The History of LENR Research at NASA Glenn Research Center

ICCF-24: Solid State Energy Summit
July 25, 2022

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Outline

• The Need: Novel Nuclear Fusion Reactions as an Energy Source
• Lattice Confinement Fusion
• Historic Experiment
• Investigating Triggers
• Definitive Proof
• Theory Development & Refinement
• Summary
Novel Nuclear Fusion Reactions as an Energy Source

- Harnessing fusion would provide humanity nearly limitless energy
- For 30 years multiple labs have observed fusion reactions suggesting Lattice Confinement Fusion (LCF)
- LCF may be the key to harnessing fusion within a compact contained system
  - Eliminates need for weapons-grade uranium (HEU)
  - Reduces safety, security, and supply concerns
  - Compact, controllable power
  - Zero radioactive waste

Potential Long-Term Applications

* Note: LCF offers near-term means for terrestrial exploration of warm dense matter, Heliophysics, and Astrophysics
How LCF Works

- Traditional fusion: Heats plasma 10x hotter than center of sun – **hard to control**
- LCF addresses the pressure, temperature, and containment challenges with fusion
  - Heats **very few** atoms at a time
  - Approaches solar fuel density
  - Lattice provides containment

**Technical Details Simplified**

**Part A:** Electron Screening  
(increases fusion probability)

**Part B:** High Fuel Density  
(billion times more dense than traditional fusion)

\[ A + B (+ \text{ trigger}) = \text{Viable Fusion} \]
J-M Gas Cycling Experiments: Description

High flux of D through Pd/Ag hydride system:

• Test Article: Johnson-Matthey (JM) hydrogen purifier
  • Hydrogen purification accomplished by gas diffusion across Pd/Ag Tube
• Inspired by electrolytic wet cell experiments and LENR claims, G. Fralick (1989) used JM purifier to load Pd with D$_2$ since it’s easier than loading D$_2$ during a wet cell experiment; looked for neutrons and heat release
  • Very little neutrons above background observed
  • Observed temp rise of 17 °C in 15 sec unloading D$_2$ but not with H$_2$
• Experiments in 2014 & 2018: pressurized cycling of D$_2$ gas produces heat & surface transmutations on PdAg tubing; evidence of LENR$^{1,2}$

Repeat of temperature rise during D$_2$ gas unloading
• 1989: 17°C temp rise in 15 s
• 2014: 25°C temp rise in 4 s
• 2018: 12 °C temp rise in 45 s

Scanning Electron Microscopy
• Showed areas of molten looking spots and craters
• Palladium melts at 1560 °C and silver melts at 962 °C yet system heater was kept under 425 °C


Timeline of NASA Events

• Several groups at NASA (LaRC, MSFC and GRC) followed various LENR researchers including Pons/Fleischman, Nagle, and Rossi (1989 to 2011)
  • Discussed and reviewed various approaches
• With GRC R&D management approval, Robert Hendricks (GRC) organized a LENR/Innovations Workshop held on Sept 21, 2011 at NASA GRC in Cleveland, OH
  • Speakers from GRC, LaRC and MSFC shared their current research
  • Dr. Bruce Steinetz, Dr. Theresa Benyo, and others attended with great interest
• Robert Hendricks briefed Center Director, Dr. Ray Lugo shortly after
  • Dr. Bruce Steinetz, Dr. Arnon Chait (representing Dr. Vladimir Pines), Gus Fralick, and Dr. Lei (GRC R&D Director) in attendance
  • Proposed a LENR research project at GRC; Dr. Lei authorized a small effort at GRC lead by Dr. Steinetz
  • Dr. Lugo orchestrated a briefing at NASA HQ where all NASA efforts were presented
• AEC Project lead by Dr. Steinetz grew from a few researchers to about 25 over the years from 2011 to 2018
  • Small amount of funding from the Director’s Discretionary Fund (~2012-2013) grew to a large effort (2014 to 2018)
  • Various NASA HQ and other gov’t agency reviews were held of the work over the active years
  • Culminated in the Phys Rev C journal papers; experiment and theory published in 2020
• AEC Project held a virtual workshop in May of 2020 to announce the results of the published work
  • Attended by 70 LENR researchers from industry, government and academia
• AEC Project transitioned to the LCF Project with the current funded effort (July 2021 to now)
  • Leadership transitioned from Dr. Steinetz to Dr. Benyo
Project Phases: Early Exploratory through Applied Research

Early: Exploration Phase
Are there any Novel Rx?

Current: Applied Research
Understand Variables and Key interactions → Heat Source

Hydrogen Purifier
D-flux in PdAg tube system: heating, transmutations

X-ray Exposure
Activation of TiD2 + D-PE

SEM/e-Gun Exposure
Activation of TiD2 + D-PE

Specimen Location
X-ray Head

Linac Exposure
100% Activation: HfD2/Mo/D-para

Plasma + Calorimeter

Electrochemistry
Cell
Calorimeter

Slow Co-Deposition
Confirm nuclear activity
Scanning Electron Microscope (SEM)
Energetic Electrons Into Deuterated Targets

Objective
• Investigate direct enhanced screening of deuterated targets via 10s keV energetic electrons (SEM)
• Evaluate literature claims of nuclear reactions (Lipson, 2009) under these conditions

GRC Findings
• Exposure of TiD$_2$ targets resulted in novel nuclear effects when exposed to electron beam energies (6-30 keV)
• Beta Scans (Tennelec) after exposure showed specimen had been activated
• CR-39: Showed evidence of fast neutrons
  • Corroborated research study by Lipson (2009)
• Activation TiD$_2$ success: <20% but exposed only to nano-amp level currents
• Exposure of unloaded Ti: No activation
X-Ray Beam
Volumetric Electron Screening Via Photons

Objective
• Investigate volumetric screening of deuterated targets exposed to X-ray photons

Findings
• Exposure of mixture of TiD\textsubscript{2} powder and deuterated polyethylene (D-PE) in Swagelok tube resulted in novel nuclear effects when exposed to X-ray energies (65-200kV; microfocus beam)
  • Beta Scans (Tennelec) after exposure showed specimen had been activated
  • Liquid Beta Scintillation: Showed beta source created with energy consistent with tritium
  • Activation of deuterated samples: success >50%
  • No Activation of unloaded materials: H-Polyethylene or Ti

Linear Accelerator (LINAC)  
Volumetric Electron Screening Via Gamma Photons

Objective

• Investigate volumetric screening of deuterated targets exposed to gamma-ray photons at sub-threshold energies (<2.226 MeV D-photo-dissociation)

Findings

• Exposure of HfD$_2$/D-Para/Mo and ErD$_3$/D-Para/Mo to 1.95 MV beam resulted in activation of 100% of 35 exposures
• Scalable with increased mass, beam energy, co-targets in the gamma beam.
• Created Mo-99/TC-99m (Important medical isotopes)
• CR-39/BubbleTech: Showed evidence of fast neutrons

CR-39 Triple track indicative of >10MeV neutron; evidence of kinetic heating and subsequent reactions

Plasma Reactor
Delivery of Ions/Energetic Electrons Into Deuterated Targets

Objective

• Investigate dynamic loading of D+ and screening electrons into deuterated targets with customized microstructure

Findings

• Tests with TiD₂ powder showed $P_{\text{excess}} \sim 4$ W
• Tests with PdAg showed $P_{\text{excess}} \sim 24$ W
• Anomalous gas changes
  •Measured during test: growth of AMU-2, 3, 5, 6; and decline in AMU-4 (D2)
• Production of excess thermal power repeat on average $\sim 20$-30%; need to better understand mechanisms
• Planned Design of Experiments: gain understanding of key variables and interactions

Colozza et al, 2016, NASA TM - Internal draft report
Electrochemistry
Dynamic In-Situ Creation of High-Density Deuterated Microstructure

Collaboration Partner: US Naval Surface Warfare, Dahlgren Division

Objective
• Investigate high current (900 mA) D+ co-deposited in-situ microstructure

Approach
• Fast Pd/D/Li Co-deposition Protocol\(^1\)
  • Heavy water (D\(_2\)O) or light water (H\(_2\)O) control electrolyte; 40-hour run
• Calorimetry\(^2\)
  • 100 mW sensitivity, calibrated against both H\(_2\)O and D\(_2\)O

Findings
• H\(_2\)O cells no heat, perpendicular magnetic field D\(_2\)O, no excess power
• 6 out 7 D\(_2\)O cells produced sustained excess thermal power, ranging from 250 mW to 1500 mW, 86% success
• High Power Density (0.0166g): 15 W/gm to 90 W/gm
• ICP-AES, XPS, TOF-SIMS, SEM/EDX show significant elemental transmutation with D\(_2\)O (e.g. Zn > 20%)

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\(^3\) Dahlgren Division, “Novel Energy Source Program”, Naval Surface Warfare Center, (2016)

LCF basic research has demonstrated nuclear reactions

Observation of D-D fusion and secondary nuclear reactions with TiD₂

Comparison of GRC observed D-D fusion neutrons with Italian Tokamak neutrons

30+ years of foundational fusion work

LCF Project: July 2021 – Sept 2022

LCF Advisory Group Recommendations

LCF Advisory Group December 2020

LCF Workshop May 2020

Published Papers

LCF Tech Team Strategic Planning

Two Phys Rev C Published Papers

Bremsstrahlung Experiments

Electron Screening Theory
The Path: Electron Screening

- Electron screening results in a more transparent Coulomb Barrier, shifting the Gamow Factor, as if deuterons were at far higher energies.
- This exponentially increases fusion rates.
- Laboratory astrophysics using accelerated deuteron beams across the Periodic Table show lattice and plasma screening provide up to 3+ keV screening.
- The PRC Theory Paper indicates a higher probability of large angle scattering of screened charged particles on screened deuterons.

However, screening is only effective below 10 keV.

$$\sigma_{\text{bare}}(E) = \frac{S(E)}{E} \exp \left[-G(E)\right]$$

Screening enhances reaction rates by Over 10 orders of magnitude.
Summary

- We have demonstrated multiple nuclear reactions initiated by various experimental techniques
  - Nuclear emissions: neutrons, alphas, protons, betas, He-3
    - Not all methods produce expected D-D reaction products
  - Transmutations, including tritium
  - Heat release
- Co-deposition and LINAC photon stimulation are highly reproducible
- Theory: astrophysics and accelerator experiments have provided insights in addressing Coulomb barrier
- Developed critical concentration of expertise in multiple disciplines + experimental and theoretical resources, and are following evidence-based approach to enable timely progress