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Abstract. The Laser MegaJoule (LMJ) facility will host inertial confinement fusion experiments in order to achieve ignition by imploding a Deuterium-Tritium microballoon. In this context an X-ray imager is necessary to diagnose the core size and shape of the DT-target in the 10–100 keV band in complement of neutron imaging system. Such a diagnostic will be composed of two parts: an X-ray optical system and a detection assembly. Each element will be affected by the harsh environment created by fusion reactions.

1. INTRODUCTION

X-ray imaging diagnostics are fundamental tools for inertial confinement fusion experiments in order to achieve ignition. Reasons for failure may be investigated by evaluating the quality of implosion symmetry. The diagnostic will record the core size and shape of a cryogenic Deuterium-Tritium imploding target in harsh environment. Perturbations will be induced by fluxes of neutrons and gamma rays which affect diagnostic performances. The diagnostic shall operate under a maximum neutron yield of 10^{16}.

2. CONTEXT

DT fusion reactions yield a large number of neutrons whose energy distribution has its maximum at 14 MeV. Figure 1b reveals that the facility equipments, mainly the target chamber and diagnostics, will modify the initial neutron spectrum due to inelastic scattering. Gamma rays will be generated in addition to neutrons by two main reactions : DT fusion reactions emit quasi monochromatic 16.8 MeV gamma rays and the (n, n' γ) reactions on surrounding materials will induce an increasing gamma ray production.

Due to a lower velocity than gamma rays, neutrons reach the target chamber wall after 100 ns increasing the dose dramatically as shown in figure 1a. The diagnostic will then benefit from a relatively quiet radiative environment in the first 100 ns of the experiment. Consequently, its architecture and its

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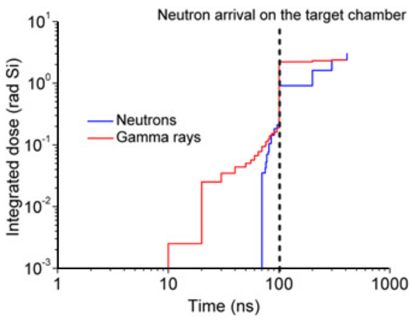
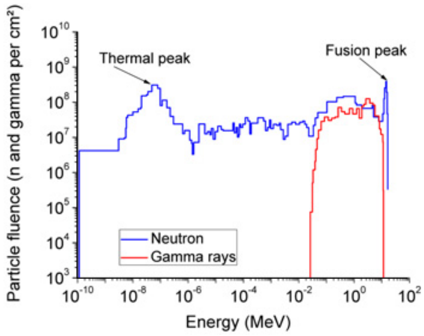


(a) Cumulated dose evolution versus time



(b) Neutrons and gamma rays spectra

Figure 1. Simulation of radiative environment at 4 m from TCC for a neutron yield of 10^{16}.

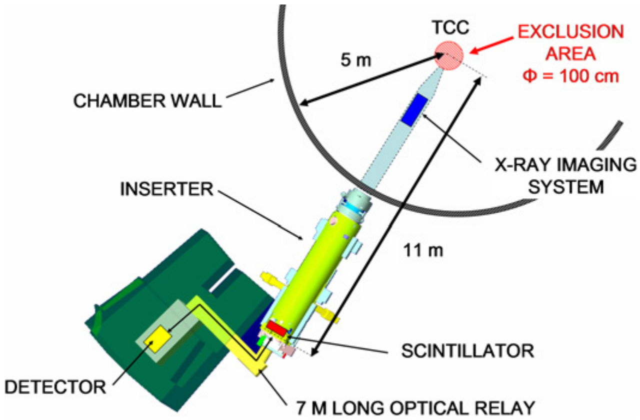


Figure 2. Diagnostic implantation in the LMJ facility.

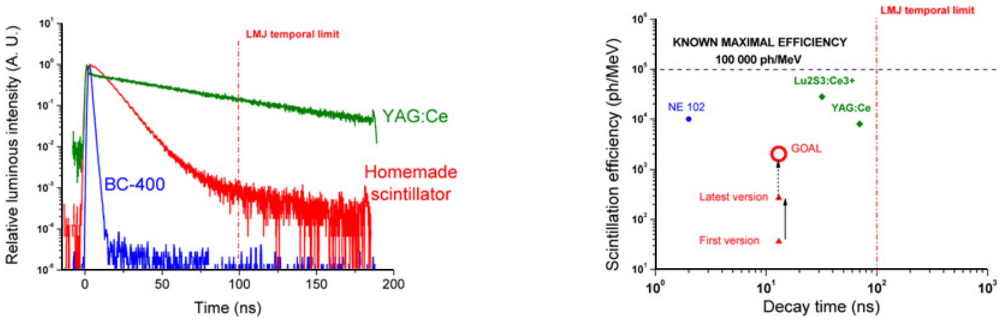
implantation in the LMJ facility will take into account of this radiative surrounding and its temporal evolution.

Previous simulations and experiments on laser facilties have shown that the use of detectors inside the target chamber will at least reduce their performances, at worst destroy them [1]. So an alternative design represented in figure 2 is considered: an X-ray imaging system images the DT target on a scintillator which converts rapidly X-rays into visible light. The resulting image in the visible spectrum is then transfered through a 7 meter long optical relay to a shielded box where the detection is realized. The shielded box which can bear a maximum shielding weight of 28 tons will reduce significantly the radiative environment. The whole system shall have a final resolution of 10 mm within a 500 mm field of view (FOV).

3. DIAGNOSTIC DEVELOPMENT

3.1 Scintillators issues and solutions

The scintillator used for the diagnostic must meet several requirements. Among them: x-ray absorption, decay time and scintillation wavelength. In order to fit with the 100 ns time window of acquisition, the scintillator's decay time should not exceed 10 ns while absorbing hard X-rays in the spectral bandwidth of 10–100 keV without resolution degradation. Furthermore, in order to distinguish the scintillator's



(a) Organic (BC-400), inorganic (YAG:Ce) and homemade scintillators decay time

(b) Scintillation efficiency versus decay time of scintillators

Figure 3. Developments towards low decay time and high efficiency scintillators.

signal light from the parasitic light generated by Cerenkov effect in the optical relay, the scintillation wavelength shall be higher than 550 nm.

No commercial scintillator[1,2] meeting all these specifications is currently available. Thus, homemade scintillator developments are in progress.

Improvement of inorganic scintillators decay time is a very hard task due to their crystalline structure. On the contrary, organic scintillators with low decay time can be easily modified to achieve requirements. Indeed, by embedding a high Z number element, like lead, into the polymer chain, the effective Z number of the scintillator increases drastically from 6 to 53, improving its X-ray absorption which increases reasonably its decay time as shown in figure 3a. Such effective Z number implies that the photoelectric effect is dominant in absorption process, consequently intrinsic spatial resolution is not affected by X-ray scattering induced by Compton effect. The use of three different fluorophores dispersed into the polymer matrix shifts the emission wavelength to 550 nm. First attempt of homemade scintillator had low scintillation yield because of lead concentration that quenches scintillation mechanism. But recent improvements have been made. The best lead and fluorophores concentration must still be tuned to maintain good x-rays absorption and to limit quenching.

3.2 Optical relay developments

In order to reduce effects of the LMJ radiative environment, the detector is placed inside a shielded box. This area is located at 7 m from the back of the inserter. Thus, a 7 meter long optical relay is necessary to transfer the image from the scintillator to the detector. Such an optical relay must not degrade the quality of the image because of its optical performances and parasitic light generated by large amount of glass. Its intrinsic spatial resolution should not exceed 100 μm within a 20 mm FOV. One way to limit glass quantity consists in using a catadioptric relay.

A first 4 meter long version [3], with commercial Maksutov objectives[3], has been already tested under irradiation on the ELSA electron accelerator facility [2]. As shown in figure [2], the experimental setup has been designed to reproduce as much as possible the LMJ configuration. The integrated gamma rays dose was relevant to the first 100 ns of the nominal LMJ shot. Masks have been placed along the optical relay in order to determine which elements are the major contributors to the parasitic light. Results show that the parasitic light generated by the 4 meter long catadioptric relay only contributes

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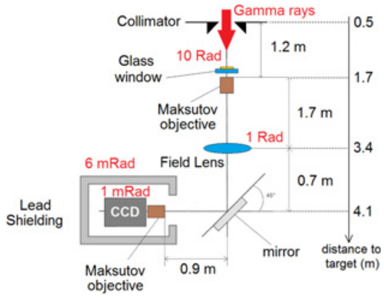
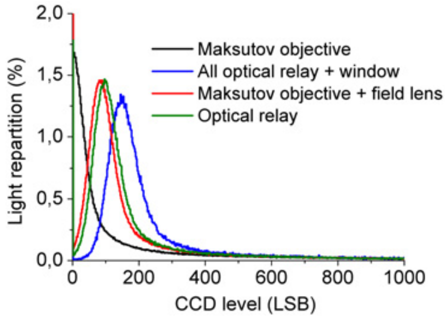
[1] Crytur: YAG: Ce.

[2] Saint-Gobain Crystals: BC-400.

[3] Astro Rubinar MC 300 mm F/4.5.



(a) Experimental setup



(b) Parasitic light repartition

Figure 4. Behaviour of the catadioptric relay under irradiation on ELSA facility.

to 1 permil of the 16 bits back-illuminated CCD[4] dynamic. Most of the parasitic light is generated by both the glass window of the inserter and the field lens. Nevertheless, this configuration has proved its robustness in term of vunerability but has poor optical qualities. An improved design of the Maksutov objective[5] has been performed so as to fit with the LMJ configuration and its specifications. The expected nominal spatial resolution of the final catadioptric relay is 50 mm within a 20 mm FOV with an F/4 optical aperture.

4. PROSPECTS

As the feasibility of both the scintillator and the catadioptric relay have been experimentally demonstrated, a prototype for the LMJ configuration are expected by 2012. It shall be tested in association with an X-ray imaging system on a laser facility or an X-ray generator.

The X-ray imaging system is still to be performed in order to meet the final diagnostic requirement of a 10 mm within a 500 mm FOV. One concept of such X-ray imaging system consists in the association of an annular aperture and an X-ray microscope. None-periodic multilayer coating allowing a constant reflectivity over the domain 10–30 keV has been already simulated. Vulnerability of such a coating under neutrons and gamma rays irradiation must still be caracterized to validate the diagnostic concept.

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