LAWRENCE
LIVERMORE
NATIONAL
LABORATORY

LLNL-CONF-418833

Assessment and Mitigation of Radiation, EMP, Debris & Shrapnel Impacts at Megajoule-Class Laser Facilities

D. C. Eder, R. W. Anderson, D. S. Bailey, P. Bell, D. J. Benson, A. L. Bertozzi, W. Bittle, D. Bradley, C. G. Brown, T. J. Clancy, H. Chen, J. M. Chevalier, P. Combis, L. Dauffy, C. S. Debonnel, M. J. Eckart, A. C. Fisher, A. Geille, V. Y. Glebov, J. Holder, J. P. Jadaud, O. Jones, T. B. Kaiser, D. Kalantar, H. Khater, J. Kimbrough, A. E. Koniges, O. L. Landen, B. J. MacGowan, N. D. Masters, A. MacPhee, B. R. Maddox, M. Meyers, S. Osher, R. Prasad, D. Raffestin, J. Raimbourg, V. Rekow, C. Sangster, P. Song, C. Stoeckl, M. L. Stowell, J. M. Teran, A. Throop, R. Tommasini, J. Vierne, D. White, P. Whitman

October 28, 2009

Inertial Fusion Sciences and Applications (IFSA)
San Francisco, CA, United States
September 6, 2009 through September 11, 2009

Disclaimer

This document was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor Lawrence Livermore National Security, LLC, nor any of their employees makes any warranty, expressed or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or Lawrence Livermore National Security, LLC. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or Lawrence Livermore National Security, LLC, and shall not be used for advertising or product endorsement purposes.

Assessment and Mitigation of Radiation, EMP, Debris & Shrapnel Impacts at Megajoule-Class Laser Facilities

D. C. Eder[1], R. W. Anderson[1], D. S. Bailey[1], P. Bell[1], D. J. Benson[3], A. L. Bertozzi[4], W. Bittle[5], D, Bradley[1], C. G. Brown[1], T. J. Clancy[1], H. Chen[1], J. M. Chevalier[6], P. Combis[7], L. Dauffy[1], C. S. Debonnel[7], M. J. Eckart[1], A. C. Fisher[1], A. Geille[6], V. Y. Glebov[5], J. Holder[1], J. P. Jadaud[7], O. Jones[1], T. B. Kaiser[1], D. Kalantar[1], H. Khater[1], J. Kimbrough[1], A. E. Koniges[2], O. L. Landen[1], B. J. MacGowan[1], N. D. Masters[1], A. MacPhee[1], B. R. Maddox[1], M. Meyers[3], S. Osher[4], R. Prasad[1], D. Raffestin[6], J. Raimbourg[7], V. Rekow[1], C. Sangster[5], P. Song[1], C. Stoeckl[5], M. L. Stowell[1], J. M. Teran[4], A. Throop[1], R. Tommasini[1], J. Vierne[7], D. White[1], P. Whitman[1]

[1]LLNL, [2]LBL, [3]UCSD, [4]UCLA, [5]LLE, USA, [6]CEA, DAM, CESTA, France, [7]CEA, DAM, DIF, France

Email: deder@llnl.gov

Abstract. The generation of neutron/gamma radiation, electromagnetic pulses (EMP), debris and shrapnel at mega-Joule class laser facilities (NIF and LMJ) impacts experiments conducted at these facilities. The complex 3D numerical codes used to assess these impacts range from an established code that required minor modifications (MCNP - calculates neutron and gamma radiation levels in complex geometries), through a code that required significant modifications to treat new phenomena (EMSolve - calculates EMP from electrons escaping from laser targets), to a new code, ALE-AMR, that is being developed through a joint collaboration between LLNL, CEA, and UC (UCSD, UCLA, and LBL) for debris and shrapnel modelling.

1. Introduction

Extending the energy of large laser facilities from the 10's of kJ's (Omega) to the MJ range (NIF & LMJ) increases the impact of operation on the facility. In this paper, we discuss the impacts of radiation, EMP, and debris/shrapnel and ways to mitigate these impacts. On the path to ignition, a series of THD (tritium, hydrogen, deuterium) shots are planned with the mix of isotopes chosen to produce relatively low yield/radiation levels for conditions that would produce ignition and high yield for a pure DT capsule. However, even for these lower yields (~ 10^{15} neutrons) appropriate collimation, shielding, and beam dumps must be designed for diagnostics. The majority of this design work is done with the 3D Monte Carlo code, MCNP [1], which we also use for our calculations of worker doses for activities in the NIF facility. It is important that all structures (diagnostics, auxiliary shielding, etc.) be designed with both background levels for diagnostics and radiation levels for workers in mind.

For all experiments on NIF and LMJ, laser-matter interactions will produce energetic electrons. The number of these electrons that escape the target primarily depends on their energy, size of target, and duration of laser pulse. Escaping electrons produce an electromagnetic pulse (EMP) that can impacts electronics in diagnostics and other facility systems. The energy of the electrons depends on

the intensity of the laser and the corresponding laser-mater interaction physics. For laser intensities in the 10^{12}-10^{16} W/cm^2 range, laser-plasma interactions (LPI) generally produce "hot electrons" with energies in the 10's of keV range with higher energies tails extending out to a few 100's of keV's. In contrast, very high intensities (10^{18}-10^{20} W/cm^2) can produce very energetic (MeV) electrons. At NIF, long (ns) pulse operation is used to heat hohlraums and other targets with LPI producing hot electrons. Electrons with energies extending out to 10's of MeV will be generated at NIF when we convert 1-4 beams to short (ps) operation as part of the Advanced Radiographic Capability (ARC). We expect large EMP with electric fields in the few MV/m range for ARC operation. We have studied EMP associated with MeV electrons on the Titan laser facility with measured electric fields up to 400 kV/m that are very broadband extending from 50 MHz to 5 GHz or beyond. Good agreement with EMP data has been obtained on Titan with the 3D electromagnetic code, EMSolve [2], using measured spatial distributions of the escaping electrons. Significant modifications of the EMSolve code were required to model EMP in laser chambers. A suite of EMP probes has been installed on NIF at locations inside and outside the chamber. The inside location is ~4 m from target chamber center (TCC).

Debris and shrapnel associated with NIF and LMJ experiments must be assessed and appropriate mitigation steps must be taken to protect optics and diagnostics. Both facilities use relatively thin (1-3 mm) borofloat glass as the final optic. On NIF they are called disposable debris shield (DDS's) and on LMJ they are EPA's. Targets including shields, etc. must be designed so that no large shrapnel fragments with velocities sufficient to penetrate the relatively thin optics are launched towards the optics. Diagnostics components, e.g., pinhole arrays, can become a source of shrapnel that can damage other components, e.g., microchannel plates. Modelling of debris/shrapnel generation is particularly challenging because the simulation domain can includes hot radiating plasma and cold fragmenting solids. A new 3D code, ALE-AMR, has been developed for this application. [3] The code combines arbitrary Lagrangian Eulerian (ALE) hydrodynamics with adaptive mesh refinement (AMR) to allow the code to dynamically add zones at interfaces and in regions with steep gradients. Validation experiments have been done at LLNL's Janus laser and at CEA's LIL laser. The code is used to model NIF experiments and will be used by CEA researchers to model LMJ experiments.

2. Neutron and gamma backgrounds

In order to achieve acceptable performance from ignition diagnostics, it is necessary to reduce neutron and gamma backgrounds by the use of well designed collimators, shields, and beam dumps. The design of these components depends on the spectrum of the neutrons (DD, THD, or DT shots), the neutron yield, and the time range of the instrument. The high-energy x-ray imager (HEXRI) is a time-gated instrument that is sensitive to the neutron and gamma radiation for 40 ns after the laser pulse. The calculated gamma fluence using MCNP at 40 ns is shown in Figure 1. [4] For this time period, the dominant sources of gammas are n-γ reactions in components near TCC, e.g., the cryogenic target positioner. (For instruments integrating over all time, e.g., image plates, the n-γ reactions in the target chamber wall are the dominant sources of gammas.) We have designed a tungsten collimator that reduces the HEXRI background by more than an order of magnitude. [4]

3. Electromagnetic pulses

EMP probes are sensitive to changing electric and magnetic fields, called Ddot and Bdot, respectively. To cover the wide frequency range of interest (~10 MHz to ~5 GHz) a suite of probes is required. We have installed EMP probes inside the NIF chamber as shown in Figure 2. They are ~1 m away from the stainless steel first wall panels and ~4 m from TCC. We have measured EMP for a wide range of target shots with electric fields generally in the 1-10 kV/m range. Given the expected $1/r^2$ scaling for the initial portion of the EMP pulse, fields ~15 times larger are expected for diagnostics located ~1 m from TCC. A significant fraction of the EMP is at relatively high (> 1 GHz) frequencies. [5] EMSolve simulations show that such fields can be produced by ~10^{12} electrons escaping in a few ns.

For ARC operation on NIF, we expect significantly larger EMP with fields at 1 m from TCC to exceed 1 MV/m and frequencies extending out to 5 GHz and beyond. This is based on field

measurements done at the Titan and Omega-EP laser facilities. In general, fields of order 1 MV/m must be reduced by ~ 80 dB (4 orders of magnitude) to avoid data disruption and electronic damage. We are testing improved EMP mitigation techniques on NIF. This work is being applied to diagnostic cables where we have observed volt level signal on well shielded, terminated coaxial cables.

For yield operation, the gammas produced from n-γ reactions in target bay components can produce Compton electrons in cables resulting in system generated EMP (SGEMP). This type of EMP requires significant radiation shielding and becomes more important as we go to high yield operation. Our approach is to place essentially all diagnostics behind 2 m of concrete for high yield operation.

4. Debris and shrapnel generation

In general, the primary target, e.g., hohlraum, is completely vaporized in NIF and LMJ experiments. This vaporized material along with debris produced from unconverted light striking the first wall panels in NIF (no unconverted light enters the LMJ chamber), and x-ray ablation from first walls and other components inside the target chamber coats the NIF DDS's and the LMJ EPA's. At both facilities, these thin optics are located in cassettes that can hold up to 10 optics. The total mass of debris is controlled (< 1g/shot) to obtain acceptable replacement rates for the cassettes.

The issue that generally requires mitigation is the generation of molten or solid fragments from auxiliary target components or diagnostics, such as supports, shields, backlighters, pinhole arrays, etc.. For ignition targets on NIF, the high-Z hohlraum is surrounded by an Al thermal-mechanical package (TMP), which has an average thickness of ~500 microns. For equatorial diagnostics located near TCC, the dominant loading is from a debris wind produced by the vaporized TMP. (For polar diagnostics, x-ray loading is important.) The Al deposited on the front of the gated x-ray imager (GXD) in shown in Figure 3. This debris wind was observed to be strong enough to bend and nearly completely shear a Ta pinhole array located behind a 500-micron thick Ta collimator as shown in Figure 4. (This shot was for a debris test with no camera being used.) In following shots, the Al wedge was replaced by a back 500-micron thick Ta collimator and the GXD was able to obtain images of imploding capsules.

It was determined that the flat Si support arms used for cryogenic targets reflect too much 1ω light into other beam lines. One short-term proposal was to replace the flat Si supports with curved Al rods until a long-term approach could be developed. We modeled this proposed configuration with ALE-AMR and found that it was acceptable for shots with ~1 MJ of laser energy but not acceptable for shots with ~1/3 MJ of energy. We show results for this lower energy case in Figure 5. The non-vaporized portions of one of the Al rods are shown at 6 different times. In the last frame, we see that there is a large fragment moving at ~1 km/s in towards an optic. A fragment with this size and velocity would penetrate even a 3-mm thick DDS as shown in Figure 7. For the 1 MJ case, a longer length of rod is vaporized and the remaining portions are directed back along the rod and not towards optics. Given these results, the Al rod idea was dropped and the long-term design using thin waffled Al layers covering the flat Si was used for all shots.

5. Summary/Conclusion

Advanced 3D simulations using a range of codes is essential for the assessment and mitigation of facility impacts associated with radiation, EMP, and debris/shrapnel. A collimator, shielding, and a beam dump have has designed for the HEXRI diagnostic. Measurements of EMP on NIF are being used to test mitigation techniques to prepare the facility for ARC operation. Experiments at Janus and LIL facilities provide additional validation data for the new ALE-AMR code used for debris and shrapnel modeling. CEA plans to use the ALE-AMR code along with their ESTER and HESIONE codes to model debris and shrapnel on LMJ. Experiments have demonstrated the effects of a debris wind on diagnostics located in the equatorial position. Simulations have shown that a proposed configuration to use Al rods to support cryogenic targets is not acceptable with respect to optics damage. A configuration using waffled Al layers over Si supports has been shown to be acceptable.

This work performed under the auspices of US DOE by LLNL under contract DE-AC52-07NA27344.

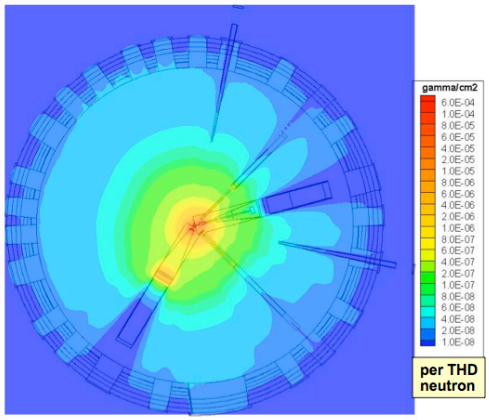

Figure 1 Gamma radiation fluence for a THD shot with 2% D 40 ns after the laser shot.

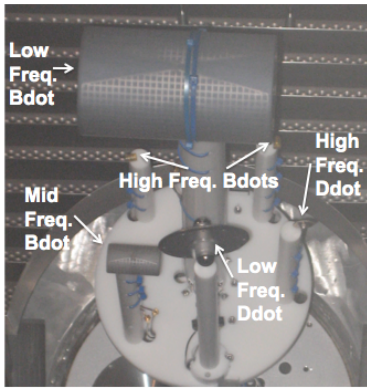

Figure 2 The suite of EMP field probes located ~4 m from TCC.

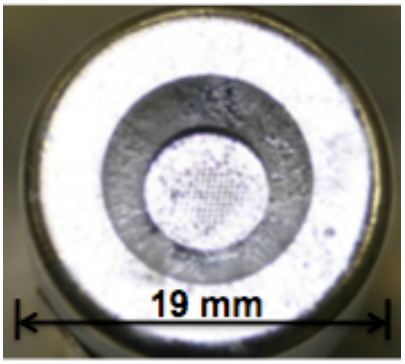

Figure 3 Front of GXD nose cone 8 cm from TCC coated with Al from TMP.

Figure 4 The front collimator, Kapton foil, pinhole array, and Al wedge placed inside GXD nose cone for a shot with nose cone 8 cm from TCC located on an equatorial position exposed to debris wind from target.

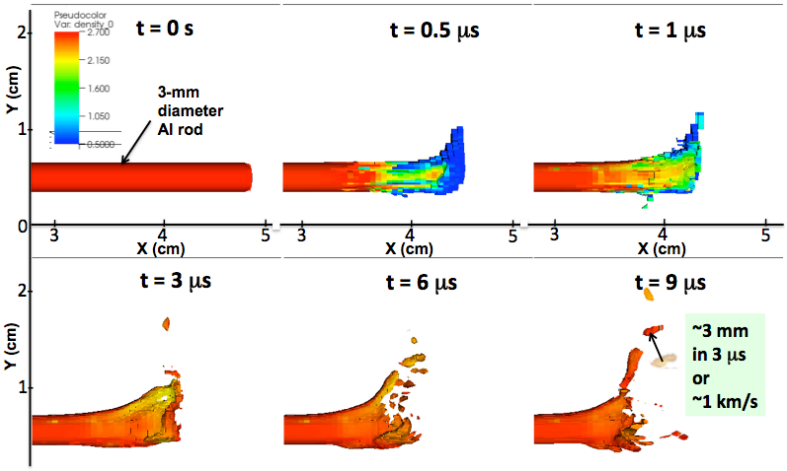

Figure 5 The effect of debris wind on proposed Al rod (only solid/molten material shown) to support cryogenic target for a laser energy of 333 kJ.

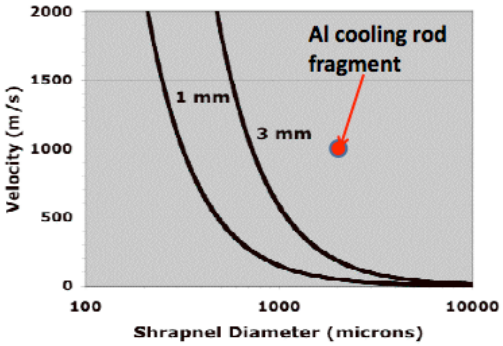

Figure 6 Penetration curves for 1 and 3 mm thick DDS's along with the calculated size and velocity of the fragment shown in last frame of figure 5.

References

[1] Brown F B, Martin W R, and Mosteller R D, 2008 "Monte Carlo - Advances and Challenges," ANS *Reactor Physics Division Topical Meeting (PHYSOR-08), (LA-UR-08-05891)*

[2] White D and Stowell M 2004 *IEEE T. Microw. Theory* **52**(5) 1404

[3] See papers by Koniges A, et al., Masters N, et al., and Fisher A, et al., 2009 in this series

[4] See paper by Khater H, et al., 2009 in this series

[5] See paper by Brown C, et al., 2009 in this series