Vaporization of Pb and Li Films in ICF Reaction Chambers

A.M. Hassanein, C.D. Croessmann, and G.L. Kulcinski

May 1983

UWFDM-505

Nucl. Tech./Fusion **4** (1983) 849.

FUSION TECHNOLOGY INSTITUTE

UNIVERSITY OF WISCONSIN

MADISON WISCONSIN

Vaporization of Pb and Li Films in ICF Reaction Chambers

A.M. Hassanein, C.D. Croessmann, and G.L. Kulcinski

Fusion Technology Institute
University of Wisconsin
1500 Engineering Drive
Madison, WI 53706

http://fti.neep.wisc.edu

May 1983

UWFDM-505

Nucl. Tech./Fusion 4 (1983) 849.

VAPORIZATION OF Pb AND Li FILMS IN ICF REACTION CHAMBERS

A.M. HASSANEIN
Fusion Power Program
Argonne National Laboratory
Building 205
Argonne, IL 60439
(312) 972-5889

C.D. CROESSMANN, G.L. KULCINSKI
Nuclear Engineering Department
University of Wisconsin
1500 Johnson Drive
Madison, WI 53706
(608) 263-2308

ABSTRACT

The A*THERMAL code is used to calculate the temperature rise and subsequent evaporation of liquid Pb and Li films bombarded with the debris of ICF targets. Temperature increases resulting from the various species are combined with vapor pressure data to yield evaporation rates and the subsequent total amount of Pb or Li vaporized from a thermonuclear explosion.

INTRODUCTION

There have been many recent proposals to protect the first walls of inertial confinement fusion reactors from target debris and X-rays. One scheme uses a liquid metal film which is thick enough to intercept the pellet debris but which is, at the same time, thin enough to let the neutrons pass through the blanket.[1,2] The thickness of the liquid metal film can be increased to moderate the neutrons and reduce the displacement and transmutation damage to the first wall. Such a scheme is used in the HYLIFE[3] and the HIBALL[4] concepts.

One of the difficulties with the designs that use liquid metals to absorb the target debris and X-rays is that an accurate description of the temperature rise and subsequent evaporation is required. The amount of liquid metal that is evaporated is very important because the rate at which that metallic vapor condenses determines the maximum rate at which the beams can be injected, and hence the power output of the reactor.

The object of this research project is to demonstrate a method by which the evaporation of liquid metals can be calculated for any arbitrary target spectrum. The usefulness of this technique is illustrated by calculating the amounts of Pb or Li that would be evaporated after 350 and 177 MJ pellet explosions.

CALCULATIONAL APPROACH AND TARGET SPECTRA

The target spectrum is a key element in these calculations. Unfortunately, there are no "unique" spectra because the ICF community has not yet demonstrated a generic target design that could give gains of 10 or more in a repetitive fashion. Therefore, target spectra are assumed. These spectra are given in Tables 1 and 2 and displayed in Figs. 1 and 2 (ref. 5). This calculation uses Ta as a typical tamper material as well as an organic of C, H and O atoms to represent components of a pusher material like TaCOH. The unburnt D and T are included as well as the helium atom reaction products.

For Target 1, the energy of the particle debris is assumed to be 3.3 keV/amu and consists of a Maxwellian distribution of particles. The X-ray energy is assumed to be represented by a 0.5 keV blackbody temperature with 3.5 MJ in X-rays. For Target 2, the energy of the particle debris is assumed to be 5 keV/amu and also consists of a Maxwellian distribution of particles. The X-ray energy is assumed to be represented by a 1.0 keV blackbody temperature with 35 MJ in X-rays.

Table 1
Target 1 Parameters
$\rho R = 3$

Component	% of Yield	MJ	Energy (keV)	Number of Particles x 10^{20}
X-rays	2	3.5	0.5 BB	
Ions	30	53	3.33/amu	
Ta	(25.6)	(45.2)	603	4.68
C	(3.24)	(5.72)	40	8.94
H	(0.54)	(0.94)	3.33	17.63
O	(0.34)	(0.60)	53.3	0.70
He	(0.08)	(0.15)	13.3	0.70
T	(0.13)	(0.23)	10	1.41
D	(0.08)	(0.15)	6.66	1.41
Neutrons	68	120.1		
	100	176.6		

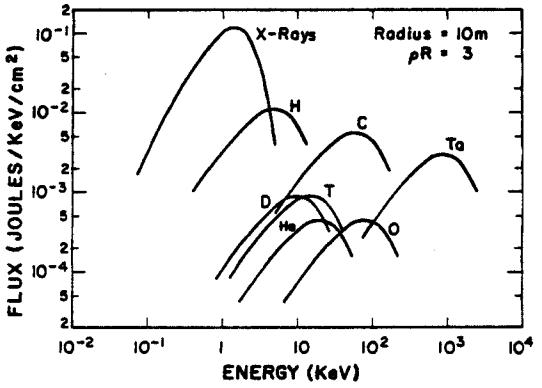

Fig. 1. The spectra of Target 1 (ρR=3).

The next decision was what environment the target debris will see on its way to the liquid metal film on the first wall. For the present study a vacuum is assumed since previous work has shown that only when the total gas pressure times the thickness of the gas exceeds a few torr-meters are modifications of the spectra incident on the first wall expected.[6,7]

The particle and photon flux on the liquid metal surface are now examined. The X-rays obviously arrive before the particles ($\sim 10^{-8}$ - 10^{-7} seconds after the TN burn) and are deposited for a time duration roughly corresponding to the "burn time" of the target. The spatial deposition of the energy from the X-rays is also taken into account.[8]

The energy of the particle debris is incident on the surface of the liquid metal in approximately 5 microseconds after the end of the burn (the exact time depends on the radius of the cavity). The time duration of particle energy flux (~ 25 microseconds) depends on the velocity distribution associated with the chosen Maxwellian energy distribution.

The calculation of the depth distribution of the energy deposited by the particles is very complex. The approach taken for this study is based on that originally developed by Hunter[9] and later modified by Hassanein.[8] It involves calculating both the nuclear and electronic energy loss rates for a variety of particle energies into the liquid metal and then fitting the results to a polynomial equation.

Table 2
Target 2 Parameters
ρR = 6

Component	% of Yield	MJ	Energy* (keV)	Number of Particles x 10^{20}
X-rays	10	35	1 BB	
Ions	35	122.2	5/amu	
Ta	(29.7)	(103.9)	905	7.17
C	(3.7)	(13.1)	60	13.6
H	(0.67)	(2.3)	5	28.75
O	(0.42)	(1.5)	80	1.17
He	(0.18)	(0.6)	20	1.875
T	(0.18)	(0.6)	15	2.5
D	(0.18)	(0.6)	10	3.75
Neutrons	55	192.5		
	100	350		

*Maxwellian distribution assumed for all ions.
BB = blackbody spectrum

After all of the energy has been deposited, both temporally and spatially, a finite difference code is used to calculate the temperature as a function of distance from the first surface and as a function of time. In order to do this properly, the appropriate thermal properties of the liquid metal have to be determined.

Once the temperature is known, the vapor pressure can be calculated and ultimately the evaporation rate of the front surface is found.[8] The mathematical models[10] and the computer code[8] used are described elsewhere.

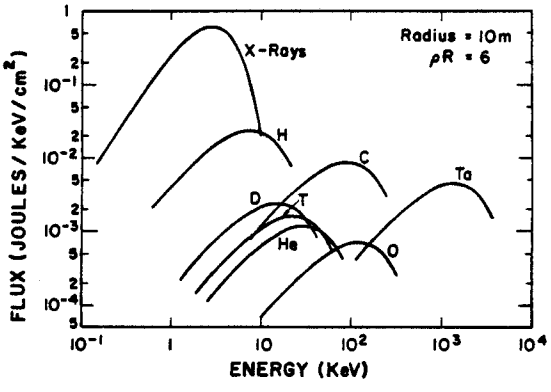

Fig. 2. The spectra of Target 2 (ρR=6).

RESULTS

A) Target 1 debris deposited in Pb.

Using the spectrum given in Table 1 and Figure 1 and considering that the 10 m radius cavity is a complete vacuum, the energy flux to the first wall was calculated. At 10 m there are 0.28 J/cm^2 of X-rays and 4.2 J/cm^2 of particles on the Pb liquid. The particles, in this example, are deposited over a time span of ~ 25 microseconds.

The spatial distribution of the energy deposited by the seven different elements in the example target is shown in Figs. 3 and 4. The latter figure is given without the Ta ions to show in detail the effect of the lighter ions. One can see from Fig. 3 that more than 90% of the energy of the particles is deposited within the first 4000 Å from the surface. All of the X-ray energy is deposited in the first micron of the Pb film.

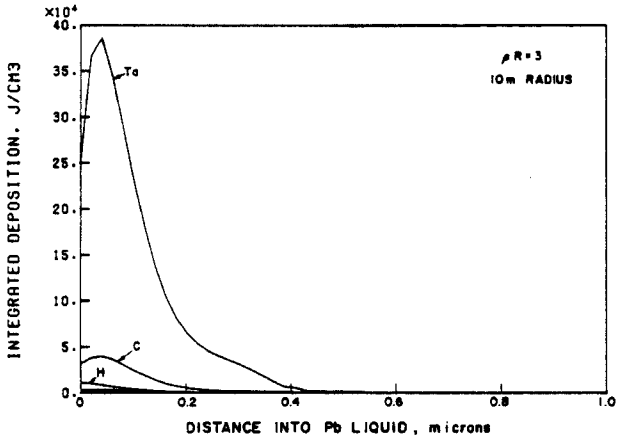

Fig. 3. Total deposited energy in Pb associated with Target 1 (ρR=3).

The energy is deposited so quickly that very little movement ($\lesssim$1 cm) of the vaporized Pb takes place. Also, the X-rays only vaporize 0.4 micron of the Pb film. Finally, the spherical geometry used in this study also means that we need not consider the vapor shielding, as energy deposited in the blowoff vapor on one side of the cavity is reradiated and deposited on the other side and vice versa.[10]

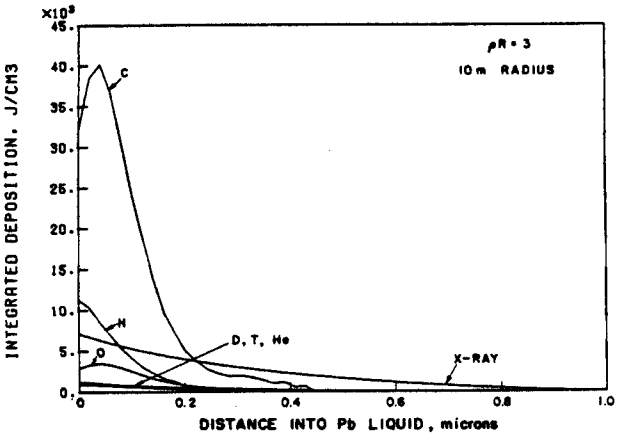

Fig. 4. Deposited energy in Pb associated with Target 1 (ρR=3), excluding Ta.

The surface temperature increase associated with this target debris is also shown in Fig. 5. After a large initial temperature rise from the X-rays, the temperature of the surface returns to near the operating temperature before the ions arrive. Very little Pb is evaporated in the first microsecond and the temperature drop is mainly determined by thermal conduction of the heat back into the liquid Pb film. The ions cause the temperature at the surface to increase again, approaching 2500°K in 5 microseconds. The vapor pressure of Pb at this temperature is approximately 8 atm. It is calculated that 0.9 microns of Pb evaporates in the 30 microseconds before the vapor pressure of the surface drops below 10^{-5} atm. Integrating this over the surface area of a 10 m radius cavity we find that ~ 12 kg of Pb is evaporated per shot.

B) Target 2 debris deposited in Pb.

There are 2.8 J/cm^2 of X-rays and 9.8 J/cm^2 of particles on the Pb liquid in an evacuated cavity of 10 m radius, using the Target 2 spectrum shown in Table 2 and Figure 2. Nearly all of the energy of the particle debris is deposited within the first 2000 Å from the surface. Greater than 90% of the X-ray energy is deposited in the first micron of the Pb film.

The change in surface temperature associated with Target 2 debris is also shown in Fig. 5. After the large temperature rise due to the X-ray energy deposition, the temperature of the Pb surface decays to 1000°K before the ion

debris deposits its energy. The temperature increases to near 4000°K in 6 microseconds. The vapor pressure of Pb at this temperature is >200 atm and consequently significant evaporation takes place. Calculations estimate that 5.8 microns of Pb evaporate before the vapor pressure of the surface drops below 10^{-5} atm. This means that in a 10 m radius cavity ~ 70 kg of Pb is evaporated per shot.

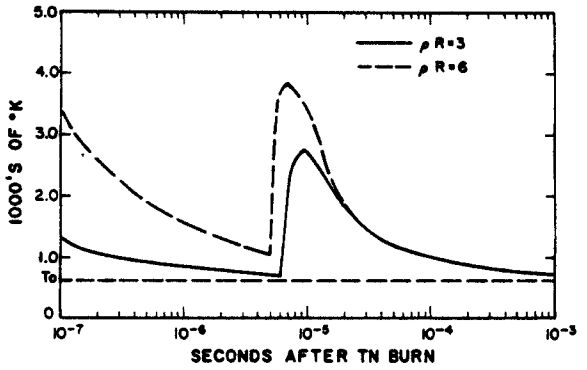

Fig. 5. Temperature response of liquid Pb surface.

C) Targets 1 and 2 debris deposited in Li.

Using the same spectra as for the Pb case, the temperature increase in Li was calculated. The results are shown in Figure 6. The same general features of the temperature increase are found in the Li metal as is evident in the Pb metal film. However, since Li has a small X-ray absorption cross section, there is no significant initial temperature increase. The higher compression target (ρR = 6) caused a higher temperature increase. The amount which was vaporized is 1.1 kg for the ρR = 3 target and 3.6 kg for the ρR = 6 target.

A comparison of the Pb and Li surface temperatures for both targets is shown in Figures 7 and 8. It can be seen that the temperature increase is considerably larger for the Pb compared to the Li, in fact almost a factor of two. This also is reflected in the total amount of material evaporated.

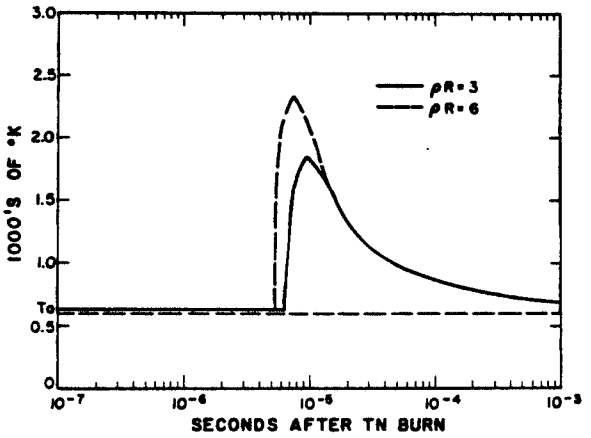

Fig. 6. Temperature response of liquid Li surface.

CONCLUSIONS

A model has been developed to handle complex target spectra and to calculate deposition and temperature increases in liquid metals. Using fairly generic target spectra, it is shown that considerable amounts (10's of kg) of Pb or Li could be evaporated even if the liquid surfaces are as much as 10 meters from the target. The differences in density, thermal properties and vapor pressure as well as the X-ray absorption cross sections reveal that more Pb than Li is evaporated for the sample spectra chosen.

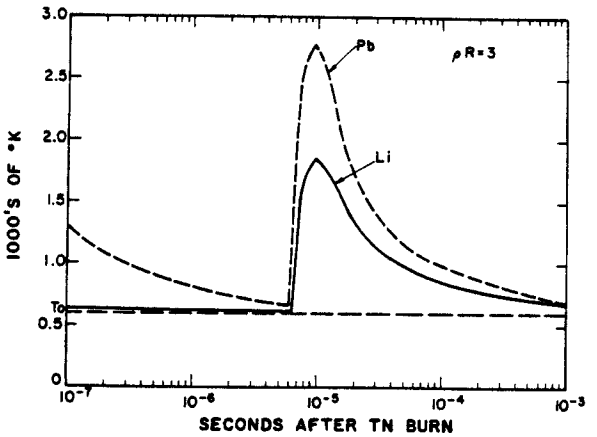

Fig. 7. Temperature response to Target 1 spectra of liquid metal surfaces.

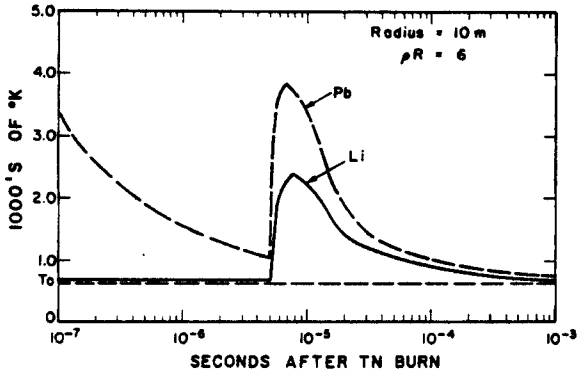

Fig. 8. Temperature response to Target 2 spectra of liquid metal surfaces.

ACKNOWLEDGMENT

The authors wish to thank the University of Wisconsin and the Department of Energy for partial support for this work.

REFERENCES

1. L.A. BOOTH, Los Alamos Report, LA-4858-MS, Vol. 1 (1972).

2. J.H. PENDERGRASS, T.G. FRANK and I.O. BOHACHEVSKY, "A Modified Wetted-Wall Inertial Fusion Reactor Concept," *Proc. 4th Top. Mtg. on Technology of Controlled Nuclear Fusion,* Oct. 14-17, 1980.

3. J. MANISCALCO et al., Lawrence Livermore Laboratory Report, UCRL-52349 (Nov. 1977).

4. B. BADGER et al., "HIBALL - A Conceptual Heavy Ion Beam Driven Fusion Reactor Study," KfK-3204, UWFDM-450, June 1981.

5. E. SUCOV et al., "The Westinghouse ICF Power Plant Study," WFPS-TME-80-014, Oct. 1980.

6. A.M. HASSANEIN and G.L. KULCINSKI, "Effect of Gas Pressure on the Amount of X-ray Energy Absorbed in the First Wall of an ICFR," University of Wisconsin Fusion Engineering Program Report, UWFDM-306, 1979.

7. A.M. HASSANEIN, T.J. MCCARVILLE and G.L. KULCINSKI, *J. Nucl. Materials,* 103 & 104, 327, 1981.

8. A.M. HASSANEIN, "Thermal Effects and Erosion Rates Resulting from Intense Deposition of Energy in Fusion Reactor First Walls," Ph.D. Thesis, University of Wisconsin, 1982.

9. T.O. HUNTER, "A General Model for the Analysis of the Transient Radiation Damage Environment from Pulsed Thermonuclear Radiation," Ph.D. Thesis, University of Wisconsin, 1978.

10. A.M. HASSANEIN, G.L. KULCINSKI and W.G. WOLFER, *J. Nucl. Materials,* 103 & 104, 321, 1981.