Novel RF Heating for Compact Fusion Devices

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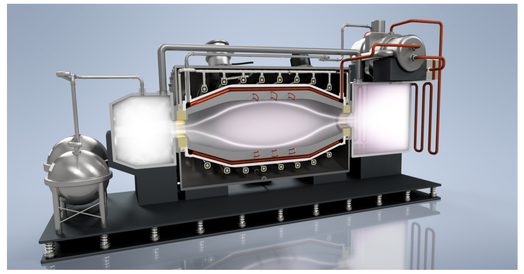
Creating a Small, Clean Reactor

The Princeton Field-Reversed Configuration (PFRC) is a magnetic plasma-confinement concept that uses a novel RF heating method.

- Linear solenoid geometry
- Steady-state operation
- Very low neutron flux
- Superconducting coils
- Plasma radius of 20-30 cm

Estimated fusion power: 1-10 MW

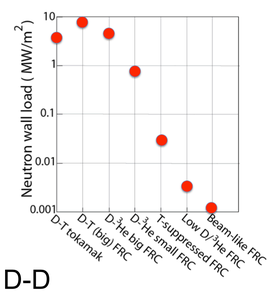


This engineering model shows the simplicity of the system. Plasma flows from left to right around the fusion region, absorbing energy, and is then recycled.

Neutrons are reduced through choice of fuels (D-^{3}He), fuel ratio (D^{3}He = 1:3), and machine size. Tritium, a byproduct of D-D fusion, is exhausted before it can fuse.

^{2}D + ^{3}He → ^{4}He (3.6 MeV) + ^{1}p (14.7 MeV) 98.4%

^{2}D + ^{2}D → ^{3}T (1.01 MeV) + ^{1}p (3.01 MeV) 0.88%
^{2}D + ^{2}D → ^{3}He (0.82 MeV) + ^{1}n (2.45 MeV) 0.72%
~~^{2}D + ^{3}T → ^{4}He (3.5 MeV) + ^{1}n (14.1 MeV)~~ 0.05%



The primary fusion reaction is D-^{3}He. Side D-D reactions are limited to < 2% and D-T reactions are near zero.

Latest Results Summary

- Electron heating experiments in progress
- ARPA-E funded measurements have improved understanding of the plasma

Measure	PFRC-1	PFRC-2 current	PFRC-2 target
RMF power	11 kW	72 kW	200 kW
Electron density	$1\times10^{12}/\mathrm{cm}^3$	$6\times10^{12}/\mathrm{cm}^3$	$1\times10^{13}/\mathrm{cm}^3$
Excluded flux	600 nWb	In progress	100μWb
RMF frequency	13 MHz	6 MHz	2 MHz
Electron temperature	200 eV	690 eV	1000 eV
Ion temperature	Not measured	In progress	500 eV
Magnetic field	400 G	320 G	600 G

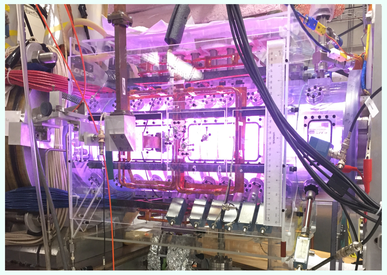
PFRC Experiment at PPPL

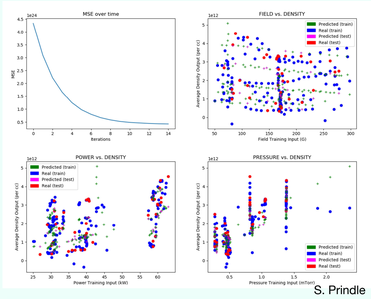
Our ARPA-E OPEN research will experimentally test a critical aspect of the theory of FRC operation: that both the ions and electrons can be heated by a single novel RF system: odd-parity rotating magnetic fields (RMFo)

- Q2: Electron density of 1e13 /cc
- Q3: electron energy >500 eV
- Q4: RF power to 200 kW
- Q5: ion energy >500 eV

PFRC in Operation

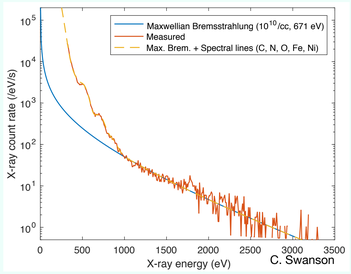
Pulse length: 300 ms
Duty factor: 1%
Field strength: 400* -1500** G
Plasma temperature:
500* - 1000** eV
** achieved ** machine goal*





S. Prindle

Machine Learning predicts the electron density in the PFRC-2. The neural network, trained on data from the PFRC-2. Inputs: field strength, power level, gas pressure. This research will be used to predict the outcome of an experiment.

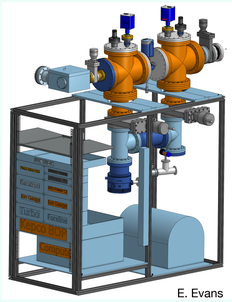


C. Swanson

The SDD X-ray detectors, sensitive to X-rays produced by energetic electrons, reveal a minority (>1%) population of electrons with temperature 671 eV.

Device next steps:
- Continue upgrades to RMF power
- Continue upgrades to magnetic field

Diagnostic next steps:
- Profile data for density, X-ray spectra
- Finalize diamagnetism measurement
- Build ion energy analyzer diagnostic

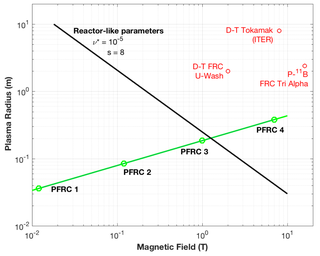


E. Evans

PPPL will build a new ion energy analyzer diagnostic under a targeted award

Development Plan

The plan follows a log linear path in field and radius to a working reactor. We propose two new near-term testbeds:

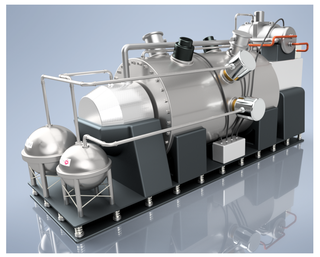


Fusion Plasma Testbed
PFRC-3 with extensive diagnostics, superconducting coils and high efficiency RMF heating. Fully characterize the plasma. Allow for optimization of the coil geometry, antenna configuration. Permit full characterization of the plasma and convergence of numerical and experimental results.

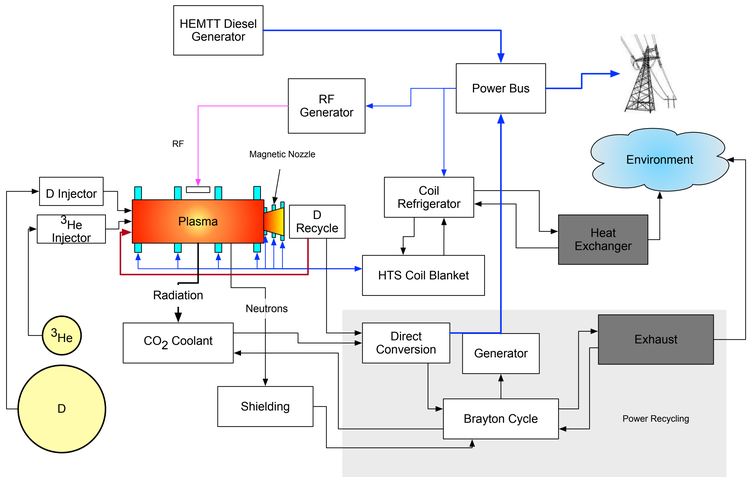
Fusion Engineering Testbed - Would generate small amounts of fusion power and demonstrate conversion to electricity. Sized between PFRC-3 and 4. Includes all hardware and software needed for a prototype reactor.

Mechanical/Engineering Model

PFRC on an HEMTT



PFRC



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