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LLNL-BOOK-576332

Perspectives 2012

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August 23, 2012

Search for the Ultimate Energy Source - A History of the US Fusion Energy Program (Book by Stephen O. Dean, Chapter 14 contribution by John H. Nuckolls)

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This work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344.

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Inertial Fusion Energy: Super-Lasers and Super-Implosions

In spring 1960 I calculated a FUSION MICROEXPLOSION, a 50 mega-joule (MJ) high gain micro-explosion, initiated by a tiny spherical implosion in a small HOHLRAUM heated by a multi MJ pulse of radiation energy. A few months later when Maiman announced the first successful laser, we began to analyze the feasibility of heating plasmas to high temperatures, laser driven implosions, MJ super lasers, laser fusion, and weapons physics applications. In 1961 I calculated use of temporal pulse shaping to create super-implosions, which initiate low cost, propagating, micro-explosions required for practical fusion power applications. Since 1963, the Livermore Laboratory has been funded by the Nuclear Weapons Program to develop a series of larger more advanced super-lasers, including the 20 beam, 10 kilojoule (KJ) Shiva laser in the 1970s, and the Nova 10 beam 30 KJ blue laser in the 1980s. In 1972 our calculations of super-implosions directly irradiated by lasers were declassified; later our indirectly driven (hohlraum) super-implosion targets were declassified. In the 1990s, when nuclear testing ended the U.S. launched the Stockpile Stewardship Program, including design and construction of the 192 beam, 1.8 MJ, National Ignition Facility (NIF). NIF was dedicated in 2009.

NATIONAL IGNITION CAMPAIGN (NIC) – As of August 2012, the very successful NIF super-laser is focusing 2 MJ, 500 TW temporally shaped pulses of blue laser light into cm-scale hohlraum targets, energizing millimeter-scale super-implosions designed to ignite propagating 20 MJ fusion micro-explosions. Experts are recording volumes of experimental data from NIF's array of several dozen advanced diagnostic instruments, analyzing this data with powerful supercomputers and codes (billions of times more powerful than in the 1960s) and improving the super-implosion.

Outstanding progress has been made. The imploded central core of deuterium-tritium (DT) has achieved ideal ignition temperatures, and is within a few-fold of the required ignition pressure. The surrounding DT shell is several thousand times liquid density – within a factor of two of the required density. To achieve ignition the hot core density-radius product must be increased two fold to absorb the DT alpha energy and enable thermonuclear bootstrapping.

Challenging difficulties have been encountered. Hydrodynamic instability growth and mix are larger than calculated, and implosion efficiency is significantly lower. Target improvements are required. Black Swans cannot be precluded.

NIF experiments are required to demonstrate that directly driven super-implosions can achieve higher implosion efficiency while avoiding excessive growth of laser and plasma instabilities.

Target designs with higher implosion efficiency – but with reduced implosion requirements may be feasible, e.g., tamped non-ablative designs, or designs with magnetized, preheated DT. Practical Fast Ignition targets (which utilize a petawatt ignition laser) may be invented to minimize laser energy, relax super-implosion performance requirements and enable enhanced thermonuclear propagation to achieve very high gains.

FUSION POWER: MAJOR ECONOMIC & TECHNOLOGICAL CHALLENGES – Systems Studies conclude that practical inertial fusion power plants are feasible. After ignition and high gains are achieved, and several beamlines of an efficient, high repetition rate diode pumped solid state laser (or other driver) are demonstrated, substantial inertial fusion energy funding will be required to construct a burst mode, high heat capacity inertial fusion energy system, including a driver, target factory and an explosion chamber protected from neutron, x-ray, and exploding debris damage by fluid shielding. Repetition rate could be gradually increased from hours to minutes to seconds – leading to an experimental fusion reactor. Fusion neutrons could also be used to burn nuclear waste.

Government funding of fusion energy development may be limited while the U.S. economy is recovering. A global fusion power system will cost trillions of dollars. Innovations that demonstrate a significant economic advantage may attract massive private sector funding and greatly accelerate deployment.

After fusion driver, target, and reaction chamber costs are minimized, significant reductions in the dominant balance of plant capital cost, and increases in thermal electric efficiency, may require invention of practical direct conversion electrical generating systems and deuterium burning targets.

John H. Nuckolls is a pioneer of the field of inertial confinement fusion and is Director-Emeritus of the Lawrence Livermore National Laboratory.