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Progress towards achieving ignition on the National Ignition Facility

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Achieving controlled thermonuclear fusion in the laboratory represents a decades-long scientific and technical challenge. The National Ignition Facility, a 1.8 MJ 192-beam fusion-class laser provides the means to pursue this challenge via the process of inertial confinement fusion. Since experiments began in 2009 considerable progress has been made in understanding and overcoming the obstacles to achieving ignition. The performance of cryogenic deuterium-tritium (DT) implosions has steadily increased to a point where self-heating of the hot-spot by fusion-generated alpha-particles now almost exceeds the compressive heating of the implosion itself. In current experiments plasma conditions have reached temperatures of 4.7 +/-0.2 keV, fuel areal densities of 0.28 +/-0.03 g/cm^2, and stagnation pressures of 360 +/-30 Gbar. Alpha-particle self-heating of the hot-spot is estimated to be boosting the total DT fusion output by a factor of 3x. Further improvements are still needed, however, to close the remaining gap to runaway self-heating and ignition. A simple measure for the proximity of current implosions to ignition is given by the no-burn Lawson parameter, or pressure-confinement time product (Pτ), and estimates are that we need to increase Pτ by 30% to reach the threshold for ignition. Identifying the physical mechanisms currently degrading performance and quantifying the improvements needed to recover this deficit are crucial to making continued progress. This tutorial will review the progress made in the experimental campaigns to date, in improved diagnostic techniques enabling us to characterize implosion conditions with unprecedented precision, and in the significant advances in large-scale computational modeling capabilities. We will discuss the major remaining challenges, and the further improvements expected to be needed to achieve ignition. This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.