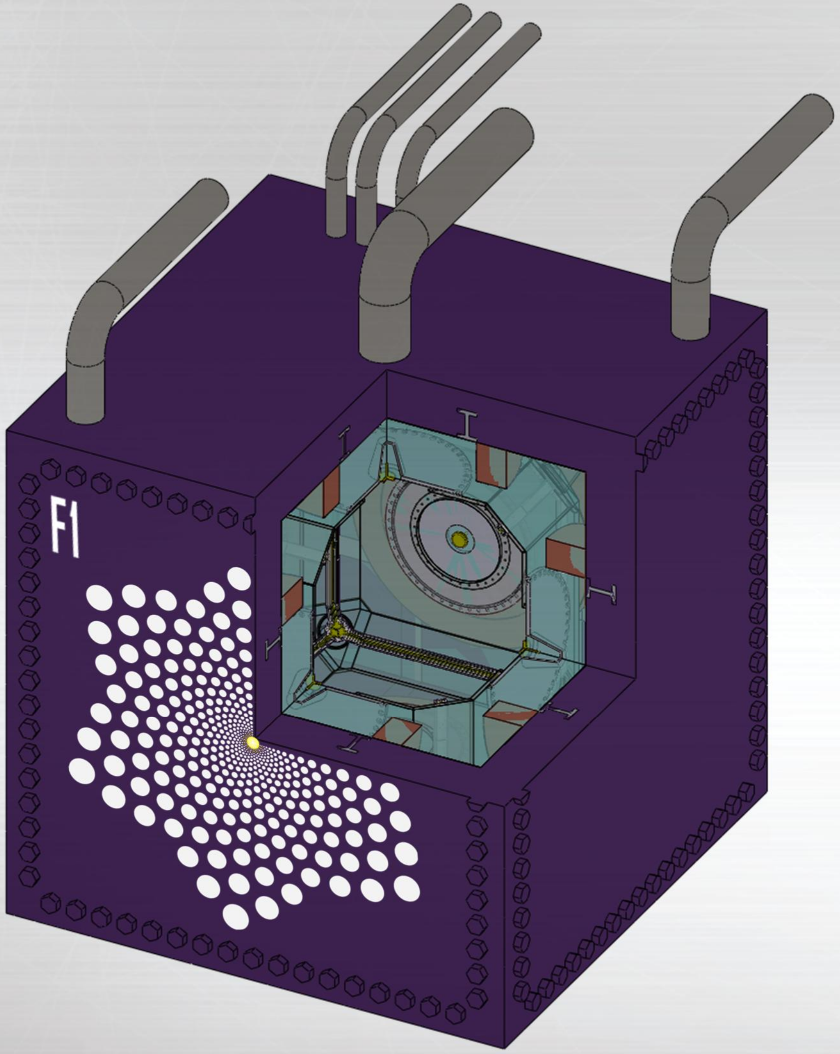
Fusion One Corporation

The F1 Reactor

An Evolution of the Magneto-Electrostatic Fusion Concept to Achieve Economical Net Power

Dr. Paul Sieck and Randall Volberg



2017 ALPHA Annual Meeting Presentation

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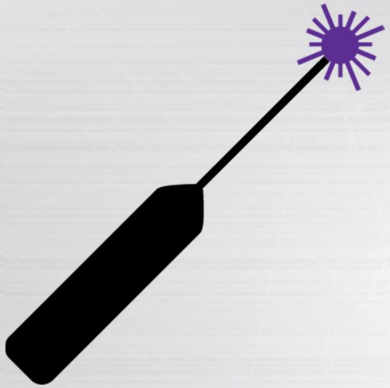
Magneto-Electrostatic Fusion (MEF)

Three main plasma confinement modalities:

MAGNETIC CONFINEMENT

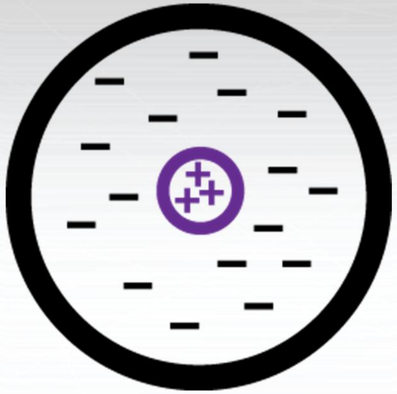
magnetic fields

INERTIAL CONFINEMENT



lasers

ELECTROSTATIC CONFINEMENT

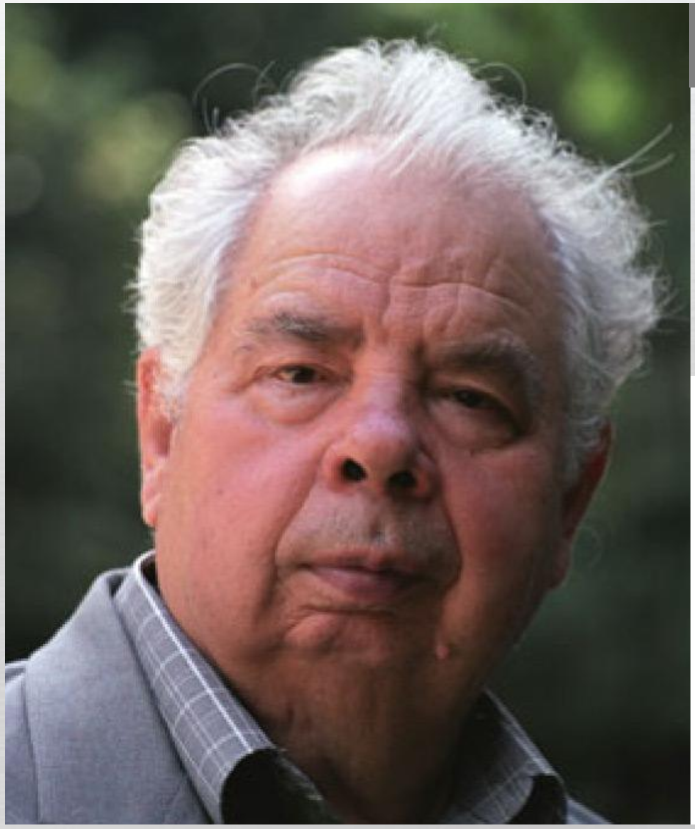


opposing charge

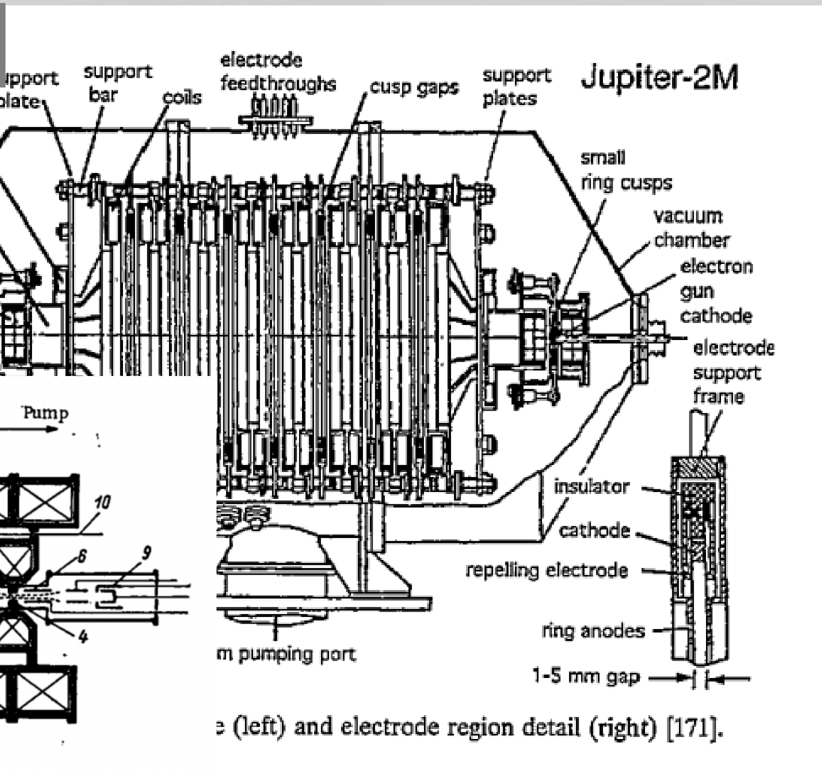
The F1 reactor is a magnetic and electrostatic hybrid.

History

Magneto-electrostatic fusion (MEF) began in the 1970s with Oleg Lavrentiev at the Soviet Kurchatov Institute.



Jupiter Project



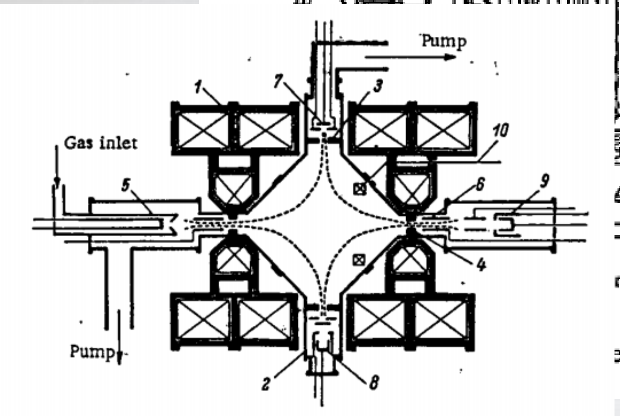
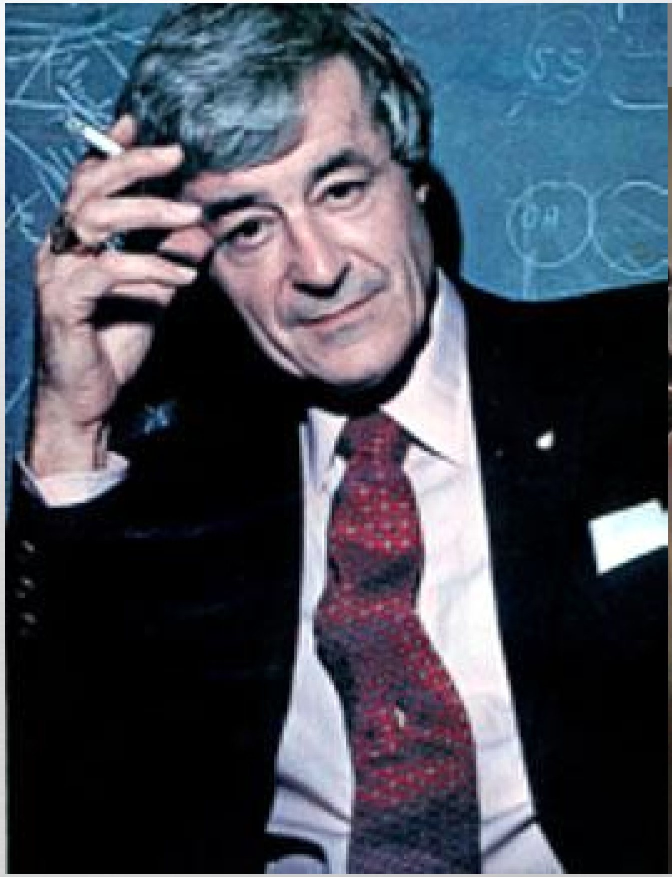


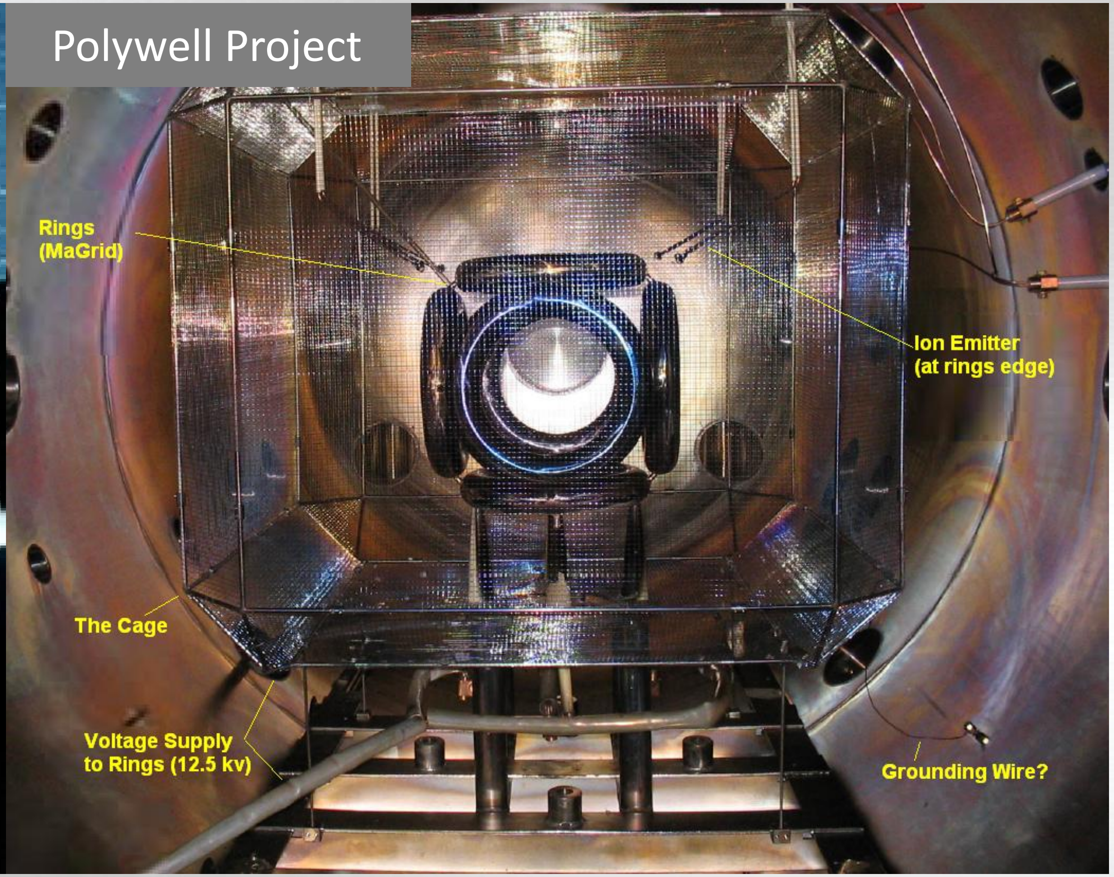
Fig. 1. The pulsed electromagnetic confinement system Yupiter 1A.

Images: Eurofusion https://www.euro-fusion.org/newsletter/the-lost-story-of-the-russian-scientist-oleg-lavrentiev/
Particle lifetime in a pulsed electromagnetic confinement system. Lavrent'ev et al. Zh. Tekh. Fiz. 46, 115-120 (January 1976)

History

Followed in America by Dr Robert Bussard in the 1980s at EMC2.

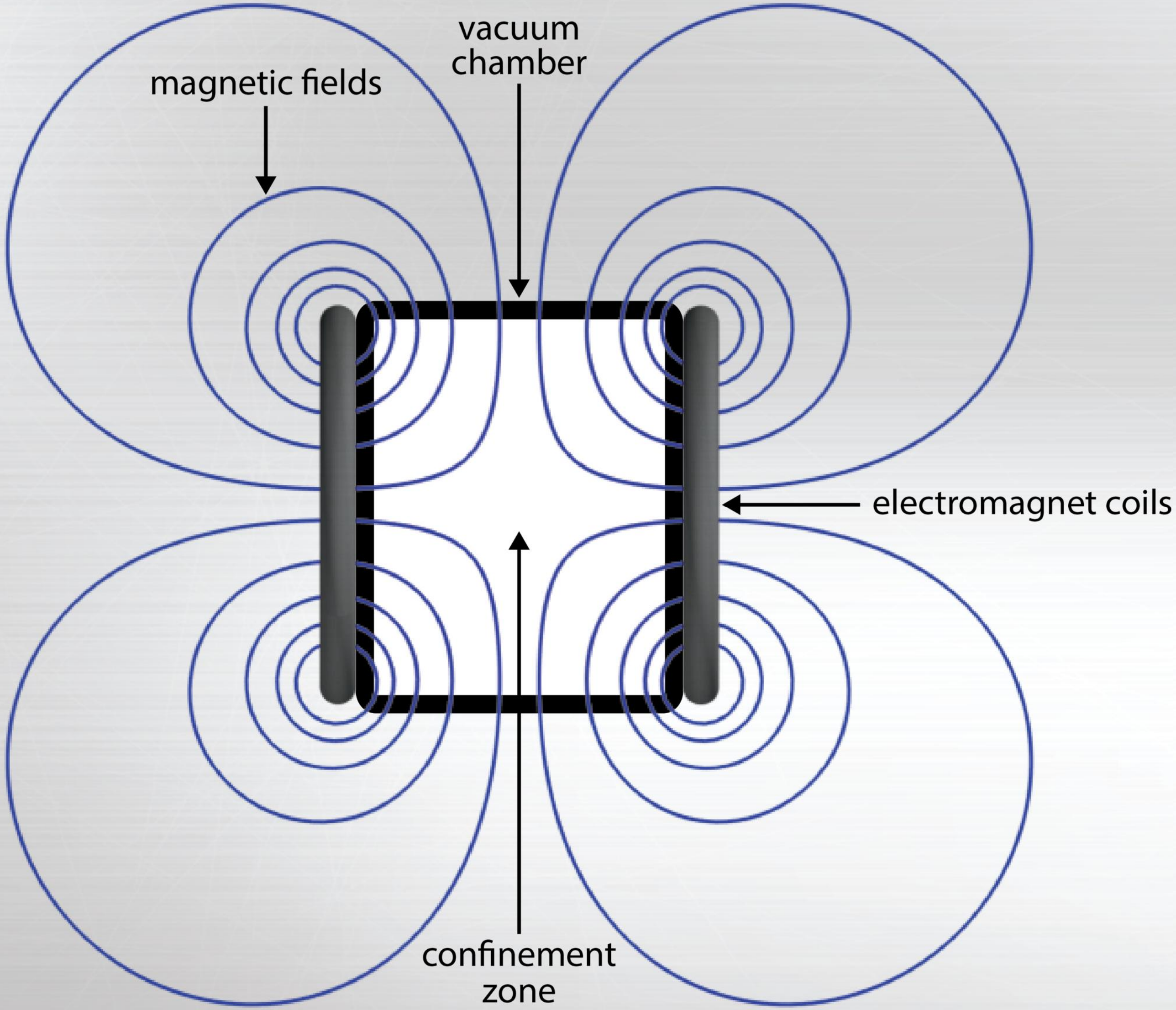




Images: Nevada Aerospace Hall of Fame website - http://www.nvahof.org/hof/hof-2012/robert-w-bussard/
The Polywel Blog - http://www.thepolywellblog.com/2012/07/the-physical-basis-for-polywell.html

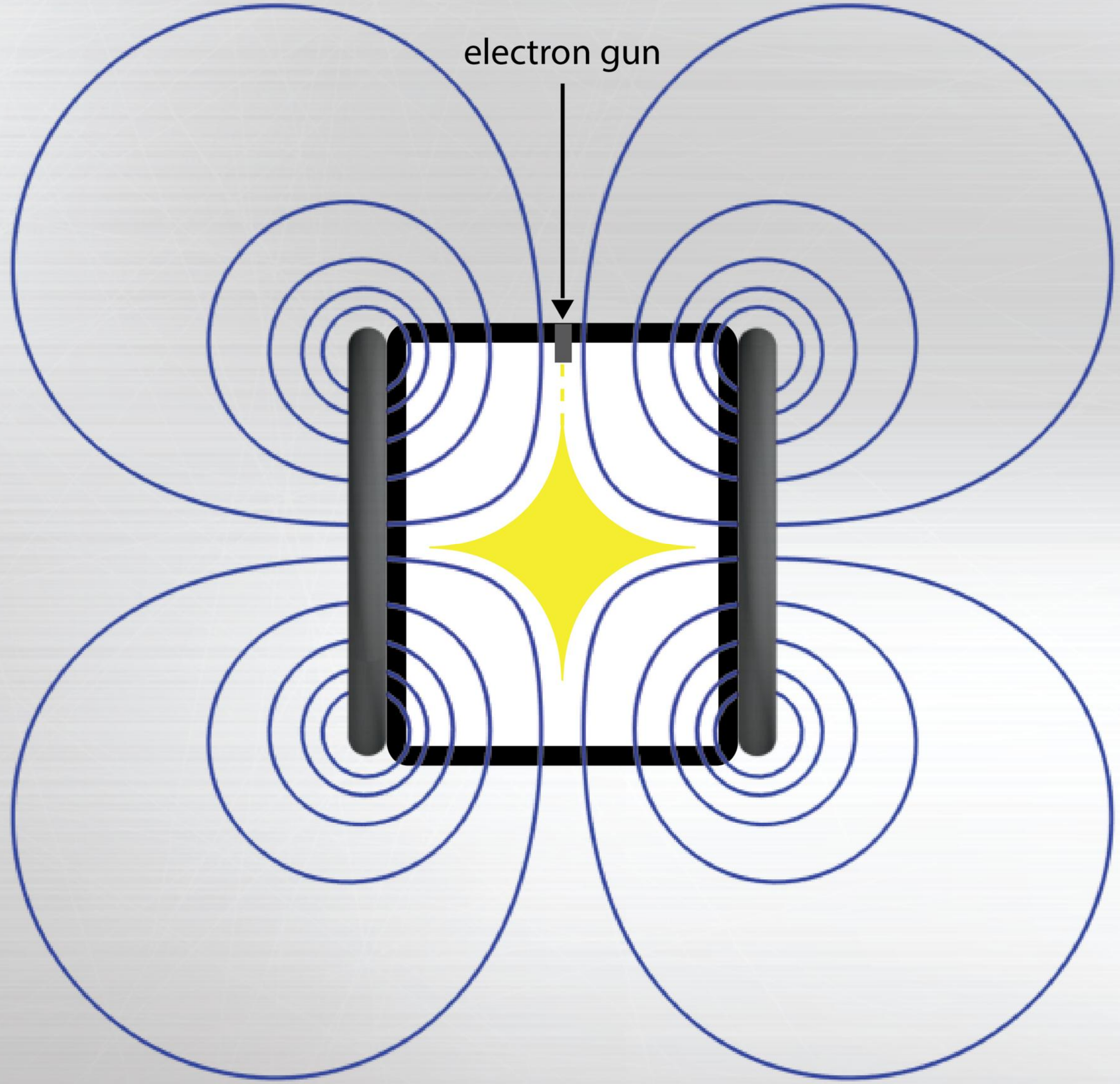
MEF - How it Works

A set of opposing electromagnets generate magnetic fields that create a central confinement zone.



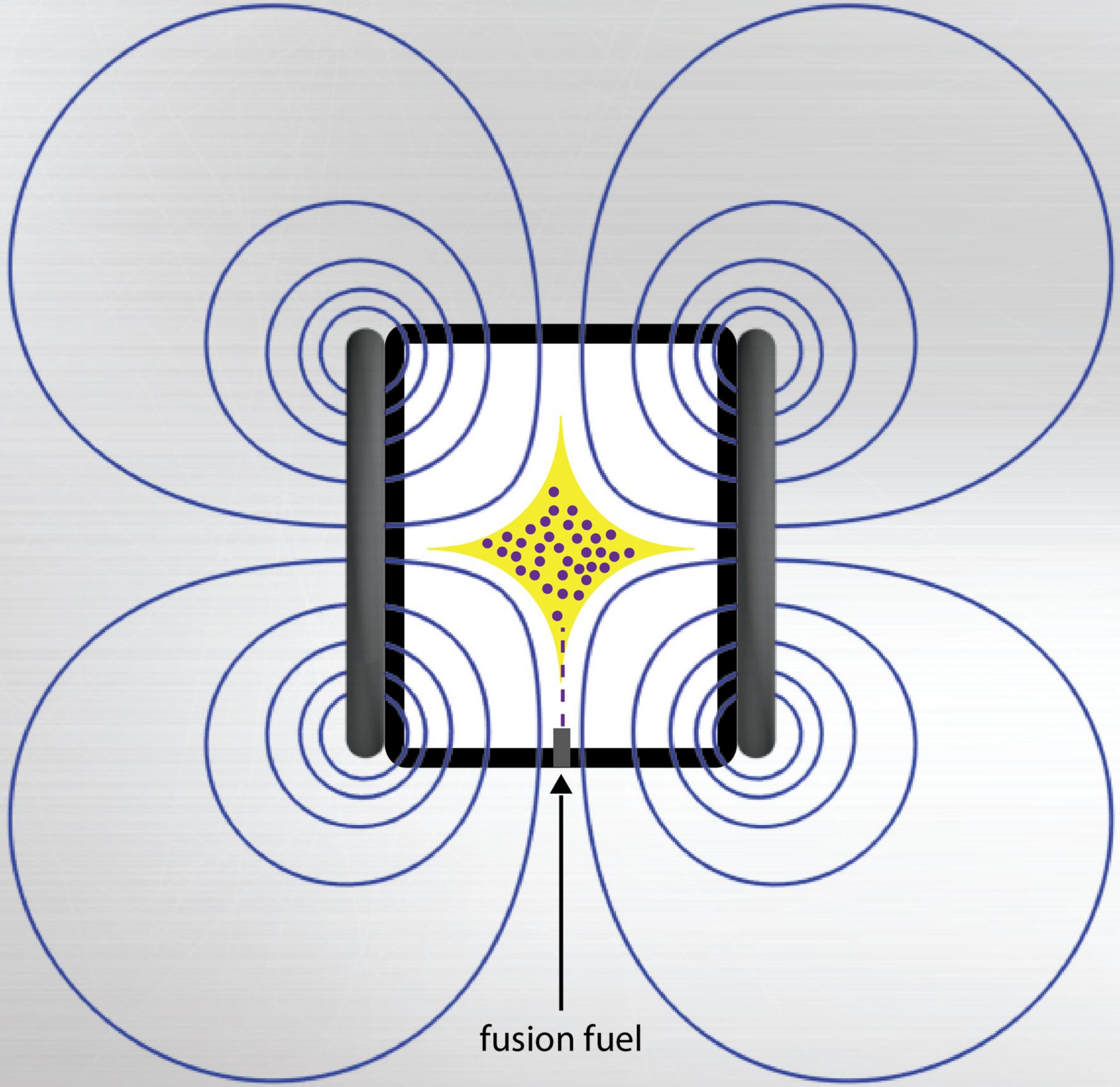
MEF - How it Works

Electrons are sent into the confinement zone where they are trapped and form a cloud.



MEF - How it Works

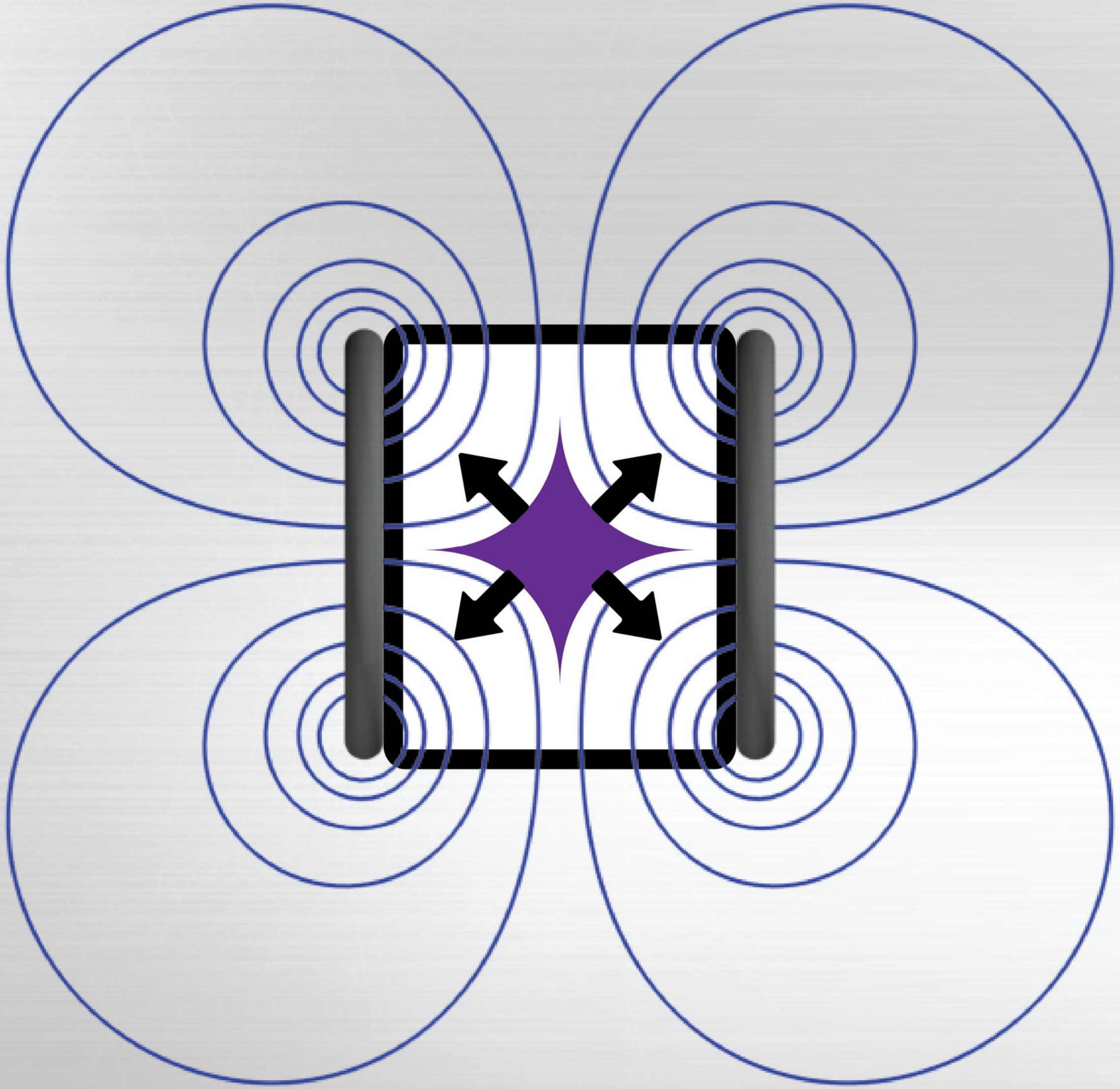
Fusion ions are injected and attracted into the negatively charged electron cloud.



MEF - How it Works

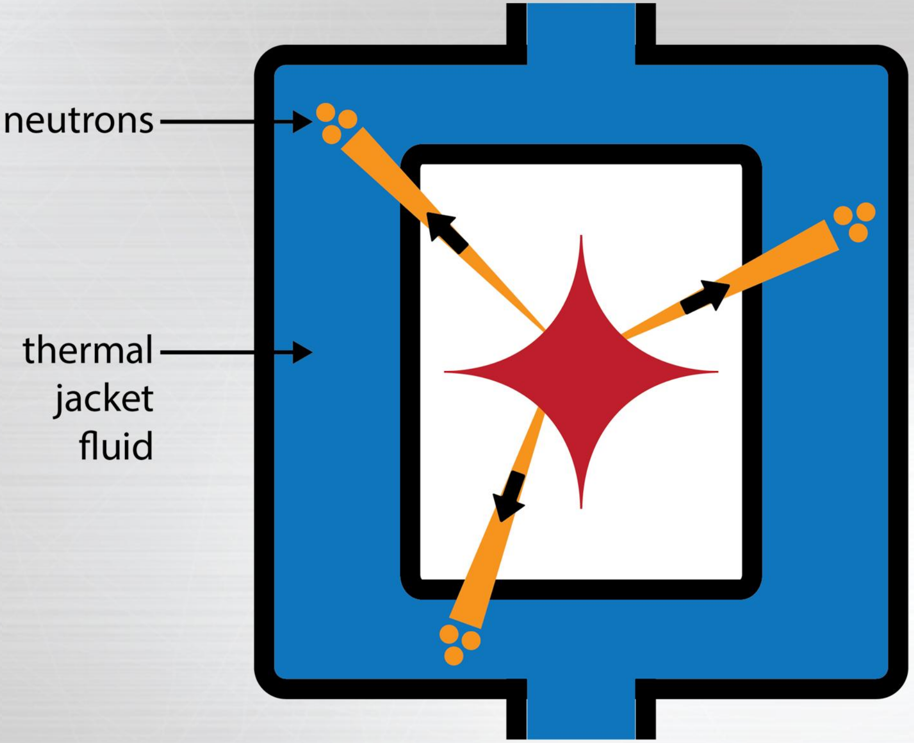
When the plasma reaches a high enough pressure, it becomes magnetized and pushes back against the magnetic fields.

This dramatically improves confinement and stability to reach fusion conditions.



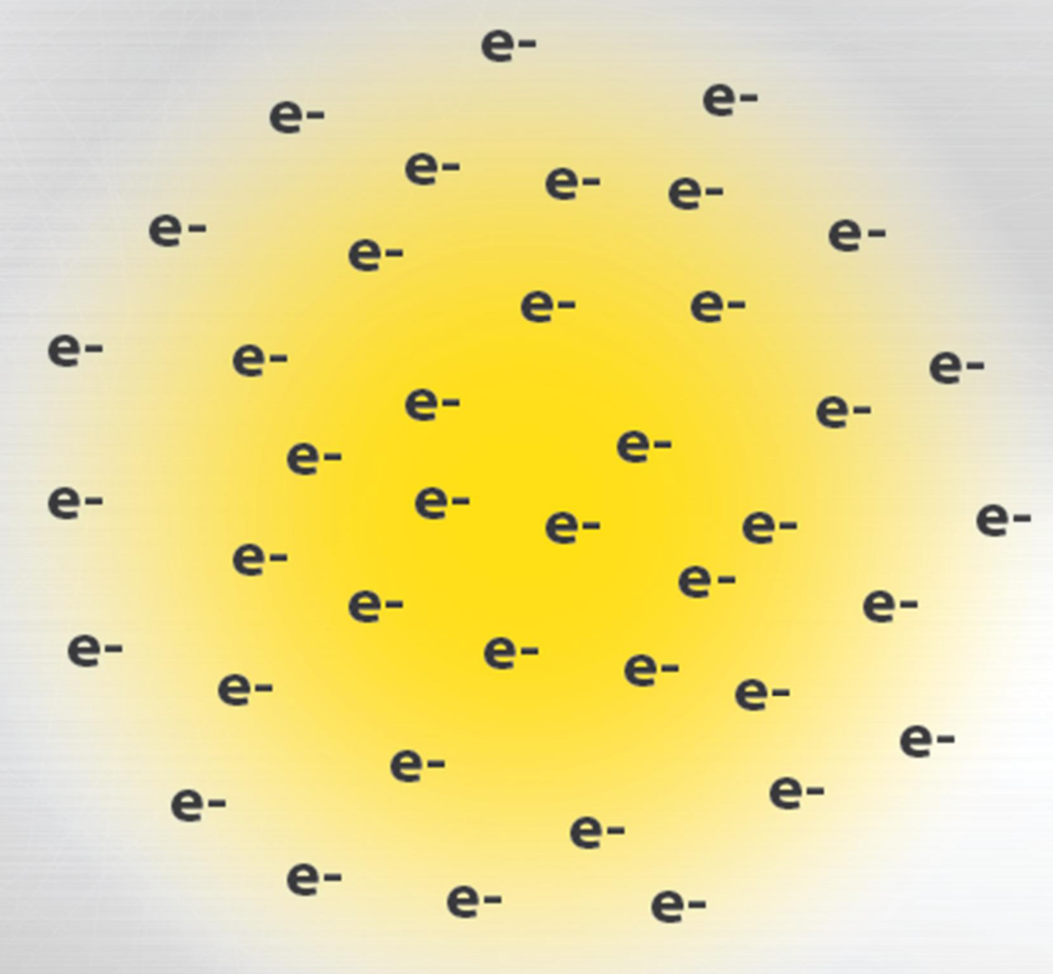
MEF - How it Works

Fusion reactions send neutrons out in all directions to heat a thermal jacket to drive a steam generator.



Why Use Electrons to Trap Ions?

Why use electric fields to directly trap ions instead of magnetic fields as with other reactors?

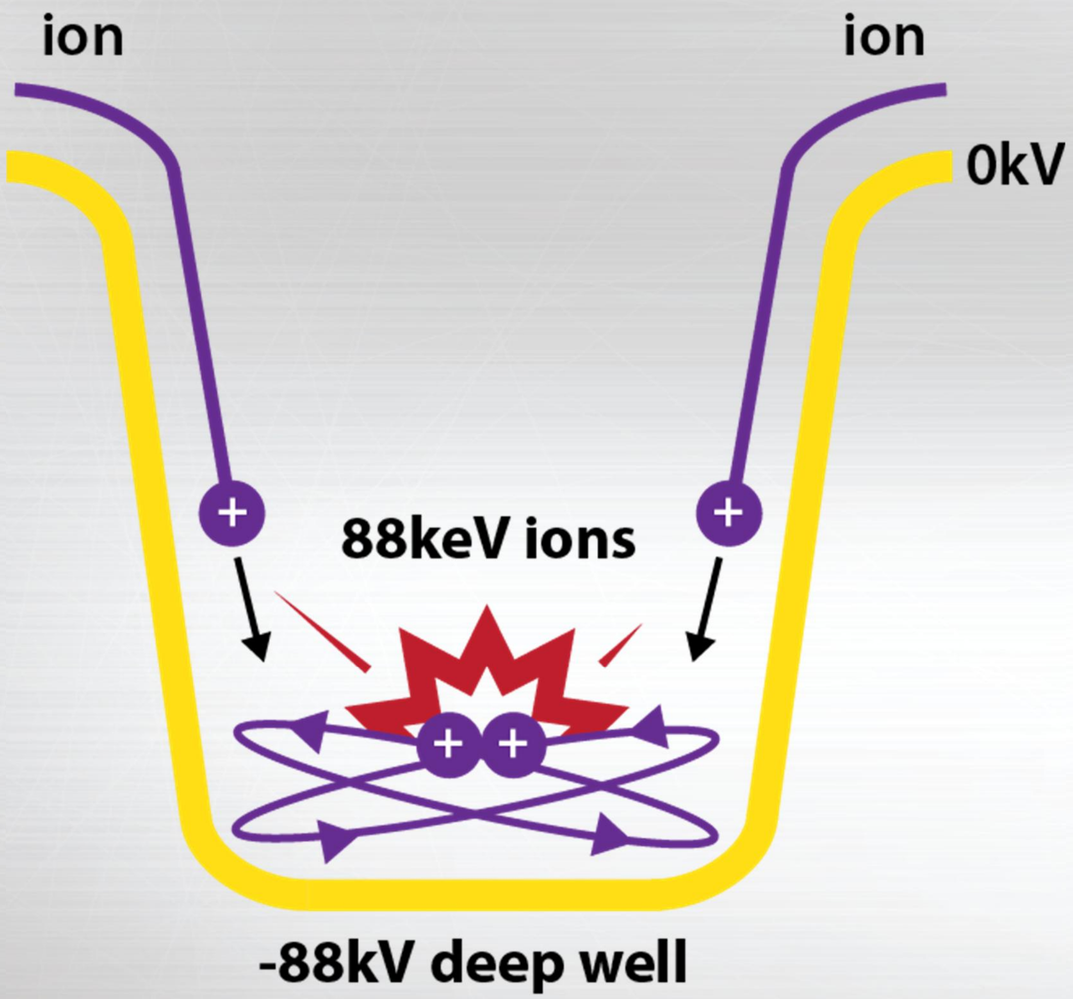


The Potential Well

The electron cloud works by forming a potential well of negative voltage.

The ions fall in and reach the bottom of the well where they collide and fuse.

The energy level at which they fuse is determined by the depth of the well, which can be controlled by the voltage.

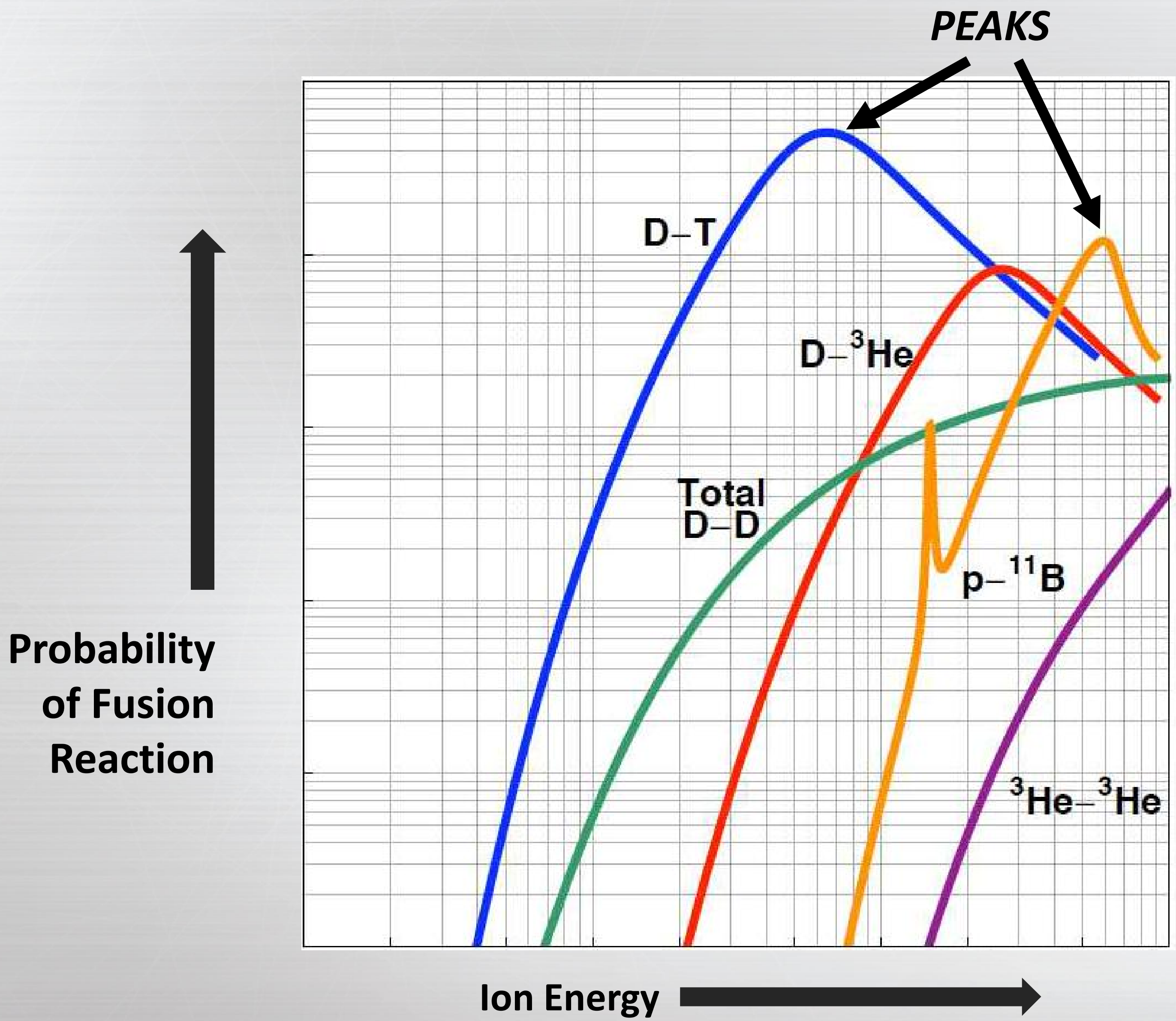


Precision Fusion

Important because every fusion fuel has a specific energy level that results in the most fusion.

Controlling the voltage of the electron cloud allows the ions to be "tuned" to their fusion peak.

This optimization is a major advantage for achieving a reactor that produces more power than it consumes.



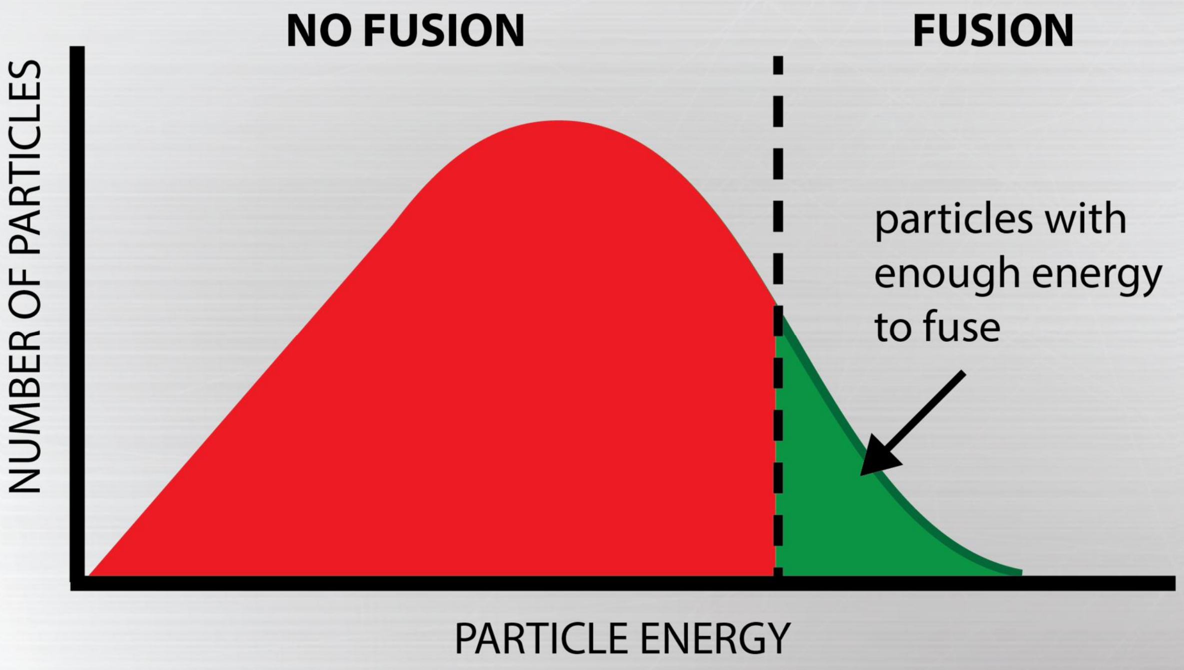
Optimized Performance

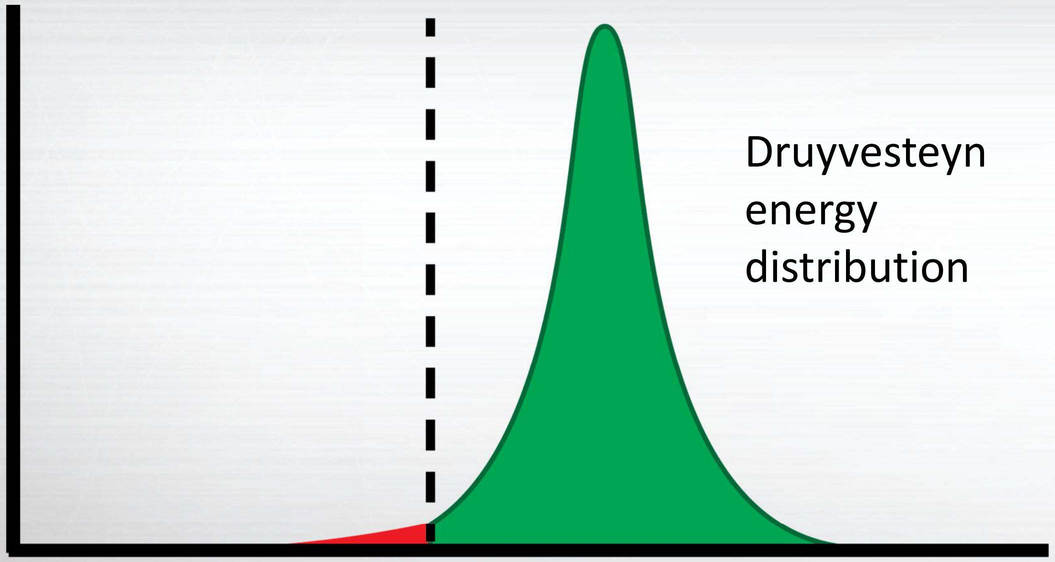
NON-ELECTROSTATIC REACTORS

Operate over a range of energies with the majority of ions at a level too slow for fusion.

ELECTROSTATIC REACTORS

Place the majority of ions at an energy level where they are best able to fuse.

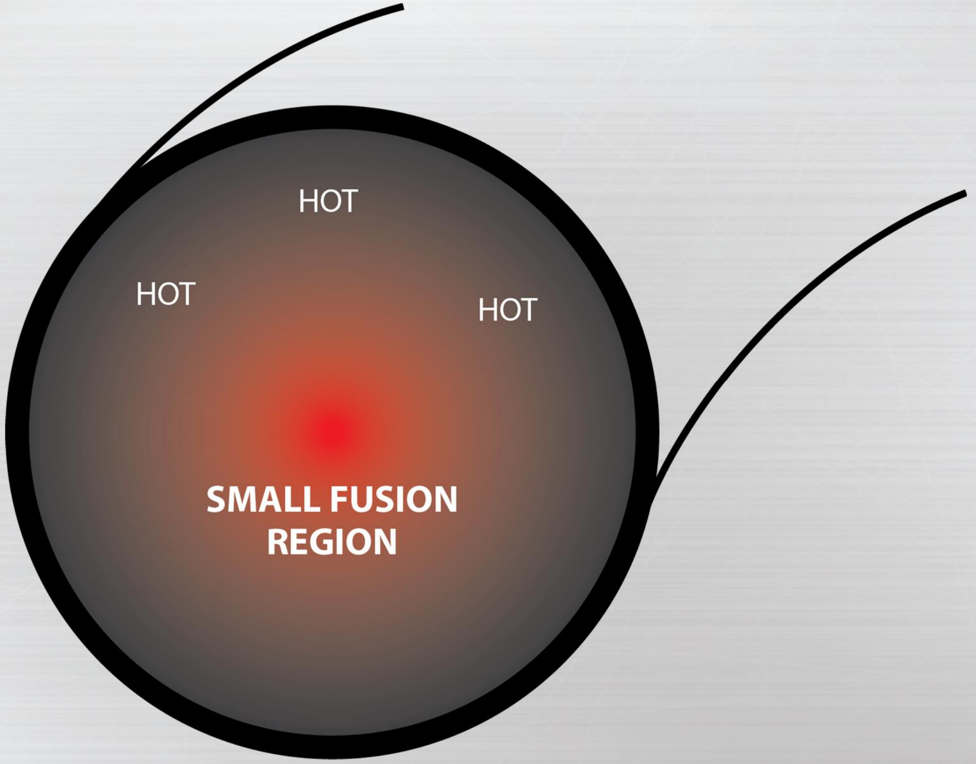




Compact Size

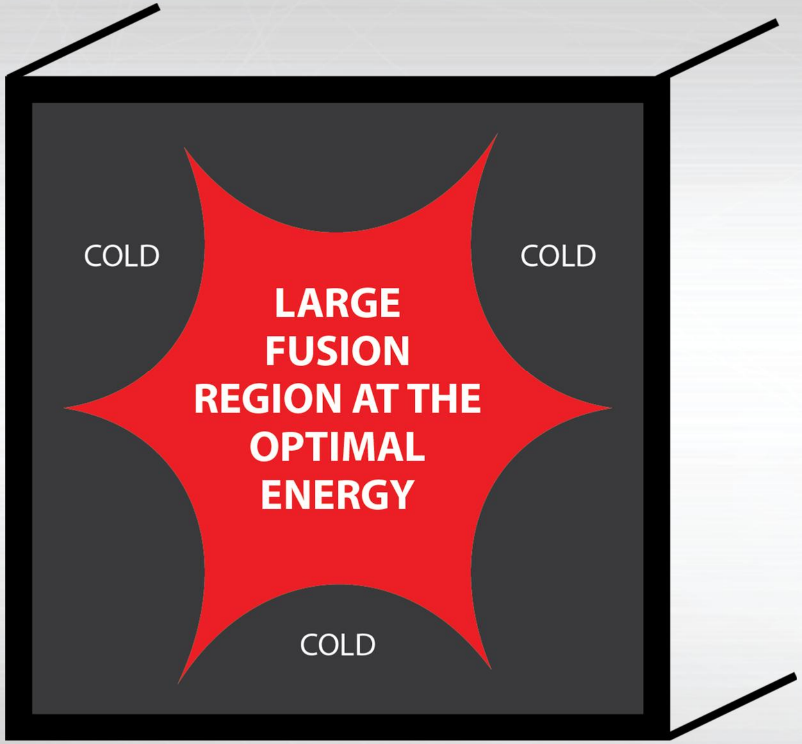
NON-ELECTROSTATIC REACTORS

Need a wide heat gradient to generate a small central fusion region.



ELECTROSTATIC REACTORS

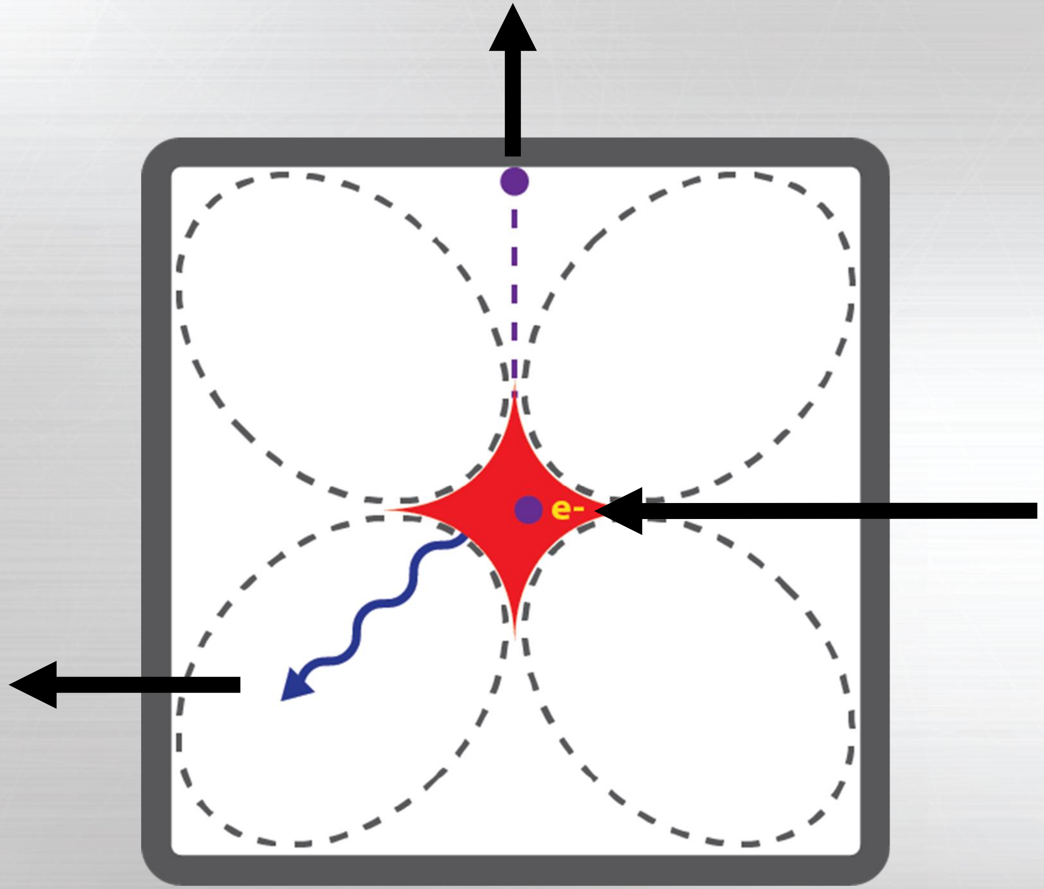
A sharp thermal gradient for a large fusion region.



The Challenges

Magneto-electrostatic reactors lose energy in three main ways:

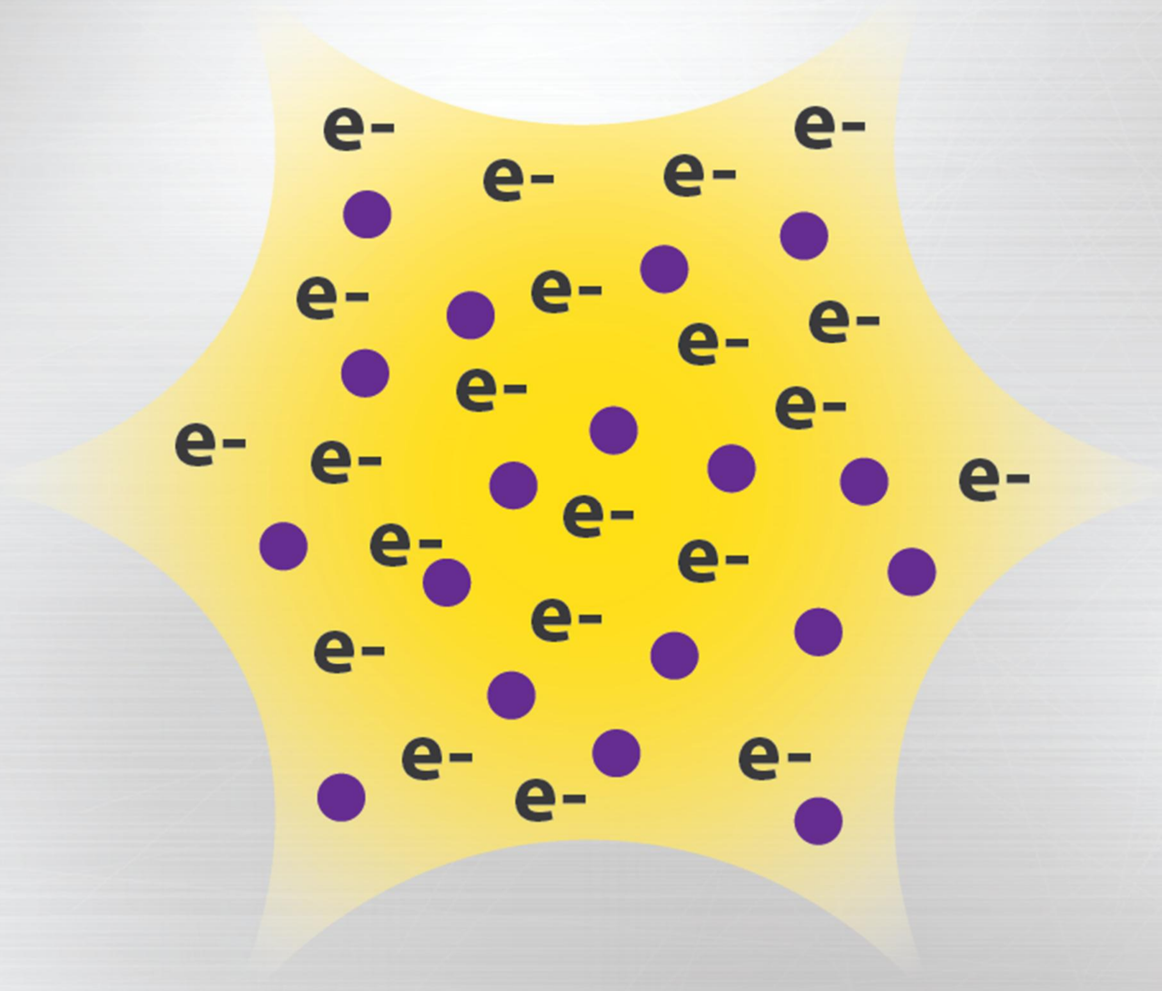
Conduction
ions and electrons escape and hit surfaces



Thermalization
ions for fusion slowed from colder electrons and ions

Radiation
accelerated particles release x-rays

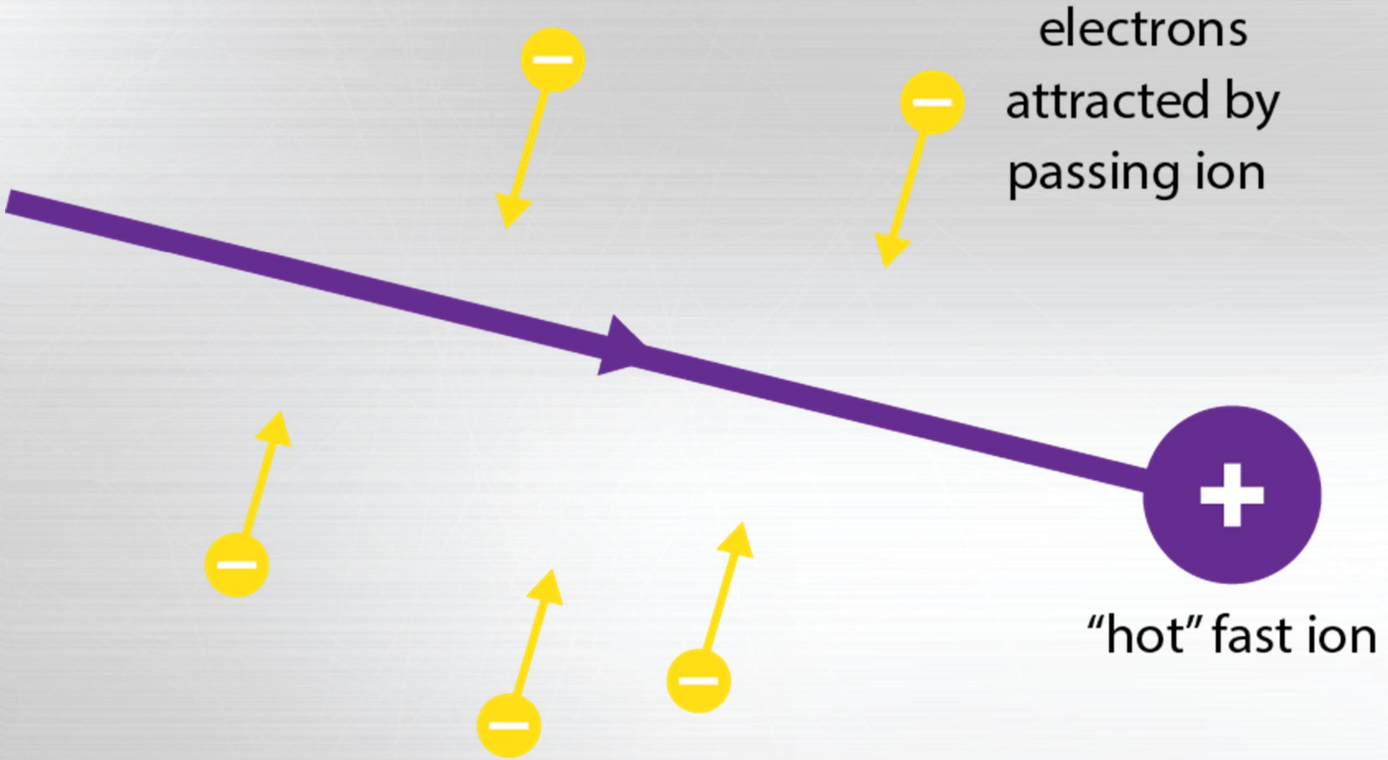
Thermalization



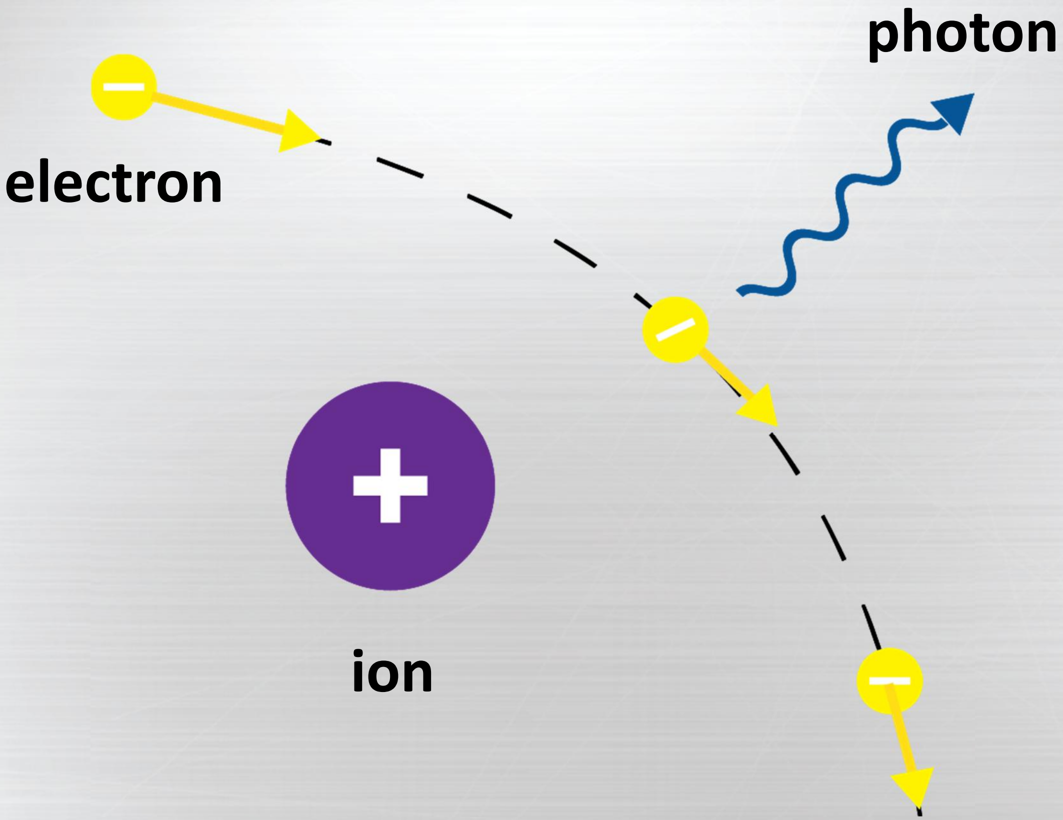
In the region where the fusion occurs, there is a mixture of ions and electrons at various energy levels.

Thermalization

Some of the hot ions intended for fusing lose their energy to colder electrons in the cloud.



Thermalization Leads to Radiation



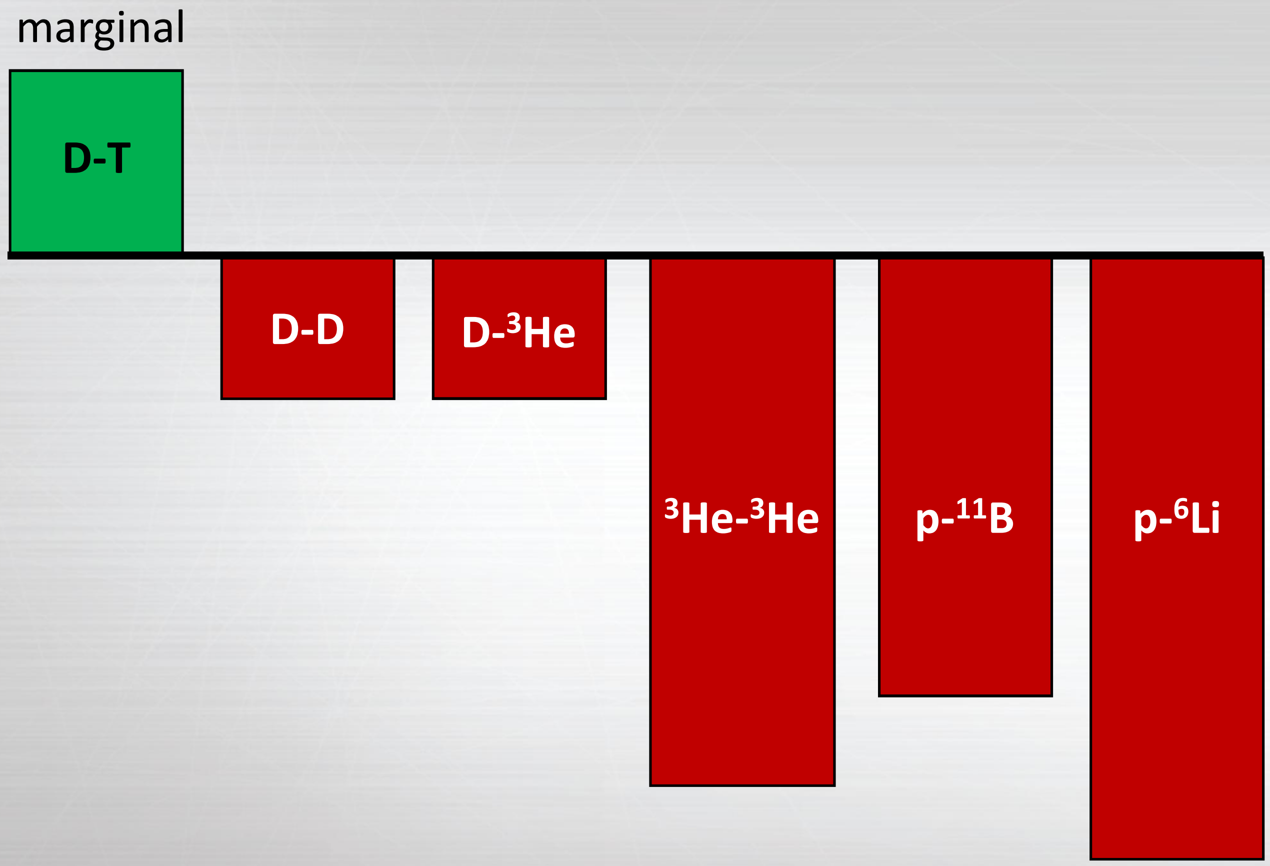
When the warmed electrons interact with ions, the acceleration causes a release of x-ray radiation.

This energy exits the reactor and is lost.

Net Loss Scenario

In the 1990s, MIT PhD student Todd Rider published his doctoral work which calculated the power output and losses in electrostatic reactors.

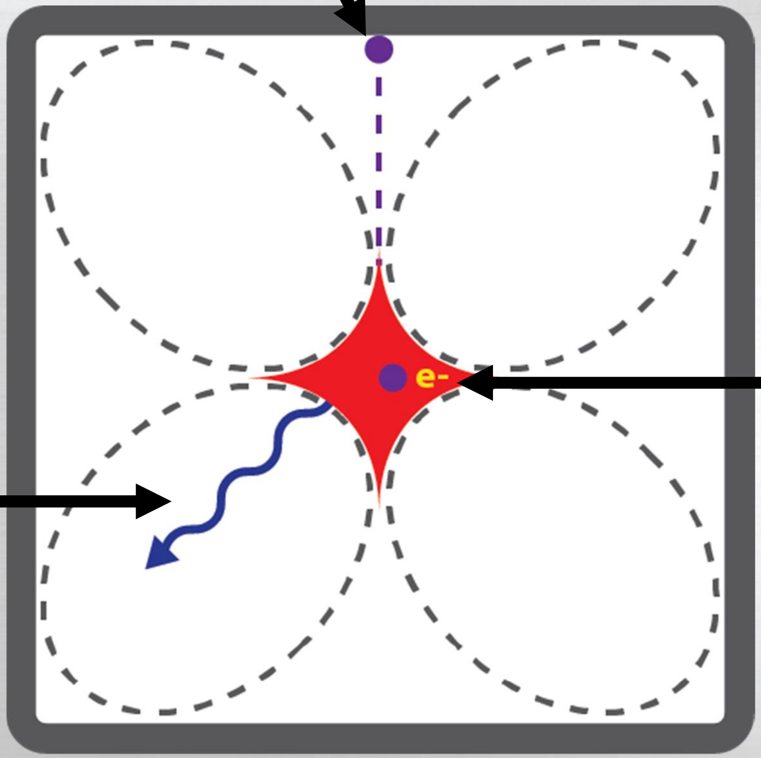
His analytical model found that the combined losses would exceed fusion output for all fuels except deuterium-tritium which had a net power gain of ~2x – an insufficient margin required for converting the heat to electricity.



Rider’s Net Loss Conclusions

Conduction

Too many ions and electrons escape through cusps removing energy that cannot be recirculated back into the fusion regions



Radiation

The heated electrons lose excessive amounts of the transferred energy as x-rays.

Thermalization

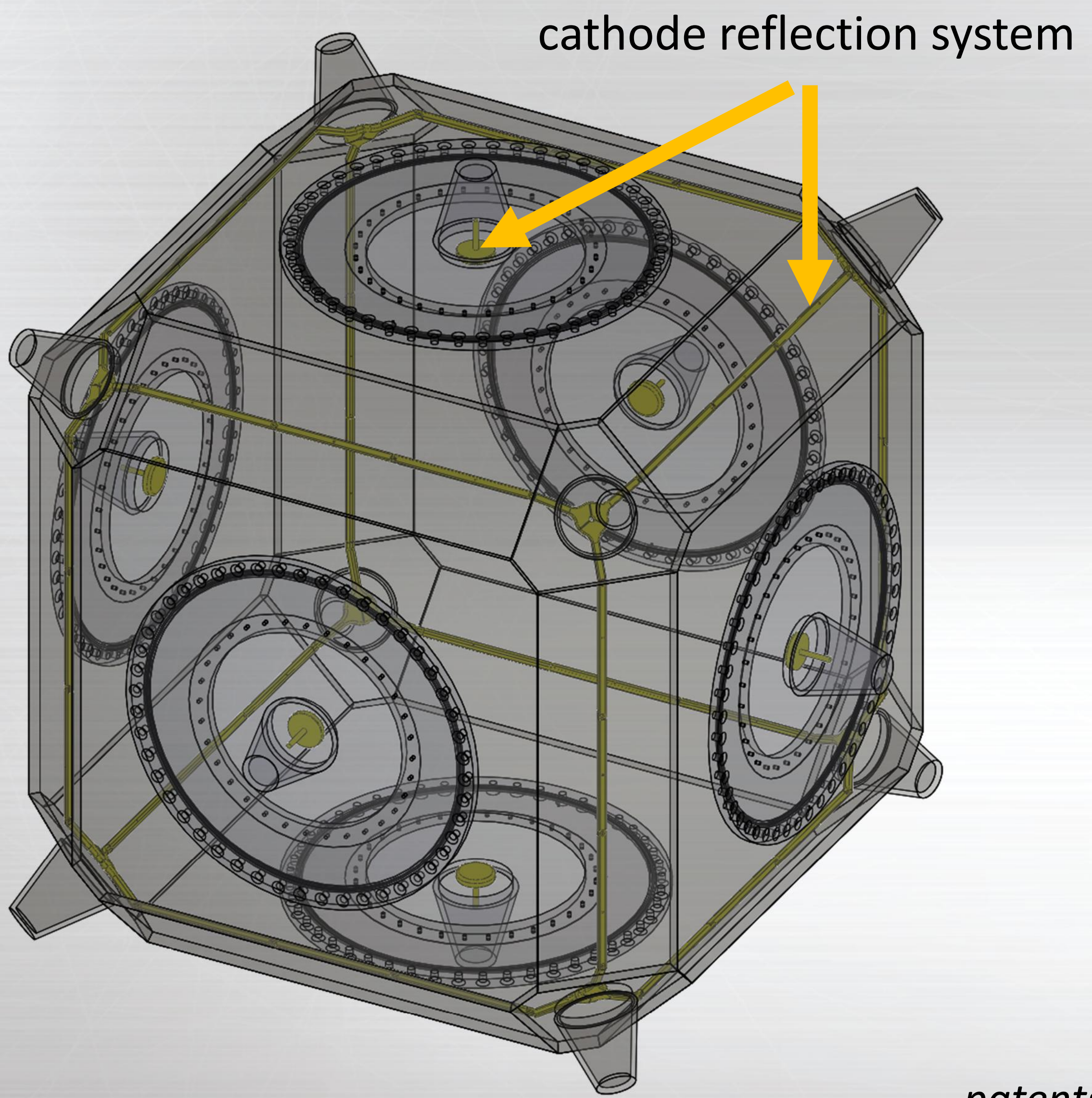
Too many hot ions lose their energy heating colder electrons and cannot fuse.

> **“In order for electrostatic systems to be used as fusion reactors, it will be necessary to find methods to circumvent these problems.”**
>
> Dr. Todd Rider

The Solution – F1 Reactor

Incorporates a cathode reflection system that uniquely couples the electrostatics with the magnetic confinement.

The cathode surfaces are strategically positioned to reflect electrons back into the fusion region to limit conduction and thermalization losses.

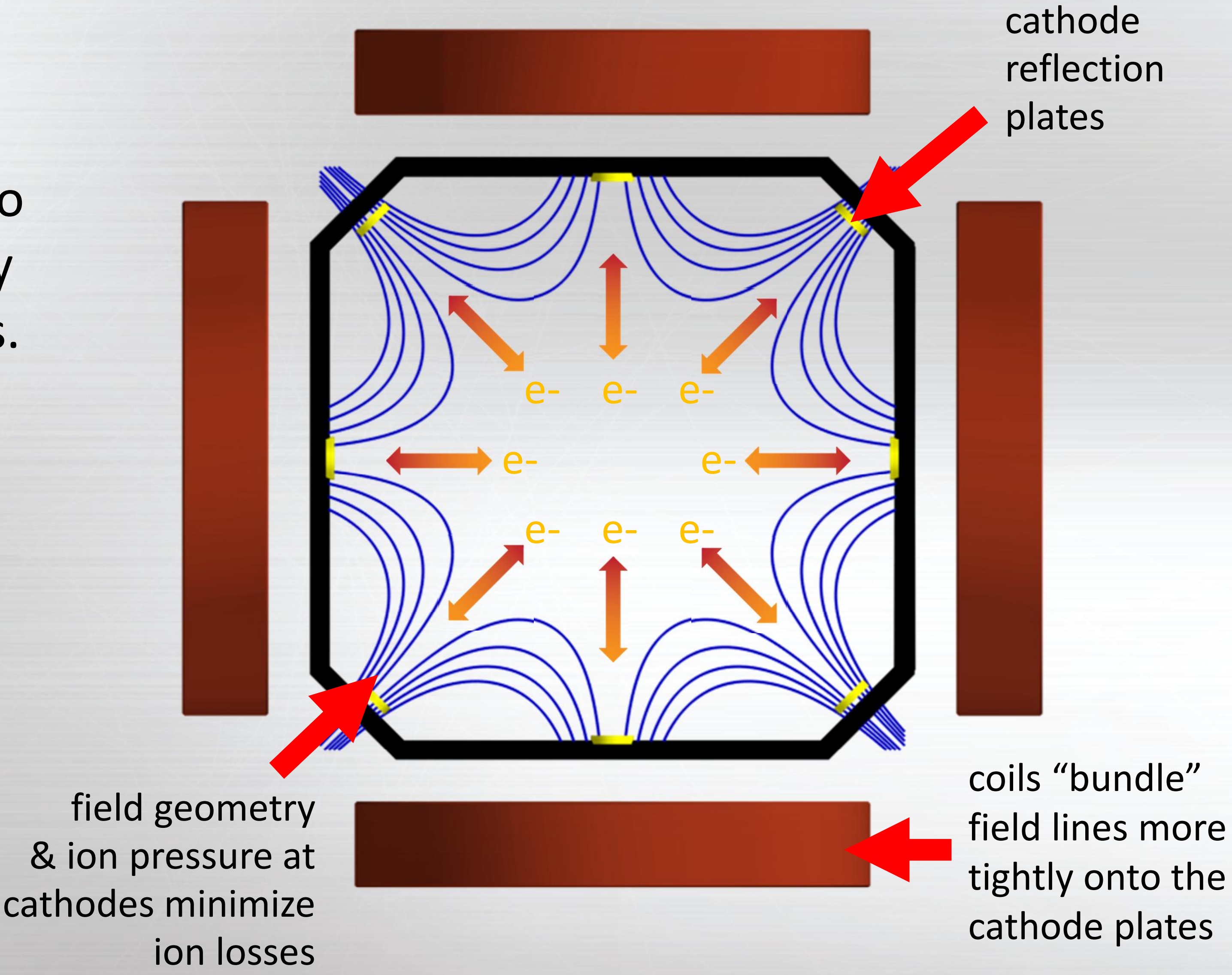


patents pending

Cathode System Lowers Losses

If electrons get too hot, they emit radiation. If they get too cold, they thermalize with the ions. The key is to keep the electrons warm so that they do not strongly interact with the ions.

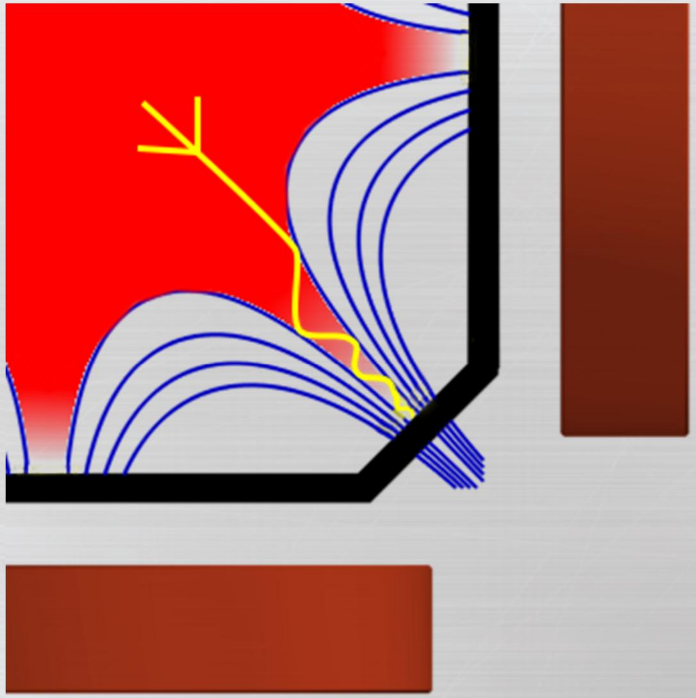
The cathode plates do this by electrostatically “plugging” the magnetic cusp regions so that escaping electrons will be reflected back to the fusion region before they hit the plates and lose their thermal energy.



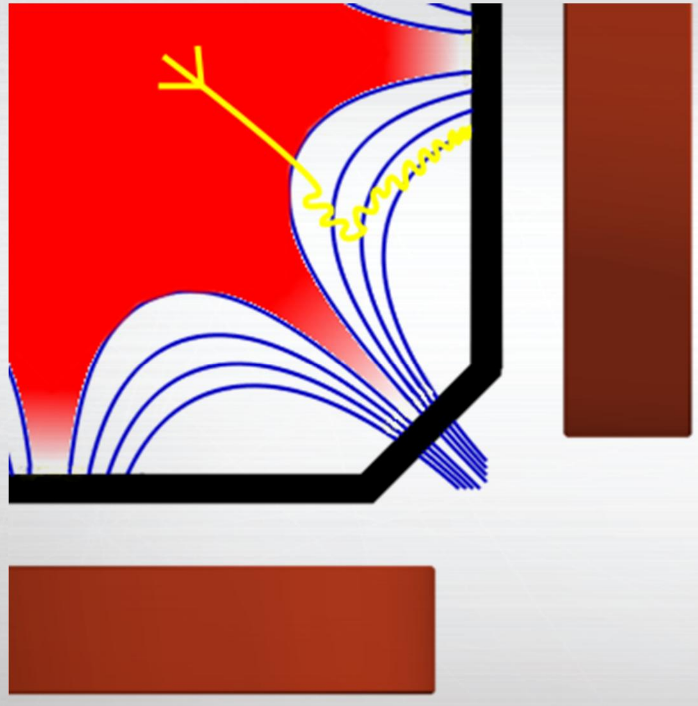
Cathode System Lowers Losses

Without the cathode system, escaping electrons have only two outcomes, both resulting in a complete loss of energy to conduction.

1. The electron leaves the potential well and is lost by escaping through the cusp.



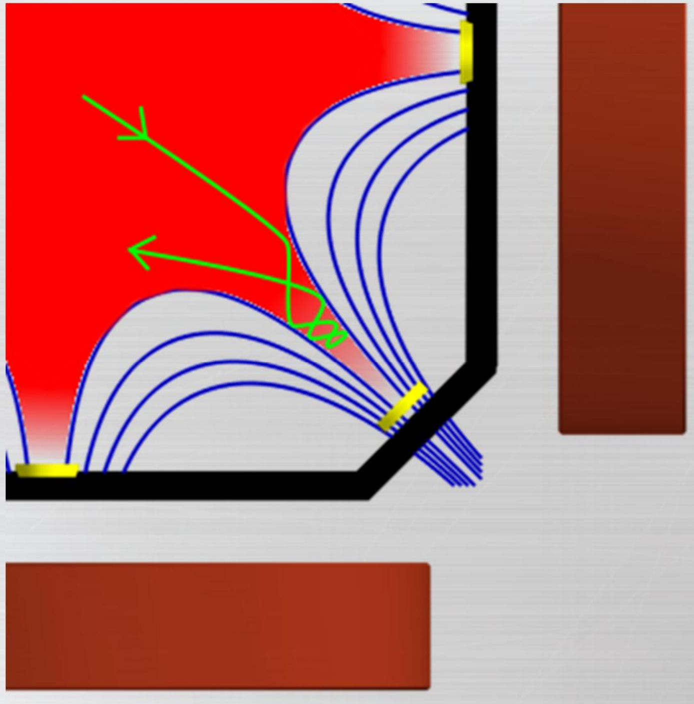
2. The electron leaves the potential well and is lost by diffusion to the wall. Both its thermal and electrostatic energy components are lost.



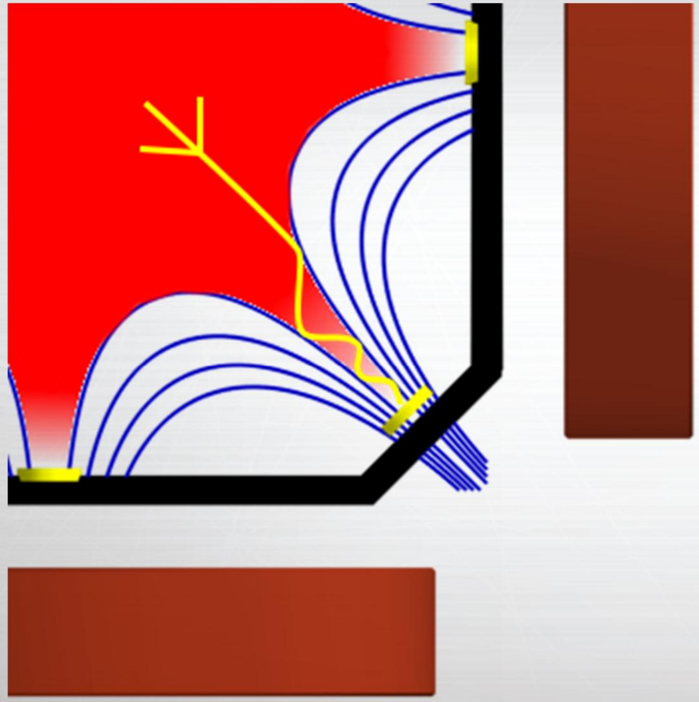
Cathode System Lowers Losses

With the F1 cathode system, recovery mechanisms are introduced for the first time:

1. The electron is not lost. If it is not confined by the magnetic field it may be reflected back by the cathode plates.



2. The electron is lost by hitting the cathode plate. However, because the cathode is at the same potential voltage as the core plasma, the electrostatic energy is not lost; only the electron's thermal energy is lost.

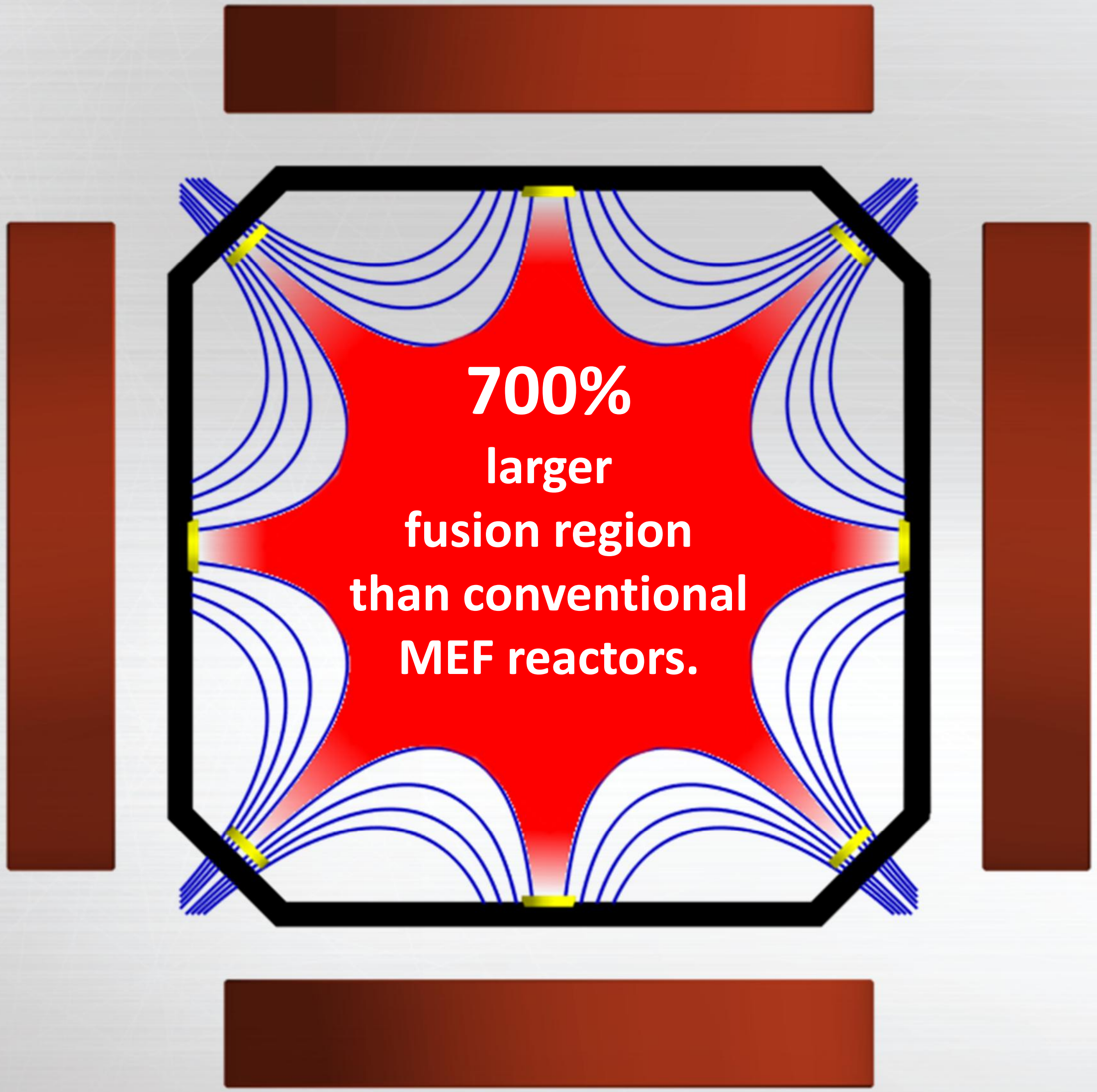


Maximized Fusion Region

The position of the cathode surfaces and electromagnets create the largest potential well.

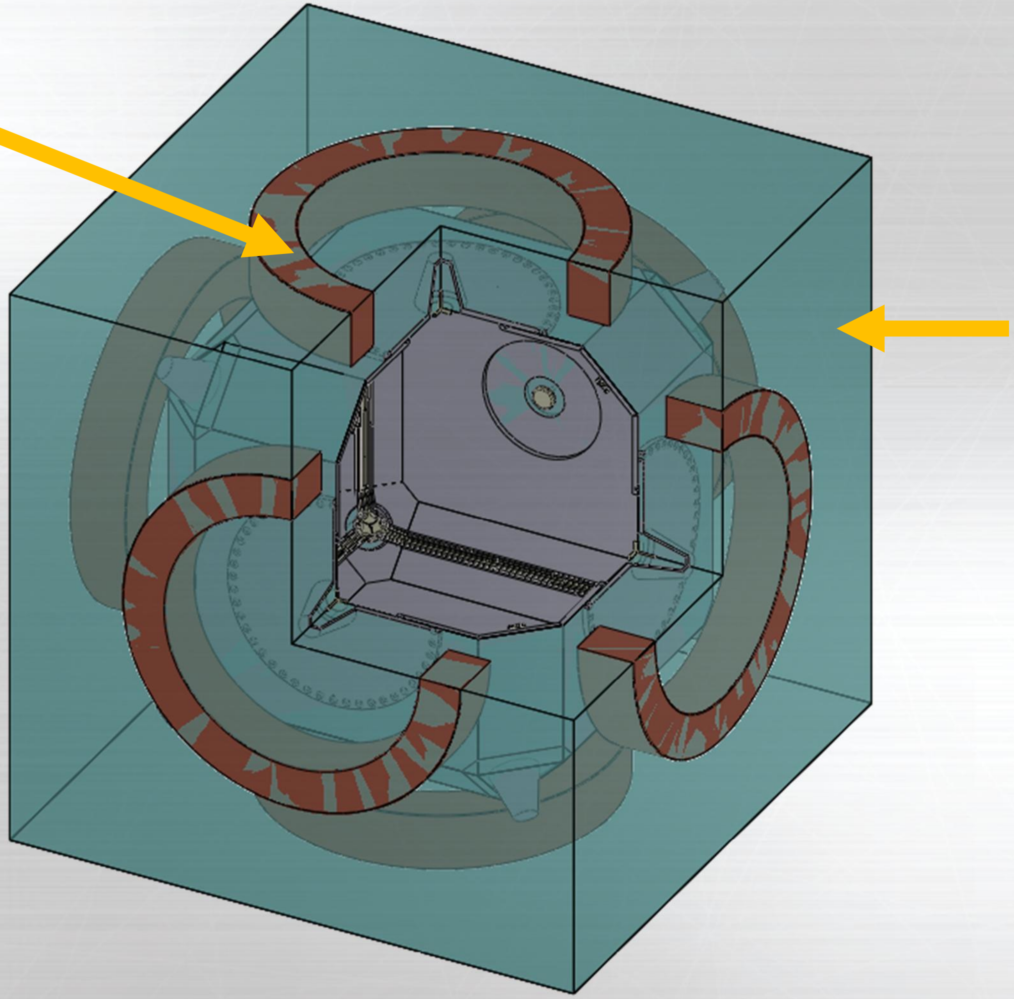
This devotes the majority of the reactor volume to fusion with more room for the ions to collide and fuse before escaping.

The cathode plates remove the need for electron guns since they are the source of electrons and provide that essential tuning control of the potential well depth.



External Coils & Fluid Jacket

Electromagnet coils are mounted externally instead of inside the chamber to avoid conduction losses, heat damage, neutron damage, size and power restrictions.

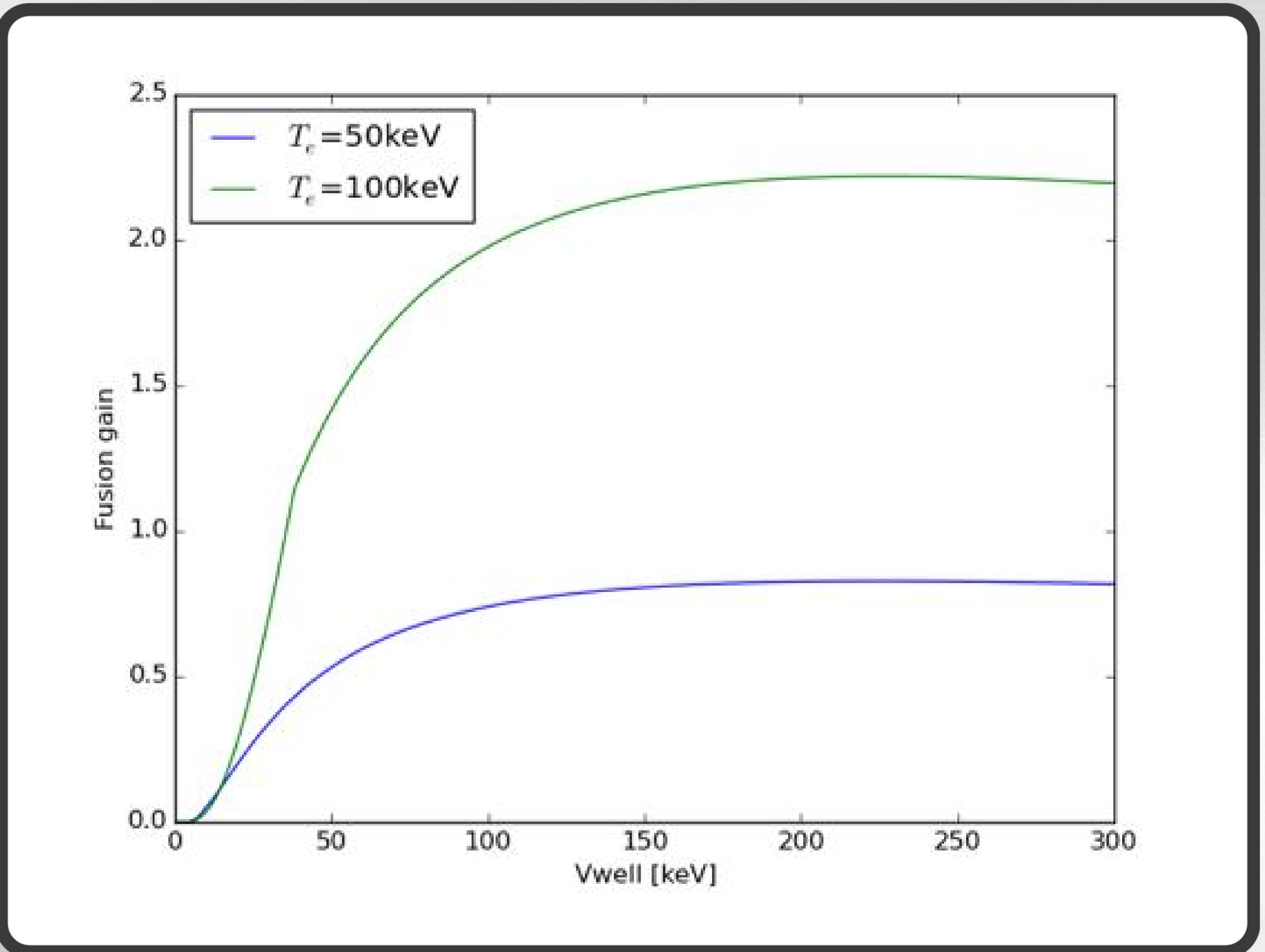


Immersed in fluid jacket
- neutron shield
- cooling
- heat exchange fluid for steam turbine

Analytical Model Predicts Net Gain

Based on the F1 design, we developed a new peer-reviewed analytical model.

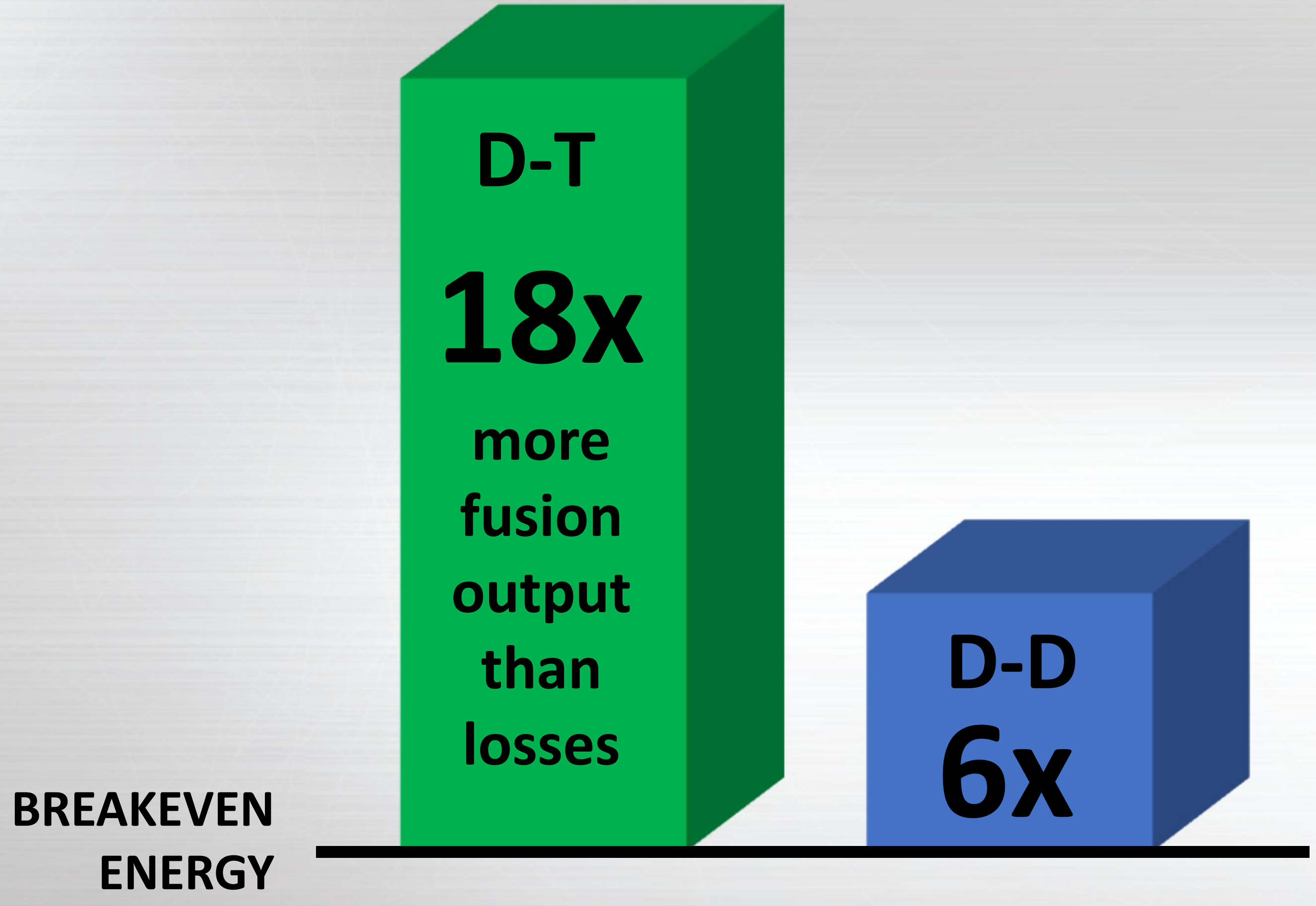
To model the power balance more accurately, we incorporated quantum relativistic effects of the radiation losses for a more sophisticated treatment to that used by Rider.



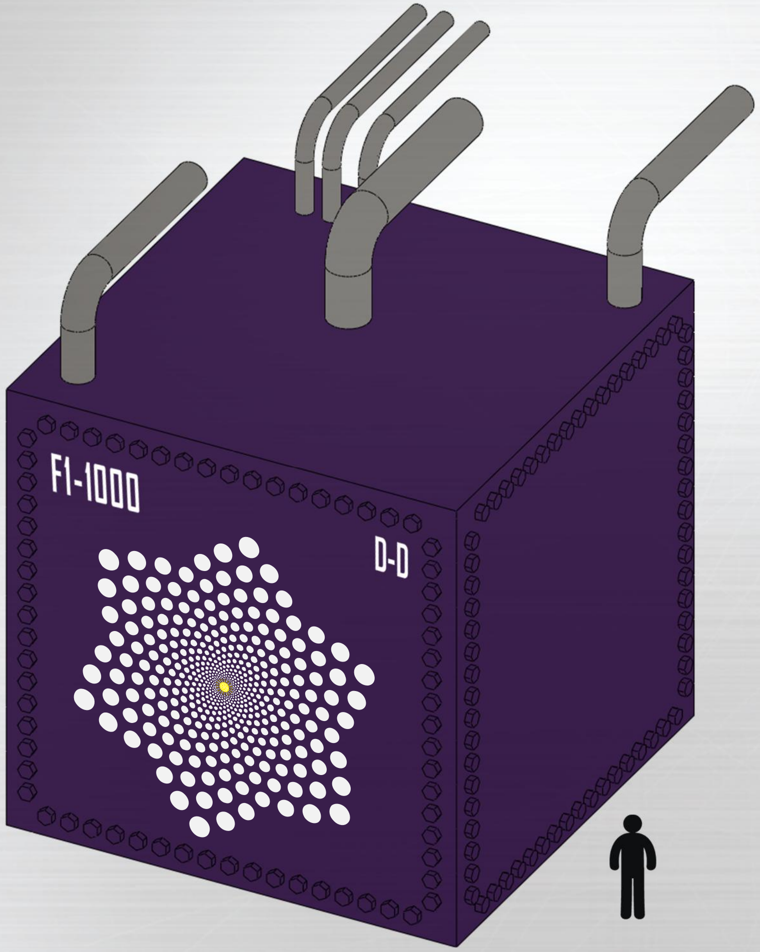
Net Gain Scenario

The model shows a high net gain multiple with deuterium-tritium and a useable net gain multiple with deuterium-deuterium.

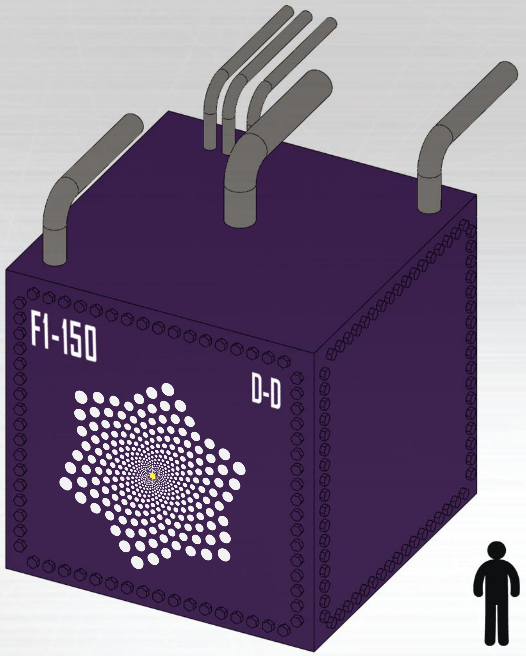
Using deuterium alone as the source fuel would remove the need to breed tritium. This will reduce the balance-of-plant costs, licensing, and shielding.



F1 – Modular Compact Deuterium Reactors



5.5 meters
(18ft)



4 meters
(13ft)

1 GWe Reactor Core

Service: centralized grid (1.2 million homes)
medical isotope irradiation, etc.

150 MWe Reactor Core

Service: marine propulsion, remote,
industrial, distributed grid, etc.

Next Steps – Validate Model & Design

Validate Model and Key Design Features ($500K for 12 months)

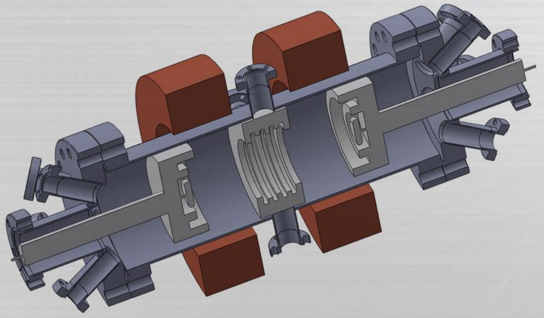
Build Reactor at Relevant Performance Scale ($5 million for 3 years)

Adaptive Mesh 3D PIC Supercomputer Simulation

Very high fidelity particle simulation to validate that the F1 reactor will generate power at sufficient multiples for producing electricity.

Benchtop Cathode Device

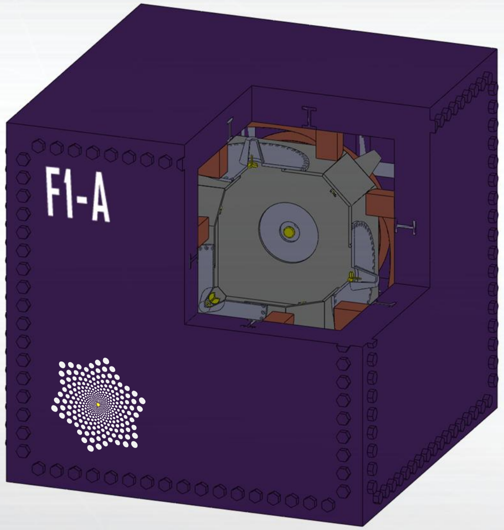
A spindle cusp with cathode repellers validates the operation of key design features of the F1 reactor.



F1A – High Yield Fusion Reactor

10^{10} neutrons/sec

Construction
Shakedown
Testing



Timeline to Commercialization

TRL 4
Low fidelity system or components demonstrate basic functionality

3-D Particle Simulation

Cathode Testing Device

8 MONTHS

VALIDATE DESIGN

TRL 5
Medium fidelity system or components that demonstrate overall performance

High Yield D-D Fusion Reactor
- pulsed
- 2m wide core

5-10 personnel

3 YEARS

10^{10} NEUTRONS SECOND

TRL 6-7
High fidelity system or components addressing all critical scaling issues

Net Gain D-D Reactor
- superconducting
- pulsed (long)
- 2m wide core

20-30 personnel

4 YEARS

NET FUSION POWER 1.5MW

TRL 8
Product is demonstrated in its final configuration

Prototype D-D Power Plant
- superconducting
- steady-state
- steam cycle
- 4m wide core

50-60 personnel

6 YEARS

150 MW ELECTRICAL POWER

TRL 9
Final product is successfully operated in an operational environment

TARGET 15 YEARS TO BEGIN COMMERICAL INSTALLATION

THANK YOU

rv@fusionone.co