Future fueling requirements for NSTX high bootstrap current discharges

In partial fulfillment of work commissioned by
DOE grant No. DE-FG03-02ER54686, for the proposal

Assessment of the feasibility of using the CTF-II injector on NSTX

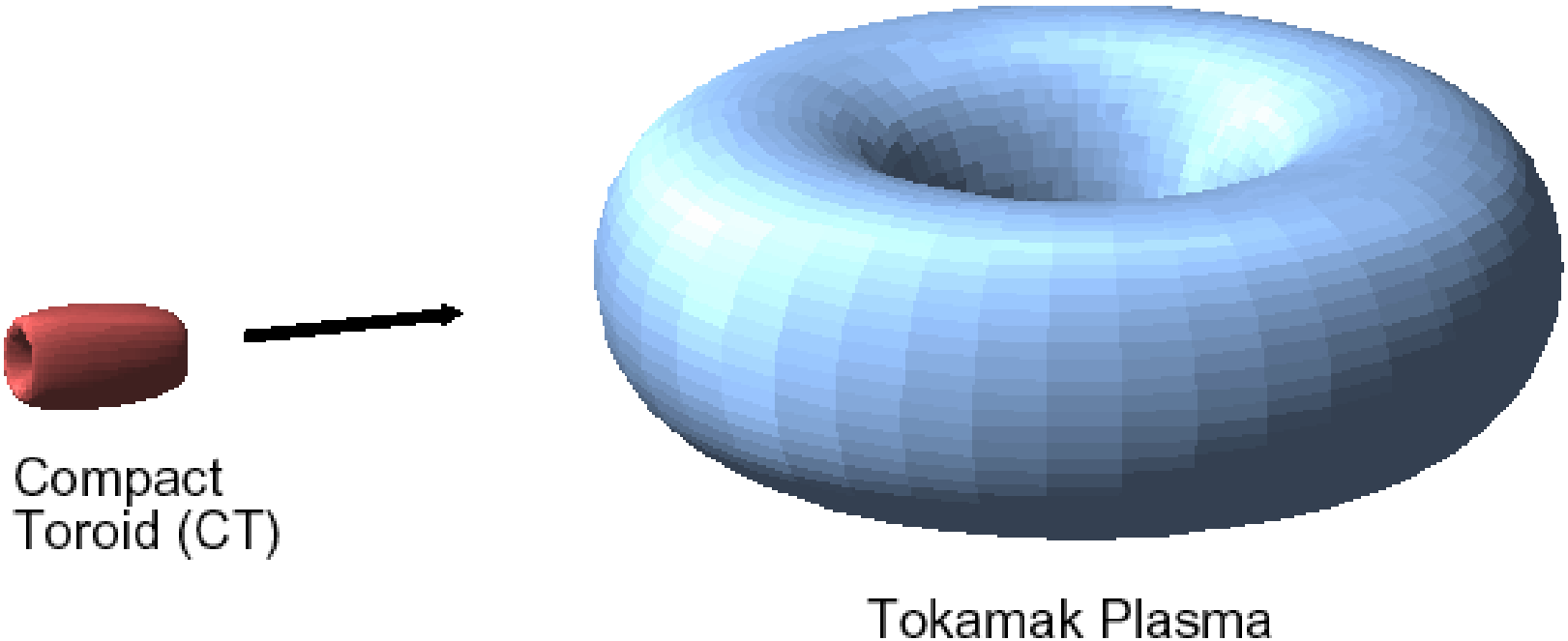
Roger Raman
University of Washington, Seattle
and the NSTX Research Team

NSTX Research Forum for Fy04
Boundary Physics Session
Princeton Plasma Physics Laboratory
April 7, 2003

The ability to inject CTs significantly expands NSTX experimental capability

- Single Pulse Injector
  - Precise H-mode initiation capability valuable for on-going XPs
  - Electron Transport Barrier studies
  - Clarification of the edge barrier seen during Neon injection
  - Transport studies by isotopic impurity tailoring
  - He ash removal studies
  - Prompt density injection to avoid locked modes
  - Reconnection studies - an important aspect of PPPL research
- Multi Pulse Injector
  - Momentum injection studies for transport barrier sustainment
  - Precise density profile control needed for NSTX SS discharges
  - Local current injection to suppress NTMs
  - Reduced divertor pumping requirements
  - Possible extension of density limits
  - Disruption mitigation by high-z plasma injection

A CT is accelerated to high velocity and injected into the target plasma to achieve deep fueling



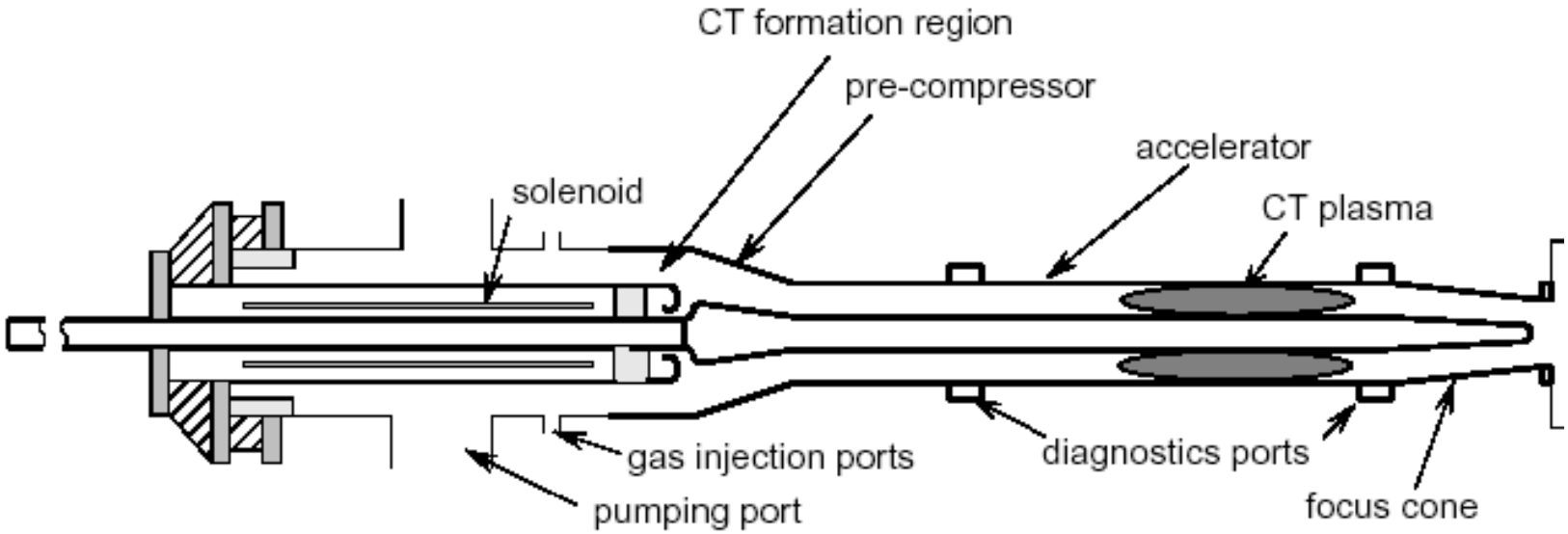
CT Penetration time: few μs

CT Dissociation time: < 100 μs

Density Equilibration time: 250 - 1000 μs

Variable Penetration depth: edge to beyond the core

A CT Fueler forms and accelerates CTs in a coaxial rail gun in which the CT forms the sliding armature



Raman et al., Fusion Techn., **24**, 239 (1993)

Amount of gas injected controls CT density

Applied voltage controls CT velocity

Control system specifies fuel deposition location for each pulse

CT Injection has the potential to meet future NSTX fueling needs

- Future NSTX high β, high bootstrap fraction plasmas require optimized profiles

- During high performance steady state non-inductive operation, <u>optimized profiles must be maintained</u>

- Fueling such discharges requires the prompt injection of small amounts of fuel <u>where needed and as often as needed</u>

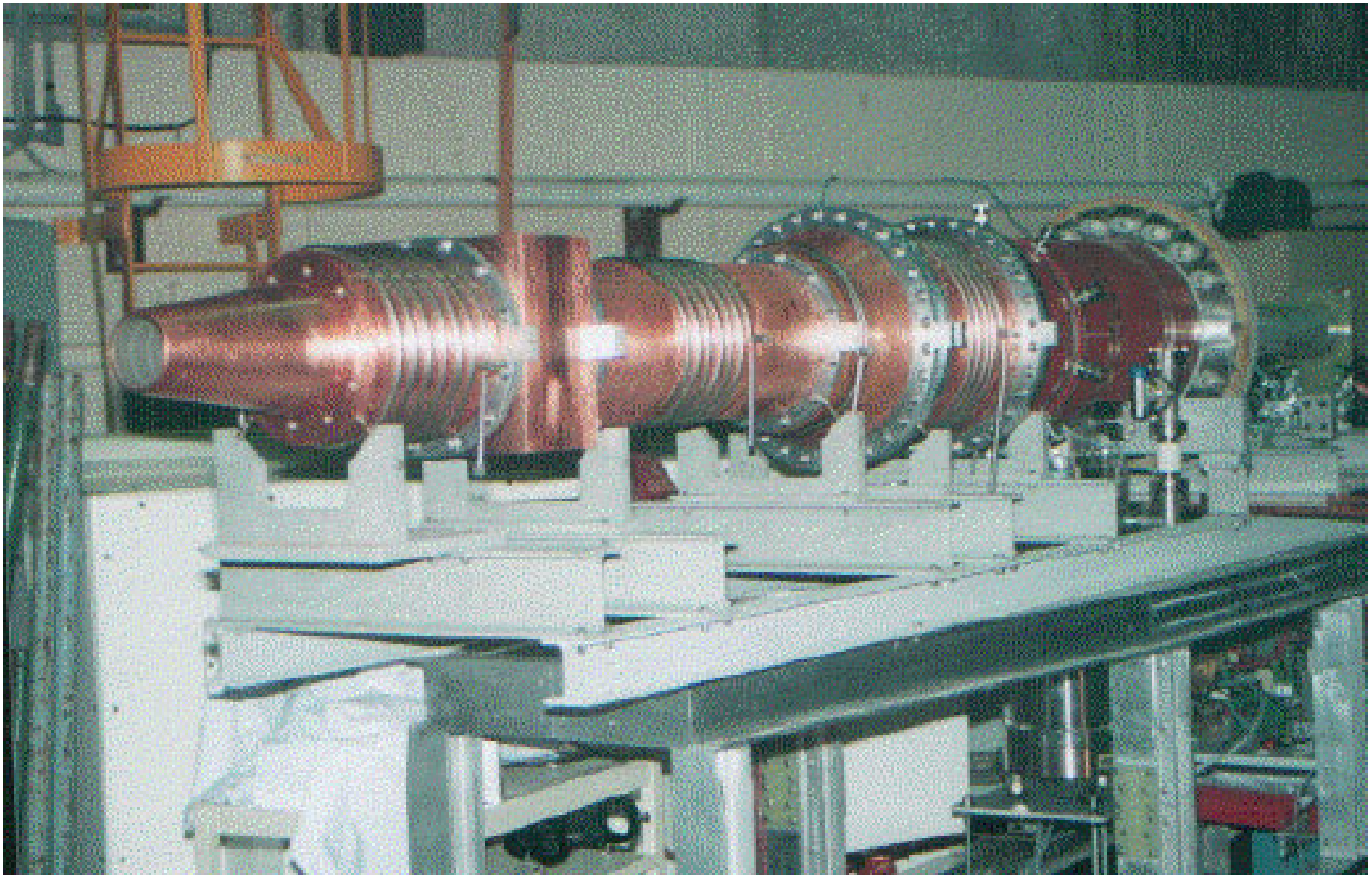
There is no existing fueling system to meet this requirement

IPPA goals relevant for CT Fueling

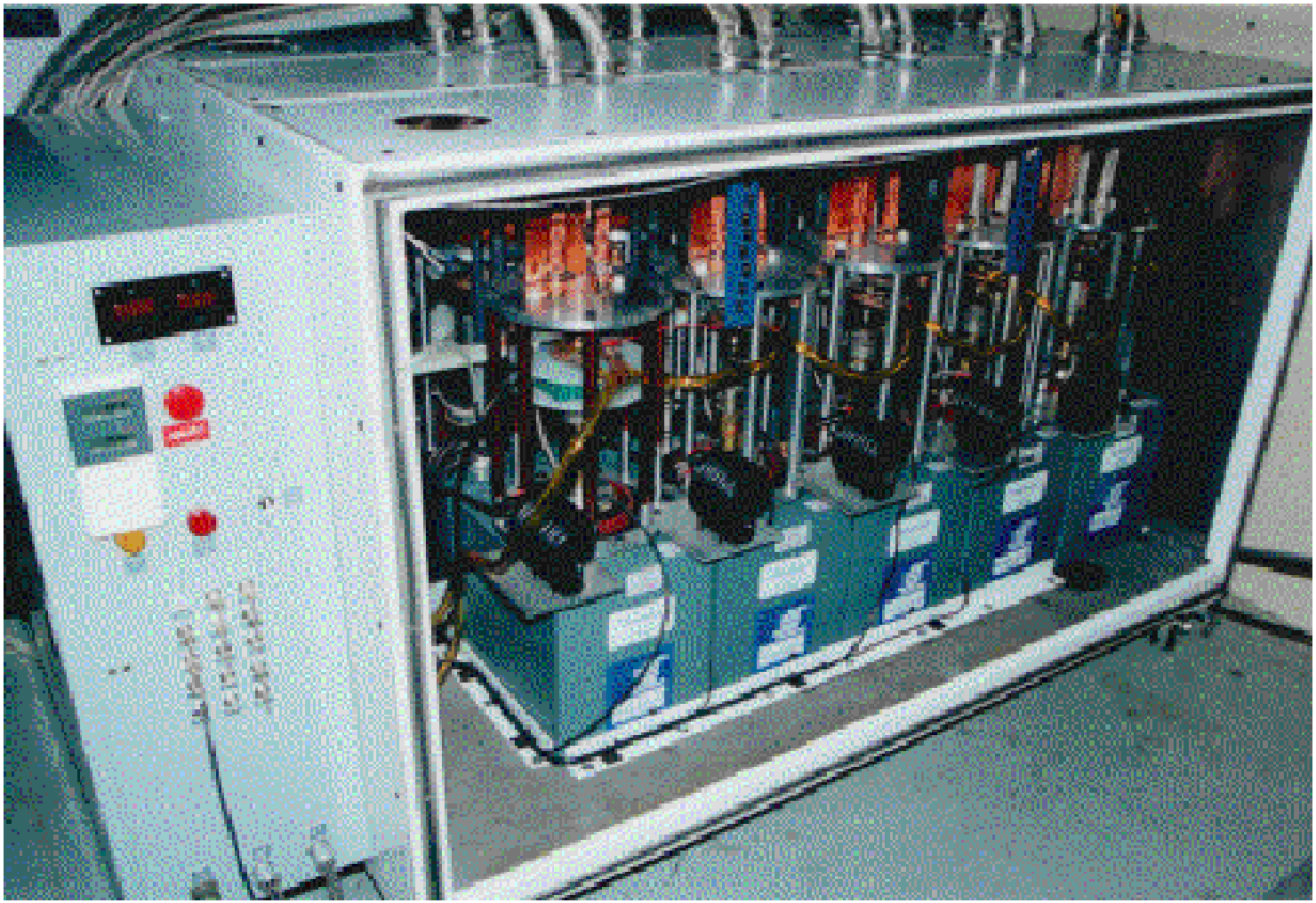
- 3.4.1.2 Fueling Technologies: "Develop systems and fueling techniques that are capable of providing a reliable, flexible particle source for controlling core plasma density and density gradients at acceptable fueling efficiencies; ...”

- Under the description of Section 3.4.1 Plasma Technologies: "The main issues for fueling technologies are to *understand and exploit advanced fueling physics (such as high field side launch) and demonstrate the performance (i.e., pellet speeds, density of compact toroids and repetition rates) required to effect adequate control of the density profile shape and high fueling efficiency*"

The CTF-II injector



The CT Formation bank power supply (110VAC input)

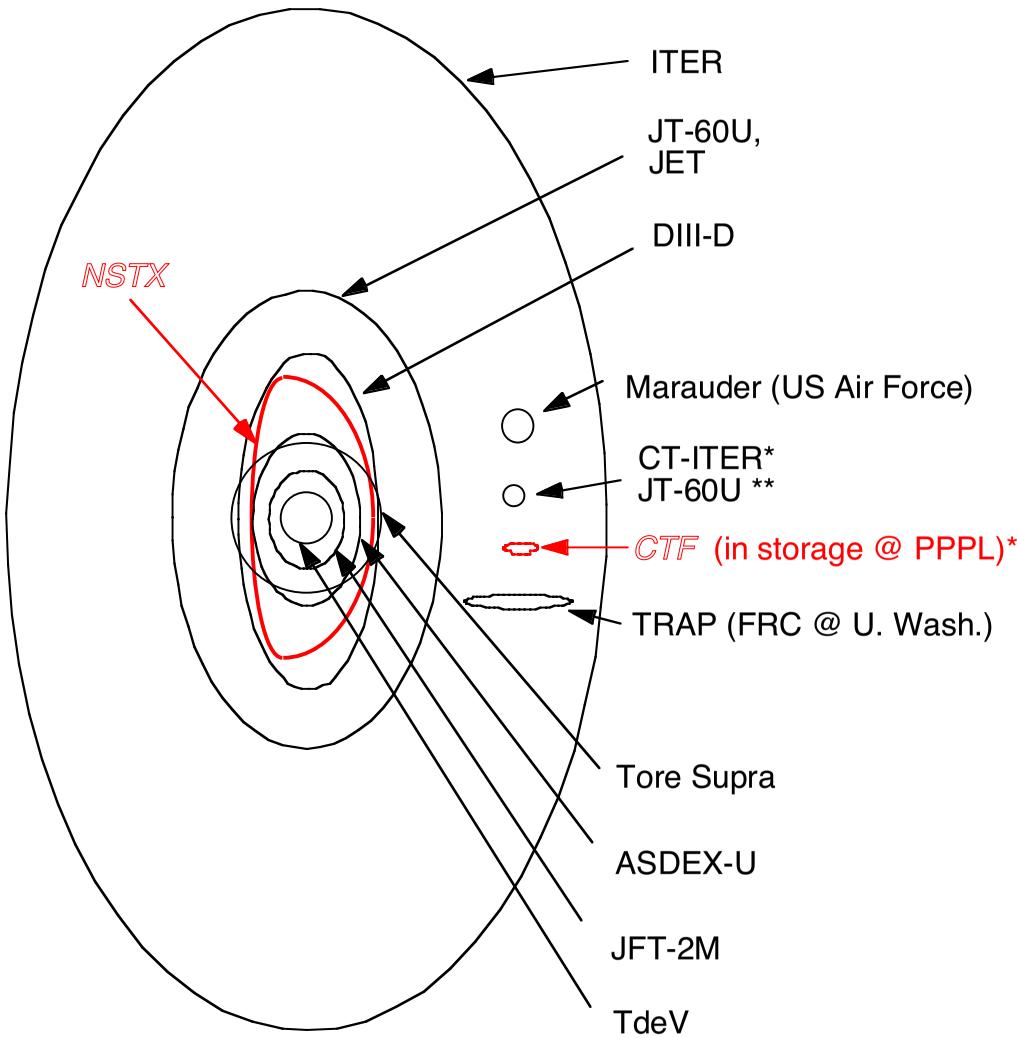


Two primary objectives for proposal

- Reliable initiation of H-modes and large surface area H-modes (during year-1)

- Establish CT parameters for controlled deep fuelling (during years 2 and 3)
  - Data needed for multi-pulse injector

Previous experiments too small to study localized core fueling



Relative sizes of various target plasmas and CTs.

A CTF sized CT will do far more localized fueling on a NSTX sized plasma

*R. Raman and P. Gierszewski, Fusion Engin. And Design, **39-40**, 977 (1998)

R. Raman and K. Itami, Journal of Plasma and Fusion Research, **76. 1079 (2000)

*Will cost >$1.5M and 2-yrs to build it from scratch

Secondary objectives

- Inject He CTs for He ash removal studies
- Inject Ne (or other impurity) doped CTs for transport studies
- Investigate capability for future tangential injection for momentum injection

CTs particularly well suited for an ST

	CT	**Pellet**
Particle invent. perturbation for deep fueling	Few % - will not destroy optimized profiles, allows precision fueling capability to adjust profiles	Typically 50% on DIII-D - large pellets needed to deposit small fraction of fuel in core
Penetration governing param.	$\alpha 1/B^2 \Rightarrow$ much easier penetration in ST as B^2 in NSTX is 2% of DIII-D	Te, fast electrons - similar to tokamak
Optimal injector location	Outboard mid-plane - tangential injection will impart momentum	'True'-Inboard mid-plane - improbable in a ST as even DIII-D does not use 'True' inboard mid-plane
Real time density feedback control capability	Yes - potential for fuel deposition location specification on each pulse using control system request	Improbable because large pellets fuel entire discharge and mechanical nature of injector.

Other remarks

- A reactor will not use NBI & Alpha power is isotropic $\Rightarrow$No momentum injection
- In a high β, high f_{BS} reactor some auxiliary current drive is needed

This leaves excellent density profile control as the method of choice to optimize reactor performance and to sustain transport barriers

Conclusions

- Excellent density profile control will enable STs to reach their highest potential
- Fueling SS discharges is much more difficult than fueling transient discharges. The needed fueling capability does not exist. Yet, the NSTX program plan calls for SS pulses with high beta and high bootstrap current drive
- The CT injection concept has the potential to meet this need, but data is needed from a single pulse injector
- The CT is also a source of momentum input and has the potential to sustain transport barriers
- A single pulse CT can make additional immediate contributions to the NSTX program
  - Precise H-mode triggering capability is useful for present XPs
  - Core injection of Neon will clarify transport issues
  - Injection of He CTs will enable He-ash removal studies