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We have successfully operated Shiva at 35 ns pulse lengths in preparation for a series of experiments in support of the Halite/Centurion program. This series of experiments is also of significant interest to the LLNL Nuclear Test Diagnostics Program.

In the Fusion Experiments section of this report, we describe the results of a series of experiments on Shiva which further our understanding of the production and transport of suprathermal electrons. We found that of the suprathermal electrons which strike a laser irradiated disk target or which interact with the rear surface of a half Cairn hohlraum target, a significant fraction of these electrons orbit the target and strike the rear of the disk. These results have significant implications in the interpretation and modeling of our laser irradiated target experiments.
Summary

We have completed calibration of the 1064-nm beam diagnostics for Argus target experiments, and the laser-target energy absorption experiments at 1064 nm are now nearing completion. Our measurements of conversion efficiency to 266 nm are continuing on the north arm.

Absorption at 1064 nm

During February, Argus fired 58 shots in support of the 1064-nm segment of the wavelength-scaling experiments. We are nearing completion of the 1064-nm absorption measurements. We have measured gold-disk absorptions from approximately 80% at $3 \times 10^{13}$ W/cm$^2$ to approximately 35% at $1 \times 10^{15}$ W/cm$^2$. These "nominal" intensities are calculated from the whole beam energy, the beam diameter at the target surface, and the pulse width. To complete this task, we are analyzing the photographic records of the intensity distribution in the target plane with the BEAMANAL code, which we expect will show that the effective intensities are somewhat higher than the "nominal" intensities. We have also measured hohlraum target absorptions for comparison with LASNEX code predictions.

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Much of the effort this month on Shiva was directed toward support of the Nova project. We conducted a number of Nova-related experiments (described below), and several engineers are participating in Nova design work. Despite this additional workload, system operation is satisfactory.

We completed a series of experiments to investigate Nova-like target-irradiation geometries in February. This followed installation and alignment of new target diagnostics on the chamber in January. We conducted nine target shots for this series with 6-ns pulses and an average energy on target of 3.7 kJ.

We took additional system shots at 5 ns to measure system A.S.E. and to test the prototype plasma shutter that has been designed to be used on Nova. From the A.S.E. tests we determined that there is 290 μJ of A.S.E. from each arm when the long-pulse oscillator was used; 120 μJ of this originates in the amplifiers and, 170 μJ results from normal leakage through the polarizers in the long-pulse switchout ("pulse-slicer").

The system was reconfigured and tested at 35 ns at the end of the month to prepare for the Halite diagnostic pinhole closure series of experiments in March. Thirty-two system shots were conducted on Shiva during the month.

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The DOE Energy System Acquisition Advisory Board (ESAAB) review rescheduled for March 17 has been cancelled. We have requested project direction from OIF. The project's status and issues were reviewed for LLNL Laser Program Associate Director John Emmett February 11.

**Laser System**

The erection of the Nova storage tent is complete (Fig. 1). Planned for use as a temporary warehouse facility, the tent and the adjacent deactivated reactor dome will provide about 15,000 ft² of storage area for the next three to five years. The space will be used to store Nova components that are valued at several million dollars and also to stage and assemble some components. Floor space in the tent costs about $3.50/ft², a significant savings over other, alternative storage solutions.

We have started small-signal-gain measurement testing of the 46-cm prototype box amplifier using one fluorophosphate laser glass split disk (Fig. 2). The test results will allow us to project to the performance of phosphate laser glass in the Nova baseline design. The projected cavity gain is about 1.8, which is consistent with our predictions. In March, we plan to start additional tests with both split disks installed.

Mechanical systems designs of Nova amplifiers, spatial filters, and Faraday rotators are proceeding through detail design. The 5-cm rod amplifier is in drafting check; a preprocurement design review of the Nova spatial filters was held February 24; and hardware for verification testing of the 31.5-cm Faraday rotator magnetic shield is in fabrication. We released for bid a specification for turning-mirror motor-control drives. We also conducted a conceptual design review of the nitrogen gas cooling system for the Nova amplifiers. A summary of the design of the cooling system and its status is provided below.

The target systems baseline design of the f/3.5 focus-lens positioners is laid out and ready for detail design. The focus lens will
be located in air for ease of lens movement, ease of maintenance, and to reduce hardware costs associated with operating in a vacuum environment. The target alignment and viewing instrument concept is evolving with increased flexibility and capabilities. We are purchasing components to set up an optical bench for proof-of-concept testing. The first 16-in. cryogenic pumps for the Nova vacuum system are on test. Preliminary results are that the nitrogen speed is 8000 litre/s, compared with the advertised speed of 5000 litre/s. An advance agreement was signed by DOE/SAN and the Penhall Company of Anaheim for $311K to drill the holes for the target diagnostics and the Phase II beams.

The plasma shutter prototype was installed on Shiva in January and tested in February. Ten full-system pulses were successfully blocked by plasmas generated from copper foils and aluminum foils. The major results of the tests are:

- A $10^{15}$-W/cm$^2$ pulse (400 J, 5 ns) was blocked with a $10^{21}$-ion/cm$^3$ exploding-wire-generated plasma.
- Transmission through the dense plasma was less than $5 \times 10^{-4}$.
- Reflection back from the plasma was approximately 10%.
- No electromagnetic interference problems were observed.
- No prefires were experienced.
- The first operational use of the Novabus fiber optic link was demonstrated.

The test verified the shutter’s capability to protect the Nova laser chains from target shot reflections. We are conducting additional tests to refine the operating characteristics of this device.

The requisition for Nova Phase I or Phase II 12.5-kJ high-density capacitors has been sent to Purchasing for release for bid. The estimated Phase II value is $5.8M. The Aydin MVA power supply successfully passed its five-hour short circuit acceptance test February 16. We sent our recommended design improvements to Aydin for inclusion during fabrication of the remaining six MVA supplies. We completed interfacing the first MVA supply with the power-conditioning control system and are using the power...
Nova Project

supply to charge the 1-MJ prototype capacitor bank. Nova-type interlocks are installed and operating on the prototype bank, and software controls are operating Nova-type fanouts for the bank. We completed the 48-cm flashlamp evaluation test (10,000 shots) without additional failures. The test verified the lamp design. Additional lamps (25 each from 3 suppliers) are on order for supplier qualification testing.

The requisition for Nova Phase I or Phase II phosphate laser glass procurement was reviewed and sent to Purchasing for release for bid. The estimated Phase II value is $14.7M. Schott Optical delivered three 20.8-cm prototype phosphate laser glass disks. The disks are being polished and will be tested in a Shiva delta amplifier. Schott's leached, nonphase-separated glass shows damage levels $\geq 10$ J/cm$^2$. Schott representatives visited LLNL February 18 to discuss leached borosilicate glass (BK-7, BK3, etc.) for the Nova output spatial filter lenses. Kodak started finishing the first 80-cm-dim f/2 diagnostics lens used in the Nova Aerojet output sensor. Kodak also activated their Nova 4-m-dim flat-lapping machine. We amended the OCLI optical coating contract to provide for production coating of large-diameter mirrors. The CPFF value was increased by $940K to a total of $1.3M.

Aerojet began placing orders for materials and commercial parts for the preproduction output sensors. LLNL mechanical engineers visited Aerojet to verify that their drawings meet LLNL drafting standards. We are preparing detailed specifications for the LLNL-supplied smaller-diameter optics for the output sensor. Orders are being placed for the optics that go into the Aerojet Nova sensors. The prototype insertable cross hair for the Nova input sensor was tested. Redesign is underway to eliminate deficiencies found during the test.

Conceptual design reviews for the Nova pulse-arrival-synchronization system (PASS) and the beam diagnostics system were conducted February 13 and 26, respectively. The PASS design satisfactorily uses the Shiva system. A prototype charge amplifier used with photodiode calorimeters
was successfully tested. The amplifier is part of the beam diagnostics system and is used to accurately measure low-level and very fast (nanosecond) energy signals. The control interface between an LSI-11 microprocessor and the charge amplifier was also successfully tested.

Nitrogen Gas System

A preconceptual design of the nitrogen gas system has been developed on the basis of engineering analyses conducted over the past year. Flow visualization experiments also have been designed to corroborate assumed uniform flow conditions in the Nova box amplifiers; these conditions are crucial in applying the analytical results obtained. The engineering analyses were directed toward establishing the thermal response of a convectively cooled laser chain for alternative gas distribution systems and a range of gas system capacities.

The principal design features adopted in accordance with the results of this effort include:

1. A group of closely-coupled amplifiers of the same size will be cooled in series to minimize nitrogen flow requirements. However, lamp cavities and disk cavities will be cooled independently to achieve even further reductions in flow requirements.

2. The system will be designed for a maximum-demand flow capacity of 5,000 cfm for Phase I, and it will be upgraded to 10,000 cfm for Phase II. It was determined that this flow capacity will result in a maximum cooling period of 4 hours for the selected distribution system.

The design of the gas system is proceeding with emphasis on identifying an acceptable low-pressure-drop filter that is required in a closed-looped system, in contrast to the open-looped system used on Shiva. In particular, the filters must be of high efficiency to preclude contamination of the laser chain components, and yet must have a sufficiently low-pressure drop to allow use of a fan or low-pressure
blower to recirculate the gas. A closed-looped system design has the advantages of minimizing both liquid nitrogen use and operating costs.

The flow visualization experiments will begin in March and should be completed in June of this year. Transparent test fixtures replicating the lamp cavity and disk cavity in the 20.8-cm amplifier have been designed and are presently being manufactured. Neutrally buoyant helium-filled soap bubbles will be seeded into the gas flow through each fixture to establish flow patterns, and attending hot-wire velocity measurements will be used as an independent check. These experiments will verify the flow patterns assumed in the analyses and provide data for any design modifications to the inlet and exhaust manifolds for any of the Nova box amplifier cavities.

Laboratory Building

By the end of February, construction of the laboratory building was 71% complete. Progress of construction is shown for both the laboratory and office buildings in the aerial view of the site shown in Fig. 3. The exterior metal siding and roofing are 80% complete. The interior plaster finish coats in the clean areas are about 90% complete. Finish painting in the target room was started, and the installation of ductwork, piping, plumbing, and fire-protection systems continues. The concrete backfill of all the shielding doors and frames is complete. All sections of door S-1 have been delivered and assembled in place. Concrete fill of all door sections is complete, and testing of the doors with temporary power is underway. Temporary power for bridge crane testing is complete.

The concrete strength in the shielding door frame installed between the laser bay and optical switchyard was evaluated by the building architect-engineer and found to be below-specification. His evaluation determined that the structural integrity of the door and building are not compromised. The contractor was asked for consideration if we are to accept work below specification requirements.
Nova Project

Office Building

Physical progress on construction of the office building was 34% complete at the end of February. The structural steel contract is complete. Electrical rough-in continues. Installation of hangers for second floor fixtures, ceiling system, and piping started. Ductwork and sprinkler piping installation continue.

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Nova Storage Tent being erected around the deactivated Reactor dome.

February 6, 1981
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Results from HEET Measurements

Introduction

In September we were able to accomplish 10 successful laser shots dedicated to the development of the High Energy Electron Thermometer (HEET) diagnostic. The series was successful and even provided us with a few surprises.

The HEET experiment consists of measuring the $\text{K}\alpha$ x-ray intensity produced by suprathermal electrons striking a prepared sample (see Fig. 4) located in either a disk or a Heinz B (half-Cairn 5/8 2.0) target geometry. The intensity of the $\text{K}\alpha$ emission is approximately proportional to the energy in suprathermal electrons striking the fluor material. Thus, the first phase in the HEET diagnostic development is to use $\text{K}\alpha$ x-ray intensity as a hot electron calorimeter. The primary goals of the experiments are:

- To determine the $\text{K}\alpha$ signal levels for a simple fluor in a composite disk directly irradiated by the laser and for a composite disk that is the end plate of a half-Cairn hohlraum target.
- To determine the contribution to the $\text{K}\alpha$ signal by photoionization or anomalous $e^-$ transport.

Secondary considerations include:

- Verify earlier Heinz series experimental results; i.e., compare a determination of the energy in hot electrons for a disk and an empty half-Cairn to that obtained by the bremsstrahlung method (FFLEX).
- Further our understanding of suprathermal $e^-$ transport and production.

Experiment

For all of the HEET series target shots we use the Heinz target-series laser parameters: 10 beams focussed in a ring on the base plate of target. Each beam has the parameters $E_L = 0.3$ kJ, $I_L = 3 \times 10^{15}$ W/cm$^2$, and $\tau_L = 600$ ps. This is also the beam-alignment scheme used for Cairn 2.0 H targets.
This series consists of irradiating multilayered "signal" and "null" targets. The signal targets were designed to determine $K_{\alpha}$ emission intensity levels. The experimental geometry for the directly irradiated composite disk is shown in Fig. 5, and the experimental geometry for the hohlraum targets is shown in Fig. 6. The multilayer disk, which also serves as the base plate for the hohlraum target, was carefully chosen to:

- Provide gold as the laser first-bounce surface and suprathermal $e^-$ generation medium. The 0.5-$\mu$m gold thickness is chosen to avoid laser burn-thru until after the peak of the laser pulse. Transport calculations indicate that a 100-keV $e^-$ loses ~7 keV in traversing gold layer. Typical $\theta_H$ values for these targets are ~40 keV, and approximately 40% of the Maxwellian distribution of electrons is stopped by the gold layer.

- Discriminate against low-energy electrons with the use of a 3-$\mu$m layer of parylene.

- Use nickel as a fluor to efficiently convert ~25 keV or higher-energy electrons into nickel $K_{\alpha}$ x rays ($E_{\alpha} \approx 7.5$ keV). The 15-$\mu$m thickness of nickel is the electron range of 30-keV electrons, and nickel attenuates, at most, only $e^{-1}$ of its own $K_{\alpha}$ emission (which is viewed in transmission).

In our experiment $K_{\alpha}$ x rays can be produced by photoionization of nickel (e.g., produced by bremsstrahlung near 8 keV emanating from the gold plasma) and by anomalous $e^-$ transport (e.g., electrons circumnavigating the target and striking the unprotected rear surface of the nickel sample). Targets have been designed to test these effects. The principal designs are illustrated in Fig. 7. In essence, thick Mylar layers are inserted in front of the nickel fluor to stop electrons with 100 keV or less kinetic energy. Two different thicknesses are used (127 $\mu$m and 254 $\mu$m) because of a theoretical uncertainty in the power of Mylar to stop electrons. Any resultant $K_{\alpha}$ signal would be produced by either photoionization from bremsstrahlung produced in the gold layer.
Fusion Experiments, Experiments Group

(Mylar layer is "thin" to photons near the nickel K-shell binding energy, $E_K = 8.33$ keV), electrons reaching the rear of the target, or both. Protected null targets were also irradiated in the HEET series to check for anomalous $e^-$ transport. Obviously, this design protects the rear of the target from electrons somehow reaching the back side. $K\alpha$ x rays could still be transported out of the Mylar layer on the target backside; for this reason, photoionization is still measured. If anomalous $e^-$ transport proves to be significant and photoionization does not, we would have to protect our signal targets by including $127$-$\mu$m-thick Mylar layers on the rear side. Targets of this construction are also shown in Fig. 7. Note that if photoionization does not contribute a significant amount to our $K\alpha$ signal, then we can determine the amount of $e^-$ transport straight-through compared with that going around. More precisely, a comparison of the $K\alpha$ yield from the thin null disk with an unprotected rear surface with the yield from a protected signal disk can provide a quantitative measurement of the $e^-$ transport around the multilayer target. A similar determination can also be made for the Heinz B hohlraum geometry.

Results and Discussion

A. Qualitative Results

Typical spectral results from the HEET series are shown in Fig. 8. A superimposed nickel x-ray spectrum illustrates the differences obtained by direct laser irradiation of a nickel disk (viewed from the front) to the spectrum obtained by the Henway crystal spectrometer during the HEET series (viewed in transmission). The spectra exhibit two important features. First, note the absence of any thermal x-ray lines in the spectrum from the HEET target (in this case a Heinz B signal target, see Fig. 7). This implies that no high temperature thermal plasma is produced in the nickel layer. Second, note the outstanding signal-to-background level associated with the HEET target measurement. The observed
background is due to film noise, i.e., there is no observable x-ray continuum. With this signal-to-noise level, we can easily observe 50 times less signal. The ALICS crystal spectrometer, which has significantly higher efficiency, indicates a very high signal level on this shot. However, the signal-to-background level is severely reduced, presumably due to gross film fogging by high-energy x rays. We are experimenting with special films to eliminate this problem.

A signal disk, a thin null disk, and a thick null disk all result in nearly the same nickel Ka x-ray yield. According to the design of our experiment, this implies that photoionization or anomalous e⁻ transport or both are major contributors to our signal. Therefore, a 127-µm layer of Mylar is placed in the back of the target, thus forming a protected thin null target. As a result, we observe a null with the HEET protected disk, which indicates that photoionization is insignificant and that anomalous e⁻ transport is appreciable.

To obtain a reasonable null with the Heinz B target, we also require that the back of the target be protected with 127 µm of Mylar. Therefore, hohlraum target geometries are also affected by anomalous e⁻ transport.

However, the Ka signal level observed with a null target is approximately 20% of the intensity observed with a signal target. This residual signal level is due to either increased photoionization because of the hohlraum target geometry or the presence of very-high-energy electrons. In the next issue of our Laser Fusion Monthly, MM 81-3, we show that our suprathermal x-ray spectra from hohlraum targets is consistent with a two component suprathermal electron distribution. There is a super hot component with \( T_{\text{super hot}} = 100 \text{ keV} \) containing \( \sim 2-4\% \) of the absorbed energy.

Having shown that photoionization is not significant and that a null can be obtained, we can determine the number of electrons traveling through these targets, as well as the number of electrons reaching the backside. A quantitative measurement requires a model for the electron
transport in order to interpret the Ka results. A LASNEX prediction for the electron transport will be discussed in the next section along with the corresponding quantitative results. For now, however, only model independent discoveries (therefore, quantitative) will be discussed.

Comparison of the Ka yield from an unprotected thin null disk (whose signal level results from electrons reaching the back of the target) with the Ka yield from a protected signal disk (whose signal results from electrons traversing the gold and 3-μm parylene layers) indicates that the signal levels are equal. Furthermore, for the Heinz B, we have also measured significant Ka x-ray yield stemming from electrons reaching the target backside. These are important observations since, unlike theoretical prediction, they illustrate that e⁻ transport to portions of the target other than the laser plasma interaction area is appreciable for both disk and enclosed hohlraum geometries.

B. Quantitative Results

Quantitative determination of such quantities as \( E_{\text{Hot}} \) or \( f_{\text{Hot}} \) from the Ka technique requires knowledge of suprathermal e⁻ transport from the laser plasma interaction area to the nickel HEET sample. In our analysis, we assume that the electrons are transported isotropically after formation and that they comprise a Maxwellian velocity distribution. Under these assumptions, we have used LASNEX to calculate the energy deposition by the hot electrons in the various target components. Using \( \theta_H = 40 \text{ keV} \) (which was measured by FFLEX in these experiments), LASNEX predicts that \( \sim 60\% \) of the energy in hot electrons (present at the laser plasma interaction region) is actually deposited in the nickel sample. Most of the remaining 40% of the energy is deposited in the gold layer. LASNEX does not predict any transport to the target backside. Furthermore, the average depth into the nickel sample (measured from the laser interaction side) where Ka x-rays are formed is calculated to be \( <x> \approx 5 \text{ μm} \). The energy deposition in various layers as well as \( <x> \) are important quantities in the interpretation of our results and are incorporated in all the discussion that follows.
Some x-ray transport corrections are also required to analyze the Kα data. The observation angle used by both the Henway and ALICS spectrographs requires that a correction be made for the effects of absorption of nickel Kα both in the nickel layer and in the Mylar. At an observation angle of 60° to the disk normal, nickel Kα x rays must travel through 30 μm of nickel (at most) and always through 254 μm of Mylar (when a Mylar protective layer is on the back of target). Although the absorption in Mylar is only 20%, the corrections are made when necessary. The compensation for the transport through the nickel is not as simple. Formally, we must determine the average depth <x> where x ray formation takes place and correct for the attenuation through the remaining thickness of nickel. As mentioned previously, using LASNEX, the average depth was calculated to be <x> = 5 μm. Because of our observation angle the transport path length for x rays produced by electrons striking the front side is 20 μm, which leads to a 57% transmission factor. Similarly, for x rays produced by electrons striking the rear side, the transmission factor increases to 76%. Obviously, we are more concerned with electrons striking the rear side of the target. We used these transport corrections in analyzing all our data. The maximum error in the transmission correction produced by uncertainties in <x> is not large, since full transport (30 μm) implies 80% absorption as opposed to 44% if transported from slab center (15-μm path length).

The conversion efficiencies for calculating the energy in suprathermal electrons from the nickel Kα yields are shown in Fig. 9. For monoenergetic electrons, these conversion efficiencies agree with experimental and theoretical values published by Green and Cosslett.1 In practice, we must have a separate measurement of the suprathermal electron temperature $\Theta_H$ in order to determine $\eta_{e\rightarrow x}$ from the curves in Fig. 9. We use FFLEX results to determine $\Theta_H$ for all the present measurements.

Quantitative summaries of all the HEET data are shown in Tables 1 and 2. The absolute energy in hot electrons as determined by HEET is
somewhat uncertain, by a factor of 2 for the absolute $K\alpha$ intensity and probably by another factor of 2 in the conversion efficiency. We have designed subsequent experiments to use electron source of known energy; this refinement should eliminate the uncertainty in the conversion efficiency. The $\theta_{\text{hot}}$ values have been determined from filter florescer x-ray spectra, and should be accurate to $\pm 10$ keV. At any rate we use a constant conversion efficiency of $\eta_{e\rightarrow x} = 3.8 \times 10^{-3}$ Joules of $K\alpha$ per Joule of e, which incorporates a 50% error due to the $\theta_{\text{H}}$ variation among targets. Thus, $E_{\text{HEET}} = \frac{E_{K\alpha}}{\eta_{e\rightarrow x}}$, so the small variation ($\theta_{H} \sim 40-50$ keV) in $\eta_{e\rightarrow x}$ as a function of $\theta_{H}$ (see Fig. 9) is ignored. As usual, the fraction of incident laser energy converted into hot electrons is denoted by $f_{\text{hot}}$.

In Tables 1 and 2 we also list the energy in hot electrons as determined from the so-called Krueer bremsstrahlung formula:

$$E_{\text{FFLEX}} = \frac{E_{\text{HEET}}}{\eta_{e\rightarrow x}} = \frac{I_{\alpha}(\theta_{\text{Hot}})}{(5\times10^{11}) \ (Z/79)}$$

where $I_{\alpha}(\theta_{\text{Hot}})$ is the bremsstrahlung x-ray intensity at a photon energy equal to $\theta_{\text{Hot}}$ and $Z$ is the atomic number of the material producing the bremsstrahlung. For our multilayer targets it is difficult to accurately apply this formula because of the presence of gold ($Z=79$) and nickel ($Z=28$) layers (bremsstrahlung production in parylene is negligible). With the assumptions discussed earlier, LASNEX calculations indicate that, for a disk, 57% of the 40-keV x rays come from the nickel layer and the remainder come from the thin gold layer. Obviously, if electrons have curved trajectories such that they preferentially deposit energy in the gold, then all the bremsstrahlung would be produced therein. Under these unlikely conditions the tabulated values of $E_{\text{FFLEX}}$ would be lower by a factor of two. Unfortunately, for the Heinz B target
geometry, the situation is completely different, since thick gold walls (~25 μm) are present almost everywhere except the entrance aperture and the laser interaction surface. For this geometry, we assume all the bremsstrahlung is produced in the gold.

The bremsstrahlung measurement is also compromised by electrons orbiting to the target backside. LASNEX calculations do not account for this effect. Our HEET measurements will show that the number orbiting is, at most, 20% of those transported through the target. As a consequence we have not corrected the FFLEX data to account for additional bremsstrahlung production in the nickel owing to electrons reaching an unprotected target backside.

Some quantitative results from the HEET disk targets now deserve emphasis. First note that (see shot 80092405 in Table 1) the energy in suprathermal electrons transported directly to the nickel is small, $f_{\text{Hot}} = 1.0 \times 10^{-2}$.

By comparison with shot 80091903, and if we assume linear scaling of $E_{\text{Hot}}$ with $E_{\text{Laser}}$, we can determine that roughly 1/6 of this amount of energy is transported to the target rear side. Thus, the total energy in suprathermal electrons incident on our nickel wafer from any direction is still small, $f_{\text{Total}} = 0.01$. (Note that, for a disk target, $f_{\text{Hot}}$ may not be the total fraction of laser energy converted into hot electrons. We only measure the electrons that interact with the target; thus, we ignore any losses due to corona plasmas into fast ions.)

For disk targets, we measure only slightly less energy in suprathermal electrons with the Kα technique than obtained with FFLEX. We have also measured similar agreement using pure Ti, Ni and Zn disks. This outstanding agreement supports our assumption about the energy deposition in various target components and also establishes the HEET measurement's credibility.
For the Heinz B hohlraum target we again observe significant electron transport to the target backside. Comparison of shots 80092514 and 80092905 shows that 1/7 the number of electrons striking the front of the HEET sample strike the rear side if we assume linear scaling of $E_{\text{Hot}}$ with $E_{\text{Laser}}$. The fraction is 3/5 if $E_{\text{Hot}}$ scales as $E_{\text{Laser}}$. This implies that anywhere from 0.4 to 1% of the laser energy is converted into hot electrons that reach the backside of the Heinz B hohlraum target.

Comparison of the energy in hot electrons measured for a disk as compared with a Heinz B target demonstrates an interesting result: $E_{\text{Hot}}^{\text{Heinz B}}$ is only 2.5 times larger than $E_{\text{Hot}}^{\text{disk}}$. This factor of 2.5 could be entirely due to the increased laser light absorption that has been previously noted for half-Cairn versus disk geometry.

Curiously, when the same comparison is made using results from the FFLEX data, the bremsstrahlung measurements indicates $E_{\text{Hot}}^{\text{FFLEX}}$ is 20 times greater for the Heinz B target than for a disk (compare energy normalized values from shots 80092905 and 80092405). If we assume that both the bremsstrahlung and $K_{\alpha}$ measurements are accurate, this discrepancy illustrates some interesting properties of suprathermal electron transport or prediction or both. First, there is no reason to have assumed a priori that for a hohlraum target, $E_{\text{Hot}}^{K_{\alpha}}$ would equal $E_{\text{Hot}}^{\text{FFLEX}}$. The $K_{\alpha}$ measurement is only sensitive to those electrons that are transported directly forward from the laser plasma interaction area into the nickel sample, i.e., it is a spatially localized measurement. On the contrary, the FFLEX measurement samples bremsstrahlung x rays from any place that suprathermal $e^{-}$ collide with the predominately gold target. If we assume that suprathermal electrons are generated at the laser first bounce surface (that is at the critical density surface of the 0.5-μm gold layer) and that they are isotropically emitted, then $E_{\text{Hot}}^{\text{FFLEX}}$ should be twice as large as $E_{\text{Hot}}^{K_{\alpha}}$. We arrive at this number by assuming that half the electrons go in the direction of the nickel sample (under these conditions, the nickel slab subtends $\frac{\Delta \Phi}{\pi} = 2\pi$ sr.) while
the other half produce bremsstrahlung at the cylinder walls and aperture. Instead, the measured ratio of $E_{\text{FFLEX}}$ to $E_{\text{Hot}}$ is $\sim 13$ to $15$ (depending on uncertainties in subtracting null signal out of $K\alpha$ yield). Thus, the bremsstrahlung measurement predicts $13$ to $15$ times more energy in suprathermal electrons.

Clearly, to be consistent with these measurements, the electrons cannot be produced at the target base plate and emitted isotropically. What if we assume the electrons are still emitted isotropically but are produced near the center of the enclosed target volume? This case supports suprathermal electron production via the stimulated Raman scattering of laser light in low-density ($1/4 N_{cr}$ or less) plasma. Under these conditions, the available surface area of gold exceeds that of nickel by a factor of $\sim 6$. Multiplying this result by the observed discrepancy between $K\alpha$ and bremsstrahlung techniques for the HEET disks (FFLEX results $\sim 50\%$ higher) implies that $E_{\text{FFLEX}}/E_{\text{Hot}} = 9 E_{\text{K}\alpha}/E_{\text{Hot}}$, which is still somewhat smaller than the observed value of $\sim 13$ to $15$. The remainder could be partially accounted for by considering the large external surface area of the gold radiation case, which is unprotected from orbiting electrons. Another mechanism that could account for the discrepancy is the preferential (nonisotropic) transport of electrons down the density gradient established at the target back plate and into the gold cylinder walls. Other mechanisms, such as electrons preferentially orbiting in the thin gold layer, could also be invoked to explain the large $E_{\text{FFLEX}}/E_{\text{Hot}}$ (this argument would only apply to hohlraum targets because the two experimental methods are much closer to agreement for disks). Only by performing further measurements can we fully understand the electron emission isotropy and production mechanisms. For example, constructing a Heinz B target out of different Z components and using the $K\alpha$ technique could obviously tell us how much electron energy goes into certain directions.
Conclusions And Summary

- HEET is a viable technique to study suprathermal e\(^-\) collisions with ICF target components.
- HEET sensitivity limit is \(\sim 0.5\) J for e\(^-\) with kinetic energies of 25 keV or higher (up to 100 keV).
- Electron transport to the backside of both disk and classified targets is significant.

We are planning measurements to use the K\(\alpha\) technique to:

- Study the e\(^-\) preheat levels at the D-T-filled fuel capsule location in a high-density target.
- Determine suprathermal e\(^-\) transport by building a Heinz B "can" out of different K\(\alpha\) fluor components.
- Measure the spatially localized electron energy distribution \(F(e)\) with specially prepared HEET samples.
- Temporally resolve the K\(\alpha\) line to determine time history of suprathermal e\(^-\) transport at different target locations.

Reference


For further information, contact

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(415) 422-5360
Figure Captions

Fig. 4. Portion of HEET disk illustrating principle of experiment.

Fig. 5. HEET signal disk target. Location of Aics (θ=120°, φ=180°), Henway (θ=120°, φ=108°), FFLEX (θ=120°, φ=288°), ZPC (θ=180°, φ=360°).

Fig. 6. HEET Heinz B signal target, unprotected.

Fig. 7. Kα fluor components for targets of various geometries.

Fig. 8. Sample of Kα data for nickel from HEET experiments (black) and backlighting series (red).

Fig. 9. Conversion efficiency for changing measured nickel Kα yield into energy deposited by suprathermal electrons as a function of e⁻ energy or temperature kT.
### Table 1. HEET Quantitative Results

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Target</th>
<th>Laser energy (J/sphere)</th>
<th>$I_X$ (J/sphere) corrected for x-ray transport</th>
<th>$E_{Kx}$ Hot (J)</th>
<th>FFLEX FFLEX EHot (hot)</th>
<th>FFLEX EHot (J)</th>
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<tr>
<td>80091808</td>
<td>Unprotected signal disk</td>
<td>1.77 kJ</td>
<td>0.012+</td>
<td>*</td>
<td>∼ 38</td>
<td>28</td>
</tr>
<tr>
<td></td>
<td>0.5 Au + 3 CH + 15 Ni</td>
<td></td>
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<tr>
<td>80091903</td>
<td>Unprotected thin null disk</td>
<td>2.63 kJ</td>
<td>0.019</td>
<td>6.6</td>
<td>[3 x 10^{-3}]</td>
<td>0.4 x 10^{-2}</td>
</tr>
<tr>
<td></td>
<td>0.5 Au + 127 Mylar + 15 Ni</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>80091911</td>
<td>Unprotected thick null disk</td>
<td>2.97 kJ</td>
<td>0.066+</td>
<td>22.9</td>
<td>[8 x 10^{-3}]</td>
<td>14 x 10^{-2}</td>
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<td>0.5 Au + 254 Mylar + 15 Ni</td>
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<tr>
<td>80092222</td>
<td>Protected thin null disk</td>
<td>3.19 kJ</td>
<td>-0-</td>
<td>-0-</td>
<td>∼ 40</td>
<td>30 x 10^{-2}</td>
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<td>0.5 Au + 127 Mylar + 15 Ni + 127 Mylar</td>
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<td>80092405</td>
<td>Protected signal disk</td>
<td>3.25 kJ</td>
<td>0.019</td>
<td>32.8</td>
<td>[1.0 x 10^{-2}]</td>
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<td>0.5 Au + 3 CH + 15 Ni + 127 Mylar</td>
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<td></td>
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</table>

+ Calibration suspect for ALICS that measured these points only.
* Unable to determine.
Table 2. HEET Quantitative Data Summary (Classified Targets).

<table>
<thead>
<tr>
<th>Shot No.</th>
<th>Target</th>
<th>Laser energy (intensity)</th>
<th>Henway (J/sphere)</th>
<th>$E_{\text{HEET}}$ (J) $f_{\text{Hot}}$</th>
<th>$E_{\text{FFLEX}}$ (J) $f_{\text{Hot}}$</th>
<th>$I(\theta)$ $5 \times 10^{11}$</th>
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<tbody>
<tr>
<td>80092503</td>
<td>Heinz &quot;B&quot; unprotected signal 0.5 Au + 3 CH + 15 Ni</td>
<td>2.96 kJ (2.4-3.3 x 10^{15})</td>
<td>0.110</td>
<td>46 [1.6 x 10^{-2}]</td>
<td>~ 46</td>
<td>700 [0.24]</td>
</tr>
<tr>
<td>80092514</td>
<td>Heinz &quot;B&quot; protected thin null 0.5 Au + 127 Mylar +15 Ni + 127 Mylar</td>
<td>3.00 kJ (2.1-3.4 x 10^{15})</td>
<td>0.020</td>
<td>14.4 [4.8 x 10^{-3}]</td>
<td>~ 51</td>
<td>700 [0.24]</td>
</tr>
<tr>
<td>80092606</td>
<td>Heinz &quot;B&quot; protected thick null 0.5 Au + 254 Mylar +15 Ni + 127 Mylar</td>
<td>3.37 kJ (2.7-3.3 x 10^{15})</td>
<td>0.021</td>
<td>15.5 [4.6 x 10^{-3}]</td>
<td>~ 50</td>
<td>720 [0.21]</td>
</tr>
<tr>
<td>80092903</td>
<td>Heinz &quot;B&quot; unprotected thick null 0.5 Au + 254 Mylar +15 Ni</td>
<td>1.31 kJ (1.1-1.5 x 10^{15})</td>
<td>~ 45</td>
<td></td>
<td></td>
<td>40 [3 x 10^{-2}]</td>
</tr>
<tr>
<td>80092905</td>
<td>Heinz &quot;B&quot; protected signal 0.5 Au + 3 CH + 15 Ni + 127 Mylar</td>
<td>3.5 kJ (3.0-4.1 x 10^{15})</td>
<td>0.074</td>
<td>38.1 [2.1 to 2.5 x 10^{-2}]</td>
<td>~ 49</td>
<td>1077 [0.31]</td>
</tr>
</tbody>
</table>

* Null signal levels have been subtracted from tabulated results.
+ Uncertainty in normalization and subtraction of null signal level from shot 80092514 causes this variation in $E_{\text{Hot}}$. 
STUDY OF SUPRATHERMAL \( e^- \) PRODUCTION USING \( K_\alpha \) X-RAY EMISSION

\[
Yield \ K_\alpha \approx E_{\text{hot} \ e^-} \quad K_\alpha \text{ x-ray}
\]

Fig. 4
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Laser in "Ring Focus"

\[ E_L = 3.0 \, \text{kJ}, \quad I_L \approx 3 \times 10^{15} \, \text{W/cm}^2 \]

\[ D_L \approx 200 \, \mu\text{m} \]

**HEET disk**

- 0.5 \, \mu\text{m} \, \text{Au}
- 3.0 \, \mu\text{m} \, \text{CH}
- 15 \, \mu\text{m} \, \text{nickel}

ALICS

or Henway

\[ \theta = 120^\circ \]

ZPC

FFLEX

Fig. 5
Laser in "Ring focus"

\[ E_L = 3.0 \text{ kJ}, \quad I_L \sim 3 \times 10^{15} \text{ W/cm}^2 \]

\[ D_L \sim 200 \mu\text{m} \]

\( \sim 25 \mu\text{m} \)

thick Au walls

500 \( \mu\text{m} \)
dia. aperture

1000 \( \mu\text{m} \)

0.5 \( \mu\text{m} \) Au

3.0 \( \mu\text{m} \) CH

15 \( \mu\text{m} \) Nickel

\( \theta = 120^\circ \)

ALICS

or Henway

ZPC

Fflex

Fig. 6
Signal

Range of 100 keV e\textsuperscript{-}

Null

Protected signal

Protected null

0.5 \mu m Au

3 \mu m CH

15 \mu m Ni

0.5 Au

3 CH

15 Ni

127 mylar

127 mylar

15 Ni

127 mylar

Fig. 7
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EXAMPLE OF CLEAN $K_\alpha$ SIGNAL

![Graph showing HEET $K_\alpha_1$ data viewed from back of disk compared to backlighting disk data viewed on laser inside (scale $\times 0.14$).](image)

Fluence (kev/kev-sphere) vs. Photon energy (kev)

- HEET $K_\alpha_1$
- Backlighting disk data viewed on laser inside (scale $\times 0.14$)
- Thermal lines

Photon energy (kev): 7.25, 7.35, 7.45, 7.55, 7.65, 7.75, 7.85

Fig. 8
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CONVERSION EFFICIENCY FOR NICKEL Kα X-RAYS AVERAGED OVER THE SUPRATHERMAL ELECTRON DISTRIBUTION

\[ \eta_K \propto E^{1/2} e^{-E/kT} \]

\[ f(E) \propto E^{-1/2} e^{-E/kT} \]

i.e., Maxwellian

Suprathermal electron temperature, kT (keV)

Fig. 9
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TARGET FABRICATION


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