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To cite this article: J. Jain *et al* 2018 *J. Phys.: Conf. Ser.* **1043** 012048

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Pulsed x-rays dose measurements from a hundred joules plasma focus device.

J. Jain^{1,2,3,*}, J. Moreno^{1,2,4}, R. E. Avila², G. Avaria^{1,2,4}, C. Pavez^{1,2,4}, B. Bora^{1,2,4}, S. Davis^{1,2,4} and L. Soto^{1,2,4}

¹Comisión Chilena de Energía Nuclear, Casilla 188-D, Santiago Chile

²Center for Research and Applications in Plasma Physics and Pulsed Power, P4

³Universidad de Talca, Chile

⁴Universidad Andres Bello, Departamento de Ciencias Físicas, República 220, Santiago, Chile

*E-mail: jalajjain83@gmail.com, lsoto@cchen.cl

Abstract. Present work is aimed to perform dosimetric measurements to characterize dosis obtained from pulsed x-rays emitted from a hundred joules plasma focus device PF-400J using thermoluminescent dosimeters (TLD-100). Two dosimeter arrays (containing 21 dosimeters in each) were used. One of the arrays was kept inside the PF-400J vacuum chamber and other outside the vacuum chamber, simultaneously. It was found that dosis obtained from the inside array (~200.7 mGy) were hundred times larger than the outside array (~1.1 mGy) for hundred pulses of x-rays. Later, the vacuum window of PF-400J, which was made of 1 mm aluminum, was replaced by a plastic window and a similar dosimeter array was kept outside the chamber over the plastic window. With this arrangement, the obtained doses (100 pulses of x-rays) were of the same order of magnitude (~106 mGy) as it was inside the vacuum chamber. Later, a lead piece was inserted inside the hollow anode of PF-400J, which increased dose (~250 mGy) per hundred pulses of x-ray outside the vacuum chamber using plastic vacuum window. Our results suggest that PF-400J could be a useful device to study low dose pulsed radiation effects on cancer cell lines in *in vitro* experiments.

1. Introduction

Plasma focus (PF) devices were built, mainly, to study fusion reactions and neutron emission [1-6]. The idea was to use PF devices as an efficient nuclear energy source. Besides the fact that PF devices have high neutron yield, it was found that ignition conditions were not fulfilled, which are mandatory to convert fusion devices in an efficient nuclear energy source. Due to this reason, PF devices left abandoned. Recently, studies on PF devices got a thrust due to their use in various applications [7-10] and a new generations of table top plasma focus devices begun [26-29]. PF devices are rich in various physical phenomena and provide a platform to study the fundamental aspects of physics. Emission of various kinds of radiation from PF devices make them useful in biological [11-15] and material sciences [16-19]. PF devices consist in a co-axial electrode assembly in which cathode bars surround the central electrode, anode, symmetrically. Partial length of the anode is covered by an insulator. The uncovered length of the anode is known as effective length. After anode connects to high



voltage, at first discharge takes place over the insulator and forms a plasma current sheet (PCS), which develops a current density between anode and cathode. Later, due to self-generated magnetic field the PCS expands and runs over the effective length of the anode under the action of Lorentz force. At the open end of the anode, the PCS compresses neutral gas and forms a plasma column, typically known as pinch. During compression and pinch phases, electromagnetic forces are induced that accelerate charged particles. Electrons impinge the anode and produce x-rays via *bremstrahlung*. Plasma dynamics and radiation emission under the framework of PF devices can be found in [20].

PF devices emit radiation in pulsed form, which can be used to study the effects of pulsed radiation on cancer cells in *in vitro* experiments, which has importance to study post-irradiation effects on cells at cellular level. Indeed, pulsed low-dose-rate radiation therapy is used to treat the recurrent cancer [21]. Cancer research has advanced a lot from technology point of view but at cellular level, it requires more studies. For instance, studies about the distinct effects of pulsed and continuous radiation on cells. In order to use pulsed radiation (x-rays) emitted from PF devices for cancer cells irradiation, it is mandatory to characterize doses. S. Zapryanov *et al* [15] used a 3 kJ PF device in order to irradiate live microorganisms by soft x-rays. Dose measurement was performed using thermoluminescent detectors (TLD). Inside the PF chamber at 15 cm from the plasma column, doses were ~ 11 mSv for 4 shots using 20 μm Al foil and ~ 65 mSv for 14 shots using 100 μm Al foil. In addition, it was mentioned that the total energy released in hard x-rays region is lower than the total energy released in soft x-rays region.

Pavez *et al* [22] used a hundred joules PF device, PF-400J, in order to study x-rays emission and equivalent dose. Dose measurements were performed using TLDs (TLD-100). Based on the observations, dose per shot of the order of 17 μSv around the symmetry axis was reported. In the present work, TLD-100 dosimeters are used in order to measure the doses inside and outside the PF-400J [3, 22-25] simultaneously. These measurements were performed keeping in mind the use of pulsed x-rays to irradiate cancer cells in *in vitro* experiments.

In section 2 experimental setup for dose measurements is presented. The results are presented and discussed in section 3. Work is concluded in section 4.

2. Experimental setup

PF-400J consists in a stainless steel (SS) hollow anode, symmetrically surrounded by eight stainless steel cylindrical cathode bars. The effective length, was 7.0 mm in this case. A schematic of experimental arrangement used for dose measurements inside and outside PF-400J vacuum chamber simultaneously is shown in figure 1(a). The chamber's vacuum window, which was made of 1 mm Al sheet, was at a distance ~ 7 cm from the top of the anode. Two dosimeter arrays, each containing 21 TLD-100 dosimeters, were placed inside and outside the PF-400J chamber, simultaneously, along the PF axis as shown in figure 1(a). Plastic petri dishes (used for cell culture preparation) of diameter ~ 3.5 cm were used to make the dosimeter array. The array located inside the chamber was kept at ~ 4 cm from the top of the anode. The dosimeter array outside the chamber was kept at ~ 7 cm from the top of the anode just over the chamber's vacuum window. The inside array was covered by a ~ 15 μm aluminum foil in order to prevent charged particles and plasma interaction with the dosimeter array. In addition, a photomultiplier tube (PMT) was kept at ~ 80 cm from the top of the anode. In this study, PMT was used as a referential device in order to count x-ray pulses. Hydrogen gas at 9 mbar was used to produce discharges in order to get 100 pulses of x-rays. With this experiment, let us say first experiment, we learnt that most of the x-rays were attenuated during their interaction with 1 mm Al window. Keeping in mind this observation, a window was prepared of the same material as petri dish, that is plastic (~ 1.2 mm) to replace with 1 mm Al window in order to measure doses outside the chamber, let us say the second experiment. During the second experiment, the dosimeter array was arranged in the same box and placed over the vacuum window that was made of petri dish material. This time, only one dosimeter array outside the chamber was placed, as shown in figure 1(b).

In all the experiments, annealed dosimeters were used prior to use them for pulsed x-rays dose measurement emitted from PF-400J. Annealing is useful to re-configure the internal structure of the dosimeters. Sensitivity of TLD-100 dosimeters used in these experiments showed a 5% standard deviation. To reduce this effect, 100 dosimeters were uniformly irradiated by a calibrated x-ray source, and 60 of them were selected, with deviation less than 3% from the common average. Further, the response from that irradiation was used for the individual calibration of the selected dosimeters, so, later, their signals from exposure to PF-400J radiation was scaled with that calibration factor.

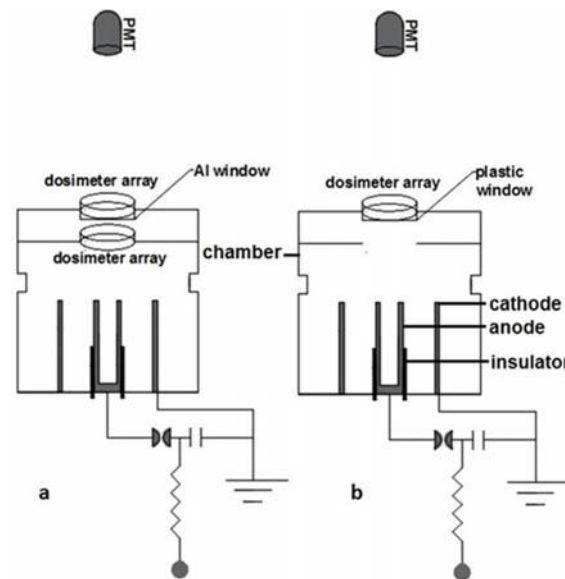


Figure 1 Experimental arrangement for dose measurement using TLD-100 dosimeters (a) inside and outside the PF-400J vacuum chamber simultaneously (b) outside the vacuum chamber only, with the use of plastic material as vacuum window. PMT was used as a referential device to count x-ray pulses.

3. Results and discussion

Figures 2(a), 2(b), 2(c), and 2(d) show schematic of the dosimeter arrays and accumulated dosis obtained from 100 pulses of x-rays inside (figures (2a), (2c)) and outside (figures (2b), 2(d)) of PF-400J vacuum chamber, respectively. The average dose in 100 x-ray pulses was found $\sim 200.7 \pm 72.69$ mGy and 1.1 ± 0.23 mGy, inside and outside the vacuum chamber respectively. In addition, relatively higher dose zones inside the chamber were identified. In figures (2a) and (2c) it can be seen that the central dosimeters (F5, H5, J8, G5, C7, I4, B9, C4, and G4), shown by italic font style, acquire relatively higher doses.

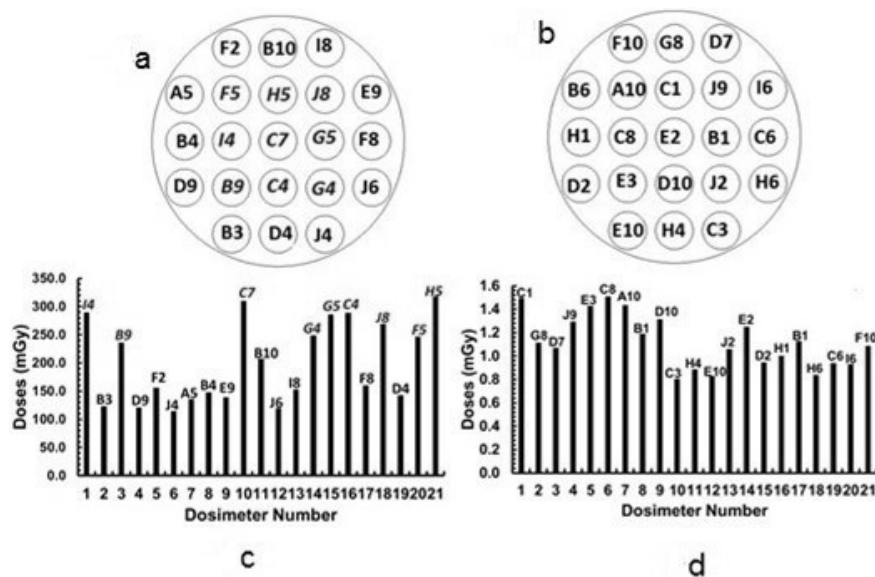


Figure 2 Schematic arrangement of dosimeters (TLN-100) in (a) inside and (b) outside arrays and obtained dosis (c) inside and (d) outside the PF-400J vacuum chamber, respectively. Inside the vacuum chamber dosis are hundred time larger than outside the chamber.

These results suggest that most of the x-rays would have been attenuated during their passage through aluminum window. Keeping in mind this observation, a vacuum window made of petri dish material, that is plastic of width 1.2 mm was used, please see figure 1(b). A dosimeter array (as shown in figure 2) was kept over this window. Figures 3(a) and 3(b) show the schematic arrangement of dosimeter arrays and obtained results, respectively with this arrangement. In this case, average dose (100 pulses of x-rays) outside the chamber was 106 ± 31.18 mGy, which has same order of magnitude as was inside the chamber. From figures 2(a) and 2(b) it can be seen that the central dosimeters (A10, B6, J4, J6, G8, D10, H4, and D7), shown by italic font, acquire relatively higher dosis. This pattern is similar as found inside the chamber, as mentioned earlier.

A lead piece was inserted inside the hollow anode of PF-400J to measure the dosis outside the vacuum chamber. In this case, 100 pulses of the x-rays provide dosis ~ 250 mGy. Please note the plastic window was used for this experiment. Insertion of lead increases dosis per hundred x-ray pulses that are almost two times than without insertion of lead.

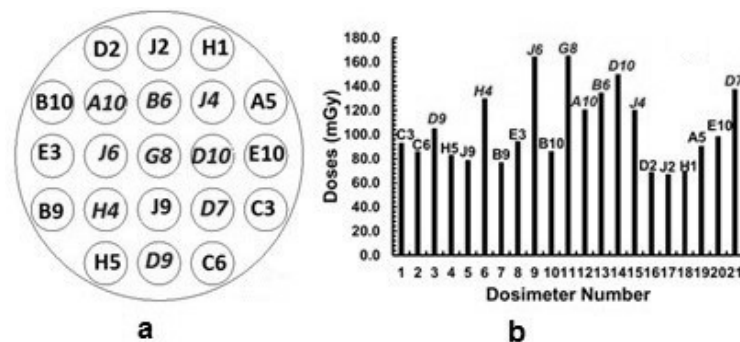


Figure 3 Dosis obtained with the use plastic vacuum window. Dosimeter array was kept outside the vacuum chamber over the plastic window.

In the first experiment, dosis outside the vacuum chamber were found hundred times smaller than inside the chamber. Please note, the dosimeter array that was kept outside had various obstacles in the path of x-rays to reach it. X-rays first interact with 15 μm aluminum foil then plastic of petri dish (~ 1.2 mm) which contains the dosimeter array inside the chamber. Later, x-rays will interact with the upper cap of petri dish, made of plastic that was kept inside the chamber and after with 1 mm Al window, over which the dosimeter array was kept outside the chamber. It has been reported that the emission of low energy x-rays is higher than the higher energy x-ray in PF devices [13]. Since transmission percentage of x-rays below 15 keV through 1 mm Al window is less than 10%, therefore low energy x-rays (say below 15 keV) are strongly attenuated by those various materials. Hence, much higher dosis inside the chamber, two order of magnitude higher than outside the chamber. These observations are consistent with the concept that low energy x-ray emission dominates in PF discharges [13].

It was observed that the use of plastic vacuum window provides similar dosis outside the vacuum chamber of PF-400J as was inside, see figure 3. Nonetheless, the dosis in this configuration were almost half the dosis inside the chamber. The decrement in dosis with the use of plastic window might be due the fact that x-rays have to pass through 1.2 mm window material and later through the box in which the dosimeter array was arranged. X-rays will be attenuated while passing through these obstacles.

Increment in dose per hundred x-ray pulses was observed with the insertion of a lead piece inside the hollow anode. Prior to discuss the effects of lead insertion inside the hollow anode on x-rays emission, let us first discuss how x-rays produce in PF devices. During compression and pinch phases of PF devices, there is generation of various kinds of instabilities and electromagnetic fields. Charged particles accelerate in the presence of the induced electromagnetic fields in various directions. Electrons accelerate toward the central anode and produce x-rays via *bremsstrahlung* upon impinging the anode. Insertion of lead may have following cause that could affect the doses. Interaction of electron beams with lead target can sputter lead material and introduce impurities in pinch phase. These impurities increase the resistivity of the pinch that further allow the induced electromagnetic fields to penetrate inside the pinch. This penetration of electric fields will allow relatively large number of electrons within the pinch to accelerate and produce x-rays via *bremsstrahlung*. In addition, these impurities themselves may work as target. Nonetheless, in the present work only an experimental observation that insertion of lead inside the hollow anode increases dose per hundred pulses of x-ray is presented. More computational and experimental efforts are needed in order to explain x-rays emission from PF-400J.

4. Conclusion

Two experiments were carried out in order to measure the dosis inside and outside the vacuum chamber of plasma focus device PF-400J, simultaneously (first experiment). In this case, average dosis were ~ 200.7 mGy and 1.1 mGy inside and outside the vacuum chamber respectively. Note that, in the first experiment the vacuum window over which the dosimeter array was kept outside the chamber was made of aluminum of thickness 1 mm. Based on these observations, it was realized that most of the x-rays would have been attenuated while passing through aluminum window. In the second experiment, a vacuum window that was made of plastic was used in order to have similar dosis outside the vacuum chamber as was inside. In this case, the dosis outside the chamber were ~ 106 mGy. Later, insertion of a lead piece inside the hollow anode increased dose per hundred x-ray pulses that were ~ 250 mGy, outside the PF-400J vacuum chamber while using plastic vacuum window. These findings suggests that PF-400J could be a useful device for *in vitro* experiments to study the effects of low dose pulsed radiation on cancer cells.

Acknowledgement

The work is supported by grant ACT-1115, CONICYT, Chile.

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