White Paper for *Frontiers of Plasma Science Panel*

Date of Submission:	***06-18-2015***

Indicate the primary area this white paper addresses by placing "P" in right column.
Indicate secondary area or areas by placing "S" in right column

	"P", "S"
• Plasma Atomic physics and the interface with chemistry and biology	
• Turbulence and transport	P
• Interactions of plasmas and waves	
• Plasma self-organization	S
• Statistical mechanics of plasmas	

Indicate type of presentation desired at Town Hall Meeting.

	"X"
Oral	X
Poster	
Either Oral or Poster	

Title:	**Need for Momentum Injection and Core Fueling in Reactor Grade Fusion Plasmas**
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**(Limit text to 3-pages including this form. Font Times Roman size 11.
1 page of references and 1 page of figures may also be included. *Submit in PDF format*.)**

- ***Describe the research frontier* and importance of the scientific challenge.**

High-performance tokamak and ST plasmas greatly benefit from plasma rotation, and rotation shear, to increase energy confinement and sustain high beta. This has been possible due to the injection of substantial momentum from tangentially injected neutral beam systems, which also contribute to important core fueling in such plasmas. In larger devices such as ITER or DEMO, higher beam injection energies are required to penetrate to the plasma core, and this reduces the momentum input per unit power. As a result, ITER is projected to have low toroidal rotation relative to present devices. Advanced Tokamak (AT) scenarios also rely on optimized density and pressure profiles that must be maintained for efficient device performance. As stated in a IEA Burning Plasma Workshop Review [A.J.H. Donne et al., Fusion Science and Technology, **49**, Jan 2006, pg. 79] "..there is not much flexibility in the fueling of ITER". Compact Toroid (CT) fueling has the potential to fill these serious needs in momentum injection, and controlled deep fueling for density profile control in burning reactor grade plasmas. The steep toroidal field gradient, and large plasma volume, in the new generation of STs soon to begin operation, such as NSTX-U, makes it an excellent and ideal test bed for developing this important capability during the next decade to improve the reactor core power density, and reduce the cost of AT systems

- ***Describe the approach to advancing the frontier and indicate if new research tools or capabilities are required.***

A Compact Toroid (CT) is a self-contained plasmoid with embedded magnetic fields. The structure is very robust and it can be accelerated to the high velocities needed for fusion reactor fuelling. The CT injection concept was first proposed by Perkins et al., [1] and Parks [2]. This first successful tokamak injection experiments, based on the RACE injector design [3,4], were conducted on the TdeV tokamak [5]. A reactor CT injector [6 to10] would typically inject 2.2 mg toroids of DT plasma or pure tritium plasmas at a fuelling rate of about 20 Hz. This 5 MW injector will impart the same momentum as a 69 MW, 500 keV neutral beam injector, while supplying 14 times more core fueling.

These would be injected at a nominal velocity of 300 km/s, but have capability to vary the velocity (200-500 km/s) in order to vary the fuel and momentum deposition location. The injector would be positioned with some tangency with respect to the radial direction to be able to inject toroidal momentum. Two to three injectors positioned at different toroidal locations, and with different tangency could be used to control rotation shear. Experiments on NSTX-U, using an existing injector in storage at PPPL, would allow for a test of the CTs momentum injection capability. The steep toroidal field gradient in NSTX-U makes it an excellent test bed for establishing the penetration scaling laws.

The outcome of this work is expected to be as follows:

<u>Localized fuelling:</u> It is necessary to show that by altering the CT injector parameters, that the CT could be used to deposit fuel at an arbitrary location within the tokamak.

<u>Momentum injection:</u> As shown in Figure 1, a tangential CT installation is possible on NSTX-U to demonstrate the momentum injection capability of the CT.

<u>Repetition rate operation:</u> CT injection from a 10-20 Hz injector into large tokamak plasma at higher values of the toroidal field is required. The present off-the-shelf hardware capability for high current switches and capacitor banks is such that a 20 Hz system can be built without the need for further research development in pulsed power technology [6,7,10].

- ***Describe the impact of this research on plasma science and related disciplines and any potential for societal benefit***.

Burning plasma devices (including stellarators) will have the tool required for injecting fuel deep into the discharge, where it is needed.

Eventually, in a burning plasma device, in addition to some need for current drive, controlled core fueling may be the ideal way to control internal pressure and rotation profiles. This would provide the tool for controlling rotation and rotation shear.

Such an optimized reactor system would have a higher core power density making it less expensive to operate, and economically more competitive, as would be required for it to have societal benefits.

References (Maximum 1 page)

[1] L.J. Perkins, S.K. Ho, J.H. Hammer, Nuclear Fusion **28** (1988) 1365

[2] P.B. Parks, Phys. Rev. Lett. **61** (1988) 1364

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[4] R. Raman, et al., Fusion Technology **24** (1993) 239

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Figures (maximum 1 page)

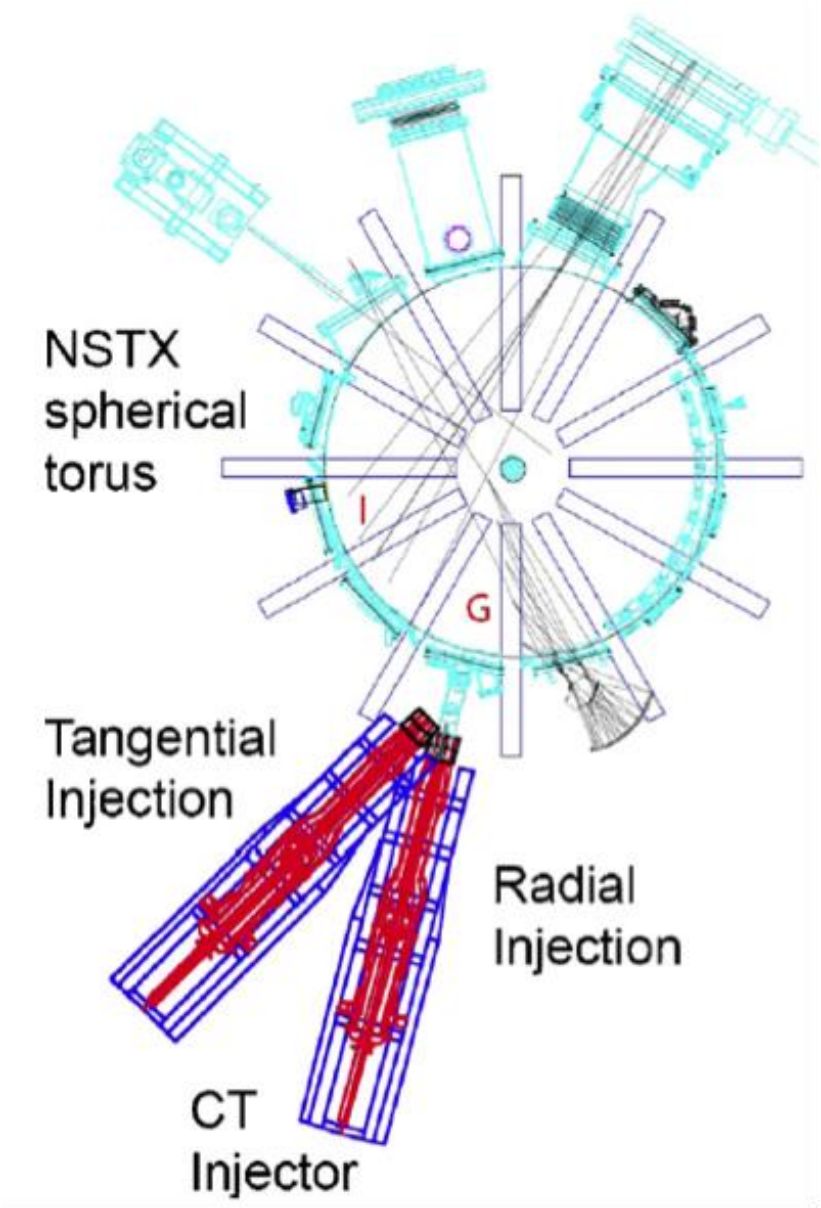

Fig. 1: Layout of a CT injector on NSTX-U for developing momentum injection and core fueling capability in support of a fusion reactor.