Krypton Fluoride Laser Target Interaction Facility*

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The krypton-fluoride (KrF) laser has significant advantages towards achieving the target performance needed for laser fusion energy. These advantages arise from its short wavelength (λ=248 nm), its capability to provide exceptionally uniform and controlled illumination of targets, and its broad bandwidth. These qualities are predicted to increase the gain of direct drive pellet implosions while at the same time reducing the risk from both laser-plasma and hydrodynamic instabilities.[1] Most large laser facilities conducting ICF and HEDP research utilize frequency tripled Nd:glass lasers (λ= 351 nm) with energies up to 30 kJ with OMEGA and 1.8 MJ for NIF. The largest KrF facility is the 3 kJ Nike facility at NRL.[2] We propose designing and constructing a much more capable KrF facility that would have high value both for understanding and predicting the physics advantages of KrF towards achieving high target performance and in advancing HED and ICF target physics.

The new facility would involve a moderate scale-up of the existing Nike amplifiers and make use of technologies developed in the Electra program. Among other achievements, the Electra KrF facility demonstrated 5 Hz operation and developed advanced electron beam diode technologies that increase the electron-beam transmission into the laser gas from the typical 30-40% in earlier systems to >75%.[3] Tested codes are available to predict performance of KrF laser systems. The proposed system would employ two angularly multiplexed beam lines each capable of providing 16 kJ on target. The system would utilize a target illumination system where the beams would be distributed in two rings as shown in Figure 1. With suitable choice of beam focal profiles and cone angles this configuration can be tailored to provide highly uniform illumination and implosion of spherical targets,[4] while also providing reasonable efficiency for cylindrical implosions or laser plasma interaction experiments in planar geometry. This flexible illumination geometry is a powerful capability that is unmatched by any existing inertial confinement laser.

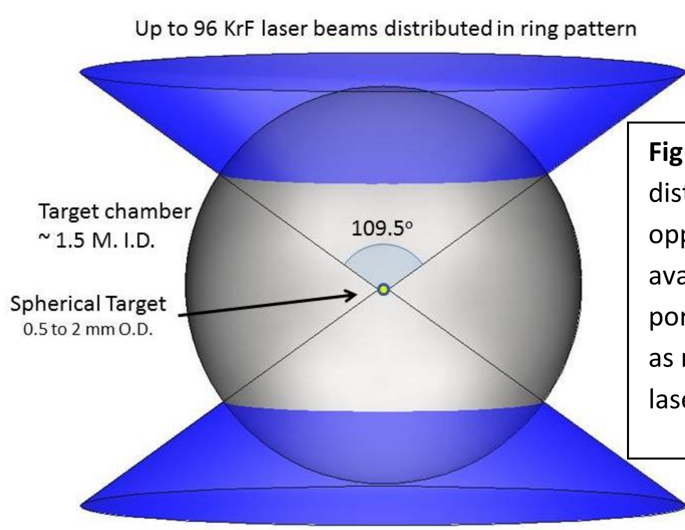

Figure 1. Up to 96 beams would be distributed uniformly in each of two opposed rings. Other ports would be available that allow redirection of a portion of the beams to other angles as needed for x-ray backlighting or laser-plasma interaction experiments.

The facility would utilize two final amplifiers with a modest increase in aperture (80 cm x 80 cm) over that used in Nike (60 cm x 60 cm). These amplifiers would employ scaled-up versions of the high-efficiency electron beam diodes demonstrated on the Electra system. The kinetics codes predict up to 18 kJ could be obtained from each of these amplifiers in multi-nanosecond pulses. The time-delays in the angularly multiplexed beams would be shortened from the 4 ns used on Nike to 2.5 ns. This shorter delay will allow most of the system energy to be delivered with pulses much shorter than 2.5 ns because the inter-pulse delay is then shorter than the KrF storage time. The system will also use vacuum or low pressure helium in the beam propagation paths after the final amplifier. This eliminates non-linearities in the beam paths. In combination, these changes will allow an unprecedented delivery of high-power (>150 TW), deep uv light to ICF/HEDP targets in 200 ps pulses. Among other areas, this facilitates exploring the physics at the high intensity (up to 10^{16} W/cm^2) envisioned for the igniter pulse of shock-ignited direct-drive implosions.[5] KrF has the bandwidth to amplify pulses as short as 500 fs, and the system should be capable of much higher power on target with such pulse lengths.

The facility would be able to answer the following key scientific questions:

- What is the maximum intensity that can be employed with a KrF laser to drive a conventional direct drive implosion and the initial phase of a shock ignited implosion?
- What is the maximum intensity that can be employed for the igniter pulse of a shock ignited target before laser plasma instability (LPI) interferes?
- Does use of KrF light substantially improve the implosion and fusion yield over frequency tripled Nd:glass? (e.g. this system would have similar energy on target as OMEGA direct drive implosions)
- Can we develop a predictive capability to understand the physics that governs the threshold, magnitude and possible saturation of LPI? AHow does the magnitude of LPI effect ICF implosions, and how can these be mitigated?

The facility would provide excellent time-averaged illumination on target due to the proven use of KrF's induced-spatial incoherence (ISI) beam smoothing and broad bandwidth ($\Delta\omega/2\pi \cong 3$THz). The low nonlinear index of this gas laser allows imaging a laser profile in the low energy front end through the amplifiers onto target. This allows 1) routine changes of the beam profile on target as no final phase plates are needed, and 2) the ability to change the beam profile during the laser pulse. The latter, called "zooming", has been installed on Nike where the beam profile is reduced during the shot. This capability would allow a great variety of basic hydro-instability and HED experiments with precise and flexible control of the target illumination parameters.

Why another laser facility?

1. The system would be the world's most energetic and powerful deep UV laser.
2. KrF has distinct advantages in the target physics and also potential to scale to the energy, efficiency and repetition rate thought to be needed for fusion power. This facility could serve as a stepping stone to the capability needed for an inertial Fusion Test Facility (FTF) that is described in one of the references.[6]
3. It is needed to advance our understanding of laser plasma interaction with KrF light with substantially higher laser power and energy than currently available.

4. As a more easily cooled gas laser it could accommodate higher repetition rates. We envision a 10 shot per hour capability with rudimentary cooling. This would allow many more target experiments and users than existing Nd:glass systems which typically have rep rates of 1 per hour or less. This system could be configured to allow later installation of the 5 pulse per second capability already demonstrated on Electra.
5. This would be the first laser facility devoted primarily to areas of interest to the office of Science: the science of inertial fusion and its potential to be an energy source.

Readiness of the Facility Concept

Using the categories in Dr. Brinkman's letter, the proposed KrF laser-target facility is ready to initiate detailed design and construction. All of the KrF laser technologies have been tested on Nike or Electra and an experienced design team has been identified and is available for this task.

System Design, Development and Cost

This system would make use of technologies and expertise from the Nike and Electra KrF systems as well as that of the large glass laser target facilities. The envisioned beam lines are moderate upgrades in size from the existing Nike facility. We would plan to use all solid state pulse power to increase the system reliability and reproducibility over the spark-gap switching used in Nike. A prototype all solid-state pulse power module was operated continuously for over ten days at 10Hz by the Electra program. We offer the following estimates of the cost and time lines for designing, building and final testing of this facility.

Year 1-3	Test new components on Nike and Electra
	Design the system
	Initiate construction of system enclosure
Year 4-7	Fabricate, install and test components
Year 8	Configure and test full system

Cost estimates:

Design and development	$19M
Enclosure	$8M
System Components	$96M (includes basic installation)
Final assembly and testing	$21M
Target diagnostics	$10M (Nike diagnostics would be transferred)
Project oversight & management	$7M
Total for project	**$161M**
Yearly Operation	**$10M/year (laser & target facility operation)**
Target fabrication	**$3M/year**
Research	**Facility could support many scientists**

Notes:

1. The facility could be built in stages at reduced initial cost. For example one could design, build and conduct target experiments with a single 16 KJ beam-line.
2. This facility would not have sufficient energy to achieve ignition or scientific breakeven While the codes predict increase performance with KrF, a minimum of about 250 to 500 kJ is still required for ignition and significant gain. However the facility would enable much higher confidence in the understanding and the ability to predict the behavior of high gain implosions. As a side benefit, the beam lines could be the modular building blocks for such a larger facility.
3. The target facility could be used for examining technical issues of a follow-on more capable IFE facility. For example one could explore the feasibility of protecting the first-wall by gas-fills or external magnetic fields.[7]
4. The dual-ring illumination configuration of this facility would be unique, and it could have distinct advantages for implementation in IFE target chambers.

References

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