NOVA TARGET EXPERIMENTS*

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INTRODUCTION

The Nova laser, at the Lawrence Livermore National Laboratory, provides unique opportunities for target experiments. It has unprecedented energy on target and significant flexibility. The paper presented by John Hunt[1] described the capabilities and the status of Nova. This paper discusses our plans for future experiments using Nova, and the present status of target experiments.

We plan to perform high-quality physics experiments that exploit the unique capabilities of Nova. Because this is our goal, we are fielding an extensive array of well-characterized target diagnostics to measure the emissions from the target. The first section of this paper discusses the basic target diagnostics. We are also taking care to quantify the performance of the laser.[1]

The primary mission of Nova is to conduct experiments in support of Inertial Confinement Fusion (ICF). Our plans for these experiments, and the specialized diagnostics they require, are the subject of the second section. Although this paper does not discuss the possibilities, we are interested in finding other experiments that exploit the capabilities of Nova. The x-ray laser experiments, discussed elsewhere in this volume, are a first example. Finally, the third section describes our progress to date toward target experiments using Nova.

BASIC TARGET DIAGNOSTICS

We make certain measurements on almost every target shot. These measurements define the conditions of any experiment and measure some properties of the irradiated target. First, the incident laser diagnostics, described by Hunt, characterize the initial conditions of each experiment by measuring the energy and pulse shape of the laser beams. Other diagnostics require dedicated shots to perform more detailed characterization of the laser beam, including its spatial profile in the target plane.

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Second, we characterize the size and shape of the heated plasma by imaging the 0.5 to 5 keV x-rays with x-ray microscopes (8x magnification, 4 channels[2]) or with x-ray pinhole cameras. Figure 1 shows results of a Nova target shot used to measure the resolution of one of the x-ray microscopes. A thin gold foil was irradiated, and the x-rays transmitted through the foil backlit a resolution grid. The image was recorded on film, digitized, and reconstructed to produce the figure, in which the grid is clearly visible. X-ray film calibrations now in progress will allow us to obtain a contrast transfer function.

Third, we measure the scattered laser light to determine the absorption fraction and the scattered light distribution. A calorimeter measures the light reflected into each lens; and filtered, calibrated photodiodes measure the light scattered at other angles. The photodiode system and the reflected energy diagnostics are making some measurements now. Figure 2 shows the angular distribution of scattered 0.35-micron light from a recent single-arm Nova shot. The gold disk target was irradiated with 1.5 kJ at an irradiating intensity of approximately 10^{15} W/cm^2. The absorption was 93 +/- 2%, which is comparable to previous results with much smaller laser spots.[3] Eventually, there will be 180 diodes measuring the fluence at several important wavelengths.

Finally, low-resolution x-ray spectrometers measure the time-integrated magnitude and spectrum of the broadband x-rays from 1.0 keV to several hundred keV. These spectrometers[4,5] measure the x-rays emitted by a) the hot, overdense, target material, which is typically a few hundred eV, b) the thermal electrons in the underdense plasma, at a few keV, and c) suprathermal electrons at tens of keV produced by nonlinear laser-plasma interaction processes. Figure 3 shows the soft x-ray spectrum from the shot used for Fig. 2. Figure 4 shows the hard x-ray spectrum from the same Nova shot; this spectrum indicates a hot electron fraction of order 0.2% with a temperature of 24 keV.

NOVA ICF EXPERIMENTS

The goal of ICF experiments on Nova is to determine the requirements for high-gain ICF. Our effort to achieve this goal has two parts. First, we intend to develop our integrated capability to design targets, and to test this ability by performing implosion experiments. We anticipate that the sequence of ICF experiments on Nova necessary to meet our goal will take several years. The following paragraphs briefly summarize these experiments, and the target diagnostics they require.

First, we intend to understand hydrodynamic instabilities that are relevant to ICF. In particular, we hope to observe ablative stabilization of the Rayleigh Taylor instability. Nova is a good tool for these experiments, because it can produce a comparatively large ablation pressure over large areas. X-ray backlighting, including short-pulse backlighting and point-projection spectroscopy, will allow a variety of experiments.

The specialized diagnostics used by these experiments include the streaked optical pyrometer, x-ray microscopes including a 22x Wolter microscope, x-ray streak cameras, and an x-ray framing camera. We are measuring the resolution of each x-ray streak camera system to be used on Nova. The contrast transfer function for one streak camera (and for its image intensifier and film) are shown in Fig. 5. The cameras have a contrast transfer function of 0.5 for a grid spacing of 2.5 to 5 line pairs per millimeter at the cathode. The x-ray framing camera is under development. Figure 6 shows a voltage pulse between the photocathode and the microchannel plate collimator. The pulse has a rise time of less than 20 ps and a duration of less than 70 ps.

Second, we will continue to study laser-plasma interactions. We need to adequately understand plasma formation, laser absorption and scattering, and hot electron production in plasmas relevant to high-gain targets. These experiments will emphasize Raman scattering,[6] filamentation,[7] and Brillouin scattering. Nova can produce large axial and radial scalelengths, and eventually will be able to do experiments involving more than one wavelength and more than one pulse shape. The specialized diagnostics used for these studies include time resolved spectroscopy, streak cameras that determine the timing of optical and x-ray emissions, the streaked optical pyrometer, high-resolution x-ray spectroscopy, and eventually optical imaging and framing. At this writing, a time-resolved spectrometer and the discrete-channel streak camera are producing data.

Third, we will study radiation physics. Our goal is to understand the heating of overdense matter, including soft x-ray production and transport. Nova can irradiate large areas with either 0.35 micron or 0.53 micron light, allowing these studies in relatively large, uniform plasmas. The specialized, time-resolved diagnostics include high-resolution x-ray spectroscopy, soft x-ray spectroscopy, soft x-ray imaging, optical pyrometry, and eventually a transmission grating spectrometer. A time-integrated soft x-ray spectrum from Nova was shown in Fig. 3.

Implosion experiments will test our integrated target design capability. We will use these experiments, in conjunction with the experiments just discussed, to improve this capability. The first implosion experiments we now plan are symmetry experiments. These experiments will develop our ability to design targets that produce symmetric implosions. X-ray backlighting and related x-ray diagnostics will image the capsule and provide the primary data for these experiments.

Once we can design targets that produce symmetric implosions, we will be able to attempt implosions that compress the fuel to high density. We hope to obtain and diagnose densities of 1000 times the density of liquid DT. Several new diagnostics will allow us to diagnose the compressed-fuel density. These diagnostics include advanced radio chemistry, neutron spectroscopy, and higher-energy x-ray microscopy.

Assuming the experiments just discussed go well, and that we improve the performance of Nova in the ways described by Hunt, we will eventually be able to attempt the implosion and compression of a target that is "hydrodynamically equivalent" to a high-gain target. Such a target is a scaled version of a high-gain target and undergoes a nearly identical implosion. It would produce high gain if it contained a larger fuel mass. This experiment would build on the results of the experiments discussed above, and would use many of the diagnostics developed for these experiments.

For historical background, it is worth noting that the performance goals for Nova changed in 1982. At that time, the energy of the laser and the number of arms were reduced as the result of funding reductions.[8] This guaranteed that Nova could not reach ignition or breakeven, and led us to develop the experiment plans described here.

NOVA PROGRESS TO DATE

During the past year, we have worked to make Nova ready for sophisticated, high quality experiments. We did not jump right into poorly executed and poorly diagnosed experiments that would have prevented us from directing effort toward making the facility function well. Instead, we worked hard to complete and activate the many systems necessary to do quality target experiments. Table 1 summarizes our progress in this effort.

In December, 1984 we fired all ten Nova beams, with frequency conversion to 0.35 microns, through a 4 mm pinhole in the center of the ten-beam target chamber and measured the energy delivered by each beam. By February, 1985, we were able to fire all ten arms, at 0.53 microns, at a gold disk target, and produce a pentagonal pattern on each side of the target. Key laser alignment hardware, necessary for accurate pointing and focusing of harmonically converted light, was installed in April, 1985, and has since been activated. During April through June we fired 27 target shots, began to activate the scattered light photodiodes and the soft x-ray spectrometer, and activated the 8x x-ray microscopes and the hard x-ray spectrometer. We fired no target shots during July, so that we could concentrate on completing the activation of the laser diagnostics. We now routinely measure the incident one micron energies, one micron pulse shape, and half or third micron incident energies on all ten arms. We also obtain the reflected energies on five arms and the short-wavelength pulse shape on several arms, with more complete data to follow.

During August and September we fired 23 target shots to complete the activation of the scattered light photodiodes, continue activating the soft x-ray spectrometers, and begin to activate the optical spectroscopy, optical pyrometry, and optical fiducial systems. This allowed us to obtain the first x-ray conversion measurements with more than 1 kJ of 0.35-micron light on target during October. In late October we irradiated and diagnosed the first ten-arm hohlraum target. In November, we will make our first systematic measurements of Raman scattering from large plasmas produced with 0.35-micron light.

As Table 1 also shows, our two-beam chamber extension of the Nova facility has also begun to produce data. The construction of this target area began less than one year ago. Two 0.53-micron beams irradiated a target with a line focus in July, and during September the first x-ray laser target was irradiated and diagnosed. Further diagnostic installation and checkout is proceeding and will lead to systematic experiments this fall.

CONCLUSION

In conclusion, you have seen our progress and plans for target experiments using the Nova facility. We have begun simple irradiations using up to ten arms at 0.35 microns, and have diagnosed them with our basic target diagnostics. We are building and installing additional hardware to allow us to carry out more complex irradiations, such as short-pulse backlighting, and more detailed measurements, such as streaked x-ray spectroscopy. The resulting facility will allow us to study important physical processes, such as the Rayleigh-Taylor instability, under conditions relevant to high-gain targets, and will allow us to develop our integrated target design capability in preparation for high-gain experiments.

ACKNOWLEDGEMENT

The effort to bring Nova into full operation involves hundreds of participants in experiments and diagnostics, laser systems, target fabrication, and target design. A large fraction of these people contributed, one way or another, to the Nova results and plans presented above. My thanks to them all.

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TABLE 1

Progress Toward Nova Target Experiments

Ten-beam chamber:		
	Dec 1984	Ten 3ω beams into target chamber
	Feb 1985	Ten 2ω beams onto a target
	Apr 1985	Key laser alignment hardware
	Apr-Jun 85	27 Target shots for diagnostic shakedown
	Jul-Aug 85	Key laser diagnostic hardware
	Aug-Sep 85	23 Target shots for diagnostic shakedown
	Oct 1985	First x-ray conversion data
	Oct 1985	First ten-beam hohlraums
	Nov 1985	Raman scattering experiments
Two-beam chamber:		
	Jul 1985	Two 2ω beams with line focus onto target
	Aug 1985	Focus characterization
	Sep 1985	First x-ray laser target
	Fall 1985	Diagnostic checkout and first experiments

FIGURE CAPTIONS

1. An x-ray microscope image, obtained during a resolution test of a Kirkpatrick-Baez x-ray microscope with 8x magnification.

2. The fluence in J/Sr of the scattered 0.35-micron light is plotted as a function of angle relative to the wave vector and the polarization direction of the 0.35-micron beam incident on a gold disk target.

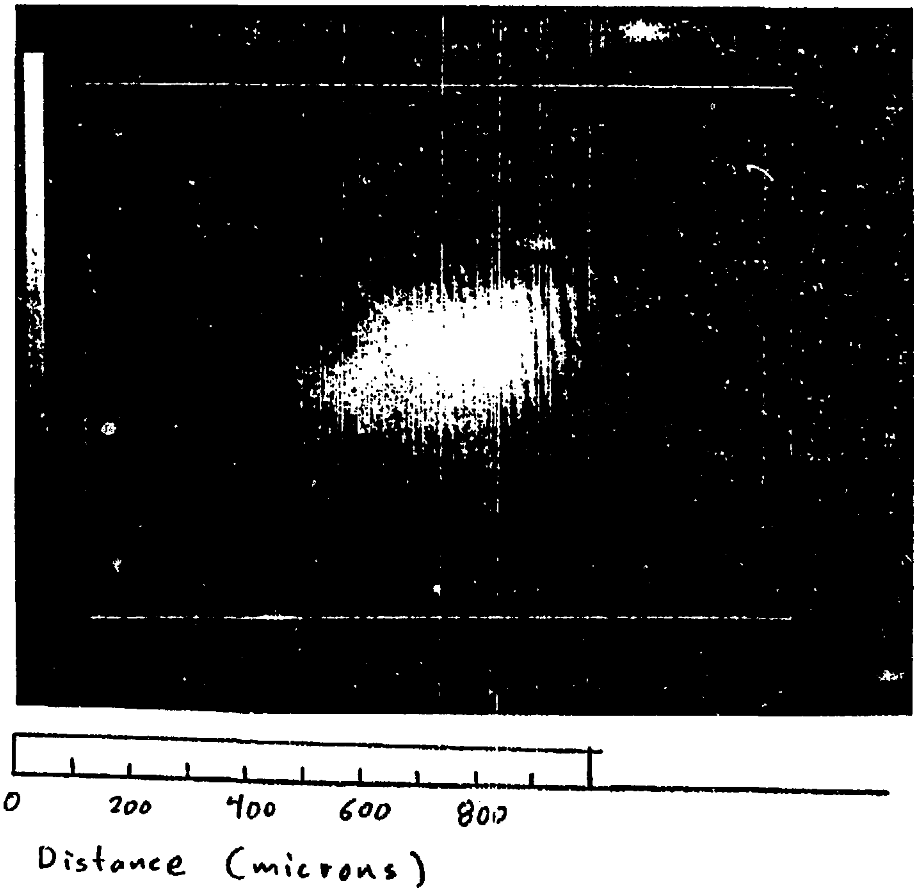
3. The soft x-ray spectrum from the shot shown in Fig. 2.

4. The hard x-ray spectrum from the shot shown in Fig. 2.

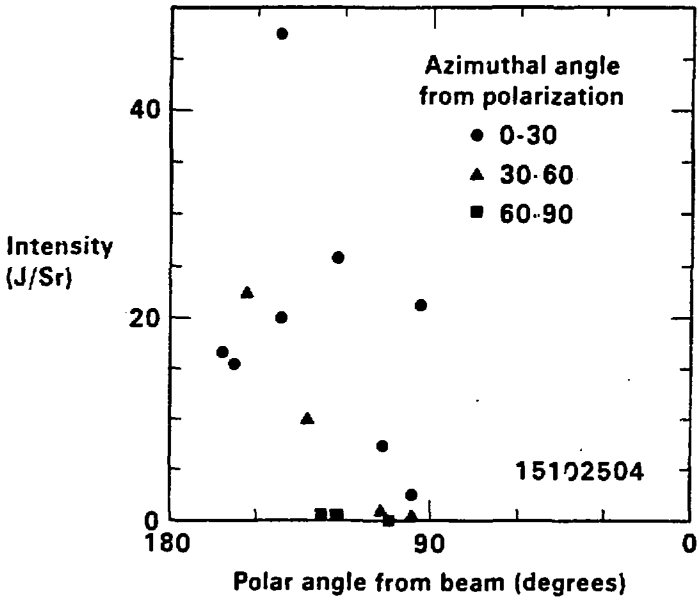
5. Characterization of an x-ray streak camera. The contrast transfer function is plotted versus line-pairs per millimeter.

6. A fast voltage pulse used to gate an x-ray framing camera, now under development.

0455C/0008C/RPD/jdb


0
200
400
600
800
Distance (microns)

Scattered 0.35 micron light from a gold disk target



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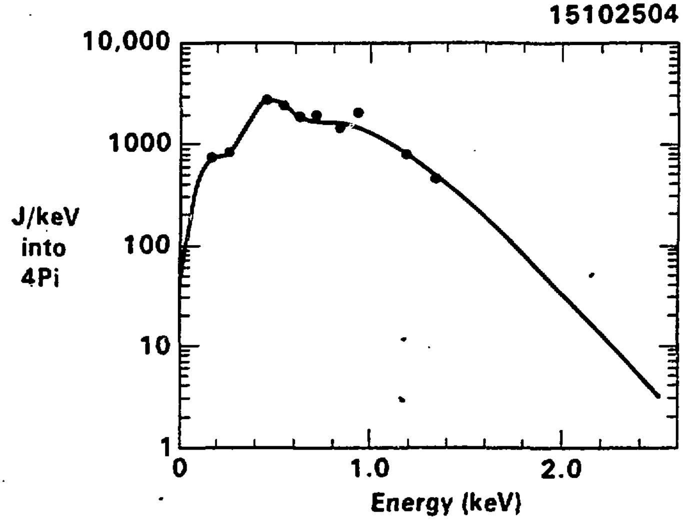
Soft x-ray spectrum from a gold disk target



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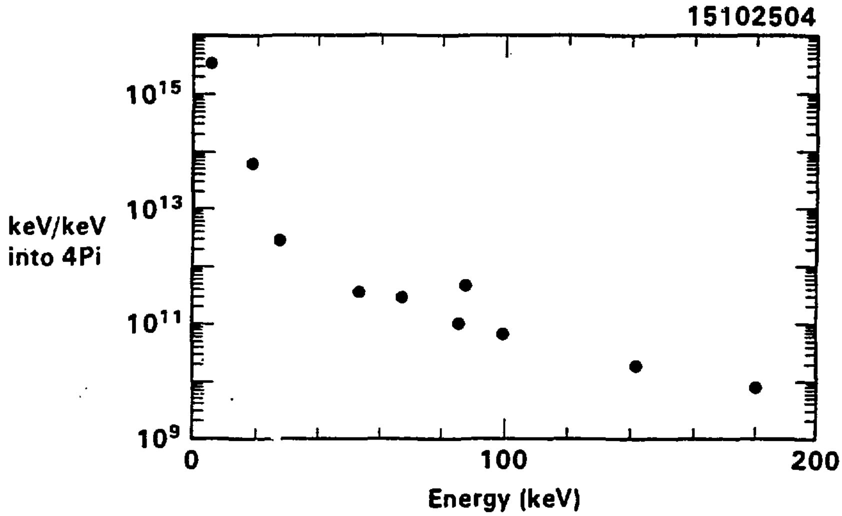
Hard x-ray spectrum from a gold disk target



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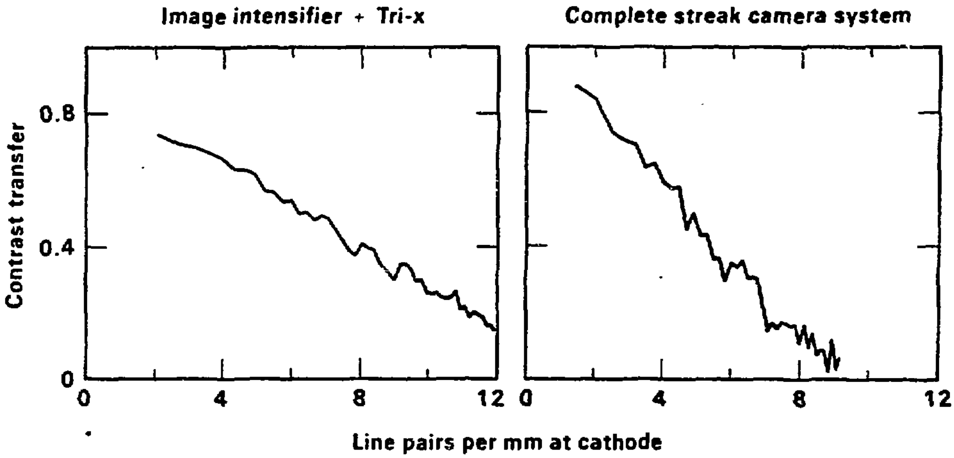
X-ray streak camera characterization improves the quality of our results

We are characterizing each x-ray streak camera to be used on Nova



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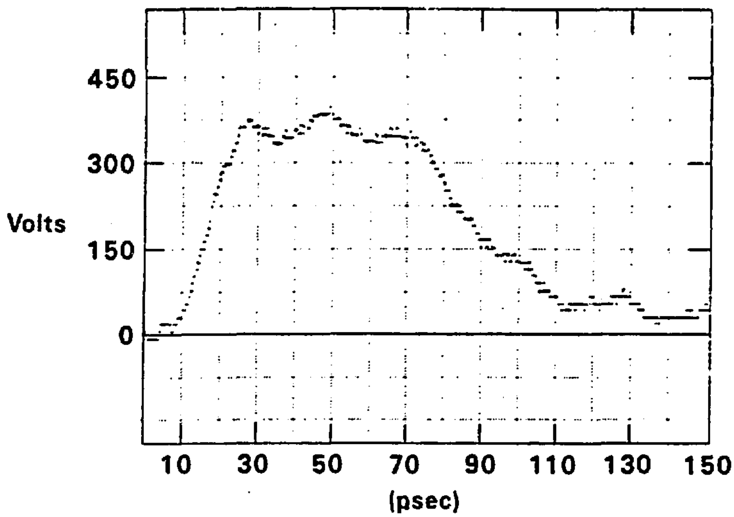
X-ray framing camera



- Temporal profile of the voltage between the photocathode and microchannel plate collimator
- Time resolution of measurement: ~10 ps

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