Volume 8

LLE Review

Quarterly Report

July, 1981 - September, 1981

Laboratory for Laser Energetics
College of Engineering and Applied Science
University of Rochester
250 East River Road
Rochester, New York 14623

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Editor: E. Williams
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The work described in this volume includes ongoing research at the Laboratory for Laser Energetics which is supported in part by the Empire State Electric Energy Research Company (ESEERCO), Exxon, the General Electric Company, the New York State Energy Research and Development Authority (NYSERDA), Northeast Utilities, the Standard Oil Company (Ohio), the University of Rochester, and various governmental agencies, including the Air Force Office of Scientific Research, the Department of Energy, the National Institutes of Health, and the National Science Foundation.

IN BRIEF

- The first *kinetic* x-ray diffraction pictures of a photoactive protein (bacteriorhodopsin) have been obtained using a laser plasma source.
- Two user groups, Larry Knight and David Gaines (Brigham Young University), and Ray Stringfield (Physics International), conducted experiments on the GDL and OMEGA facilities respectively.
- A new technique, capillary gas filling, has been developed to load high-Z diagnostic gases into microballoon targets. The usual permeation technique is unworkable for these materials because of their very small permeation coefficients.
- Near field equivalent plane intensity and phase distribution measurements were made using two beams of the OMEGA system. With 200 GW per beam at 600 psec the maximum phase distortion measured across the beam was $\sim 1.5\lambda_0$, with maximum peak-to-valley variance in intensity in the near field distribution of $\sim 20\%$, and in the equivalent target plane of $\sim 50\%$.
- An extensive data base has been generated in a study of the $2\omega_p$ instability and stimulated Raman scattering on the GDL system. Simultaneous observations of the scattered light intensity, angular dependence and spectrum, as well as observations of the soft and hard x-ray spectra, high energy electrons and ion blow-off were made. The results indicate low conversion into Raman ($\sim 10^{-5}$) and low conversion into high energy electrons ($< 10^{-4}$ of incident energy).

CONTENTS

Staff scientist Robert D. Frankel (right) and senior scientist James M. Forsyth (left) in the x-ray laboratory at LLE. Using monochromatic x-ray pulses produced by focussing frequency tripled GDL pulses onto chlorine targets, they are studying the kinetic structure of photostimulated membrane proteins via x-ray diffraction. Some preliminary results of these measurements are presented in this issue.

Section 1
LASER SYSTEM REPORT

1.A GDL Facility Report

The GDL facility continued operations during the third quarter of FY81.

A total of 430 shots were delivered by the facility in the period July 1 to September 30, 1981. The shot distribution was as follows:

3ω target experiments	237 shots
damage test facility	49
NLUF	74
alignment and calibration	70
total	430 shots

National Laser Users Facility operations for GDL during this period included 58 shots for the x-ray biophysics experiments and 16 shots for the Brigham Young University group.

Some of the experimental work carried out under the 0.35 μm Interaction Physics Program and the kinetic x-ray diffraction experiments are reviewed elsewhere in this volume.

1.B OMEGA Facilities Report

In the quarter July 1 to September 30, some 427 shots were fired on the OMEGA system. Of these, 104 shots were part of the beam uniformity characterization campaign which will be reported on in a later issue. Table 1 gives a breakdown by usage of the laser shots in the quarter, and Figs. 1 and 2 show the energy distribution of the 12 and 24 beam shots during August and September.

July 1, 1981 - September 30, 1981

CATEGORY	NUMBER OF SHOTS	
Target Shots	101*	(24%)
Driver Align and Test	211	(49%)
Beamline c/o and Calibration	72*	(17%)
Software Test and Timing	43	(10%)
TOTAL	427	(100%)

* Including laser uniformity series - 104 shots

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Table 1
OMEGA laser system shot category distribution July 1 to September 30, 1981.

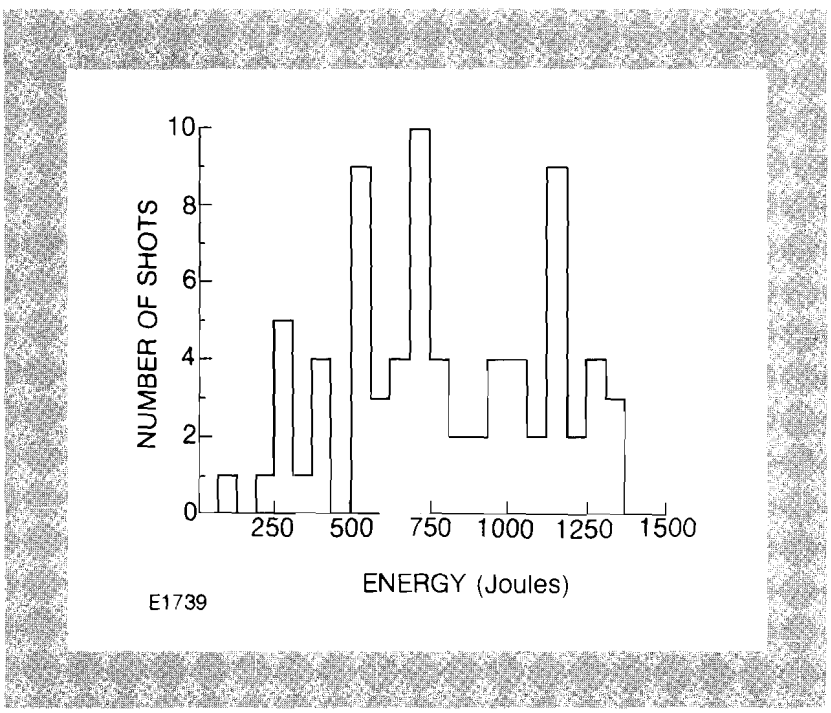

Fig. 1
12-Beam target shots from August 1 to September 30, 1981.

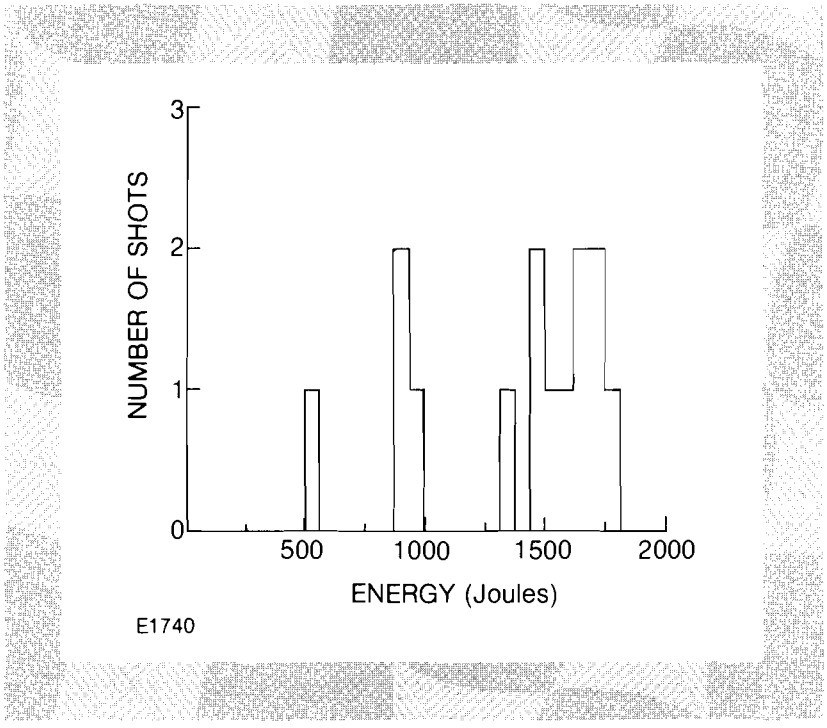

Fig. 2
24-Beam target shots from August 1 to September 30, 1981.

Section 2
PROGRESS IN LASER FUSION

2.A Exploding Pusher Experiments on OMEGA

Exploding pusher experiments have been conducted on the 24-beam, 10 TW OMEGA laser system. The purpose of these experiments was to activate and check out the system with targets whose behavior is relatively well understood and easily diagnosed.[1] The experimental plan also included studies of (1) the dependence of target behavior on irradiation uniformity and (2) the scaling of neutron yield with absorbed energy. Typical laser parameters were on-target energy of 500 to 800 joules and pulse width from 80 to 120 psec. Targets were 170 μm to 230 μm diameter, 0.8 μm to 1.2 μm thick glass shells filled with an equimolar mixture of DT at 20 atmospheres.[2]

During the program, the laser operations crew demonstrated the ability to consistently fire 24 laser beams on target once every half hour. On May 19, the highest yield efficiency (ratio of fusion energy to absorbed energy = 1.8×10^{-4}) for any laser driven target was obtained when 1.35×10^{10} neutrons were produced at a power of 7.0 TW. An additional accomplishment during this series was the successful implementation of the "knock-on" diagnostic which will be used in future high density implosion experiments to directly measure the product of density and radius, "ρR", in the compressed DT fuel.[3]

Exploding Pusher Behavior[4]

In an exploding pusher shot, a short high-powered laser pulse rapidly heats a thin-wall glass microballoon (or "pusher") containing a gaseous mixture of deuterium and tritium. At the high incident intensity

($\sim 10^{15}$ W/cm^2), suprathermal electrons ($\gtrsim$ 10 keV in energy) are produced by the process of resonance absorption. Since the electron mean-free-path under these conditions is greater than the shell thickness, the glass is heated throughout and explodes inwardly and outwardly. The inwardly moving (or imploding) glass drives a shock wave into the DT fuel and, like a piston, does mechanical work on the fuel. High temperatures in excess of 5 keV result in the fuel and a thermonuclear burn occurs. Density in the fuel does not exceed liquid density because of premature heating of the target by suprathermal electrons and hydrodynamic shocks. (To burn a significant portion of the fuel, the DT must be compressed to over 1000 times liquid density.) The burn is quenched as the DT cools by thermal conduction to the glass and expansion.

Irradiation Uniformity

Uniformity of target irradiation or "uniformity" was varied by changing the focal point of each of the 24 lenses (f/3.0) with respect to the center of the target. Two extreme cases are shown in Fig. 3. Target irradiation is more uniform for "tangential focus" which corresponds to a focal point about 6 target radii (+6R) behind target center. All 24 beams overlap on the surface of the target and the average intensity is about 10^{15} W/cm^2. Irradiation is less uniform for "surface focus" for which the focus is 1 radius (−1R) in front of target center. The beams

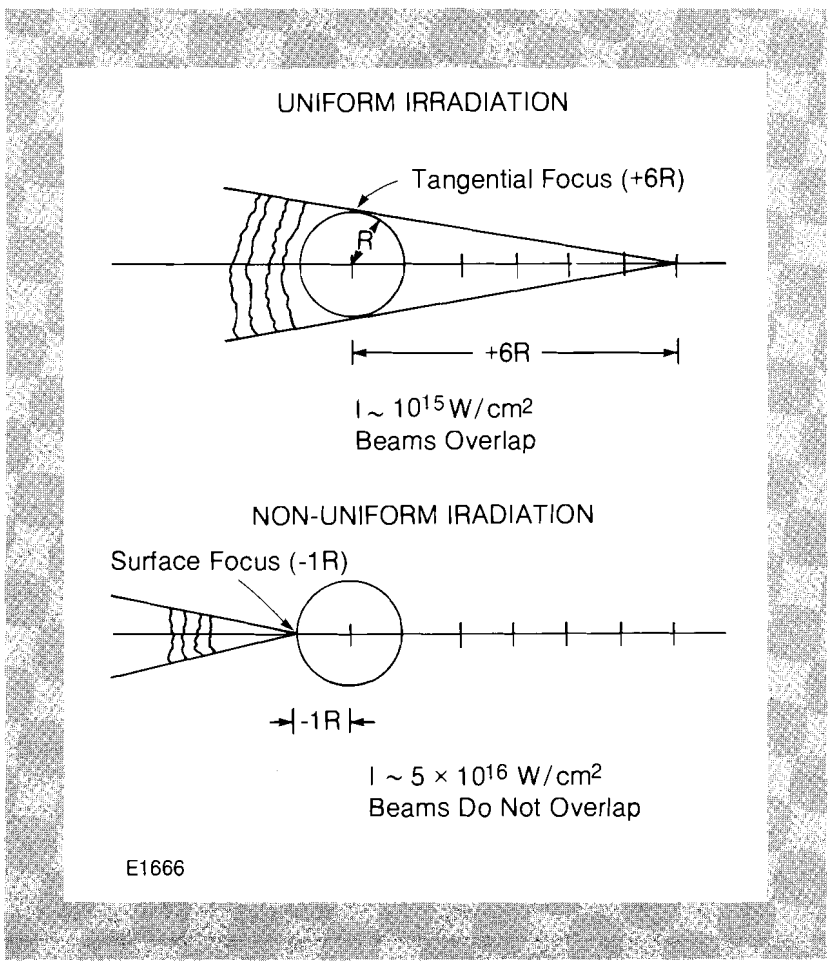

Fig. 3
Focussing geometries for most uniform (+6R) and least uniform (−1R) irradiation.

do not overlap; the energy of each beam goes into a 30 μm diameter spot in which the average intensity is about 5×10^{16} W/cm^2.

The sensitivity of target behavior to uniformity can be illustrated by comparing two shots which have nearly the same initial laser and target conditions but different focal positions. The initial conditions of shots 6037 and 6030 are given in Table 2. The implosion symmetries of these shots, as diagnosed with an x-ray pinhole camera, differ appreciably as shown in Fig. 4. For shot 6037 (− 1R, surface focus), there are hot and cold x-ray emission regions in the core. The structure suggests that the glass did not remain uniformly spherical as it was imploded by the 24 non-overlapping beams. For shot 6030 (+ 4R, rear focus), the near circular x-ray emission suggests that the glass retained its integrity as it imploded and stagnated against the DT fuel. The implosion symmetry is more spherical for this case in which the overlapping beams applied energy more uniformly to the surface of the pusher.

	Shot 6037	Shot 6030
Number of Beams	24	24
Energy on Target	694 Joules	710 Joules
Pulse Width (FWHM)	89 psec	89 psec
Power	7.8 TW	7.5 TW
Focal Position	-1 R	+4 R
Shell Diameter	207 μm	200 μm
Wall Thickness	1.0 μm	1.2 μm
DT Fill Pressure	20 atm	20 atm
Target Mass	365 ngm	389 ngm
Implosion Symmetry (see Figure 4)	Non-spherical	Nearly Spherical
Absorbed Energy	228 Joules	149 Joules
Absorption Fraction	0.33	0.21
Neutron Yield	1.01×10^{10}	3.93×10^{9}
LILAC Yield	3.81×10^{10}	7.97×10^{9}
Yield Ratio	0.27	0.49

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Table 2
Comparison of diagnostic data for shots with different focussing.

Shots 6037 and 6030 illustrate how both absorption and neutron yield change as the focal position is varied from − 1R to + 4R. As shown in Table 2, the absorption and yield for shot 6037 are 33% and 1.01×10^{10} neutrons versus 21% and 3.93×10^{9} neutrons for shot

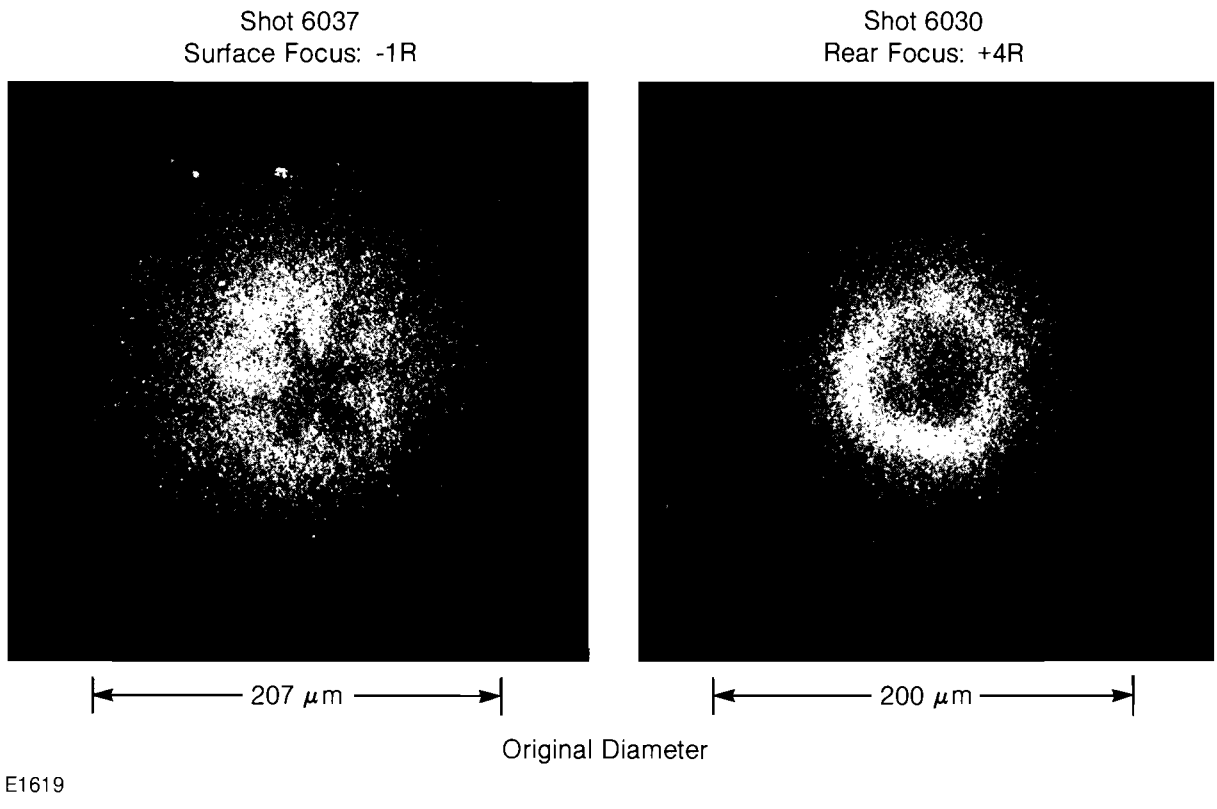

Fig. 4
Symmetry effects in 24-beam exploding pusher shots.

6030. Results of other shots are consistent with these values. Figure 5 is a plot of absorption fraction versus focal position. Absorption varies from about 35% at surface focus to about 20% at tangential focus. For laser intensities of about 10^{16} W/cm^2, a resonance absorption model can be used to account for absorptions of about 20%. It is possible that the spatial modulation of the incident intensity due to non-overlapping beams and an accompanying deformation of the critical surface may explain the observed values of ~35% at surface focus.

Figure 6 is a plot of observed yields versus focal position for shots with incident energies between 625 and 725 joules and pulse widths between 80 and 120 psec. The higher yields at surface focus are mainly attributed to the higher absorption at that focal position.

Computer Simulations

The one-dimensional hydrodynamics code *LILAC* was used to simulate shots 6037 and 6030. The different irradiation conditions were modeled with an algorithm which estimated the on-target intensity as a function of focal position. The intensity was taken as the total laser power divided by the nominally illuminated target area. From this intensity, the suprathermal electron temperature and the corresponding fraction of the absorbed energy lost to "fast ions" was calculated.[5] The results are given in Table 2. As a comparison criterion, the ratio of mea-

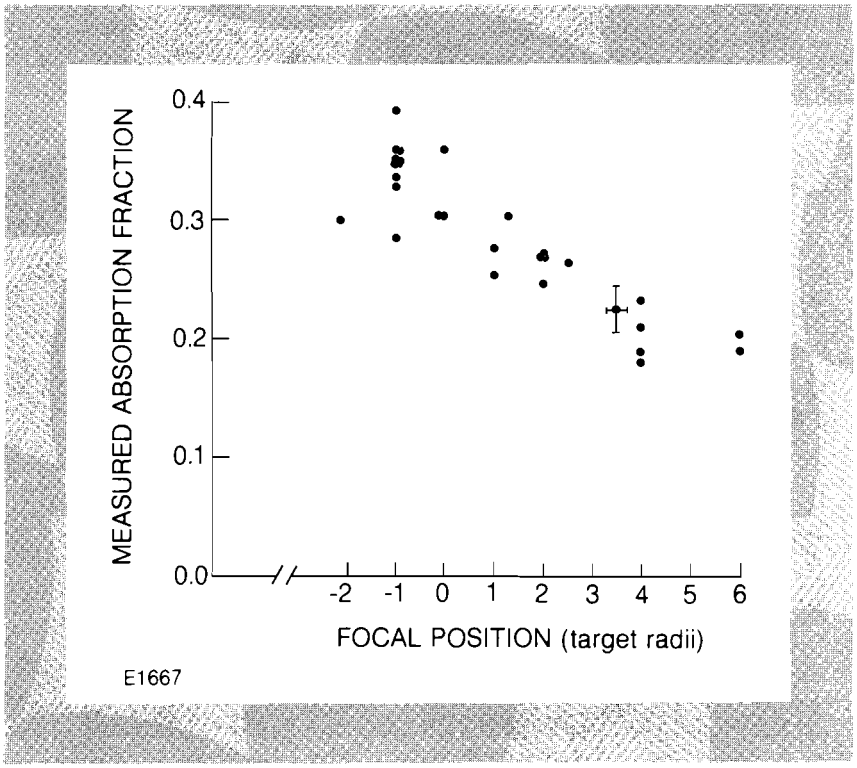

Fig. 5
Measured absorption versus focal position.

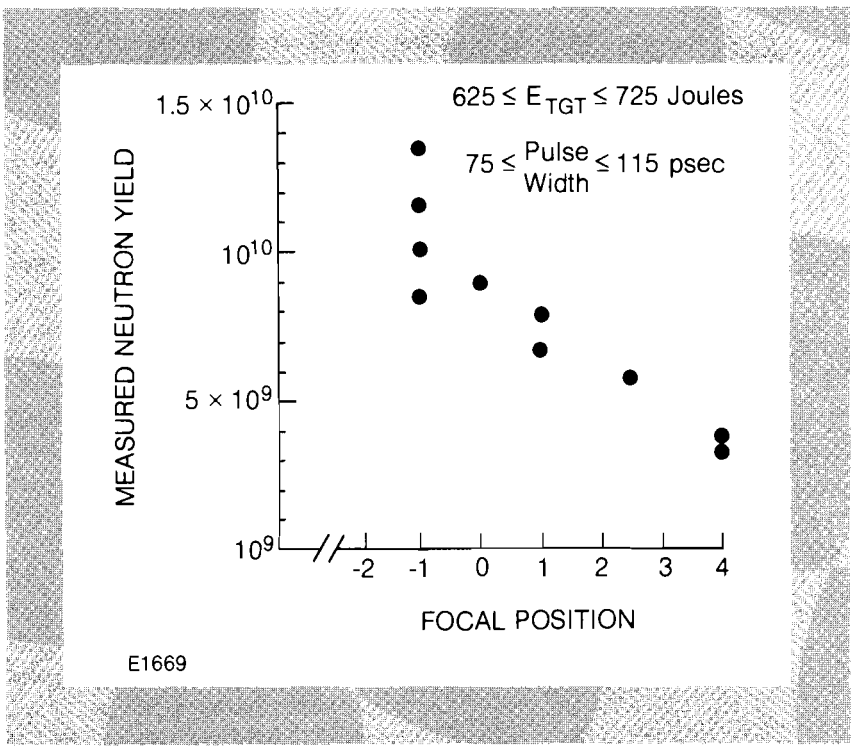

Fig. 6
Measured neutron yield versus focal position.

sured to simulated neutron yield is used. For the shot at − 1R, this yield ratio is 0.27; for the shot at + 4R, the ratio is 0.49. The better relative agreement of shot 6030 with simulation is attributed to its more uniform irradiation which led to a more spherical implosion symmetry. This symmetry is in better agreement with the assumption of one-dimensionality which underlies the code calculation.

It is interesting to note that target performance is only a factor of 2 higher for the uniform (+ 4R) shot than for the non-uniform shot (− 1R). This is an attribute of fast electron driven implosions in which energy smoothing due to the large fast electron range tends to reduce sensitivity to irradiation uniformity.

Neutron Yield Scaling

The observed dependence of neutron yield on specific absorbed energy, ε_A, is shown in Fig. 7. The reason for plotting the data against ε_A (absorbed energy divided by target mass) is that alpha particle and neutron time of flight spectra indicate that the DT ion temperature, θ_i, scales almost linearly with ε_A[6]; an approximate (±30%) relation is $\theta_i \approx 10\ \varepsilon_A$ where ε_A is in joules per nanogram and θ_i is in keV. The yields acquired for + 1R to + 4R focusing are consistent with a curve of simulated *LILAC* yields scaled by a factor of 2. The *LILAC* simulations

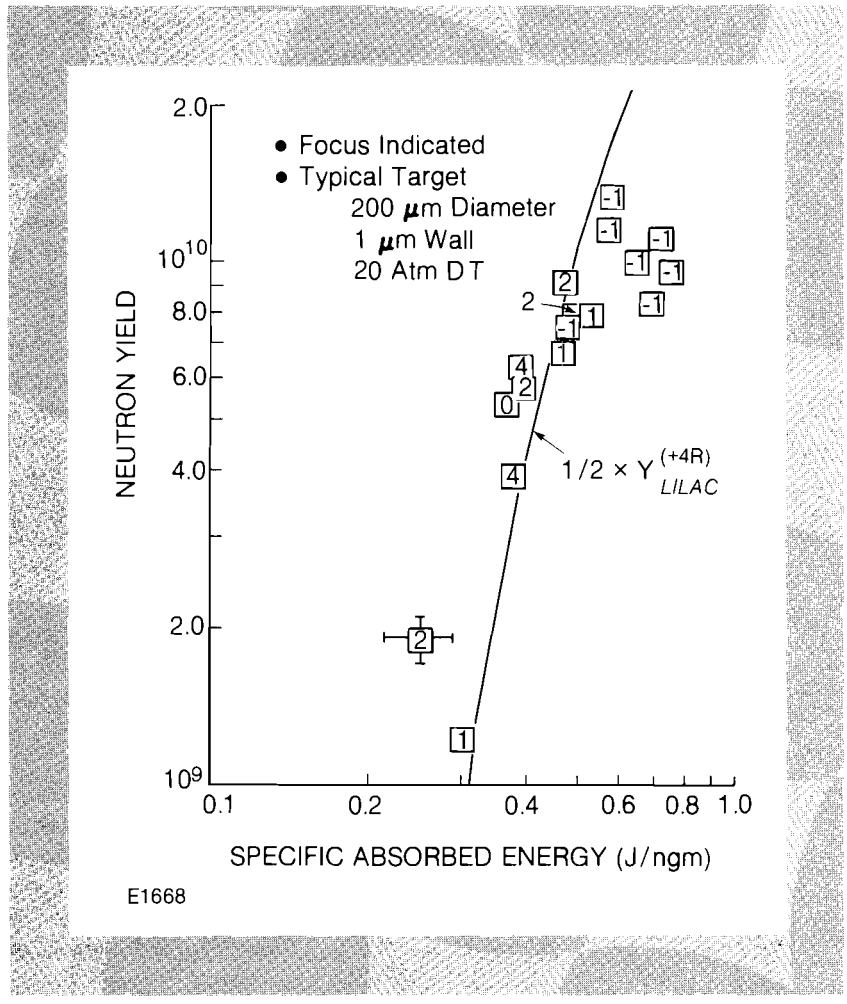

Fig. 7
Measured neutron yield versus specific absorbed energy.

were done for a focus of + 4R and a typical target of 200 μm diameter, 1 μm wall, and a 20 atmosphere DT fill. At $\varepsilon_A = 0.5$ J/ng, the curve of simulated yields scales as $Y_{LILAC} \sim \varepsilon_A^{3.9}$. This scaling is primarily due to the ion temperature dependence[7] of the Maxwell velocity-averaged DT cross section $<\sigma v>$ which, at an equivalent temperature $\theta_i = 5$ keV, varies as $\theta_i^{3.2}$. The relative normalization between the data and code is, in part, dependent on the code's simulation of focusing conditions which affects both the implosion symmetry and the partition of absorbed laser energy between fast ions and the implosion.

Fuel ρR

The Lawson Criterion for scientific breakeven is expressed as a requirement that the product, "ρR," of the density and radius in the compressed fuel be greater than ~0.3 gm/cm² for an ion temperature of about 5 keV. A method—called the "knock-on" diagnostic—has been developed to directly measure the fuel ρR. Track detectors[8] made from CR-39 are used to count the deuterium and tritium ions elastically scattered out of the fuel by 14 MeV neutrons. The observed number of D and T ions is proportional to the average fuel ρR at peak burn.

The feasibility of the knock-on diagnostic has been demonstrated by measuring (simultaneously) various portions of the velocity-squared (or E/A, kinetic energy per nucleon) spectrum of the D and T ions. A different thickness tantalum foil was used to slow and shift each part of the spectrum into an E/A range where both track registration and background discrimination can be achieved with the CR-39. To separate knock-on particles (deuterons and tritons) from the dominant background due to protons, track criteria based on velocity and range are used. Track diameter is used to determine particle velocity. A minimum particle range is established by requiring a spatially coincident pair of track diameters from the particle's entering and exiting the 150 μm thick CR-39.

Four spectral regions probed with different detector-foil combinations (tantalum thicknesses 50 μm, 75 μm, 95 μm, and 115 μm) are shown in Fig. 8; a fifth combination (160 μm thick) was used to make a null measurement by stopping all knock-on particles. Tracks were obtained from an integrated exposure to two similar OMEGA shots (shots 6037 and 6038). The bar graph at the bottom shows that the measured (shaded) and expected fractions of the total signal are consistent for each region of the E/A spectrum. This consistency demonstrates the feasibility of using track detectors to probe the knock-on spectrum. Moreover, this same data can be used to determine the average ρR for the two shots. The result is $\rho R \sim 1.5 \times 10^{-4}$ gm/cm² which is within 30% of the value predicted by *LILAC* simulation.

Summary

The OMEGA laser system has been activated for 24-beam implosion experiments at a wavelength of 1.054 μm. Good reproducibility has been demonstrated in the control of laser parameters such as total energy, beam balance, and pulse shape. The effect of irradiation uniformity on implosion symmetry, absorption fraction, and neutron yield has been studied. The neutron yields measured in initial exploding pusher experiments are reasonably consistent with expectations

based on *LILAC* computer simulations. In addition to the usual diagnostics for energy balance, x-ray imaging, and fusion yield, a new technique has been developed to directly measure the ρR of the compressed fuel.

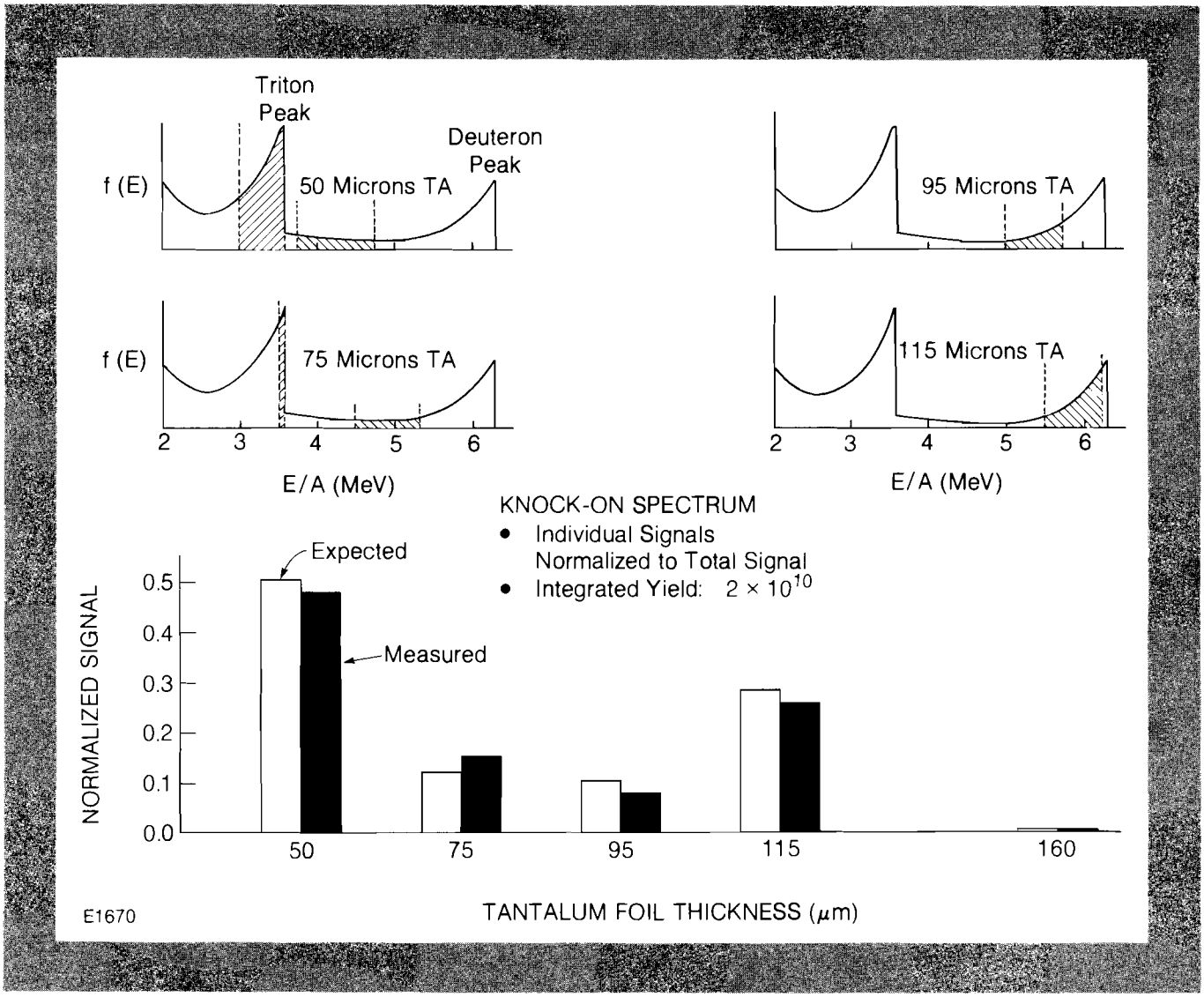

Fig. 8
Measurement of different intervals of the "knock-on" spectrum.

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Section 3
OTHER DEVELOPMENTS

3.A Capillary Gas Filling of Laser Fusion Targets

Introduction

Non-fuel gases are sometimes specified in inertial fusion (IF) targets to aid the diagnosing of the temperature, density, fusion yield and hydrodynamic stability achieved during driver-target interaction experiments and to calibrate various diagnostic instruments. For diagnostic gases other than helium and neon, the usual fuel gas permeation process into the glass microballoon (GMB) target fuel core is not a workable fill procedure because of the small permeation coefficient of glass. Various non-permeation techniques have been developed to load diagnostic gases into IF targets including adding gases by the drill-fill-plug technique,[1-4] adding gases during the GMB fabrication step (drop oven filling),[5,6] or by using some type of gas filling capillary.[7-9] A new fabrication technique has been developed to add diagnostic gases to IF targets by using a gas fill capillary. This technique is more general than those previously used and permits the addition to IF targets of arbitrary gases or gas mixtures over a wide density range.

Fabrication Technique

The production steps of the new technique for fabricating the capillary gas fill IF targets include: (1) attaching a GMB to a hollow glass mounting stalk, (2) laser drilling a hole through the GMB at the stalk location, (3) depositing any additional required target layers, (4) filling the target with the specified gas mixture, and (5) sealing closed the fill capillary to trap the gas. The gas fill capillary, equivalent in dimensions to the usual target mounting stalk, supports the target during the driver irradiation.

The mounting stalk is made from 1.5 mm diameter glass tubing that is drawn to a fine taper using a micropipet puller and that is then ground flat by ultrasonic agitation in water solution while held in contact with an alumina abrasive wafer. Typical dimensions of the drawn and ground tip of the stalk used for mounting a 250 μm diameter GMB are 14 μm outer diameter and 7 μm inner diameter.

The mounting stalk tip is wetted with adhesive and then cleared of any adhesive that may be drawn up into the hollow capillary by applying positive air pressure to the opposite end of the stalk. Fast setting epoxy, RTV silastic, and ultraviolet curing adhesive have been used to attach the GMB to the stalk. The low viscosity and long working time of the UV curing adhesive (Norland Optical Adhesive #60 UV) made it the easiest to use for this application.[10] Equally important, this material has superior adhesion and/or tensile strength properties as evidenced by surviving a higher gas fill failure pressure than did the other types of adhesives tested.

Drilling a hole through the GMB with a short-pulse length 1.05 μm wavelength laser at the location of the attached stalk is the next fabrication step.[11] Using the reverse drilling procedure the laser is focussed through the transparent GMB onto the position where the stalk is mounted.[12] Alignment is facilitated by having a CW helium neon laser coaxial with the drilling laser and by forming an aiming point on the interior surface of the GMB at the correct location. This is achieved by directing white light along the target stalk which serves as an optical waveguide to illuminate the location to drill the hole.

A photomicrograph of a mounted and drilled GMB is shown in Fig. 9. The GMB is 250 μm in diameter with a 1 μm thick wall. The mounting

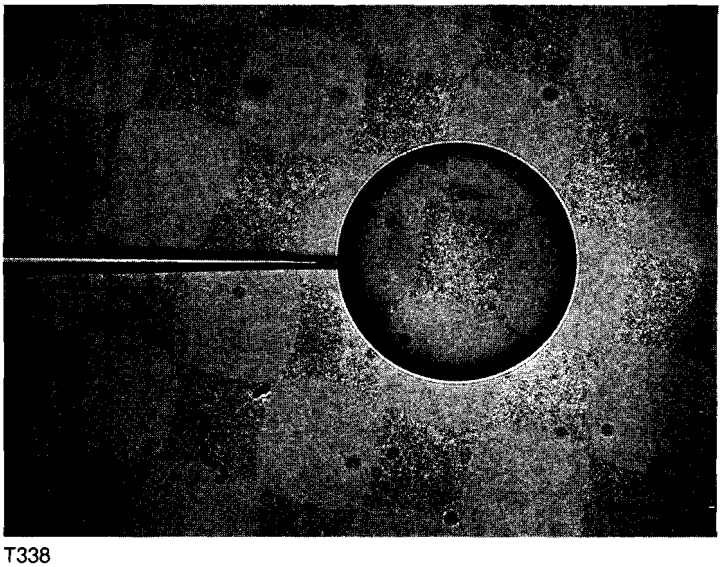

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Fig. 9
Photomicrograph of capillary stalk mounted glass microballoon (GMB). The 250 μm diameter has a 2.5 μm diameter hole drilled through its wall at the stalk position.

stalk diameter at the GMB surface is 10.5 μm. Figure 10 is a scanning electron micrograph of the drilled hole as viewed from the GMB interior. As shown in Fig. 10, the hole is approximately 2.5 μm in diameter at the interior surface of the GMB and is tapered. The sub-micrometer high ridge encircling the hole is formed during the laser drilling opera-

tion. At this step in the fabrication process, other materials can be deposited onto the stalk mounted GMB to form pusher and ablation layers, or hemispherical shells can be assembled over the stalk mounted GMB to form a colliding shell target.[13]

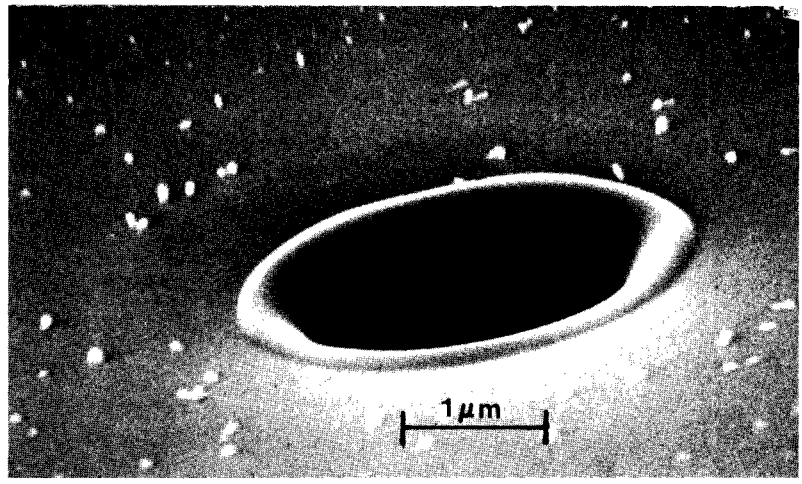

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Fig. 10
Scanning electron micrograph of the 2.5 μm diameter laser drilled hole through the GMB as viewed from the GMB interior. The interior diameter of the capillary stalk at the attachment point is approximately 5 μm.

Adding a single gas or a gas mixture to the target through the capillary mounting stalk is the next fabrication step. Due to the limited conductance of the fill capillary and laser drilled hole in the GMB, no attempt is made to evacuate the target prior to filling. Rather, the target is dilution flushed to reduce gas impurities. The target is filled to about 20 atm pressure with the desired gas, held for a few minutes to allow equilibration, rapidly bled down to a pressure just above atmospheric, and then this cycle is repeated five additional times. This dilution flushing process reduces gas impurities in the target to much less than a fraction of a percent.

After the last flush cycle, the target is filled to the desired pressure and the fill capillary is closed and sealed. A steel ball, coated with UV adhesive and loaded into the glass tubing before the start of the flushing cycle, is moved up to the tapered position in the tube with an external magnet and irradiated with UV light to set the adhesive. Figure 11, a photomicrograph of the steel ball sealed in the glass stalk, shows the dark band of the UV adhesive contact circle. Helium leak tests of this type seal show leak rates less than 1.4×10^{-9} STDcc/s. The gas reservoir volume of the stalk connected to the target is determined by the steel ball diameter and the taper of the glass mounting stalk. The calculated reservoir volume in the fill capillary shown in Fig. 11 is 8.2×10^{-6} cm^3, approximately 8.5 times the volume of the mounted GMB. This fabrication technique permits the addition of most gases or gas mixtures in IF targets up to a pressure of 22 atm, a value determined by the strength of the GMB-capillary fill stalk adhesive material.

Summary

A general fabrication technique for adding diagnostic gases to IF targets has been described. This technique offers distinct advantages to target fabricators. By keeping the reservoir volume in the fill capillary small, the technique can be used with tritiated gas mixtures. In addition, the capillary gas filling fabrication technique has been used to

construct a target which serves as a gas fill calibration standard for interferometric characterization.[14]

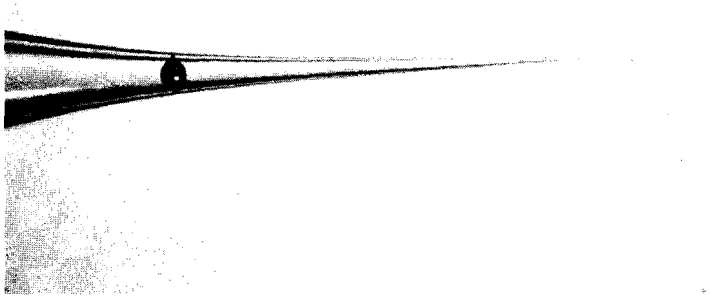

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Fig. 11
Photomicrograph of capillary gas filled and sealed GMB. The adhesive contact circle on the 250 μm diameter steel sealing ball is evident.

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3.B Kinetic X-Ray Diffraction of Purple Membrane

Since the demonstration at LLE of good quality x-ray diffraction photographs from membrane specimens using a laser plasma x-ray source just over one year ago,[1] we have been preparing to perform kinetic protein structure experiments. This note will serve as a progress report on these experiments and show the first kinetic x-ray diffraction results obtained using the laser plasma source.

The protein system we are studying is the purple membrane of the *Halobacterium halobium*. Purple membrane contains a single protein, bacteriorhodopsin (BR), which serves as a light activated hydrogen ion pump.[2] The BR protein contains retinal, the same chromophore which activates the mammalian visual process. As a result, BR may serve as a model transmembrane ion pump, as well as a model for visual phototransduction. The goal in our experiment is to observe conformational changes in the BR protein during the photopumping cycle.

Our experimental arrangement is shown schematically in Figure 12. A pulse of light is used to stimulate photoactivity in our protein specimen. This light pulse is synchronized to the fire command signal of the GDL laser system, the output of which is used to produce an intense, point source pulse of monochromatic x-rays to interrogate the molecular structure of the protein. The purple membrane system is organized in the form of a perfect two-dimensional crystal; the naturally occurring membrane fragments are 50 Å thick and typically have a lateral extent of 1-2 μm. The static structure of the protein has been worked out to 7 Å resolution using a variety of biochemical and physical techniques including Fourier transform electron microscopy and x-ray diffraction.[3,4] Recently the complete amino acid sequence of BR has been deduced.[5,6] In addition, a model has been proposed for the positions of the amino acids in the BR structure.[7]

A specimen consisting of a large number of membrane fragments may be studied in a standard power diffraction camera. In our experiment a special focussing x-ray diffraction camera was constructed to enable a laser produced plasma to serve as the x-ray source,[1] providing nanosecond time resolution of the protein structure.

To stimulate our BR samples we have assembled the laser system shown in Figure 13. A CW pumped Nd^{+3}:YAG oscillator is Q-switched by an acousto optic modulator to produce pulses of 150 nsec duration at 1.064 μm. In our experiments the acousto optic Q-switch is external-

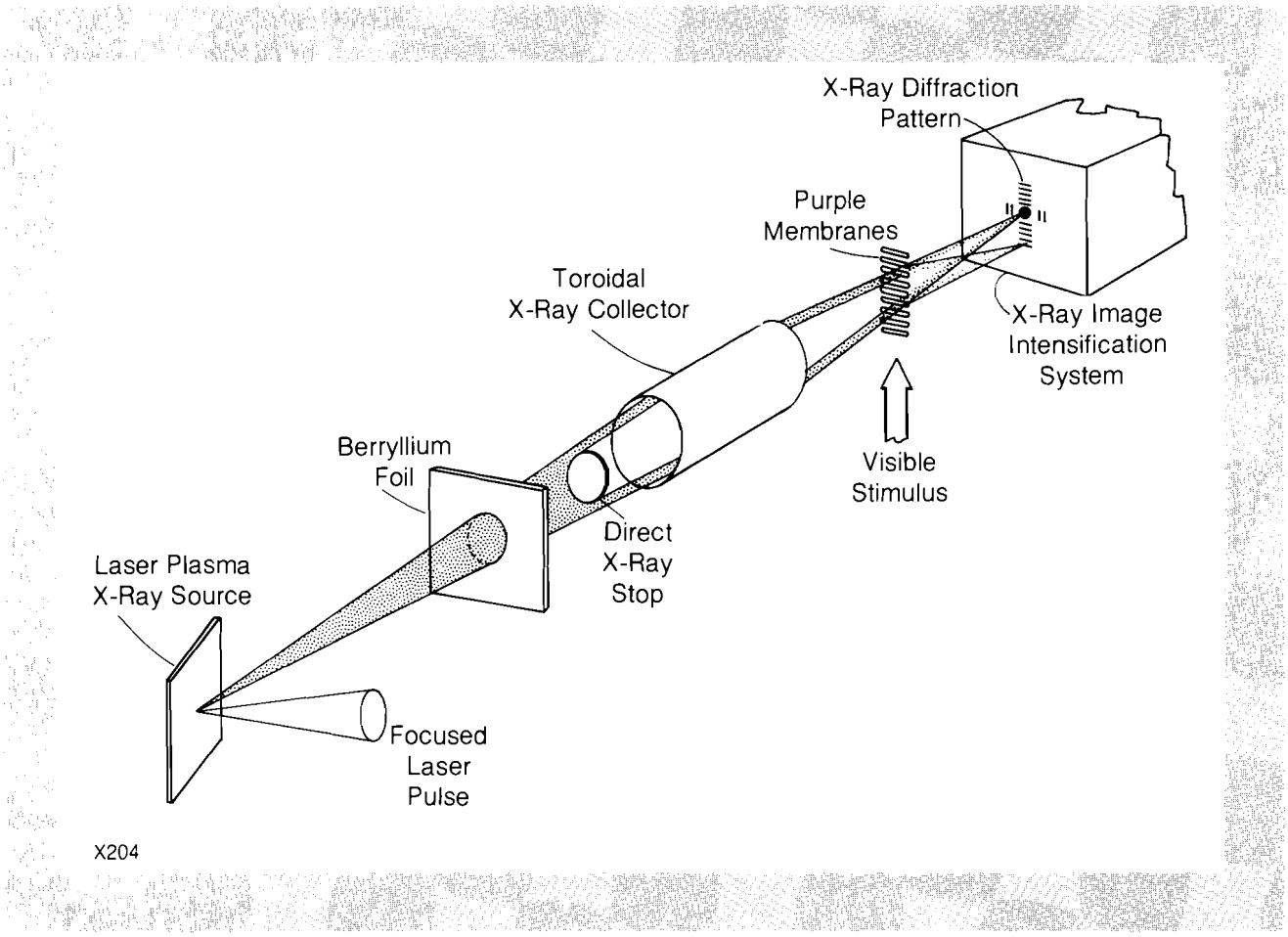

Fig. 12
Conceptual layout of pulsed x-ray diffraction experiment.

ly triggered by a burst generator, allowing us to produce a pulsetrain of arbitrary length, with interpulse spacings down to 40-50 μsec. The train of pulses is then amplified by a double pass, pulsed pumped, Nd^{+3}:glass amplifier and focussed into a temperature tuned CDA crystal to produce a train of 0.53 μm pulses. This pulsetrain is transported to our BR specimen in our x-ray diffraction camera by a series of dielectric coated mirrors which attenuate the unconverted 1.064 μm radiation from the crystal.

The optical stimulus pulsetrain is supplied to our BR specimen by placing in the x-ray diffraction camera a dichroic mirror consisting of a thin (600 Å) aluminum coating on a 1.5 μm thick mylar foil. This thin mirror is transparent to the focussed soft x-ray radiation from the laser plasma and highly reflecting to the green light pulses.

Since our demonstration of single shot recordings of protein x-ray diffraction patterns we have constructed a lens coupled, two-dimensional, digital vidicon recording system for our camera. The diffraction pattern is formed on a ZnS:Ag scintillator deposited on a fiberoptic plate which is directly coupled to a 25 mm Amperex microchannelplate image intensifier. The image intensifier output is lens coupled to the PAR OMAII vidicon and 1216 controller which are operated by interfacing to a DEC 11/23 computer equipped with 128 K of 16 bit memory,

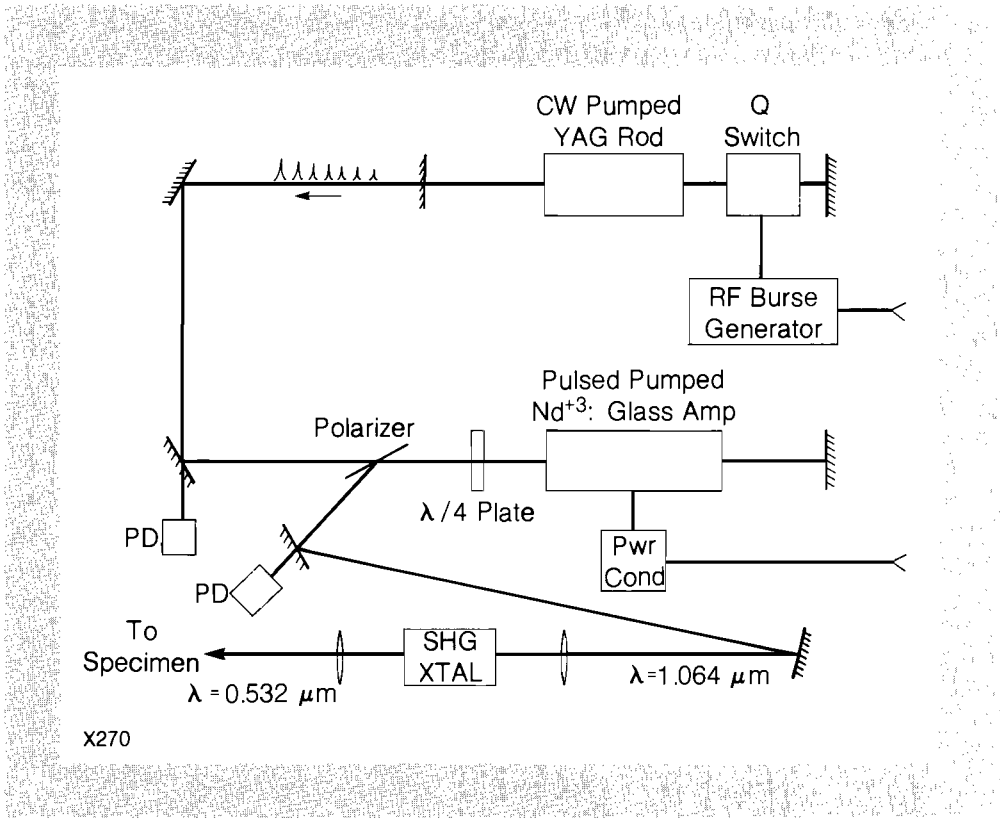

Fig. 13
Photostimulus system for purple membrane.

an RL-01 disc drive, and a Lear-Sigler graphics display terminal. Software has been written to permit fully two-dimensional scanning of a 256 x 512 point image field by the OMA head. To enable us to record the low light level events from our x-ray scintillator the OMA head is mounted in a refrigeration unit which operates at −40 °C. The vidicon unit is slow scanned, requiring approximately 10 seconds to read an x-ray diffraction pattern into the computer.

At this point our data reduction techniques are still under development and several components in our x-ray camera are awaiting final installation. However, we have been able to observe stimulated changes in purple membrane diffraction patterns during preliminary tests of our system.

In our recent experiments we have converted our laser target irradiation facility to the ultraviolet, third harmonic output of the GDL facility.[8] This change was dictated by the measurement of greatly enhanced conversion of high intensity UV laser light into x-ray radiation in previous GDL experiments.[9] In the results presented here approximately 40 Joule, 490 psec FWHM pulses of third harmonic laser energy were focussed by a 14 cm diameter f/12 lens to a 120 μm diameter focal spot onto flat targets made of saran foil. The strongest emission lines are produced by the helium-like and hydrogen-like ions of chlorine in the wavelength range of 3-4.5 Å. By foil filtration in the x-ray camera a single group of lines with overall spectral width of less than 1% may be isolated at 4.45 Å with high efficiency.[1] The use of this radiation wavelength dictates a protein specimen thickness of 50-60 μm for optimum x-ray diffraction efficiency. With purple membrane,

such specimen dimensions result in an optical density in the range of 2-3 at the wavelength of our stimulus system. (The use of shorter wavelength x-ray radiation would dictate the use of thicker specimens which would prove much more difficult to photostimulate. The use of longer wavelength radiation would reduce the potential structural resolution which could be obtained and prevent simple foil filtration for monochromatic radiation.)

Our specimens were prepared by air drying a centrifuge concentrated suspension of membranes obtained from a purified preparation supplied to us by Dr. Janos Lanyi.[10] The samples were air dried onto saran foil supports which also served to monochromatize the plasma x-ray radiation. For the experiments reported here the samples were placed directly in the x-ray diffraction camera which was then evacuated.

Representative results are shown in Fig. 14. In this figure we plot the average diffracted x-ray intensity observed as a function of linear distance on the scintillator plate away from the axis of our camera. To obtain these plots the digitized patterns are computed to assign each point a radius value from the coordinates corresponding to the camera axis. (The latter coordinates are determined initially by trial and error.) The average intensity for each radius value is then computed. Apart from this processing no other corrections to the raw data have been made in Fig. 14.

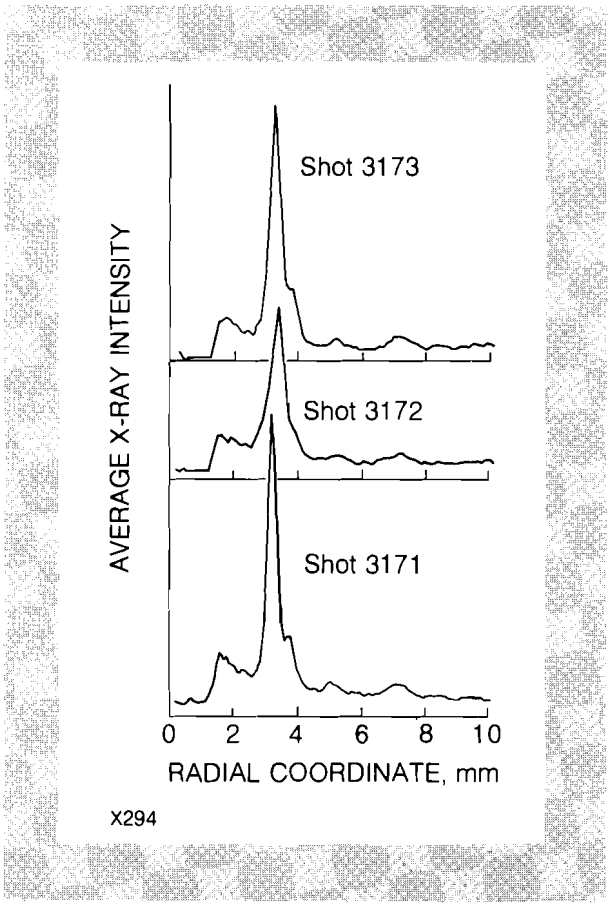

Fig. 14
Time-resolved x-ray diffraction from dried purple membranes of the halobacterium halobium.

The diffraction patterns for three shots are shown, all taken using the same purple membrane specimen. Shot 3171 was taken with the specimen unstimulated. On shot 3172 approximately 300 microjoules of 0.53 μm energy was delivered to a 1 mm² area of the specimen in a train of 5 pulses. A train of pulses was used to stimulate this system because during any photoactivation event only 30% of the BR can be "launched" on the photopath, the remainder of the system being constrained to the ground state. However, 2 μsec after an impulse excitation, 30% of the remaining ground state population may be photoactivated. By repeating this process (i.e. using a pulsetrain) we can reversibly photoactivate the entire system, as our measurements of the time dependent absorption have shown. The stimulated diffraction pattern was recorded 50 msec after the stimulus pulsetrain was delivered. It shows a distinct shift in the position of the strongest diffraction peak and an overall reduction in the diffraction efficiency of the sample. (The x-ray beam samples an annular area of the specimen approximately 0.6 mm in diameter, well inside the overall dimensions of the stimulated region.) On the next shot, number 3173, we recorded an unstimulated diffraction pattern again, and observe a return to the original pattern features, indicating that the system is recycling. However, we observed that repeated stimulation of the sample on subsequent shots caused the diffraction pattern to return to that of shot 3172 and to remain in that form for the rest of the day even when left in the dark. We observed that if the specimen were then exposed to normal laboratory atmosphere overnight, the diffraction pattern would be restored to that of shot 3171 the next morning. It appears that in the dried state a certain portion of the molecules cannot complete the photocycle (proton release followed by proton uptake) due to diffusion and loss of some of the hydrogen ions. Rehydration in normally humid air appears to correct this problem and suggests that we may observe a different time course of structural evolution when we repeat the experiment with fully hydrated specimens.

We have recently completed tests with a special specimen chamber which supports a humidified atmosphere for the specimens inside the camera. Stimulated experiments with this chamber and with an improved scintillator detector system should begin soon. Exciting possibilities for a great many kinds of structural kinetic experiments are suggested by the present results, particularly as developments in laser and materials technology continue to make higher x-ray intensities available.

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Section 4
NATIONAL LASER USERS FACILITY NEWS

This report covers the activities of the National Laser Users Facility (NLUF) during the quarter July to September 1981. During this period two users were on the facility. Larry Knight (Brigham Young University) completed the data collection portion of his user experiment, and Ray Stringfield (Physics International Co.) spent two weeks testing the operation of a particle spectrometer on OMEGA. An additional user, George Miley (University of Illinois), visited the facility to discuss the planning of his experiment.

Larry Knight and David Gaines (Brigham Young University) conducted two weeks of shots on the Glass Development Laser (GDL) to examine the x-ray spectra from laser irradiated targets using "multilayer" crystals. A total of 22 shots were taken on the GDL for their experiment. Their experiment examined the x-ray spectra from different target materials including both flat and curved crystal configurations for the elements of fluorine, titanium, and aluminum. They will now analyze the observed spectra and crystal parameters, examining both resolution, reflectance, and plasma parameters.

Ray Stringfield (Physics International Co.) spent two weeks on OMEGA, testing a spectrometer which measures alpha particles and protons from the fusion reaction. The purpose of their experiments is to measure the electrostatic potential caused by the escaping fast electrons. A total of 16 shots were taken with exploding pusher targets for these tests. The next phase will be to use the spectrometer for detailed electrostatic potential measurement during January 1982.

George Miley (University of Illinois) will have a time-of-flight spectrometer installed on the OMEGA target chamber. The purpose of this experiment is to measure the energy loss of fusion products (alpha particles, protons, and tritons) through the hot outer regions of the target. The experiment is expected to be run in early 1982. Barukh Yaakobi's (University of Rochester) curved crystal spectrometer is under construction and his user experiment is expected to begin target shots in late 1981.

The experiments described above represent the first set of users at the National Laser Users Facility. All of these are supported by contracts with the U.S. Department of Energy.

The next set of users includes Francis F. Chen and Chan Joshi (UCLA) and Nizarali A. Ebrahim (Yale University); Uri Feldman and George Doschek (Naval Research Laboratory); Hans Griem and J. Adcock (University of Maryland); and C. F. Hooper (University of Florida). These user contracts have been funded by the U.S. Department of Energy and will begin in 1982. Additional information on these user experiments can be found in the last issue of the LLE Review.

The NLUF will be represented at the 3rd American Physical Society Plasma/Fusion Show in New York City (October 13-15), and at the 9th Symposium on Engineering Problems of Fusion Research in Chicago (October 25-27).

Further information on the NLUF is available from:

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(716) 275-2074

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