Development of X-ray Tracer Diagnostics for Radiatively-Driven Copper-Doped Beryllium Ablators

NLUF FY1999 Report

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Introduction and Scientific Background

This report covers the fiscal year 1999 portion of our ongoing project to develop tracer spectral diagnostics of ablator conditions in the hohlraum radiation environment. The overall goal of the experimental campaign is to measure the turn-on times of K_α absorption features from tracers buried in planar witness plates. The tracers are thin and at a specific, known depth in the witness plates so that the turn-on times are indicators of the arrival of the Marshak wave at the specified depths. Ultimately, we intend to compare the delay in the turn-on times of the tracer signals between doped and undoped ablator materials, and thus study the effect of ablator dopants on the Marshak wave velocity. During FY 1999, our primary goal was to simply measure an absorption signal, matching tracer depth to drive temperature and testing the overall feasibility of our experimental scheme.

In indirect-drive inertial confinement fusion (ICF) energy is deposited rapidly on the outside of a spherical capsule, ablating the outer layers of the capsule and compressing the interior. If this process is carefully controlled, then hydrogen fuel at the center of the capsule can be compressed and heated such that fusion reactions may proceed[1,2]. The efficiency of the compression depends crucially on the time-dependent energy deposition onto the ablator material on the outside of the capsule. The nature of this coupling can be controlled through the use of ablator dopants, which modify the density and opacity of the ablator layer[3]. Clearly, it is crucial to the success of indirect-drive ICF to have a means for testing the effects of ablator dopants, and more generally for having a diagnostic that is capable of determining time-dependent ablator properties.

To this end, we are adapting tracer spectroscopy techniques to make time-dependent measurements of the ionization state of planar ablator materials mounted on the sides of hohlraums. Specifically, we are doing backlighter point-projection spectroscopy of K_α features from tracers placed in the interiors of planar witness plates made of ablator materials. As the radiation wave, or Marshak wave, diffuses into the ablator material it drives a shock ahead of it. When the shock arrives at a given point in the witness plate it heats the tracer to roughly 20 eV. Soon after, the radiation wave arrives, heating the tracer to well above 100 eV nearly instantaneously. Thus, the "turn-on" of tracer absorption from high ionization states is an indicator that the radiation wave has arrived at the tracer. Furthermore, the time-dependent ionization balance in the tracer is, our simulations show, indicative of the efficiency with which the radiation field couples to the ablator material. Note that this technique holds out the possibility of making a determination of the instantaneous impact of the radiation field on the ablator physics, as opposed to something like a shock breakout measurement, in which the observed signal reflects the *integrated* time-history of the impact of the radiation field on the ablator.

The ablator dopants have the effect of slowing the radiation wave (both because of the increased opacity and the increased density). So the tracer K_α absorption turn-on time is expected to be delayed by the dopant, and in addition, the ionization balance will be skewed toward higher stages by the ablator dopant. By measuring the tracer absorption signal from two samples—one doped and one undoped—we can measure the effects of the dopant on the radiation wave properties. In Figures 1 and 2 we show hydrodynamical simulations comparing the response of two different ablators to the same radiation field and the type of time-dependent spectra we expect to obtain in such an experiment.

Backlit absorption spectroscopy has been used successfully in many types of experiments[45]. It has the advantage that, because it does not rely on self-emission it can be used to diagnose relatively cold plasmas. And because we are looking at K_α features, all of an element's ionization states are visible in one small portion of the spectrum.

Experimental Planning

To implement the tracer absorption technique, we developed an experimental set-up that has a science package mounted on the barrel of a stretched scale-1 hohlraum at the midplane. A backlighter foil was attached to a wire and hung off of the side of the hohlraum. The foil was hit with several tightly focused beams in order to generate a hot spot or spots to serve as a backlighter(s). The resulting backlighter x-ray photons propagated through a hole drilled on the side of the hohlraum, through the witness plate(s), and on to a TIM-mounted spectrometer where the tracer absorption signal was recorded on a streak camera.

The primary science package consisted of two plastic witness plates, one doped with germanium and one undoped. Planar witness plates are used to simplify the geometry of the experiments. In addition, 1 ns square pulses were used for all experiments, for the purpose of simplifying the modeling and isolating the relevant physics. One witness plate had a chlorine tracer and the other had a potassium tracer. In this way, a single time-dependent spectrum can be recorded, and the chlorine signal can be assumed to arise in one witness plate and the potassium signal in the other. The motivation for this side-by-side witness plate scheme was to remove the uncertainty of shot-to-shot variations. In other words, both witness plates see the same drive, and so any differences in tracer spectral response can be assumed to reflect the differences in the ablator physics.

In order to record the two spectra in one instrument, we have designed and built a new spectrometer (the LXS) which can accommodate two separate flat crystals. Each crystal is sensitive the spectral range of the K_α lines of one of the tracers. In these experiments, we used an ADP crystal and a PET crystal. The photons from both crystals illuminate a single photocathode, with the resultant microchannel plate signal recorded on a streak camera.

Finally, we intended to cross check the effects of the ablator dopants, and acquire additional data to constrain our modeling, by making shock breakout measurements from similar side-by-side witness plate pairs. These witness plates did not, however, have tracers, but rather were wedge shaped to facilitate a time-dependent shock breakout measurement.

The fiscal year 1999 experiments described in this report were a continuation of an experimental campaign begun in fiscal year 1998. The 1998 campaign did not produce a measureable tracer absorption signal. We identified several possible reasons for this. The most likely candidate for the failure of the previous year's experiments was a mismatch between the tracer depths and the drive temperature. The tracers depths were optimized for a hotter drive than that which we actually achieved. The lower than expected drive temperatures were likely due to the fact that the beam pointings were farther toward the LEHs than is usual. This was done purposely to keep the laser hot-spots away from the witness plates mounted at the hohlraum midplane. Other possible causes of the lack of an absorption signal in 1998 are: degradation of tracer layers in the witness plates; target manufacture or alignment problems; contamination by gold emission from inside the hohlraum; and cross-talk between the signals from the two different backlighter/crystal pairs.

The goals for the fiscal year 1999 campaign (the subject of this report) were modified after the proposal had been accepted, based on the negative results from the 1998 experiments (as was detailed in a letter sent to John Soures on 27 April 1999). Rather than moving on to beryllium ablators as we had originally proposed, we kept working with plastic ablators and instead concentrated on making sure that our experimental scheme was workable.

To this end, in March 1999 we shot targets that had tracer layers buried in planar plastic witness plates, but only at depths of 1 or 2 microns. This was intended to verify that the lack of signal seen the previous year was indeed due to the tracers being too deep for the drive temperatures. We also planned on further refining our understanding of the hohlraum drive based on DANTE data collected during this day of shots. We also tested bismuth, rather than thorium, as a backlighter for potassium. Then in July 1999 we went back to deeper tracer layers, though not as deep as we had used in 1998. Furthermore, in the July shots, we used the VISAR instrument for the first time (previously we had used a SOP provided by John Oertel of LANL) to measure the shock breakout times.

Target Design and Assembly

The witness plates were manufactured by General Atomics, under the direction of Jim Kaae and Abbas Nikroo, using the GDP deposition technique for building up the initial (doped) plastic layer, to roughly 20 microns thick. Next, this plastic wafer was transferred to a coating machine where several thousand Angstroms of either sodium chloride or potassium fluoride was coated onto the plastic. Finally the coated plastic was put back in the GDP machine where an additional layer of (doped) plastic was deposited. The samples were then machined smooth, with a uniformity of better than 1 micron. The thicknesses of the plastic layers were measured with interferometry and the tracer layers were probed with a electron microscope. The tracer layers were not very uniform, consisting of crystalized concentrations with a spatial scale of several tens of microns. The backlighter beam widths were several hundred microns in diameter, and averaged over this scale, however, the tracers were effectively uniform. After these three-layer plastic wafers were produced, they were cut into squares roughly 0.5 mm on a side and shipped to Livermore, where they were assembled by Russell Wallace.

The target assembly involved drilling the hole through which the backlighter x-rays propagate into the barrel of the hohlraums, mounting pairs of witness plates onto the barrels opposite these holes, and mounting the backlighter foils onto the exterior of the hohlraums. See Figure 3 for an image of a typical hohlraum target.

The wedge witness plates were also produced by GA using the GDP technique. Here a roughly 50 micron thick planar sample was deposited, and then the wedge shape was machined. See Figure 4 for an image of one of these wedge witness plates. These witness plates were mounted on the hohlraums in the same manner as the tracer witness plates, but no backlighter hole was necessary. Rather, a smaller DANTE hole was drilled in their barrels to facilitate a measurement of the drive temperature using DANTE.

Experimental Data

The data from the March 1999 shots showed a relatively strong backlighter signal with a fair amount of spectral structure in the backlighter. Also like the previous year's data, the March 1999 data showed that the germanium dopant provided additional continuum opacity, but that the backlighter signal was still relatively strong. However, unlike the data from the previous year, there is a detectable signal from the tracer layer. It turns on quite quickly, which is not surprising considering that the tracers depth was very small. A time-resolved spectrum, including several lineouts, is shown in Figure 5.

These data indicated that the primary cause of the negative result in 1998 was that the tracers were indeed too deep. However, the March 1999 data also indicate additional problems. For one, there seems to be some signal associated with the gold emission from within the hohlraum. In addition, with the two crystals, there is some overlap of the spectra on the film. This overlap makes it especially difficult to see tracer absorption signals on the potassium side. And finally, because the side-by-side scheme involves two separate backlighters, there is a possibility that the x-ray emission from both spots generates a signal in each crystal. The photons from the unwanted side essentially become an additional source of noise.

The spectral data from the July shots is somewhat ambiguous. Because of the spectral overlap problem, it is impossible to see a signal from the potassium in any of the side-by-side spectroscopy shots. In the case of the chlorine tracers, we may be seeing a marginal signal (see Figure 6), but nothing strong enough to make a meaningful determination of the time-dependent ionization balance.

We were only able to perform two shock-breakout shots during July 1999. In the first shot, the VISAR did not acquire any meaningful data. By changing the filtering and pointing on the second shock breakout shot, we were able to detect a signal that seemed to arise in one of the two witness plates. But, perhaps because of the narrow field of view, we could not simultaneously obtain a signal from both witness plates.

Conclusions

The complexity of the side-by-side witness plate experimental scheme using the two-crystal LXS may have too many inherent problems to facilitate a meaningful measurement. The general scheme of backlit K_{α} tracer absorption spectroscopy seems to be sound, based on the March 1999 results. However, contamination from both hohlraum radiation and unwanted photons from the second backlighter in combination with the spectral overlap may thwart any attempt to make the simultaneous measurement of both tracer layers in one instrument.

On the positive side, we were able to measure a strong, time-dependent spectral signal from the chlorine tracer when it was not buried too deeply and when only one backlighter was used. We also continued to refine our modeling of the experiments, especially of the hohlraum radiation drive using our view factor code[6], incorporating a hohlraum model and exploring the effects of the backlighter hole on the uniformity of the drive temperature across the witness plate face. This modeling also showed that the hole was a significant, but not overwhelming, temperature sink. Additionally, because the hole is not directly on the midplane, but rather is displaced to one side, it contributed to a small temperature difference from one witness plate to the other.

From the results reported here, we have concluded that several refinements are needed to successfully carry out these experiments. These changes include: aperturing the witness plates to restrict the gold hohlraum emission; concentrating on the chlorine tracer backlit by bismuth; and using a single crystal to record the tracer spectra. These changes, and several others, have been implemented in our fiscal year 2000 campaign.

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[1] Lindl, J. D., *Phys. Plasmas* **2**, 3933 (1995)

[2] Nuckolls, J. H., *Physics Today* **35**, no. 9, 24 (1982)

[3] Dittrich, T. R., et al., *Phys. Plasmas*, **6**, 2164 (1999)

[4] Perry, T. S. et al., *JQSRT*, **51**, 273 (1994)

[5] MacFarlane, J. J., Wang, P., Bailey, J. E., Mehlhorn, T. A., and Dukart, R. J., *Laser Part. Bearms*, **13**, 231 (1995)

[6] MacFarlane, J. J., *APS Division of Plasma Physics meeting*, Seattle 1999

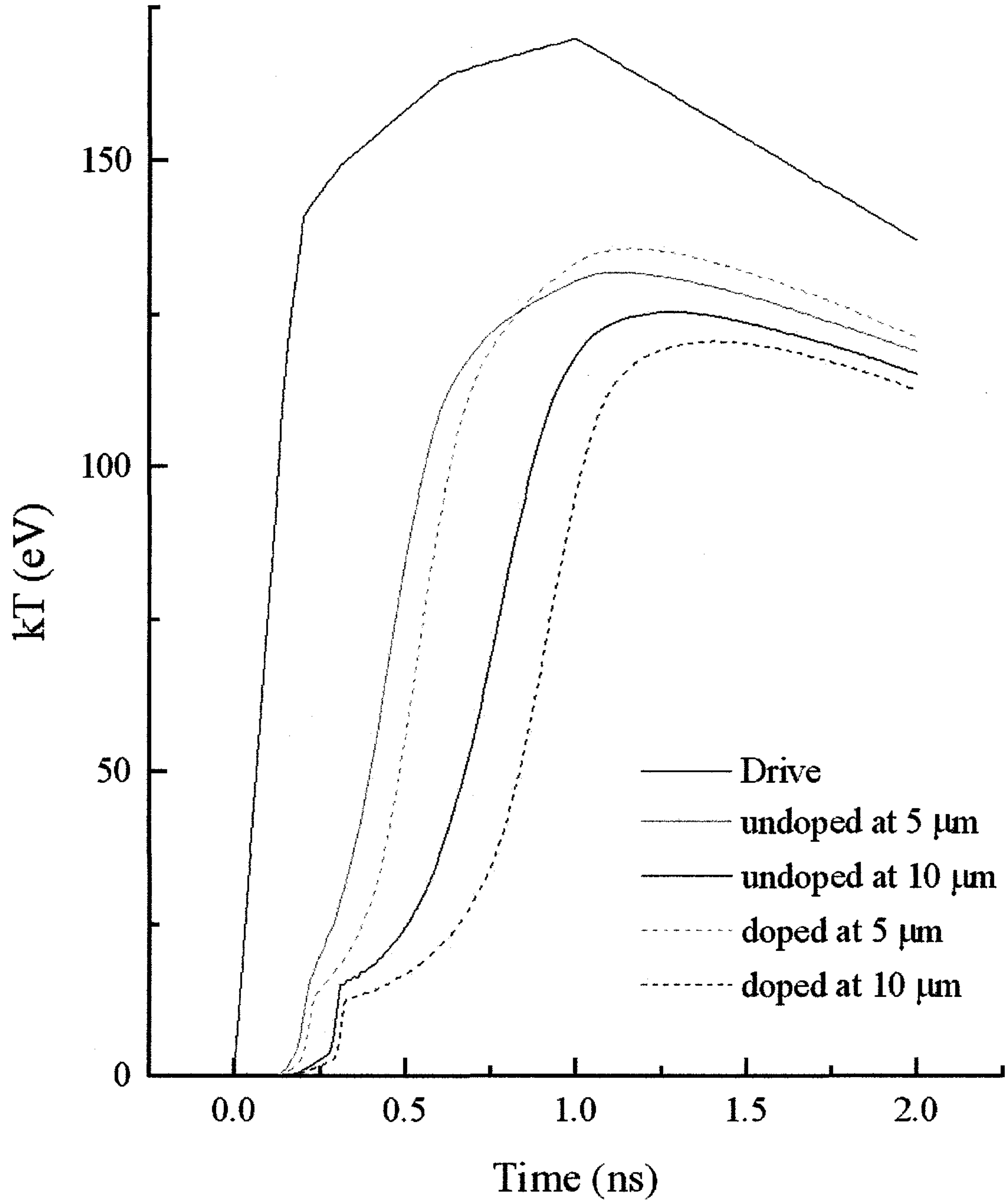

Figure 1 - Radiation-hydrodynamics simulation of the response, at two different depths, of both a doped and an undoped sample to the hohlraum drive provided by a 1 ns square pulse. Note the initial, moderate heating caused by the shock is followed by rapid and much stronger heating caused by the Marshak wave. The "turn-on" of the doped sample is later than for the undoped sample. This delay is greater for deeper tracers and higher dopant concentrations.

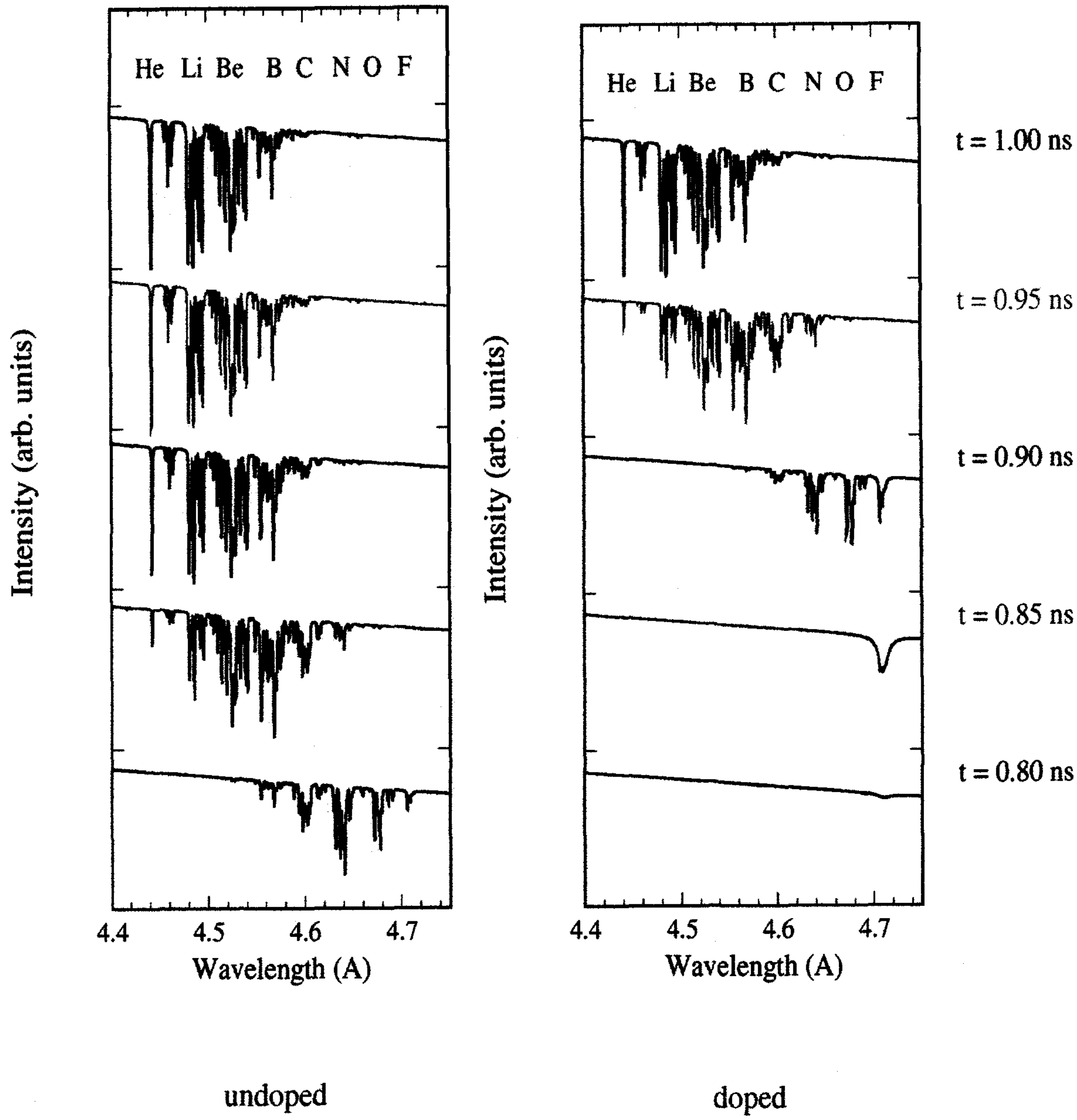

Figure 2 - The spectral response of chlorine tracers buried about 10 microns from the front of two different witness plates, one doped and one undoped. Note the later turn-on times in the doped sample. Also note the rapid burn-through to high ionization stages. In our experiments, one of these tracers would be potassium, but here both are modeled as chlorine to facilitate comparison.

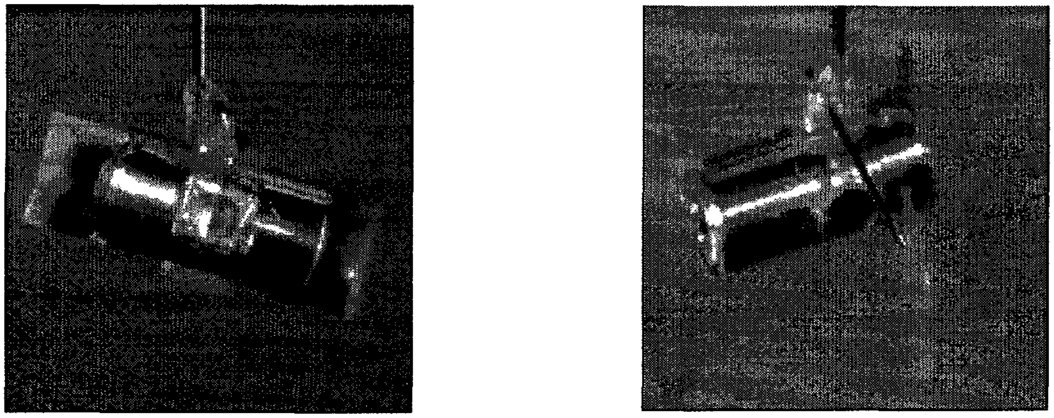

Figure 3 - Two views of a tracer spectroscopy target taken on the LLE Powell scope. The left view is taken from the position of the LXS, and shows the two different witness plates mounted on the hohlraum barrel. The right view is from the opposite side of the hohlraum, and shows the backlighter foil in the foreground, as well as the hole in the barrel through which the backlighter photons propagate. Two shields can also be seen. Their purpose is to keep stray light from the LEHs out of the LXS.

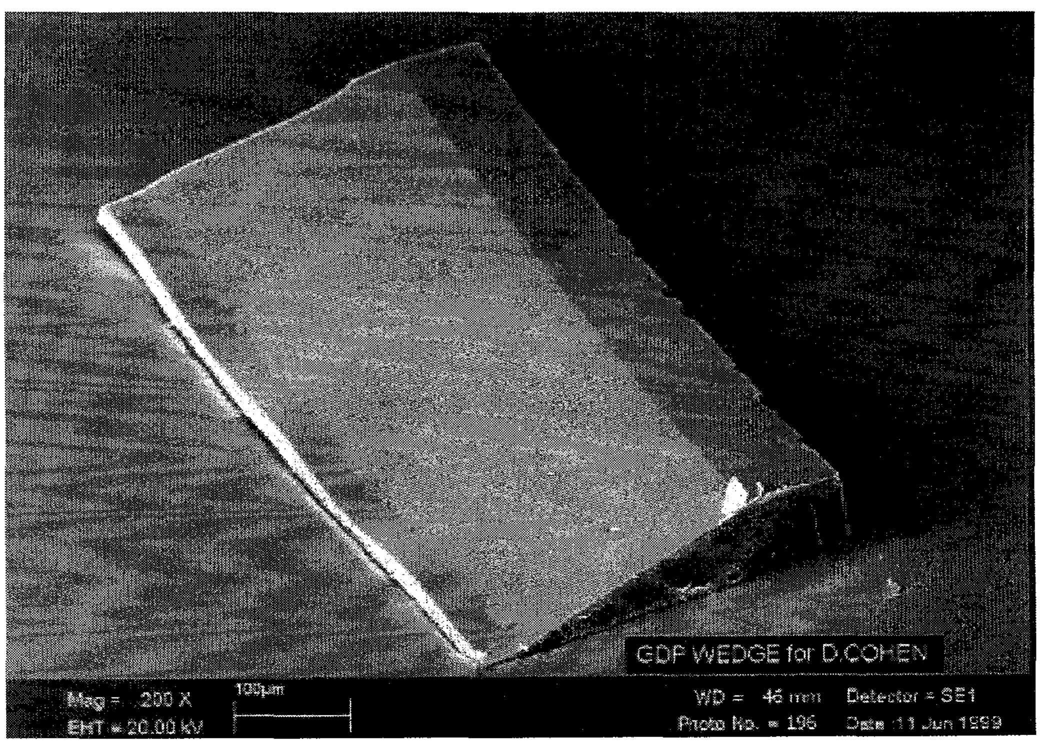

Figure 4 - A scanning electron microscope image of a wedge witness plate.

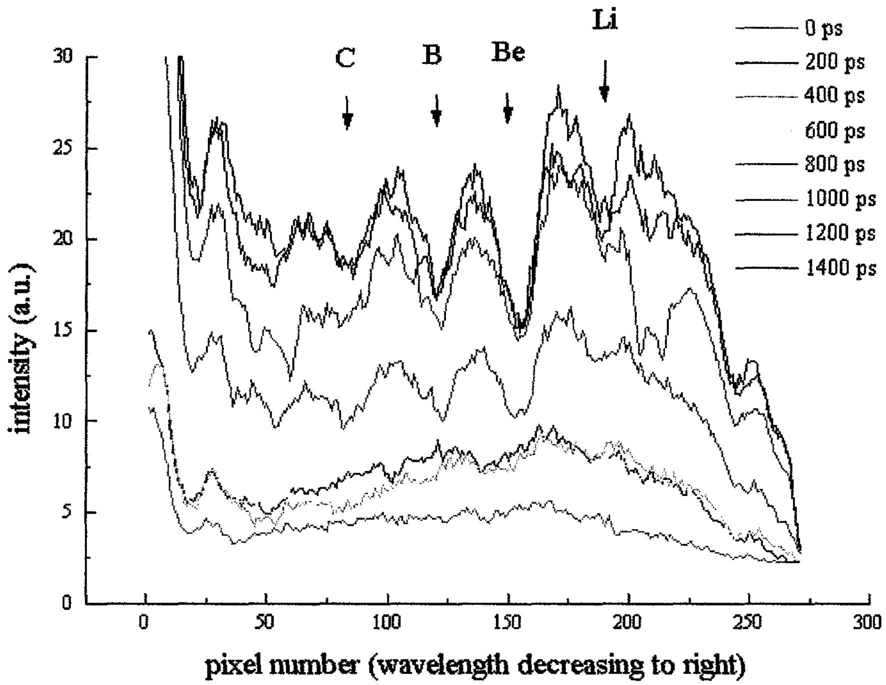

Figure 5 - A series of line-outs from the LXS for a shot in March 1999, in which the tracer layer was only a few microns from the surface. The witness plate was undoped, and the backlighter was bismuth. Strong signals from several high ionization stages are present.

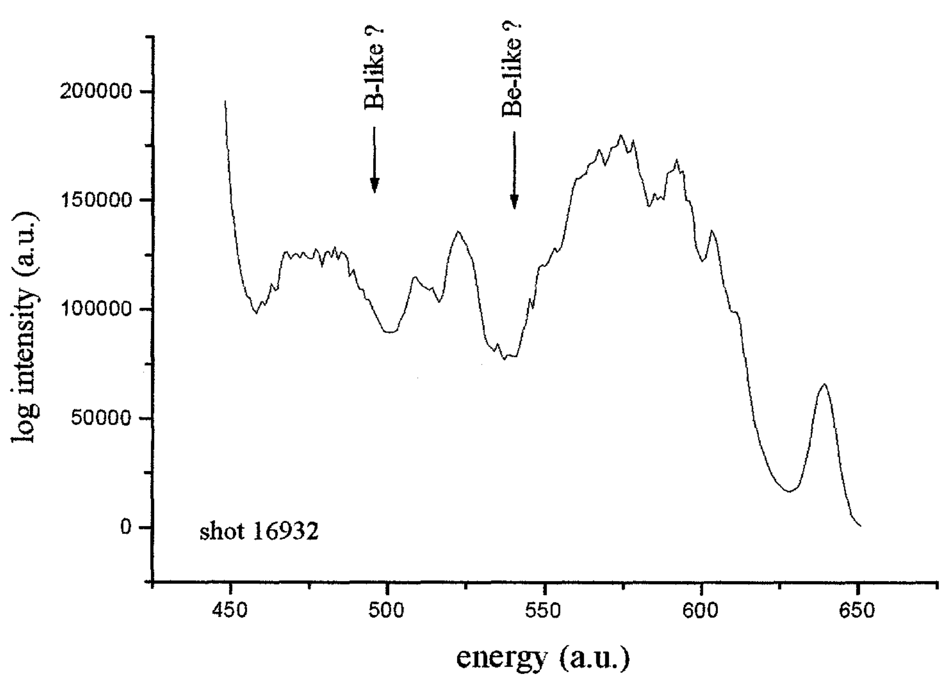

Figure 6 - A single lineout (averaged from roughly 700 ps to 1000 ps of the bismuth/chlorine side of a tracer target shot from July). In this integrated data, it appears that B- and Be-like features are present, but their reality is somewhat uncertain, due to the presence of structure in the backlighter spectrum itself.