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PADC Detected External Neutron Field by Nuclear Tracks at RFX-mod

W. GONZALEZ[1], G. ESPINOSA[2,*], M. ZUIN[1], G. VIESTI[3], F. PINO[4], J. I. GOLZARRI[2], E. MARTINES[1], J. BERMUDEZ[5], D. MORO[5], J. K. PALFALVI[6] AND L. SAJO-BOHUS[4]

[1]Consorzio RFX, EURATOM-ENEA Association, Corso Stati Uniti 4, 35127 Padova, Italy

[2]Instituto de Física, Universidad Nacional Autónoma de México, Circuito de la Investigación Cientifica, Ciudad Universitaria, 04520 México, D.F.

[3]Dipartimento di Fisica ed Astronomia, Università di Padova,Italy

[4]Universidad Simón Bolívar, Caracas 1080A, Venezuela

[5]INFN, Laboratori Nazionali di Legnaro, 35020 Legnaro, Italy

[6]Centre for Energy Research of the Hungarian Academy of Sciences. POB 49, H-1525 Budapest. Hungary

***Email: espinosa@fisica.unam.mx**

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Abstract: Measured neutron signals relevant for plasma diagnostics on Reversed Field pinch eXperiment, RFX-mod, are obtained by nuclear track methodology with PADC-NTD's. This technique provides the external neutron field values around the RFX-mod installation during pulsed operation. Charged particles from (n, p) and (n, α) reactions are related to formed latent tracks. These are etched in a thermoregulated water bath with a 6.25M, KOH solution at 60^{o}C. Observed tracks were analyzed to determine track density from which neutron fluence spatial values should be derived. Results indicate that the neutron density in the surrounding environment change at most 40%. The epithermal component is 60% higher than that corresponding to the thermal region. The estimated neutron fluence for the whole experiment is 7.5×10^{10} neutrons cm^2/s.

Keywords: Neutron diagnostics, Plasma, Track detectors.

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CHITKARA UNIVERSITY

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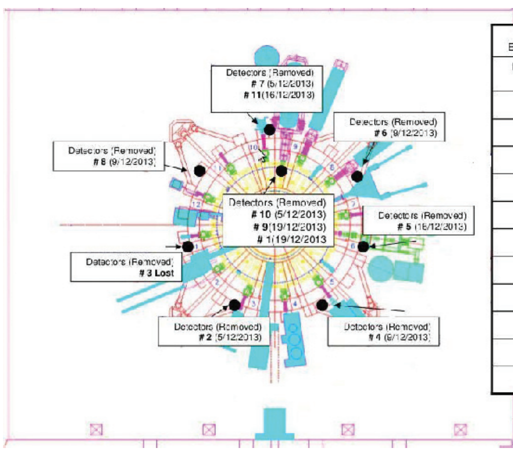
1. INTRODUCTION

Deuteron plasma diagnostics are of increasing importance for future fusion (D-D) devices and efforts are being made to improve the accuracy of underlying experimental and computational methods that in turn give basic characteristics of the plasma as a neutron source. Further it is required also to have experimental data of changes in both the neutron energy spectra as well as the fluence of the emitted neutrons. On the other hand neutron data are required to evidence improvements in the measurement, simulation and analysis procedures from which plasma parameters are driven. These can be derived also by measuring neutrons leaving the plasma vessel since its spectra contain information on plasma density and diagnostic parameters. Leakage of neutrons provides a field around the RFX-mod device and measuring its intensity is important since they scatter and are absorbed in the structural material. The plasma characterization based on neutron field anisotropy has been studied for different plasma focus systems employing passive detectors [1, 2, 4, 6].

In the present article the neutron external field for reversed field pinch experiment (RFX-mod, within the framework of the ITER project) is studied employing an integrating technique based on PADC detectors, aimed to correlate the neutron yield with the magnetic configuration and the plasma parameters, and in perspective try to measure 2.45 MeV neutron spectrum broadening in order to determine plasma ion temperature. In Fig. 1 a schematic RFX–mod lay-out is given for reference. RFX-mod is a toroidal device



Start Exposition	27/11/2013
Detector #	Date (Removed)
1	19/12/2013
2	5/12/2013
3	Lost
4	9/12/2013
5	16/12/2013
6	9/12/2013
7	5/12/2013
8	9/12/2013
9	19/12/2013
10	5/12/2013
11	16/12/2013

Figure 1: Passive track detectors locations at the experimental RFX-mod installation. The numbers refer to the PADC-detector code and position. Date indicates the exposure time.

(major radius 2m, minor radius 0.459m), where plasmas (i.e. ionized gases) of thermonuclear interest are produced and magnetically confined. Basically, in fusion devices plasmas are formed by inducing an electric field along the toroidal direction through the rapid variation of an externally induced magnetic flux. This electric field drives a current which ohmically heats the plasma and produces the poloidal component of the twisted confining magnetic field. The magnetic field along the toroidal direction is produced by external coils. The ratio between the intensity of the toroidal and the poloidal magnetic field components characterizes the various magnetic topologies which can be explored for plasma confinement. In the so-called tokamak configuration the externally induced toroidal magnetic field is one order larger than that produced by the current flowing in the plasma, while in the reversed field pinch (RFP) configuration the two have comparable amplitude. In RFX-mod both tokamak and RFP plasma discharges (pulses) can last up to 1 second, characterized by electron and ion densities of the order of few 10^{19} particles/m^3 (average value over the whole plasma volume) and ion and electron temperatures of about 1keV. The mechanical structure of the device mainly consists on an Inconel vacuum vessel (about 5mm thick), whose inner surface is fully covered by a system of graphite tiles (18mm thick) in order to sustain the high heat fluxes due to possible plasma-wall interactions.

2. GENERAL ASPECTS ON PADC´S BASED NEUTRON FIELD MAPPING

The detector material chemical structure is a poly-allyl-diglycol-carbonate (PADC, $C_{12}H_{18}O_7$) and in the past has been successfully employed for neutron field mapping [7, 5]. These detectors are integrating devices and provide information when pulsed neutron field should be monitored. The advantage of employing passive detectors is related to the fact that microscopic damage due to absorbed charged particle by scattering (n, p) and (n, α) reaction are visualized as small holes by chemical treatment as described below. To improve the passive detector recording efficiency it is convenient to rely on converting material. These are selected from isotopes with a relatively high transversal reaction cross section (3830 b for $^{10}B(n,\alpha)$ thermal reaction. The limiting factor for indirect neutron recording is related to the impinging energy: for scattering it is required that the induced particle carry an energy above the threshold value (E_{th}~200keV) with an impinging direction above the critical angle (ϕ_{cri}~30^o) to produce a latent track that in turn, can be visualized by chemical treatment. In the case of converting material the energy limiting factor is less stringent; most of the converting employed material has the reaction Q-value well above the E_{th}. The total number of the emitted pulsed neutrons (D-D) reaction in a given solid angle and direction reaching the PADC detector volume, can be determined through track density measurements. Therefore the number of etched nuclear tracks gives discrete information on neutron spatial distribution (neutron field map) and intensity at the localized point. Resulting values are the normalized to the average current related to the experiment.

3. REACTION PRODUCT ANALYSIS BY ETCHED TRACK

Charged particle reaction products (protons and alphas), originating from neutron leaving the RFX-mod confinement vessel, induce, as mentioned, a damage in the detecting material to form etchable tracks. The chemical process to enlarge the latent tracks up to an observable one is carried out by employing a solution of 6.25M, KOH at 60°C ±1. It is very important to operate at constant etching conditions otherwise large errors arise. Figure 2 shows the influence on track diameter values for etching condition employed in this work compared to that employed elsewhere [8]. The equation shows that e.g. for a 0.2 µm difference in the value of the removed layer the variation in the track diameter may be 4 times larger than expected.

Enlarged or etched tracks were analyzed and counted by a custom made optical system having amplification up to 400X. The digitalized image analyzer program was developed at the UNAM-laboratory for a relatively rapid track reading. A set of histograms of the track pit diameter obtained for the exposed detectors is given in Figure 3, for comparison. For instance parameters such as

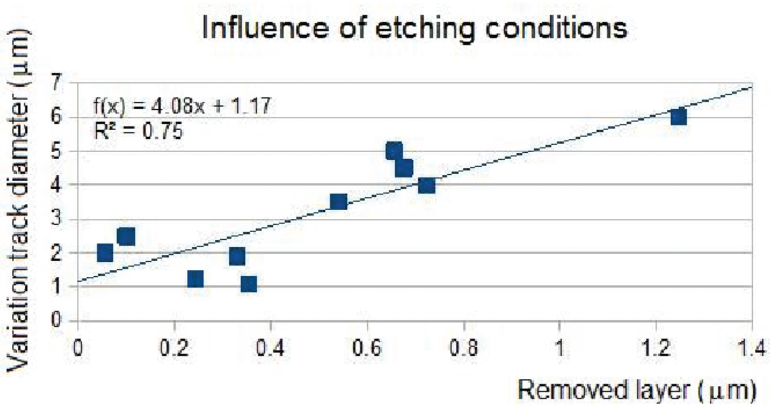


Figure 2: Influence of variation of removed values on diameter determination for etching condition given in this work compared to that employed by Palfalvi et al., (2011).

diameter and area are classified according to their size and geometrical shape so that information on particle energy and mass can be inferred. To reduce loss of information, the nuclear track methodology requires to follow a procedure that include the determination of the track etch rate ratio (e.g. V=1.35 μmh^{-1}) and the Linear Energy Transfer (LET) and layer thickness removed during etching (e.g. Δh=6 μm). These quantities depend on the etching composition, temperature of etchant, etching time and the manufacturer curing cycle of the PADC. Following the method developed by Palfalvi et al., (2011), the Δh value is determined utilizing collimated alpha particles. A large number of data has been collected by Felix-Bautista (2013), that provides the Δh and diameter-values. The following fitted equation is obtained $\Delta h=1.569+2.602\ \ln_d$, where ***d*** is the mean diameter of the alpha tracks.

4. EXPERIMENTAL SET-UP

The RFX-mod vessel has several windows to measure plasma characteristics. PADC detectors were positioned in selected points near these access windows numbered at the site indicated in Figure 1. Detectors (CR-39) were covered by ^{10}B wrapped in small zip lock bags to reduce track production by Naturally Occurring Radioactive Material (NORM) such as radon ($^{222,220}Rn$) and daughters as charged suspended particulate matter (spm); each one was properly identified with a code. The time of exposure, the type of experiment, number of impulses, and duration are taken into account for data interpretation. In Table1, are shown the detectors position in the reactor and detector number.

Table 1: Location ID and Detectors number, as given in Figure 1.

ID	Detector number
1	96
2	80
3	Lost
4	70
5	67
6	55
7	56
8	83
9	60
10	s/n
11	98

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5. RESULTS

Track diameter distribution of the detectors, is given in Figure 3 for every detector and in Figure 4 integrated values.

6. DISCUSSION

Etched track density for different locations has a distribution (histograms) that show differences that are related to scattered protons from the detector material having a estimated track diameter values in the range up to 7μm. Values above this range are related to alpha particle from the $^{10}B(n, \alpha)$ reaction. Since the neutron spectra originating in the plasma is distorted (moderated) by structural material and existing equipment, belong to a region below few MeV, we do not expect complex reaction in the passive material (e.g. $C(n, 3\alpha)$ or C, O nuclear recoils). However materials may absorb neutrons part of the energy group around 2.5 MeV before reaching the detectors and those are not accounted. Its effect is shown in the fluence difference for a given location. Dividing in two groups the histogram data reported in Fig. 4, we can relate the total number of track in a first approximation to two regions of the neutron energy spectrum. The converting reaction has higher probability to occur for neutron energies close to the thermal region. Analyzing the reported histograms we may deduce that track diameters above let say 12 μm correspond to thermal neutron region (based on previous study). Therefore we have the possibility to identify location around the plasma vessel where the surrounding material induces at least a partially moderating effect. We observe in fact a position depending change of 62% from the comparison of histograms of detectors 10 and 4. It is interesting to observe that similar variation exist for the detectors positioned at location 1, 9 and 10; since their exposure time is different this suggest that the plasma current achieved by the RFX devise is quite different depending on the experimental conditions. The external neutron field varies depending on location as Fig. 4 shows. From the position of the detector No.10 and No 2 we observe a fluence change of almost 40%. From that we deduce that the neutron field intensity depart strongly from the original neutron spectrum.

7. CONCLUSIONS

Leakage of neutron fluence around the RFX-mod during (pulsed) plasma operation was measured applying nuclear track methodology taking advantage of the passive detectors characteristics. We pointed out that the nuclear track density gives neutron fluence values with its spatial dependence. It was possible to determine neutron field intensity and that has a variation of 40% depending on the location of the PADCs. From track diameter distribution we deduced

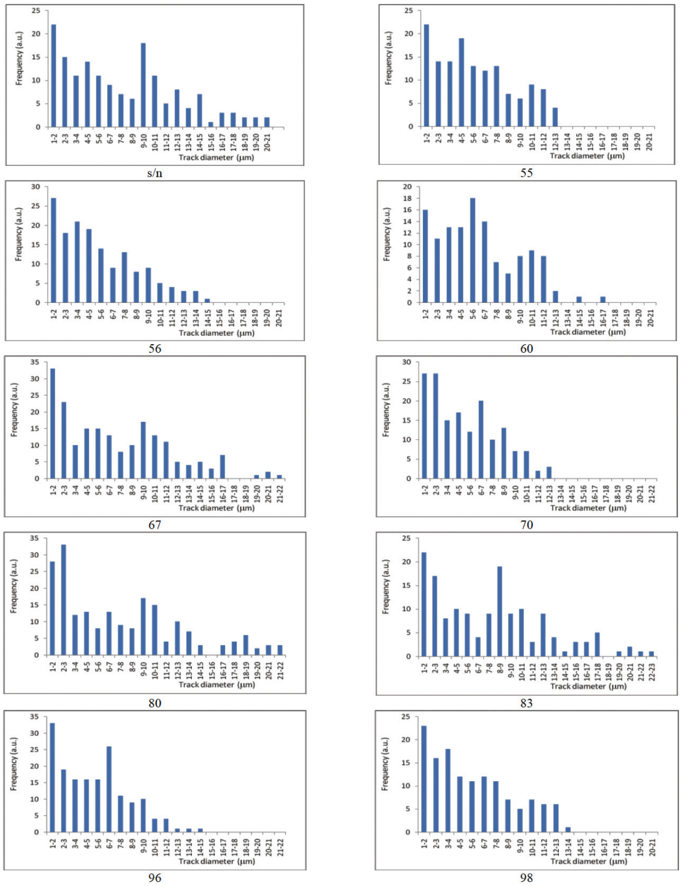

Figure 3: Track diameter distribution of the detectors on the external RFX-mod wall.

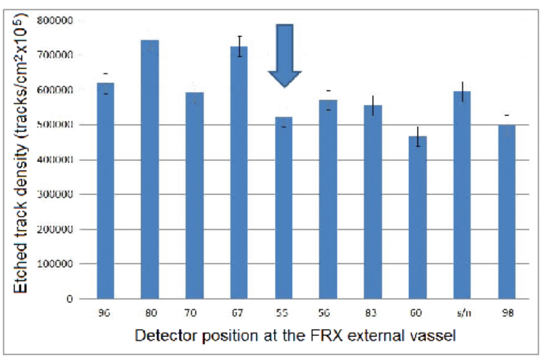

Figure 4: Neutron density as given by NTD etched track density. The arrow indicated the detector location at No. 6 track distribution related to 12 days exposure.

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a strong moderating effect due to existing structural materials including equipments between the plasma and the detectors; its value is estimated to be at most 60% due to neutron moderator. To establish the effect of neutron attenuation further measurements is necessary.

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