

SPECTRAL OUTPUT OF Z-MACHINE IMPLOSIONS

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Abstract

Sandia National Laboratories Z-machine has developed into a reproducible, high power (>200 TW), high temperature (>200 eV) driver for radiation physics experiments.

Imploding cylindrical wire arrays on the Z-machine produce a radiation source with a bolometric temperature of about 200 eV. By surrounding the z-pinch implosion with a vacuum hohlraum a nearly Planckian source of about 140 eV temperature is created with peak radiation powers of about 200 terawatts and integrated energy of 2 megajoules or more. In this energy rich environment we can field a dozen experiments all being driven by an identical source.

In addition to 'standard' vacuum hohlraums we also use dynamic hohlraums consisting of two nested wire arrays converging onto an axially centered foam cylinder. Radiation flowing from the ends on the cylinder indicates a Planckian source temperature well over 200 eV. Only two experiments can be fielded on a dynamic hohlraum (one on each end) but the higher source temperature justifies the added complexity of the set-up.

We routinely use arrays of filtered silicon photodiodes (SiD) and filtered photocathode x-ray diodes (XRD) to determine the temperature of the source.

Three different techniques for unfolding spectra from the XRD and SiD detector data are being used. They are: 1) Treat each detector independently and find the Planckian temperature for a given source size and solid angle that would give the measured detector signal, 2) Use all detector signals and detector spectral responses simultaneously and find a spectrum that best fits the observed data, 3) Use all detector signals and averaged detector spectral responses and find a histogram spectrum that best fits the observed data. When used as complementary set of analysis tools these techniques generate remarkably consistent results showing nearly Planckian behavior on our vacuum hohlraum experiments.

I. THE Z-MACHINE

Sandia National Laboratories Z-machine pulsed power facility [1] consists of 36 Marx modules driving 36 pulse-forming lines which converge onto magnetically insulated transmission lines connected to a cylindrical wire array. The Marx generators are charged to 90 kV and when fired dump a 5 MV pulse into the pulse forming lines. The pulse lines convert the 1.2 microsecond, 15 TW Marx pulses into 100 nanosecond, 45 TW electrical pulses and synchronize the pulses to arrive simultaneously at the wire array target. In our vacuum hohlraum source the target consists of 300 ten-micron diameter tungsten wires symmetrically arranged in a 20 mm diameter cylinder 1 cm high. The converging electrical pulses reach a peak current of 20 MA in the wire array which then implodes radially due to the $\mathbf{J} \times \mathbf{B}$ forces on the vaporized wires. When the wire plasma converges on axis the kinetic energy is converted to heat producing temperatures of about 200 eV. The 11.4 MJ of stored electrical energy in the Marx modules is converted to about 2 MJ of radiation with peak radiation power in the 200 TW range [2].

II. VACUUM HOHLRAUM SOURCE

Surrounding the 20 mm wire array is a 24 mm diameter gold plated stainless-steel hohlraum can that absorbs the wire array pinch radiation and then re-emits it in a nearly Planckian spectrum with a temperature around 140 eV. A two dimensional radiation magnetohydrodynamic calculation of a wire implosion implosion inside a gold hohlraum is shown in figure 1. Diagnostic holes in the can wall are viewed with arrays of well-characterized x-ray filtered silicon photodiodes (SiD) [3] and carbon cathode photoemissive X-Ray Diodes (XRD) [4].

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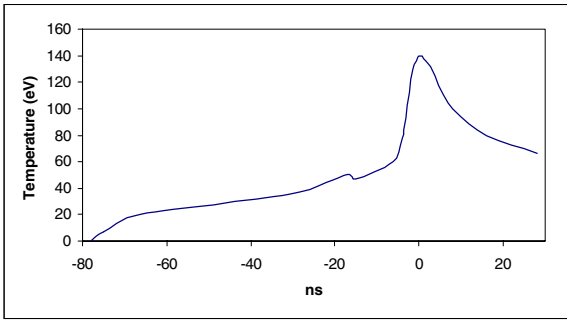


Figure 1. 2-D calculation of Z-hohlraum

A. Planckian Table Unfold

By folding the calibrated detector x-ray spectral response with the source-detector geometry and calculated Planckian spectra and then integrating the result a table of Planckian source temperature versus detector signal output can be generated.

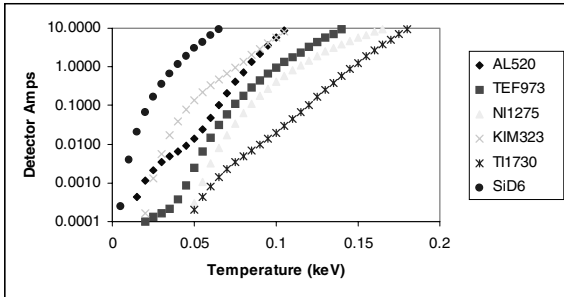


Figure 2. Planckian table

Using this table the time versus detector signal data measured from a shot can be converted into time versus Planckian temperature data. This method assumes a single temperature Planckian source, a known source size, and the same source size for all measured photon energies. If any of the assumptions fail then detectors with overlapping responses will give inconsistent temperatures. In that case more sophisticated techniques must be used which assume only the same source size for all photon energies and unfold a spectrum by iterating a best fit spectrum to the overlapping detector responses [5]. Figure 3 shows a simple Planckian table unfold of 6 SiD's viewing a 2.4-mm diameter hole in the hohlraum wall. The hole was positioned so the detectors view the inside wall of the hohlraum and avoid seeing the z-pinch centered in the hohlraum. The SiD detectors were filtered to observe the low temperature initiation of the wires all the way through the implosion phase until the high temperature stagnation on axis. Filter materials and thickness were chosen to provide well spaced and overlapping detectors covering the temperature range from 10 eV to 150 eV. At peak power only the most heavily filtered detectors are not in saturation. This can

be problematic as the peak provides a timing fiducial to cross check system timing.

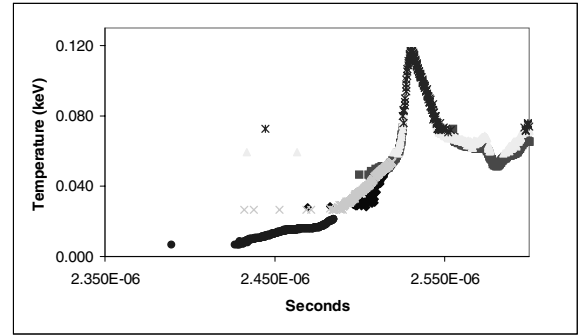


Figure 3. Planckian table unfold of vacuum hohlraum.

The early time high temperature outliers are due to signals just above background noise levels on heavily filtered high energy channels. The signal hanging at 60eV after the peak is caused by detector and digitizer saturation recovery. Our unfolded Planckian data shows a peak temperature of about 120 eV which is only about half the power of the calculated temperature of 140 eV. The viewing aperture being heated at early time and closing off the effective viewing area causes this difference. Measured and calculated hole closure [6] at peak power show a decrease in effective aperture size by a factor of two. A powerful feature of this Planckian table unfold technique is the crosscheck on the detector and recording timebase. If the unfolded temperature curves match well in shape but appear shifted in time then it is a good bet there was an error in recording setup. Examination of the raw data or unfolded spectra from the detectors does not reveal these problems as clearly as this table unfold technique.

B. Spectral Unfold

If the x-ray source spectral shape is unknown then signals from multiple detectors with differing photon responses must be used to determine the spectrum. Because the problem is underdetermined the fitting codes have implicit assumptions built into them. Our code, SHAMPC, assumes: 1) The spectrum is smooth, 2) Negative intensity is not allowed, 3) Source size is constant for all photon energies. The code operates by first scaling an initial guess spectrum to roughly fit the total source power. Then adjusting each spectral bin depending on the measured detector signals and the detector response in that bin. Because the adjusting procedure tends to distort the spectrum at points of discontinuous response a three-point running average smoothing is applied to the adjusted spectrum and then the adjustment process is repeated until the calculated spectrum best fits the measured detector signals.

C. Histogram Unfold

Another method [5] to reduce the underdetermined spectrum problem is to coarsely bin the spectrum and use average detector responses in each bin. By choosing the bin boundaries at the filter absorption edges the discontinuity problems can be avoided. Typically four or five bins representing four or five independent detectors are used and the unfold problem then reduces to a set of linearly independent equations. Direct matrix inversion then yields the spectral output within the bins. A comparison between a SHAMPC unfold a histogram unfold shows reasonable agreement between the two techniques.

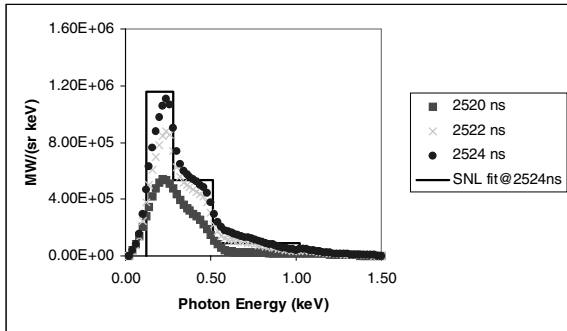


Figure 5. Histogram and full spectral unfolds

Note the 'wrinkles' in the SHAMPC unfold correspond to the filter absorption edge bin boundaries. The 'wrinkles' illustrate the difficulty the unfold code has at discontinuities in the response functions.

D. Source Reproducibility

An important characteristic of a pulsed power machine is the amount of variation in source performance from shot to shot. Figure 6 shows an overlay of source performance from four separate shots. Other than occasional nanosecond shifts in the peak time the pulse shapes and amplitudes are identical.

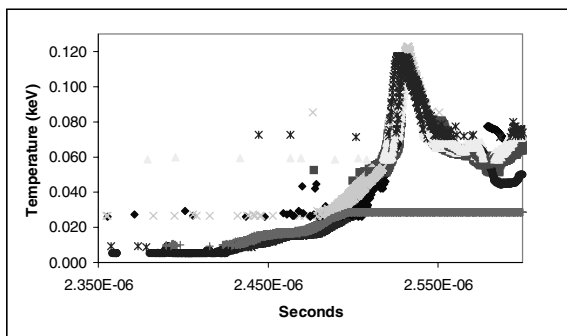


Figure 6. Vacuum hohlraum reproducibility

The remarkable reproducibility is a credit to the high quality of the engineering design and operation of the Z-facility.

III. DYNAMIC HOHLRAUM

To achieve higher source temperatures the dynamic hohlraum concept is used. In the dynamic hohlraum source a 1 cm tall cylindrical array 40 mm diameter, 240 x 7.5 micron tungsten wire is imploded onto a 20 mm diameter, 120 x 7.5 micron tungsten wire array. The collided arrays then implode onto a 5 mm diameter, 14 mg/cc TPX plastic foam cylinder. The tungsten shell surrounding the foam traps the radiation inside the foam and compresses the assembly. Evidence of the efficiency of the radiation trapping is shown in figure 7. The x-ray detectors looking down the axis of the foam cylinder (thin line) see the radiation power peak about 1.5 ns before the radiation emitted from the side of the cylinder.

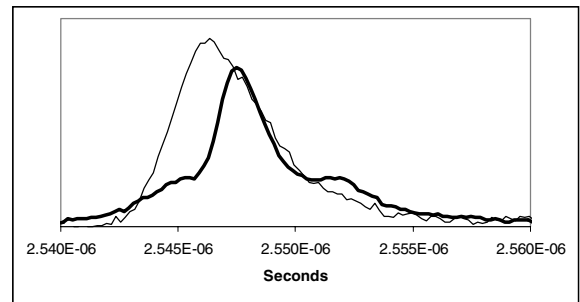


Figure 7. Axial and side x-ray output

An added feature of the dynamic hohlraum source is absence of a radiation foot seen in the vacuum hohlraum source. SiD arrays viewing on axis show can see a source as cool as a few eV. Figure 8 shows no evidence of preheat in the foam. Lack of preheat eliminates hole closure problems. This also allows experiments to be directly coupled to the dynamic hohlraum without the need for a sacrificial burn-through foil [7] to protect the experiment from being damaged before the desired main radiation pulse arrives.

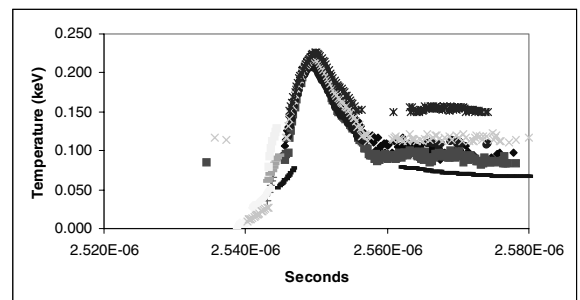


Figure 8. Planckian table unfold of dynamic hohlraum.

V. SUMMARY

The Z-machine provides a fast pulsed high temperature source for radiation flow experiments.

The vacuum hohlraum source has excellent reproducibility with an almost Planckian spectrum with peak temperature of about 140 eV. In addition the relatively large 20 mm diameter Z-machine vacuum hohlraum allows multiple experiments to be fielded simultaneously all driven by an identical source thereby eliminating the often difficult corrections to results obtained from multiple shots with a single experiment.

The dynamic hohlraum provides a higher temperature nearly Planckian radiation source without the bothersome preheat foot pulse. Work is ongoing to characterize the dynamic hohlraum source for up/down axial symmetry and reproducibility.

VI. REFERENCES

- [1] R. B. Spielman, et al., "Pulsed Power Performance of PBFA-Z," in Proc. of the 11th IEEE International Pulsed Power Conference, 1997, pp.709-714
- [2] R. B. Spielman, et al., "Tungsten wire-array Z-pinch experiments at 200 TW and 2 MJ," *Physics of Plasmas*, vol. 5, (no. 5), pp. 2105-2111, May 1998
- [3] G. C. Idzorek and R. J. Bartlett, "Silicon Photodiode Characterization from 1 eV to 10 keV," in *Proc. of SPIE*, Vol. 3114, 1997, pp. 349-356
- [4] G. A. Chandler, et al., "Filtered x-ray diode diagnostics fielded on the Z accelerator for source power measurements," *Rev. Sci. Instrum.* Vol. 70, pp. 561-565, Jan. 1999
- [5] D. L. Fehl, et al., "Time-dependent, x-ray spectral unfolds and brightness temperatures for intense Li⁺ ion beam-driven hohlraums," *Rev. Sci. Instrum.* Vol. 68, pp. 843-846, Jan. 1997
- [6] R. E. Chrien, et al., "Measurement and simulation of apertures on Z hohlraums," *Rev. Sci. Instrum.* Vol. 70, pp. 557-560, Jan. 1999
- [7] G.C. Idzorek, et. al., "Radiation Experiments on the Z-machine," in Proc. of the 12th IEEE International Pulsed Power Conference, 1999, pp.1060-1062