LA-UR -88-3304

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

LA-UR--88-3304

DE89 002053

TITLE

EXPERIMENTAL STUDIES OF X-RAY EMISSION PHYSICS AND HYDRODYNAMICS USING SHORT WAVELENGTH LASERS

AUTHOR(S)

P. D. Goldstone, D. E. Casperson, J. A. Cobble, S. V. Coggeshall, C. C. Gomez, A. Hauer, G. A. Kyrala, P. H. Y. Lee, W. C. Mead, G. T. Schappert, and A. J. Taylor

SUBMITTED TO

19th ECLIM
Madrid, Spain
October 3-7, 1988

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

MASTER

By acceptance of this article, the publisher recognizes that the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or to allow others to do so, for U.S. Government purposes.

The Los Alamos National Laboratory requests that the publisher identify this article as work performed under the auspices of the U.S. Department of Energy.

Los Alamos
Los Alamos National Laboratory
Los Alamos, New Mexico 87545

EXPERIMENTAL STUDIES OF X-RAY EMISSION PHYSICS AND HYDRODYNAMICS USING SHORT WAVELENGTH LASERS

P. D. Goldstone, D. E. Casperson, J. A. Cobble, S. V. Coggeshall, C. C. Gomez, A. Hauer,
G. A. Kyrala, P. H. Y. Lee, W. C. Mead, G. T. Schappert, and A. J. Taylor

Los Alamos National Laboratory
Los Alamos, New Mexico, USA 87545

ABSTRACT

Several experimental efforts are currently under way at Los Alamos to study issues of importance for inertial confinement fusion with short wavelength lasers. These issues include the physics of x-ray conversion and the dynamics of short-wavelength laser interaction with high-Z plasmas; filamentation and self-focusing processes; and the growth of instabilities in laser-driven implosions. Most of these experiments are being pursued in collaboration with other laboratories, notably the University of Rochester and Lawrence Livermore National Laboratory. In addition, we are undertaking basic studies of the interaction of both atomic systems and solids with ultra-intense ($\sim 10^{17}$ W/cm^2) subpicosecond lasers at Los Alamos. These experiments explore the response of atomic systems to strong fields, multiphoton excitation, and transient phenomena in dense plasmas.

INTRODUCTION

While Los Alamos is developing KrF lasers for Inertial Confinement Fusion (ICF) applications[1,2] an ongoing experimental program has been pursued to provide greater understanding of issues important to achieving high-gain target performance in a Laboratory Microfusion Facility. All of these experiments have involved collaboration with other laboratories with short-wavelength laser facilities. The primary experimental efforts involve studies of x-ray conversion, hydrodynamic instability growth and fuel-pusher mix, and filamentation and self-focusing. The first two studies will be described in more detail below. In addition, preparations are in progress for experiments using the Aurora KrF laser to study these and other issues; these will not be described here. Theoretical, laser development, and target fabrication work at Los Alamos related to ICF is described in separate papers in this conference.

In addition to experiments directly related to ICF, fundamental processes in laser-plasma physics, atomic physics in strong fields, and multiphoton excitations are being investigated with the new Los Alamos Bright Source (LABS) laser. Current experiments use 700 fs, 248 nm (KrF) pulses providing focused intensities in excess of 10^{17} W/cm^2. Specific experiments are being pursued with this source to study: solid target interactions and x-ray production; multiphoton ionization; inner-shell excitations via collective electron oscillations; nuclear excitations; harmonic generation; above-threshold ionization; and some x-ray laser concepts. Below, we discuss the study of inner-shell excitations in more detail.

X-RAY CONVERSION PHYSICS

X-ray conversion is an important efficiency step for indirect-drive ICF. Together with collaborators at the University of Rochester and NRL[3] we have continued to investigate the physics of x-ray conversion in high-Z plasmas using short-wavelength lasers. These experiments have been performed using spherical targets on the 351-nm, 24-beam Omega laser at Rochester. Our earlier work[4] indicated that the x-ray conversion efficiency was well-reproduced by LASNEX calculations for kilojoule, 24-beam irradiations of gold spheres over the intensity range 4×10^{12} - 4×10^{15} W/cm^2. Conversion efficiencies in excess of 70% were achieved for intensities below ~4×10^{14} W/cm^2. However, the conversion efficiency for more nonuniform 6-beam illumination, using lower energy and smaller targets to preserve incident intensity, was significantly reduced. Subkilovolt x-ray spectra were also measured using a transmission grating spectrograph and were significantly different from LASNEX calculations. Our recent experiments were aimed at determining the relative effects of illumination uniformity and energy/target size in the 6-beam/24-beam discrepancy. In addition we have studied whether x-ray conversion could be enhanced by varying the target Z or by significantly reducing initial target density, as suggested by some simulations.

Figure 1 shows the previous (1985) data of reference 4, together with a preliminary analysis of new x-ray conversion data for gold, bismuth, and uranium targets. No significant change in x-ray conversion efficiency is observed.

Figure 2 shows that the reduced x-ray conversion for the 6-beam data was apparently due to the nonuniformity of illumination. Repeating the previous 24-beam experiments and then reducing the laser energy and target size to the values used in the previous six-beam experiments produced high x-ray conversion efficiency in both cases, consistent (to within the uncertainties of this first analysis) with the previous 24-beam results. The 24-beam illumination produces rms nonuniformities of ~20%; the six-beam illumination produced an rms nonuniformity of ~50% and had "macroscopic" intensity variations of ~2:1 with a lateral scale size comparable to the target radius.

More uniform illumination than provided by the 24 nominal Omega beams can be achieved by the use of distributed phase plates[5]. However, a comparison of gold x-ray conversion using both illumination conditions at ~4 x 10^{14} W/cm^2 showed no change in the conversion efficiency. These experiments may provide an indication of the magnitude or scale size of the illumination nonuniformity necessary to produce detrimental effects on x-ray conversion.

Comparative measurements of conversion efficiency for solid gold and 1.4-2.4% density gold targets, at 10^{14} and

10^{15} W/cm^2, showed no enhancement of x-ray conversion for the low-density targets.

Most spectroscopic results from this experiment are still being analyzed. However, it is apparent that the subkilovolt spectra are in general agreement with the previous data, and that subtle differences in the width of the N- and O-band features still appear as a function of target size.6)

HYDRODYNAMIC INSTABILITY GROWTH

Most laser-driven measurements of hydrodynamic instability growth have used planar geometry because of its diagnosibility. However, there have been recent significant advances in x-ray backlighting technology, x-ray gated-imaging technology, target fabrication, and non-LTE theoretical modeling. As a result it is possible to obtain and interpret spectroscopically resolved, <100 ps "snapshots" of medium-Z tracer materials embedded as a shell or band into a low-Z pusher. Ultimately, high spatial- and spectral-resolution imaging may allow detailed studies of mix and the state of the fuel-pusher interface. Los Alamos' effort to develop and use these techniques involves collaboration with several laboratories.

An experiment has been designed in collaboration with LLNL[7] to use x-ray imaging techniques for studies of instability growth in spherical geometry. Diagnostic techniques correlative to these experiments are being tested on the Omega laser at Rochester and at KMSFusion, Inc., in collaboration with those institutions.

Conceptually, in these experiments a thin x-ray absorbing tracer layer is embedded in a low-Z shell (e.g. plastic). A flash x-ray backlighting source is then used to produce an (absorption) image of this layer at characteristic times during the implosion. Initial measurements will stress proving the technique by imaging the growth of simple perturbations (e.g. bumps on the surface of a low-Z shell) that have large amplitudes (in the nonlinear regime) as the shell is imploded to approximately 1/3 its initial radius. Estimates, assuming half-classical growth, suggest that an initial perturbation of 7 microns amplitude would grow to approximately 40 microns, which is expected to be readily observable. These techniques will be extended in the future to combine spectroscopy with imaging.

Preliminary tests of some of these ideas have been initiated on the NOVA laser at LLNL. An unfilled shell with a 5000-Angstrom KCl tracer layer was backlit during its implosion. The backlit image was projected onto the slit of an x-ray streak camera by a Wolter x-ray microscope. A shadow of the limb of the shell is apparent on one side, but not on the other, possibly suggesting breakup of the shell. The backlight was well-resolved in time from the spike of radiation at final collapse of the shell.

THE LOS ALAMOS BRIGHT SOURCE

Atomic excitations in strong fields, and other fundamental issues in laser-matter interactions, are being investigated with the Los Alamos Bright Source (LABS), a subpicosecond, ultra-high-flux laser.[8)] The system in its current incarnation (LABS I) uses KrF amplifiers to produce 20-mJ, 700-fs pulses at several Hz. Using f/1 optics spot areas of ~5 micron^2 have been achieved, resulting in irradiances of >10^{17} W/cm^2. A modification and upgrade of LABS (LABS II) is under way, using XeCl as an amplifying medium, to as much as 1 J in 150 fs at 1 Hz. Several experiments are in progress on LABS I. Multiphoton ionization of Xe gas has been investigated and the results compared with theoretical models. The laser interaction with solid targets (or more accurately, interaction with the small plasma produced at the solid surface by the low-level ASE preceding the subpicosecond pulse), and the production of picosecond bursts of kilovolt x-rays, has been discussed elsewhere.[9,10)] Here we discuss the results of a search for inner-shell excitations produced via collective oscillations of the valence electrons in the strong laser field.

SEARCH FOR MULTIPHOTON-INDUCED INNER-SHELL EXCITATIONS

Boyer and Rhodes[11)] recently conjectured that atomic inner-shell excitations could be induced by laser-driven coherent oscillations of the outer-shell electrons, if the laser field strength exceeds an atomic unit, e/a_0^2. Lambropoulous, however, suggested[12)] that sequential ionization of the outer shell occurs as the laser intensity rises and these channels become energetically allowable, thus competing with possible collective oscillations. However, inner-shell excitations will radiatively decay in <<1 ns, making a measurement of prompt, high-energy photons a reasonable signature of the production of inner-shell excitations. Several of the authors[13,14)] have undertaken a photon-counting experiment to search for inner-shell excitations, and these results are briefly summarized here.

The LABS I laser was focused to ~3 x 10^{17} W/cm^2 ($E \sim 3e/a_0^2$) in a 0.12 torr Xe gas target. The maximum ionization state achievable was measured in a separate experiment[15)] to be ~11^+. Radiative transitions characteristic of inner-shell excitations would therefore be photons in the range 90-140 eV (O->N transitions) and 500-1000 eV (N->M transitions). Filtered microchannel plate (MCP) and MCP/phosphor/photomultiplier detectors were used to search for photons in these energy ranges and determine, with 1-ns resolution, the time distribution of these photons with respect to the laser pulse. A schematic of the setup is shown in figure 3. Three runs with different filters or geometries were accomplished, with $>10^4$ laser shots in each run. A run with $\sim 10^{-7}$ torr of Xe established a background count rate of ~ 0.3 events per 10^3 laser shots.

In each of the three data runs, several delayed photons were observed, but no prompt photons. The earliest events in the three runs occurred 2 ns, 3 ns, and 6 ns after the laser pulse. From this null result an estimate can be made of the probability of producing an inner-shell excitation which radiatively decays by prompt x-ray emission. Using conservative estimates of filter transmissions and detector efficiency, knowing the detector solid angle, and knowing the number of Xe atoms in the focal volume (spot area x Rayleigh range). this probability is estimated to be $<5 \times 10^{-5}$ per Xe atom. Thus, at laser intensities corresponding to $E \sim 3e/a_0^2$, inner shell excitation by collective electron oscillation of the outer shell(s) is a negligible process.

CONCLUSIONS

Experiments, many in collaboration with other laboratories, are elucidating important issues in ICF and in fundamental laser-matter interactions from the nanosecond to the sub-picosecond regime. In both regimes, the experimental studies of x-ray emission suggest areas of atomic and plasma physics needing further theoretical explanation. Experimental studies of hydrodynamics and fundamental instability growth processes are reaching new levels of sophistication and similarly hold promise for testing theoretical models.

ACKNOWLEDGEMENTS

In addition to our colleagues and collaborators noted in the references, we wish to thank D. C. Cartwright, D. Giovanielli, R. J. Trainor, and F. A. Morse for their support of various aspects of this work. We also wish to thank R. L. McCrory and E. M. Campbell for their support of collaborative experiments with their laboratories.

REFERENCES

1) Rosocha, L. A., et al., "Aurora: Multikilojoule KrF laser system prototype

for Inertial Confinement Fusion," Fusion Technology 11, 497 (1987)

2) McDonald, T., et al., "High power KrF laser development at Los Alamos," elsewhere in this volume

3) Bradley, D. K., Jaanimagi, P. A., Knauer, J., Marshall, F. J., Pien, G., Richardson, M. C., Seely, J. F., and Feldman, U.

4) Goldstone, P. D., et al., "Dynamics of high-Z plasmas produced by a short-

wavelength laser," Phys. Rev. Lett. 59, 56 (1987)

5) See Laboratory for Laser Energetics Quarterly Report, DOE/DP 40200-65, 1987, pp. 1-10

6) Goldstone, P. D., et al., "X-ray emission from high-Z spherical laser plasmas: implications for plasma dynamics," in SPIE Vol. 831-- X-Rays from Laser Plasmas, 1987, pp. 54-61

7) Bach, D., Glendenning, G., Wallace, R., and Kilkenny, J.

8) Roberts, J. P., Taylor, A. J., Lee, P. H. Y., and Gibson, R. B., "High-irradiance 248-nm laser system," Opt. Lett. 13, 734 (1988)

9) Cobble, J. A., et al., "Kilovolt x-ray spectroscopy of a sub-picosecond-laser-excited source," submitted to Phys. Rev. Lett.

10) Gomez, C. C., et al., "Study of laser-plasma interaction with picosecond lasers," presented at the 18th annual Anomalous Absorption Conference, L'Esterel, Quebec, Canada, June 27-July 1, 1987

11) Boyer, K., and Rhodes, C. K., Phys. Rev. Lett. 54, 1490 (1985)

12) Lambropoulous, P., Phys. Rev. Lett. 55, 2141, (1985)

13) Lee, P. H. Y., Casperson, D. E., Schappert, G. T., "Are there multiphoton induced inner-shell excitations?," submitted to Phys. Rev. Lett.

14) Lee, P. H. Y., Casperson, D. E., and Schappert, G. T., "Collisionless x-ray generation from picosecond laser-gas interaction," presented at the OSA Topical Meeting on Short Wavelength Radiation, N. Falmouth, MA, September 1988

15) Kyrala, G. A., Casperson, D. E., Lee, P. H. Y., Jones, L. A., Taylor, A. J., and Schappert, G. T., "Multiphoton ion production in intense fields," presented at the 4th International Conference on Multiphoton Processes, Boulder, CO, July 1987

Fig. 1. Preliminary analysis of x-ray conversion efficiency data compared with previous[4] results

Fig. 2. Low-energy experiments (150-250 J) can produce high x-ray conversion if illumination uniformity is good (e.g. 24-beam Omega)

Fig. 3. Schematic of apparatus used to search for multiphoton-induced inner-shell excitations at Los Alamos Bright Source

Conversion efficiencies for Au, Bi, and U are similar.

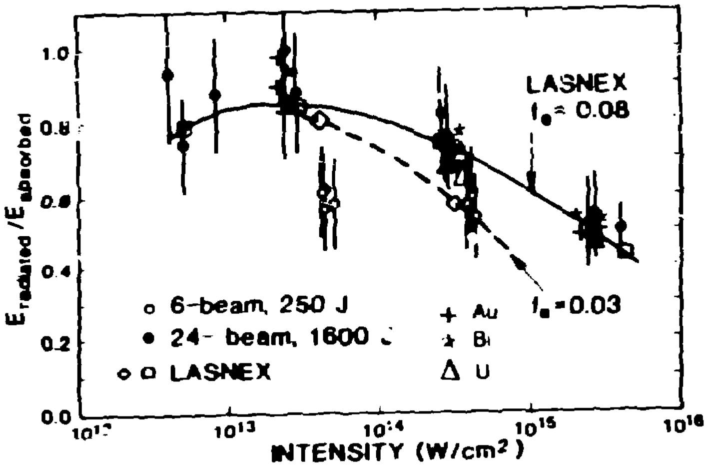
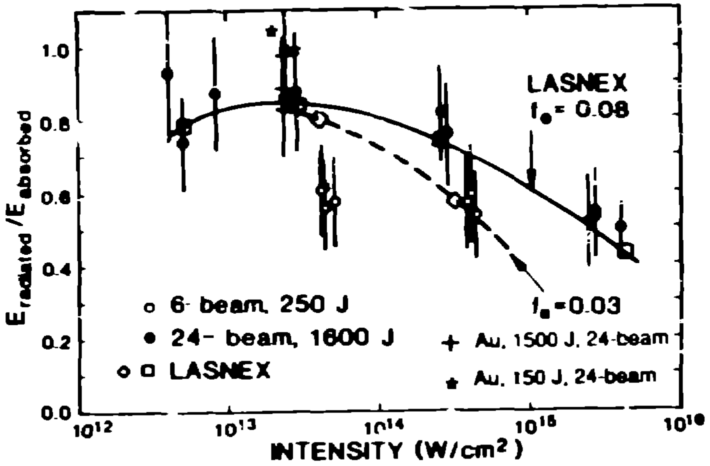


Fig 1

Small targets irradiated with 24 beams and low energy show similar conversion efficiency to high-energy, large target experiments – but quite different from 6-beam data.



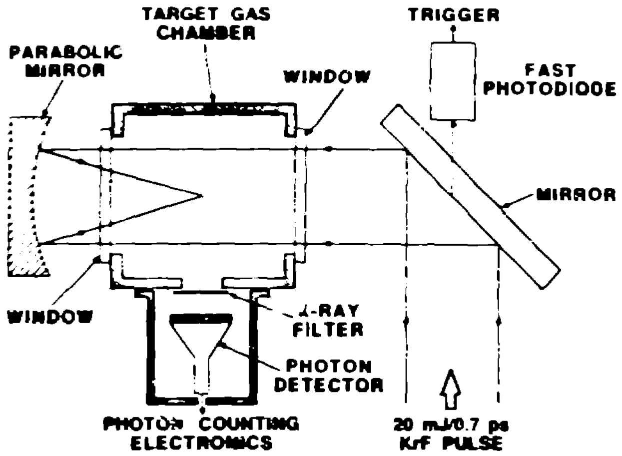

TARGET GAS CHAMBER
TRIGGER
PARABOLIC MIRROR
WINDOW
FAST PHOTODIODE
MIRROR
WINDOW
X-RAY FILTER
PHOTON DETECTOR
PHOTON COUNTING ELECTRONICS
20 mJ/0.7 ps KrF PULSE

Fig. 3