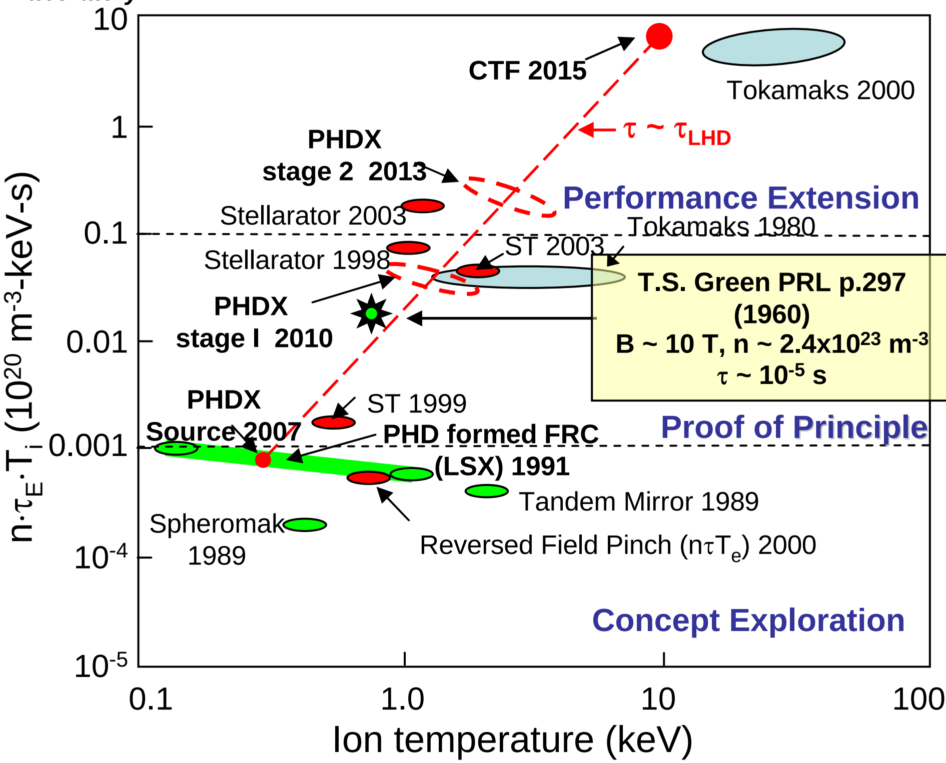
Plasma Dynamics Laboratory

Pulsed High Density (PHD) Fusion



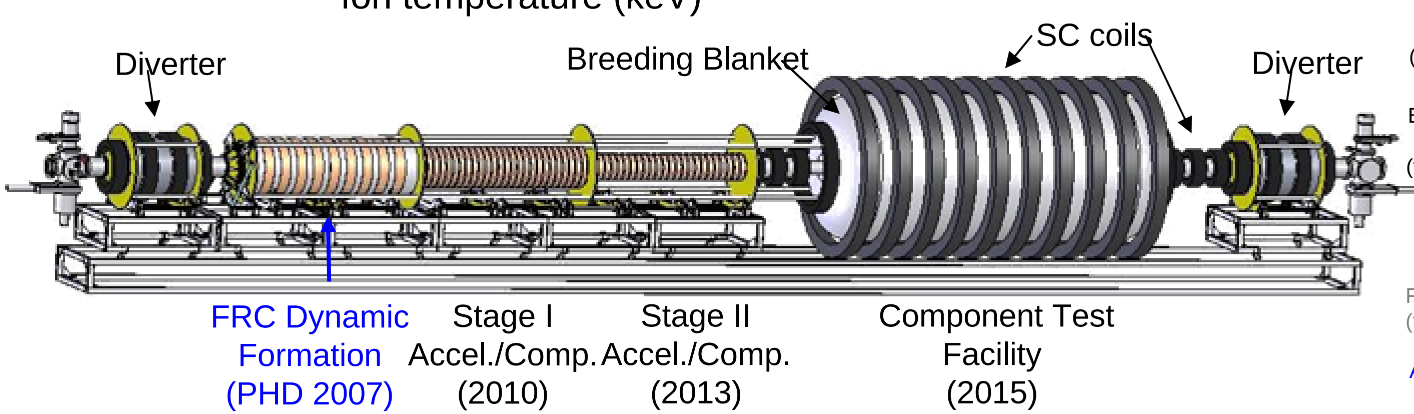
Quasi- steady PHD FRC fusion ***uniquely*** provides

Reactor:

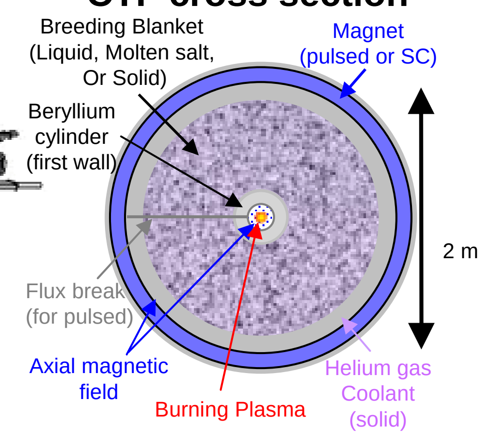
- Remote burn in ideal breeding geometry
- Greatly simplified PFC management
- High efficiency ion heating to fusion temperature
- Direct electrical conversion of fusion α

Key Physics Demonstrated:

- Kinetic stability from formation thru fusion burn
- Observed transport scaling sufficient for Q > 1
- Magneto-kinetic heating (M ~ 3) forming robustly stable FRC
- Confinement scaling better than prediction from *in situ* PHD FRC $\tau > \tau_{LHD} \sim r^2 n^{1/2}$



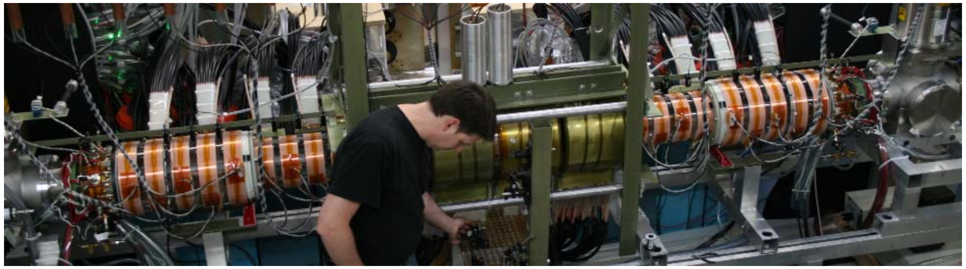
CTF cross section

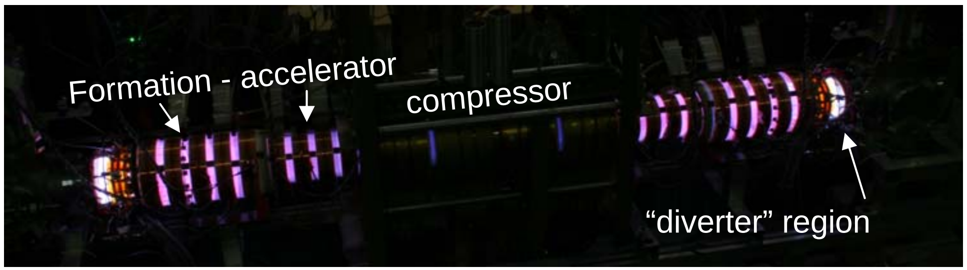


Magneto-kinetic heating to fusion temperatures: Kinetic energy is transferred from array of axially sequenced low field coils and thermalized by self compression into high field burn chamber

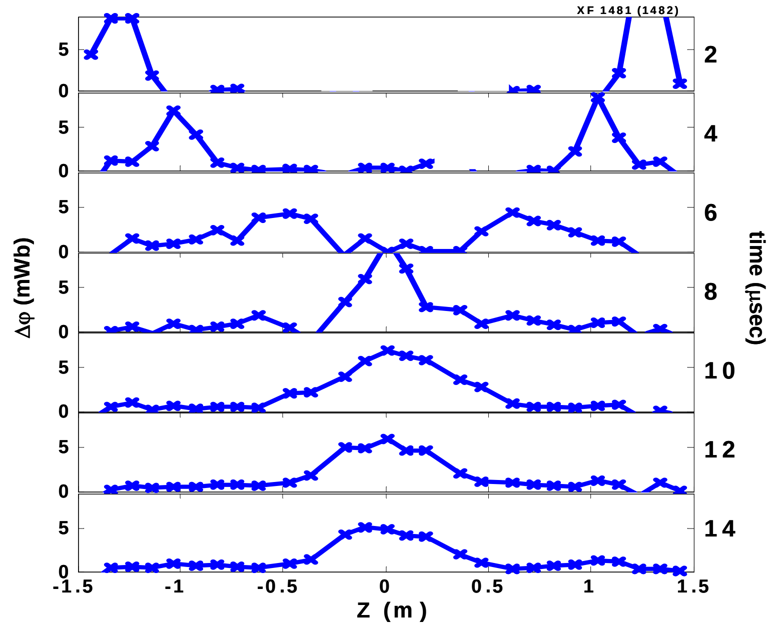
Proof of Concept Experiment IPA-C

(Inductive Plasma Accelerator w Compression)

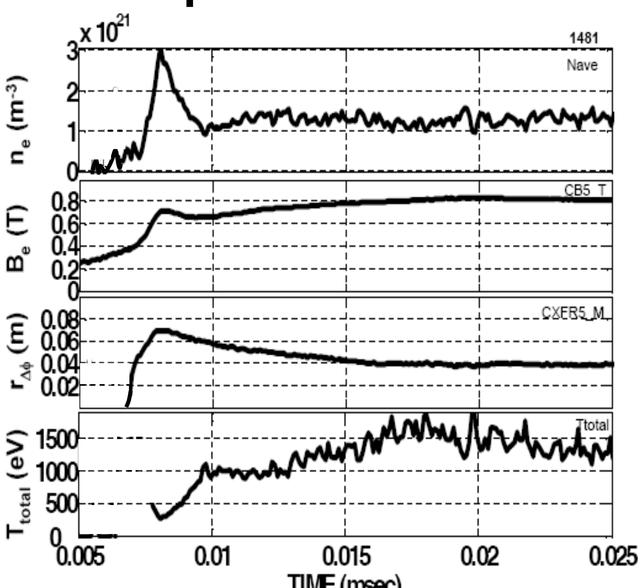




Excluded Flux Along Length of IPA-C



Midplane Parameters



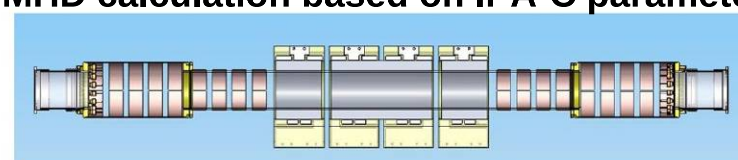
$\Rightarrow n\tau_E T_i$

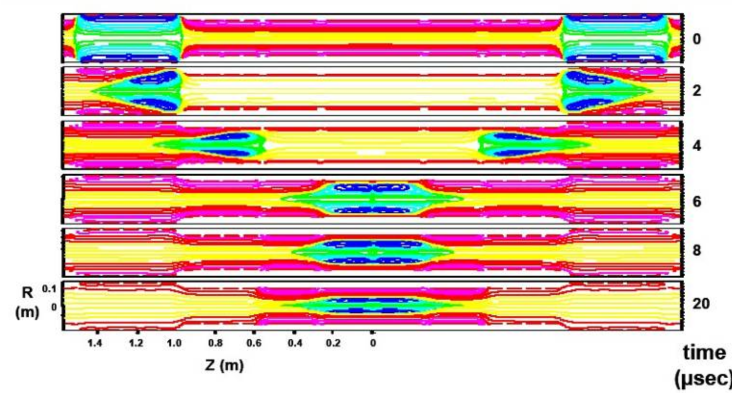
4x10^{16} m^{-3}-keV-s

Comparable to MST RFP

~ 10^4 greater than TCSU RMF

2D MHD calculation based on IPA-C parameters





PDL

Plasma Dynamics Laboratory

Concept Key Parameters

Parameter/Issue	Present/ Past Value	ITER-era Reactor	Comments
Confining Field	0.5 -10 T	20 T	10 T employed by Green 2 T in r_c = 0.4 m by Rej 5 T (12 T in mirror) by Wells
Pulse length Δt, $(\Delta t/\tau_E)$	0.4 ms (1)	0.5 ms (1)	Pulsed fusion
External sustainment Current drive power Current drive efficiency	Not Needed	Not Needed	What it is all about
Major radius r_s	0.02 to 0.2 m	0.05 m	(minor radius = rs$\cdot$(1-$\sqrt{2}$). r_s is typically = ½ r_{coil} in PHD FRCs
Elongation $(l_s/2r_s)$ Central density (range) T_e (max) keV T_i (max) keV	3 to 10 $1\text{x}10^{21}$- $2\text{x}10^{23}$ 0.5 (LSX) 6 (TRISOPS)	15 – 20 $1\text{x}10^{23}$ 2 5 - 10	Increased elongation is favorable to stability and is the result of $l_s \sim r_s^{0.4}$ with adiabatic compression
$\langle\beta\rangle$ within separatrix	0.76 to 0.98	0.87	Axial Equilibrium constraint: $\langle\beta\rangle = (1- ½\, x_s^2)$ $x_s = r_s/r_c$
Energy confinement time FRC form/accel/comp time Ion axial transit time	0.4 ms (LSX) 10 μs (IPAC) 0.25 μs (IPAC)	0.5 – 1.5 ms 25 μs 0.2 μs	For Q_{fus} = 1 – 3 Other quantities of interest: $\lambda_I \sim 10$ m $\tau_{ex} \sim 0.05$ ms $\rho_\alpha = 2.5$ cm

PDL Plasma Dynamics Laboratory

Key Parameters (Continued)

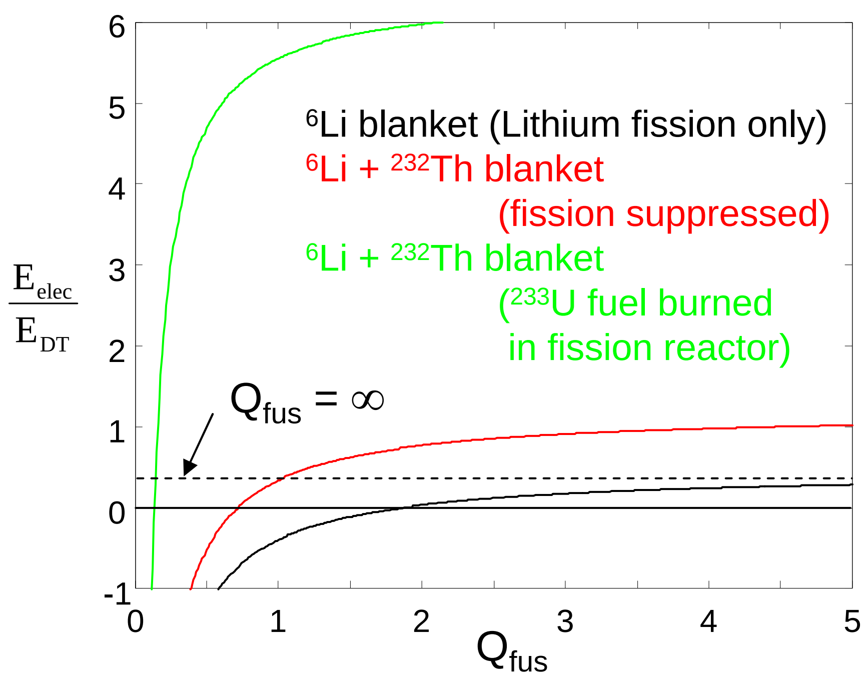
Parameter/Issue	Present/ Past Value	ITER-era Reactor	Comments
Fusion power density	$2\mathrm{x}10^{-4}$ T·s	$1\text{-}2\mathrm{x}10^{-3}$ T·s	
Global particle transport	2 m^2/s (LSX)	0.2 m^2s	PHD FRC is vacuum insulated. Convective end loss is dominant with ($\tau \sim \tau_N$). $D_s \sim r_s^2/16\tau$ for prolate FRC$\Rightarrow$ $D_s \sim n^{-1/2}$ (LHD)
Stability parameter s/ ε	4.7/ 7 (LSX)	3.3/ 15	s is defined below. ε is FRC elongation ($l_s/2r_s$). Ratio < 0.5 for good confinement
Fusion Energy (MJ)	NA	1.5-5 MJ/pulse	Assumes $1 < Q_{fus} < 3$
Neutron Wall loading Plasma exhaust (MW/m^2)	NA	1 – *10 MW/m^2 1 – *10 MW/m^2	A free parameter to be optimized based on techn. and economics *Liquid wall for high power dens.
Heat load to wall - ΔT (E_{in}=0.1E_{pl} and A_{wall}=3 m^2)	NA	50-150 kJ/m^2 ΔT= 66-200 °C	Be PFC - particle flux negligible $\Delta T = 2E_{in}(\pi\kappa\rho C_p t)^{-1/2}$
Magnetic pressure pulse to wall / yield str Be tube	NA	700 / 3500 bar	Pulse is less than wall inertial time so that impact is minor

$$s = \frac{1}{r_s}\int_{null}^{r_s} \frac{r}{\rho_i}\,dr = \frac{r_s}{2\pi r_c}\frac{r_s}{\rho_{ie}} \sim \frac{1}{12}\frac{r_s}{\rho_{ie}}$$

Low Q More Than Sufficient for Fissile/Fusile Breeder Reactor

PDL
Plasma Dynamics Laboratory

$$\frac{E_{elec}}{E_{DT}} = \frac{1}{\eta_{th} Q}\left(\eta_{th} + (1 + M_{bl})\eta_{in}\eta_{th} Q - 1\right)$$



E_{DT} - energy from fusion reaction
= 17.6 MeV × N_{DT}

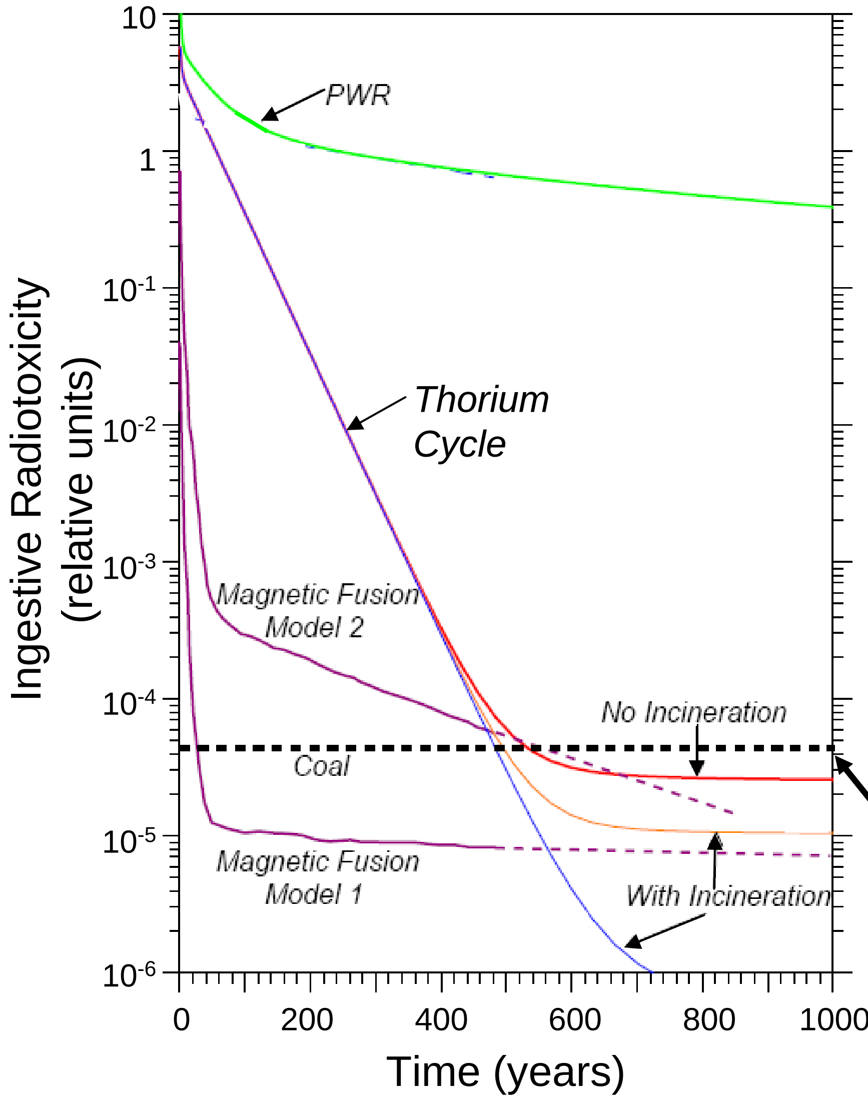
η_{th} - therm. to elect. conv. eff. **= 0.4**

η_{in} - ion heating efficiency **= 0.7**

M_{bl} – effective blanket multiplication
= 0.14 [^{6}Li ⇒ 1.1 T + 4.8 MeV]
= 2.0 [^{6}Li,^{232}Th ⇒ 1.1 T, 1.3 ^{233}U + 49 MeV)
= 5.0 [^{233}U,n ⇒ FP, 2.5 n+198 MeV]

- Fusion electrical energy generation per fusion increases little beyond Q_{fus} ~ 5 with high ion heating efficiency
- Blanket heating from fissile fuel production dominates electrical energy production for $Q_{fus} > 1$
- Even for Q < 1 additional energy generation from bred fissile fuel dwarfs energy production from Q = ∞ fusion alone

Ingestive Radiotoxicity for Fission, Fusion, and Thorium Hybrid



- Fusion produces the least toxic waste in both duration and intensity

BUT -

- Thorium cycle produces negligible long lived waste - **allows local storage**
- Incineration of fission fragments is unnecessary for the thorium cycle.
- Current PWRs can convert to thorium if seed ^{233}U can be produced in hybrid

Coal burning associated, long lived ingestive radiotoxicity due to impurities in coal - used as a good reference point for no need of geologic storage