

**"COLD FUSION" IN TERMS OF NEW QUANTUM CHEMISTRY:
THE ROLE OF MAGNETIC INTERACTIONS IN DENSE PHYSICA MEDIA**

Neutron and X-ray detection in plasma focus and "capillary fusion" experiments

R.D. Antanasijevic, Dj. Konjevic, Z. Marie, D.M. Sevic, J.P. Vigier & A.J. Zaric

Abstract

Various recently reported "break even" in different types of "cold fusion" experiments have a common physical origin if one assumes that one should add, in dense states, the action of magnetic interactions of oriented nuclear spins to the usual Coulomb forces. In that case one is led to predict a) the existence of new "tight" quantum molecular states (associated to new "tight" Bohr orbits) which correspond to the emission of X-ray lines and excess energy b) the associated apparition of a certain amount of nuclear fusion reactions due to those magnetic interactions and enhanced tunneling by strong electron concentrations. They appear in the form of neutron (or γ) bursts and various types of "ashes" of particular nuclear fusion reactions in electrolysis, glow discharge, capillary devices, resonance sonoluminescence and plasma discharge experiments. They both contribute to observable energy excess in amounts which vary which chosen set-ups.

To explore this assumption two experiments are presented here i.e. 1) discharge experiments in plasma focus and "capillary fusion" devices (i.e. nuclear fusion) of 10^8 neutrons/burst 2) X-ray measurements in deuterium plasma focus which confirm the existence of new Bohr orbits.

New possible experiments to check it are also briefly discussed.

Introduction

The question of the physical interpretation of the growing set of experiments showing (apparent) energy-momentum violations (mostly in the form of the heat creation first observed by Pons and Fleischmann ⁽¹⁾ is evidently still open. Publicly known under the label "cold fusion" the experiments now covers a wide range of different physical processes going from electrolysis (with water and heavy water) with Pd or Ni cathodes) to glow discharge; plasma focus, capillary fusion, sonoluminescence. The original idea that they had a common physical origin in nuclear fusion process realized in dense media i.e., different from the usual line of research based on Tokamak-type devices, has not been supported by subsequent experiments. The problem is that the fusion "ashes" which have been observed are nearly always a few orders of magnitude too low to explain this excess energy ⁽⁸⁾ and that it is not even clear that these experiments should be explained within a single theoretical frame.

In this paper we shall assume however that this is indeed the case and that "cold fusion" processes, or more precisely "break-even" energy production, are just the manifestation of the intervention of polarized nuclear magnetic moments in dense matter: a type of force which is negligible (w.r.t. the Coulomb force) in ordinary conditions.

To summarize this model assumes

- a) That in certain particular physical conditions (in dense matter, under certain external or internal magnetic fields, the nuclear and intervenir electron spins, are oriented and one should add short range magnetic interactions to the usual Coulomb forces
- b) This implies the existence of new "tight" Bohr orbits and the formation of new "tight" molecular states, which yield new quantum transitions within the frame of the usual quantum mechanical formalism.
- c) If one imbeds such molecular states within electronic concentrations generated in metal lattices or convection currents their screening allows "tunneling" effects and thus allow fusion between nuclei which does not depend on high temperatures.
- d) This implies the apparition of a new quantum chemistry in certain conditions which appears at our level, in the form of exothermic reactions accompanied by observable fusion reactions.

In other terms the new phenomena correspond to the usual quantum mechanical formalism acting in special physical circumstances.

POSSIBLE EXPERIMENTAL TESTS OF THE MAGNETIC INTERACTION MODEL

At the present stage of the experimental situation on "cold fusion" it appears possible to confront the preceding model/interpretation with the results of different experiments.

A) In order to test the assumption of the existence of new Bohr orbits one can

1) test directly the existence of new "tight" molecular states on hydrogen and deuterium in metal loading experiments.

Indeed their existence in metals (due to nuclear spin polarisation) implies that their internal density is high enough to correspond to a new phase in metals (they behave somewhat like a liquid or solid state at low temperature) so that one would expect

– to observe the creation of Cooper pairs in H or D in the metal i.e. the apparition of superconducting phenomena within loaded Palladium-Nicket etc.

– to observe a contraction of the loaded metal since internal thermal metal agitation would be reduced by the pressure of "tight" \overline{H}_2^+ or \overline{D}_2^+ molecules.

2) try to detect directly the existence of these "tight" \overline{H}_2^+ or \overline{D}_2^+ molecules in mass spectroscopy performed on gaz derived from such experiments and also try to measure their lifetimes in corresponding experiments.

3) examine (as already done by Reifenschweiler ⁽⁹⁾) the β decay of new "tight" radioactive molecules. Indeed the formation of "tight" states implies a new type of recoil in β or γ emissions which can explain apparent "anomalous" nuclear decay rates.

B) In order to test directly the existence of new electronic levels one can try to detect the corresponding soft X-ray lines. This has already been done in various cases (one will be discussed in this paper) with positive results. (See S. Szpak and P.A. Mosier-Bodd "On the behaviour of the cathodically polarized Pd/D system: Search for emanating radiation". PLA (in press) ⁽¹⁰⁾).

C) In order to test directly the possibility that the existence of such "tight" states can, when associated with strong electron concentrations (which favor "screening" processes) favor real nuclear fusion reactions (which, in their turn, decay into various types of isotopes, not present in the initial sets ups) one should follow the path opened by Prof. Takahashi and his group.

D) In order to test the possibility of a magnetic interaction as basic origin of the new energy producing mechanism one can develop non-electrolytic experimental devices such as

1) - the Lochte-Holtgreven capillary experiments ⁽¹¹⁾

2) - the Graneau-type water-plasma explosion devices in ceramic and metal cavities ⁽¹²⁾

3) Direct energy producing devices from magnetic materials (some of which will be discussed after this talk) which rest on the idea that the apparition (by resonance excitation) of increased magnetic fields (resulting from the contribution of "tight" molecules in the ferrites of the stators of Gram-type machines) will result in stronger output currents.

This implies the validity of Ramsey's initial suggestion ⁽¹³⁾ (N. Ramsey Phys. Rev. 103 July 1 (1956) 20) that one can utilize nuclear spins as a separate (negative temperature) thermal bath to create a heat engine operating in a closed cycle that will produce no other effects than the extraction of heat from a negative temperature reservoir with the performance of the equivalent amount of work.

In this work we want to present the results of some experiments which seem to support:

- the existence of new Bohr orbits associated with X-ray emission i.e. resulting from magnetic interactions.
- the existence of neutron emission in plasma focus and « capillary fusion » experiments, which support the idea that fusion process are related with the existence of such interactions.

The experiments concern the measurement of the total neutron yield, achieved by using the large volume liquid scintillator neutron detector (NE343). The capacitor bank is charged up to 20kV giving current up to 400kV. Maximum neutron yield is about 10^{11} /pulse. The detection and analysis of the X-ray is done using roentgenographic method with aluminium foils of varying thickness. Soft X-ray ($\lambda > 20nm$) were detected.

The experiments we have performed (plasma focus and "capillary fusion.") require high detection efficiency of the neutron detector. ⁽¹⁴⁾ Among many possible types we have chosen a detector based on a large loaded liquid scintillation medium. The main features of this type of counter is slowing down of neutrons in a large volume of a hydrogenous liquid and absorption by the loaded element (Gd) ⁽¹⁵⁾. In section 2 the construction and calibration of the detector will be explained, and in section 3 preliminary results concerning detection of the total neutron yield in the plasma focus and "capillary fusion" experiments will be presented. Section 4 is devoted to the study of X-ray emitted in the deuterium plasma focus devices.

2. Description of the experimental set-up

2a. Plasma focus and "capillary fusion" chambers

The plasma focus chamber is the Mather type (16) and consists of two brass coaxial electrodes (outer electrode consists of 18 cylindrically positioned brass rods, separated by the glass insulator sleeve at one end, where the breakdown of a gas discharge at an initial density of about 10^{17} cm^{-3} takes place. This chamber has been designed for the currents up to 1 MA and 10^{10} *neutrons/pulse*.⁽¹⁴⁾ Development and acceleration of the plasma focus current sheath have been measured by means of the fiber optic cables that are "looking" at the certain spots inside the chamber. Corresponding windows are intended for the laser scattering measurements. Electric circuit parameters (charging voltage, capacitance and external inductance), electrode geometrical dimensions and gas filling are chosen in such a way that the radial compression starts near the current maximum. A low inductance capacitor bank ($45 \mu\text{F}$ with triggered spark gap as a switching device) is used as an energy source with power transmission line between the power supply and two coaxial electrodes.

The main part of the data acquisition system is digital storage oscilloscope Tektronix 2440 (500 MSamples/s). It enables all voltage and current measurements. This is also most convenient and accurate way of taking data from neutron detector. Data transfer from Ibis oscilloscope to the personal computer is completed, so all data are available for numeric analysis.

Voltage measurements are taken with high voltage probes. A Rogowski coil between the power transmission, plates monitors variations with the time of the electrode current.

2b. Construction and calibration of the large liquid scintillator neutron detector

The efficiency of a large volume liquid scintillator neutron detector strongly depends on the shape and dimension of a scintillator tank. In order to check detector properties before construction, a simulation of detector performance, especially of the detection efficiency, was done using the Monte Carlo DENIS computer program.⁽¹⁸⁾

The neutrons are moderated by the hydrogenous material (toluene). After thermalization and diffusion, they are captured by the loaded element (0.2 per cent of gadolinium $\sigma_{abs} = 3.6 \times 10^1$ barn). Gadolinium deexcitation by emission of three gamma rays (9 MeV total energy) and their interaction with scintillator are the second step in the neutron detection. Finally, light collection and detection are considered. Consequently, the total neutron efficiency of the detector is a product of the captured neutron efficiency, gamma rays detection efficiency and light detection efficiency. The input variables in the program are the diameter of the sphere, the initial neutron energy and the discrimination threshold of the photomultiplier signal. The capture time distribution and neutron detection efficiency as a function of discrimination threshold for gamma ray energy are the output results.

The calculated efficiency of neutron detection for a sphere of 1 meter in diameter, as a function of the initial neutron energy, is shown in Fig 1. We conclude that such a detector satisfies our demands on the total neutron yield measurement in plasma focus and “capillary fusion” experiments since the expected detection efficiency for neutrons from the D-D reaction ($E=2.45\text{MeV}$) and those from spontaneous fission ($\bar{E} \approx 2-2.5 \text{MeV}$) is about 90% for a source of neutrons placed in the center of the sphere. The results of simulation for fission neutron energy spectra are compared with the results of calibration made by a californium spontaneous fission source (Fig. 2 and Fig. 3).

The main body of our detection system is a spherical tank of 1 meter in diameter, made of stainless steel, filled with the scintillating solution (Fig.4). Twelve photomultipliers (Hamamatsu R1512, 5 inches in diameter) are mounted on quartz glass viewing windows. For the improvement of light collection (reflection), the inner walls of the sphere are electrochemically polished. The scintillating solution was kept oxygen free with argon gas.

The photomultiplier pulses are summed in two branches (six photomultipliers in each) and via a preamplifier, amplifier and discriminator transmitted to the coincidence unit. When coincident pulses are observed from both branches, signals are accepted as neutron events and counted. Since at least two photomultipliers must give a signal, the effects of ran-

dom noise from photomultipliers are minimized. A block diagram of the electronic circuit used for calibration of the detector is given in Fig. 5.

The capture time distributions of simultaneously emitted neutrons is broad and has a peak at about 10 μs after their production (Fig. 2). In this way, about 83% of all emitted neutrons (for neutron energy fission spectra) are captured within a 35 μs time interval. The detection system was calibrated by a californium-252 spontaneous fission neutron source placed at the center of the spherical detector. A surface barrier detector was placed very near to the californium source and pulses from fission fragments were used as triggers for a neutron counting start. The fission rate of The source was about one per second and neutron counting was initiated after 1 μs delay with respect to the last fission, 1 μs so as to eliminate all prompt gamma signals from the source. The gate duration was set to 35 μs . Since the detector is very sensitive to cosmic and laboratory background, measurements without any source were also made. The detection efficiency is then obtained by using the equation:

$$\epsilon = (n_m - n_b) / n_e \quad (1)$$

where: n_m is the mean value of measured neutrons, n_b is the background activity and $n_e (= 3.72)$ is the average number of neutrons emitted per fission.

Corresponding measurements were performed for different discrimination thresholds (Fig.3).

For the threshold corresponding to 2 MeV of gamma ray energy, the detection efficiency for ^{252}Cf neutrons is about 83% (Fig. 6). The neutron capture time distribution was also measured and compared with calculated values (Fig. 2). The agreement between measured and calculated values is satisfactory. We conclude that the detection system is able to detect simultaneously emitted neutrons within a broad time interval (about 40 μs). This is important for the case of the ‘‘capillary fusion’’ and plasma focus experiments since electro-magnetic interferences due to discharges can be avoided by a few μs delay of a neutron counting start.

2c. Data acquisition and analysis system

Since in detection experiments of spontaneous fission events of superheavy elements and of neutron yield from plasma focus and "capillary fusion" the frequency of the events is much lower than in the case of calibration with the californium source, the data acquisition and analysis system has been adapted in order to optimize the detection process, (dead time reduction, process automation).

The data acquisition system consists of nuclear detectors and electronic equipment, probes for high voltage and current measurements, and various diagnostics for plasma characteristics. The data analysis system is composed of a PC computer and software support. The main interface between the data analysis system and the data acquisition system are the digital storage oscilloscopes Tektronix 2440 (500 MSamples/s) and 2430A (150 MSamples/s). This is a convenient and accurate way of taking data from neutron detectors. The oscilloscopes also transmit all voltage and current measurements. Data are transferred from the oscilloscopes to the computer and thus are available for numerical analysis.

Although the whole setup of the experiment is properly grounded and well shielded, our nuclear electronic equipment is very sensitive to electromagnetic interferences (EMI) generated by the discharges of the capacitor bank in the plasma focus chamber. Because of that, the signals from the photomultiplier tubes are mixed and recorded on the aforementioned digital oscilloscopes, which are excellently protected from EMI. EMI is also avoided by a few microsecond delay of a neutron counting start. The shape of signals are easy to analyze on the computer, thus reducing possible errors from EMI.

3. Preliminary results concerning neutron yield measurements in plasma focus and "capillary fusion" experiments

In the case of plasma focus experiments the position of the source of neutrons (plasma focus chamber) must be at a distance of several meters

from detector (shock hazard, EMI) and the overall detection efficiency decreases by several orders of magnitude. For example, the solid angle of the detector for a distance of 10m is only 0.066 per cent. The neutrons are detected with a few microseconds delay in a broad time interval of about 40 μ s. This fact is very important for plasma focus experiments because of high EM radiation emission due to the discharge of the capacitor bank which occurs simultaneously with the neutrons.

The neutron yield experiments were performed with the detector 8 meters away from the plasma focus and "capillary fusion" chambers. The threshold neutron count rate was one event per pulse, meaning 10^3 emitted neutrons into a solid angle of 4π . Typical results obtained for a plasma focus experiment at constant pressure of 1.3 mbar is shown in Table I.

At higher pressures the neutron yield increases to reach 10^{10} neutrons per pulse at 4.5 mbar (Fig. 7).

Neutrons from the "capillary fusion" experiments could not yet be detected with this unfavorable geometry. Work is in progress to permit decreasing the distance between the source and the detector.

TABLE I

Neutron yield as a function of the involved energy at constant pressure for plasma focus experiments

Energy [kJ]	2.0	2.2	3.2	4.4	5.8	9.0
Voltage [kV]	9.2	10	12	14	16	20
J_{\max}	200	210	240	290	350	450
Yield [n /pulse]	$<10^3$	8×10^5	1×10^5	2×10^5	2×10^5	$<10^3$

4. Studies of the emitted X-ray

The analysis of the X-ray emitted from the Mather type plasma focus device is carried out by the roentgenographic method. Two kinds of experiments were conducted. The discharge through the pure deuterium gas and through the mixture of 94% deuterium and 6% argon gases. The motivation for a use of the above mixture comes from the study of Japanese group. ⁽¹⁰⁾

Spatial resolution of emitted X-ray was achieved using collimator disk made of stainless steel. The diameter of the collimator holes was 1mm,

the length 10mm and distance from central electrode 130mm. In the case of the soft X-ray detection the aluminum foil of 20 μ m in thickness was used to protect roentgenographic film from the visible light also emitted in the plasma focus (figure 8.). For the analysis of hard X-rays different thickness of an aluminum absorber, up to 400 μ m was used (figure 9.). When the working gas was pure deuterium only soft X-rays ($\lambda \geq 10nm$) are detected. The geometry of the experiment shows this emission might appear at times before the plasma takes its final form. Although it is known that the existence of the hot spots in the plasma focus are connected with the neutron pulses emission. The coincidences between them and X-rays emission can not be affirmed as the established phenomena.

In the case of the deuterium-argon mixture beside the soft X-rays of the energy up to 8keV (which might belong to the argon K-lines) the hard X-rays are detected. The origin of these hard X-rays emission is uncertain, although the geometrical consideration made by the pinhole images suggests that it comes from a zone near the central electrode in the final stage of the plasma formation in the focus device.

CONCLUSION

In the experimental runs we have detected the neutron pulses of 10^8 in the plasma focus device. For the "capillary fusion" experiments, one concludes our experiment depends on the geometry which can be arranged in the way to detect the "threshold" of about 1062 neutron/pulse.

The detected soft X-ray in the discharges when the focus is filled by deuterium have energies of about 5keV. The hard X-rays ($E \approx 8keV$) appear in the deuterium-argon mixture. This suggests the strong dependence of the "fusion" reactions on electronic surroundings.

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- (7) See R. Stringham and Russ George's experiments
- (8) See discussion in ref. (3) and (4)
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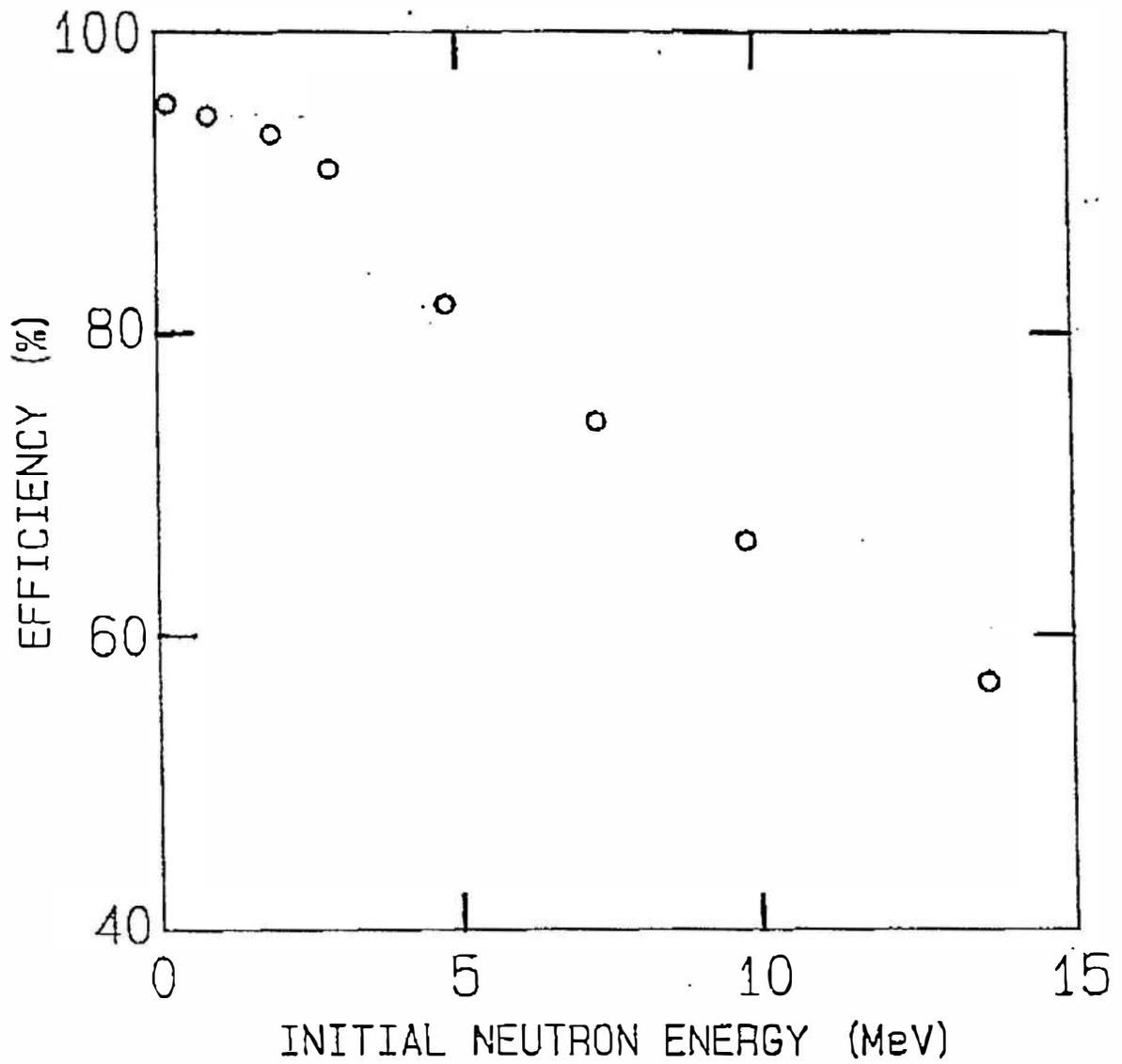


Figure 1: Efficiency of the large volume gadolinium loaded liquid scintillator detector calculated using the Monte Carlo method as a function of the initial neutron energy

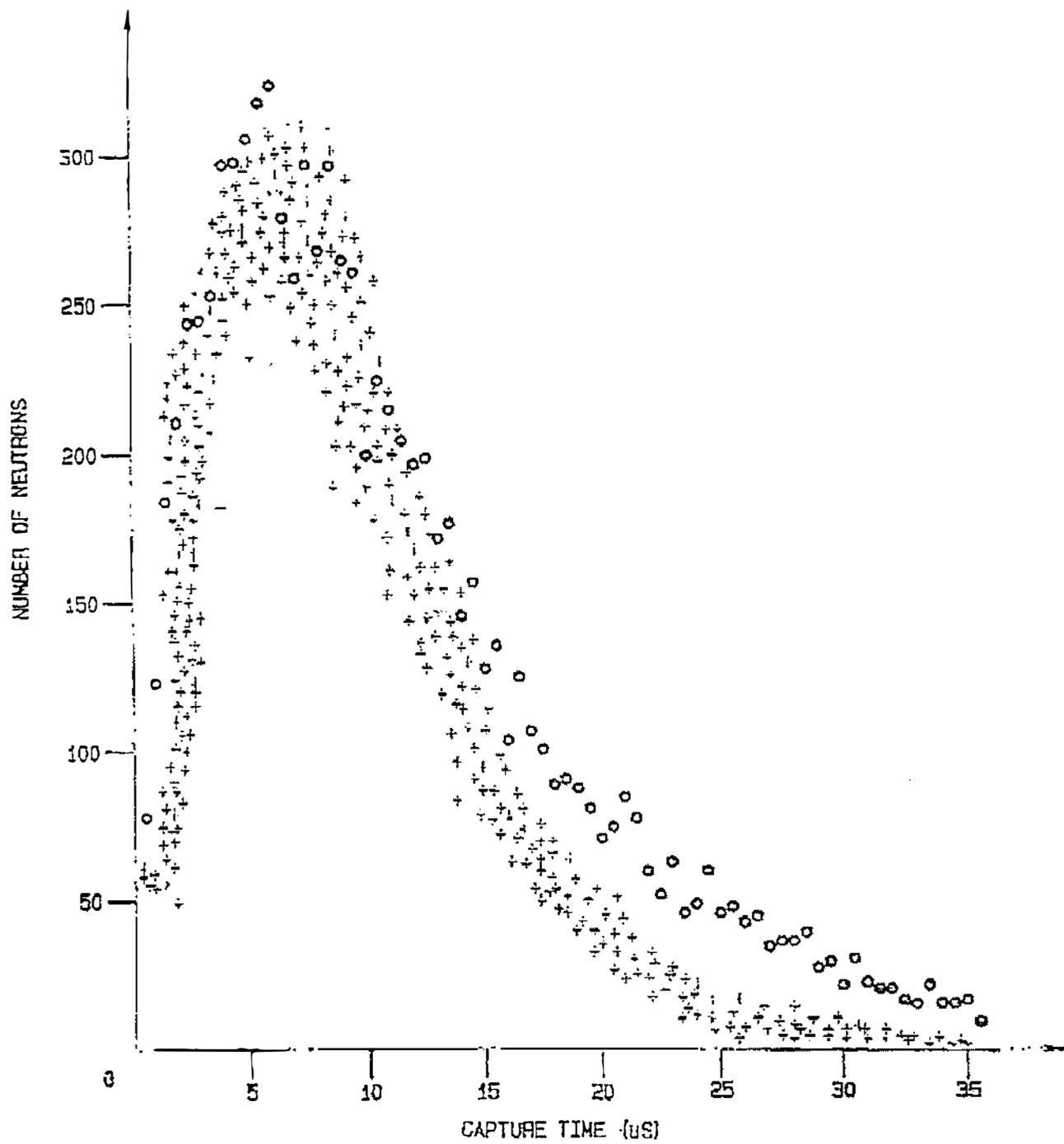


Figure 2: Neutron capture time distribution: o - calculated values and + - measured values

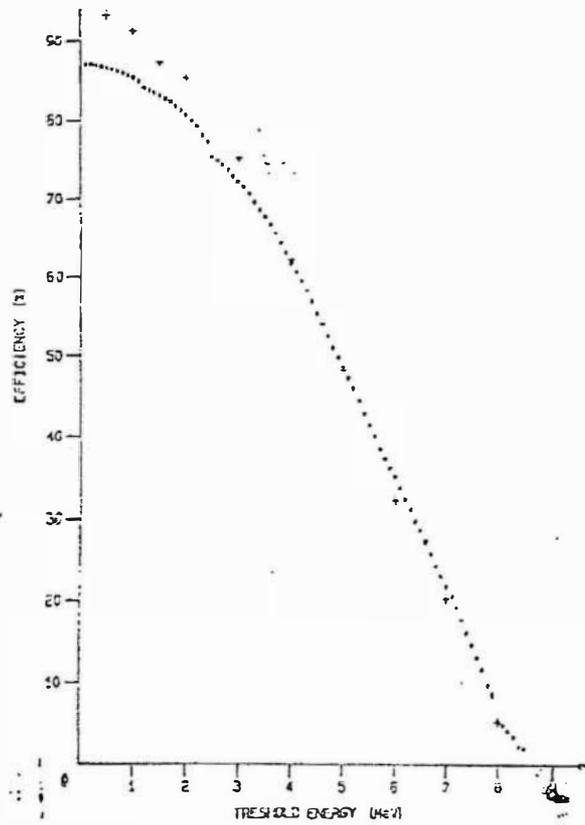


Figure 3: Neutron detection efficiency as a function of the threshold gamma ray energy: o - calculated values and + - measured values

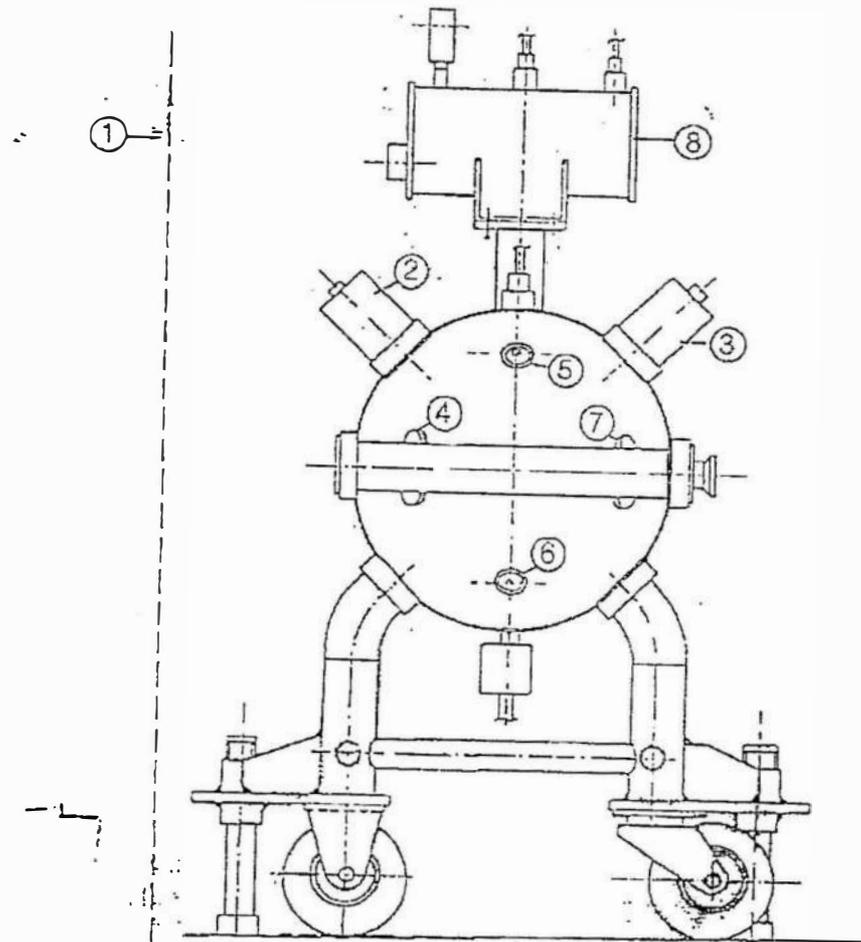


Figure 4: The large volume gadolinium loaded liquid scintillator detector: 1 - electromagnetic shield, (2 - 7) - photomultipliers and 8 - expansion tank

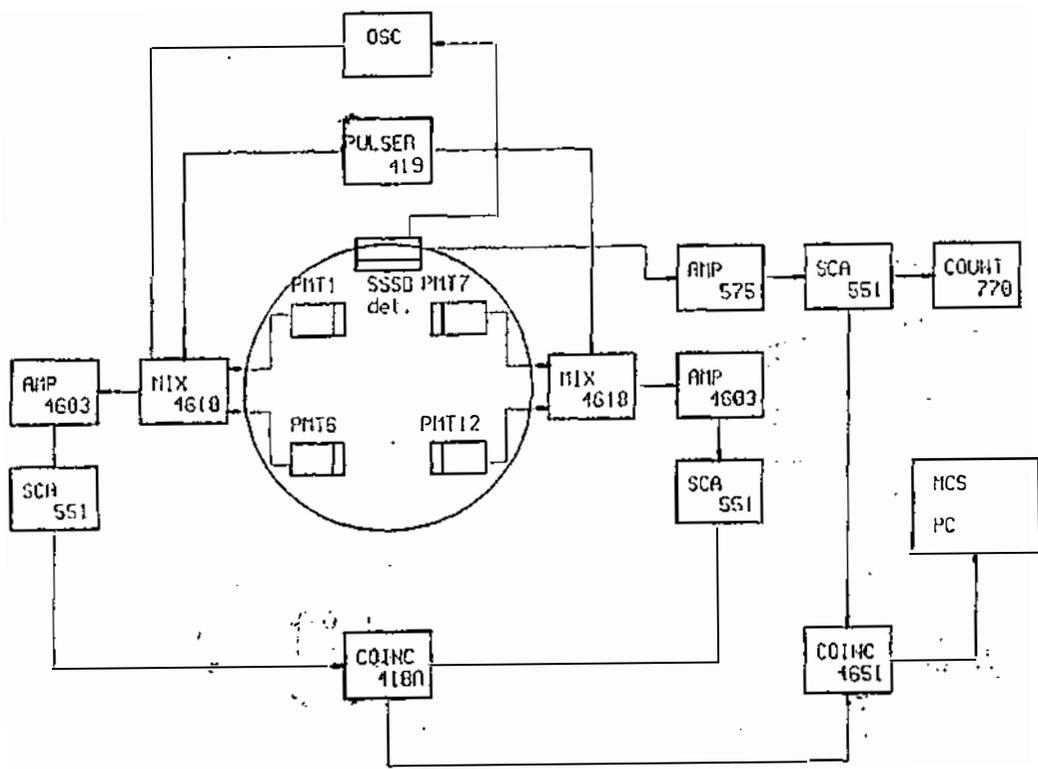


Figure 5: Block diagram of the electronic circuit for the large volume liquid scintillator detection system.

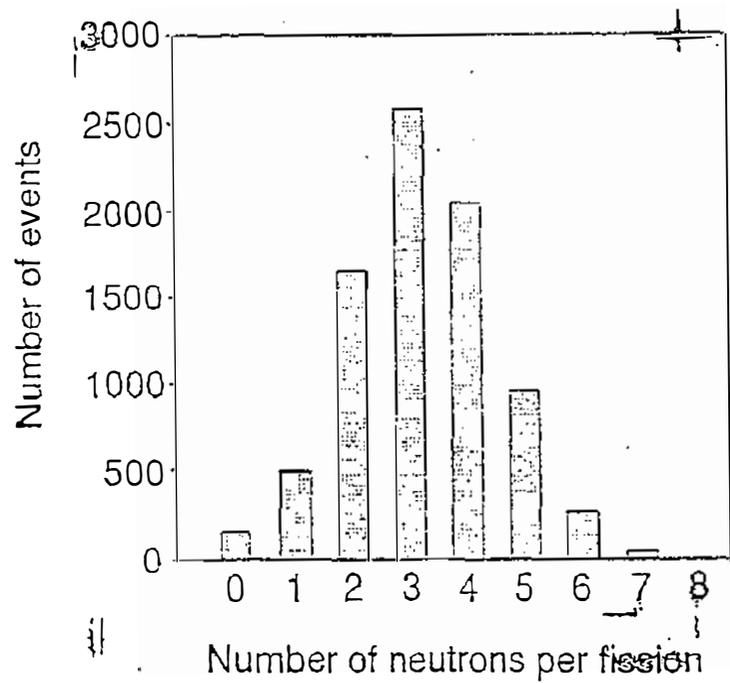


Figure 6: Neutron multiplicity distribution for the ^{252}Cf source. The average value is 3.48 and the corresponding efficiency is 83%.

NE 343 DETECTOR SIGNALS

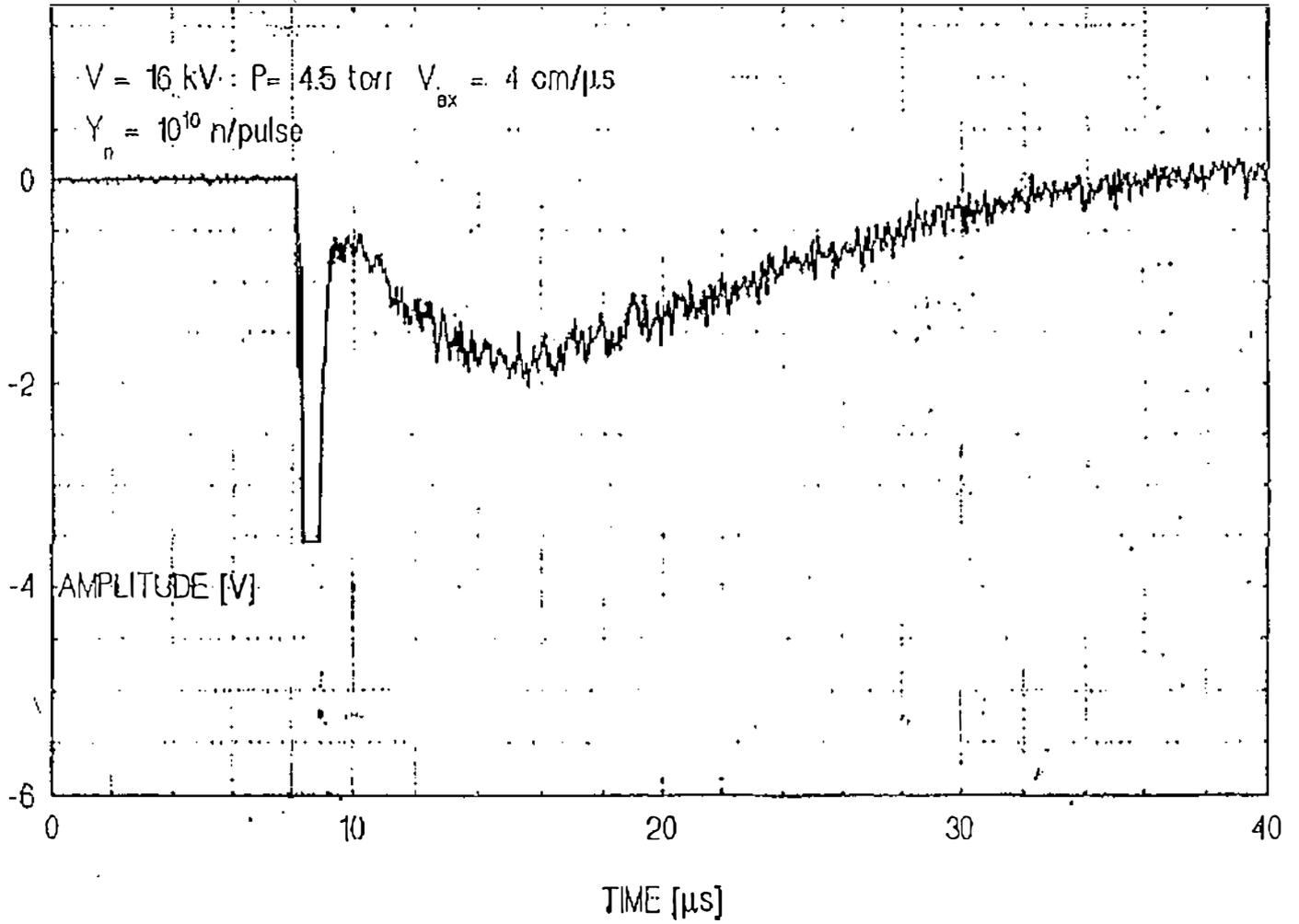
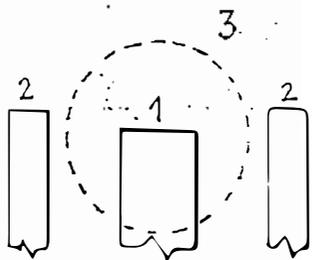
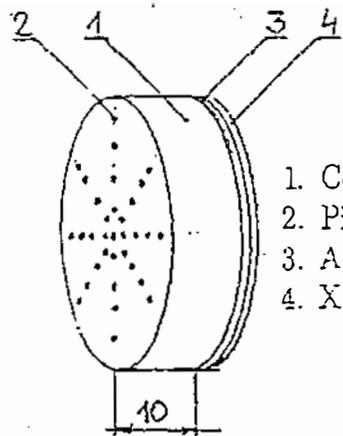
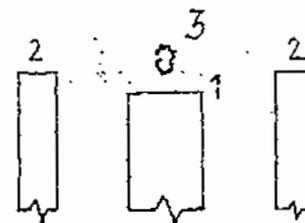


Figure 7: Signal from NE343 based neutron detector for plasma focus.

1. Central electrode
2. Outer electrodes
3. Soft X-ray emission area

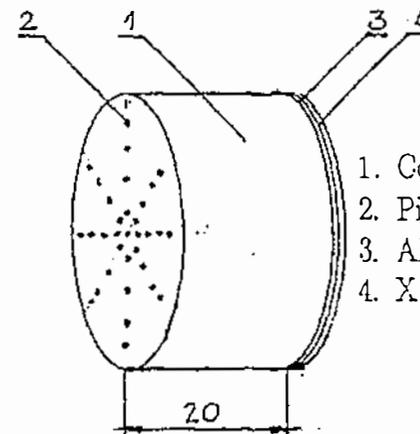


1. Central electrode
2. Outer electrodes
3. Hard X-ray emission area



1. Collimator
2. Pin hole $d = 1mm$
3. Al $d = 80\mu m$
4. X - film

Figure 8: Zone of emission of soft X-rays from deuterium plasma focus



1. Collimator
2. Pin hole $d = 1mm$
3. Al $d = 0.4mm$
4. X - film

Figure 9: Zone of emission of hard X-rays from deuterium-argon plasma focus