Design and assembly of the neutron imaging lens for the National Ignition Facility

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The housing of a large, state-of-the-art relay lens rejects 93% of unwanted neutron-scintillator light.

The National Ignition Facility (NIF) at the Lawrence Livermore National Laboratory is the world’s largest and most powerful laser system for inertial-confinement fusion (ICF) and experiments studying high-energy-density science. Neutron imaging of ICF targets provides a powerful tool for understanding the implosion conditions of deuterium- and tritium-filled targets, primarily to determine the symmetry of the fuel in imploded targets. Image data is then combined with other nuclear information to gain insight into the laser and radiation conditions required to drive the targets to ignition.

To perform neutron imaging, a pinhole assembly is placed 26 cm from the target-chamber center (TCC). It consists of an array of 37 pinholes that produce multiple images at a scintillator on an optics table located 28 m from the TCC (see Figure 1). Upstream collimators limit the extent of the neutron beam. The large, pixelated scintillator is composed of 50 mm-long rods that emit light in both the forward and backward directions. The forward-directed light makes use of a coherent fiber-optic bundle to send the recorded image to a CCD camera. The backward-directed beam is collected by a large lens system that relays it onto a gated microchannel-plate (MCP) intensifier. Light from the MCP phosphor is further focused onto a CCD camera. The scintillator light reflects off a large turning mirror, so that the large lens system is kept out of the neutron flux.

To keep the optical-element diameters small, the stop needs to be located as closely as possible to the turning mirror. All lens elements (some singlets, some doublets) are mounted into their own cells (see Figure 2). The lens edges are blackened to suppress stray light. All metal-cell diameters (except for that of element 5) are slightly convex to facilitate assembly. This prevents binding of the cell as it is inserted into the metal housing. The metal cells were assembled into a single housing envelope.

The scintillator rods emit light at very wide angles (numerical aperture, NA = 0.56). The relay lens collects 0.15 NA light from the scintillator, which is only 7.2% of the available emission. We performed careful ghost-imaging and stray-light analyses and took care to improve contrast by baffling and blocking unwanted light. The remaining 93% of the light must be accounted for in a stray-light calculation to ensure that undesirable light artifacts do not interfere with the imaging.

Figure 1. The pixelated scintillator is positioned 28 m from the target-chamber center (TCC) where the fusion reactions occur. The scintillator emits light in both the forward and backward directions. Neutron images are recorded at two different times. Not shown in the figure is extra lead shielding to protect the two CCD cameras. The two paddles in the neutron beam are used to record the time history of the γ and neutron emissions. The beam enters into a beam dump after leaving the optical table (not shown). MCP: Microchannel plate.

Figure 2. The figure shows the assembly of the neutron imaging lens.
Figure 2. All lens elements are mounted inside individual metal lens cells, which have rolled edges that allow easy assembly. Total weight of the lens housing including the glass is 73.8 lbs. The labels at the bottom refer to glass types manufactured by Ohara GmbH (Germany).

Figure 3. Stray-light analysis performed on the metal housing. NA: Numerical aperture. BCF-95-55: Fiber type.

We imported the computer-aided-design model of the metal housing with all its components into illumination-design software with all glass materials. This allowed ray tracing through the metal housing into the lens elements. We assigned the correct glass materials to all lenses. While we ran the stray-light analysis, we tested different metal-housing surfaces as absorbers. To eliminate unwanted stray light, we turned only the important surfaces into absorbers and subsequently measured the number of stray rays affected by each of these surfaces. Consequently, we chose three surfaces to have light-blocking V-form threads (see Figures 3 and 4).

As the NIF becomes more successful, the coherent fiber bundle will start to suffer from increasing radiation damage. A copy of the current lens system will replace the coherent-bundle system. The second lens may be larger in diameter to collect more light. Full spectral analysis of the lens system needs to be performed.

Figure 4. Looking through the front of the lens at the two threaded surfaces between the first two lens elements. The first lens shows dim reflections from room lights.

The goal is to equate the numbers of photons recorded to the numbers of neutrons that arrive at the scintillator.

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