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# The History of LENR Research at NASA Glenn Research Center

ICCF-24: Solid State Energy Summit

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Theresa L. Benyo[1]: Principal Investigator, Lattice Confinement Fusion Project

Lawrence Forsley[2]: Deputy Principal Investigator, Lattice Confinement Fusion Project

Bruce Steinetz[1]: Principal Investigator, Advanced Energy Conversion Project

[1]NASA Glenn Research Center, Cleveland, OH

[2]Global Energy Corporation, Annandale, VA

# 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

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- 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

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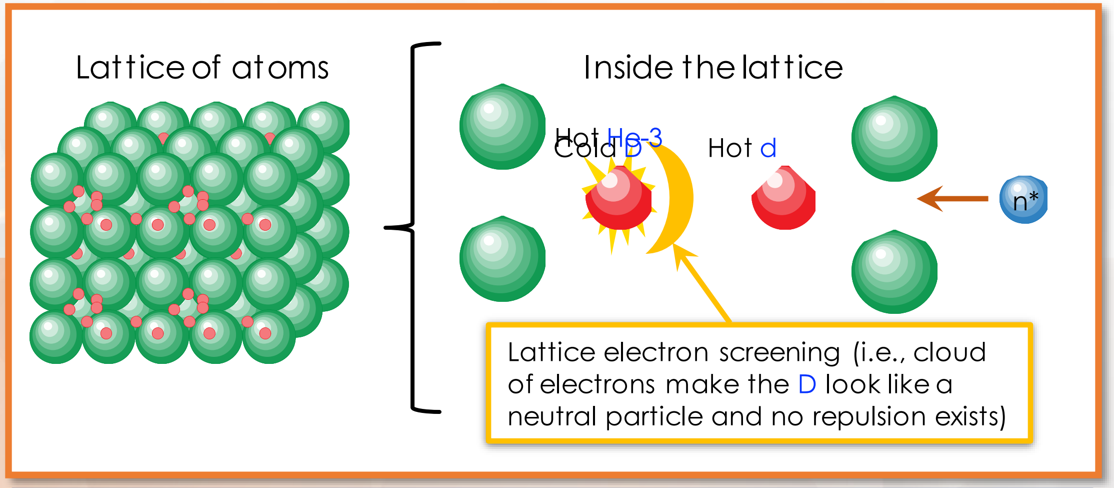
- Traditional fusion: Heats plasma 10x hotter than center of sun – *hard to control*
- LCF addresses the pressure, temperature, and containment challenges with fusion
    - Heats **very few** atoms at a time
    - Approaches solar fuel density
    - Lattice provides containment

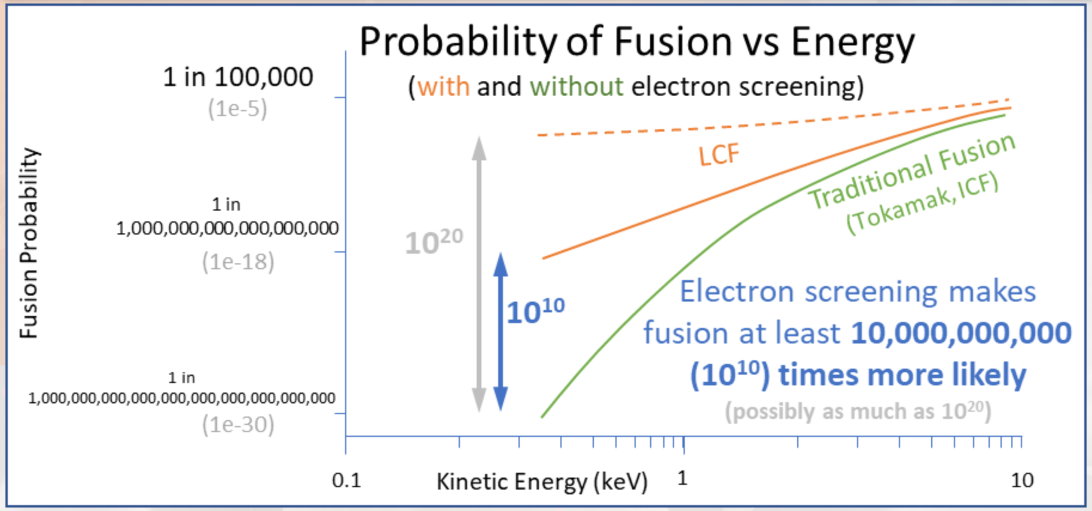
## Technical Details Simplified

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

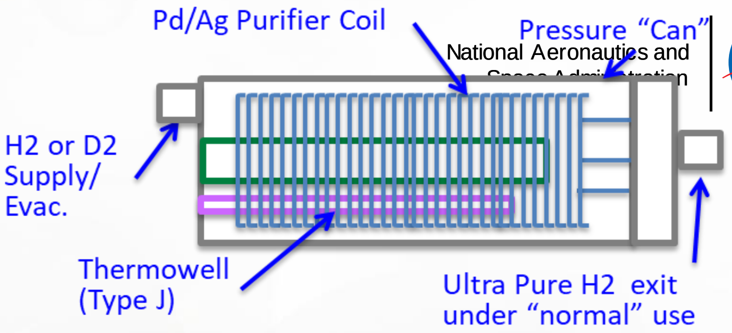
**Part B:** High Fuel Density
(billion times more dense than traditional fusion)

**A + B (+ trigger) = Viable Fusion**



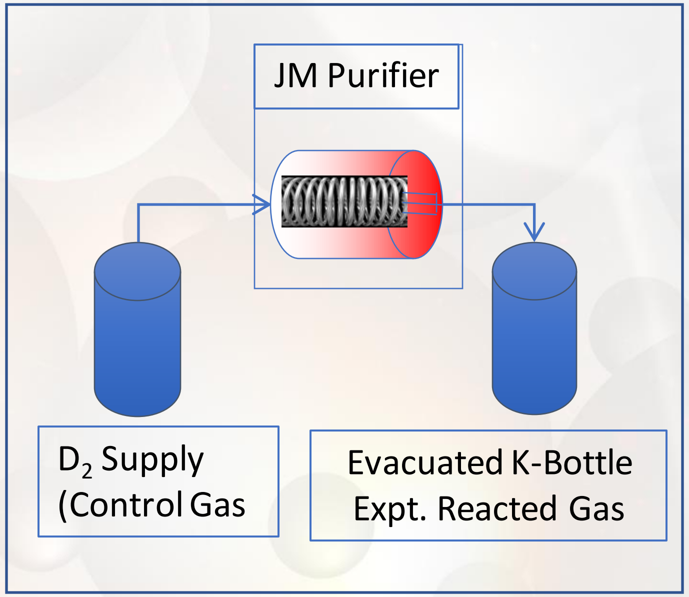
# J-M Gas Cycling Experiments: Description




**Schematic of H2 Purifier**
Anomalous Heat observed: flux of Deuterium (D2);
Temp Rise: 2009: °5 C; 2012: 25°C during unload

## 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

[1]G. Fralick, et al, "Transmutations observed from pressure cycling palladium silver metals with deuterium gas", International Journal of Hydrogen Energy, vol. 45, no. 56, pp. 32320-32330, 2020.
[2]B. Liu, et al, "Nuclear transmutation on a thin Pd film in a gas-loading D/Pd system," J. of Condensed Matter Nuclear Science, 13, pp. 311–318, 2014.

# Timeline of NASA Events

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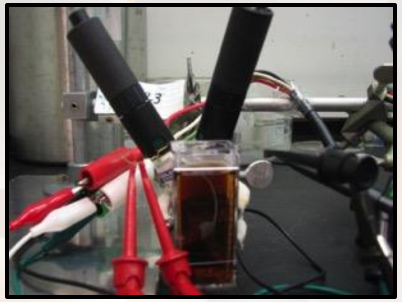
- Several groups at NASA (LaRC, MSFC and GRC) followed various LENR researchers including Pons/Fleischman, Nagle, and Rossi (1989 to 2011)
  - Discussed and reviewed various approaches
- With GRC R&D management approval, Robert Hendricks (GRC) organized a LENR/Innovations Workshop held on Sept 21, 2011 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?

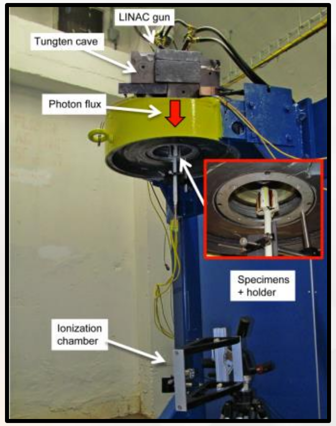
**Hydrogen Purifier**
D-flux in PdAg tube system: heating, transmutations



**Slow Co-Deposition**
Confirm nuclear activity

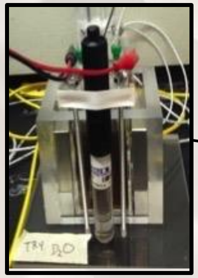
**SEM/e-GunExposure**
Activation of TiD2 + D-PE

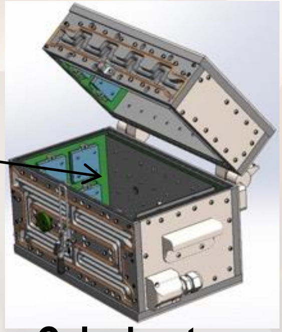

**X-ray Exposure**
Activation of TiD2 + D-PE




**LINAC Exposure**
100% Activation: HfD2/Mo/D-para

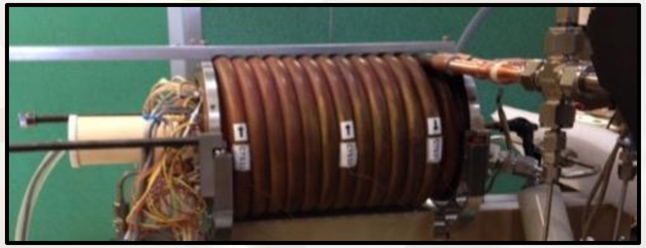
**Electrochemistry**





**Cell** **Calorimeter**

**Plasma + Calorimeter**



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

# Scanning Electron Microscope (SEM)
# Energetic Electrons Into Deuterated Targets

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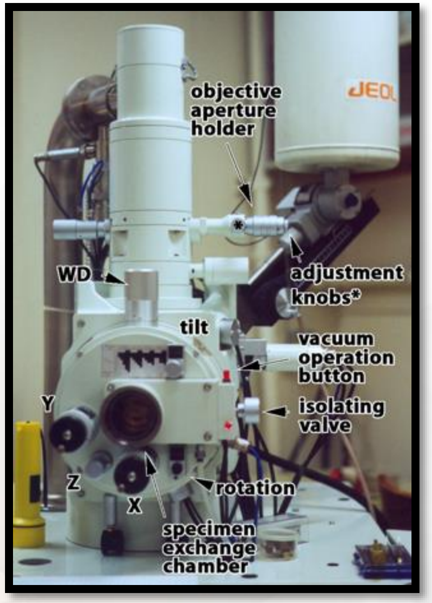
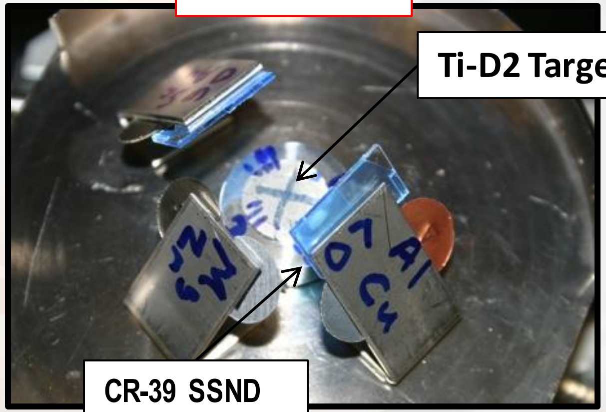
## Objective

- 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

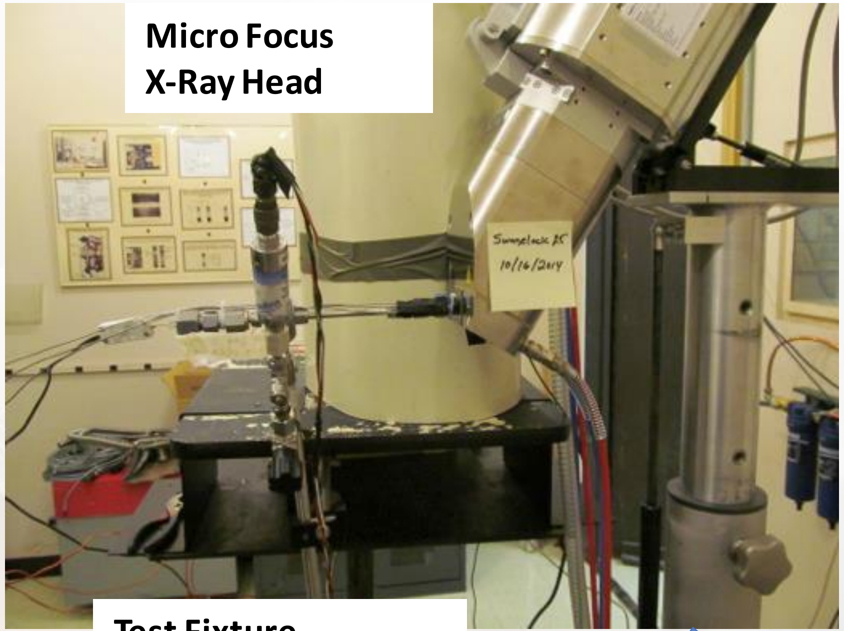


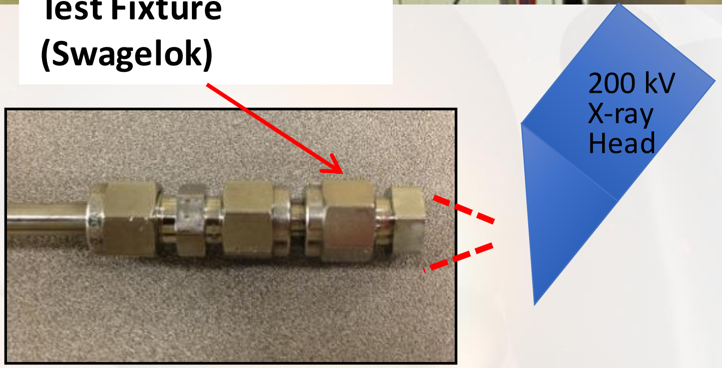
## Objective

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

## Findings

- Exposure of mixture of $TiD_2$ 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




Ref D-Fuel Number Density:
$TiD_2$: $10^{23}$ atom/cm3; D-PE 0.7x $10^{23}$ atom/cm3

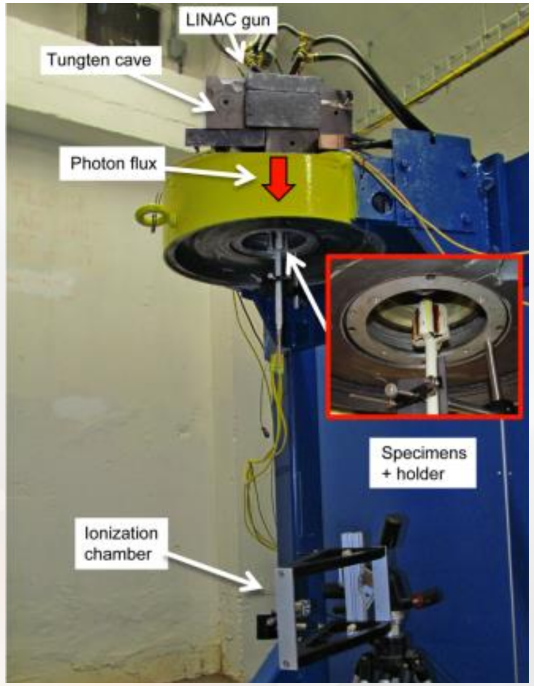
Benyo et al, 2015, NASA TM-2015-218491

# Linear Accelerator (LINAC) Volumetric Electron Screening Via Gamma Photons



## Objective

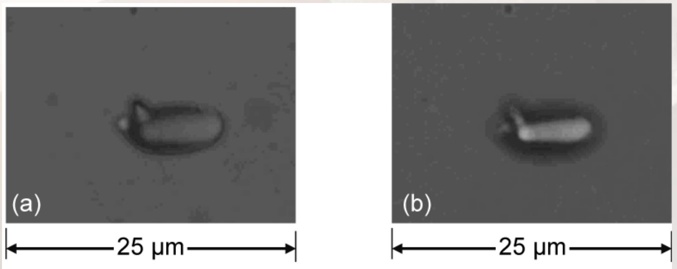
- Investigate volumetric screening of deuterated targets exposed to gamma-ray photons at sub-threshold energies (<2.226 MeV D-photo-dissociation)




## 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

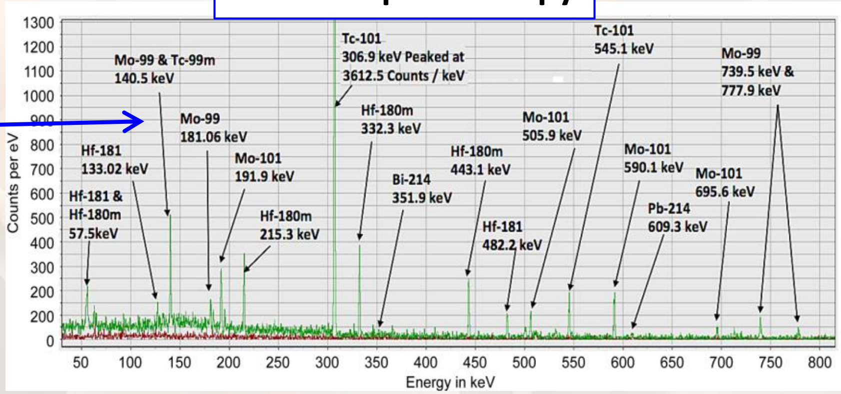



**CR-39 Triple track**

**Comparable to D-T fusion neutrons**

**Gamma Spectroscopy**

**Mo-99/ Tc99m**




Steinetz et al, 2017, NASA TM-2017-218963

# Plasma Reactor
# Delivery of Ions/Energetic Electrons Into Deuterated Targets

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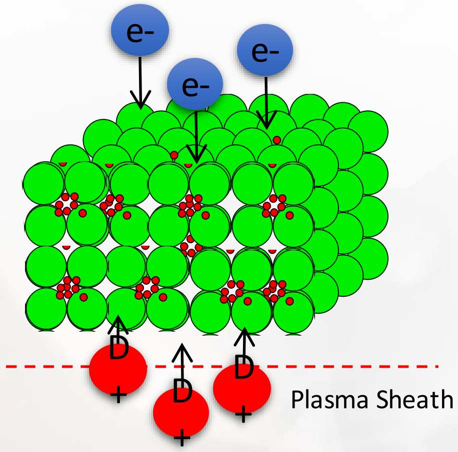
## Objective

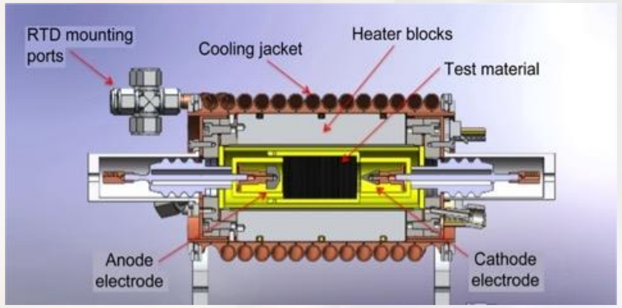
- Investigate dynamic loading of D+ and screening electrons into deuterated targets with customized microstructure

## Findings

- Tests with $TiD_2$ powder showed $P_{excess}$ ~4 W
- Tests with PdAg showed $P_{excess}$ ~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 ~20-30%; need to better understand mechanisms
  - Planned Design of Experiments: gain understanding of key variables and interactions




**Deuterated Metal Lattice**
(e.g. Pd-D, TiD2, Ni-D)




**Plasma Reactor B (B105)**
Central Ni foam+ Coatings+ Silica Spacer assy

Colozza et al, 2016, NASA TM - Internal draft report

# Electrochemistry
# Dynamic In-Situ Creation of High-Density Deuterated Microstructure

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**Collaboration Partner: US Naval Surface Warfare, Dahlgren Division**

## Objective

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

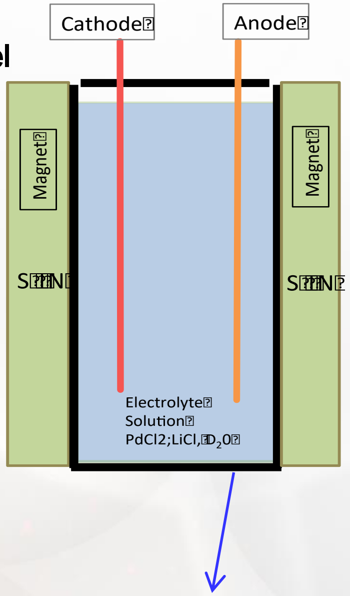
## Approach

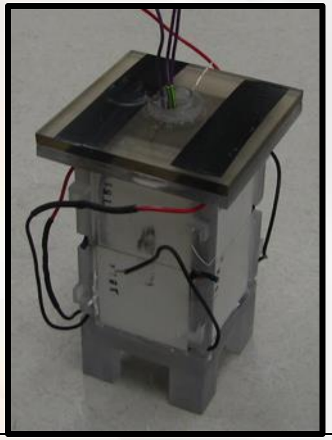
- Fast Pd/D/Li Co-deposition Protocol[1]
  - Heavy water ($D_2O$) or light water ($H_2O$) control electrolyte; 40-hour run
- Calorimetry[2]
  - 100 mW sensitivity, calibrated against both $H_2O$ and $D_2O$

## Findings

- $H_2O$ cells no heat, perpendicular magnetic field $D_2O$, no excess power
- 6 out 7 $D_2O$ 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 $D_2O$ (e.g. Zn > 20%)

Anti-parallel B-field



E-Chem Cell w/integrated TEG for calorimetry (Navy Dahlgren)

[1] Letts, D. and Hagelstein, P., "Modified Szpak Protocol for Excess Heat", *J. Condensed Matter Nucl. Sci.* **6** (2012)
[2] US Patent #8,419,919, "System and Method for Generating for Particles"
[3] Dahlgren Division, "Novel Energy Source Program", *Naval Surface Warfare Center,* (2016)
[4] Smith, P., Hendricks R. C., and Steinetz B. M., "Electrolytic co-deposition neutron production measured by bubble detectors", *J. Electroanal. Chem.,* **882** (2021) 115024

# LCF basic research has demonstrated nuclear reactions

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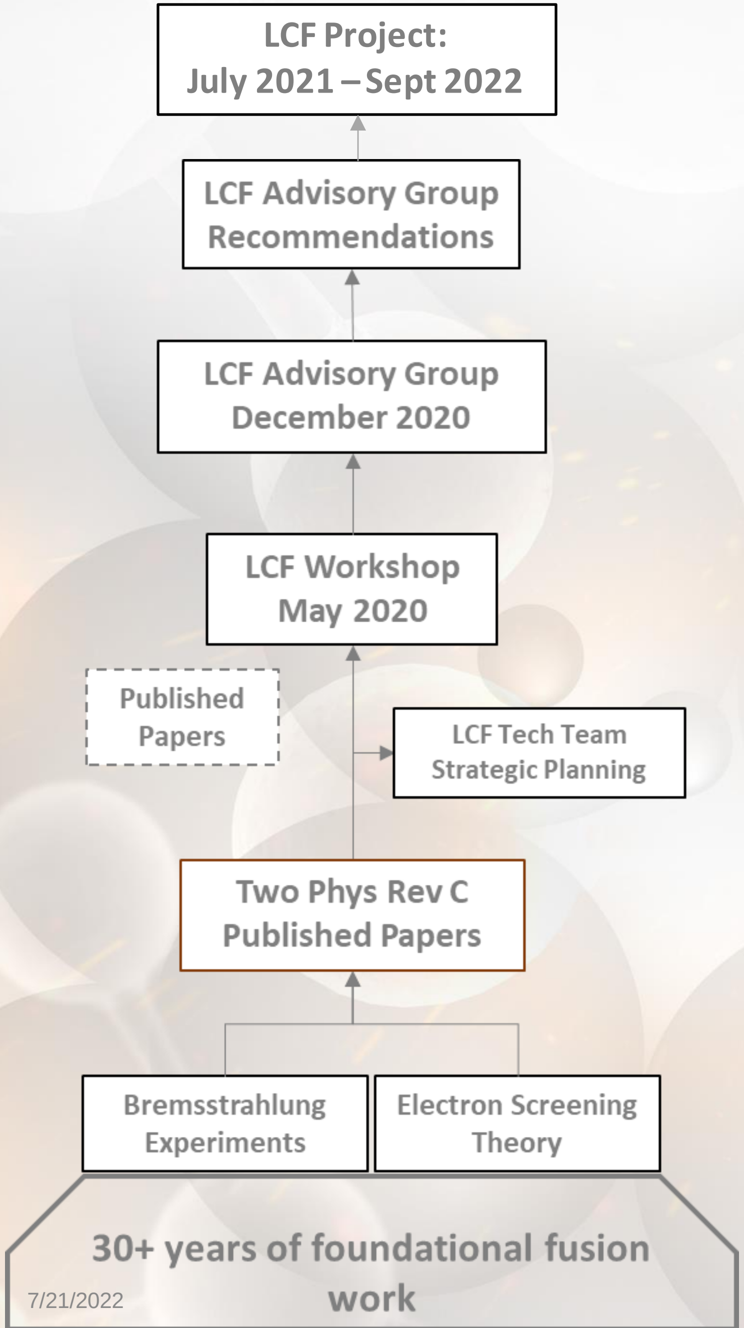
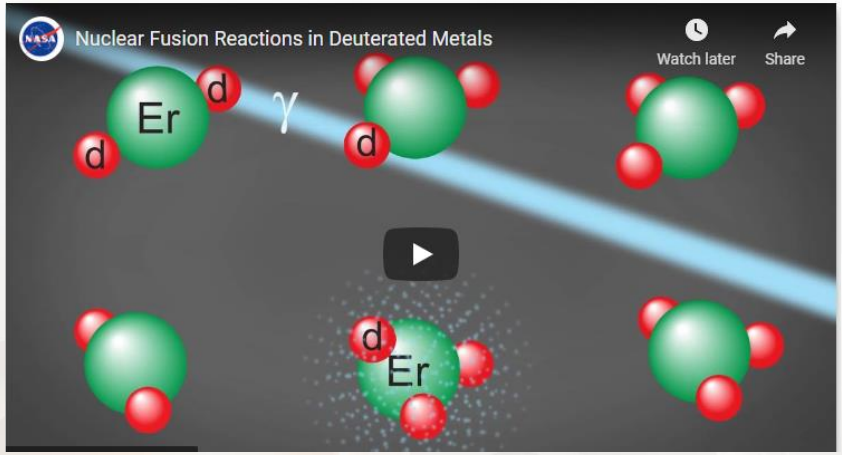
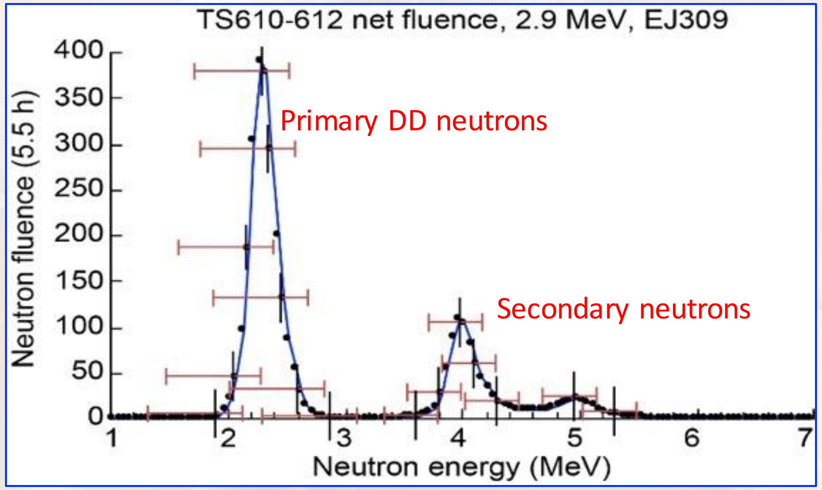
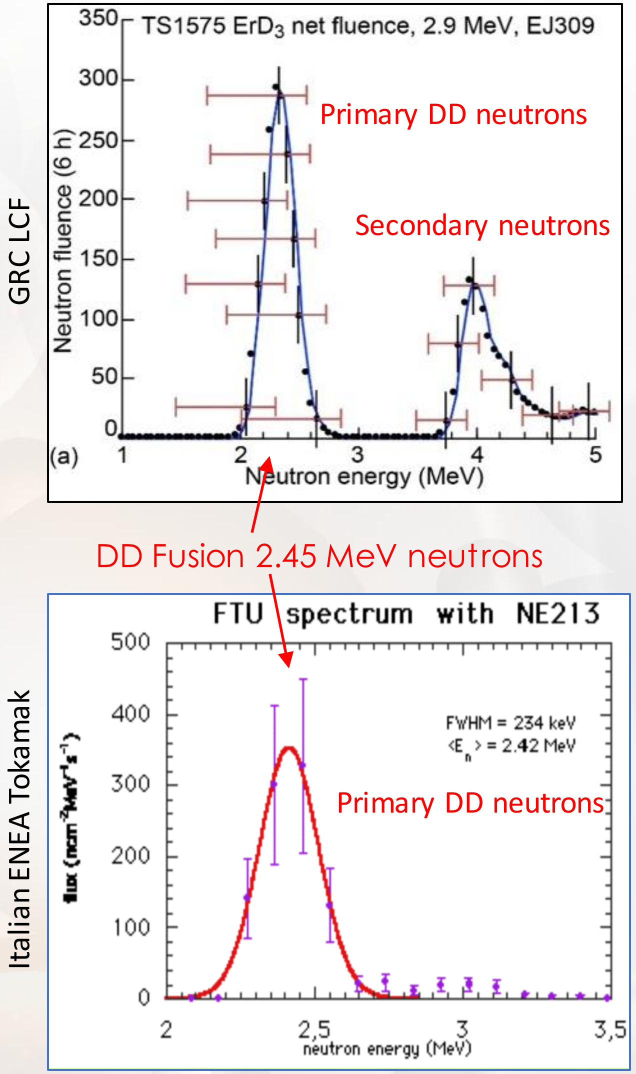



## Observation of D-D fusion and secondary nuclear reactions with $TiD_2$




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



# The Path: Electron Screening

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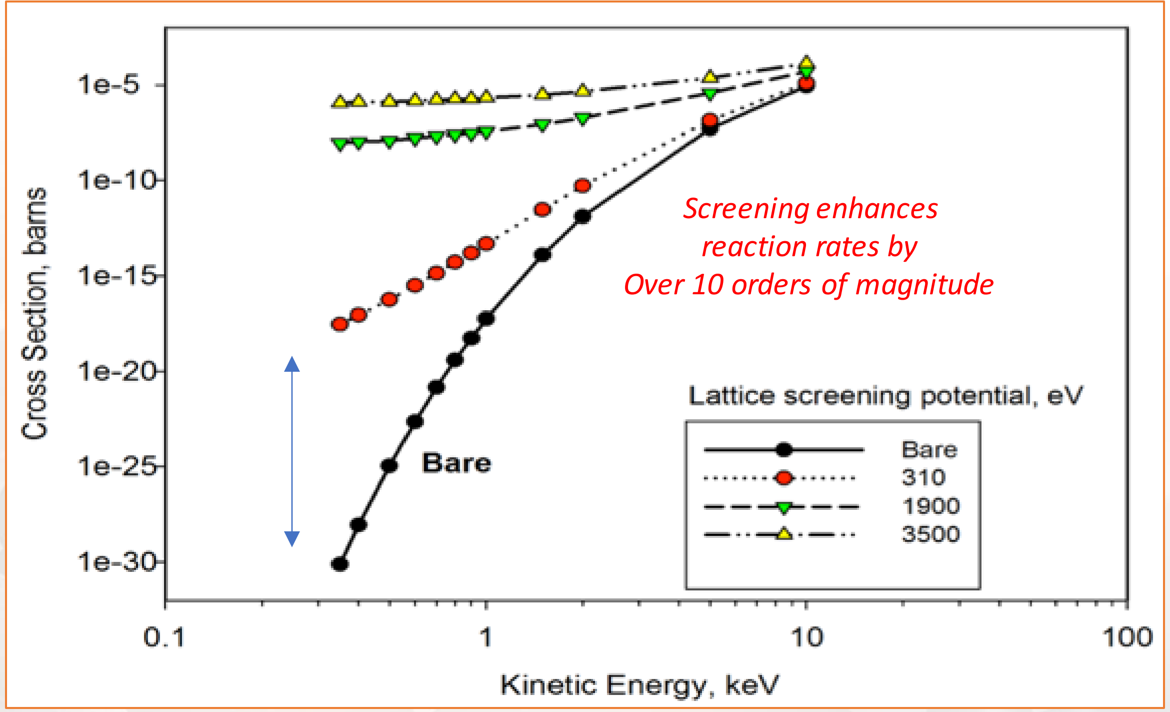
- Electron screening results in a *more transparent Coulomb Barrier*, *shifting the Gamow Factor,* as if deuterons were at far higher energies.
- This exponentially increases fusion rates.
- Laboratory astrophysics using accelerated deuteron beams across the Periodic Table show lattice and plasma screening 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.




***Electron Screened Enhanced Cross Sections***

***However, screening is only effective below 10 keV.***

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

# 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