A summary of the first NISP workshop, Oct 27-28, 2015

1. Agenda:

Tuesday, October 27, 2015, B481, room 2005

8:00am	Gathering and refreshments	
8:30am	Welcome and opening remarks	K. LeChien
8:40am	Charter and deliverables	J. Frenje/S. Regan
9:00am	MDI	K. Peterson (discussion lead)
12:30pm	Lunch (will be provided)	
13:30pm	DDI	R. Bahukutumbi (discussion lead)
16.00pm	Day 1 wrap-up discussions	All

Wednesday, October 28, 2015, B481, room 2005

8:00am	Gathering and refreshments	
8:30am	IDI	P. Patel (discussion lead)
12:00pm	Lunch (will be provided)	
13:00pm	Workshop wrap-up discussions	All
15:00pm	Generate report out	All

Attendees:

A. Schmitt, S. Velicovich, R. Bahukutumbi, J. Knauer, V. Goncharov (web), A. Simakov, T. Murphy, M. Gomez, P. Knapp, K. Peterson, B. Spears, P. Patel, T. Ma, A. Pak, I. Nobuhiko, D. Casey, C. Yeamans, R. Mancini, B. Appelbe, J. Chittenden, M. Gatu-Johnson, W. Hsing, J. Kilkenny, J. Edwards, B. Sims (NNSA), K. Levedahl, K. LeChien, S. Regan and J. Frenje.

1. Summary of the magnetic-drive session

Sandia's highest priority with the MagLIF program is to develop a well understood and repeatable preheating platform. Currently, the initial conditions of the preheated fuel and the observed conditions at burn and stagnation are not well understood. At peak burn, an electron temperature of 2-4 keV, a density of ~0.1 to 0.5g/cc, a burn duration of 1-2 ns, a height of 5-10 mm, a width of 50-100 um, a B-field of 5-15 kT (at stagnation), a peak liner velocity of 70-100 km/s are observed, which correspond to an inferred stagnation pressure of ~1 GBar, whereas clean 2D simulated values predict values of 2.2 GBar assuming optimal laser energy coupling to the fuel.

1.1 Hypotheses for the observations

Several hypotheses explaining the observations and discrepancies to modeling were discussed. These are:

1. Low laser energy is coupled to the fuel, with little to no mix of the liner/endcap/window. The implosion is also essentially 1D (accounting for end losses) in nature at stagnation. Simulations of the early MagLIF experiments explain the observables assuming only ~200 J (10%) of laser energy couples to the fuel. This hypothesis may explain the initial integrated experiments that used relatively thick (3 μm) LEH windows.
2. A moderate amount of laser energy (~50%) is coupled to the fuel, while a few percent of the liner/endcap/window material is mixed into the fuel. The observables can be described by near-1D (accounting for end losses) modeling of the implosions at stagnation. This may explain integrated MagLIF experiments that used thinner (1.5 μm) LEH windows where the expected laser energy transmission increased significantly, but neutron yields dropped 10×. Recent experiments have shown that integrated performance is significantly degraded with Al endcaps compared to Be, implying endcap mix is important in experiments with improved laser coupling.

3. In contrast to hypotheses #1 and #2, the observed helical structure at stagnation represents a significant departure from a 1D stagnation description and results in inefficient conversion of kinetic energy, inadequate confinement, and the presence of residual flows. This hypothesis is based on 3D simulations, which can also describe experimental observables with a moderate amount of laser energy (~50%) coupled to the fuel with minimal amounts of liner/endcap/window mix.

These hypotheses were formulated with one or more of the following assumptions:

- The stagnation column is contiguous and the axial magnetic field lines follow perturbation contours at stagnation.
- Non-symmetric laser heating generates vorticity, enhanced scrape mix from liner walls and limits compression.
- Hard X-ray diagnostics are adequate surrogates for neutron burn history.
- Sufficient magneto thermal insulation has been obtained. Transport models are reasonably accurate and thermal conduction losses are not significantly degrading implosion performance.
- Axial mass/flux losses are not degrading performance more than expected from simulations and analytic estimates.

2. Summary of the direct-drive session

A major goal with the direct-drive program at LLE is to demonstrate a well-understood and well-modeled cryogenic implosion reaching a pressure in excess of 100 Gbar. To date, the highest hot-spot pressure inferred from x-ray and nuclear diagnostics is 56±7 Gbar for an α~3.3 implosion of a layered DT target, which should be compared to the 1-D simulated value of ~90 GBar. The 1-D simulation includes cross beam energy transfer, which reduces the target absorption and resulting ablation pressure of direct-drive ICF targets. Relative to 1-D simulations. 3-D simulations suggest that low-mode distortion of the hot spot seeded by laser-drive non-uniformity and target-positioning error truncates the neutron rate and reduces the hot-spot pressure. This trend is consistent with the measured neutron rate and the hot-spot pressure. When burn truncation is taken into account the 1-D simulations for implosions with a convergence ratio CR≤17 and $\alpha \geq 3.5$ are in closer agreement with the experimental values of the hot-spot pressure and the compressed areal density. In addition, ion temperatures (Ti) measured with neutron-time-of-flight detectors, positioned in different locations around the implosion, indicate significant variations in cryogenic implosions (generally displaying ~10-14% rms, but up to 50% variations are occasionally observed), which should be compared to room-temperature implosions with a Ti variation of ~2.8% rms. In cryogenic implosions, the observed burn rate generally tracks the 1-D simulated rates but then deviates from experiment (burn truncation) prior to the 1-D bang time. To effectively address these issues, better diagnostic information (time resolved and viewed from different directions) about the compressed core including the hot spot and cold shell is required.

2.1 Hypotheses for the observations

Reasons for reduced hot-spot pressure in the cryogenic implosions include:

- Long-wavelength growth during deceleration phase that can result in low-mode hot-spot distortion, incomplete stagnation, an increased hot-spot volume, and consequently a decrease in hot-spot pressure.
- Too much mass in the vapor before deceleration.
    - Decompression of the rear surface of the shell, which could be due to 1D effects such as additional rarefaction waves, EOS, opacity uncertainties etc.
    - Short wavelength growth at the ablation surface.

The evidence for these hypotheses are: a lower inferred hot-spot pressure compared to the 1-D simulation is observed for experiments with CR≥16; 3D simulations that include the effects of beam-to-beam laser imbalance and target positioning offset (long wavelength non-uniformities) also indicate the same trend; Measured burn rate tracks 1-D simulations and then truncates prior to the 1-D simulated bang time, which is reproduced in 3-D simulations.

3. Summary of the indirect-drive session

Discussions focused on hot-spot shape, hot-spot flow, hot-spot temperature and fuel/ablator areal density and asymmetry.

3.1 Hot-spot shape

Hypothesis: Hohlraum drive asymmetry, especially time-varying asymmetry, due to Cross-Beam-Energy Transfer (CBET) or wall-induced spot motion is driving asymmetric (oblate) and incomplete stagnation.

Evidence:

- Multiple line-of-sight measurements of x-rays and neutron self-emission broadly indicate that the size of x-ray and neutron images (P0) are similar on a ~10% level, but higher modes can be different.
- The variation in P2 from ConAs (shell) to hot spot emission (hot spot) appears to depend on design (gas fill and case-to-capsule ratio). The late-time shape swings are not understood and are difficult to predict due to the uncertainties in CBET in high-gas fill hohlraums, and Au wall expansion in near-vacuum hohlraums.
- Understanding the evolution of the hot-spot shape during the 'missing time window' between the 2D ConA radiography and self-emission imaging measurements will be essential.

3.2 Hot-spot flow

Hypothesis: An unknown source of one-sided drive asymmetry is generating hot-spot flow and incomplete stagnation. Flows from this and other drive imbalances (see 3.1) lead to incomplete stagnation and a loss of hot-spot internal energy to unconverted kinetic energy in the shell and hot spot.

Evidence:

- A similar picture of the fuel bulk motion (translational velocity) is provided by neutron and x-ray measurements. It is also observed in x-ray data that the bulk motion is function of signal contour suggesting that differential motion of brightly emitting regions within the hot spot can be determined. Source of bulk motion is not understood at this point. It is clear from simulation that this type of translational imbalance produces damaging hot-spot flow and incomplete stagnation.
- Ti measured with different neutron-time-of-flight detectors, positioned at various locations around the implosion, indicate a fairly isotropic temperature distribution (< 400 eV). However, post-shot simulations with sizable asymmetries show temperature distributions that vary about 200 eV. The data isotropy and the code-predicted level of anisotropy are not consistent.
- Using an energy balance model, the total residual kinetic energy in the dense shell and hot spot is estimated to be in the range of 70-100% and 0-30%, respectively. Uncertainties in the modeling are large, of the order of several kJs.

3.3 Hot-spot temperature

Hypothesis: The differences in DD and DT Ti differences and the associated DD/DT yield ratios are caused by 3D asymmetries that produce both hot-spot flows and distortions of the angular fuel areal density distribution.

Evidence:

- The observed differences in the DT and DD Brysk Ti are larger than expected for a static, equimolar, Maxwellian fluid.
- Measured DT to DD neutron yield ratio is also larger than expected on the basis of measured Brysk Ti and a simple model to account for the difference in down-scatter fractions. Fuel stratification cannot be an explanation as this would drive the ratio in the opposite direction. One hypothesis is that the simple down-scatter corrections are not accurate due to significant 3D distortions of the fuel.
- The observed electron temperatures (Te) are currently not accurate enough to evaluate the effect of bulk flows on the Brysk Ti.

3.4 Fuel/ablator areal density

Hypothesis based on this data: Time-varying drive asymmetry and engineering support features are damaging the cold fuel configuration leading to large areal density variation.

Evidence:

- Time-varying, low-mode drive asymmetries and the tent perturbation are believed to be the dominant factors affecting the implosion performance. In high-foot implosions, the yield reduction due to low-mode drive asymmetries and tent perturbation is estimated to be 20× and 5×, respectively, while in low-foot implosions the yield reduction is estimated to be 5× and 10×, respectively.
- Significant areal-density asymmetries are often inferred from FNADS data. This data measures the composite effect of hot-spot neutron source distribution and out-scattering of primary neutrons by cold fuel areal density. The areal density is believed to dominate the angular variation. From fits to FNADS data, the areal density is generally much higher at the poles, resulting in 1-1.5g/cm^2 asymmetries.

3.5 Summary of Hypotheses

We hypothesize that the stagnation phase of IDI implosions is compromised by non-spherical effects. The evidence suggests that both the hot spot and cold shell show 3D asymmetries. Measurements further suggest that the hot spot is incompletely stagnated and consequently suffers a reduction in internal energy due to residual flows.

Incomplete stagnation is likely due to two effects:

(1) Hohlraum drive asymmetry and

(2) Perturbation from the support tent

Hohlraum drive asymmetry, especially time-varying asymmetry, is likely due to CBET or wall-induced spot motion. Drive asymmetry contains both P1 and P2 components (and likely other low modes). Further perturbations from the support tent lead to areal density variation in the confining cold fuel as well as additional damage to hot spot stagnation.

4. List of action items:

1. Non-radial flow: emphasis on nTOF analysis, with peer review by LLE and LLNL. Sandia will look for precision requirements
2. X-ray emission analysis: compare images and resolutions at LLE and LLNL. Are the images different (smooth, lumpy). Sandia might offer a non-spherical analysis perspective

3. Compare consensus on image shapes and Ti variation. Shouldn't round images and isotropic temperatures go together?
4. Scrutinize and compare current analysis of the pressure.
5. Measurements of Te: Sandia, LLNL do nearly same differential filtration. Compare. Also compare to continuum spectrometry at LLE. Potentially develop a comparison with continuum and ross pairs at Omega
6. Cold fuel analysis: think about cold fuel, dark region and hot spot. Can we backlight the shell, compare to hot spot?
7. DD/DT yield ratios to understand scattering, species separation…
8. Compare Te and Ti to understand thermal/non-thermal contributions.

5. Date and rough agenda for the second NISP workshop

The second NISP workshop is planned to be held the week of March 7, 2016. At this workshop, action items 1-4 in Section 4 will be addressed in detail.

Appendix: Questions/suggestions by the panel

A.1 Magnetic Drive

- How stable is the Image plane of the ZBL laser?
- What is the radial and axial field distribution and how does this effect triton/alpha trapping?
- What effect does the observed morphology have on stagnation pressure, density, temperature, and confinement?
- How do we define the convergence ratio in the presence of a helical stagnation?
- Explore options for a burn history diagnostic on Z. Could we put a sacrificial scintillator within roughly a meter of the load to measure the burn history?
- Develop stronger collaborations with LLE and LLNL to learn potential ways to use our neutron diagnostics more effectively (better ion temperature measurements – axially resolved Ti? higher nTOF moments, Be back-scatter, environmental effects, DT spectral analysis, IRF effects, forward analysis, etc.)

A.2 Direct Drive

- Can we reduce the timing uncertainty for the NTD on OMEGA to make a better case for burn truncation as opposed to an overall reduction in neutron rate?
- Are we confident that other sources of non-uniformity (ice roughness etc.) are not responsible for the degraded performance?
- Hot spot radius is measured from a different direction compared to the areal density. So should there be consistency between the hot spot radius and areal density?
- Can a phase velocity of x-ray emission be extracted from the time-resolved hot spot images by using an indexed SEM grid instead? Or x-ray Doppler velocimetry can be used to extract RKE?
- Can fNADS be investigated for areal density anisotropy in areal density?
- Is there a correlation between Ti variations and the areal density variations between the MRS and nTOFs?
- Is there a correlation between neutron yield and Ti variations? In other words, can scattering from various fixtures etc. contribute to the Ti variations?
- Is there a correlation between CR and Ti variations?
- Is there a scenario from simulations where hot spots images including motion blurring, instrument response etc. are quasi round but there is significant Ti variations?

- Can deliberate non-uniformities such as increased power balance or increased offset be studied in cryogenic implosions?
- Since d(n,2n) results from a different portion of the compressed core relative to the n-D edge, how can you correct for that background when inferring areal density from backscattered neutrons?

A.3 Indirect Drive

- What are we learning from the calculations– 3D simulations low mode/high mode?
- What is not being done with the codes?
- What about density measurements of hot spot?
- Is a neutron temporal diagnostic possible on NIF?
- Is the Te inferred from time-integrated, Ross-filtered images measuring the same hot-spot plasma as the Ti inferred from nTOF diagnostic?
- Has a Fourier analysis of the DIXI hot-spot images been performed to study the evolution of the modal structure?
- How do magnetic fields in the hohlraum affect the drive asymmetry?
- Regarding nTOF calibration data, are hard x-rays a good surrogate for neutrons?