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M. Shaw, R. House, W. Williams, C. Haynam, R. White, C. Orth

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# **Laser Performance Operations Model (LPOM): A computational system that automates the setup and performance analysis of the National Ignition Facility**

**Michael Shaw<sup>1</sup>, Ronald House, Wade Williams, Christopher Haynam, Ronald White, Charles Orth**

Lawrence Livermore National Laboratory, 7000 East Avenue, Livermore, CA, 94550, USA

E-mail: shaw7@llnl.gov

**Abstract.** The National Ignition Facility (NIF) is a stadium-sized facility containing a 192-beam, 1.8 MJ, 500-TW, 351-nm laser system together with a 10-m diameter target chamber with room for many target diagnostics. NIF will be the world's largest laser experimental system, providing a national center to study inertial confinement fusion and the physics of matter at extreme energy densities and pressures. A computational system, the Laser Performance Operations Model (LPOM) has been developed and deployed that automates the laser setup process, and accurately predict laser energetics. LPOM determines the settings of the injection laser system required to achieve the desired main laser output, provides equipment protection, determines the diagnostic setup, and supplies post shot data analysis and reporting.

## **1. Introduction**

For its various missions, the NIF laser must generate pulses with a wide range of energies, pulse lengths, and temporal pulse shapes that must be balanced among the 192 beams. Since slight differences in amplifier gains, optical transmission losses, and converter configurations cause the output vs. input characteristics to differ among beams, a calibrated computational model of the facility is required to accurately determine the input conditions required for each beam and for each shot. That model must be part of the NIF controls system to provide real-time setup information within the NIF shot cycle. The laser performance operations model (LPOM)<sup>1,2</sup> has been developed to provide this functionality. LPOM is run from the control room, where it communicates with a software supervisor, integrating it directly with the NIF Integrated Computer Control System (ICCS). In addition to generating shot setup information, LPOM provides an equipment protection function for NIF operations, analyzes system performance, and provides data visualization and archiving. LPOM is a fully automated system that has been designed, both in hardware and software, to scale to support full NIF operation within a time period consistent with shot rate goals.

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<sup>1</sup> To whom any correspondence should be addressed.

## 2. Functional Description of LPOM

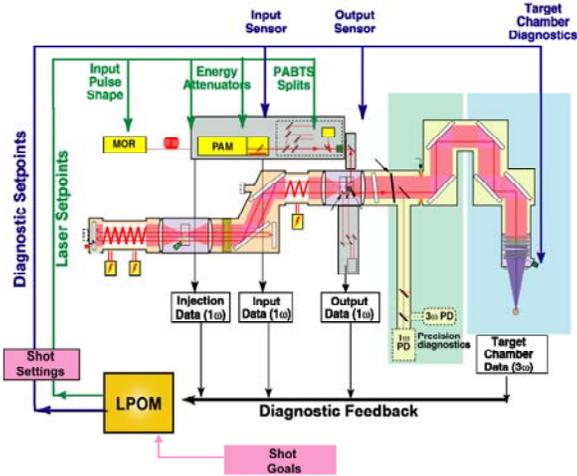
To provide accurate predictive capabilities, LPOM maintains a current description of each of the individual NIF subsystems that comprise a beamline. This description includes component locations, component gains and losses, optical aberrations on each component and frequency converter configurations. LPOM employs an optical physics simulation code, which uses this information both to predict laser performance and to provide inverse problem solution capability. To accomplish its equipment protection function, LPOM assesses the probability that a calculated shot might initiate optical damage, based on the predicted spatially-varying beam fluence, and it prevents the setting up of conditions that would lead to shots outside an acceptable operating envelope. During the shot set-up cycle, LPOM compares the measured and predicted diagnostic signals and verifies that the laser is functioning as required. After each shot, LPOM archives shot data, and presents data visualization of the results of post-shot analysis.

LPOM starts the beam set-up process from the request of desired energies and temporal shapes (power) of the beams at a user-specified location. To support both NIF operations and commissioning and diagnostic calibrations, LPOM must enable experimenters to specify energies at a variety of locations along the NIF beamline such as at the target chamber, the roving mirror diagnostics assembly, or the PDS  $1\omega$  or  $3\omega$  locations. To perform this function, LPOM incorporates a model of the laser system having enough fidelity to produce realistic and accurate performance calculations. For useful predictions, the laser model must be kept current with the evolving state of the laser system; thus LPOM is designed to continually acquire data from past shots and update its models. LPOM uses a detailed energy extraction and propagation code called the Virtual Beamline (VBL)<sup>3,4</sup> to calculate the energetics. VBL models beam propagation in three spatial dimensions plus a number of time slices. Energy extraction is simulated by solving the Frantz-Nodvik equation, while pulse propagation is modeled as a far-field diffractive phase applied in split-step with the preceding near-field effects. Optical aberrations are included either as measured metrology data (where available) or as power spectral density-based simulated phase screens. Nonlinear refractive index (B-integral) effects are included as a position-dependent near-field phase pushback.

Figure 1 illustrates the LPOM shot set-up process. LPOM reads the goals of an experiment and information about the laser configuration (e.g., the number of amplifier slabs to be used, the level of flashlamp pumping of the slabs) from the ICCS setup database. From this information, it generates beamline-specific input files for VBL and conducts a series of VBL calculations to self-consistently determine the settings for the injection laser system (ILS) that will produce the required output laser power. This calculation sequence also predicts the energy and power expected at each diagnostic location, thus determining the attenuation settings necessary to accurately measure a shot. These settings are written to the NIF shot database, where they are subsequently read by several NIF subsystems in preparation for a shot.

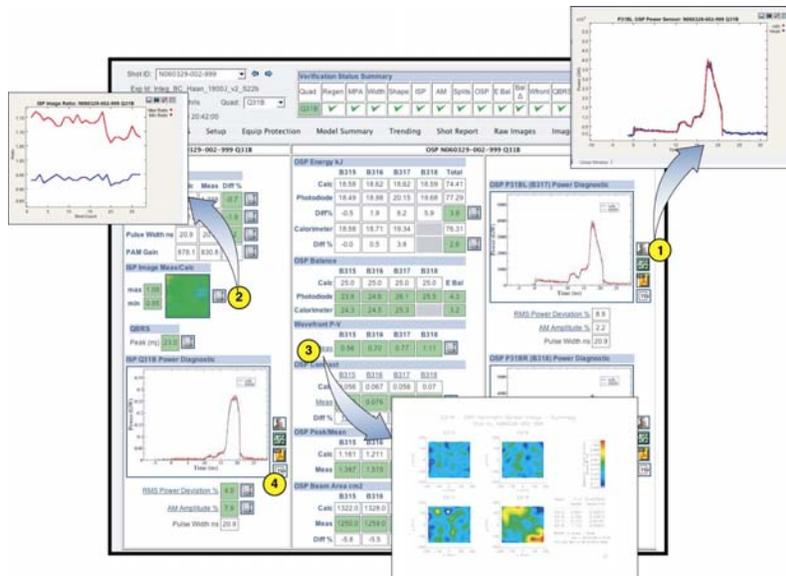
As part of the setup solution procedure, LPOM directs VBL to perform an end-to-end simulation of all beamlines involved in the shot. That simulation produces a report to the shot director assessing whether the shot goals are achievable within an acceptable operating envelope. LPOM provides an additional level of equipment protection by verifying that energies and powers measured during the shot setup cycle match those calculated by the model. Prior to a main laser system shot, NIF conducts a series of rod shots (shots for which only the ILS amplifiers are energized). LPOM compares the measured energies, powers, and spatial beam shapes, as well as the energy split among the four beamlines of a quad to predicted values in order to verify that the injection system is performing as required. If any of these checks fail, LPOM flags an error to the controls systems, recommends changes to the set-points and requests an additional rod shot. After a main laser shot, LPOM performs a more extensive set of analyses to verify the success of the shot and to assure that its models are up to date.

After a system shot is conducted, LPOM reads the shot data from the ICCS database and performs post-shot analyses. Within several minutes of the archiving of the raw shot data, LPOM provides the NIF Shot Director and the experiment team with a web-based shot report that compares the laser performance metrics (including energetics, near-field beam contrast, and residual wavefront distortion) with the pre-shot predictions. It also displays the raw and processed near-field and far-field images, power sensor traces, and trends of selected laser metrics.



**Figure 1.** Illustration of the LPOM shot setup process

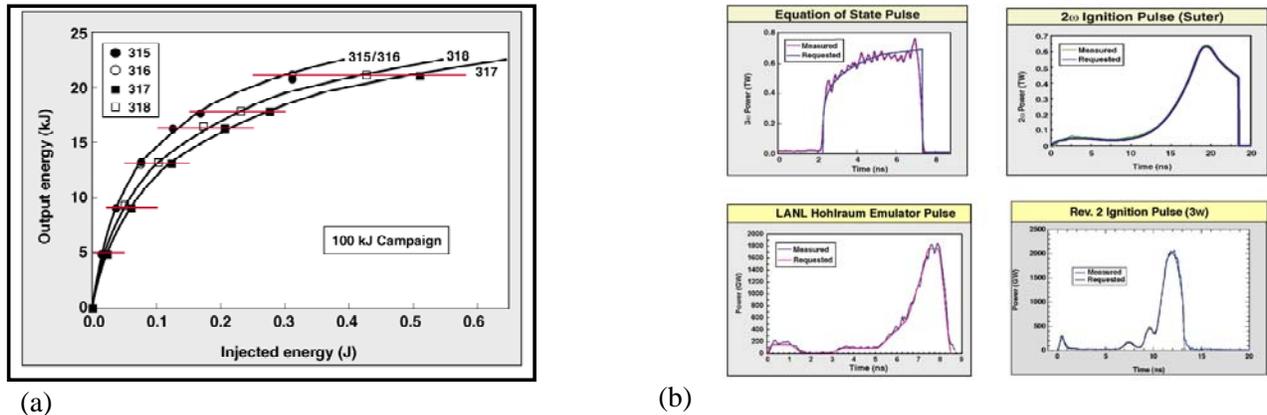
These results are presented on the LPOM web browser. The report is organized as a series of linked web pages that can be navigated to provide successive levels of detail, starting with a high-level status report for each participating quad, progressing to detailed reports from the underlying analyses. Figure 2 illustrates the drill-down capabilities of the LPOM shot verification report.



**Figure 2.** LPOM's web interface provides a powerful suite of data trending and analysis tools.

### 3. Results

LPOM was deployed in NIF in 2002 prior to the NIF Early Light (NEL) campaign. That version was isolated from ICCS, and required manual operation. Since that time, a great deal of effort has been made to integrate, automate and scale LPOM to a system that can support full NIF operations. Over the past five years, an automated version of LPOM has involved in the over 500 high-energy system shots, playing a key role in both commissioning (96 beams have been commissioned up 22-kJ per beamline in 1 $\omega$ ) and operations<sup>5</sup>. The use of a detailed propagation model that is calibrated with diagnostic data has allowed LPOM to accurately predict the energetics of the system to the levels that will be required for NIF missions. Typically, LPOM has been able to match the requested energies on each beamline to within 2-4% over a wide energy range (Figure 3a), with beamline-to-beamline balance of 1%. In addition, LPOM is able to match the requested pulse shapes extremely well (Figure 3b). This is a result of model calibration techniques that separate the effects of gain from transmission loss.



**Figure 3.** Comparison of predicted and measured output energy as a function of injected energy (a) and comparison of predicted and measured output pulse shapes (b).

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