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# Spectral Analysis of Al/$MgF_2$ Foils Heated by Z-pinch Radiation

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## Abstract

Sandia National Laboratories' Z machine provides a good test bed for conducting basic plasma research on the interaction of x-rays with matter. In particular, recent experiments have been conducted that irradiate thin Al/$MgF_2$ metal foils by the radiation pulse from the side-on emission of a fast z-pinch. In these experiments, time-resolved and time-integrated spectra of K-shell absorption lines, backlit by the high-energy tail of the z-pinch radiation, are the primary diagnostic of the foil plasma conditions. The experiments are simulated by 1-D radiation-hydrodynamics calculations using a time- and frequency-dependent radiation boundary condition determined by 3-D view factor simulations of the z-pinch diode region. The calculated plasma conditions are then utilized in a detailed configuration accounting model of the atomic level populations to determine the relative amplitude of absorption features over the spectral range of interest. These calculations, and their comparison to the experimental data, will be presented and discussed.

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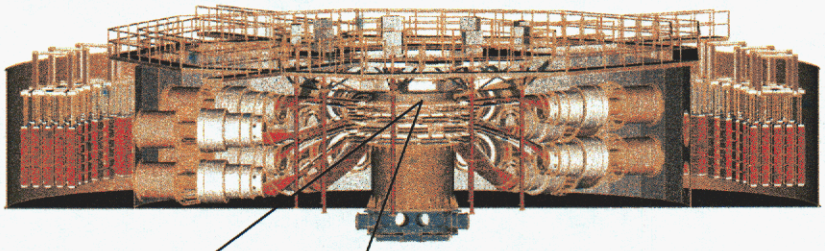
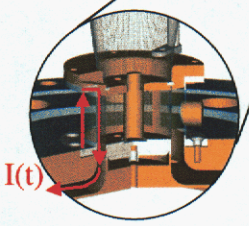
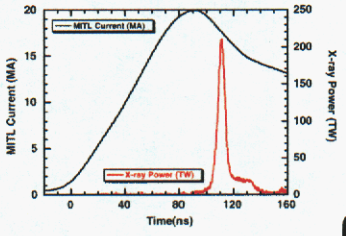
## Sandia's Z machine provides a test-bed for basic science experiments on the interaction of x-rays with matter.






Z-pinch current/power profiles*




*R. B. Spielman et. al., Plasma Phys. Control. Fusion, **42**, p. B157 (2000).

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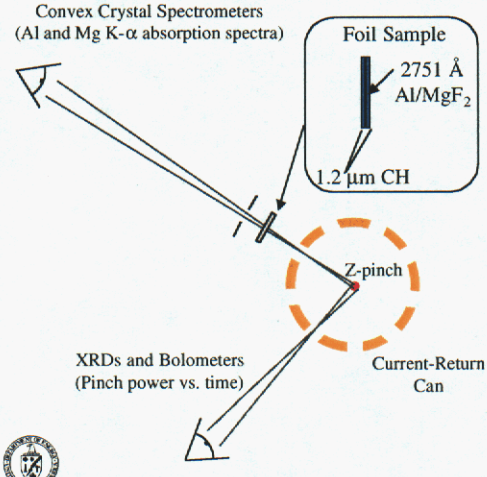
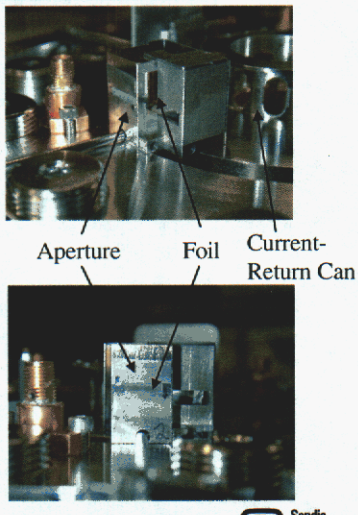
## A planar $Al/MgF_2$ foil was fielded on Z shot 597 to investigate the radiative heating of a heterogeneous plasma.

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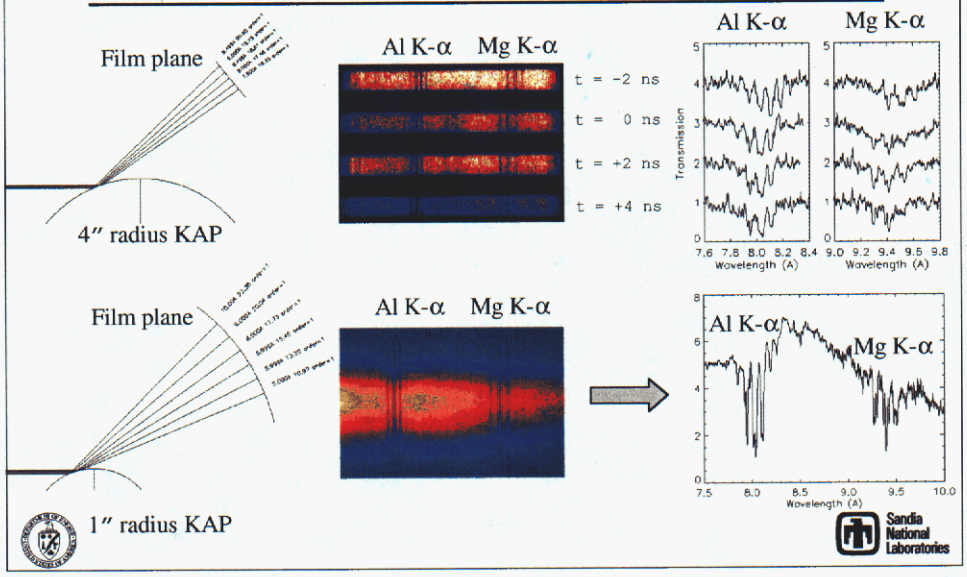
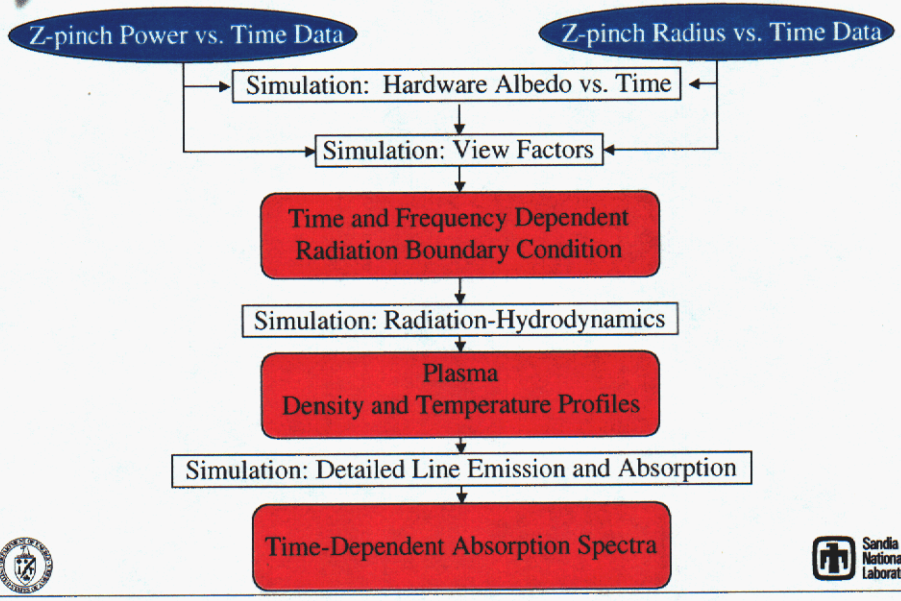
Time-resolved and time-integrated convex crystal spectrometers measured Al and Mg K-α transitions in absorption.

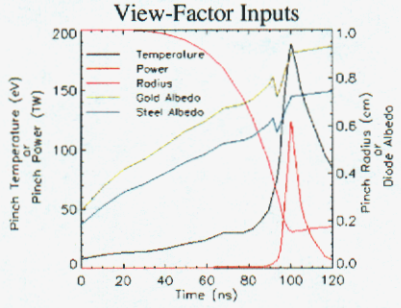



Calculating the plasma conditions in the $Al/MgF_2$ foil requires coupling together a number of simulations

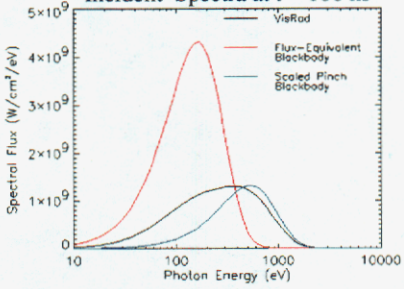


3-D simulations using the VISRAD view-factor code are utilized to calculate time-dependent, non-thermal drive spectra on the sample surface.

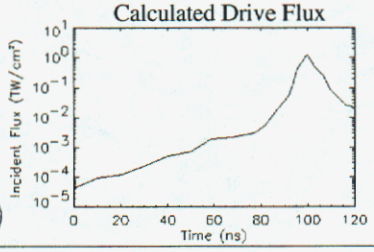
View-Factor Inputs



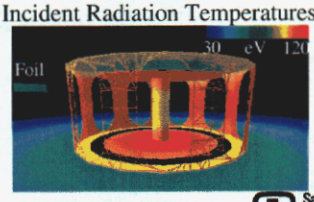

Incident Spectra at t = 100 ns




Calculated Drive Flux




Incident Radiation Temperatures

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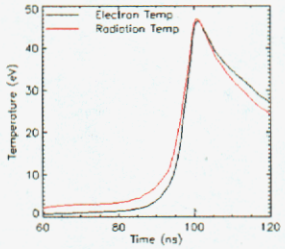
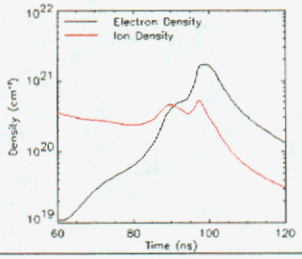
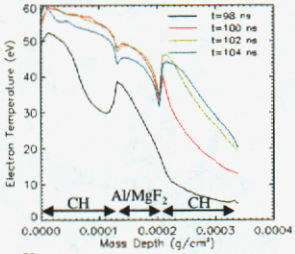
1-D simulations using the BUCKY radiation-hydrodynamics code are utilized to calculate the plasma temperature and density evolution.

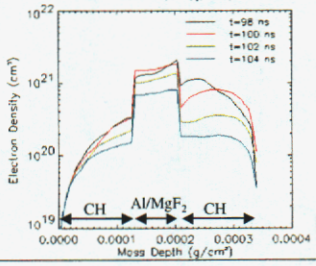
Average Conditions In the Al/$MgF_2$ Plasma




Spatial Profiles of the Calculated Plasma Conditions

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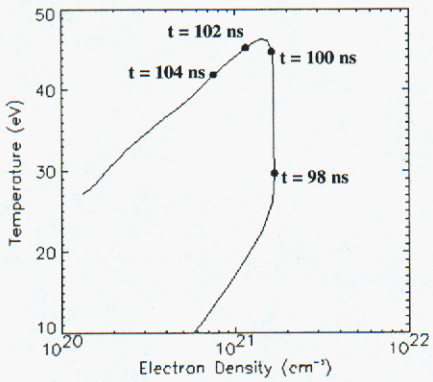
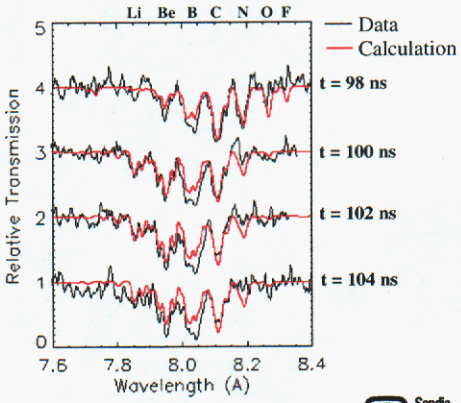
SPECT3D calculations of the atomic level populations under the calculated plasma conditions yields good agreement between the computations and the experimental data.

Average Calculated Al/$MgF_2$ Plasma Conditions




Calculated vs. Measured Aluminum K-α Spectra

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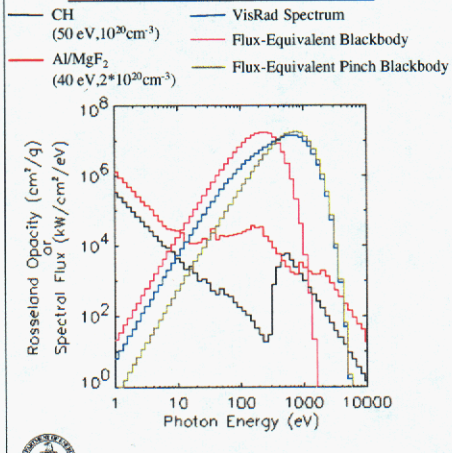
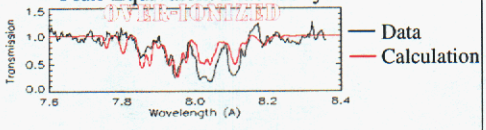
Opacity Structure in the 100 eV to 1000 eV photon energy range makes the plasma conditions in the Al/$MgF_2$ layer sensitive to the incident spectra.

Incident Radiation Spectra at Peak Power

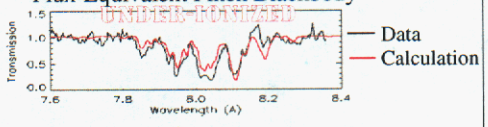



Comparison of Al K-α Absorption at Peak Power Under Different Drive Spectra

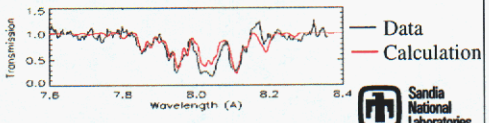
Flux-Equivalent Blackbody




Flux-Equivalent Pinch Blackbody




VisRad Non-Thermal Spectrum

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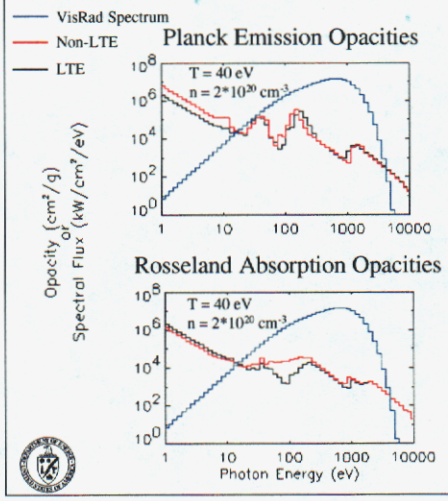
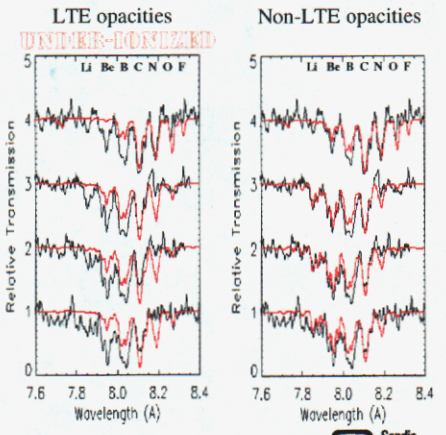
The calculated plasma conditions
are also sensitive to non-LTE opacity effects
requiring a detailed calculation of atomic transition rate coefficients.

Comparison between LTE and non-LTE absorption and emission opacities




Comparison of Time-Dependent Al K-α Absorption

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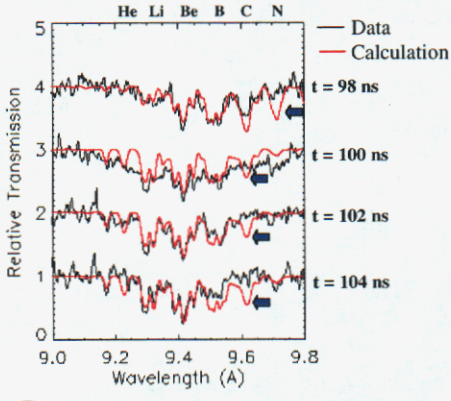
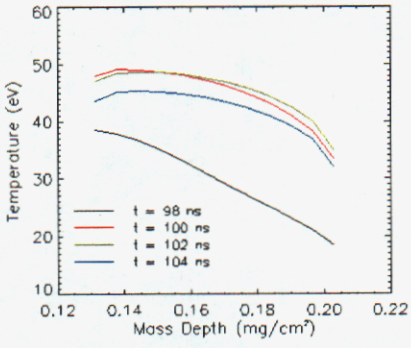
Calculated Mg K-α spectra are also in fair
agreement with experimental data, but indicate that the
calculations may contain too large of a temperature gradient.

Calculated vs. Measured Magnesium K-α Spectra




Calculated Temperature Profiles in the Al/$MgF_2$ Layer

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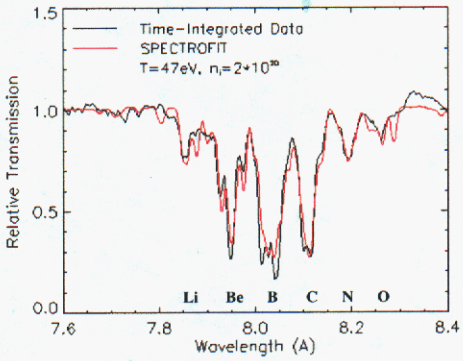
In addition to the time-dependent analysis, the time-integrated data can be analyzed by an automatic chi-squared fitting program called SPECTROFIT.

## SPECTROFIT

- Reads detailed line-opacity tables generated by the JATBASE code
  - LTE and Non-LTE opacities
  - Arbitrary plasma mixtures
- Compares two relative transmission absorption spectra (i.e. experiment vs. calculation) at discrete temperatures and densities.
- Computes chi-squared fit parameter for a user-defined grid resolution over a specified temperature and density range.
- Reports fit-variance, $\chi^2$, and $+1\sigma$

Comparison between time-integrated Al K-α data and the SPECTROFIT best fit for $n_i = 2*10^{20}$ cm$^{-3}$.

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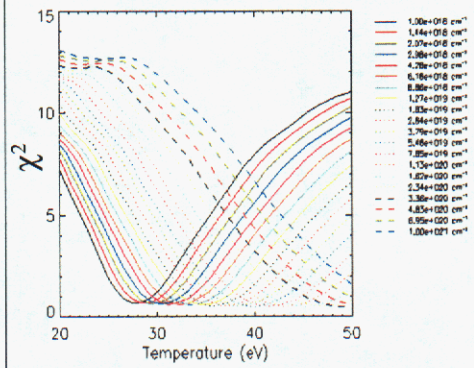
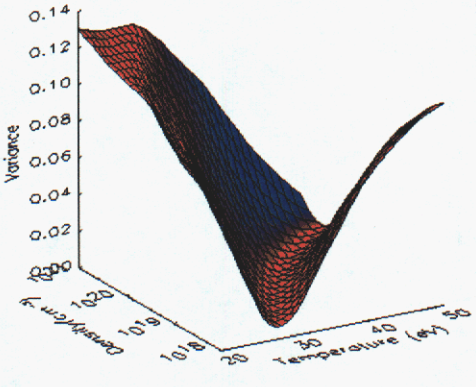
The SPECTROFIT $\chi^2$ and fit-variance curves show the contour in temperature-density phase space where the calculated spectra best match the data.

$\chi^2$ plots at discrete densities for the comparison between time-integrated data and the calculated Al K-α spectra




Fit variance over the searched T-ρ phase space

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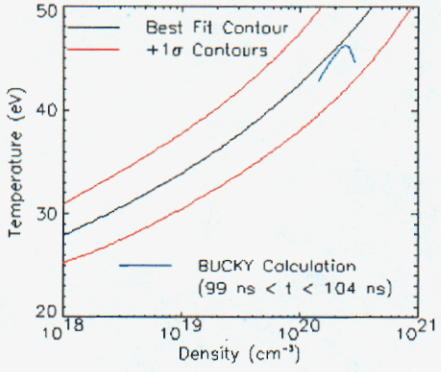
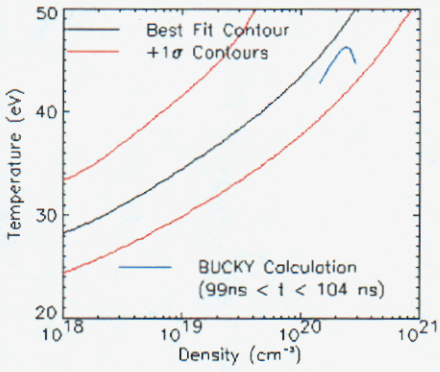
Plotting the SPECTROFIT results of the time-integrated K-α data versus the BUCKY calculated average Al/$MgF_2$ conditions during the peak of the x-ray pulse shows relatively good agreement.

Aluminum K-α Fits




Magnesium K-α Fits

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## Summary

- Time-resolved and time-integrated data of Aluminum and Magnesium K-α absorption lines were measured in an Al/$MgF_2$ foil irradiated by z-pinch radiation on Sandia's Z machine.
- The data has been successfully analyzed and computationally reproduced by coupling together simulations of the radiation drive spectra, the sample radiation hydrodynamics, and detailed configuration analysis of atomic energy level transitions.
- Calculating the proper distribution of ionization states (and therefore the plasma temperature and density conditions) requires detailed consideration of the time-dependent non-thermal drive spectra and a thorough calculation of the atomic transition rate coefficients in non-LTE multi-group opacities.
- A new $\chi^2$ spectral fitting code called SPECTROFIT has been applied to the time-integrated K-α absorption data and shows the aluminum and magnesium to be in near-equilibrium, and in good agreement with peak plasma conditions in 1-D BUCKY radiation-hydrodynamics calculations.

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