RADIATION ISODOSE MEASUREMENTS INSIDE INTERACTION CHAMBER DURING THE COMMISSIONING EXPERIMENTS OF THE CETAL FACILITY- GAS TARGET CASE.

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Abstract

The high-power laser facilities has demonstrated their ability to accelerate ion beams to considerable energies. The CETAL facility owns a 1 PW laser. High power laser beam interaction with a gas target under Laser Wakefield Acceleration results in a high energy electron beam. Due to exceeding norms limits, the CETAL facility proceeded the full commissioning phase considering radiation protection requirements. In the paper we present the measured values of isodose inside the interaction chamber for different experimental periods. The measurements were performed using gafchromic EBT3 films. The films were positioned around the interaction point. All measured values were normalized for 30 cm distance. The measured values show that the measured values are high enough and have to be considered for radiation protection purposes.

1. INTRODUCTION

PW class laser installations are able to generate ionising radiation upon interaction with the target. Nowadays there are more than 50 high power laser systems in use or in development throughout the world [1]. The laser wake field acceleration by the interaction of the high-power laser beam and gas target trap and accelerate high energy electrons towards relativistic velocities. A part of them is able to accelerate particle beams in relativistic regime and generate high energy electron, proton or ion beams by specific mechanisms. For example, electrons can be accelerated when the intensities of the laser pulses are higher than IL ~ 10^{18} W / cm^2, because the energy gain of an electron at a distance of the order of an atomic diameter exceeds the binding energy of the electrons in the outer energy shells of the atom, and therefore ionisation occurs, mainly by the field effect. Subsequently, longitudinal plasma waves develop in the wake of the laser pulse, which accelerates the electrons to high energies (hundreds of MeV) over short distances (less than 1 millimetre).

Two of these high-power lasers are developed in Romania: first developed is from INFLPR, CETAL, and second one ELI-NP [2]. CETAL-PW laboratory in INFLPR is hosting a Ti:Sa PW class laser system (800 nm, 25 fs, 25 J, 0.1Hz) with a pulse power of up to 1 PW.

INFLPR during the commission of the CETAL-PW laser demonstrated the ability to accelerate electron beams to considerable high energies.

2. HIGH POWER LASER BEAM – GAS TARGET INTERACTION AT CETAL FACILITY

One of the types of experiments performed during the commissioning activities was ultra-intense laser interaction with gas target aiming to accelerate high energy electrons. For these experiments the laser wake field acceleration (LWFA) mechanism was considered [3].

At CETAL-PW, accelerated electron beams with maximum energies up to ~500 MeV were obtained by laser wake field acceleration (LWFA) in supersonic gas jet targets using a classical experimental setup, as it is shown in Fig. 1. Ultra-short laser pulses of 35 fs with energies up to 5 J before compression were focused with an off-axis f/27 parabolic mirror in a focal spot of 35 μm in diameter so that the energy on the target level effectively used for the acceleration process was up to 1.2 J.

The gas target is a supersonic jet produced with a gas valve properly synchronised with the laser pulse. In order to enhance the LWFA process, instead of pure He, a mixture of He 99% with N_2 ~ 1% was used to produce a supersonic jet with a 3 mm diameter 10° Laval profile nozzle, with a density in the range 10^{18} - 10^{19} cm^{-3}.

The electron energy distribution was measured with a magnetic dipole electron spectrometer. The high-intensity magnetic field (0.86 T) inside the spectrometer, was created using permanent magnets with a length of 80 mm and a gap of 10 mm. In order to precisely define the electron entrance point in the magnetic field, a lead brick with 2 mm central pierce was used as a collimator.

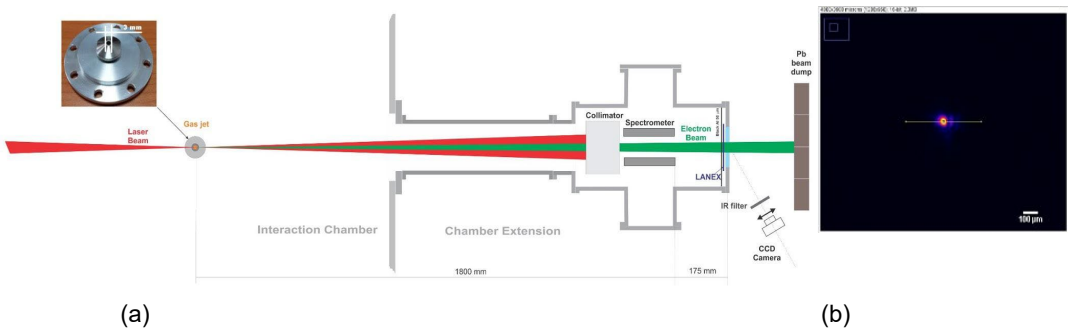
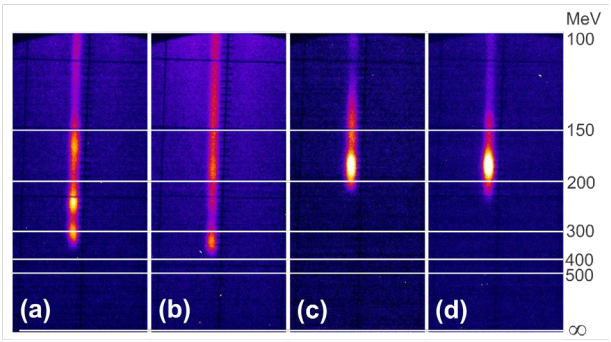


FIG. 1. Sketch of the experimental set-up for laser-plasma electron acceleration (a) and the focus image (b).

Depending on the laser-plasma conditions (parameters), electron beams with different types of spectral characteristics were obtained. Examples of electron spectra, measured with the high-resolution magnetic spectrometer are presented in Fig. 2.



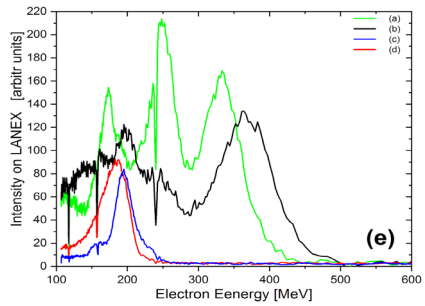


FIG. 2 Electron spectra as raw data from the LANEX screen;
τ_L=35 fs, w_0=17 µm
a) E_{LonF}=1.26 J, ne = 3.2 x 10^{18} cm^{-3} ;
b) E_{LonF}=1.16 J, ne = 3.2 x 10^{18} cm^{-3}

Electron relative spectra, as profile curves

c) E_{LonF}=1.06 J, ne = 4.4 x 10^{18} cm^{-3} ;
d) E_{LonF}=1.06 J, ne= 5.2 x 10^{18} cm^{-3}

3. ISODOSE MEASUREMENTS INSIDE INTERACTION CHAMBER

INFLPR demonstrated the ability to accelerate electron beams to considerable high energies in interaction of the ultra-intense laser pulses with gas targets, during the commission of the CETAL-PW laser system. For these experiments the laser wake field acceleration (LWFA) mechanism was considered [3].

Isodose measurements inside the interaction chamber represent the dose measurements around the focus. During the interaction of the laser beam and target the high electromagnetic field is presented. The interaction takes place in an interaction chamber in vacuum. During the experiments the exposure doses have been measured around the interaction point. The experimental isodose measured inside the interaction chamber are performed in the presence of a high electromagnetic field in vacuum. Due to these experimental characteristics of the experimental set-up, the dosimetry systems which can be used are limited. For this reason, passive dosimeters, like gafchromic films, were chosen.

For each experiment inside the interaction chamber, the radiation isodose measurements were performed using EBT3 gafchromic films. It is used to protect the sensitive layer of the EBT3 gafchromic film from exposure to ultraviolet radiation. The EBT3 films respond in a wide dose range: 0.01 – 40 Gy. The response of the EBT3 film is independent of the radiation incident angle and has energy independent dose response. The EBT3 films are used in dosimetry measurements of the photon, electron and proton beams. EBT3 films turn black by themselves.

Optical density of the exposed films is measured using a special dedicated transmission scanner type EPSON Expression 11000XL scanner. Gafchromic films are scanned using a high resolution of 4800 dpi in transmission mode. Calibration curve of the response of the EBT3 gafchromic film was performed in an electron beam delivered by a medical linear accelerator [4].

The interaction takes place in an interaction chamber in vacuum. The laser pulses generated by the CETAL-PW laser system focused on a gaseous target can produce accelerated electron beams. To achieve this, a valve was used to properly synchronise the gas jet with the laser beam. He + N_2 gas targets were used in these experiments. For each experiment inside the interaction chamber the radiation isodose measurements were performed using EBT3 gafchromic films. The distribution of the detectors used for isodose measurements inside the interaction chamber is presented in Fig. 3.

(a) (b)

FIG. 3. Position of EBT3 detectors (a) inside the interaction chamber (b) for radiation isodose measurements.

During the experiments, the gafchromic films were screened at optical radiation with Al foil. Due to the experimental conditions, which involve vacuuming and unwinding the interaction chamber, it is not possible to perform isodose measurements for each laser pulse. The detectors were read after the accumulation of a noticeable degree of blackening due to exposure to ionising radiation following the laser-target interaction.

The radiation isodose measurements were normalised at a distance of 30 cm from the target. Table 1 shows the measured values of radiation dose for specific measurement period. The results are normed at a distance of 30cm from the target. The high energy accelerated electrons on forward the laser beam were measured outside the interaction chamber. Radiation doses measured in high energy electron beam axes are not presented in this paper.

TABLE 1. MEASURED VALUES FOR RADIATION ISODOSE MEASUREMENTS, Gy, INSIDE THE INTERACTION CHAMBER FOR DIFFERENT EXPERIMENT PERIOD

Measurement point	27.08-17.10.2019	28.10.2019	29.10-10.12.2019	11.02-19.04.2021	19.04-03.06.2021	03.06-02.09.2021
1 (340°)	12	13,4	5,1	0,18	0,20	0,07
2 (51°)	5,7	4,5	8,9	1,30	3,66	0,13
3 (78°)	2,4	1,7	2,5	0,75	14,52	0,38
4 (102°)	1,3	1,3	2,3	0,89	1,20	0,42
5 (135°)	7,2	4,4	1,5	0,78	5,79	0,16
6 (226°)	13,8	13,9	3,1	0,31	0,29	0,10

The isodose measurements diagrams according to the Table 1 data are presented in Fig 4. Due to the experimental conditions, which involve vacuuming and unwinding the interaction chamber, the isodose measurements cannot be made in real time (for each laser shot).

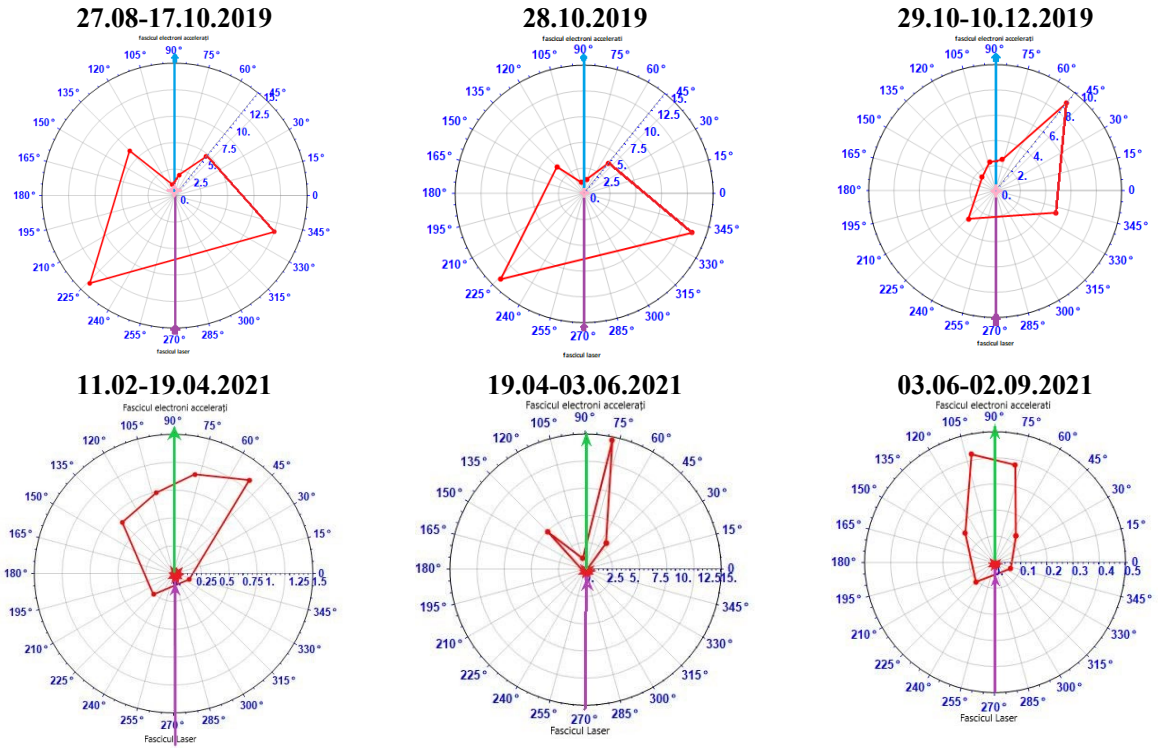


FIG. 4. Radiation isodose measurements during high power laser target interaction.

Isodose distribution of the radiation dose measurements inside interaction chambers shows the dose level exceeds the exemption levels for radiation protection purposes. The isodose distribution depends on the high-power laser target interaction parameters. Isodose distribution also shows that a part of the dose is backward. This suggests the necessity of the experimental geometry consideration for all parts inside the interaction chamber.

4. CONCLUSIONS

In this paper there are presented measured values for radiation isodoses obtained during the high-power laser gas target interaction.

Experimental data of radiation isodoses, obtained at CETAL-PW during high-power laser-gas target interaction, are presented. Isodose measurements shows a high level of exposure inside interaction chamber. The Gy level was achieved. Also, the isodose shows a backward exposure due to laser-target interaction. The isodose shapes suggests the necessity to consider full geometry setup inside interaction chamber to avoid scattering radiation.

The measured values suggest that they need to be considered for the evaluation of experimental data and for radiation protection purposes.

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