PATH TO COMMERCIAL FUSION ENERGY BASED ON SHEARED-FLOW-STABILIZED Z PINCHES*

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Sustained fusion reactions have been measured in a > 2 keV deuterium Z-pinch plasma which is stabilized by radially sheared axial flows. Thomson scattering results show the onset of high plasma temperature is coincident with a stabilized quiescent period and neutron production. The neutron yield scaling shows strong dependence on pinch current in both model and experiment, agreeing with a simple scaling model consistent with $\propto I^{10}$ [1]. Measurements from neutron detectors demonstrated that 2.45 MeV neutrons were emitted from an extended portion of the 50-cm plasma column, the length of which can be controlled by the specifics of the deuterium gas injection[2]. Neutron spectroscopic measurements indicate a thermonuclear production process with limited beam-target effects[3]. These promising results indicate that a sheared-flow-stabilized (SFS) Z pinch could scale to an extremely compact, economical fusion power plant.

In a traditional Z-pinch equilibrium, an axial pinch current radially confines plasma pressure such that increasing the current results in higher densities and temperatures. While virulent pressure-driven instabilities are known to quickly destroy the traditional Z-pinch equilibrium, theory showed that introducing a sheared axial flow stabilizes the plasma[1]. Closely coupled with computational studies, a series of Z-pinch experiments at the University of Washington tested the theory of sheared-flow stabilization. Experimental measurements of the plasma equilibrium and stability confirmed that in the presence of a sufficiently large flow-shear, gross Z-pinch instabilities were mitigated, and radial force balance was achieved. Z-pinch plasmas of 50, 100, and 126-cm lengths were held stable for durations much longer than predicted for a static plasma, i.e. thousands of growth times[1].

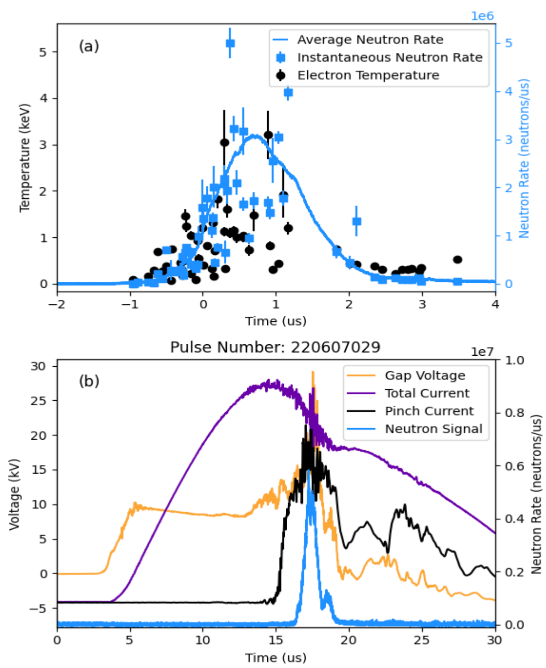

Figure 1 (Top) Elevated electron temperature as measured by Thomson scattering is coincident with neutron production. (Bottom) Z pinch electrical parameters before, during, and after neutron production.Neutron production

Zap Energy is developing the SFS Z pinch for fusion energy applications. The efforts to achieve the necessary performance improvements are aided by a suite of diagnostics. In collaboration with Lawrence Livermore National Laboratory (LLNL) and UC San Diego, Zap Energy performed multi-point, time resolved Thomson scattering measurements on over 300 pulses. Electron temperatures in excess of 2 keV were achieved simultaneous with neutron production and peak current, as shown in Figure 1. Also with LLNL, neutron scintillators were used to measure the spatial and temporal fusion production, calibrated neutron yields, and the thermonuclear nature of the fusion reactions. Figure 2 shows that an extended source of ~30 cm provides the best fit to the neutron measurements. The figure also shows a visible light image of the plasma consistent with this axial extent, taken by an optical fast framing camera provided by LANL collaborators.

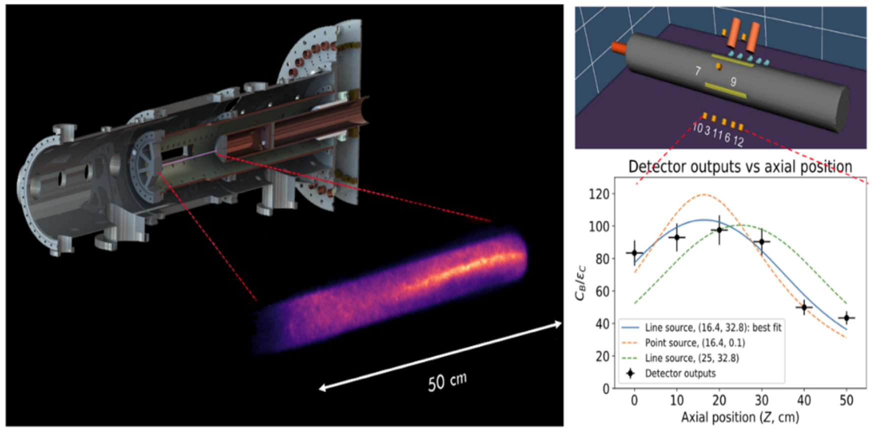

Figure 2 (Left) A visible fast camera image of the FuZE SFS Z-pinch. (Right) An array of neutron detectors were used to measure the axial spatial extent of neutron production in FuZE.

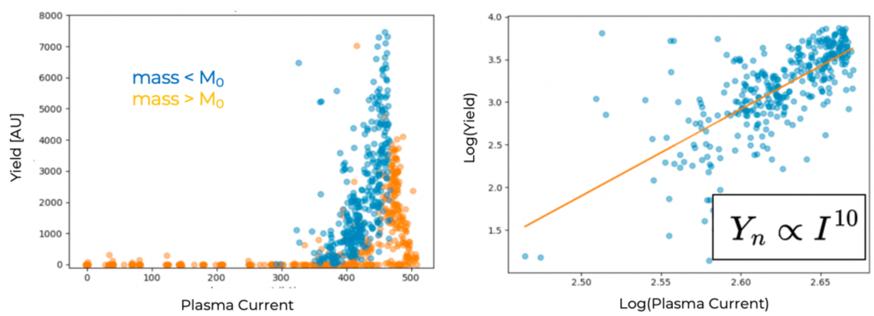

Figure 3 Experimental neutron yield vs plasma current for hundreds of Z pinch discharges on Zap Energy's FuZE device. Linear, (a), and log-log (b) plots. The results are plotted for two categories of deuterium fuel mass. The log-log plot is consistent with a scaling of $Y_n \propto I^{10}$.

Increasing the pinch current has demonstrated a corresponding increase in neutron yield, with yields $Y_n > 1\times10^8$ neutrons per pulse in our next generation FuZE-Q device, which was recently commissioned. Neutron yield scales strongly with plasma current, as shown in Figure 3, which summarizes the results from a recent campaign on the FuZE device. These new results show that when mass inventory and gas injection characteristics are properly coupled to the current waveform, the expected neutron scaling with plasma current is observed, as shown in Figure 3b.

The new FuZE-Q device, along with its newly commissioned 1 MJ class current driver, is predicted to be able to generate Z-pinch discharges characterized by triple products meeting Lawson criterion. Assuming continued performance scaling as shown here, the SFS Z pinch would make a compact fusion power plant. The simplicity of the device, enabled by its lack of need for external magnetic confinement, allows for a robust and economical plant design. For example, the use of a liquid metal first wall would help minimize the total volume of activated material as well as total necessary tritium inventory. Thus, a fusion power plant based on the SFS Z pinch has strong advantages over other approaches in a variety of aspects including size, cost, simplicity, and safety.

ACKNOWLEDGEMENTS

The information, data, or work presented herein was funded in part by the Advanced Research Projects Agency – Energy (ARPA-E), U.S. Department of Energy, under Award Nos. DE-AR-0000571, DE-AR-0001010, DE-AR-0001260 and by the Air Force Office of Scientific Research under Grant No. FA9550-15-1-0271. This research used resources of the National Energy Research Scientific Computing Center (NERSC), a U.S. Department of Energy Office of Science User Facility located at Lawrence Berkeley National Laboratory, operated under Contract No. DE-AC02-05CH11231

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* This work is supported by an award from US ARPA-E.