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Understanding the Fusion Yield and All of Its Dependencies Using Statistical Modeling of Experimental Data

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Statistical modeling of experimental and simulation databases has enabled the development of an accurate predictive capability for OMEGA DT layered implosions, leading to new target designs and record fusion yields, threefold higher than previously achieved.[V. Gopalaswamy et al., Nature 565, 581 (2019)] In addition to enhancements in fusion performance, a new application of statistical modeling has been devised to greatly improve our understanding of the underlying physics, various dependencies, and all degradation mechanisms affecting the fusion yield of OMEGA implosions. Since the statistical framework relates the outputs of 1-D simulations to experimental results, a judicious choice of simulation outputs can identify and quantitatively assess the different dependencies and degradation mechanisms. Each dependency is validated by comparison with trends in 3-D simulations. We find that the yield is reduced by four factors: the ratio of laser beam to target radius (a proxy for laser beam geometry mode); the variance of inferred ion temperatures (a proxy for $l = 1$ mode from offset and mispointing); the time span over which the tritium fuel has decayed (a proxy for tritium damage and 3He buildup, subsequently included in codes as a result of this work); and the normalized pulse length [Tpulse/(R/Vimp)], related to the in-flight aspect ratio (a proxy for the growth of short wavelength modes from sources like laser imprinting). We find that the degradation from beam geometry illumination nonuniformity is greater than predicted by 3-D simulations and accounts for 30% to 40% reduction in yield in best-performing implosions. The degradation from short wavelength modes limits the yield at convergence higher than best performers. The degradation from DT-fill age is significant, and is mitigated by reducing fill-to-shot time to under three days. The $l = 1$ mode is only important when Ti asymmetries exceed 10%. This material is based upon work supported by the Department of Energy National Nuclear Security Administration under Award Number DE-NA0003856.