

A STUDY OF THE NEUTRON EMISSION FROM Ti LOADED WITH D IN GAS PHASE BY MEANS OF A TIME-OF-FLIGHT SPECTROMETER

T. Bressani, D. Calvo, A. Feliciello and C. Lamberti
Dipartimento di Fisica Sperimentale dell'Universita' di Torino (Italy)
and I.N.F.N., Sezione di Torino (Italy)

and

F. Iazzi and B. Minetti
Dipartimento di Fisica del Politecnico, Torino (Italy)
and I.N.F.N., Sezione di Torino (Italy)

and

R. Cherubini, A.M.I. Haque and R.A. Ricci
Laboratori Nazionali di Legnaro dell'I.N.F.N., Legnaro (Italy)

ABSTRACT

The final results of an experiment carried out in order to detect and measure the energy of the neutrons emitted from Ti metal loaded with D in gas phase are reported. A neutron spectrometer based on the time-of-flight and double scattering technique was used. We observed a 2.5σ signal for the emission of 2.45 MeV neutrons, corresponding to 1.3 ± 0.5 neutrons $s^{-1} g^{-1}$.

1. INTRODUCTION

In this paper we report the final results of an experiment performed in order to detect and measure the energy of the neutrons emitted from Ti metal loaded with D in the gas phase. It became rather evident, following the first announcements of the Cold Fusion phenomena and the virulent debate that immediately grown up, that a clear-cut positive answer on the nuclear origin of the reported unusual phenomena could be given by an unambiguous detection of 2.45 MeV neutrons, the signature of the D-D fusion. For this reason we started in 1989 to design, assembly and finally calibrate a rather sophisticated neutron detector. In June-July 1990 we performed a series of measurements with a cell containing Ti, filled with D₂ or H₂ (for blank measurements) and whose temperature was cyclically varied. Preliminary results were already presented ¹⁾. A careful analysis of all the runs was subsequently performed, and a positive result was observed.

2. EXPERIMENTAL APPARATUS AND TECHNIQUES

It is well known from more than thirty years ²⁾ that the most reliable technique for detecting neutrons and in particular for measuring their energy is that of the Time-of-Flight (TOF). However, for the 2.45 MeV neutrons emitted from a Cold Fusion device, the method looks very hard to be adopted, mostly due to the absence of a "Start" timing signal. We overcame this difficulty by means of a double scattering technique, in which a neutron, in order to be detected, had to be scattered by two arrays of plastic scintillators, the first giving the "Start" signal and the impact position, the second one the "Stop" signal and again the impact position. The price to be paid to this technique is a quite low efficiency, but we estimated that the advantages

(energy resolution, complete insensitivity to environment and cosmic rays background, complete control of each "neutron" event by several parameters) were largely superior.

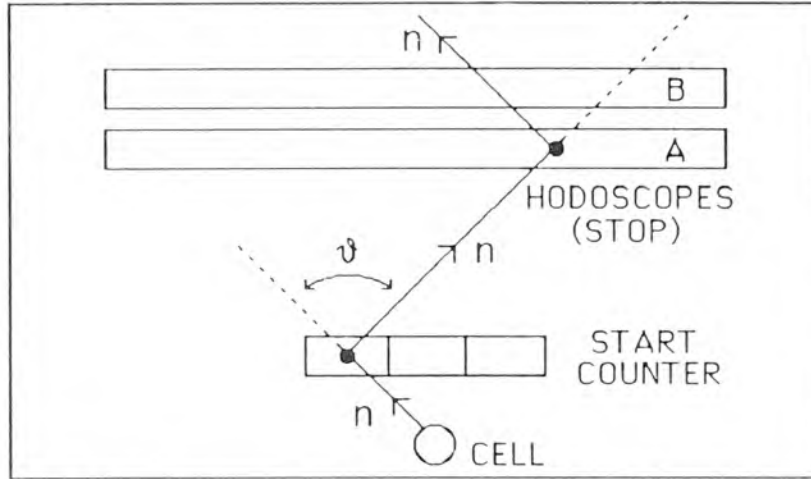


Fig. 1 Scheme of the neutron spectrometer based on the double scattering technique.

Fig. 1 shows a scheme of the spectrometer which is installed at the Laboratorio Tecnológico of I.N.F.N., Sezione di Torino. It consists of two blocks, a START array made of three plastic scintillators (NE 110) $28 \times 4 \times 9$ cm³ each, and a STOP hodoscope made of two arrays of 25 slabs of NE 110 plastic scintillators, $120 \times 2 \times 5$ cm³; each scintillator is viewed by two Philips XP 2020 Photomultipliers (PMs). The PMs' signals are sent to Constant Fraction Discriminators, whose threshold was set to detect a proton (scattered by the neutron) energy loss of 100 KeV. The instrumental time resolution on the TOF was measured to be 1ns fwhm. The apparatus is controlled on-line by a Micro-Vax II computer, and the data are recorded on 6250 bpi magnetic tapes. More detailed descriptions of the spectrometer, the electronics and the calibration procedures are reported in previous papers^{3, 4}). The only difference is that in the measurements, reported in the following, the number of elements in the START hodoscope was three instead of nine. We found in fact that the energy resolution was better by using only one layer of scintillators, instead of three.

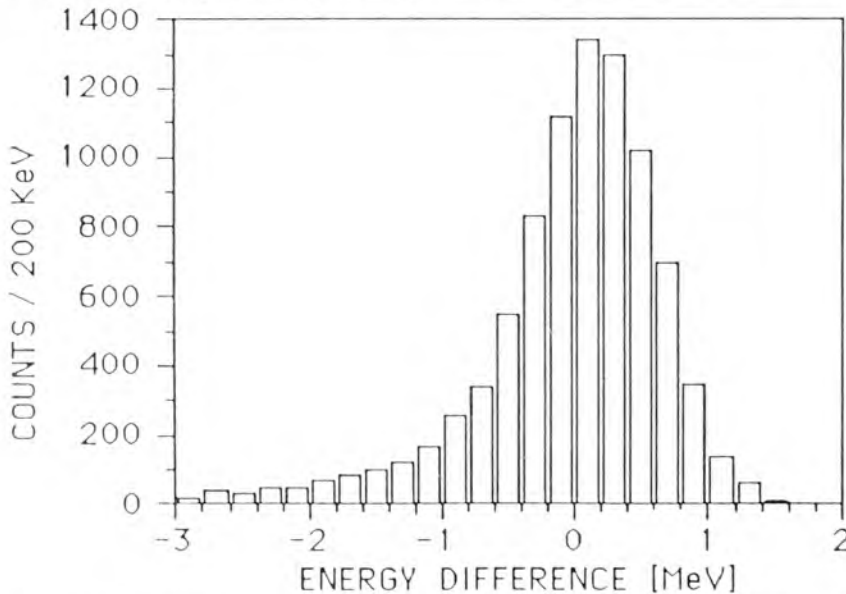


Fig. 2 Difference between the simulated and reconstructed neutron energy as obtained by the Monte Carlo simulation.

The energy resolution of the spectrometer was evaluated by means of a Monte Carlo simulation. For 2.45 MeV neutrons it is of $\sim 40\%$ fwhm, as shown by Fig. 2.

The overall efficiency of detection (including the solid angle) depends obviously from the distance of the cell to the START array. For the measurements reported here it was $\sim 3 \times 10^{-4}$.

We decided to start the experiments on Cold Fusion by a cell designed to study the absorption of deuterium gas in metals as a function of the temperature. We believed that this Cold Fusion device was better suited in order to exploit the performances of our sophisticated, energy-measuring, neutron array instead of an electrolytic cell, possibly surrounded by a thermostatic bath. In this case practically all the neutrons would be moderated and then not detected by our spectrometer.

The Cold Fusion device consisted of a stainless steel cell of cylindrical shape (3 mm thickness, 20 cm³ total volume), containing 3 gr of metallic Ti shavings, that could be filled with D₂ or H₂ (for blank measurements). The pressure in the cell could be controlled between 10^{-5} and $1.5 \cdot 10^3$ Torr, and the temperature from 25 °C to 540 °C, by means of a small heater put under the cell, in contact with the lower basis. The temperature was controlled by means of a thermocouple inserted into a copper ring surrounding the basis of the cell. We estimated that the temperature of the Ti shavings in the cell could be ~ 40 °C lower (500 °C instead of 540 °C). Fig. 3 shows a scheme of our Cold Fusion set-up.

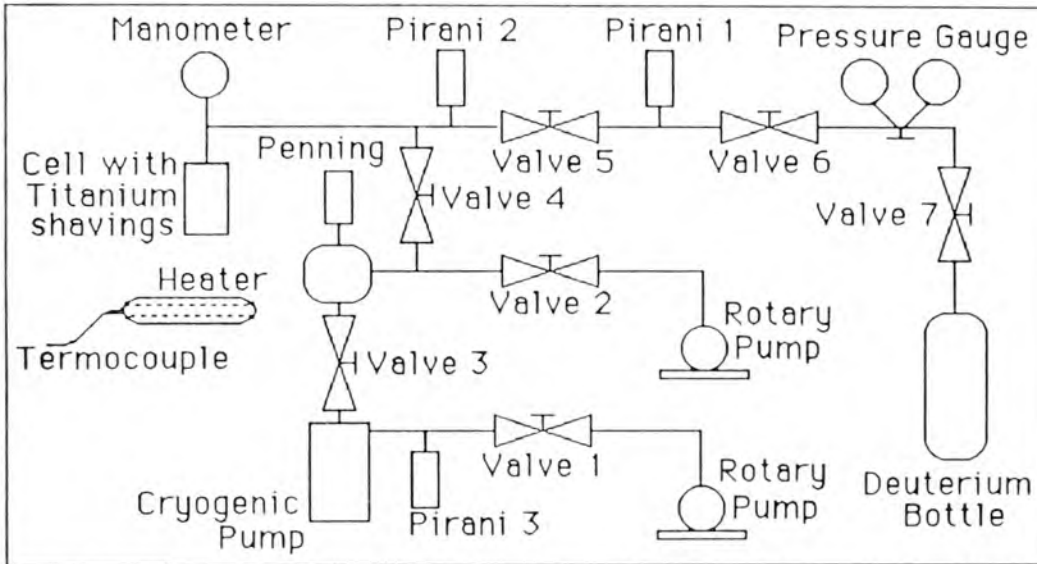


Fig. 3 Scheme of the vacuum system and of the gas loading circuit for the Cold Fusion set-up.

3. MEASUREMENTS AND ANALYSIS OF THE DATA

Before starting the runs, the cell was degassed in vacuum for 24 hours at 540° C. Two sets of measurements have then been performed filling the cell with D₂ and H₂ respectively; each set consisted in a sequence of measurements with the cell heated and cooled alternatively. During the heating phase the heater was kept on for a period of ~ 2 hours (~ 1 hour in a temperature ramp up from ~ 25 °C up to ~ 540 °C and ~ 1 hour at steady temperature); during the cooling phase the heater was kept off for a period of ~ 22 hours (~ 4 hours in a temperature ramp-down from ~ 540 °C down to ~ 25 °C, ~ 18 hours at steady room temperature). In the cycle up, the Ti reached the conditions of complete degassing, while in the cycles down it was filled again by D₂ or H₂. The number of complete cycles was 9 with D₂ and 6 with H₂.

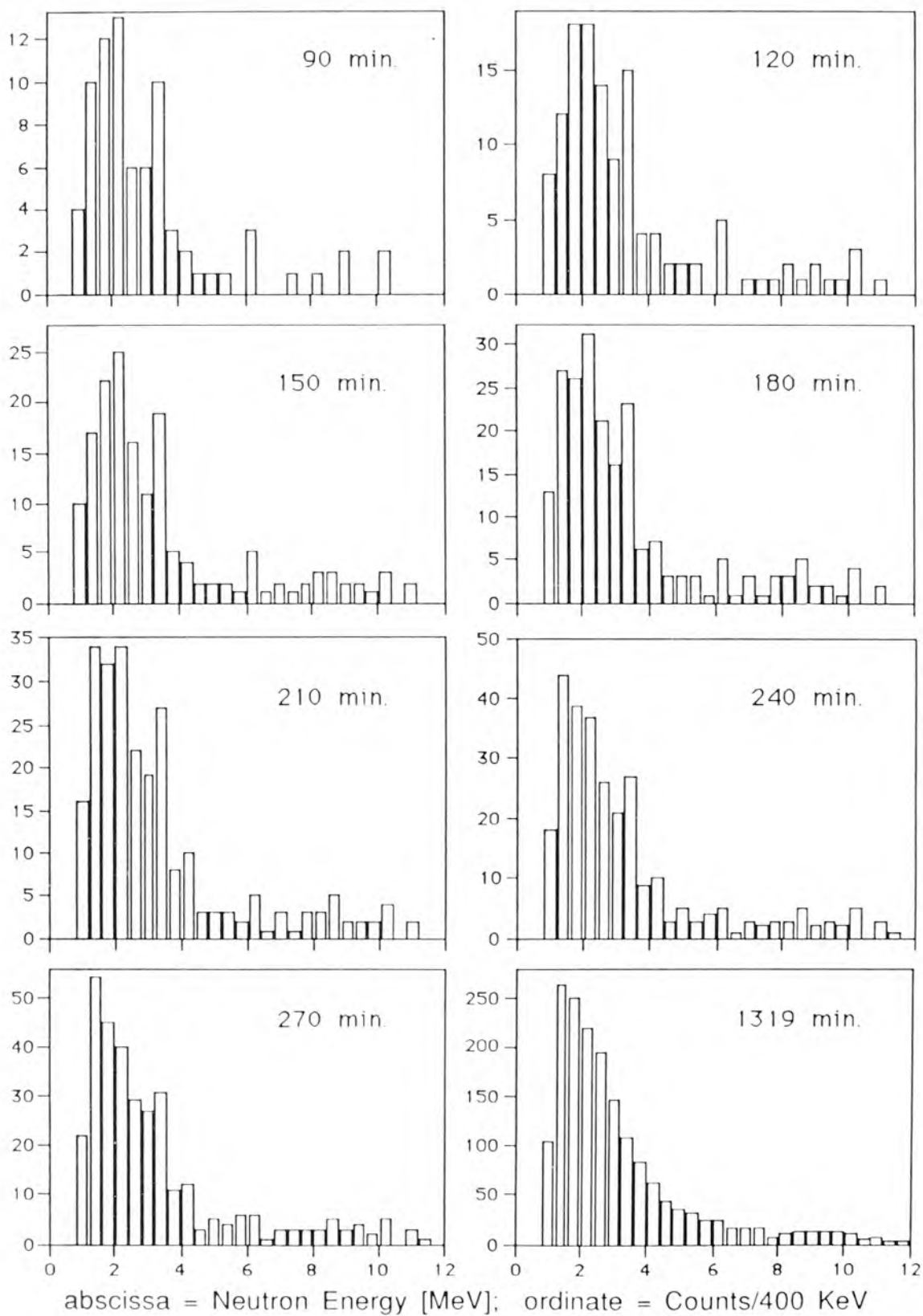


Fig. 4 Time sequence of the growing of the neutron energy spectra during a cooling down run, as observed in the on-line monitor.

During the cycles down with the D_2 filling we observed in the on-line monitors some abnormal behaviors of the neutron energy spectra, namely a small enhancement of the events around 2.45 MeV in the first hours. Fig. 4 shows the spectra of the detected neutrons at different times in a cycle down. No such enhancement was observed with the H_2 filling. At the end of the cycle down the enhancement is hardly visible in the spectrum, which closely resembles to that measured in a blank run (see Fig. 5).

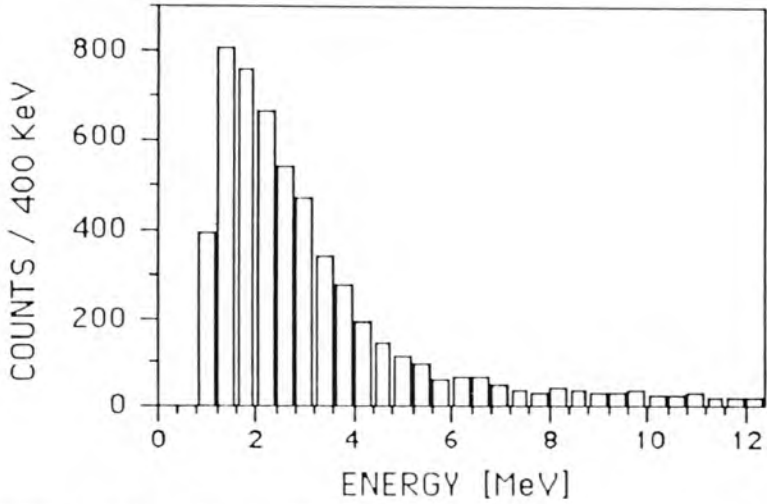


Fig. 5 "Neutron" energy spectra obtained in a blank run.

The first, obvious, trial to make more evident such an effect was that of subtracting the spectra obtained in all the runs with H_2 , properly normalized to the total running times, from those obtained in all the runs with D_2 . The resulting difference spectrum, was not completely satisfactory. Another approach, based on the normalization of the total number of events contained in the D_2 spectra to that contained in the H_2 spectrum, with the exception of those falling in the energy range from 2.0 to 2.8 MeV is shown in Fig. 6.

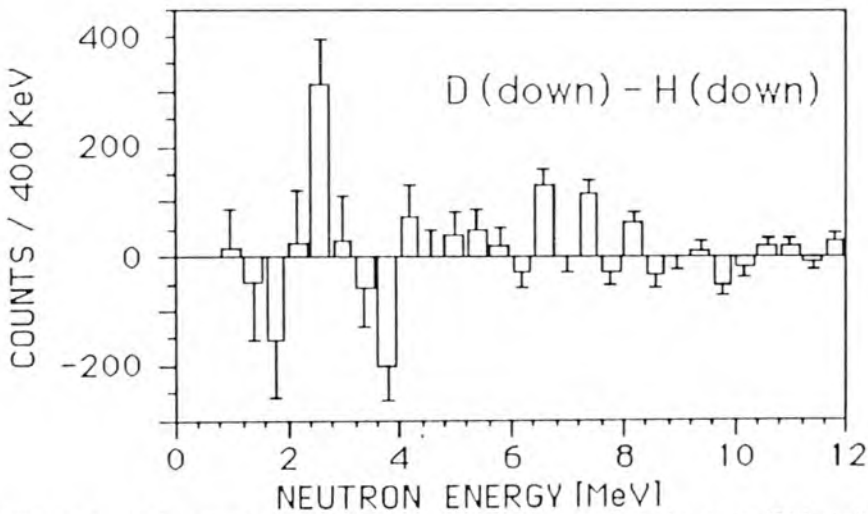


Fig. 6 Difference of the neutron energy spectrum measured in the runs D(down) and that measured in the runs H(down), normalized at the total number of events with the exception of those falling in the energy range from 2.0 to 2.8 MeV. The errors are the statistical ones.

A rather clear signal around 2.45 MeV was observed, but the overall behavior of the event distribution around the signal was not consistent with a statistical analysis, showing some systematic effect.

A careful inspection of the runs, in particular of the spectra and of the correlation plots showed the most likely reason of this unsatisfying behavior. The background in our "neutron energy" spectra (see Fig. 5) is not due to physical events (cosmic rays, natural radioactivity), but is totally instrumental, inherent to our technique. In order to detect with the maximum of efficiency the recoil protons scattered by the neutron in the first and second hodoscope, respectively, we kept in fact the threshold on each of the 26 photomultipliers of the detector at a very low value, close to the peak due to the single electron emission from the photocathode. We had then a certain amount of random coincidences, about 260/hour in the full spectrum, corresponding to ~ 20 /hour reconstructed in the channels around 2.45 MeV. The shape of the background spectrum (no cell) is fully consistent with this hypothesis (see Fig. 5). On the other hand, the spectra corresponding to the D₂ and H₂ filling were taken at about 3 weeks of delay and the "average" room temperature was then different. As a result the photomultiplier's noise was different, slightly larger in the runs with the H₂ filling. Consequently the background spectra were slightly different too.

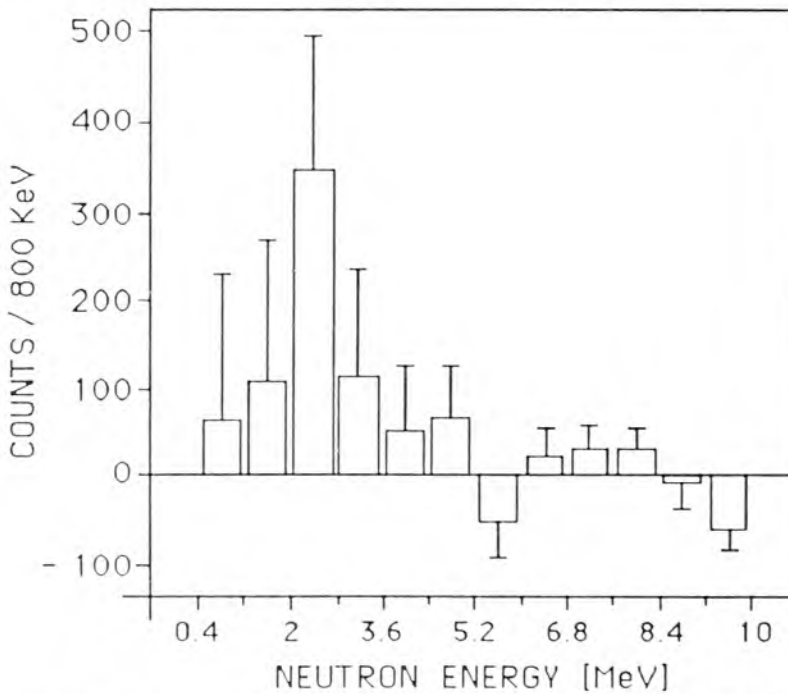


Fig. 7 Difference of the neutron energy spectrum measured in the runs D(down) and that measured in the runs D(up), normalized to the same time. The errors are the statistical ones.

A better, daily, control on the background was obtained by comparing directly the runs "down" with those "up" even if statistically quite different. Fig. 7 shows the spectrum obtained by subtracting the sum of the runs "up" normalized in time to the sum of the runs "down". A clear peak centered at ~ 2.45 MeV is visible with a satisfactory background subtraction around the peak. The resolution of the peak is fully compatible with that expected by a Monte Carlo simulation. The same procedure of subtraction, applied to the runs in which the cell was filled with H₂, gave a spectrum statistically compatible with zero everywhere.

4. DISCUSSION OF THE RESULTS AND CONCLUSIONS

The neutron emission measured in this experiment is $4.0 \pm 1.5 \text{ n s}^{-1}$, corresponding to $1.3 \pm 0.5 \text{ n s}^{-1} \text{ g}^{-1}$. It must be noticed that this value has to be considered as a lower limit for these measurements, just due to our subtraction technique. In fact, if the neutron emission would be the same for the runs "up" and "down", we should observe a null effect. If some neutron emission would be present even in the runs "up", this should lower the neutron emission reported for the runs "down".

It appears that the neutron emission seems not concentrated in a few bursts of short duration, as reported by several authors ^{5, 6)}, but perhaps distributed along the runs. Attempts to correlate the neutron emission to particular temperature conditions were in fact unsuccessful.

A final remark is that, from the volume and pressure measurements, we estimated that the D/Ti ratio in this experiment was 0.32. On the other hand, this value is totally inconsistent with the Ti-H Phase Diagram ⁷⁾. In the range of temperatures and pressures scanned in this experiment we would expect in fact a D/Ti ratio of ~ 1.8 . A possible explanation is that the surface condition of the Ti shavings was such to avoid a complete filling of Ti with D near the value expected from the Phase Diagram and that only a reduced portion of the sample could reach the equilibrium conditions expected from the Phase Diagram. Our results are also in qualitative agreement with those reported by Seeliger et al. ⁸⁾, with a less sophisticated neutron detection device.

In conclusion we report a $\sim 2.5 \sigma$ evidence for 2.45 MeV neutron emission following absorption of D₂ from a Ti sample. The main source of background was the photomultiplier's noise, which gave the main contribution to the experimental error. The experiments will be continued with a more carefully monitored cell, already built ⁹⁾, and with electrolytic cells. Finally, a system for cooling the photomultiplier's photocathodes is under design. This would decrease the instrumental background by at least an order of magnitude.

We are indebted to Prof. A. Zecchina for enlightening discussion on the Ti/D system and to Prof. G. Preparata for his continuous encouragement.

REFERENCES:

- 1) M. Agnello et al., in "Anomalous Nuclear Effects in Deuterium/Solid Systems", Provo (Utah) 22-24 Oct. 1990, AIP Conference Proceedings 228, edited by S.E. Jones, F. Scaramuzzi and D. Worledge, pag. 17 New York 1991
- 2) L. Cranberg and J.S. Lewin, Phys. Rev. 103, 343 (1956)
- 3) G.C. Bonazzola et al., in Proc. on "Understanding Cold Fusion Phenomena", Conf. Proc. Vol. 24 (ed. Ricci, E. Sindoni and F. De Marco), S.I.F., Bologna (1989), p.313
- 4) G.C. Bonazzola et al., Nucl. Instr. Meth. A299 (1990), 25
- 5) H.O. Menlove et al., Report LA-UR-89-1974
- 6) A. De Ninno et al., Europhys., Lett. 9, 221 (1989)
- 7) A.D. Mc Quillan and M.K. Mc Quillan "Titanium", Butterworths Scientific Publications, London (1956), p.211
- 8) D. Seeliger et al., published in Proc. 2nd Annual Conference on Cold Fusion (Como, 29 June-4 July 1991)
- 9) M. Agnello et al., published in Proc. 2nd Annual Conference on Cold Fusion (Como, 29 June-4 July 1991)

