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LAYERED-DISK TRANSPORT EXPERIMENTS AT
1.064 μ m and 0.355 μ m

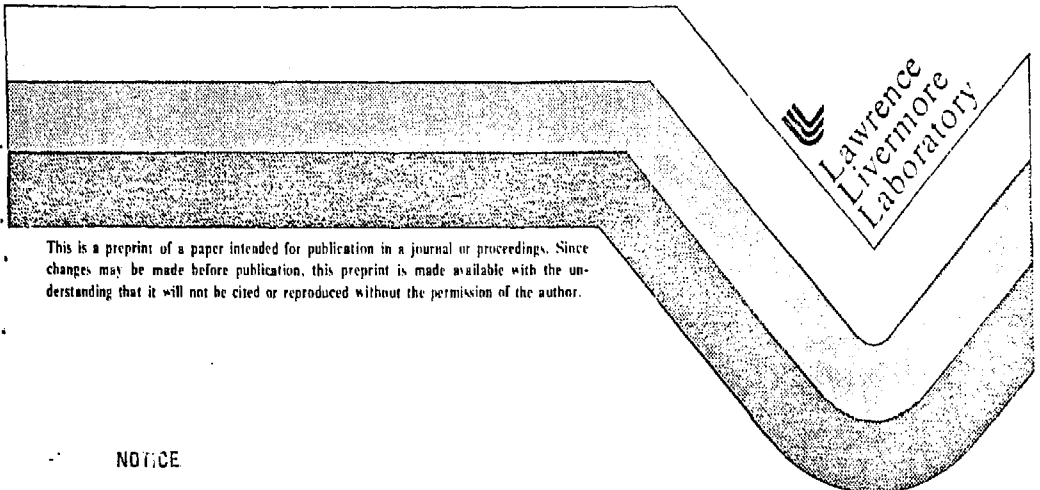
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LAYERED-DISK TRANSPORT EXPERIMENTS AT

1.064 μm and 0.355 μm *

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Abstract

The results of electron transport experiments conducted at 1.064 μm and 0.355 μm with the Argus Laser will be presented. The experiments were conducted at a fixed absorbed intensity and pulse width of approximately $1\text{-}2 \times 10^{14} \text{ W/cm}^2$ and 600 psec (FWHM) respectively. Energy on target ranged from 30 to 90 joules. To explore axial transport a variable thickness beryllium layer is coated onto an aluminum substrate. The effectiveness of electron heat conduction is studied by measuring the fall-off in aluminum X-ray yield (line and continuum) as the beryllium thickness is increased. In addition to the axial transport studies, lateral conduction is examined by placing the axial transport target onto a titanium disk.

*Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract #W-7405-ENG-48.

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Electron transport plays a central role in the physics of laser driven inertial confinement fusion. Electrons transport energy from the absorption region ($n_e \leq n_{crit}$) into the overdense plasma, regulating the target ablation and affecting the temperature, density, and velocity profiles of the ablating plasma. These profiles in turn, control both the overall target absorption and its partition between collisional (thermal heating) and collective (suprathermal electron production) processes. Important quantities such as thermal x-ray production and hydrodynamic efficiency are thus strongly influenced by the effectiveness of electron energy transport. Furthermore, electron thermal conduction can affect the overall symmetry of the capsule implosion by determining how non-uniformities in the laser deposition region (caused by passive beam modulation and/or filamentation) are transmitted to the ablation front.

The heat-flow rate inferred from experiments has generally been parametrized by comparing it with that calculated by a hydrodynamic computer code which employs flux-limited diffusion. Such codes generally use Spitzer's thermal conductivity $[r]$ until the heat-flux reaches a free-streaming limit in the form of:

$$Q_{fs} = f_e n_e m_e v_e^3 = f_e n_e m_e^{-1/2} (k T_e)^{3/2} \quad (1)$$

where f_e is a flux-reduction factor (commonly referred to as the flux limiter). Heat flow in such a code shifts from conduction-limited to flux-limited in regions of the plasma where the temperature scale-length becomes steep compared with the mean-free-path of electrons having velocity $\sim 2-3v_e$ (the thermal velocity). This shift to flux-limited transport occurs most strongly in the over-dense region, just beyond the laser deposition region. Heuristic estimates suggest $f_e \sim 0.2-0.6$ in the absence of significant turbulence or electric or magnetic field effects. More recently, Fokker-Planck computer calculations have obtained heat transport rates which can be approximated by flux-limited diffusion modelling in hydrodynamic codes using $f_e \sim 0.06-0.2$.

An "anomalous" reduction in the flux limiter by a factor of 5 to 10 from classical values may thus be due to the inadequacy of the simple, single group flux limited diffusion model in the presence of the steep temperature gradients normally found in laser produced plasmas.

However, a wide variety of experiments have generally led to inferred flux limit values of $f_e \sim .03$. This value is even lower than what at present can be justified theoretically even with the more recent advances. The majority of the experiments, however, have been conducted with short pulse ($\tau \sim 100-300$ psec), high intensity ($I \sim 5 \times 10^{14} - 10^{16} \text{ W/cm}^2$), $1.064 \mu\text{m}$ light in which both thermal and suprathermal electron transport plays an important role. Such irradiation conditions are far removed from the long pulse ($\tau \geq 1$ nsec), moderate intensity ($I \leq 5 \times 10^{14} \text{ W/cm}^2$), and short wavelength ($\lambda_L < 1.064 \mu\text{m}$) irradiators planned for future high gain capsule implosions. Moreover, even without the additional difficulties imposed by the presence of long range suprathermal electrons, the non-linear interactions of the laser-plasma coupling processes makes the determination of electron transport properties from integrated experiments very difficult. The presence of substantial levels of suprathermal electrons complicates both the physics and the interpretation of the experiments to the level that detailed transport properties of the electrons cannot be reliably inferred.

In this report we present the results of layered disk experiments (beryllium coated aluminum targets) designed to observe the characteristics of energy transport in the highly collisional plasmas produced by long pulse, moderate intensity light at laser wavelengths of $1.064 \mu\text{m}$ and $0.355 \mu\text{m}$.

Vugraph 1

This viewgraph shows the title of the talk and the major contributors to the experiment

Vugraph 2

Many interesting experiments have been conducted at Argus during the past 18 months at laser wavelengths of 1.064 μ m, 0.532 μ m, and 0.355 μ m. Some of the talks that present the results are given in this viewgraph.

Vugraph 3

In this viewgraph we show a schematic of the target that was used, the diagnostics that were employed, and the laser irradiation conditions.

The targets consisted of aluminum microdisks overcoated with varying thicknesses of beryllium. The Be thicknesses ranged from 0.27 to 6.5 μ m. For the shock measurements described below the Al had an ion melted channel 40 μ m wide and 3.7 μ m deep. The thickness of the Al was 21 μ m (base of the channel). On some of the shots, to examine lateral transport and prevent energy flow to the rear of the target, a 4mm diameter titanium shield with a 340 μ m diameter hole was placed on the aluminum disk.

A multitude of diagnostics were employed on these experiments. Target absorption was measured using an enclosing scattered light box calorimeter. Three multichannel K edge filtered spectrometers utilizing pindiodes and fluor photomultiplier combinations measured the x-ray spectra from 3.5keV to 100keV. Line emission the Al and Ti was measured with crystal spectrometers. The yield and time dependency of the subkilovolt x-rays were measured with two multi-channel K and L edge filtered x-ray diodes and a 3 channel x-ray streak camera. The spatial profile of the x-ray emission was measured with a 4 channel (0.28keV, 0.6keV, 1.2keV, 2.5keV) x-ray microscope. Finally, an imaging optical streak camera measured the time of arrival and speed of the laser ablation launched shock wave at the rear of the target.

The irradiation conditions at both 1.064 μm and 0.355 μm were chosen so that the absorbed irradiances at both wavelengths were identical and that the interaction physics were classical, i.e., suprathreshold electron production was minimal. The laser parameters are summarized in Table 1.

Table 1

	LASER PARAMETERS	
	1.064 μm	0.355 μm
Energy (J)	~ 90	30
τ (ps)	600-700	600-700
Spot size dia (μm)	240	240
Peak Incident Intensity	$\sim 3 \times 10^{14}$	$\sim 1 \times 10^{14}$

Vugraph 4

We summarize the absorption values obtained in these experiments. The enhanced absorption obtained with $0.355\mu\text{m}$ is readily observed. In addition, a slight increase in absorption at $1.064\mu\text{m}$ is seen as the target Z increases from Be ($Z = 4$) to Al ($Z = 13$).

Vugraph 5

The suprathemal x-ray yield for Al at both $1.064\mu\text{m}$ and $0.355\mu\text{m}$ is displayed in this viewgraph. In the $1.063\mu\text{m}$ case, the x-ray spectrum implies a suprathemal electron distribution at a temperature of $\sim 10\text{keV}$ which contains about 10^{-2} of the absorbed energy (hydro losses are neglected). A surprising but similar temperature is seen at $0.355\mu\text{m}$, although, at a much lower energy content ($\sim 10^{-4}$ of absorbed energy).

Vugraph 6

In this viewgraph we show an image of the back reflected light from the target with $0.355\mu\text{m}$ irradiation. High spatial frequency modulation is observed which may represent beam filamentation. This may explain the low level hot electron component inferred from the x-ray spectrum.

Viewgraph 7

In this figure we show the surprising fall-off in the suprathemal x-ray yield as the beryllium overcoat is added to the aluminum. For example, at $0.8\mu\text{m}$ Be thickness the 70keV x-ray yield falls by a factor of 6 compared to that of pure aluminum. This result shows that the electrons do not radiate in the Al substrate. This maybe due to 1) reduced suprathemal electron production in the Be plasma; 2) increased fast ion losses in the Be plasma; or 3) that the fast electrons are inhibited from reaching the aluminum.

Vugraph 8

In this viewgraph we show a comparison Al line spectrum from 1.064 μ m and 0.355 μ m irradiation. The emission with the short wavelength light is about 5 times higher per incident joule than that from the 1.064 μ m irradiation. The spectral bin includes the resonance lines of helium-like and hydrogenic aluminum.

Vugraph 9

Here we show the rapid fall-off in the Al line emission as the Be thickness is increased from .54 μ m to 1.5 μ m. The laser wavelength is 0.355 μ m.

Viewgraph 10

The fall-off in the He α resonance line with increasing Be thickness is shown for both 1.064 μ m and 0.355 μ m irradiation. The increased ablation depth at the shorter wavelength is clearly seen. An e-folding thickness of \sim 0.3-0.4 μ m is observed at 1.064 μ m whereas \sim 1 μ m is inferred at 0.355 μ m.

Vugraph 11

In this viewgraph we show a similar behavior of the subkilovolt x-rays as the Be thickness is increased for both wavelength irradiations. Larger burn thru depths are also implied at 0.355 μ m from this data.

Vugraph 12

Here we summarize the shock velocity measurements obtained with the optical streak camera. A timing fiducial and the ion milled channel on the target allow us to measure both the shock transit time and the shock velocity. Shock speeds of 2km/sec and 2.5km/sec were obtained at 1.064 μ m and 0.355 μ m respectively. These implied pressures are 6MB and 10MB. These results show the enhanced pressures obtained with the shorter wavelength for identical absorbed irradiances.

Vugraph 13

Here we summarize the preliminary results of the experiments.

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LAYERED DISK TRANSPORT
EXPERIMENTS AT $1.064\ \mu\text{M}$ AND $0.355\ \mu\text{M}$

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D. L. MATTHEWS, N. C. HOLMES, G. TIRSELL, R. J. TRAINOR, W. C. HATCHER,
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1981 APS MEETING, DIVISION OF PLASMA PHYSICS

ADDITIONAL PRESENTATIONS OF INTEREST
(EXPERIMENTS AT THE ARGUS LASER)

1E2 (W. MEAD, ET.AL.), 1E3 (J. TRAINOR, ET.AL.),
2E14 (C. MAX, ET.AL.), 5G9 (D. PHILLION, ET.AL.),
5U1 (F. ZE, ET.AL.), 5U2 (R. TURNER, ET.AL.),
5U3 (G. STRADLING, ET.AL.) 6A2 (K. MANES)

WAVELENGTH SCALING



The irradiation conditions for the layered target experiments were chosen to equalize the absorbed intensities at $1.064 \mu\text{m}$ and $0.355 \mu\text{m}$

$\tau_L \sim 600-700 \text{ psec}$

Laser spot (dia) $\sim 250_{-20}^{+50} \mu\text{m}$

$1.064 \mu\text{m}$

$(90 \text{ J}, I_{\text{inc}} \sim 3 \times 10^{14} \text{ W/cm}^2)$

F_{ABS} :

Be

$32 \pm 5\%$

Al

$39 \pm 5\%$

$0.355 \mu\text{m}$

$(30 \text{ J}, I_{\text{inc}} \sim 1 \times 10^{14} \text{ W/cm}^2)$

F_{ABS} :

Be

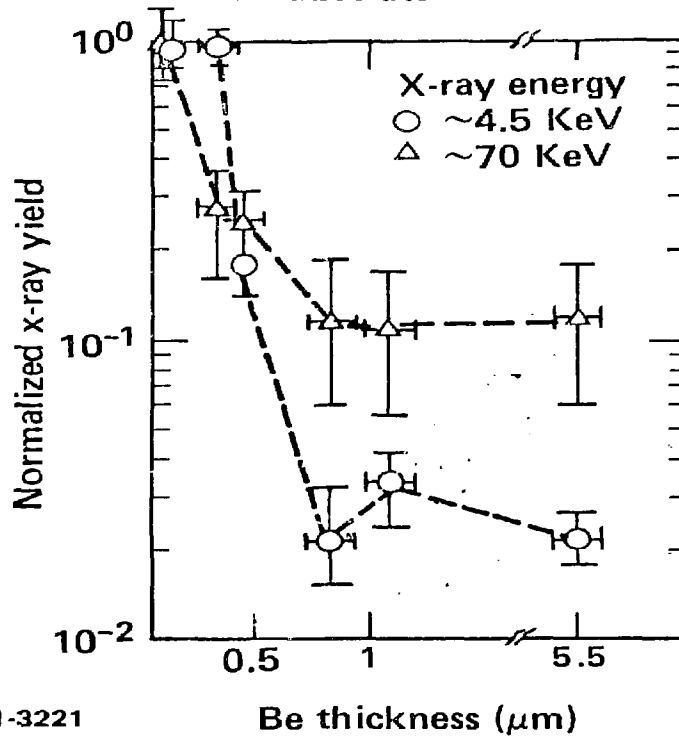
$90 \pm 5\%$

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WAVELENGTH SCALING (ELECTRON TRANSPORT)



Continuum X-ray Emission Falls Rapidly as the Be Layer Thickness is Increased on the Al Substrate



$$\lambda_L = 1.064 \mu\text{m}$$

$$I_{\text{ABS}} = 1.5 \times 10^{14} \text{ W/cm}^2$$

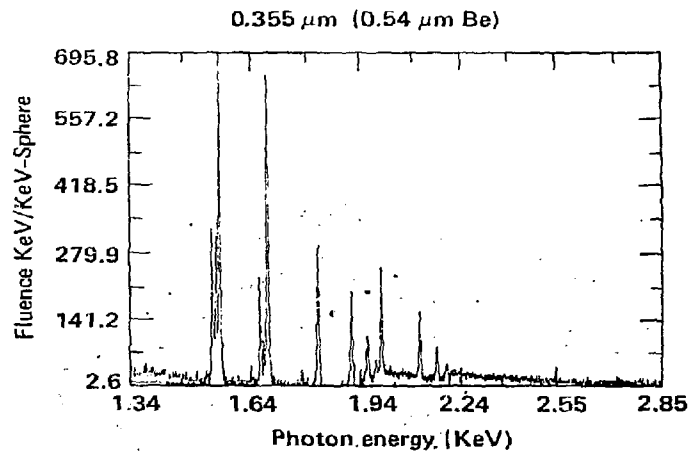
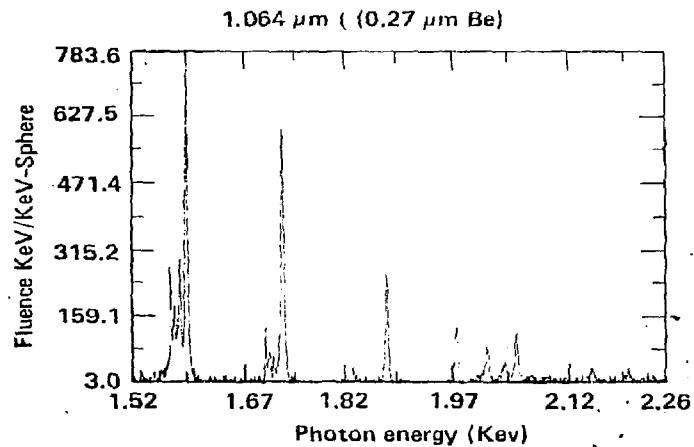
$$\tau_L \sim 600\text{-}700 \text{ psec}$$

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WAVELENGTH SCALING (Electron Transport)



Aluminum Spectra

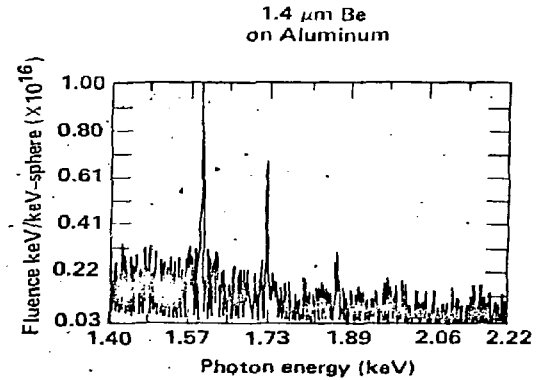
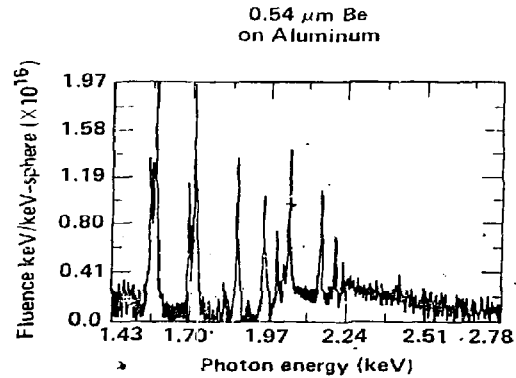
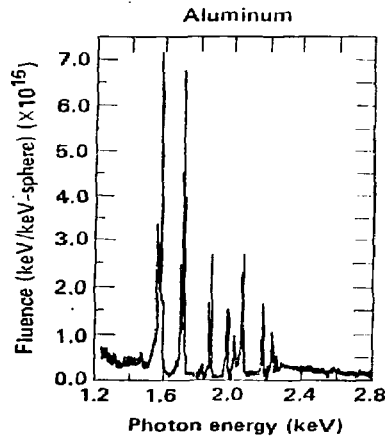


$3\omega_0$ TRANSPORT



Aluminum line spectra depends strongly on the Be layer thickness

$\lambda_L = 0.355 \mu\text{m}$ $I \sim 10^{14} \text{ W/cm}^2$ $\tau \sim 500\text{-}700 \text{ psec}$

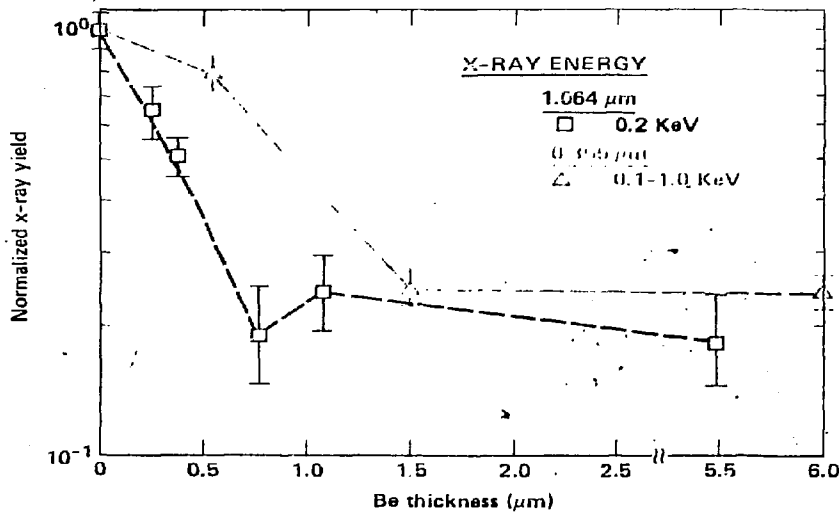


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WAVELENGTH SCALING (Electron transport)



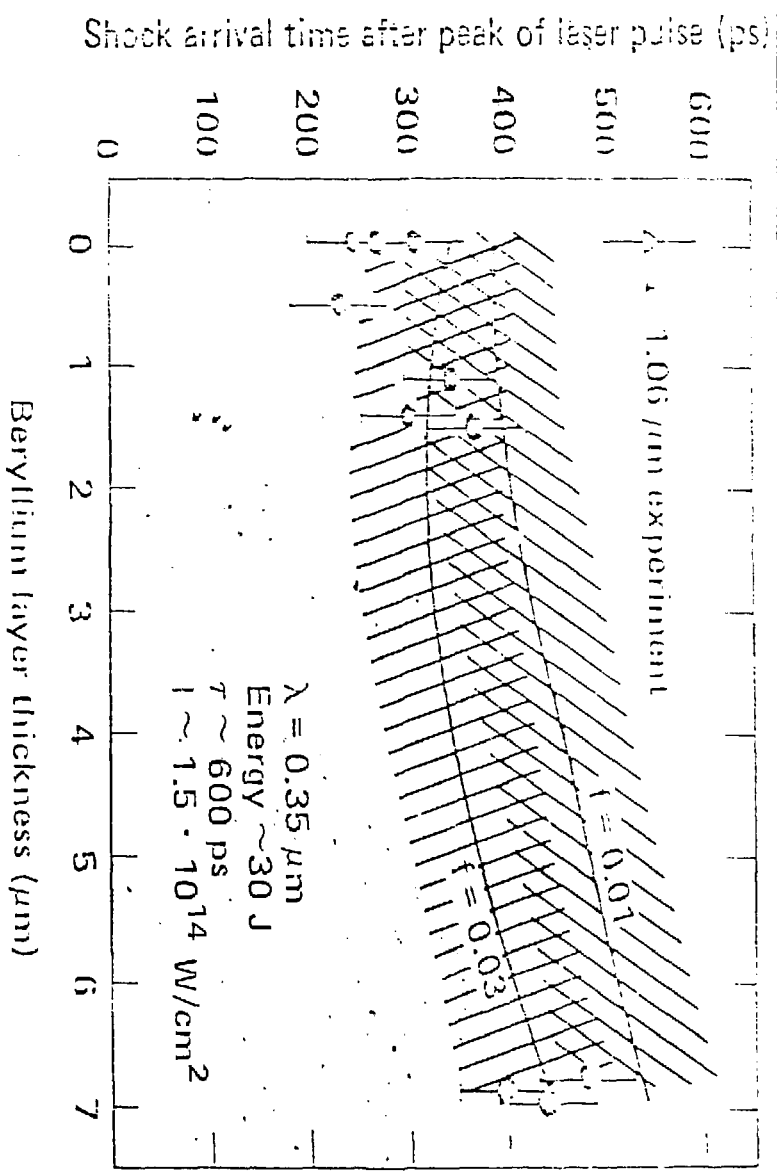
Sub Kilovolt x-ray emission implies an enhanced burn through depth as the laser wavelength is decreased from $1.064\mu\text{m}$ to $0.355\mu\text{m}$



$$I_{\text{ABS}} \sim 1.5 \times 10^{14} \text{ W/cm}^2$$

$$\tau_L \sim 600\text{-}700 \text{ psec}$$

SHOCK TRANSIT TIME DATA FOR $\lambda = 0.35 \mu\text{m}$
 INDICATE STRONGER SHOCK WAVES

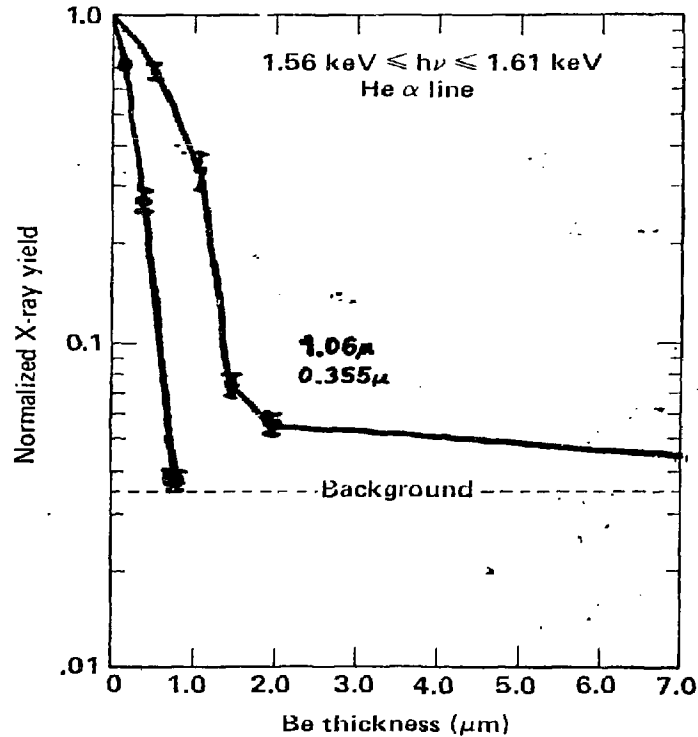




SUMMARY:

- LOW LEVELS OF SUPRATHERMAL ELECTRONS ARE INFERRED
AT BOTH $1.064 \mu\text{M}$ ($\sim 10^{-2} E_{\text{ABS}}$)
AND $0.355 \mu\text{M}$ ($\sim 10^{-4} E_{\text{ABS}}$)
- SUB KILOVOLT X-RAYS AND LINE RADIATION MEASUREMENTS
IMPLY ENHANCED BURN THRU DEPTHS AS THE LASER
WAVELENGTH DECREASES FROM $1.064 \mu\text{M}$ TO $0.355 \mu\text{M}$.
- FOR EQUIVALENT ABSORBED INTENSITIES, SHOCK VELOCITIES
INCREASE FROM 2KM/SEC (6MB) TO 2.5 KM/SEC (10MB) AS THE
LASER WAVELENGTH DECREASES FROM $1.064 \mu\text{M}$ TO $0.355 \mu\text{M}$.
- STAY TUNED FOR BILL MEAD (LASNEX VIEW) OF $0.355 \mu\text{M}$ AND
LATERAL TRANSPORT AND JIM TRAINOR (SHOCK MEASUREMENTS).

WAVELENGTH SCALING (Electron Transport)



Increased burn through depths are observed as the laser wavelength decreases from 1.064 to 0.355 μ

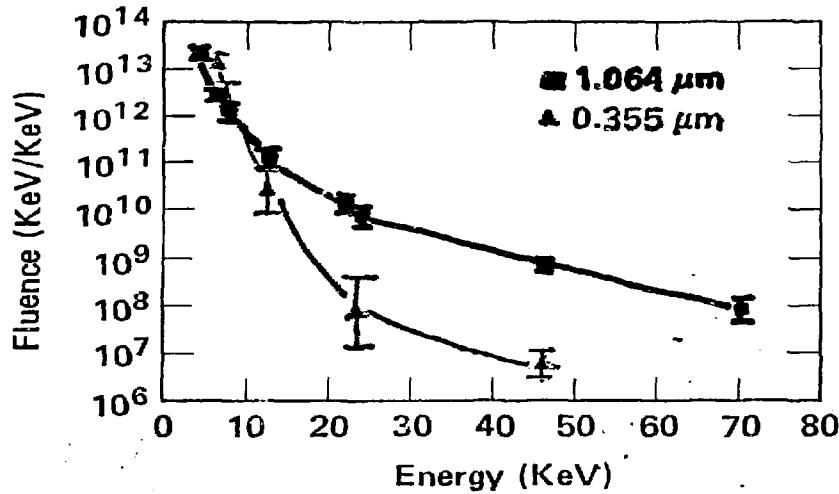
$$I_{\text{ABS}} \approx 1.5 \times 10^{14} \text{ W/cm}^2$$

$$\tau \approx 600\text{--}700 \text{ psec}$$

WAVELENGTH SCALING



-Suprathreshold x-ray production decreases dramatically as the laser wavelength is decreased from 1.064 μm to 0.355 μm



Target: Al disk

Laser: $\tau \sim 600-700$ psec

$E_{\text{ABS}} \sim 30-34$ Joules

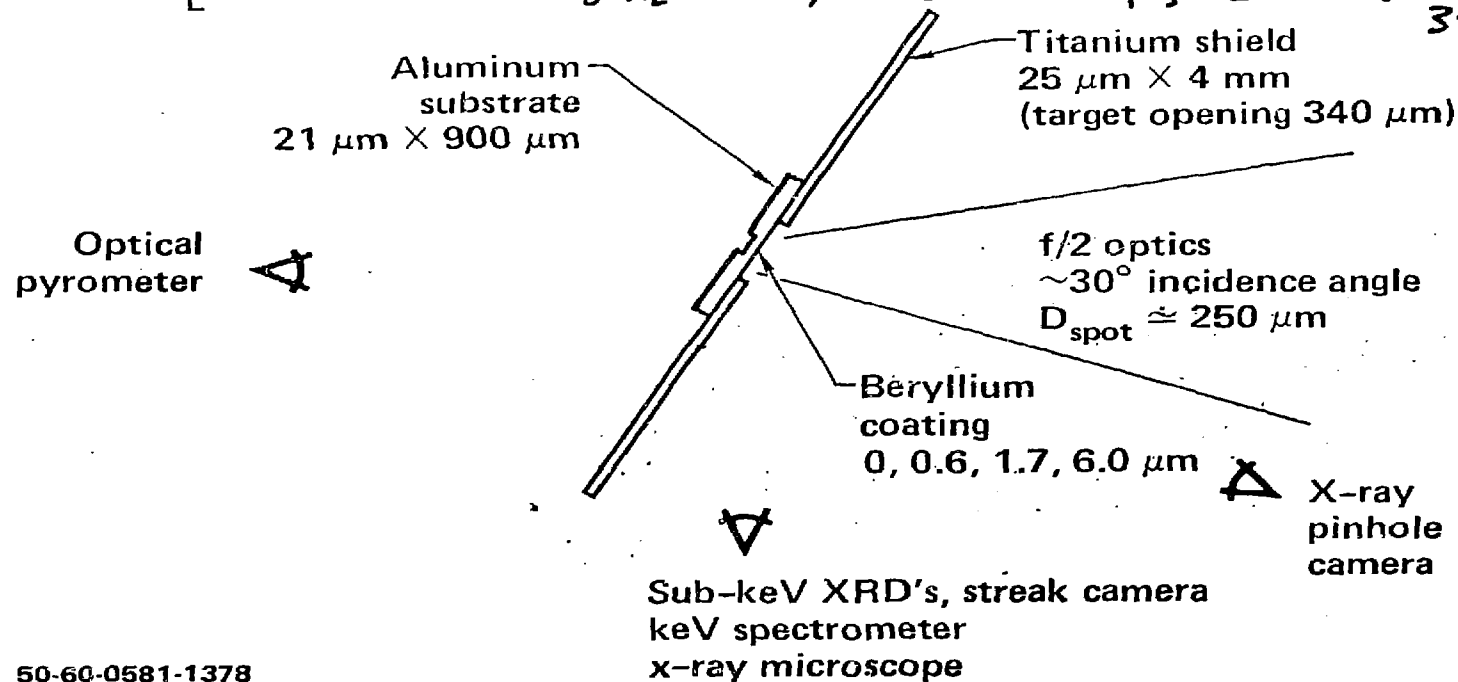
$I_{\text{ABS}} \sim 1.5 \times 10^{14}$ W/cm²

	<u>1.064 μm</u>	<u>0.355 μm</u>
Θ_{C}	~ 1.3 KeV	$\sim 0.7-1.0$ KeV
Θ_{H}	~ 10 KeV	~ 8 KeV
F_{H}	$\sim 10^{-2}$	$\sim 2 \times 10^{-4}$

LAYERED-SLAB TARGETS USED TO MAKE MULTIPLE OBSERVATIONS OF ELECTRON TRANSPORT



Irradiation parameters: $\lambda_L = 0.35 \mu\text{m}$, $\tau_L = 600 \text{ ps}$, $E_L \approx 30 \text{ J}$
 $I_L \approx 1 \times 10^{14} \text{ W/cm}^2$; $\lambda_L = 1.064 \mu\text{m}$, $\tau_L = 600-700 \text{ ps}$, $E_L \sim 90 \text{ J}$; $I_{\text{inc}} \sim 3 \times 10^{14}$



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