Radiation Protection issues for diagnostics on the PETAL Experimental System (Petawatt) of the LMJ Facility

J. Baggio[1], D. Raffestin[1], N. Blanchot[1]

[1] *Commissariat à l'Énergie Atomique,*

CESTA, 15 Avenue des Sablières CS 60001, 33116 Le Barp cedex, France

1. INTRODUCTION

Within 2 years, PETAL [1], a multi-Petawatt laser beam, will be operated on the LMJ facility at the CEA/CESTA research centre. In addition to the LMJ nanosecond beams, it will provide an ultrahigh-power short-pulse (500 fs to 10 ps), with a high-energy beam (few kJ compressed energy). With respect to intensity and energy, the expected interaction experiments will lead to a large amount of high energy radiation and particles, leading to spatially dependant activation of materials.

2. TARGET DESCRIPTION AND SOURCE TERMS

Two different types of experiments will be conducted during PETAL laser operations. The first one, labeled TS1, uses a tungsten target of 2 mm-thick for X-ray production. Laser-matter interaction leads to high energy electron source term production calculated by a PIC (Calder [2]) code and X-rays conversion in Tungsten by Bremsstrahlung evaluated by using MCNP5[3]. The Figure 1a shows the X-ray spectrum at different angles of emission from the backside of the target.

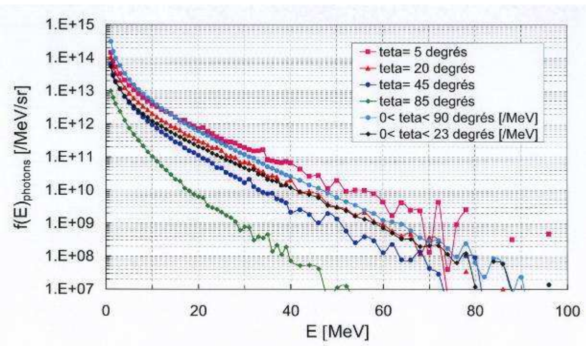

Fig. 1a: Transmitted X-rays spectrum from tungsten target

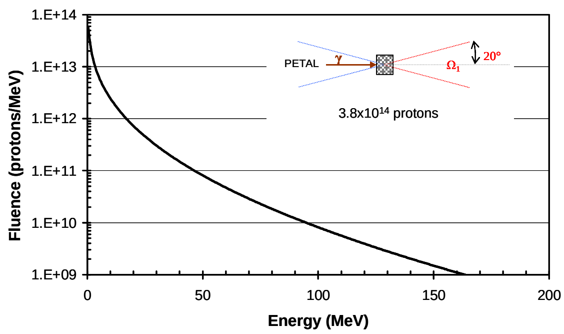

Fig. 1b Transmitted proton spectrum

The second source term, labeled TS2, is obtained by laser interaction with a thin foil of aluminum (100x100x20 μm^3) that produce protons ejected mainly from the back side of the target. Nevertheless, as a part of this emission is emitted from the front side, we assume that the emission is similar on the both side of the target, in order to be conservative. Figure 1b shows the transmitted proton spectrum ranging up to 150 MeV.

3. MODELING THE TARGET BAY

A cross-sectional view of the target bay with the Target Chamber (TC) in the middle, and the inserters connected on it is presented in figure 2b. The closest structures to the particle source are the plasma diagnostics (10 cm from centre) and the target positioner that will be the most activated (Fig. 2a). A detailed 3-D model of the LMJ target bay has been developed using the MCNPX radiation transport code [4]. The Target Chamber, initially designed for 14 MeV neutron shielding produced by LMJ fusion operations, is made of a 10 cm-thick aluminum wall surrounded by 40 cm of borated concrete. The design is therefore very efficient to reduce the number of particles outside the TC during PETAL experiments.

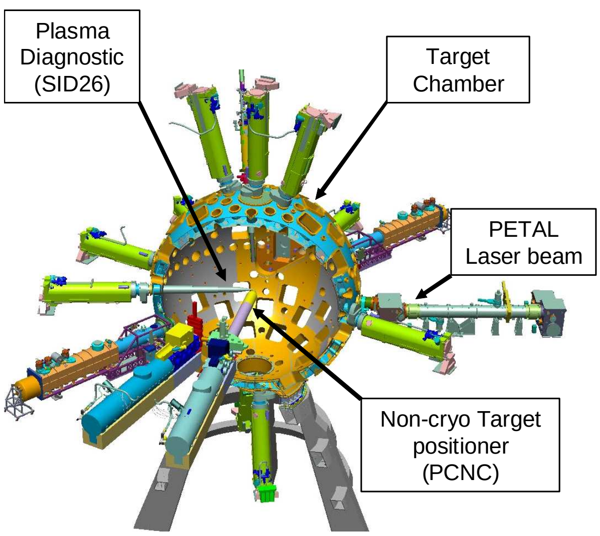

Fig. 2a: View of the Target Chamber with diagnostic inserters and target positioner

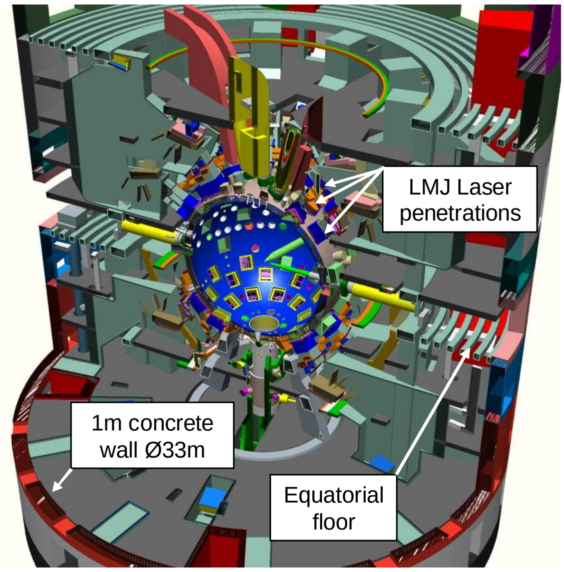

Fig. 2b: Target bay modeling including floors, LMJ final optics systems, target chamber equipments,…

4. PROMPT RADIATION

In a first step, radiation sources previously described in section 2 are propagated within the target bay model to determine photon, neutron and proton fluences in each volume of the geometry.

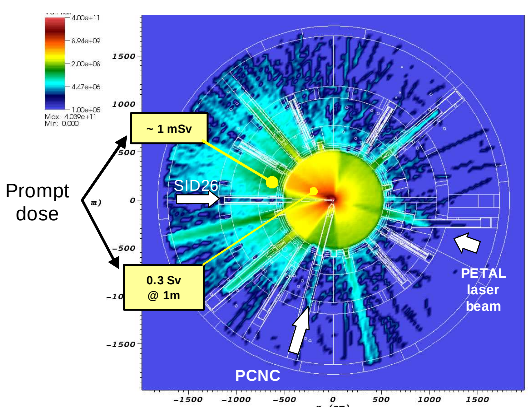

Fig. 3a: Photon Fluence map at Z=0 from TS1

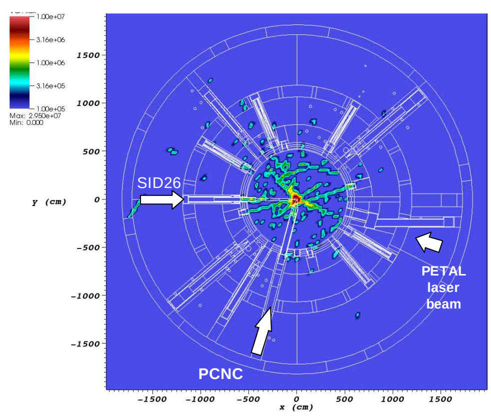

Fig. 3b: Secondary neutron fluence fromTS1

As we can see in Figure 3b, most of secondary neutrons, created by photonuclear reactions, are produced on target, plasma diagnostic and target positioner materials. The prompt dose, mainly due to primary X-rays (Figure 3a), is 300 mSv at 1m from source and decreases to about 1 mSv outside the chamber.

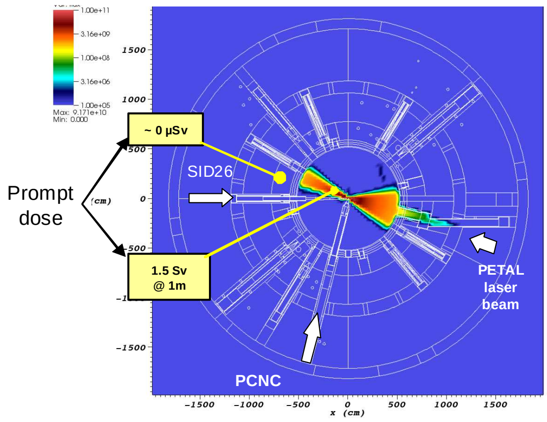

Fig. 4a: Proton Fluence map at Z=0 from TS2

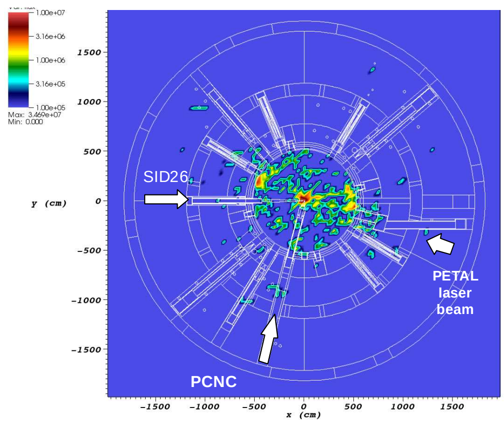

Fig. 4b: Secondary neutron fluence fromTS2

The proton fluence map presented on Figure 4a, shows the directive emission along the PETAL axis and the efficiency of TC walls to stop protons (1.5 Sv at 1m from source, to about 0 outside the chamber). We notice that part of the proton beam can penetrate in the PW-laser beam pipe leading to a potential activation of the final optical materials.

Figure 4b, showing secondary neutron production map, highlights locations of (p,n) reactions.

5. ACTIVATION PRODUCTS, RADIOACTIVE CONTAMINATION

The first type of experiment (TS1), vaporizing a few tens of grams of activated matter lead to a significant contamination deposited on the diagnostics inserted in the TC. For safety studies, the whole target (tungsten foil 4x4 cm, glue 1g and Al. post 1g) is supposed completely vaporized by the laser leading to conservative values for contamination.

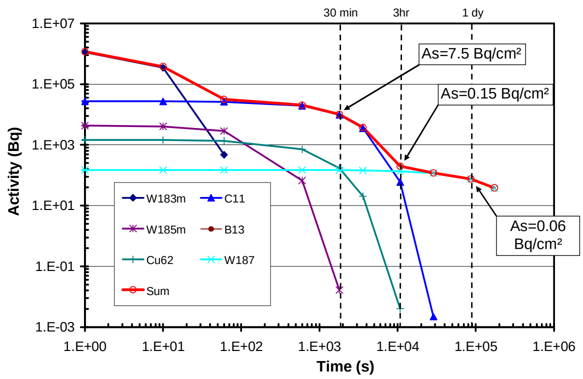

Fig. 5a: Activation products from TS1 target structure (62g of W + 1g of AL5083 and 1g of glue)

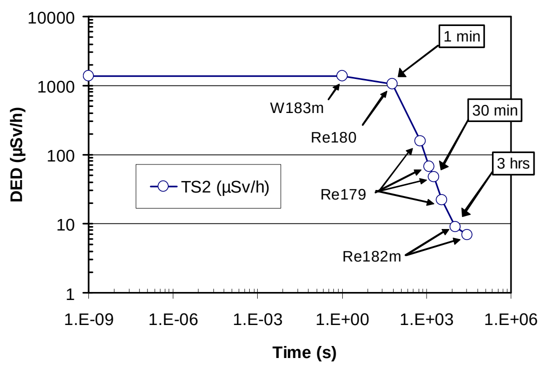

Fig. 5b: Effective dose rate @0cm of the activated diagnostic versus time after a TS2 shot

Figure 5a shows the decay of radio-nuclides from the vaporized target calculated with the inventory code FISPACT 2005 [5]. The surface activity (As), mainly driven by ^{11}C (from the glue) remains above the value of 0.4 Bq/cm² (regulatory β,γ contamination threshold) for about 2 hours after a shot. Consequently personnel operations will deal with this constraint by using if necessary a confined transfer box to manipulate the contaminated parts.

TS2 experiments will use a proton spectrometer diagnostic located at 10 cm from the back side of the target. A total of 3 kg of tungsten (stacked with films) is used in the first stage to form energy filters [6]. Figure 5b present the evolution of the effective contact dose rate versus the cooling time after aTS2 shot. A significant dose rate of 47µSv after 30 min of cooling time indicates that appropriate procedures should be implemented to manipulate this part of the diagnostic.

6. SUMMARY

This study presents some results of activation and contamination issues on diagnostics inserted in the target chamber. Radioprotection issues during the TS1 experiments (X-rays production) are mainly driven by the contamination deposited on inserted diagnostics due to the mass of the vaporized target. On the other side, protons produced by TS2 experiments mainly result in the activation of materials within the source cones. Therefore, operations on activated parts should be minimized during the first 2 hours after a shot. While it is believed that these are conservative estimates (PW-laser performances, target volumes,…) they will be updated and improved upon during the phases of the laser energy increase, scheduled by the project during the first years of PETAL operations.

7. ACKNOWLEDGMENTS

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8. REFERENCES

[1] N. Blanchot, *et al*, "Overview of PETAL, The muti-Petwatt project in the LMJ facility", proceedings of the IFSA conference, Bordeaux, 2011.

[2] E. Lefebvre, *et al*, « Electron and photon production from relativistic laser plasma interaction « , Nuc. Fusion, 43, p. 629-633 (2003).

[3] "MCNP - A General Monte Carlo N-Particle Transport Code, Version 5," Los Alamos National Laboratory, LA-UR-03-1987 (2005).

[4] "MCNPX – Monte Carlo All-Particle Transport Code System", Los Alamos National Laboratory, LA-CP-11-00438.

[5] "Fispact 2005 : User manual", RA Forrest EURATOM/UKAEA Fusion Association.

[6] J.E. Ducret, "Diagnostic development for the PETAL facility", paper I6.503, presented in this conference.