the production of neutrons in thick targets.

Actually, the original goal of this experiment, carried out by the ORION collaboration (GANIL-Berlin-SATURNE-Orsay-Liège), was to study the formation and decay of hot nuclei produced in p and ^3He-nucleus collisions as compared with production in heavy ion collisions. The apparatus used is the 4π liquid scintillator detector loaded with gadolinium, ORION, which can measure the number of emitted neutrons event by event. This type of detector has a very good efficiency (up to 80%) for low energy neutrons ($E_n < 20MeV$) while it fails to register most of the more energetic neutrons. The ORION detector is divided into 5 sectors so it allows also to have a rough estimation of the angular distribution of the neutron distribution. Light charged particles, intermediate mass fragments and fission fragments were also recorded in coincidence with the neutrons.

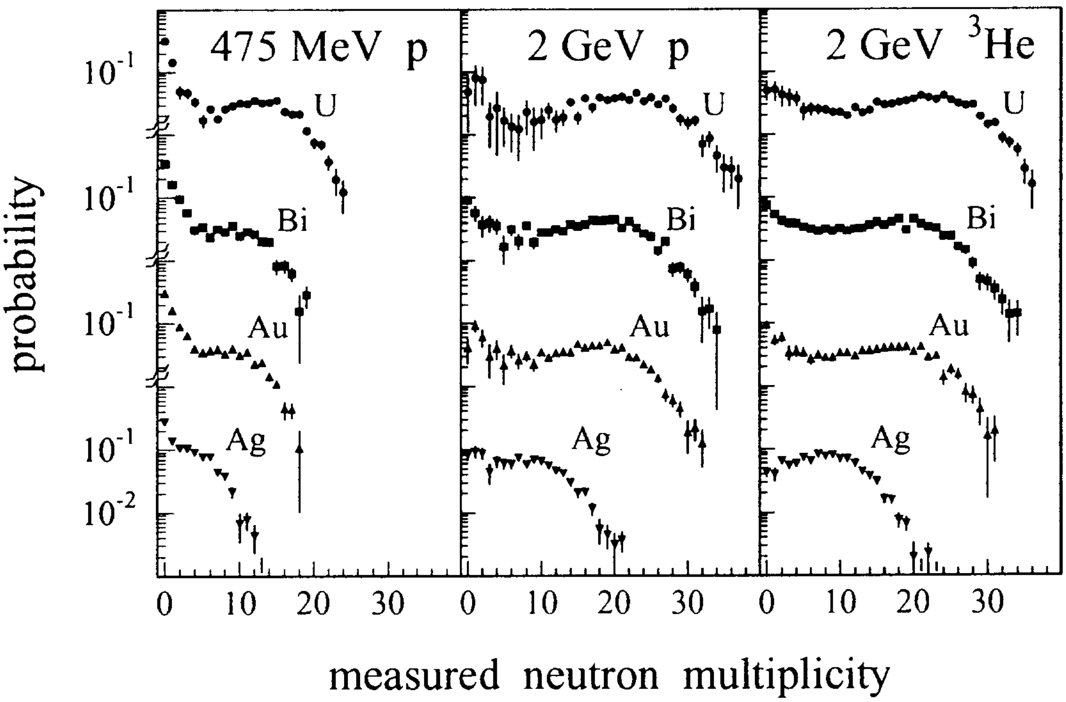

Figure 1: *Neutron mutltiplicity distributions as measured for three different types of projectiles impinging on different targets*

The experimental neutron multiplicity distributions obtained for three different projectiles and on a serie of targets [4] are shown in fig.1. It can be seen that all the distributions exhibit a similar pattern with a maximum at low multiplicity resulting from peripheral collisions and a broad bump at high multiplicity arising from more central collisions. A strong dependence on the target and on the projectile energy can be observed while, on the other hand, protons or ^3He lead to very similar multiplicity distributions. These results could be helpful for choosing the best conditions for producing the maximum number of neutrons.

Results have been compared to model calculations. In fig.2 the 2 GeV proton distribution on Au target is compared with the INC code of Cugnon [6] followed by evaporation (GEMINI). Fig.3 shows a comparison with HETC [5] . In both cases, simulations were corrected by detector efficiency but did not take into account secondary reactions in surrounding materials which, according to a first rough estimation could arise to 10% spurious detected neutrons. A qualitative agreement between data and calculation is found.

It is interesting to note that this detector, provided that it is adapted to voluminous targets

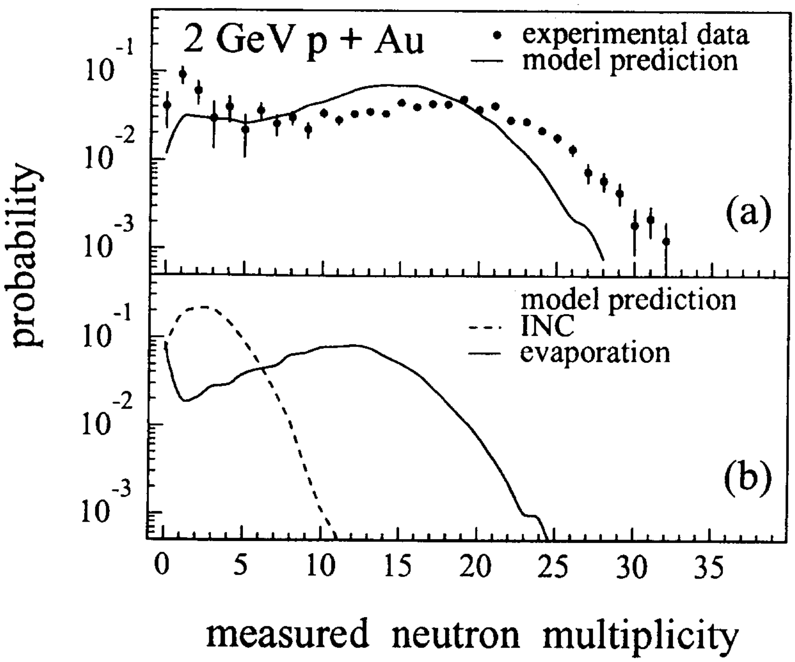

Figure 2: *Measured neutron multiplicity distribution (dots) as compared to model predictions, corrected for detection efficiency (solid line)*

and higher multiplicities, could also be used to measure event by event the neutron multiplicity distributions in thick targets.

3 Neutron production double differential cross-sections in thin targets

It has been emphasized, in this meeting, that there were no data concerning neutron production at energies higher than 800 MeV or with other projectiles then protons. Even below 800 MeV, there are discrepancies between existing data. A new programme, aiming at measuring the double differential cross-sections for the production of neutrons induced by reactions of protons and deutons on different targets, is just beginning at SATURNE. This is mainly a collaboration between Bruyères-le-Châtel, SATURNE, Saclay (DAPNIA) and Uppsala University.

Since SATURNE is not a pulsed machine, conventional time-of-flight measurements are not possible. Two different experimental techniques will thus be used for these measurements: for the low energy part of the neutron spectrum, time-of-flight between the incident tagged proton and a NE213-scintillator detecting the neutron will be employed. This will allow the detection of neutrons with energies between 1 MeV and 300 MeV. At higher energies the tof length is too small to permit a good resolution so the neutron energy spectrum will be obtained through the

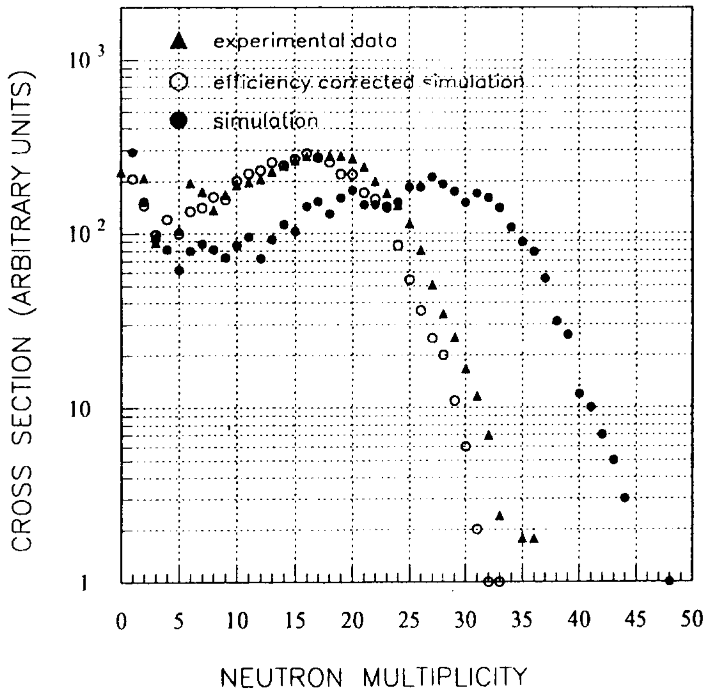

Figure 3: *HETC simulation of the neutron multiplicity distribution for 2 GeV protons on Au (solid dots) and after folding by the detector efficiency (open dots). Experimental data are given by solid triangles.*

detection of recoil protons, after diffusion in a liquid hydrogen target, in a magnetic spectrometer. This technique will allow the measurement of the high energy part of the spectrum between 200 MeV and the beam energy. The first experiments will be performed at 0°, the direct beam and charged particles produced in the reaction being deflected by a magnet. Then, the deviation of the incident beam on the target will enable us to measure the energy spectrum at angles between 0 and 25°.

One of the main problems of this type of experiment is the difficulty to determine 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 deuton beam. By deuton break-up on Be target, it is possible to realize a monokinetic neutron beam which will then be used to determine experimentally the efficiency response of the detection system.

The programme will begin in November 94 by the measurement of neutrons produced at 0° by 800 MeV protons on a lead target, to make a comparison with existing data, and 1.2 Gev protons on several targets. Then, data will be taken with protons and deutons of different energies on different targets. After some modifications of the experimental set-up, measurements at angles larger than 25° are planned.

4 Residual nuclide production

A good knowledge of the residual nuclide, in particular radioactive species, produced in spallation reactions is also essential for the design of accelerator-based systems. Since, at present, models not able to reliably predict the yield of particular nuclides, a large amount of data are needed. A collaboration leaded by Pr. R. Michel from Hannover University [8] has been working at SATURNE and on other facilities for several years on the study of nuclides produced in spallation reactions, in view of interpreting the observed abundance of nuclides resulting from interaction of solar and galactic cosmic rays on matter. This programme is now extended to measurements on targets relevant for accelerator-based systems with protons between 200 MeV and 2.6 GeV energy and will be completed by experiments on other accelerators at lower energies. A typical example of the quality of data that can be obtained is shown on fig.4.

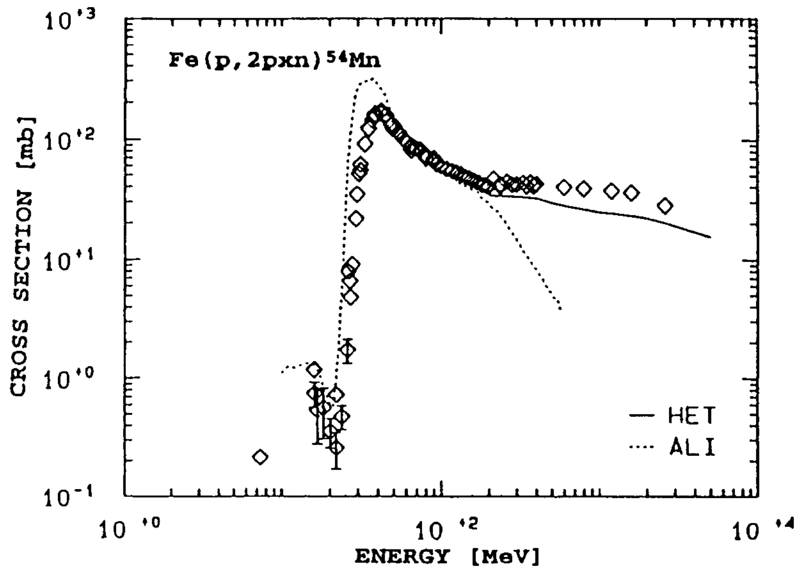

Figure 4: Cross-sections for the reaction $Fe(p,2pxn)^5Mn$ as measured by Michel and coll. [5]

5 Integral neutron production on thick targets

A group from LANL working on the design of targets for ATW project is considering the possibility to extend the experiments done in LAMPF [9] up to 800 MeV to higher energies at SATURNE. The purpose is to determine the absolute proton-to-neutron production rate by protons, deutons and other particles on simulations of spallation targets that have been proposed for ATW, ABC and ATP. The considered beam energy would be 400 MeV to 1.6 GeV for protons, deutons and ^3He.

6 Conclusion

The energy range of SATURNE, its variety of accelerated beams and detection systems, makes it a unique facility for measuring intermediate energy nuclear data relevant for accelerator-based system design. New programmes are now starting up. They mostly are devoted to thin target measurements but thick targets experiments are also under consideration. Other experiments could also be foreseen, as for instance, study of (p, xp) or (n, xn) reactions. Unfortunately, despite a large amount of physics projects, SATURNE is intended to be closed by the end of 1997.

References

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