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ABSTRACT

The target chamber of the National Ignition Facility must maintain an environment in which the laser optics can remain clean enough to avoid damage. Therefore melting and vaporization of target chamber materials by target explosions must be minimized. Computer simulations have been performed of the response of target chamber wall materials and laser debris shields to the target explosions. Additionally the deposition of tritium from the targets in the wall and optical materials have been calculated.

I. INTRODUCTION

To avoid excessive condensation on the laser optics, the first wall of the target chamber of the National Ignition Facility (NIF)[1] is designed to minimize the total mass of vapor produced by target emanations. The primary concern is clouding of the laser optics by recondensed materials. The target chamber of the NIF will have an inner coating of one of several low atomic number high temperature materials. Low atomic number materials have longer x-ray and ion deposition lengths, so peak surface temperatures are lower. Emanations from the NIF targets, both direct and indirect drive, include x rays and ions[2] that deposit in the target chamber first wall.

Target emanations have been calculated for direct and indirect drive NIF targets. The x-ray spectra from direct and indirect drive NIF targets[3] has been calculated with both LASNEX and BUCKY.[4] The x rays from direct drive targets are very hard but only make up about 1% of the yield, while indirect drive targets have much softer spectra that make up about 19% of the yield. Direct drive targets are made of less mass than indirect drive targets and have much more debris energy, so they have higher velocity ions. Typically, direct drive targets emit 50 keV tritium, 35 keV deuterium and 3 MeV carbon. Indirect drive targets emit mostly gold at energies of a few 100 keV. Both x-ray and debris spectra are isotropic for direct drive and non-isotropic for indirect drive.

The BUCKY code has been used to calculate the response of several materials to these target spectra. First wall materials considered in this study are Al_2O_3, C (graphite), and B. SiO_2 is also studied because response of the laser optics and beam dumps needs to be considered. Details of these simulations will be presented in this paper.

II. VAPORIZATION AND MELTING OF WALL

The vaporization and melting of the NIF target chamber first wall has been calculated with the BUCKY code. Target x-rays and debris parameters from the BUCKY calculations discussed in Ref. 2 are used as inputs for these calculations. There were three materials considered: boron, Al_2O_3, and SiO_2. Direct and indirect drive spectra were considered. The energy partitioning and spectra are quite different, as shown in Table I. The direct drive spectrum is much harder and much more energy from the direct drive target is in debris.

In these calculations, the BUCKY code deposits the x-ray and debris energy in the material and then uses the local energy density to determine whether the material is vaporized or melted. The details of ion deposition and vaporization models are discussed elsewhere.[9] Both forms of energy are deposited in a time-dependent manner, which competes with the

TABLE I

Target Energy Balance

	Direct Drive		Indirect Drive	
	Pure DT	CH Coated	Ignited	Significant Yield
E_{laser}	1.26	1.27	1.31	1.33
TN yield (MJ)	38.6	39.7	0.11	9.40
Neutron losses (MJ)	32.4	33.1	0.08	7.12
X-ray losses (MJ)	0.38	0.40	0.45	1.98
Debris energy (MJ)	7.04	7.44	0.89	1.63
Maximum total energy (MJ)	39.8	41.0	1.42	10.73

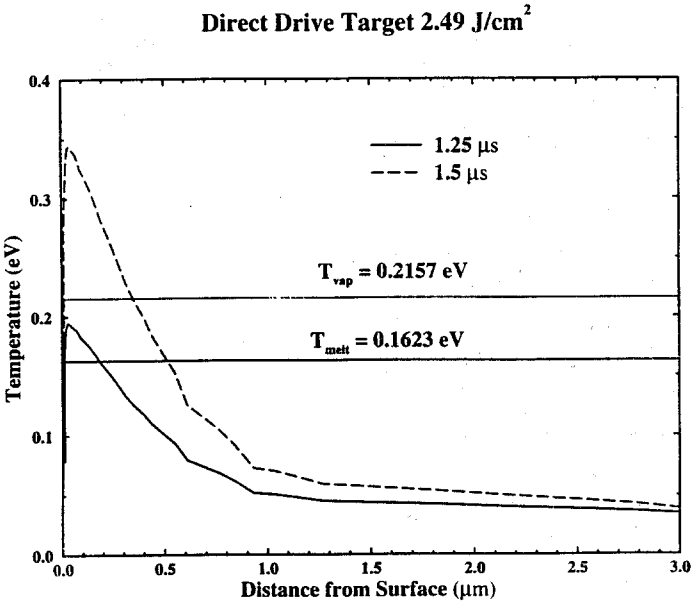

Fig. 1. Temperature profile in SiO_2 due to debris from a 40 MJ NIF direct drive target.

conduction of heat away from the surface. This results in a temperature profile as shown in Fig. 1 for SiO_2 in the path of debris from a 40 MJ direct drive target. The material that is above the melting temperature is assumed melted. The heat of fusion is ignored. Material is evaporated from the surface of the material at a rate determined by the surface temperature and the lattice separation energy.

No melting or vaporization was seen on boron or Al_2O_3 from the radiation from the base of the case or the oblique radiation from a 20 MJ indirect drive target. The response of SiO_2 to this radiation and debris has not been studied. A parametric study of the response of boron and Al_2O_3 as a function of target yield has been performed. The results are given in Table II. Boron experiences no vaporization or melting for either x-ray spectrum up to a target yield of at least 45 MJ. Al_2O_3 is not damaged at either 100 kJ or 20 MJ yield for either spectrum, but is slightly melted at a 45 MJ yield. Therefore, these calculations show that boron is a marginally better first wall coating material, from the point of view of x-ray vaporization by indirect drive NIF targets.

The target debris from direct drive targets does some damage to the target chamber materials. The target x-ray fluence is much lower than the debris fluence and the x-ray spectrum is hard enough that the deposition length is long in the chamber materials so the specific energy in the material is relatively low. Neglecting the effects of x rays, the melting and vaporization caused by the debris from a 40 MJ plastic coated direct drive target has been calculated with BUCKY, using the debris spectrum discussed above. The results are summarized in Table III. Here, boron is clearly superior to Al_2O_3. Also, the debris shield, which is made of SiO_2, will be damaged by a full yield direct drive target.

III. TRITIUM DEPOSITION IN NIF TARGET CHAMBER WALLS

The deposition of tritium ions in carbon, boron, alumina and glass has been calculated with the BUCKY code. At the time the calculations were performed, only a discrete spectrum was available for the NIF targets. In the future, calculations with continuous ion spectra will be performed. The discrete spectra are enough to give a rough indication of how deeply the ions penetrate into the materials.

BUCKY considers the effects of free electrons, bound electrons and target nuclei in the calculation of ion stopping. The traditional approach in BUCKY has been to divide the contributions from free and bound electrons and treat them separately. In the

TABLE II

Wall Damage by Indirect Drive Target X Rays

	B			Al_2O_3		
Target Yield (MJ)	0.1	20	45	0.1	20	45
CASE SPECTRUM						
X-Ray Fluence (J/cm^2)	0.281	0.905	1.684	0.281	0.905	1.684
Debris Fluence (J/cm^2)	0.292	0.942	1.753	0.292	0.942	1.753
Vaporized Mass (mg/cm^2)	0	0	0	0	0	0.0098
Vaporized Thickness (μm)	0	0	0	0	0	0.025
Melted Mass (mg/cm^2)	0	0	0	0	0	0.098
Melted Thickness (μm)	0	0	0	0	0	0.25
OBLIQUE SPECTRUM						
X-Ray Fluence (J/cm^2)	0.258	0.831	1.547	0.258	0.831	1.547
Debris Fluence (J/cm^2)	0.315	1.015	1.891	0.315	1.015	1.891
Vaporized Mass (mg/cm^2)	0	0	0	0	0	0
Vaporized Thickness (μm)	0	0	0	0	0	0
Melted Mass (mg/cm^2)	0	0	0	0	0	0.051
Melted Thickness (μm)	0	0	0	0	0	0.13

TABLE III

Wall Damage by 40 MJ Direct Drive Target Debris

	B	Al_2O_3	SiO_2
Vaporized Mass (mg/cm^2)	0	0.0035	0.079
Vaporized Thickness (μm)	0	0.009	0.35
Melted Mass (mg/cm^2)	0	0.29	0.12
Melted Thickness (μm)	0	0.75	0.55

calculations presented in this section, this approach is used. In this work, free electrons in the stopping medium are not important because the medium never gets hot enough to do much ionization. The bound electron contribution is calculated in two ways, depending on the ion energy. At low energy, the Lindhard-Scharff[5] model is used which is valid when the velocity of the projectile ions is small compared to the orbital velocities of the bound electrons in the stopping medium. Here the stopping power is proportional to the projectile ion velocity. This expression derives from the treatment of the electrons in the stopping medium as a cloud.

When the velocity of the projectile ions is greater than the orbital velocities of electrons in the stopping medium, BUCKY uses the Bethe[6] stopping power. The Bethe model treats the bound electrons in the stopping medium as point charges. In this expression, the stopping power decreases with increasing projectile velocity.

Since the Lindhard model predicts increasing stopping power at low ion energy and the Bethe model predicts a falling stopping power at high ion energies, a maximum exists in the interface between the regions of validity of the two models. This is when the projectile ion velocity is approximately equal to the orbital velocity of the bound electrons in the stopping medium. BUCKY does a linear interpolation between these two methods in this regime. A new feature in BUCKY allows a more general calculation of the stopping power, where the interaction of bound electrons in a muffin-tin potential are explicitly calculated.[7] This gives the same results as the Lindhard model at low ion energies and the Bethe model at high energy, but it is a better approach in this intermediate region. The range calculated with the old model is compared with calculations from the TRIM[8] code that uses fits to experimental data, which is discussed in Ref. 9.

In these calculations, the charge state of the tritium ions is assumed to be constant at 1.0. BUCKY has the ability to calculate the time dependent in-flight charge state of the projectile ions. This is an important effect for high atomic number projectiles, though hydrogen is a trivial case.

A typical result of the BUCKY tritium deposition calculations is shown in Fig. 2. BUCKY has been modified to record the positions where ions deposit in the solid materials. The density of tritium ions is plotted against distance into the material in arbitrary units. The calculations were performed for

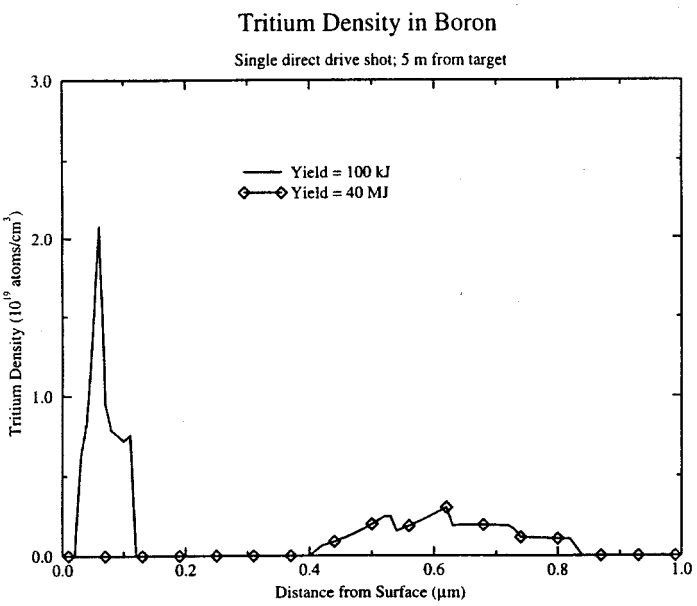

Fig. 2. BUCKY simulations of the deposition of tritium from direct drive NIF targets into boron.

a spectrum of ion energies, so the ions deposit over a range of depths. The input parameters for these simulations are summarized in Table IV. The results are summarized in Table V, for a direct drive target with a yield of 40 MJ, and in Table VI, for a direct drive target with a yield of 0.1 MJ. In all cases, the same total number of tritium atoms is assumed to be the same. The minimum, maximum and peak ion energies in the continuous spectrum are given. For the 40 MJ NIF direct drive target, the profiles of velocity and mass density, discussed in Ref. 2, have allowed the choice of three discrete tritium energies. The relative numbers of ions at each energy are determined by these profiles.

Calculations have also been performed for indirect drive targets. The tritium ion debris spectra from indirect drive NIF targets are softer than the 40 MJ yield direct drive spectrum. The indirect drive yield will be no higher than about 20 MJ and the total number of tritium atoms is comparable to the direct drive target, so the energy per tritium atom is less than or comparable to the direct drive target. In the indirect drive targets, most of the tritium ions collide with the remnants of the hohlraum case, converting much of their energy into radiation. Those tritium ions pointed toward the laser entrance holes will lose some energy going through the cloud of gold vapor that has been blown off of the case. These effects substantially reduce the tritium ion energies seen on the wall of the target chamber.

TABLE IV

Tritium Deposition Parameters for 40 MJ

First wall radius (m)	5
Total number of tritium atoms	2.25×10^{20}
Column density of tritium on wall (cm^{-2})	7.16×10^{13}
Minimum ion energy (keV)	26.4
Peak ion energy (keV)	62.5
Maximum ion energy (keV)	114

The results of these calculations indicate that for all of the materials studied, tritium will penetrate no more than about 2 μm into the material. From a single shot, about 10^{18} tritium atoms per cm^3 are added to the material. The glass in the debris shield experiences the deepest penetration, while the other materials all have very similar penetration distances. For the 0.1 MJ yield direct drive target, the tritium deposits within 0.2 μm for boron. Graphite and Al_2O_3 will have similar results. The diffusion of tritium in the material has not been calculated, and is suggested as future work.

IV. CONCLUSIONS

A boron or B_4C target chamber wall will not melt or vaporize due to x rays and debris from direct and indirect drive targets. Al_2O_3 is only vaporized or melts to a small degree. SiO_2 experiences more melting. In all cases, tritium is deposited to a depth of about 1 μm.

ACKNOWLEDGEMENT

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REFERENCES

1. M. Tobin, et al., "Target Area Design Basis and System Performance for the National Ignition Facility," *Fusion Technology* **26**, 772 (1994).

2. R.R. Peterson, et al., "X-Ray and Debris Ion Spectra Emanating from NIF Targets," *Fusion Technology* **26**, 780 (1994).

3. R. R. Peterson, J. J. MacFarlane and Ping Wang, "X-ray and Debris Emissions from Direct and Indirect Drive National Ignition Facility Targets," these proceedings.

TABLE V

Tritium Deposition Results for 40 MJ Direct Drive Target

Ion Energy (keV)	26.4	62.5	114
Al_2O_3			
Range for 3.9 g/cm^3 (μm)	0.20	0.55	0.75
Range for 3.7 g/cm^3 (μm)	0.22	0.60	0.82
Boron			
Range for 2.5 g/cm^3 (μm)	0.20	0.60	0.75
Range for 2.38 g/cm^3 (μm)	0.21	0.63	0.80
Range for 2.25 g/cm^3 (μm)	0.22	0.66	0.82
Graphite			
Range for 1.8 g/cm^3 (μm)	0.20	0.70	0.95
SiO_2			
Range for 2.26 g/cm^3 (μm)	0.76	1.15	1.62

TABLE VI

Tritium Deposition Results for 0.1 MJ Direct Drive Target

Ion Energy (keV)	0.895	2.12	3.86
Range for 2.5 g/cm^3 boron (μm)	0.02	0.10	0.15
Average tritium density (cm^{-3})		5.5×10^{18}	

4. J.J. MacFarlane, G.A. Moses, and R.R. Peterson, "BUCKY-1 – A 1-D Radiation Hydrodynamics Code for Simulating Inertial Confinement Fusion High Energy Density Plasmas," University of Wisconsin Fusion Technology Institute Report UWFDM-984 (August 1995).

5. J. Lindhard and M. Scharff, "Energy Dissipation by Ions in the keV Range," *Phys. Rev.* **124**, 128 (1961).

6. H.A. Bethe, Handbuch der Physik, Edited by S. Flugge, Springer-Verlag, Berlin, Vol. 24, 273 (1933).

7. J.J MacFarlane and P. Wang, "Numerical Simulation of High Energy Density Plasmas in KALIF Beam-Target Interaction Experiments," University of Wisconsin Fusion Technology Institute Report UWFDM-1002 (December 1995).

8. J.F. Ziegler, "TRIM-90: The Transport of Ions in Matter," IBM - Research, Yorktown, New York (1990). Also, J.F. Ziegler, J.P Biersack, and U. Littmark, "The Stopping and Range of Ions in Solids," Pergamon Press, New York (1985).

9. R. R. Peterson, et al., "The BUCKY and ZEUS-2D Computer Codes for Simulating High Energy Density ICF Plasmas," these proceedings.