Contribution ID: **952** Type: **Regular Poster**

# Sheared-Flow-Stabilized Z Pinch as a Compact Fusion Device

*Wednesday, 12 May 2021 18:25 (20 minutes)*

Sustained fusion reactions have been measured in a quiescent deuterium Z-pinch plasma, wherein unity beta was achieved, and sheared flows alone provided stability. Measurements from multiple scintillator neutron detectors demonstrated that 2.45 MeV neutrons were emitted uniformly along the majority of the 50-cm plasma column and that the neutrons were produced from a thermonuclear process with negligible beam-target effects. Theory and simulations indicate that neutron yield will increase rapidly with pinch current, \propto I^{10}.

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 plasma1. 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 times2. Experimental results were combined with adiabatic scaling relations and detailed single-fluid, multi-fluid, and kinetic computational studies to explore the limits of plasma properties that can be achieved in a sheared-flow-stabilized (SFS) Z pinch.

The collaborative FuZE (Fusion Z-pinch Experiment) project between UW and LLNL scaled the SFS Z pinch to fusion conditions. Flow-shear stabilization was demonstrated to be effective even when a 50-cm long plasma column was compressed to small radii (3 mm). Improved understanding of the stabilization mechanism provided a means of increasing plasma parameters, e.g. ne > 1e17 /cc and Ti > 1 keV. Steady neutron production3 was observed for durations up to 8 microseconds (Fig. 1) during which the plasma was stable, and the current was sufficiently high to compress the deuterium plasma to fusion conditions. Measurements of neutron energy demonstrated a thermonuclear origin of the fusion process with negligible beam-target contributions. Neutron observations were not associated with MHD instabilities, and measured neutron yields[4] scaled with the square of the deuterium concentration and agreed with thermonuclear yields calculated with the measured plasma parameters.

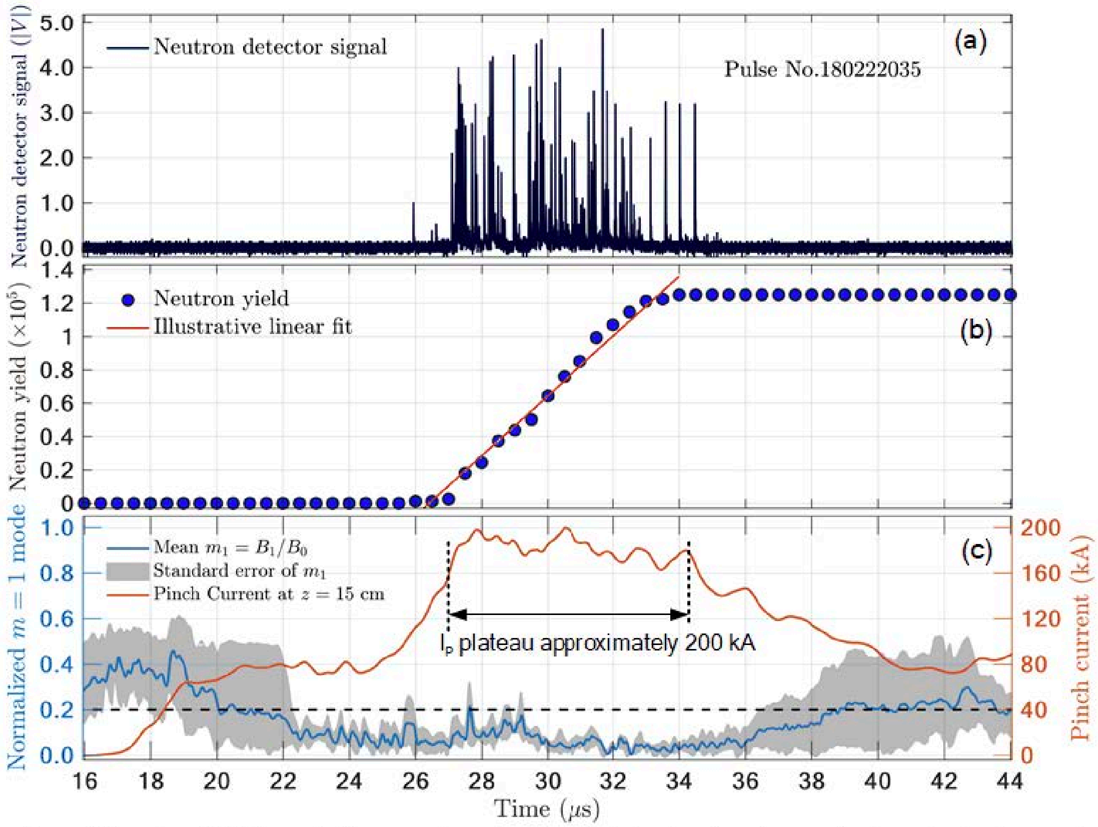


*Figure 1 Overview of FuZE results. Time waveform of neutron detector signal, neutron production rate, pinch current, and normalized m=1 magnetic field component.*

Figure 1:

Increasing the pinch current has demonstrated a corresponding increase in neutron yield, with yields of up to Yn = 5e6 neutrons per pulse. Neutron yield scales strongly with pinch current, as the Bennett relation (for fixed linear density N) gives T = I^2, and the d(D,3He)n fusion reactivity for T = 1-10 keV scales as sigma-v \propto T^4.

Initial experimental studies of neutron yield with pinch current show Yn dependent on the current to the 8-10th power. These results are supported by two-temperature MHD simulations of the FuZE device, which shows the neutron yield asymptotically increasing as I^{10}. See Fig. 2.

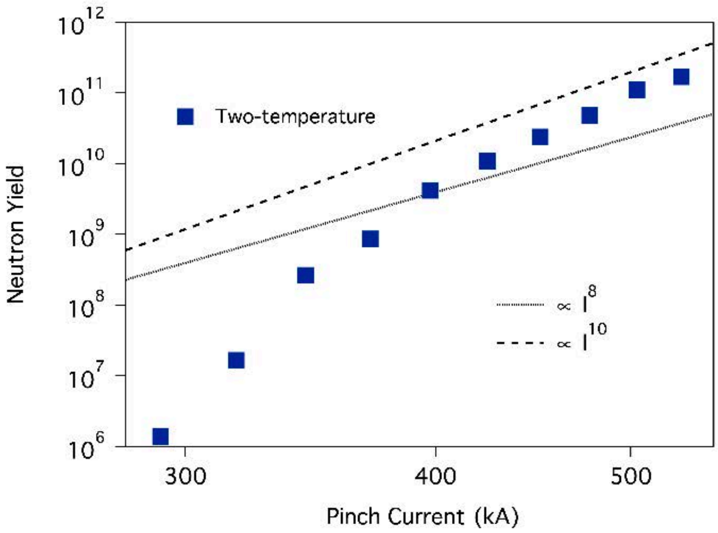


*Figure 1 Neutron yield scaling from two-temperature, single-fluid MHD plasma simulations of the UW FuZE SFS Z-pinch device. Yield scales strongly with current.*

Figure 2:

Kinetic simulations using the LSP code5 show stabilization of the m=0 mode with increasing flow shear for experimental conditions and continuing for fusion reactor conditions, shown in Fig. 3.

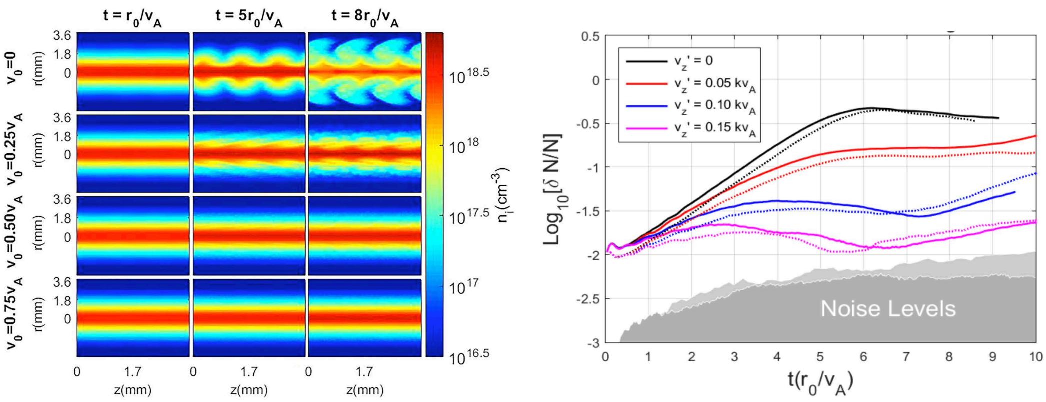


*Figure 3 PIC simulations of ion density contours of the kr₀=5, m=0 mode for FuZE conditions show improved stability and confinement with sheared flows (left). Sheared flows cause mode damping in FuZE (right, solid) and reactor (right, dashed) conditions.*

Figure 3:

Experimental observations generally agree with theoretical and computational predictions, indicating that sheared flows can stabilize and sustain a Z-pinch equilibrium. If performance continues to improve with pinch current as experimentally observed and computationally predicted, the SFS Z pinch would make a compact fusion device for energy or neutron production applications.

## Affiliation

University of Washington

## Country or International Organization

United States

**Primary author:** SHUMLAK, Uri (University of Washington)

**Co-authors:** MCLEAN, Harry (Lawrence LIvermore National Laboratory); Dr NELSON, Brian (Zap Energy Inc.); HIGGINSON, Drew (Lawrence Livremore National Laboratory); Mr CLAVEAU, Elliot (University of Washington); Ms FORBES, Eleanor (University of Washington); Mr KHAIRI, Aqil (University of Washington); Dr MEIER, Eric (University of Washington); Dr MITRANI, James (Lawrence Livermore National Laboratory); Mr PARSONS, Collin (University of Washington); Dr STEPANOV, Anton (University of Washington); Dr TUMMEL, Kurt (Lawrence Livermore National Laboratory); Dr WEBER, Tobin (University of Washington); Dr ZHANG, Yue (Zap Energy Inc.)

**Presenter:** SHUMLAK, Uri (University of Washington)

**Session Classification:** P4 Posters 4

**Track Classification:** Innovative and Alternative Fusion Concepts