Inertial Electrostatic Confinement; Small Scale Nuclear Fusion for Non-Energy Applications

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Major Current Projects in Nuclear Fusion

Laser Inertial Confinement
National Ignition Facility, LLNL, US

Tokamak
ITER, Cadarache, FR
Some Other (Smaller) Approaches to Nuclear Fusion

Z-Pinch (Sandia Laboratories Z-Machine)

“Field Reversed Configuration” (Tri Alpha Energy)

Dense Plasma Focus (Lawrenceville Plasma Physics)

Magnetized Target Fusion (General Fusion Inc.)

Stellarators (e.g. Wendelstein 7-X in Germany)
The topic of this presentation (still smaller devices):

Inertial Electrostatic Confinement (IEC) Fusion:

- Farnsworth-Hirsch Fusor
- Polywell® (EMC2)
- Other gridless IEC designs
- Lockheed’s new device (IEC?)

(IEC is NOT “Cold Fusion” !!!)
Nuclear Fusion Reactions

$^2\text{H} + ^3\text{H} \rightarrow ^4\text{He} \ (3.5 \ \text{MeV}) \ + \ n^0 \ (14.1 \ \text{MeV})$

$^2\text{H} + ^2\text{H} \rightarrow ^3\text{H} \ (1.01 \ \text{MeV}) \ + \ p^+ \ (3.02 \ \text{MeV}) \ [50\%]$

$^2\text{H} + ^2\text{H} \rightarrow ^3\text{He} \ (0.82 \ \text{MeV}) \ + \ n^0 \ (2.45 \ \text{MeV}) \ [50\%]$

$^2\text{H} + ^3\text{He} \rightarrow ^4\text{He} \ (3.6 \ \text{MeV}) \ + \ p^+ \ (14.7 \ \text{MeV})$

$p^+ + ^6\text{Li} \rightarrow ^4\text{He} \ (1.7 \ \text{MeV}) \ + \ ^3\text{He} \ (2.3 \ \text{MeV}) \ [50\%]$

$p^+ + ^{11}\text{B} \rightarrow 3 \ ^4\text{He} \ (8.7 \ \text{MeV}) \ \text{“aneutronic”}$

* where it all started – Cockcroft & Walton, 1932
Nuclear Fusion Cross Sections

Temperature in degrees Kelvin
1.1 X 10^8  1.1 X 10^9  1.1 X 10^10

Energy of Light Particle (p or D) in KeV

Cross-Section in Millibarns
Beam-Target Nuclear Fusion

$^2\text{H}^+$ ion beam

Ti target

Schlumberger Ltd.
Beam-Target Nuclear Fusion – Gas Phase Target

Philo Farnsworth
inventor of electronic television
8/19/1906-3/11/1971

The Farnsworth Invention
a play by Aaron Sorkin
Music Box Theatre
Broadway, New York
December 3, 2007 – March 2, 2008
Farnsworth's Other Invention - IEC Fusion Device

Farnsworth wasn’t actually the first:

As Professor Linder mentioned last week, Oleg Lavrentyev actually put forth the idea first (1950), but Andre Sakarov didn’t think it would work.

After the secrecy surrounding fusion work was lifted, Lavrentyev ultimately published his idea:

Farnsworth Fusor

Farnsworth–Hirsch Fusor

high negative potential (tens of kV.) on center “cathode”

“ion source” grid (positive relative to both cathode and anode)

c. 1 Pa. deuterium gas

grounded shell “anode”

Filament electron source

Basic “Farnsworth Fusor”

-vacuum & gas supply

Diagram of the Basic “Farnsworth Fusor”
Bremsstrahlung losses exceed the fusion power produced.


Coulomb collisions → Maxwellian distribution on the ion–ion collisional time scale; power required to prevent this is greater than the fusion power produced.

Applications of Nuclear Fusion

1. Energy production

2. Neutron and other energetic particle sources
   a. landmine detection
   b. nuclear materials detection
   c. neutron radiography
   d. neutron transmutation doping
   e. medical isotope production
   f. research applications

3. Spacecraft propulsion
IEC Neutron Source \((10^7/sec)\) for Landmine Detection

Institute of Advanced Energy, Kyoto University
Pulsed 200 kV IEC Device for Nuclear Materials Detection

Institute of Advanced Energy, Kyoto University
Commercial IEC Fusion Neutron Generator

NSD-GRADEL-FUSION, Luxembourg
Medical Isotope Production Using IEC Neutron Generator

Molybdenum-99 precursor of Technetium-99m

The most widely used isotope for medical imaging

\[ ^2H + ^2H \rightarrow ^3He \ (0.82 \text{ MeV}) + n^0 \ (2.45 \text{ MeV}) \]

\[ ^{235}\text{U} \ (\text{low enrichment; water solution}) + n^0 \rightarrow ^{99}\text{Mo} \ (\text{fission product}) \]

Molybdenum-99 \(^{99}\text{Mo}\) \(\rightarrow\) Technetium-99m \(^{99m}\text{Tc}\)

Madison, Wisconsin, USA
University Research Groups Pursuing IEC Fusion Research

1. University of Wisconsin (US)
2. University of Illinois (US)
3. University of Maryland (US)
4. Tokyo Institute of Technology (Japan)
5. Kyoto University (Japan)
6. Tokai University (Japan)
7. Kansai University (Japan)
8. University of Sydney (Australia)
9. Shahid Beheshti University (Iran)
10. Gazi University (Turkey)

Primary scientific meeting: U.S.-Japan Workshop on Inertial Electrostatic Confinement Fusion
11th – 2009 University of Wisconsin
12th – 2010 Kansai University, Osaka
13th – 2011 University of Sydney
14th – 2012 University of Maryland
15th – 2013 Kyoto University
16th – 2014 University of Wisconsin
Problems Presented by the Grid in a Gridded Fusor

1. Ion bombardment heats the grid leading to thermionic electron emission.

2. Electron emission causes power loss and neutralization of the fuel ions.

3. Grid heating eventually melts the grid.
Grid Heating in Fusor
Polywell Devices – EMC2 Inc.

WB-1 permanent magnets

WB-2

WB-3

WB-4

WB-5

WB-6

$10^9$ DD fusions/sec at a potential well of 10 kV.
Polywell Research Support from the U.S. Navy

“R&D- ENERGY: NUCLEAR (APPLIED RESEARCH/EXPLORATORY DEVELOPMENT)”

www.fpds.gov/ezsearch/

May 21, 2013 $780,000 “Plasma Wiffleball 8.0”
April 29, 2013 $300,000 “Plasma Wiffleball 8.0”
Feb. 25, 2013 $600,000 “Incremental funding for Plasma Wiffleball 8.0”
Aug. 23, 2012 $1,120,000 “Plasma Wiffleball 8.0”
May 03, 2012 $1,200,000 “Plasma Wiffleball 8.0”
June 22, 2011 $2,022,678 “Plasma Wiffleball concept exploration”
June 08, 2011 $100,000 “R&D concept exploration on Plasma Wiffleball 8.0”
Jan. 20, 2011 $1,000,000 “Research & development of the AGEE Plasma Wiffleball”
Sept. 10, 2010 $1,350,000 “The contractor shall construct and test a small scale MG insulated, Wiffleball Polyhedral device, WB8”

Sept.11, 2009 $3,216,825 “..concept exploration and technology demonstration of the Advanced Gaseous Electrostatic Energy (AGEE) concept..WB8”

May 20, 2009 $331,174 “Wiffleball 7.1”
March 03, 2009 $299,843 “Wiffleball 7.1”
Dec. 17, 2008 $99,355 “Research study for the AGEE Development”
Dec. 08, 2008 $99,355 “Polywell Fusion Device Ion Injection Gun”
Nov. 5, 2008 $93,123 “Advanced Gaseous Electrostatic Energy”

August 21, 2007 $1,750,000 “applied/exploratory engineering (fusion research)”

Total Polywell funding to date - $17,558,191 (including 1997-2005)
Direct Energy Conversion

\[ p^+ + ^{11}\text{B} \rightarrow 3\ ^4\text{He} \ (8.7 \ \text{MeV}) \]
The first regular publication by the EMC2 group:

Multiple Ambipolar Beam Line Experiment (“MARBLE”)

Linear Electrostatic Ion Trap


Multiple Ambipolar Beam Line Experiment ("MARBLE")

Turning Regions in Electrostatic Traps

Linear Electrostatic Trap

Hirsch - Farnsworth Fusor

turning regions
Fusor in “Star Mode”

Photo from Wikipedia Commons
Gridless Planar (Disc) Electrostatic Ion Trap

turning region
Planar Electrostatic Ion Trap

Proposed Planar Electrostatic Ion Trap Mass Spectrometer

Planar Electrostatic Ion Trap

Simulation of ion trajectories for ions originating at single point with 0.1 eV tangential K.E

Rotate around vertical axis

Cutaway view with top electrode rings removed
How to Generate Ions with Tangential K.E. Inside the Trap?
Brooks Automation VQM 830 Residual Gas Analyzer
Prototype Single Potential Trap under Construction
What’s new in fusion development?
Recent Report of Work at the Lockheed Martin Skunkworks

“Solve For X is a place to hear about and discuss radical technology ideas for solving global problems.”

Posted January 11, 2013  www.solveforx.com
Compact Fusion

100MW

Lower development costs
Faster design cycle: 2025 vs 2050
Lower magnetic fields: Lower weight
Distributed power generation

© 2013 Lockheed Martin Corporation. All Rights Reserved
The Adjacent Possible

T4 experiment

New magnetic configuration

High $\beta$: 10-fold improvement

$\beta = \text{Plasma Pressure} / \text{Magnetic Pressure}$

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Summary

Several alternative approaches to nuclear fusion are under study.

Some offer the possibility of small power reactors.

Some are particularly useful for non-energy applications.

IEC devices are particularly simple for such applications.

Gridless IEC devices could yield much improved performance.
End
Extra Slides
Proposed Beam – Beam Collision Device

Ion Sources Biased at High Positive Potential

Magnetic Field Coils

A Conceptual Drawing of the Neutron Generator

The Wilhelm Bratwurst Institute for Applied Physics Research
Elmore-Tuck-Watson Device

Hirsch - Farnsworth Fusor

Elmore - Tuck - Watson

Farnsworth–Hirsch Fusor

“ion source” grid (positive relative to both cathode and anode)

high negative potential (tens of kV.) on center “cathode”

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Filament electron source

Taylor Wilson explaining his fusor science fair project to Barak Obama. 2/7/2012