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National Ignition Facility Experiments in Support of Stockpile Stewardship Program (SSP)

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Experiments on NIF contribute to the enduring U.S. Nuclear deterrent in the absence of additional nuclear testing by:

- Elucidating key weapons performance issues left unanswered when testing stopped,
- Improving the physics models incorporated in and validate the Advance Simulation and Computing (ASC) numerical simulation design codes upon which the SSP relies,
- Maintaining aspects of test readiness, and
- Recruiting, training, and retaining weapons program personnel.

The improved numerical simulation codes, which will be benchmarked and validated against underground nuclear test results and experiments at the NIF, will enable nuclear weapon scientists to improve the fidelity of nuclear weapon performance simulations and reduce uncertainties in U.S. and foreign nuclear weapon assessments and U.S. warhead certifications. NIF is unique in its capabilities to provide data needed by the SSP because of its ability to produce extreme energy density conditions over reasonably large volumes combined with high-resolution diagnostics.

NIF has already provided critical data to the SSP. Results from a series of non-ignition experiments on NIF, and precursor experiments on Omega and Z, validated a physics-based theory and simulation capability that was a major factor leading to the resolution of a long-standing anomaly left unanswered when underground testing was suspended. Data obtained from NIF showed that the theory and simulation capabilities developed to remove this anomaly were correct. The elimination of this anomaly represents a significant accomplishment for the SSP; eliminating one of the key technical reasons for having to potentially return to underground testing and enabling production decisions in support of stockpile sustainment. The experimental campaign (defined as a series of shots/experiments to achieve a common objective) on NIF was preceded by many months of (platform development) experimental shot time on Omega and Z to test diagnostics, targets, and data acquisition and reduction. The effort on Omega and Z enabled this experimental platform to be implemented on NIF very rapidly and the experimental series completed to support the closure of the effort.

The acquisition of weapon-physics-relevant data in the high-energy-density (HED) physics regime to validate these physics-based models is essential to the development of predictive capabilities for stockpile applications. Data generated from both ignition-relevant and non-ignition HED experiments are categorized into four main topics: nuclear, thermonuclear, radiation, and output and effects.

Nuclear: The *nuclear* area focuses on the physics during the implosion phase of the system. During the implosion phase, the components are driven at high-pressure and high-rate, and are compressed hydrodynamically leading to criticality. The most important physics areas are the material properties at these conditions, the implosion hydrodynamics, and the nuclear properties (such as nuclear cross sections) at the pressure and temperature conditions similar to those at the centers of giant planets and stars. Key HED efforts in this area are the measurement of relevant material properties at the high-pressure and high-rate condition, the study of hydrodynamics of imploding systems, and the measurement of key nuclear physics cross sections, such as fission and fission fragments.

Accurate data about material properties near or at thermonuclear conditions is needed to improve the physics models in weapon performance simulation codes. NIF experiments provide precision data in high pressure (millions to billions of atmospheres) and high temperature (surface of the sun to the interior of massive stars) regimes that are otherwise inaccessible in the absence of nuclear testing. The material properties data broadly fit into three categories: equation-of-state, material strength and phase structure. Current experiments on NIF focus on obtaining material dynamic data at high pressure and density and at high strain rate. Experiments include the measurements of diffraction data to discern the phase structure and strength data to bound the constitutive properties. Figures 1 (strength) and 2 (phase) show the high-level summaries of these two experimental campaigns,

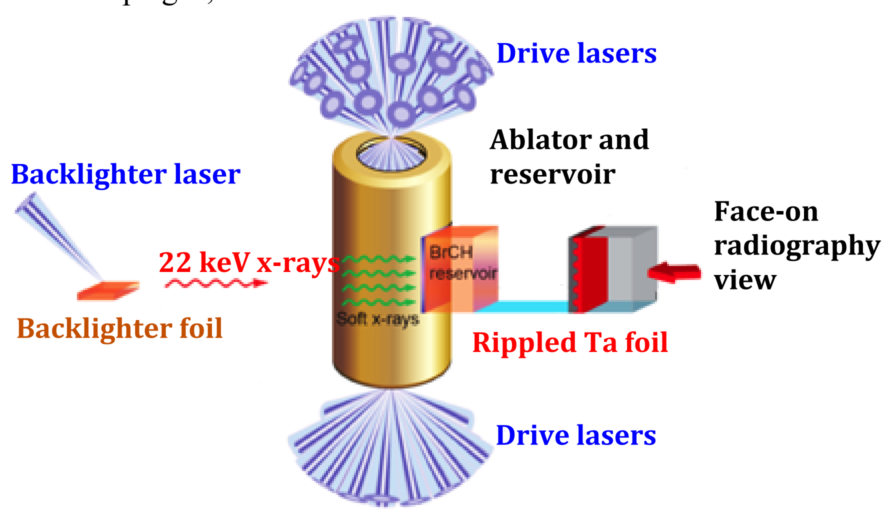

Fig. 1. The material strength experimental campaign measures the deformation of solids under high pressure and high rate.

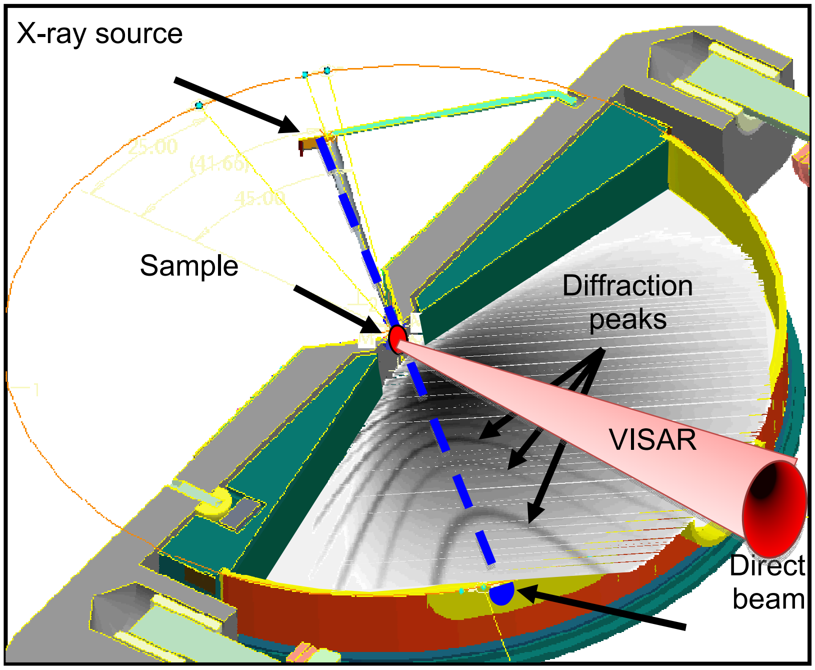

Fig. 2. The material diffraction (material phase) experimental campaign measures the diffracted line pattern, which is a unique signature of material phases at various pressures and temperatures.

Scaled experiments on NIF are being used to address complex hydrodynamic phenomena important to predicting nuclear weapon performance. Experiments are "scaled" when physical quantities for the experiment—size, density, and pressure—are selected in a coordinated manner so that the hydrodynamic behavior is same as the weapons-physics problem, albeit on a different scale—just as scaled airplanes in wind tunnels stand in for yet-to-be-built full scale airplanes. They help to "set or eliminate calibration parameters" and provide a means for validating physics codes used to examine issues during the nuclear phase of weapons functioning. They are also vital for development of computational models, helping nuclear weapon scientists develop and choose alternative models and computational methods to solve the stockpile problem of concern. Scaled experiments have begun on the NIF and Fig. 3 provides some of the key NIF capabilities required support this experiment.

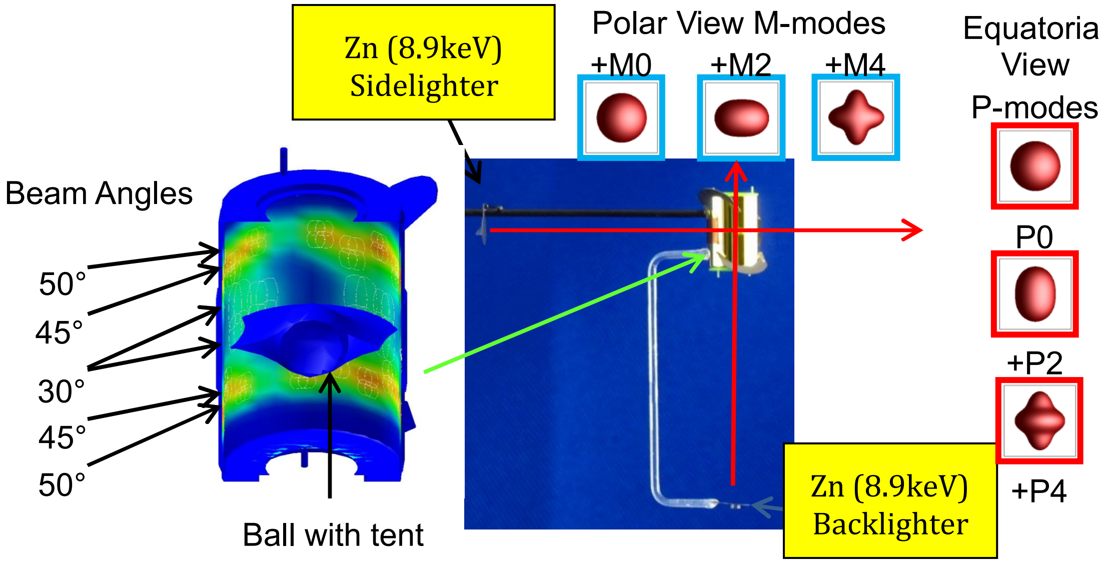

Fig. 3. The complex hydrodynamics experimental campaign studies the dynamic evolution of system driven by imposed perturbations.

With recent results that delivered neutron yield in the high 10^{15} range, we have started experimental campaigns to utilize the high neutron flux to study nuclear physics and measure key fission and radiochemical cross sections. Data will enable us to bound the nuclear cross sections in a regime not accessible by traditional neutron sources.

Thermonuclear: During the *thermonuclear* phase, the system reaches criticality and subsequently explodes. Here the system reaches very high temperatures and densities, similar to those at the center of stars and that of a supernova. At these conditions, the materials turn into hot plasma and are subject to strong mix driven by turbulence. Turbulent-driven mix and symmetry have impact on the efficiency of burn performance. Key HED efforts in this area include acquiring mix data at various conditions to validate the models, and to assess the integral performance of burning plasma in the presence of mix and symmetry issues.

Currently even the most powerful computers are incapable of calculating high-speed turbulence and mixing processes on the smallest scales of interest. As a result, most codes incorporate simplified models for instability growth, turbulence, and/or mixing. Different algorithms and models may produce different results. Hence, it is necessary to use experimental data to select the most appropriate model and/or set model parameters. Data from underground nuclear test results have been used to calibrate these models. These data are limited in quantity, level of detail, and range in parameter space of interest. Application of simulations calibrated in this manner to a wider set of problems leads to results of increasingly uncertain validity as the problems deviate from the experimental baseline. Figure 4 displays a simulated result on the extent of mix at the fuel-ablator interface of an imploding NIF capsule with a prescribed mix model. Figure 5 shows a planar experimental platform to study the increasing mix width due to shear instabilities.

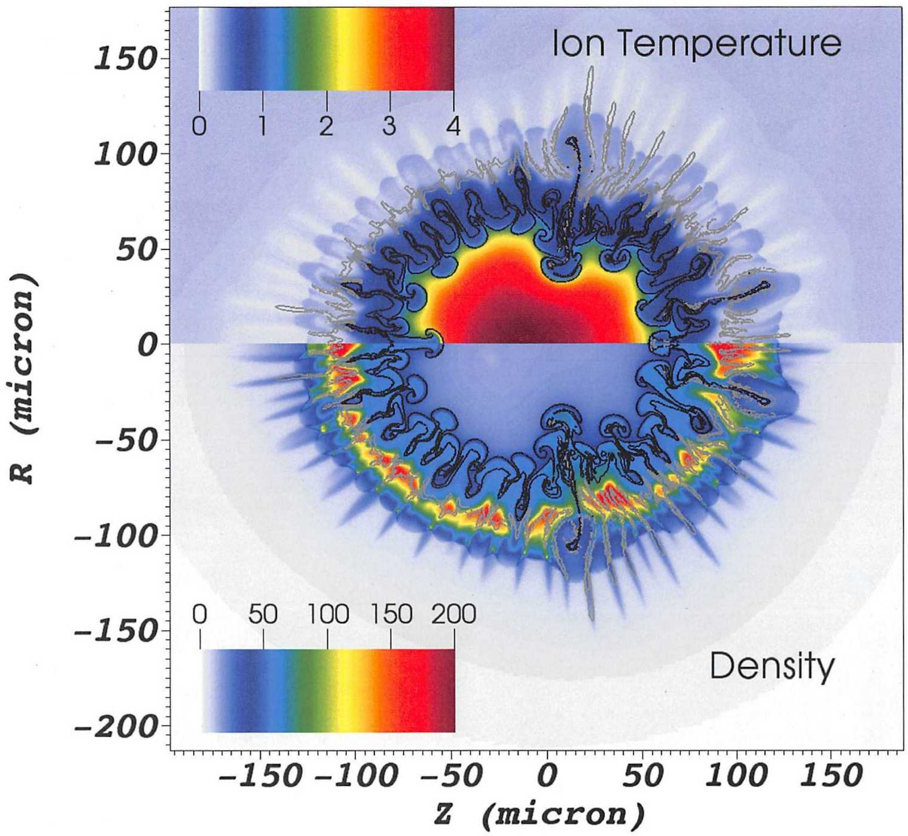

Fig. 4. HED experiments on NIF is used to study mix at the fuel-ablator interface and its impact in degrading implosion performance.

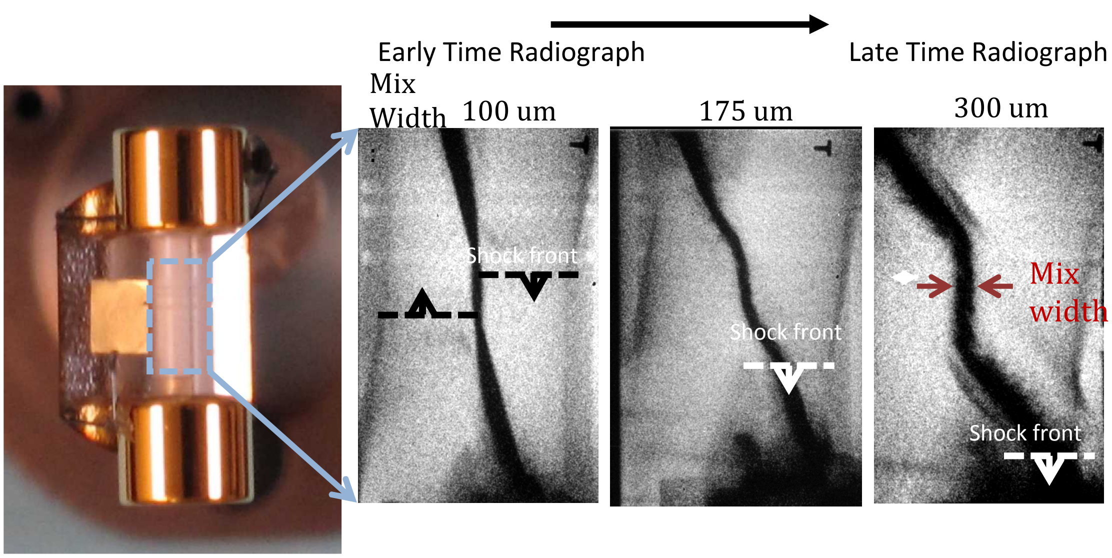

Fig. 5. NIF platform is used to quantify rate of instability growth and benchmark the mix model parameters.

With the improvement of imploding capsule performance and robustness on NIF, we are beginning to explore the utilization of current and future capsules to study burning plasma and thermonuclear physics. Planned near-term applications include the validation of code and model of capsules with significant self-heating with imposed perturbations. As the capsule performance continues to improve, that will allow the SSP community to expand the application of capsule yield. More detailed applications were delivered in a 90-day study report submitted in 2012. [Ref: (U) Classified Appendix to the Application of Ignition 90-day Study, Alan Wan et al., SRD report, Lawrence Livermore National Laboratory document no. COPD-2012-0031, February 2012]

Radiation: The *radiation* effort focuses on the study of radiation transport in modern system configurations and the validation of opacity models at relevant temperature and density conditions. Key HED efforts in this area are the measurement of radiation propagation in complex geometries to validate the radiation flow algorithms incorporated in the design codes and obtain data to validate first-principle opacity models, which govern the absorption and transmission of x-rays in nuclear devices.

Numerical modeling of radiation transported in a nuclear weapon is complicated by the extremes in conditions encountered and the complicated geometrical configurations that must be addressed. NIF provides a platform to conduct experiments that allows the validation of radiation numerical algorithms in these relevant regimes.

The opacity of a material governs the absorption and transmission of x-rays in a nuclear explosive device. The opacity of materials is necessary data for codes that simulate the transport of radiation in weapons, a key factor in device performance. First-principles computer models used to calculate opacities are beyond the scope of today's largest supercomputers. Instead, models that generate opacity data use approximate methods and give inexact data with difficult to quantify uncertainties as input into the large simulations. Opacity experiments to date have been very important in improving opacity theory and models, but they have been restricted to lower temperatures and densities than those critical to nuclear-phase weapon performance. NIF provides the conditions required to obtain opacity data to significantly advance models in the relevant high temperature regime.

Output and Environment: The *output and environment* efforts focus on post explosion phase where the nuclear weapon releases x-ray, neutron, and gammas on the intended targets. In addition, the study of physics of weapon output and effects allows us to assess the consequence of using the weapons, both intended and unintended, in near- and long-terms. Key HED efforts include developing relevant sources that model weapon output and utilize these sources to study the coupling of radiation for effects assessment and validation.

After the weapon as a whole has functioned, the device emits its energy into the environment through its output, in the function of time-, energy- and spatial- dependent x-ray, neutron, gamma fluxes. These radiation fluxes interact with the environment (e.g. the atmosphere, space) to produce a wide variety of effects, which has far-ranging impacts on overall consequence of execution, forensics, and counter-proliferation. NIF delivers the energetics to develop the needed platforms to validate the models that assess the interaction of radiation with a variety of targets.

Near-term Milestones and Deliverables for SSP Experiments on NIF

Currently Lawrence Livermore and Los Alamos National Laboratories are planning to conduct more than 10 experimental campaigns in the FY 2014-15 time frame across the four key topics described above. The major near-term deliverables include:

- FY 2014
    - Continue to advance the understanding of ignition science
    - Develop the high-Z material experimental platforms at high-pressure and strain rates
    - Complete experimental campaign to validate mix at fuel-ablator interface for imploding capsules at two convergence ratios.
- FY 2015
    - Complete the readiness to conduct first SSP-relevant high-Z material dynamic diffraction experiment at high strain rate and high pressure
    - Launch development of new hydroburn HED platform on Omega & NIF for the Marble campaign, including initial decision point on target design feasibility
    - Obtain first high-energy backlit (using Advanced radiographic Capabilities) images of evolution of complex hydrodynamics experiment
    - Complete the acquisition of shear low energy density, high energy density, and direct numerical simulation data that will be used to impact the FY16 LEP L1
    - Start first radiation transport experiment in complex SSP-relevant geometry