Shock Mitigation Studies in Voided Liquids for Fusion Chamber Protection

Mark Anderson[a], Jason Oakley[a], Ed Marriott[a], Jesse Gudmundson[a], Kumar Sridharan[a], Virginia Vigil[a], Gary Rochau[b], Riccardo Bonazza[a]

[a]Fusion Technology Institute, University of Wisconsin-Madison

[b]Sandia National Laboratories, Albuquerque, NM

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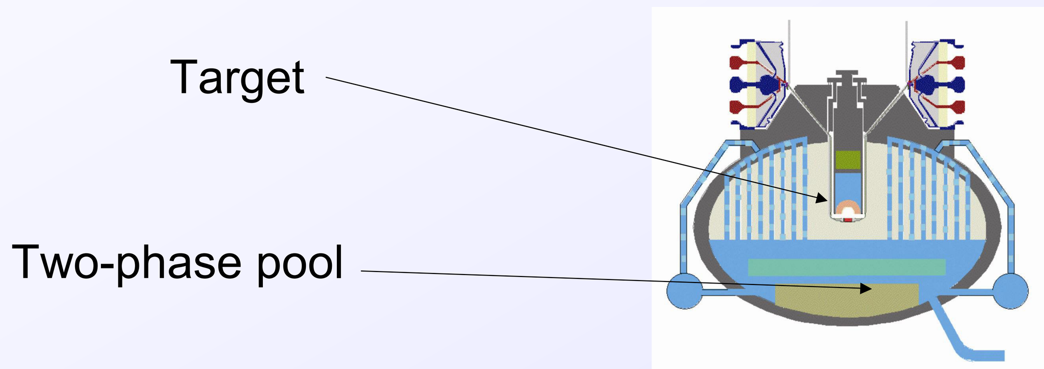
Abstract

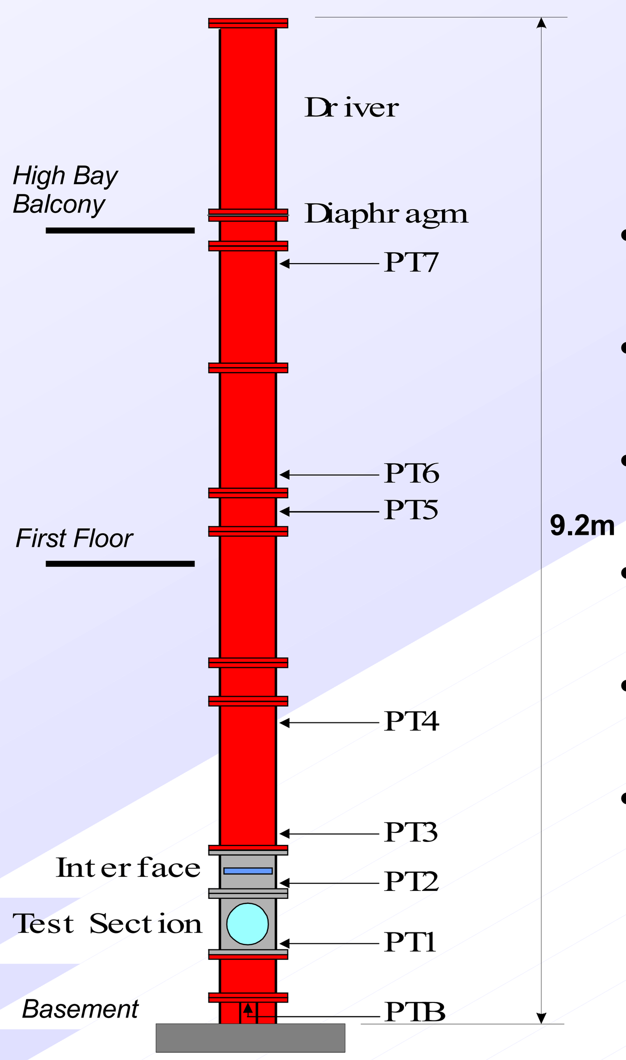
A liquid pool, with and without void fractions, was subjected to dynamic compression testing in a vertical shock tube to model the bubbly-pool concept being considered for use in an inertial fusion energy reactor. Water and oil were used to model the Flibe coolant that collects at the bottom of the chamber and serves as first wall protection at that location. The experiments (shock strengths M=1.4, 2.0, and 3.1) were conducted in atmospheric pressure argon, and argon was bubbled through the liquid to achieve void fractions of 5-15% in the 30.4 cm deep pool. The presence of the gas voids in the liquid had a strong effect on the dynamic pressure loading but did not reduce the shock impulse significantly at the low and intermediate Mach numbers, but did exhibit a mitigating effect at the higher shock strength. Polished stainless steel witness samples, placed at the bottom of the pool, experienced a high degree of surface abrasion/pitting when subjected to the shock loading. A very high void fraction foam was also studied that resulted in a 22% reduction of the shock wave impulse.

Introduction

- Inertial fusion energy (IFE) power plant designs require a shock mitigation strategy, Z-Pinch 3 GJ yield at 0.1 Hz, See Fig. below
- Two-phase fluid shock mitigation strategy
- Reaction chamber at 10-20 mtorr will have chamber gas, argon, bubbled through coolant, Flibe
- Hydrodynamic shock tube experiments to model blast loading, scaled to ICF environment
- Coolant modeled with water and mineral oil using different argon void fractions. High void fraction shaving foam studied.



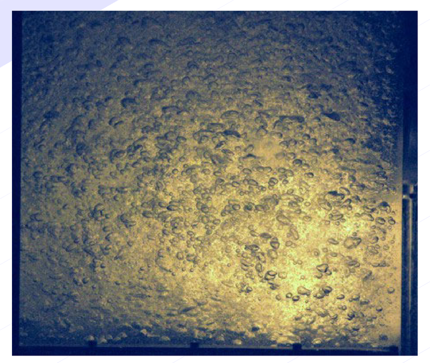
Wisconsin Shock Tube Laboratory



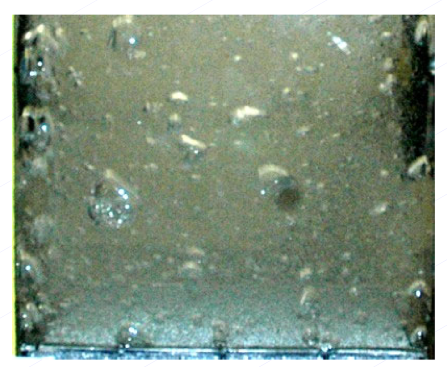
- 9.2 m long, vertical shock tube
- Square internal cross section, 25 x 25 cm
- Up to Mach 5 into atmospheric air
- Bubbly-pool created in lowest section
- Atmospheric argon, M=1.4, 2.0, 3.1
- Pressure measurements at vertical increments of 2.54 cm in the pool

Experiment

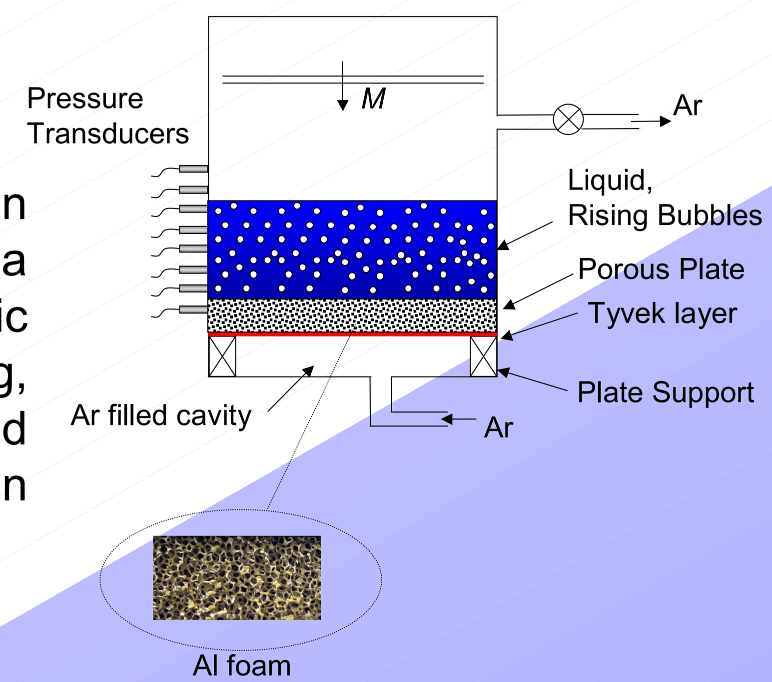
The two-phase pool was created (schematic at right) by bubbling argon up through a open-cell aluminum foam (porosity 0.89) supported by a layer of Tyvek (to prevent cavity from filling with liquid). Atmospheric pressure was maintained in the volume above the pool by venting, which was ceased just prior to the rupture of the diaphragm. Void fractions as high as 15% argon were created using this technique in both water and mineral oil (see images above).



Water with 15% Ar
Uniform bubbles D≈0.5 cm

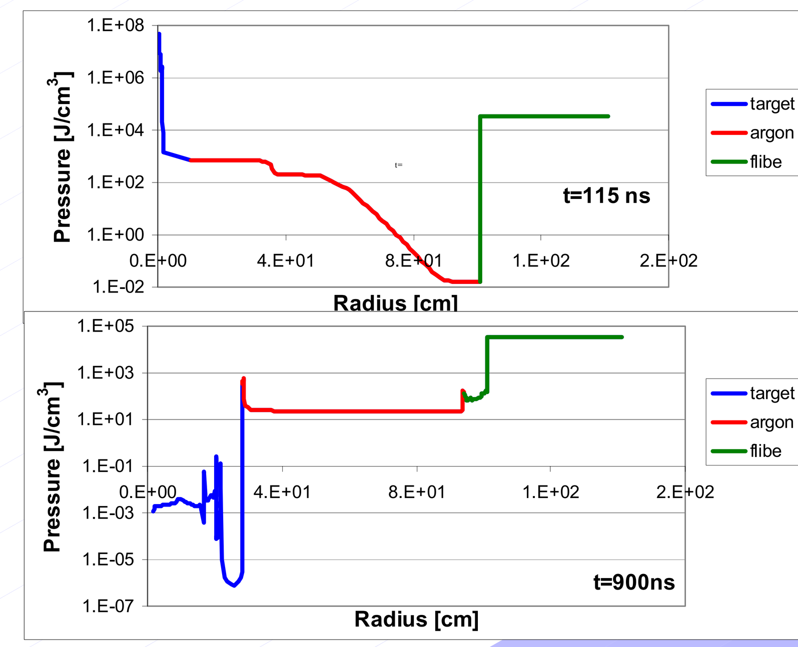


Mineral oil with 15% Ar
Bimodal bubble distribution
D_1<0.2 cm, 1.5<D_2<3 cm



Scaling with ICF

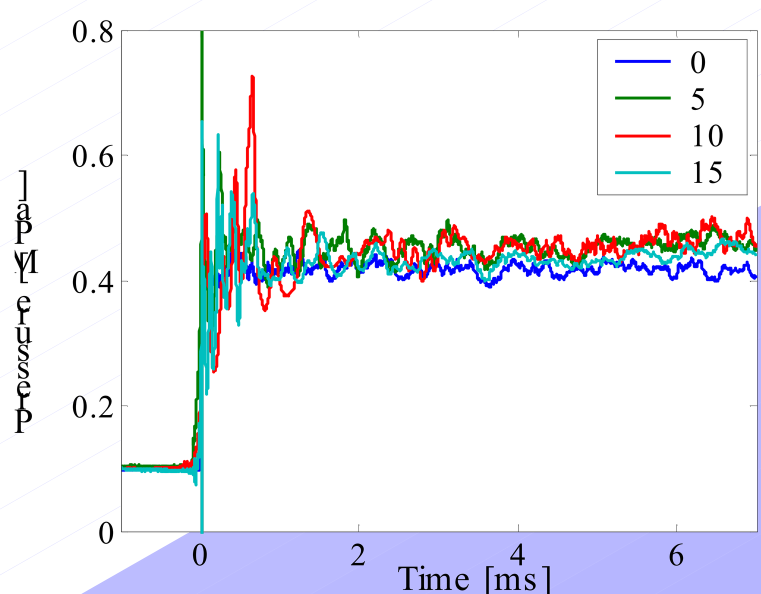
The pressure traces (right) are from a 1D Bucky radiation-hydrodynamics simulation for a 3 GJ target yield with an initial argon gas pressure of 12 mtorr. The contact pressure for the blast wave with the Flibe is 1 MPa (just after t=115 ns) and the reflected wave off the Flibe is 23 MPa. This compares with a pressure load from a shock tube experiment, M=2.85 in argon, of 1 MPa contact, but 4.2 MPa reflected. Thus, the pressure loading for the shock tube hydrodynamic experiments are on the same order as in the ICF reactor.

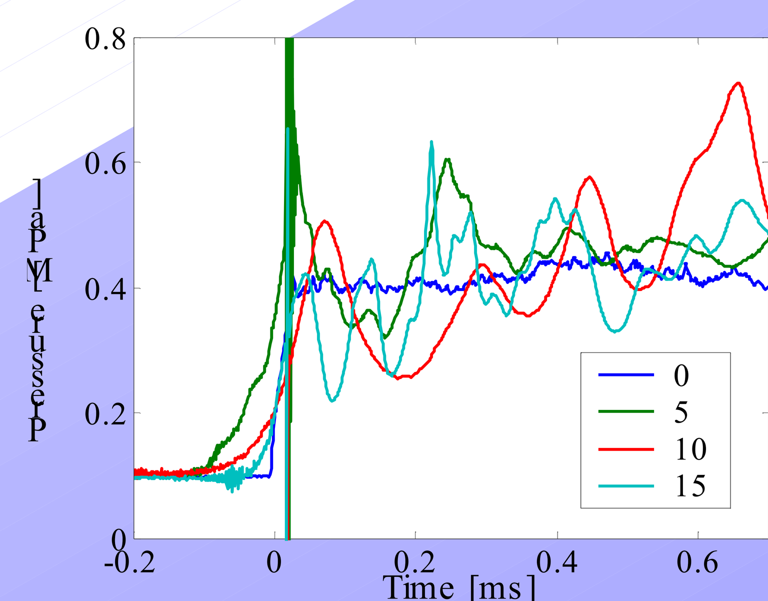


Bubbly-pool Results

The two pressure trace plots (below) show the late and early time behavior for void fractions of 5, 10, and 15% for a M=1.4 shock wave in water. The late-time behavior is similar to the 1D gasdynamics prediction while the early time shows oscillations due to the gas voids. The impulse results for water (table) show little difference at the low and medium Mach numbers, but a significant reduction is measured for M=3.1.

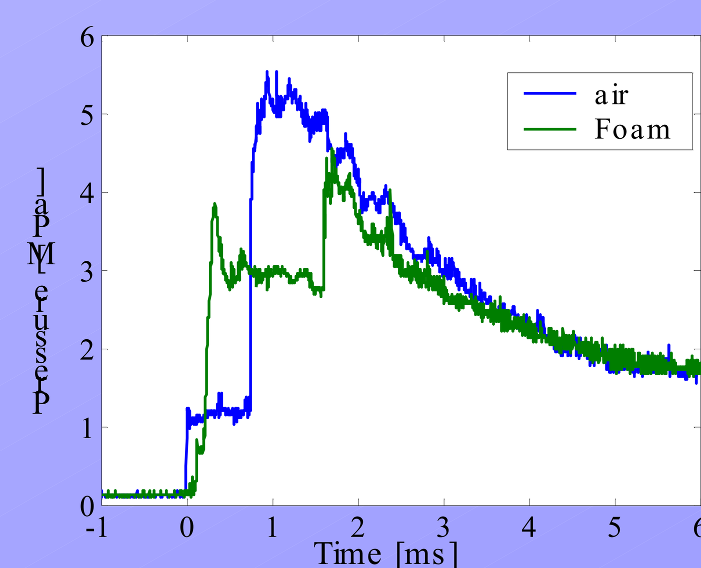
M	I_0 [N s]	I_5 [N s]	I_{10} [N s]	I_{15} [N s]	t_1 [ms]
1.4	13.2	14.9	14.5	13.1	0.67
2.0	40.3	39.8	38.2	41.7	0.47
3.1	82.0	-	-	72.0	0.31





High Void Fraction Foam

A shaving cream foam with a void fraction of 94% had a significant reducing effect on the pressure load (right) and effectively reduced the impulse from 441 N-s to 344 N-s for a time window of 2 ms.



Corrosion Studies, SEM Analysis

- Polished stainless steel material samples
- M=3.1 0% and 15% void fraction
- Surface oxidation particles were concentrated in pitted regions
- The presence of gas bubbles did not exacerbate the observed corrosion/erosion.

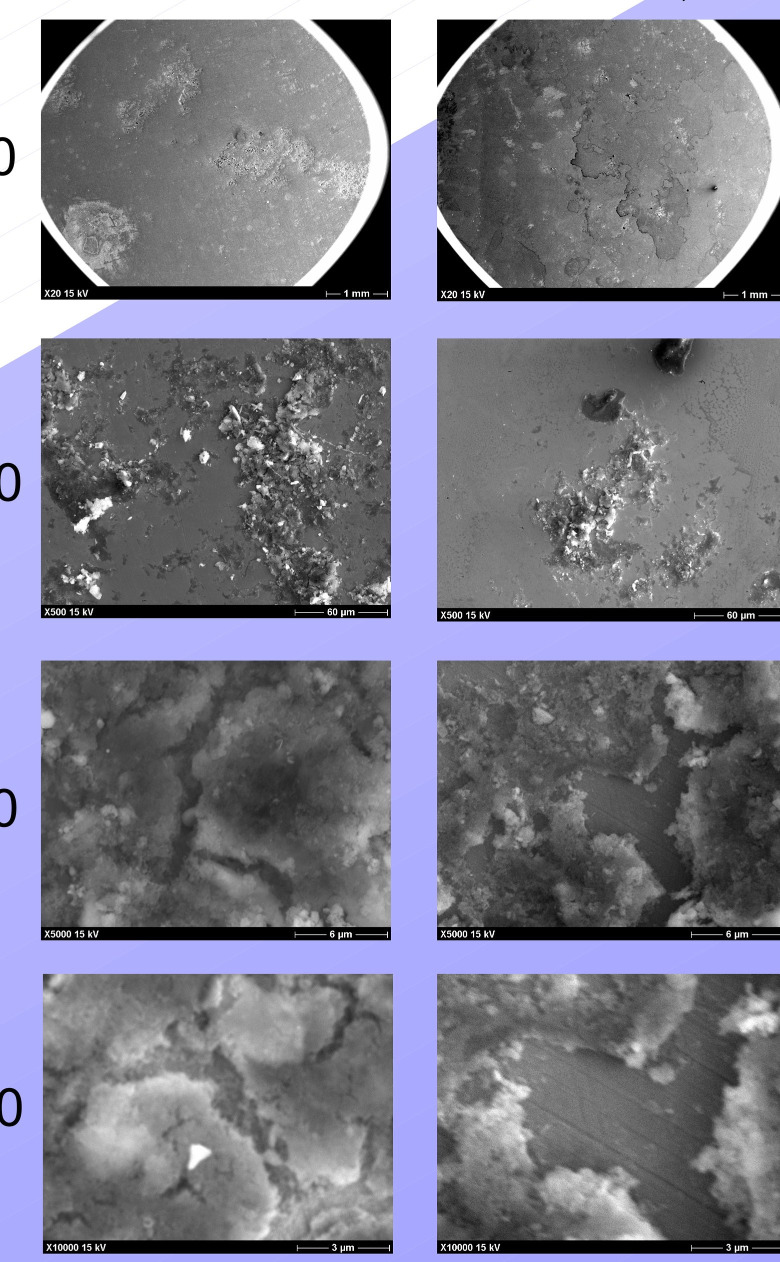
100% Water | 85% Water, 15% Ar

Mag. X20

Mag. X500

Mag. X5,000

Mag. X10,000



Conclusions

The shocked bubbly-pool experiments exhibited different behavior in the pressure traces, although the average pressure load did not change much. A noticeable impulse reduction was observed for the high Mach number experiments. High void-fraction experiments showed the greatest reduction in impulse (22%). The corrosion/erosion of a wetted surface, enhanced by being repeatedly exposed to shock waves, will need to be a consideration for first-wall material selection.

Acknowledgements

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