Detection of Water by Neutron Scattering Using a Small Plasma Focus

A. Tartaglione(1), R. Ramos(2), J. González(2), A. Clausse(3), and C. Moreno(1)

Interinstitutional Program of Dense Magnetized Plasmas
PLADEMA Argentina
(1) Departamento de Física, FCEyN – UBA, INFIP – CONICET
(2) Instituto Balseiro, Centro Atómico Bariloche, CNEA
(3) Departamento de Computación y Sistemas, FCE – UNC, CNEA, CONICET

Received on 9 February, 2004; revised version received on 30 April, 2004

A compact Plasma Focus operated in deuterium which produces 2 10^8 neutrons per pulse, has been used as a radiation source for water detection by neutron scattering. The detecting system is composed by two silver activation sensors operated simultaneously on every shot. These detectors have quite different responses depending on whether the incoming neutrons are energetic or thermalised. Energetic neutrons come from the Plasma Focus itself, whereas those thermalized come, scattered, from the substance to be detected. The comparison between the readouts of each detector allows to reveal the presence of the blanket. The shot to shot variation of the Plasma Focus neutron yield does not preclude the detection. In practice shots with yields belonging to the 2 10^7– 2 10^8range, can be conveniently used. The obtained results indicate that the method is able to detect water contents of few percents in volume placed about 8.5 cm away from the Plasma Focus chamber. The presented method admits side-on as well as directional detection.

1 Introduction

Among other non-conventional applications [1], neutrons produced by DD reactions can be used as probe radiation to detect the presence of hydrogenated substances, water, for instance [2, 3]. Conceptually, the detection mechanism is similar to that of echography: a pulse of energetic neutrons (2.45 MeV) is sent to the region of interest, and then, using an adequated sensor, the medium response is registered, which consist in the dispersion (and thermalisation) of the incident neutrons.

Due to the high effective cross section of hydrogen for neutron dispersion, as compared with the rest of the elements, the experimental analysis of what happens to a neutronic flux used as probe radiation, gives valuable information to reveal the presence of hydrogenated substances. Application examples are: soil humidity studies [2], water content in oil, and detection of hidden dangerous substances.

Recently, the feasibility of water detection using a small Plasma Focus as a pulsed neutron source was demonstrated [3, 4]. Two silver activation detectors [5] were used: one to register the number of emitted neutrons, and the other one to detect the scattered neutrons. The experimental set up is shown in Fig. 1. The comparison between both readouts allows to determine whether the water is present or not.

In this paper, a directional detector of scattered neutrons is proposed and experimentally tested. Its sensibility to different water quantities is also studied.

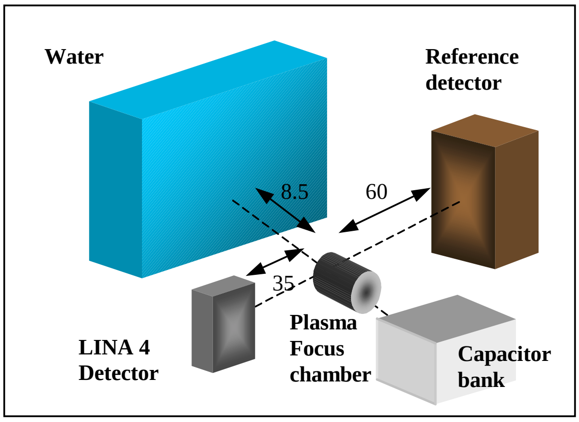

Figure 1. Basic set up for water detection by neutron scattering. Dimensions are in cm.

2 Experimental method

A small 10.5 uF, 30 kV (4.7 kJ) Plasma Focus, called GN1, was used as neutron source. This device is detailed elsewere [6, 7]. The optimum average neutron yield, $\sim 10^8$ n/shot, is attained when operating at 3 – 4 mbar of deuterium. The measured neutron anisotropy for this device, defined as the neutron flux ratio emitted in the electrode axis forward direction respect to the flux emitted 90 ° appart is 1.4.

Both neutron detectors have 4 Geiger tubes Victoreen 1B85, polarized at 800 V, each of them covered by a 0.3 mm thick silver foil. Silver has a resonance peak for neutron capture, with a beta decay, at 5 eV. The reference detector is a 28 x 34 x 14 cm^3 box containing paraffin to moderate fast neutrons. The scattered neutron detector does not contain paraffin for it to be sensitive to neutrons scattered by the substance and, at the same time, to be insensitive to the direct Plasma Focus neutron radiation. The reference detector has a background of 66 ± 8 counts in a time interval of 20 sec, whereas the scattered neutrons detector reads 60 ± 8 counts in the same conditions.

2.1 LINA 4 detector

Directionality in scattered neutrons detection requires shielding against neutrons moderated in the Plasma Focus sourroundings. Laboratory walls, floor and other structures, appart from the Plasma Focus itself, specially its capacitor bank, are sources of unwanted thermalized neutrons.

The ^{10}B has a high cross section for thermal neutrons capture. Therefore a substance containing a high proportions of boron, placed as a shield arround the Geigers, can be used to diminish the neutron flux coming from undesired directions. A common substance rich in boron is the sodium tetraborate ($Na_2B_4O_7$) usually known as borax. In Fig. 2 a drawing of LINA 4 detector using borax powder is shown. It consists of a metallic box containing the four Geigers attached to one of its faces. The rest of the box is filled with borax. There are about 5 cm of borax sourrounding the Geigers except on one side, which acts as a collecting window. The borax thickness used is about 5 times the free mean path of 5 eV neutrons in this substance.

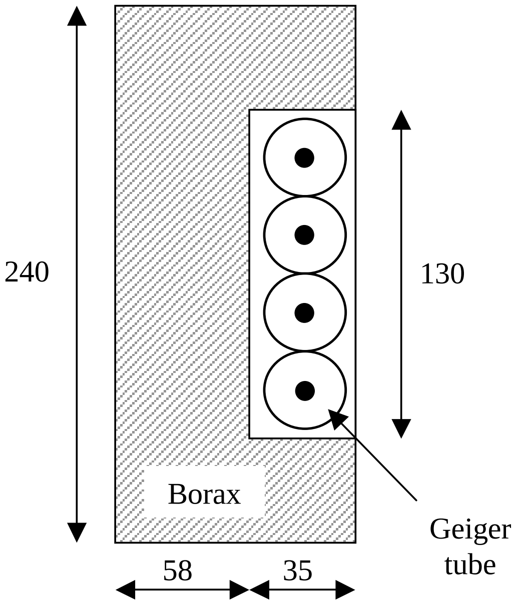

Figure 2. Drawing of the scattered neutrons detector LINA 4. Borax encasing allows for detection directionality. Dimensions are in mm.

To verify the detector's directionality a water wall was used as scattering substance, as shown in Fig. 1. The LINA 4 detector was placed 35 cm away from the chamber and at 8.5 cm from the 33.6 dm^3 water wall. Two extreme orientations were tested: one (A) with the window facing the water wall, and the other one (B) with the window oriented in the oposite direction. In this last orientation, the window can collect neutrons coming from the capacitor bank, which contains substantial amounts of plastic and insulating oil.

The readouts of both detectors were registered for each orientation with and without the water wall. Between 10 and 15 shots were performed for each one of the four resulting configurations. The obtained results are shown in Fig. 3, where the LINA 4 counts are ploted against those from the reference detector. According to its calibration, a readout of 1000 counts from the reference detector correspond to a total of 10^8 emitted neutrons.

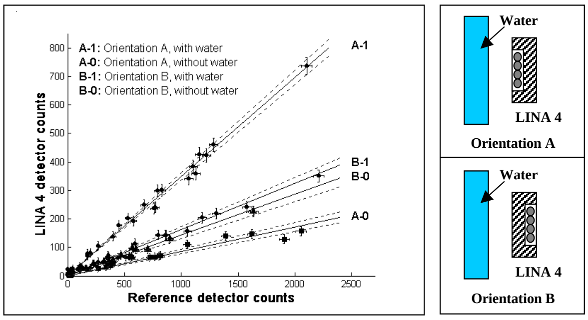

Figure 3. Plot of detected scattered neutrons versus emitted ones, with and without water present, for orientations A and B of LINA 4 detector. Dashed lines correspond to 95% confidence bands.

Firstly, cases A-1 and A-0 (corresponding to the orientation A with and without water, respectively) can be distinguished, where a substantial difference in slopes is evident (0.348 ± 0.013 and 0.0856 ± 0.0078). The uncertainty bands correspond to 95 % confidence interval. Since the measured data exhibits errors of the same order of magnitude in both coordinates, the method of reference [8] was used to obtain the slopes and their uncertainties.

Secondly, when the orientation is B, the presence of water does not produce significative difference on the LINA 4 response (slopes are 0.162 ± 0.010 and 0.143 ± 0.013 for the cases with and without water, respectively). This illustrates the low sensitivity of LINA 4 detector to neutrons not coming through its window.

Additionally, since the slopes corresponding to cases B are significantly higher than that of case A-0, it can be concluded that the capacitor bank has a sensible effect on the moderated neutrons field in the Plasma Focus head sourroundings. Therefore, the borax shielding effectively contributes to the detection efficiency.

3 Aplication and sensibility

As an application example of water detection and to illustrate the method sensibility, a configuration like that of Fig. 1 was set up, where the water distribution was implemented using 56 plastic bottles of 600 cm^3 in volume and 7 cm in diameter (see Fig. 4).

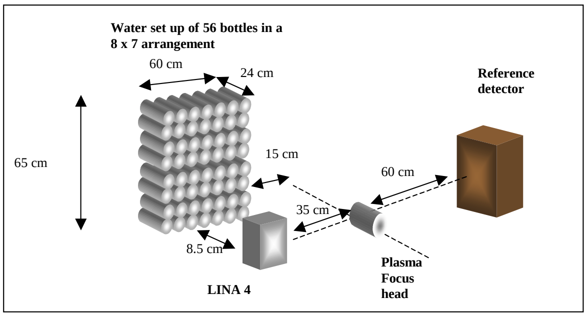

Figure 4. Experimental set up used to study the sensibility to different water quantities.

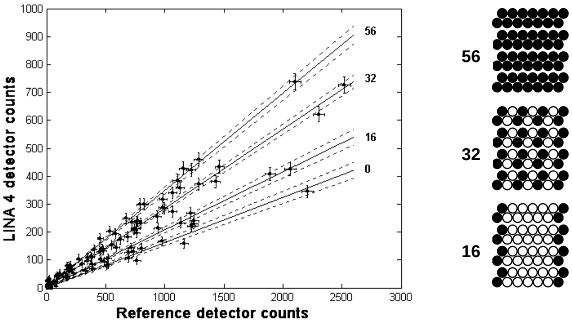

Figure 5. Experimental results of detected scattered neutrons versus emitted ones for the configurations depicted on the right.

Filling either all or some of them, different water concentrations can be obtained.

Four configurations were considered, one with all bottles empty, and the other three, filling 56, 32 y 16 of them (see the sketch of Fig. 5). LINA 4 detector was placed in orientation A. The obtained results are ploted in Fig. 5.

It is observed that the method permits to distinguish between configurations, since the corresponding slopes of the linear fits are different (0.348 ± 0.013, 0.2838 ± 0.0092, 0.208 ± 0.011 and 0.162 ± 0.011).

According to these results, the minimum detectable water volume is $\sim$ 16 filled bottles, that is, $\sim$ 9.6 dm^3, for the geometric configuration depicted in Fig. 5. Since the considered distribution of water in volume is discrete, the relationship between the water volume and the corresponding slope is not expected to be simple. Nevertheless, a calibration conducted to distinguish between different situations, is always possible.

4 Conclusion

In the hydrogenated substances detection by neutron scattering framework, a scattered neutrons detector that uses borax to block neutrons coming from unwanted directions was proposed and experimentally checked.

From the obtained results, it can be seen that $\sim 1 \times 10^8$($\sim$ 1000 counts on the reference detector) is, in practice, the lowest number of neutrons per shot needed to detect water quantities of about 10 dm^3 in configurations like those considered in this communication. For a less intense neutron source, more sensitive neutron detectors must be used.

In general cases of practical interest, related for instance, to different amounts and/or concentrations of the prospected substance, or different geometrical configurations, or even different substances; adequated calibrations must be conducted to discriminate between specific situations. It is also suitable to mention that due to the scattered nature of the prospection neutrons, the presented method admits side-on substance interrogation, i.e., the interrogated substance does not need to be placed in the Plasma Focus-to-detector line of sight. This fact can be conveniently used to widen the applicability field of the discussed technique.

Acknowledgements

Dr. Roberto Vieytes is kindly acknowledged by the critical reading of the manuscript and valuable suggestions. This work was supported by Fundación Antorchas (Proj. 14068-24), IAEA (TC Proj. ARG1026-11099L), PLADEMA-CNEA and UBA (X074).

References

[1] F. Beg, K. Krushelnick, C. Gower, S. Torn, A. Dangor, A. Howard, T. Sumner, A. Bewick, V. Lebedenko, J. Dawson, D. Davidge, M. Joshi, and J. Gillespie. Appl. Phys. Lett. **80** (16), 3009 (2002).

[2] J. Pouzo, M. Milanese, and R. Moroso, AIP Conf. Proc. **669** (1), 277 (2003).

[3] R. Ramos, C. Moreno, J. González, A. Clausse, and P. Florido. Feasibility of a water detection system based in Plasma Focus technology. American Nuclear Society, Nuclear Odyssey 2001, CD Proceedings Nuclear Odyssey 2001, Next Generation Technologies **I**, 23-27, Texas, March 28 - April 4, (2001).

[4] C. Moreno, A. Clausse, J. Martínez, R. Llovera, A. Tartaglione, M. Vénere, R. Barbuzza, and M. del Fresno. Using a 4.7 kJ Plasma Focus for introspective imaging of metallic objects and for neutronic detection of water. *IX Latin American Workshop on Plasma Physics*, La Serena, Chile, AIP Conference Proc **563**, H. Chuaqui and M. Favre Eds, 300-305, Nov (2000).

[5] A. Gentilini, J. Rager, K. Steinmetz, M. Tacchi, D. Antonini, B. Arcipiani, P. Moioli, E. Pedretti, and R. Scafe. Nuclear Instrum. and Meth. **172** (3), 541 (1980).

[6] C. Moreno, M. Vénere, R Barbuzza, M. Del Fresno, R. Ramos, H. Bruzzone, P. Florido, J. González, and A. Clausse, Brazilian J. of Phys. **32**, 20 (2002).

[7] C. Moreno, A. Clausse, H. Bruzzone, J. Martínez, R. Llovera, A. Tartaglione. Small-chamber 4.7 kJ Plasma Focus for applications. *IX Latin American Workshop on Plasma Physics*, La Serena, Chile, AIP Conference Proc **563**, H. Chuaqui and M. Favre Eds, 276-281, Nov (2000).

[8] C. Moreno. Meas. Sci. Technol., **7**, 137 (1996), and **8**, 951 (1997).