SAN097-1750 C
SAND--97-1750C

Dynamic Hohlraum Experiments on SATURN*

CONF-970503--195

T.J. Nash, M.S. Derzon, G. Allshouse, C. Deeney, J.F. Seaman, J. McGurn, D. Jobe, T. Gilliland
Sandia National Laboratory

J.J. MacFarlane and P. Wang
U. Wisconsin

D.L. Petersen
Los Alamos National Laboratory

RECEIVED
JUL 30 1997
OSTI

Abstract

We have imploded a 17.5 mm diameter 120-tungsten-wire array weighing 450 μg/cm onto a 4 mm diameter silicon aerogel foam weighing 650 μg/cm, using the pulsed power driver SATURN. A peak current of 7.0 MA drives a 48 ns implosion to strike time followed by 8 ns of foam compression until stagnation. The tungsten strikes the foam with a 50 cm/μs implosion velocity. Radiation temperatures were measured from the side and along the axis with filtered x-ray diode arrays. There is evidence of radiation trapping by the optically thick tungsten from crystal spectroscopy. The pinch is open to less than a 1 mm diameter as measured by time-resolved x-ray framing cameras. The radiation brightness temperature in the foam reaches 150 eV before the main radiation burst or stagnation.

Introduction

In the concept of the dynamic hohlraum an imploding z-pinch has sufficient mass that it is optically thick to the radiation inside the pinch. The concept is also known by the names flying radiation case(1), imploding liner hohlraum (1a) and double liners (2). The purpose of the dynamic hohlraum is to reach radiation temperatures sufficient to drive ICF capsules and to perform experiments relevant to ICF and high energy density physics.

The dynamic hohlraum temperature scales very favorably with machine current because the pinch mass scales as the current squared and increased pinch mass provides opacity. Also the radiated power from a pinch scales as the square of the current. The scaling of mass and power with current indicate that dynamic hohlraum temperatures will scale more rapidly than the square root of the current. It is important to provide measurements of the radiation temperature on different machines, such as ANGARA (3.5 MA), SATURN (7MA), and PBFAZ (18 MA), to establish the scaling with current. In this paper we present the measurements of dynamic hohlraum radiation temperature on SATURN and discuss the scaling issues.

SATURN is a 20 TW electrical pulsed power machine. (3) It drives up to 10 MA of current into a z-pinch load with a 50 ns rise time. For efficiently radiating z-pinches the load current rises to only 7.0 MA because of pinch inductance.

Recent advances in the stabilization of z-pinches have made possible the demonstration of dynamic hohlraum radiation temperatures well in excess of 100 eV presented in this paper. These advances include the improved radiated power and stability from using large-wire-number arrays (4), and the demonstration of 80 TW of radiation from the accelerator SATURN using a 120-tungsten-wire array (5). The performance of a wire array as a radiator without an inner liner is an indication of its performance with an inner liner. For this reason we used the large-wire-number tungsten array as the outer liner driver for the dynamic hohlraum experiments on SATURN.

Improved stability increases the radiation temperature of a dynamic hohlraum by increasing radiated power and decreasing hohlraum area. Since the radiation temperature goes as the radiated power divided by hohlraum area, increased stability can greatly increase dynamic hohlraum radiation temperature.

Experimental Design

The outer liner is a 120-tungsten-wire array on a 17.5 mm diameter weighing 450 μg/cm. The inner liner is solid cylindrical aerogel foam 4 mm in diameter weighing 650 μg/cm. Both are 2 cm long.

The load current is measured by B-dot monitors placed in the anode plate 4 cm from the pinch axis. The implosion time is measured by the time difference between the current rise and rise of the x-ray pulse as measured by a four channel x-ray diode array.

The x-ray diodes use carbon photocathodes. Four energy cuts are provided by four different filters: 4 μm of kimfol, 1.9 μm of titanium, 2 μm of chromium, and 8 μm of beryllium. The energy cuts of the above filters are at 250, 400, 500, and 800 eV. Two sets of the four-channel x-ray diode arrays are fielded, one views the pinch from the side to record temperatures outside of the outer liner, the other views the pinch from the axis to measure temperatures inside the foam.

For the x-ray diode arrays to measure radiation brightness temperatures the surface area of the imploding pinch must also be measured. The diameter of the pinch as a function of time is measured by two time-resolved pinhole cameras. One is filtered with 5.5 μm of lexan to record emissions in the carbon window at 250 eV. The other is filtered with 8 μm of beryllium to record images of emissions above 800 eV. Both instruments were fielded from the side and both used gated microchannel plates to provide sequential time-resolved images.

A bolometer is fielded from the side of the pinch to measure to total radiated yield. This signal is usually too noisy to be differentiated to give the time history of the total radiated power. A representative x-ray diode channel, typically the kimfol channel at 250 eV, can be integrated in time and normalized to the bolometer yield, to give an estimate of the time-history of the total radiated power.

A time-integrated radially-resolved crystal spectrometer measures the continuum of tungsten emission above 900 eV. It is capable of recording silicon K-shell radiation from the silicon in the aerogel, and can therefore provide information on the optical trapping of the silicon K lines by the tungsten outer liner.

Experimental Results

Figure 1 shows traces of the load current and radiated power versus time for SATURN shot 2261. Peak current is 7 MA and radiated power at stagnation is 54 TW. The power trace has a linear foot before stagnation due to the compression of the foam. Peak radiation temperatures for a dynamic hohlraum are taken at the end of the linear foot just before the inflection point leading to peak power at stagnation. The time from current rise to the striking of the foam is about 48 ns and the time from strike to stagnation is 8 ns.

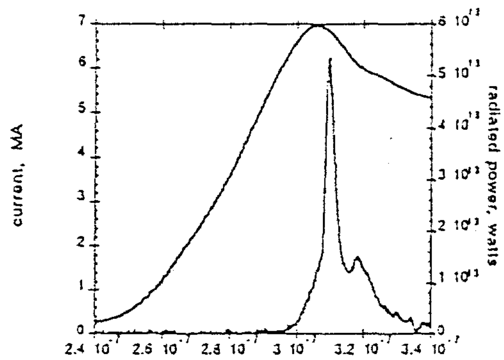

Figure 1. Load current and Radiated Power for SATURN shot 2261

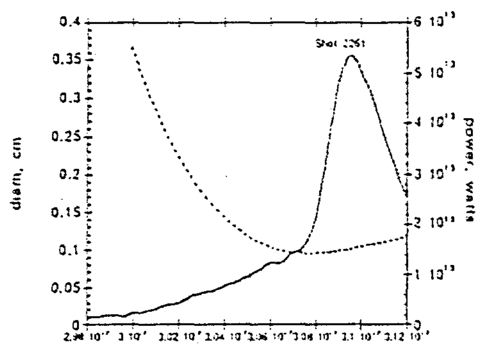

Figure 2. Increasing Power and Decreasing diameter show the concept of the dynamic hohlraum.

In figure 2 we present the same radiated power of figure 1 blown up to show the linear foot and main stagnation burst in more detail. Also plotted in a quadratic fit to the pinch diameter using discrete points from the time-resolved pinhole cameras. With the fit we can produce a continuous time history of the radiation temperatures from the x-ray diodes.

It is worth mentioning that the FWHM of the radiation pulse in shot 2261 is a very sharp 2.5 ns. The fwhm of radiation with the outer tungsten driver alone is 4 ns. (5)

In figure 3 we present the brightness temperatures from each of the x-ray diode channels for both the side-on and axial views. The two soft channels at 250 and 400 eV show temperatures inside the foam significantly greater than the surface temperature outside the foam. This is likely due to the opacity of the tungsten. The data indicate internal temperatures in these channels exceeding 150 eV before compression of the foam is terminated at stagnation. This upper time limit is 307.5 ns on the scale of figure 3. Less trapping is shown in the 500 eV channel and none at all in the 1 keV channel.

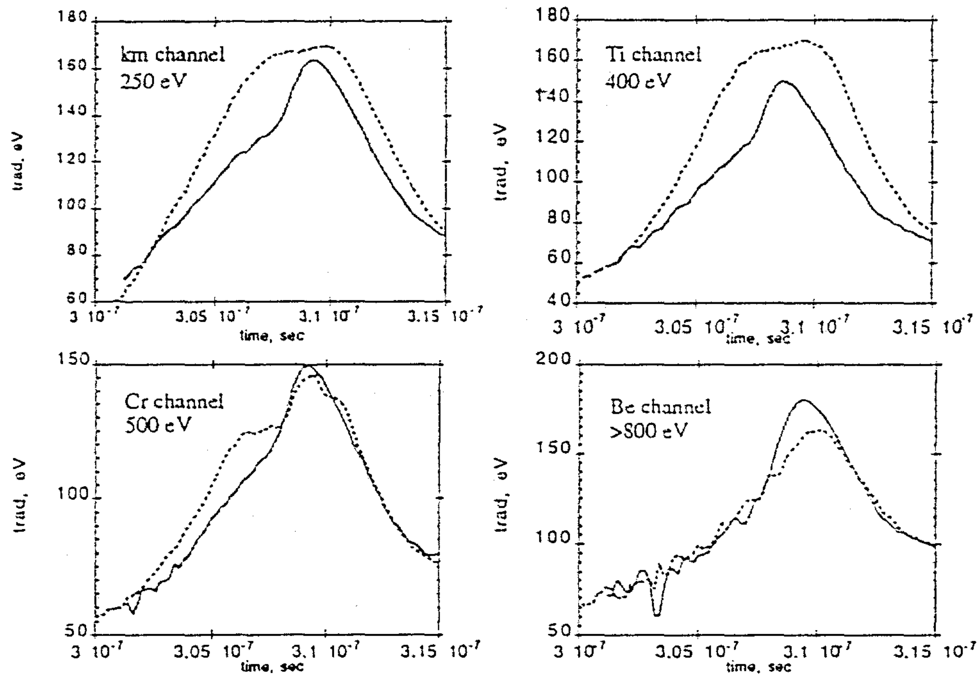

Figure 3. The lower energy XRD channels show radiation temperatures inside the foam exceeding 150 eV before stagnation. Dashed curves are temperatures inside the foam from an axial view. Solid curves are temperatures on the outside of the tungsten from a side view.

The internal radiation temperature, exceeding 150 eV before compression, should scale to temperatures above 200 eV on PBFAZ. Such temperatures are adequate to consider driving ICF capsules. Besides adequate temperature, other issues for driving ICF capsules include stability and symmetry. These issues will be studied on PBFAZ. Rayleigh-Taylor (RT) is the most deleterious instability(6). The large format time-resolved pinhole camera has recorded images with the wavelength of the RT instability during the compression of the foam.

In figure 4 we present the timing gates of frames 4 and 5 of the large format camera with respect to the radiated power trace. Frame 5 is the last frame recorded before stagnation.

In figure 5 we present radial line-outs of the pinch averaged over all z for time frames 4 and 5. One observes the increasing radiation with the increasing foam compression. It is worth noting that the diameter measured from frame 5, 700 μm, actually falls below the value from the quadratic fit, 1 mm, used in the radiation temperature measurements. The large format camera also gives a foam-compression velocity of 25 cm/μs.

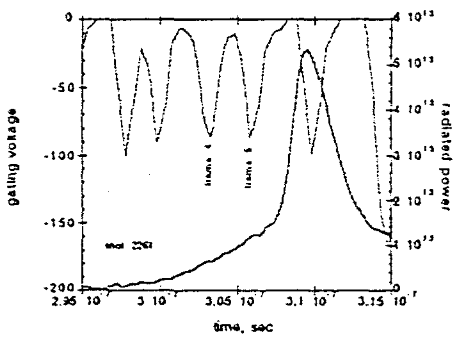

Figure 4. Timing gates of large format pinhole camera with respect to power pulse. Frames 4 and 5 are gated during the compression of the foam.

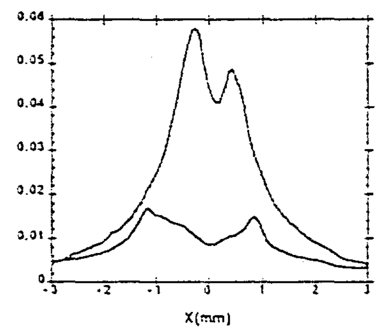

Figure 5. Horizontal line-outs of large format camera frames 4 and 5. The line-outs show increasing radiation with increasing foam compression.

In figure 6 we present axial line-outs of the pinch averaged over 300 μm in radius at the current sheath for SATURN shot 2261. During frame 5 the RT instability is quite evident with a wavelength of about 400 μm. This instability is the limiting factor in creating a uniform radiation cavity. The RT instability in figure 6 is likely too severe to be useful in driving an ICF capsule. For the dynamic hohlraum to be useful for ICF near the end of the time of foam compression the RT instability must be mitigated. The RT instability may be more severe on PBFAZ than SATURN because the implosion times of 100 ns on PBFAZ are twice as long as the implosion times on SATURN, and this necessitates larger diameter loads.

There is reason to believe that the instability can be overcome from the data of figure 7 which compares the RT of SATURN shot 2261 to that of ANGARA shot 30 taken during US/Russia collaborative experiments in 1993. Both shots had similar strike velocities and foam compression times. For the shot the gating pulse is 1 ns before stagnation. The ANGARA implosion used a xenon gas puff as the outer liner and an annular agar foam doped with molybdenum as the inner liner. The reduced RT of the ANGARA shot may be due to the use an annular foam or due to snow-plow stabilization of the outer liner implosion (7).

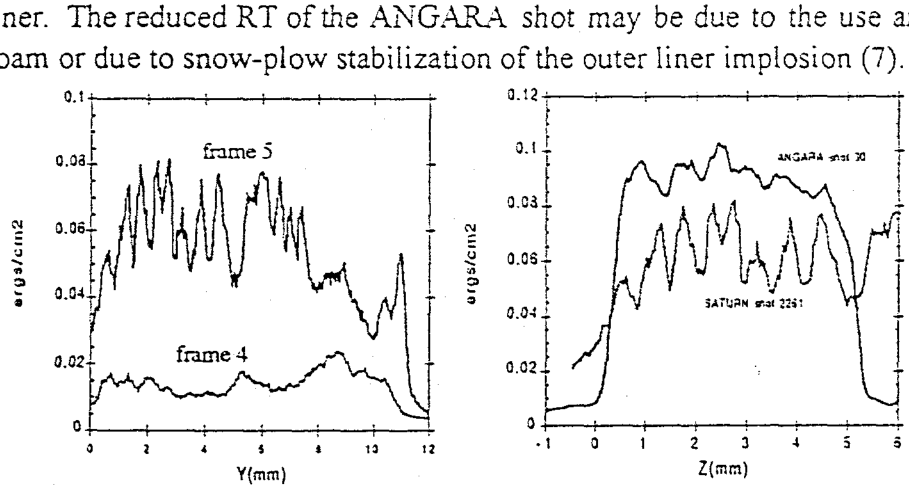

Figure 6. Vertical line-outs along z over 300 μm in radius reveal the growth of Rayleigh-Taylor instability as the foam is compressed.

Figure 7. The annular target of ANGARA shot 30 shows less Rayleigh-Taylor instability than the solid foam of SATURN shot 2261.

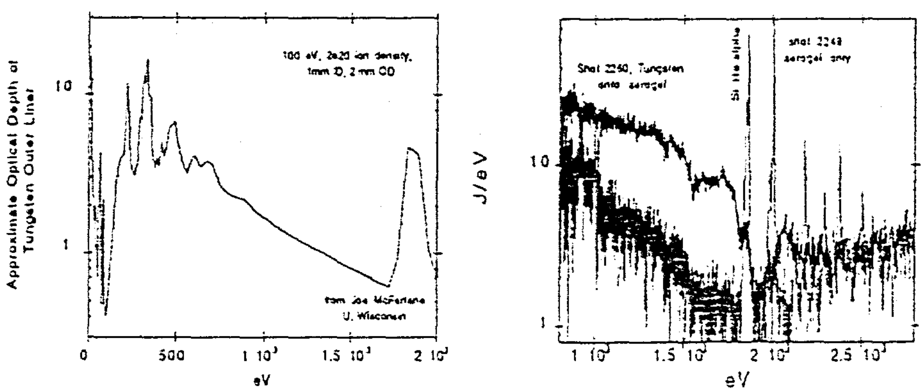

Figure 8. The optical depth of the tungsten should provide some trapping of radiation in the foam.

Figure 9. A time-integrated crystal spectrometer shows that the tungsten is trapping silicon K radiation. The two shots depicted are with and without the tungsten wire array.

An advantageous feature of the dynamic hohlraum z-pinch is that the outer liner will trap radiation inside the foam provided the RT instability does not make it leaky. An estimate of the optical depth of the tungsten for SATURN shot 2261 is shown in figure 8. (8) The trace indicates that significant trapping will occur for energies below 1 keV. This computational prediction is born out by the x-ray diode traces of figure 3 which show radiation trapping in all but the 1 keV channel.

In figure 9 we show data from the time-integrated crystal spectrometer which indicates trapping of silicon K line radiation. This would be due to the tungsten M shell absorption feature at 1.9 keV in figure 8. Figure 9 compares the crystal spectra above 900 eV for SATURN shot 2260 (identical to shot 2261), and

SATURN shot 2249, a shot with only aerogel and no tungsten. Shot 2249 emits silicon K line radiation, while the dynamic hohlraum shot 2260 does not, even at stagnation. Either the tungsten is trapping the silicon K line radiation or the electron temperatures in the dynamic hohlraum are never hot enough (200 eV) to excite the silicon K line radiation.

Radiation temperatures inside dynamic hohlraums have the potential for scaling greater than the square root of the machine current due to the benefit of optical trapping of the internal radiation. This benefit of trapping is predicted to be evident in dynamic hohlraum experiments to be performed on PBFAZ, an 18 MA driver. In figure 10 we compare the predictions of the optical depth of the tungsten for SATURN and PBFAZ.(8) The optical depth will increase as the square of the current. This is in addition the current-squared scaling of radiated power due to the machine power itself.

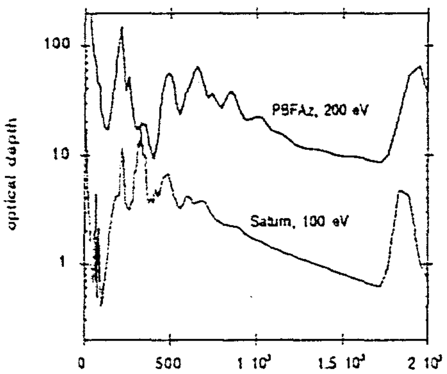

Figure 10. The increased mass loading of the machine PBFAz should provide better trapping of radiation in the foam with respect to the smaller machine SATURN.

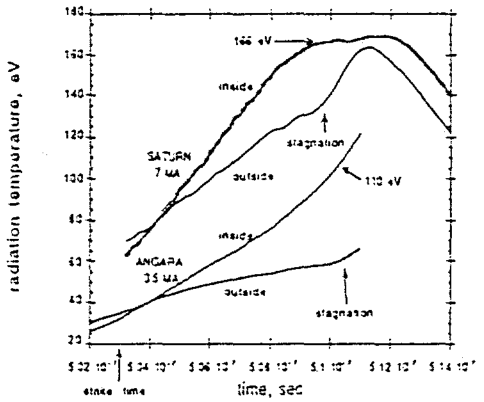

Figure 11. Comparison of radiation temperature on ANGARA and SATURN shows favorable scaling with machine current.

With regard to scaling of dynamic hohlraum temperature with machine current we show inside and outside radiation temperature time histories for SATURN shot 2261 and ANGARA shot 30 in figure 11. Both machines provide similar strike velocities and foam compression times. The peak radiation temperatures before stagnation show scaling slightly greater than the square root of the current. This is to be expected as the mass driven by SATURN is transitional between an optically thin and optically thick radiation case.

Conclusion

We have imploded a 17.5 mm diameter 120-tungsten-wire array weighing 450 μg/cm onto a 4 mm diameter silicon aerogel foam weighing 650 μg/cm, using the pulsed power driver SATURN. Measurements using x-ray diodes and time-resolved pinhole cameras indicate that the radiation temperature inside the foam exceeds 150 eV before stagnation. The narrow 2.5 ns fwhm of the stagnation radiation pulse indicates excellent pinch stability. Stability increases dynamic hohlraum temperature in three ways: increased radiated power, decreased hohlraum area, and increased radiation trapping. Radiation temperature may scale more rapidly than the square root of the current due to optical trapping. Presently Rayleigh-Taylor instability is the limiting factor in achieving high temperature in dynamic hohlraums.

*Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under Contract DE-AC04-94AL85000.

References

1. R. Bauers and J. Brownell, private communication
1a. T. Hussey and K. Matzen, private communication
2. V. P. Smirnov, Plasma Physics and Controlled Fusion, 33, #13, 1697, (1991)
3. R. B. Spielman, M.K. Matzen, M.A. Palmer, P.B. Rand, T.W. Hussey, and D.H. McDaniel, Appl. Phys. Lett., 47, 229, (1985).
4. T.W.L. Sanford, T.J. Nash, B.M. Marder, R.C. Mock, M.R. Douglas, R.B. Spielman, J.F. Seaman, J.S. McGurn, D.O. Jobe, T.L. Gilliland, M.F. Vargas, R. Humphreys, K.W. Struve, W.A. Stygar, J.H. Hammer, J.H. DeGroot, J.S. Eddleman, K.G. Whitney, J.W. Thornhill, P.E. Pulsifer, J.P. Apruzese, D. Mosher, Y. Maron, Proc. oth the 11th Confg. on High Power Particle Beams, ed. P. Sunka, K. Jungwrith and J. Ullschmied, Prague, June, (1996), paper O-4-2.
5. C. Deeney, T.J. Nash, R.B. Spielman, J.F. Seaman, G. Chandler, K.W. Struve, J.L. Porter, W.A. Stygar, J.S. McGurn, D.O. Jobe, T.L. Gilliland, J.A. Torres, M.F. Vargas, L.E. Ruggles, S. Breeze, R.C. Mock, M.R. Douglas, D. Fehl, D.H. McDaniel, and M.K. Matzen, submitted to Phys. Rev. E., (1996).
6. D.L. Petersen, R.L. Bowers, J.H. Brownell, A. E. Greene, K.D. McLenithan, T.A. Oliphant, N.F. Roderick, and A.J. Scannapieco, Phus. Plasmas 3 (1), P. 368, January 1996
7. Alexander Velikovich, F.L. Cochran, and J. Davis, Phys. Rev. Lett., 77 (5), p. 853, July 29, 1996
8. Joe MacFarlane, U. Wisconsin, private communication

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.