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The LMJ program: an overview

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Abstract. The Mégajoule laser Program (LMJ) is one of the most important parts of the French Simulation Program. The LMJ is designed to deliver about 1.8 MJ of ultraviolet light for high energy density science. It is designed so that fusion can be achieved with it. The first experiments are to be carried out at the end of 2014. Achieving fusion with LMJ requires a coordinated program associating the facility itself, as well as optimized fusion targets, plasma diagnostics, and simulation tools. This paper presents an update about this overall program.

1. Introduction
The Laser Mégajoule (LMJ) facility will deliver up to 1.8 MJ and 550 TW of ultraviolet light. It is one of the most important pieces of the “Simulation Program” in support of the French nuclear weapons stockpile stewardship, and is devoted to laboratory experiments in a large domain of Plasma Physics. It is a key facility for the French national security program and for basic science research. The project has gone through a number of phases including completion of design and building construction, commissioned in December 2008. Presently, the laser bundles amplification section are being assembled; Laser Bay 1 shown in figure 1 is complete. Details about the buildings and the laser system can be found in [7]. The LMJ more stringent specifications are dictated by fusion experiments. Achieving ignition on LMJ requires an integrated plan including the facility itself, target systems, diagnostics, target physics as well as a preliminary experimental program on different laser facilities.

Figure 1: View of amplification sections in Laser Bay 1
2. Ignition target design
The main approach for achieving ignition on the LMJ relies on the indirect drive scheme. Ignition target design uses intensively our simulation tools; central to our approach is the use of 2D and 3D codes validated by experiments. In order to explore the large parameter space available for ICF on the LMJ, a variety of ignition targets have been designed [5]. These targets are linked to different strategies of risk mitigation. The baseline LMJ ignition design has a graded-doped CH capsule in a hohlraum made of a uranium-gold composite. High yield fusion targets requiring no more than 1.4 MJ of laser energy have been identified, allowing first attempts to achieve ignition in a 160-beam configuration, grouped in 2 cones (33.2° and 49°). Rugby-shaped hohlraums are extensively studied, as they offer better energetics and improved symmetry in a 2-cone operation.

We are still dealing with the years-long process of setting requirements for the LMJ ignition targets. For this purpose, multivariable sensitivity models are built in order to assess and manage risks due to combined technological uncertainties and laser dispersions. For instance, a neuronal network model of the 1D yield versus 22 parameters has been built, giving access to a robustness map in the shell thicknesses parameter plan, as shown in figure 2; 1D margin is defined as the highest multiple of all the nominal 1D requirements that returns at least 50 % yield.

![Figure 2: Robustness map of LMJ capsules in the shell thicknesses parameter plan](image)

3. Target system
Ignition targets consist of a complex set of components requiring precise assembly and capsules with nanometer roughness surface finish. The nominal target designs are now based on cocktail hohlraums, whose fabrication has started at the CEA target lab. An important cryogenic program is under way to manufacture the Cryogenic Target Assembly, including its filling and its transportation at cryogenic temperature. The conformation of the DT ice is studied in specific cryostats to meet the required specifications. The target development program to prepare the LMJ experimental campaigns is detailed elsewhere [6].

4. Experimental campaigns
Experiments are presently done on different laser facilities to better ensure success for the fusion program. The LIL facility has been designed as a LMJ prototype, intensively used to test and improve the laser components. In addition, it is used to perform laser-plasma experiments, and is well adapted to test some issues of the experimental tuning. The first Laser Plasma Interaction experiment on LIL was devoted to test the specific longitudinal LMJ smoothing [13]. The simulated Raman spectrum given by the FCI2 code post processed with the linear gain code PIRANAH is coherent with the experimental results (figure 3). Experimental backscattered power has been successfully recovered by
complex 3D simulations done with the full hydro-code HERA including a paraxial propagation package [8].

![Post-processing of the hydro simulations](image1.png)

**Figure 3:** LIL experiment: Simulated and experimental Raman spectra

A shock timing campaign on planar targets is planned in 2010, in order to already control as much as possible this major source of uncertainty for ignition.

Controlling hohlraum energetics in the limit of high radiation temperatures is a key to target performances and has motivated a number of experiments over the past two decades (figure 4). In April 2009, radiative temperatures up to 260 eV have been reached on Omega by the CEA teams using scale ¾ cylindrical hohlraums. Valuable LPI data have then been obtained; hard X rays with energies up to 140 keV have been observed. As hydrodynamic instabilities are a known difficulty of ignition capsules, we have begun experiments on Omega to validate an innovative concept for ablator structuring: the use of a laminated ablator should dramatically reduce Rayleigh-Taylor growth at the ablation front. First experimental results are encouraging [9].

Since 2002, the rugby-shaped hohlraum concept has been tested at small scale on Omega [4], and has exhibited the expected benefit in a 2 cone-operation. It is now used for implosion experiments [11].

The CEA/LLNL/MIT implosions showed a significant drive enhancement (around 18% peak x-ray flux) with rugby hohlraums compared to cylindrical hohlraums. The highest yield for indirectly driven DD/Argon capsules was obtained during this campaign: $1.5 \times 10^{10}$ neutrons. This yield was high enough to allow for a full suite of neutron and proton diagnostics, giving the first burn history measurements in indirect drive. Figure 5 shows the unfolded neutron image.

5. **Plasma diagnostics**

Two main types of plasma diagnostics can be identified for use on the LMJ: they are respectively dedicated to x-ray and nuclear measurements. The LMJ diagnostic designs include hardening for harsh environment. Part of the target design effort is also devoted to study diagnostic signatures in simulated experiments, in order to progress on the specifications for analysis of LMJ plasmas.

X-ray imagers and spectrometer will be first activated on LMJ for laser measurements, such as pointing stabilities, structure and power balance of beams, and for hohlraum physics experiments; they may also be used for specific radiography experiments. The imagers design take into account the environmental issues, mainly hard x-rays and debris/shrapnel during this preparation phase without significant fusion gain.
Diagnostics deployed on LIL and OMEGA experiments will be transposed to LMJ, as the wide band spectrometer DMX or the Neutron Imaging System (NIS). A new Large NIS camera, scaled for MJ class lasers, was tested in May 2009 on Omega at 13 m from the Target Chamber Center. This large NIS allows us to consider a 7-8 µm spatial resolution for ICF experiments on the LMJ facility 40 meters line of sight.

Figure 4 : Radiative temperatures reached experimentally on different laser facilities, to compare to the 300eV LMJ nominal drive  

Figure 5 : Neutron image of a Omega implosion in a rugby-shaped hohlraum

6. Conclusion
LMJ will provide unique capabilities for the french Simulation program. Every component of the LMJ’s ignition program is well underway. Since [1], new targets have been designed and optimized to achieve ignition with less than 1.4 MJ. The first experiments will be carried out at the end of 2014.

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