ICCF24 Solid State Energy Summit

LENR SHORT COURSE 2022

Plasma Loading

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National Aeronautics and
Space Administration

Plasma Loading and Nuclear Reactions in Condensed Matter

ICCF-24 Solid State Energy Summit Workshop

July 25-28, 2022

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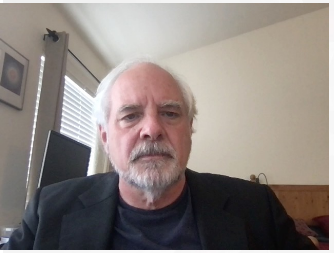

Outline

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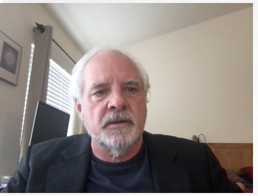
1. Context
2. Overcoming the Coulomb Barrier
3. Plasma Loading Considerations
4. Case Studies
5. Common Characteristics and Measurement Difficulties
6. Electron Screening
7. Summary
8. Conclusion

This talk isn't exhaustive but is representative of plasma loading research, analyses and considerations.



Context

There is a distinction between aneutronic LENR reactions and hot fusion reactions. Either may occur within or near a lattice and both may occur in a given system.

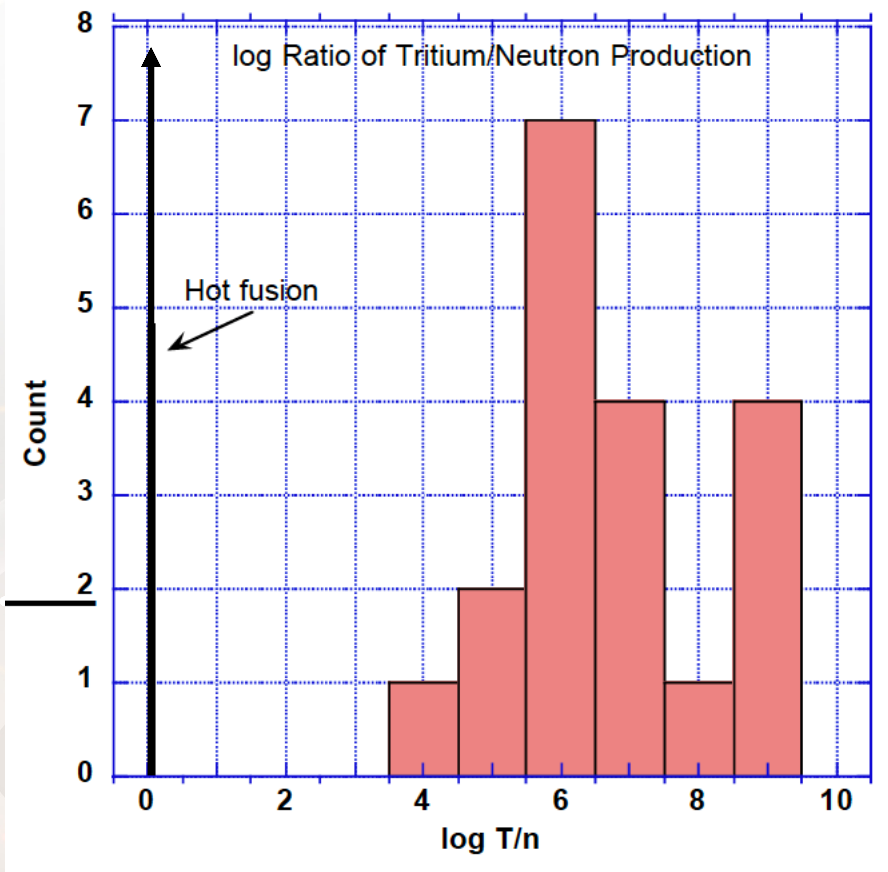
Both are seen in plasma loaded and triggered LENR. Plasma loading is an experimental way to load hydrogen isotopes into a metal lattice and potentially trigger nuclear reactions.

Helium-4 ($^4He_2$) and tritium (T or $^3H_1$) are indicative of largely aneutronic LENR reactions.

Fast neutrons and protons, ^4He and T are indicative of hot fusion reactions.

Fission reactions are observed with non-actinides (no uranium).

"Unlike the near-vacuum of HF [Hot Fusion], the ambient environment of cold fusion is the lattice, which is a dynamical system capable of storing and exchanging energy."[1]



Tritium to Neutron Production[2]

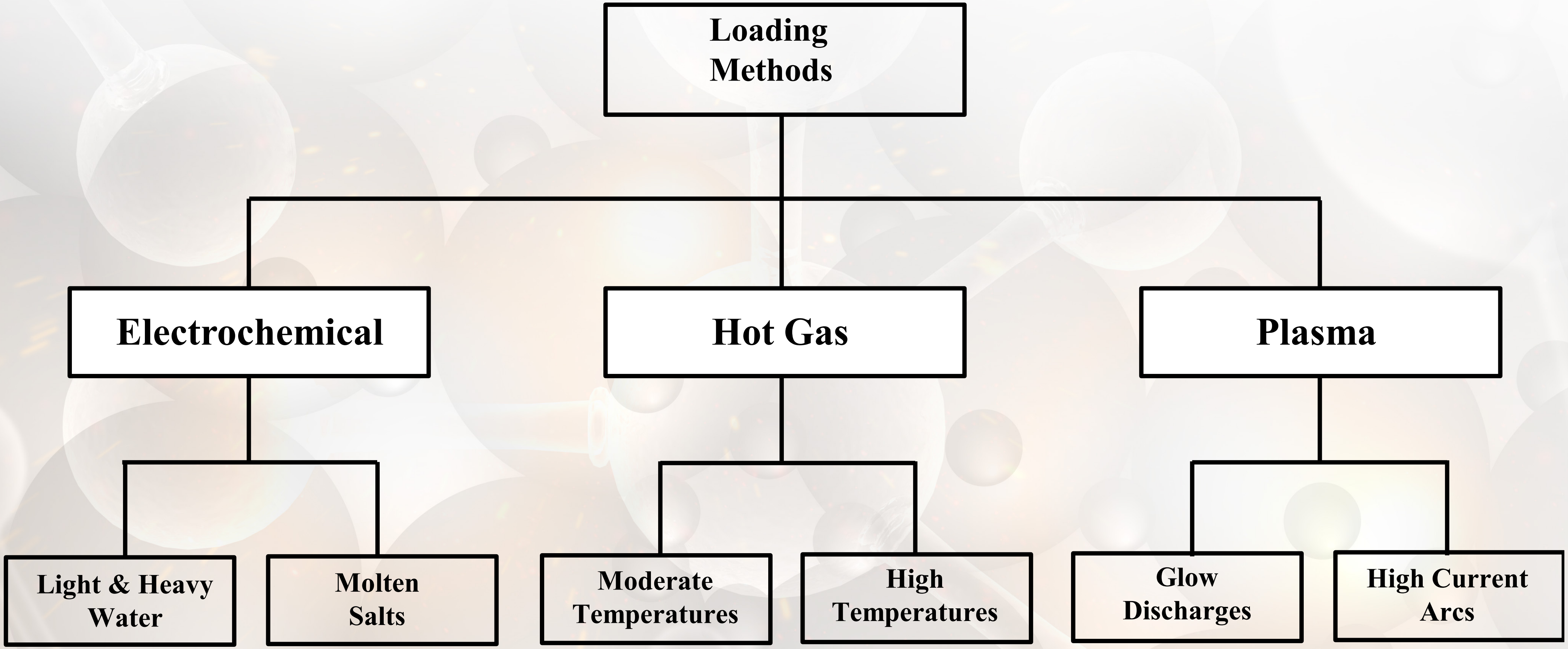
Hot fusion observes T/n ratio of 1 vs 10^6

[1] J. Schwinger, "A Progress Report: Energy Transfer in Cold Fusion and Sonoluminescence", *Infinite Energy*, **24,** (1999) pp 19-21

Schwinger shared the Nobel Prize in Physics in 1965 for his work on quantum electrodynamics (QED), along with Richard Feynman and Shin'ichirō Tomonaga.

[2] Storms, "The Nature of Cold fusion (Cold Fusion Made Simple)", *ICCF-24*, (July 24-28, 2022)

Hydrogen Isotope Loading and Triggering[1]

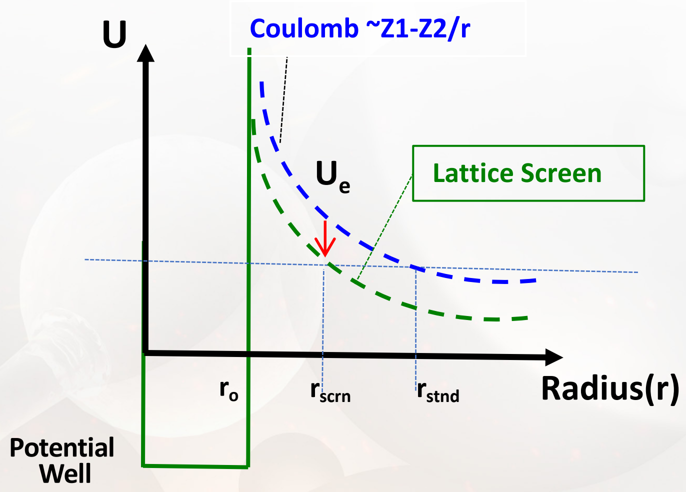


[1] loading method chart provided by D. Nagel.

Overcoming the Coulomb Barrier

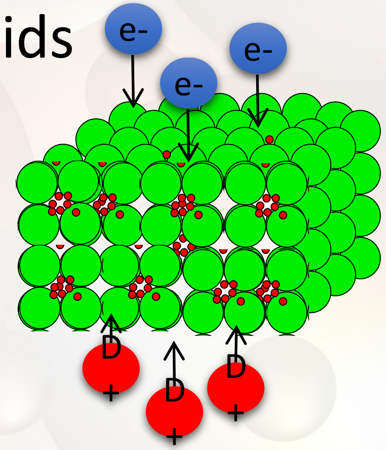
Like charges repel one another preventing nuclear reactions

- Electron Screening
  - Lattice screening
    - Enhanced Gamow factor *f(E)* (fusion probability)
  - Deep screening
    - *Glow Discharge or Plasma Ion source*
    - X-ray and gamma photon source
- Quantum "cold" plasma
  - Hydrided metal conduction bands are Fermi degenerate, supporting a cold plasma
  - Creation of special microstructures (super dense deuteron clusters)
- Neutral nucleus
  - Weak force mediated electron capture leading to quark conversion
    - p-e^--p and p-e^--d reactions
    - *Proposed by many researchers*



Condensed Matter Nuclear Reactions

- Fusion and related nuclear reactions at low energies
- Rates potentially enhanced by
  - Near/greater than solid state fuel density (> 10^{21}-10^{23} atoms/cm^3)
  - Presence of metal lattice for electron screening
  - Near Fermi Degenerate Electrons: “*Cold” Plasma!*
  - Presence of Nuclear Active Environment (NAE) Nano-voids
  - Flux of energetic electrons, H+ and/or D+
  - E- and B- Fields
  - Reaction multiplication (scaling) through:
    - Kinetic heating?
    - Nuclear cascades?
    - nuclear phonon-coupling[1]?
    - Microstructures?



[1] P. Hagelstein has modeled nuclear-phonon coupling and conducted experiments with F. Metzger following up on A. Karabut’s electric discharge experiments.

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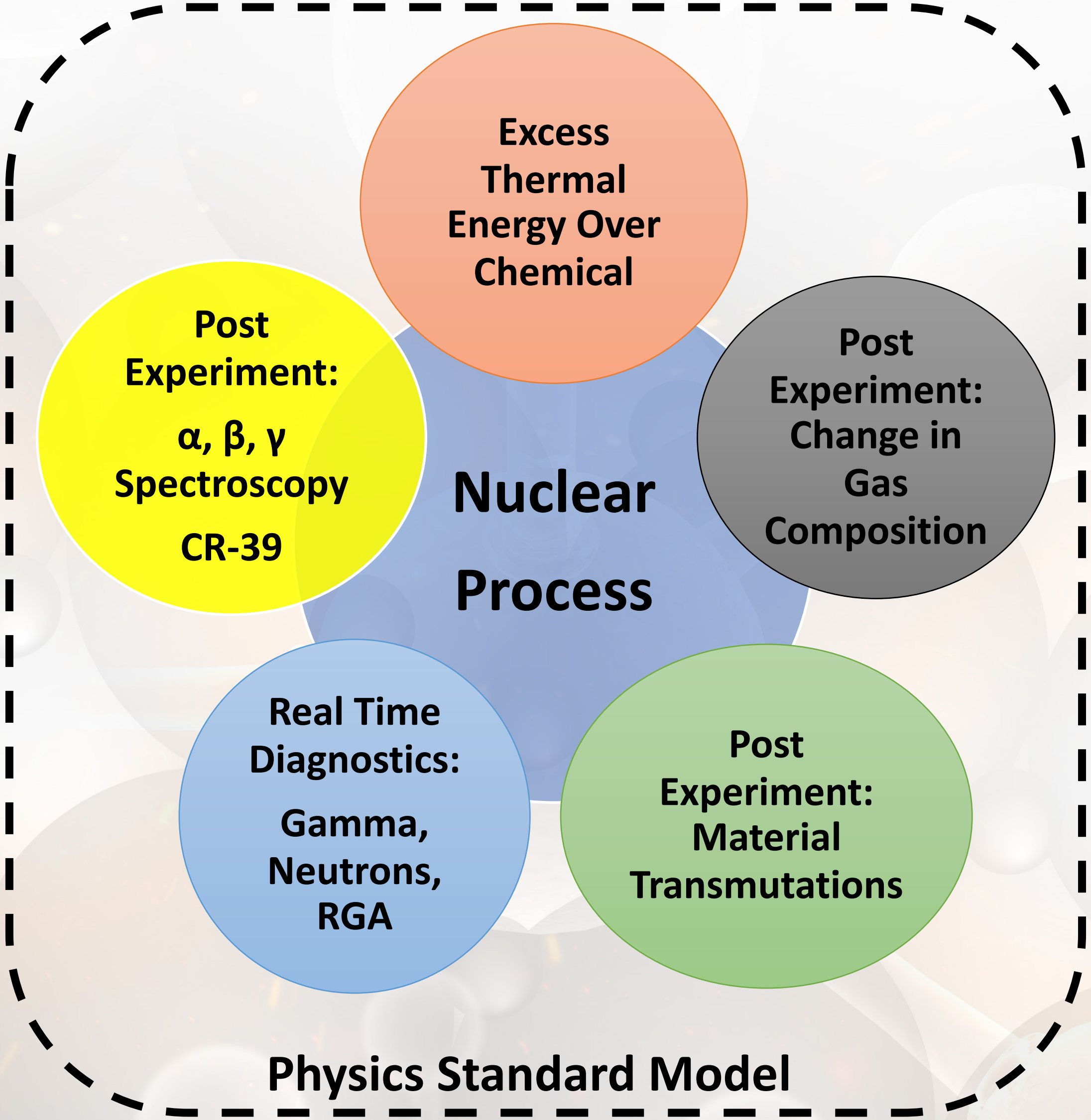
Orthogonal Diagnostics

HPGe and NaI(Tl)
Liquid Scintillator Spectroscopy
Solid State Nuclear Track Detectors

HPGe and NaI(Tl) gamma
Geiger Mueller
Residual Gas Analyzer (RGA)
Neutron spectroscopy
Charged particle spectroscopy
Neutron counting
Optical spectroscopy



Calorimetry vs thermometry

Hydrogen isotopes, H, D and T
noble gasses

SEM/EDS, TOF-SIMS, ICP-OES
ICP-MS

Plasma Loading Considerations

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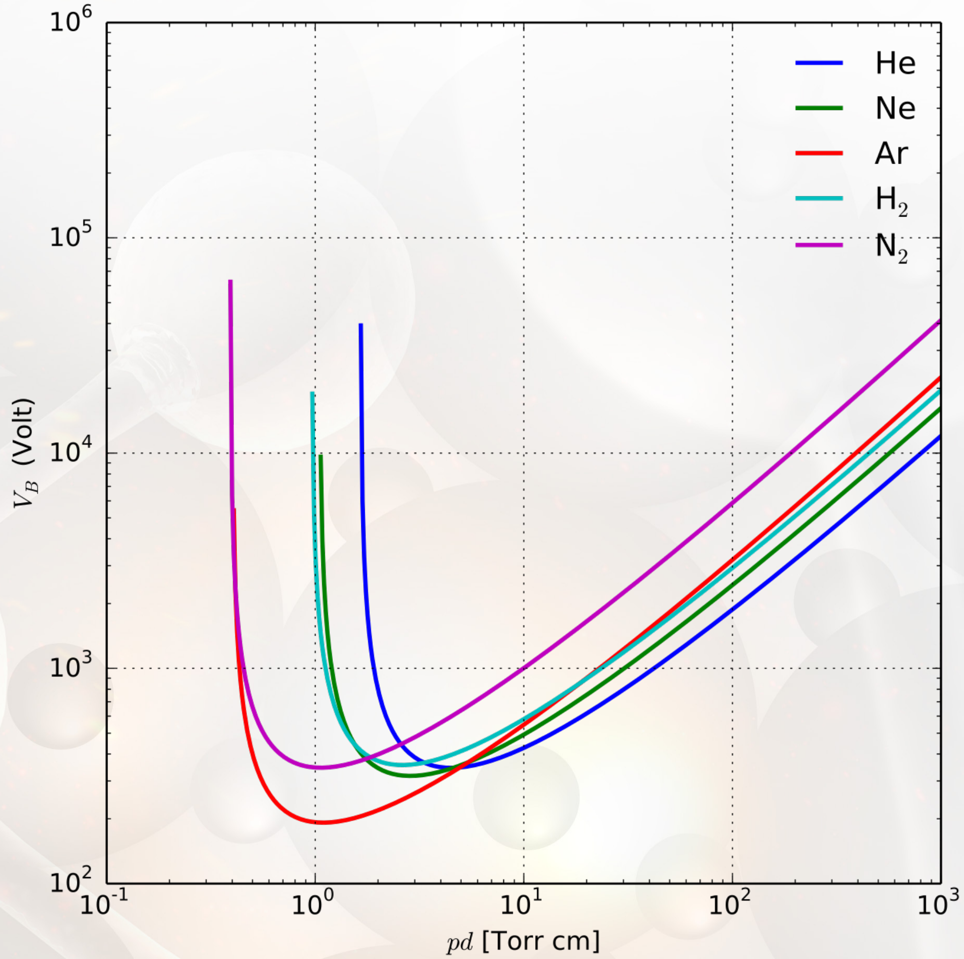
- Plasma is the 4th State of Matter with ions and electrons forming a “neutral” gas
- Results in a highly non-equilibrium system with:
  - *Increased hydrogen isotope concentration*
  - *Increased number of resident electrons*
  - *Localized heating*
  - *Induced electron and hydrogen isotope flux*
- Secondary resonant effects with time-varying capacitance and inductance
  - *Short time-scale lattice/fuel interaction*
- Induced defects through scattering
  - *Sites for nuclear reactions*

Paschen curves for 5 gasses[1]



Modeling Approaches[1]

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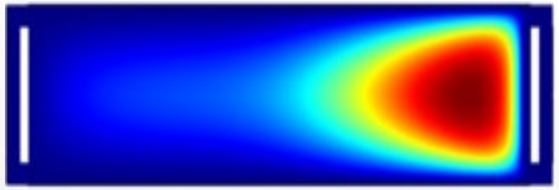
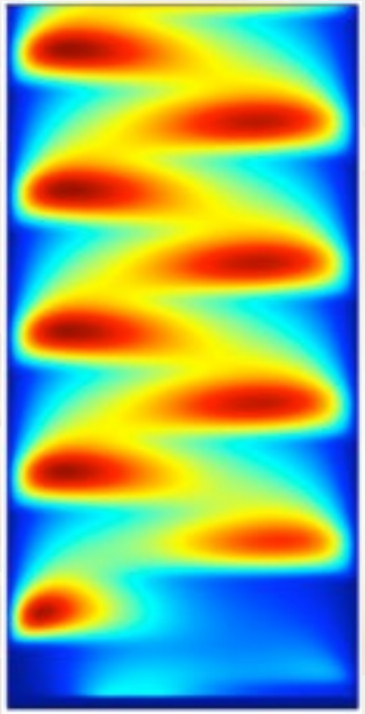
- **First Principles/Analytic**
  - MATLAB/Mathematica (Plasma)/SPICE(Circuit)
  - Zero’th to First order behavior
  - Incorporates observed power supply characteristics and circuit interactions
- **Detailed Physics**
  - Commercial:
    - COMSOL Plasma Physics Package



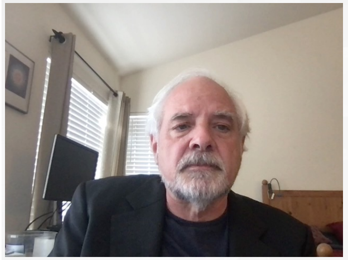
DC GLOW DISCHARGE: Electron density along a cylindrical Argon glow discharge at 100 V.



DIELECTRIC CURRENT DISCHARGES: A small gap is filled with a gas between two dielectric plates. Voltage is applied so that any free electrons will be accelerated and cause ionization.

COMSOL Plasma Physics Package

[1] J. Gilland and T. Gray, NASA Advanced Energy Conversion Project



Plasma Discharge[1]

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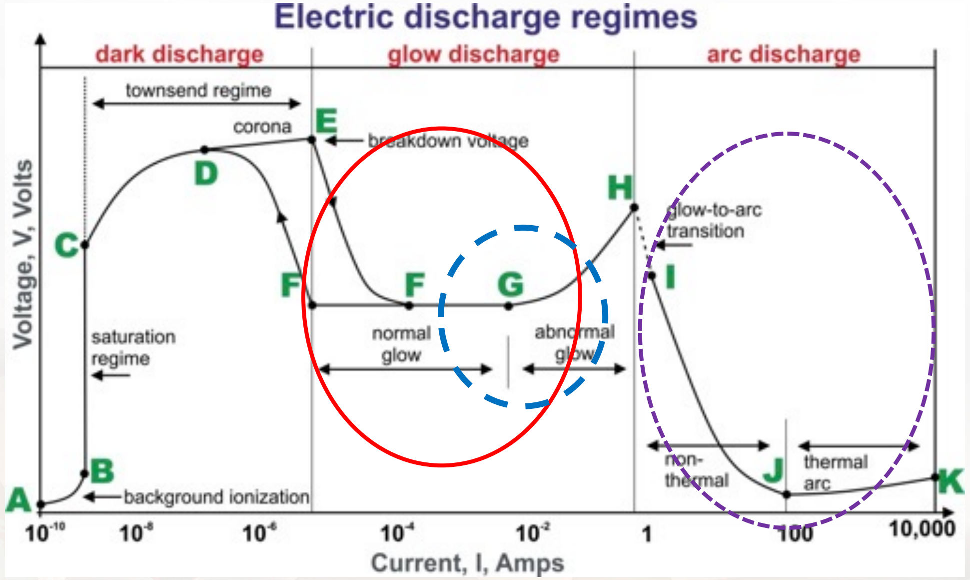
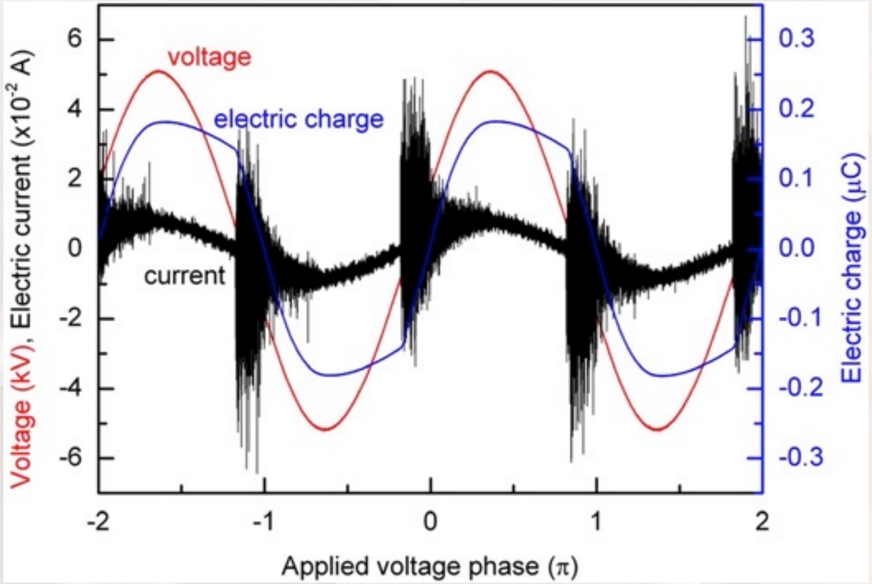
- **Plasma Experiments span range of possible discharges**
- Glow
- Dielectric Barrier
  - Streamers
  - Continuous
- Arc/Spark



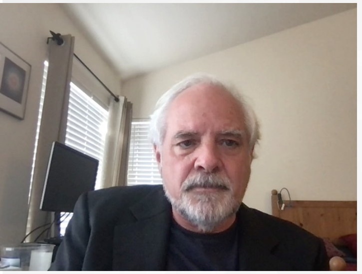
Source/circuit interactions

- Discharge chamber is part of overall circuit
- *System capacitance, inductance may result in resonances with pulsed power to cause high power discharges and radiated noise*



[1] J. Gilland and T. Gray, NASA Advanced Energy Conversion Project

Phys. Plasmas 20, 083509 (2013); doi: 10.1063/1.4818795



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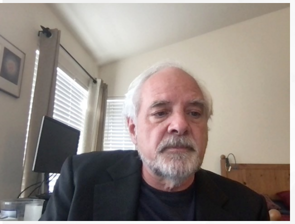
Case Studies

1. Claytor, *et al., Los Alamos National Lab, & Coolescence, US*	*Tritium, excess power*
2. Karabut, *LUCH, Russia*	
1. Glow Discharge	*x-rays, excess power*
2. High Voltage Electrolysis	*x-rays, excess power*
3. Storms, *Kiva Labs, US*	*x-rays, charged particles*
4. Savvatimova and Gavritenkov, *LUCH, Russia*	*x-rays, transmutation, excess power*
5. Lipson, *et al, Academy of Science, Lebedev, LUCH, Russia*	*Fusion protons, alphas, x-rays*
6. Godes and Tanzella, *Brillouin and SRI*	*Excess power, ^{64}Ni enhancement, Tritium*
7. Schenkel, *et al., Lawrence Berkeley National Lab*	*Fusion neutrons*
8. NASA Glenn Research Center	
1. Plasma Reactor A	
2. Plasma Reactor B	*Tritium*



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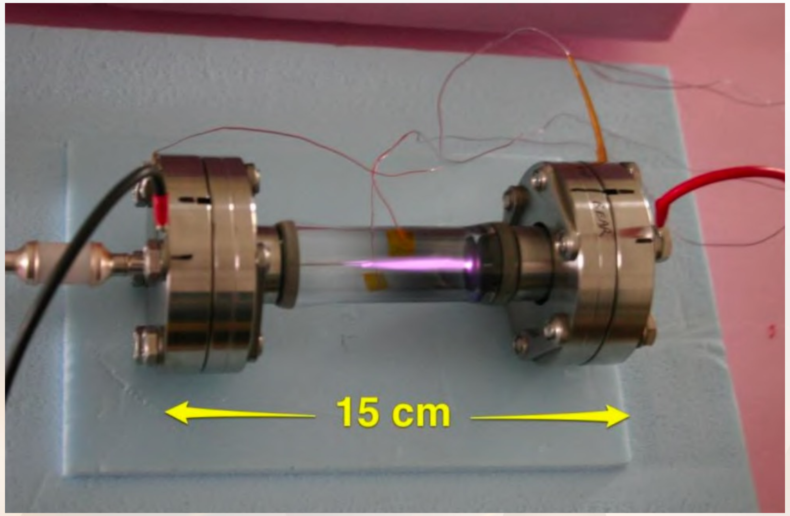
Claytor (LANL) et al.: Glow Discharge, Helium and Tritium[1]



Operation
- 150-250 torr D2 and H2
- 900-1300 V
- 5-10 A
- 5-20 µs pulse, 50-100 Hz
- Constant power
- Sample V&I @100 Msamples/sec, 14 bit

Successful Materials
- Ni, Ni alloy
- Pd/ alloys
- Pt

Electron Screening"
- Pd 800 eV
- Pt 670 eV
- Ni 380 eV

1 eV = 11,000°K
Cold Plasma!

Observations

Tritium: Femtotech
- with 20% D2: .2 – 1 pCi/hr

Excess Power:
- with Ni alloy 1.5%

Helium: Finnigan 270
- ^{4}He
  - BG: D_2 gas: 90 ± 30 ppb
  - $H_{.24}D_{.75}$: 400 ppb 4x Background
- ^{3}He
  - BG: D2: < 1 ppb
  - $H_{.24}D_{.75}$: < 200 ppb 200x Background

Conclusions
- Ni Alloy is reproducible
- Tritium can be several sigma > background
- Effect can be obtained in 1-2 days
- Excess heat is small but consistent with ^{4}He data
- Inherent electron "shielding" (screening, U_e) significant factor

[1] T. N. Claytor[a], M. M. Fowler[a], D. G. Tuggle[a], R. Cantwell[b], M. McConnell[b], "Search for Excess Heat and Tritium in Nickel Alloys Exposed to Pulsed H/D Plasmas", *International Low Energy Nuclear Reactions Symposium, ILENRS-12* (July 1-3, 2012) William and Mary Univ., Virginia (July 1-3, 2012)
[a] Los Alamos National Laboratory; [b] Coolescence, LLC

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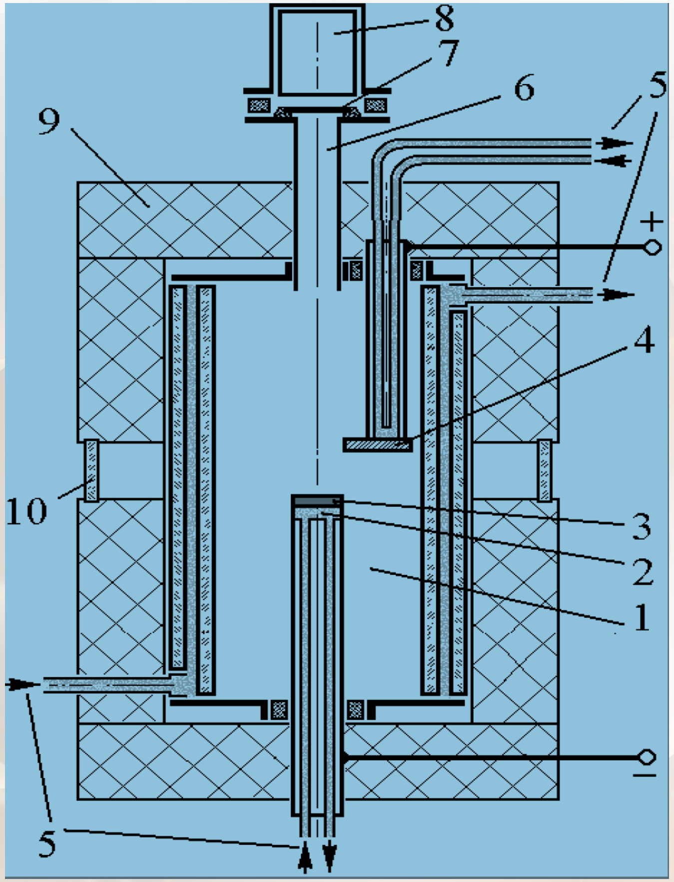
Karabut (LUCH): Glow Discharge Apparatus



Glow Discharge

Glow Discharge Device (flow calorimeter)

1 – vacuum discharge chamber
2– cathode holder unit
3 – cathode sample
4 – anode unit
5 – input and output of the water-cooling system
6– X-ray emission output channel
7 – 15 Be shield allowing x-rays
8 – X-ray detector
9 – heat insulation cover
10 – windows in the heat insulation cover

[1] A.B. Karabut, “Experimental Research on 0.5 – 10 keV High-Energy Process Resulting from H_2 and D_2 Ions Flux Interaction with Cathode Solid in Electric Discharge”, *7th International Workshop on Anomalies in Hydrogen/Deuterium Loaded Metals, ISCMNS, Catania, Sicily (October, 2007)*

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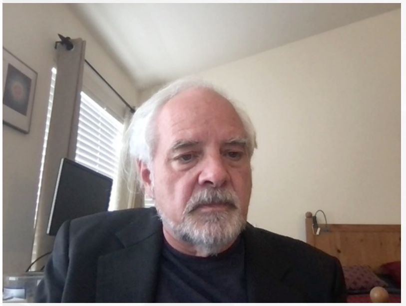
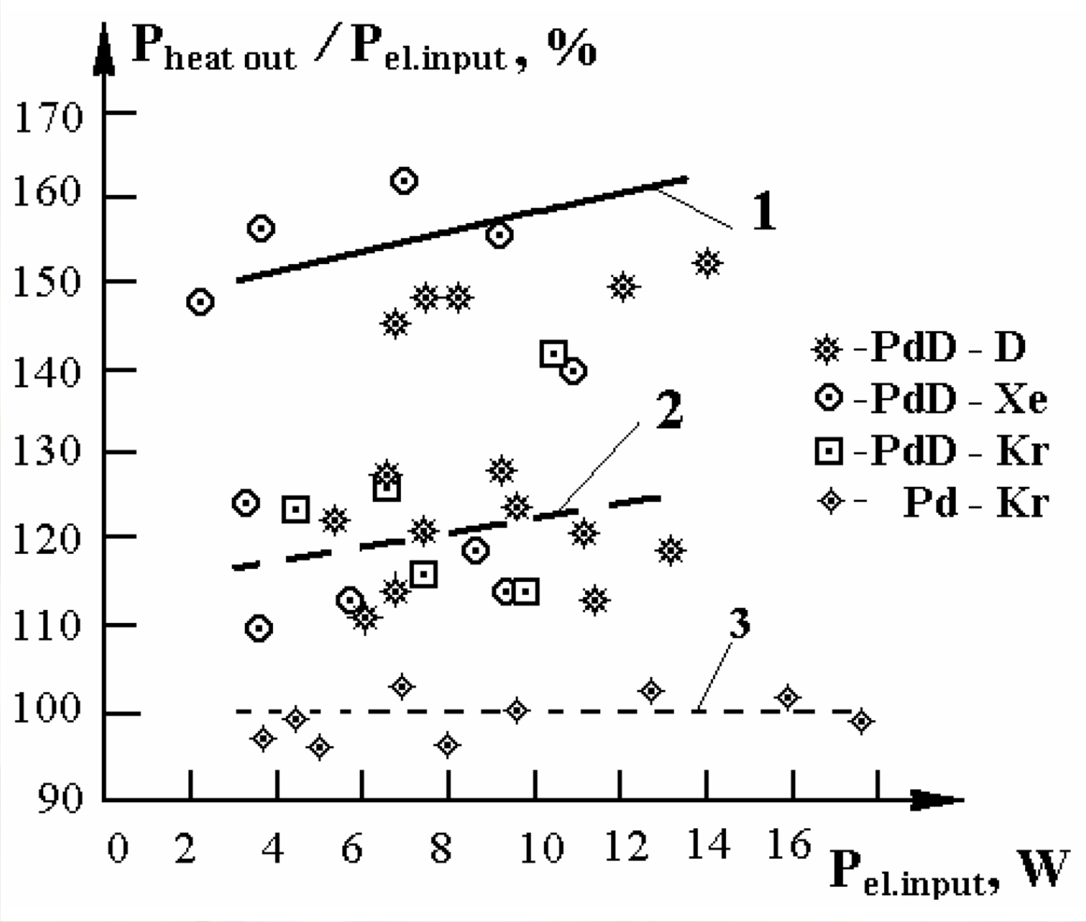


Karabut:
Glow Discharge: input to output power[1]



Output heat dependent upon input power

1, 2 - Deuterium pre-charged Pd cathode samples in D2, Xe and Kr discharges, current is 50 - 100 mA.

1 - optimal (1100 - 1300 V) Glow Discharge voltage,

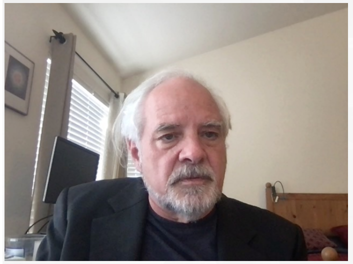
2 - not optimal Glow Discharge voltage,

3 - Not deuterium pre-charged Pd cathode, Kr discharge

Conclusion:

- Excess Heat Power 10 –15 W, efficiency to 150 %
  5 W/cm^2
  Pd cathode pre-charged with D2 in Xe and Kr
- ^4He and impurity nuclides in cathode with high-current

[1] A.B. Karabut, "Experimental Research on 0.5 – 10 keV High-Energy Process Resulting from H_2 and D_2 Ions Flux Interaction with Cathode Solid in Electric Discharge", *7th International Workshop on Anomalies in Hydrogen/ Deuterium Loaded Metals, ISCMNS, Catania, Sicily (October, 2007)*



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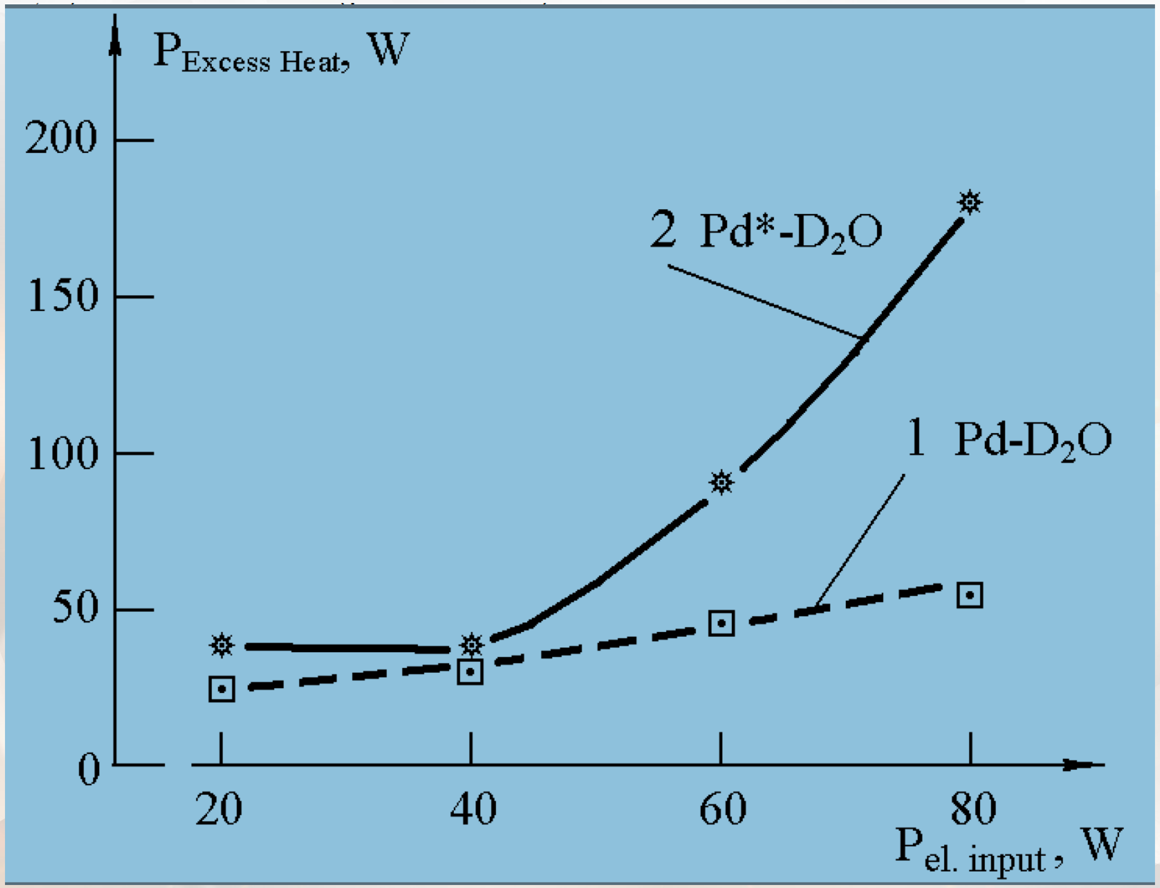
Karabut: Comparing Runs With and Without D Preloading



Excess Heat Power vs Input Electric Power

1 –electrolysis in D2O, Pd cathode
(not pre-treated Pd);
2 –electrolysis D2O, Pd cathode
(pre-treated Pd).

Conclusion:

Pre-loading of cathode with D enhances the excess power

[Value of preloading the cathode: introduction of defects?]

[1] A.B. Karabut, “Experimental Research on 0.5 – 10 keV High-Energy Process Resulting from H2 and D2 Ions Flux Interaction with Cathode Solid in Electric Discharge”, 7th International Workshop on Anomalies in Hydrogen/ Deuterium Loaded Metals, ISCMNS, Catania, Sicily (October, 2007)

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Karabut: Summary

Observations[1]

D(*d,p*)T, 3.0 MeV p^+

Pulsed D glow discharge on Ti cathode

V ranges {0.8–2.5 kV}

I ranges {300–600 mA/cm^2}

Estimated screening potential from DD proton yield:

I > 10^3 X!

U_e = 610 ± 150 eV with D_{KE} *ranges* {0.8 – 2.45 keV}

[comparable to accelerator values up to 800 eV]

Accelerator experiments: $D_{KElab} \geq 2.5$ keV

I ranges {50–500 μA/cm^2}

[more efficient low KE Gamow Factor enhancement measure]

Ti soft x-ray photons

range {1.2 – 1.5 keV}

$I_x = 10^{13} - 10^{14}\ s^{-1}cm^{-2}$,

Yield is strongly dependent on the deuterium diffusivity in or near cathode surface

[Near surface effect]

Raison d'etre?[1]

Non-equilibrium excited energy states with temperature of > 1.0 – 3.0 keV, may create long-lived LENR excited levels formed in the Pd cathode.

Energy Levels for the primary and secondary optic phonons:

0.8– 0.84 keV,

1.3 – 1.5 keV,

2.5 – 2.9 keV.

Result in a compound, excited Pd* nucleus with either:

1) Pd* de-excites -> Pd and ^{4}He.
2) Pd* splits into two nuclei fragments masses < Pd *A* (A=101-110) as excited isomers
   Experiments show nuclear *KE* is not given to fragments
   low neutron yield!
3) Pd*may lose its excitation and form stable nucleus with *Z* > Pd_{46}

[1] A.B. Karabut, "Experimental Research on 0.5 – 10 keV High-Energy Process Resulting from H2 and D2 Ions Flux Interaction with Cathode Solid in Electric Discharge", *7th International Workshop on Anomalies in Hydrogen/ Deuterium Loaded Metals, ISCMNS*, Catania, Sicily (October, 2007)

Storms (Kiva Labs): Glow Discharge, Energetic Particles[1] (and x-rays)

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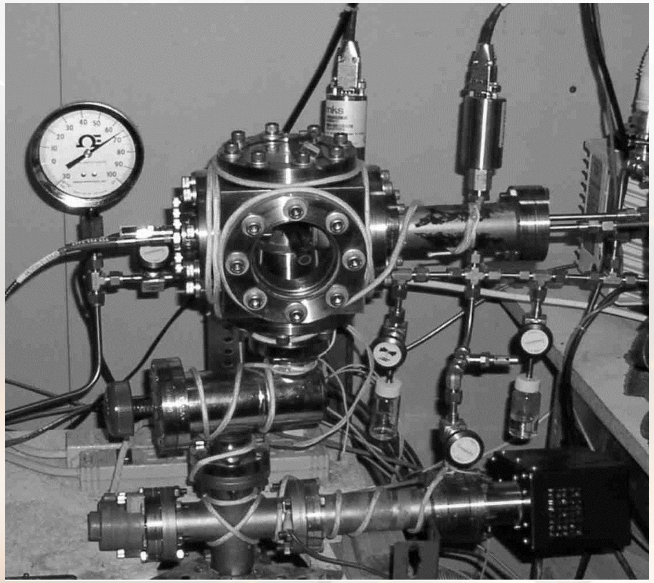
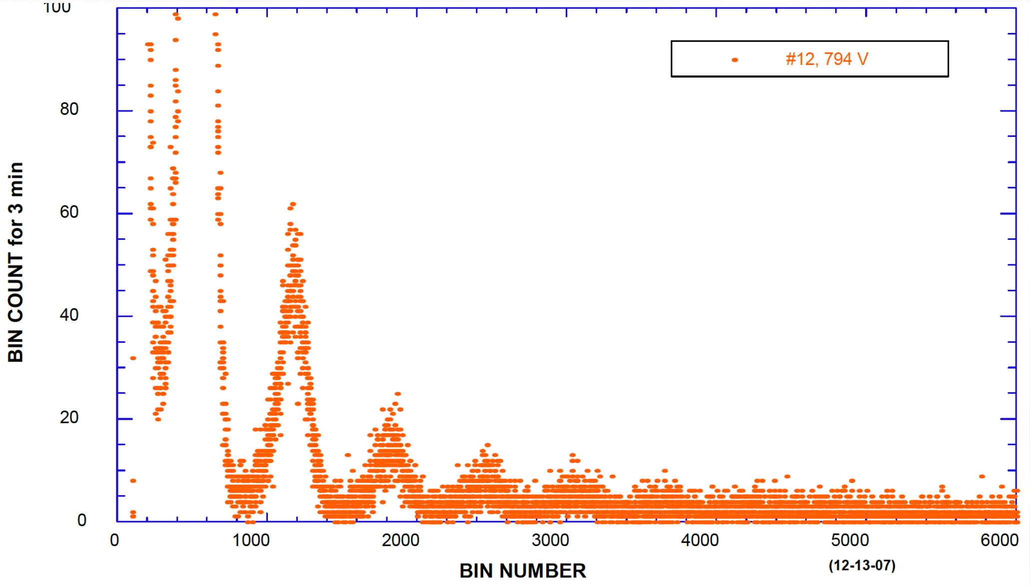
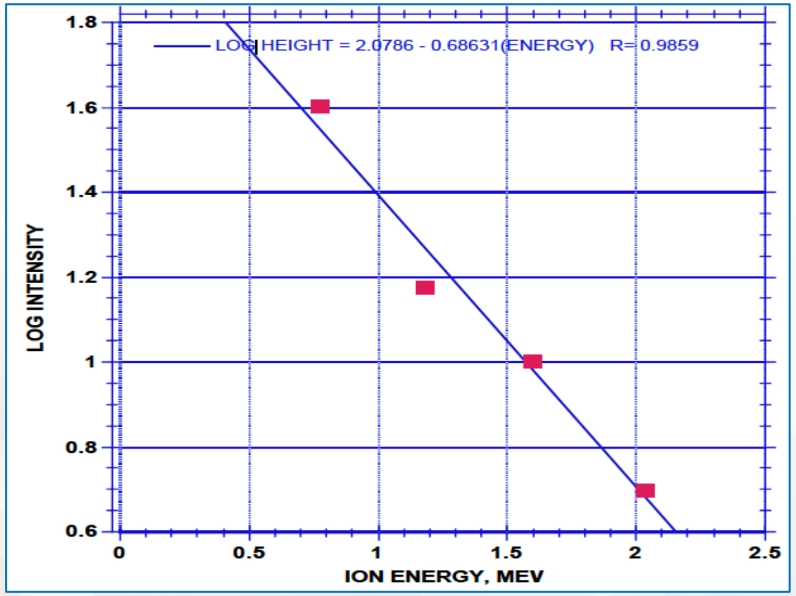


Glow Discharge Setup[1]



Silicon Surface Barrier (SSB) Detector Spectra[1]



Linear Energy Transfer ion energy loss[2]

Energetic ions were observed by both Storms (SSB) and Karabut[2] (SSB and Solid State Nuclear Track Detector: CR-39) with similar spectra.

Karabut assigns his as $^4He_2$ (α particles) whereas Storms indicates a $^4H_1$ is formed, detected, then decays by β emission to $^4He_2$ (α particles). Godes[4] also posits an $^4H_1$ intermediary that β decays and has also observed tritium, but not $^4He_2$.

These conjectures are based upon overcoming the Coulomb Barrier and the absence of fast neutrons *but with observed products*.

1. E. Storms and B. Scanlan, "Detection of Radiation Emitted from LENR", *ICCF-14 International Conference on Condensed Matter Nuclear Science*, Washington., DC. (2008).
2. E. Storms, "The Nature of Cold fusion (Cold Fusion Made Simple)", *ICCF-24*, (July 24-28, 2022)
3. A.B. Karabut, Y.R. Kucherov, I.B. Savvatimova, Nuclear product ratio for glow discharge in deuterium, *Phys. Lett. A* **170** (1992) 265-272.
4. R. Godes, "Brillouin Helium vs. Hydrogen Why the COP Goes Up Final Oct'20", https://drive.google.com/file/d/1GxaPzJ1HGuQzCgHLhDPA8jI-Vz7-u_NE/view

Savvatimova (LUCH): Glow Discharge Transmutation[1]

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Glow Discharge, 300 – 850 V in D2

Possible Transmutation products due to Fusion/fission reactions with Ti and Pd cathodes. *Inaddition other published results showed isotopic anomalies with PdD:*

> "$^{10}B/^{11}B$; $^{12}C/^{13}C$; $^{60}Ni/^{61}Ni/^{62}Ni$; $^{40}Ca/^{44}Ca$ and $^{90}Zr/^{91}Zr$ were observed and were published in paper [6]. The change of the isotope ratio for $^{109}Ag:^{107}Ag$ from 1:1 in the initial unused Pd up to 3:1 and in some cases 9:1. This was described in Refs. 7 - 9."[1]

> ^{4}He increased (10 – 100X) in a Pd cathode.[2]

noting:

> *"The observed effects can be explained by a fusion-fission reaction on the cathode. That is, by an interaction of palladium with deuterium, and by the subsequent decay into more light elements."[1]*

1. I. Savvatimova and D. Gavritenkov, "Results Of Analysis Of Ti Foil After Glow Discharge With Deuterium", *11th International Conference on Condensed Matter Nuclear Science*. Marseille, France. (2004).

2. I. B. Savvatimova, Y.R. Kucherov, A.B. Karabut, "Cathode Material Change After Deuterium Glow Discharge Experiments", *EPRI, Fourth International Conference on Cold Fusion,* Lahaina, Maui (1993).

Lipson (Russian Academy of Science)
Glow Discharge with TiD,, Fusion Protons[1]

Specific 3.0 MeV proton yield at different GD voltages <U>

<U>, [V]	<I>, mA	W_{m}, [W]	N(5.2μm), [cm^{-2}]	k(W,T)	$\langle N_p \rangle$, cps	<n/ε>, p/s in 4π	Y_p, [p/C]
805	250	201.3	30	2.2x10-3	2.6x10-6	4.7x10-4	1.9x10-3
850	225	191.3	28	1.6x10-3	1.8x10-6	3.3x10-4	1.5x10-3
1000	370	370	35	3.6x10-2	5.0x10-5	9.0x10-4	2.5x10-3
1145	370	420	54	5.3x10-2	1.1x10-4	2.0x10-2	5.3x10-2
1190	240	286	30	1.3x10-2	1.6x10-5	3.0x10-3	1.3x10-2
1435	250	359	50	3.3x10-2	7.0x10-5	1.3x10-2	5.2x10-2
1500	450	675	71	0.16	4.5x10-4	8.1x10-2	0.18
1647	300	495	62	8.3x10-2	2.1x10-4	4.0x10-2	0.13
2000	370	740	159	0.19	1.2x10-3	0.21	0.57
2175	250	544	252	0.11	1.1x10-3	0.20	0.80
2450	370	906.5	317	0.27	3.4x10-3	0.61	1.65

Proton
Yield
Increases
With
Voltage

Less on I
(current)
Or W
(power)

5.2 um CR-39 track measured against cyclotron-accelerated protons correspond to 3 MeV proton.

[1] Lipson, A.G., A.B. Karabut, and A.S. Roussetsky." Anomalous enhancement of DD-reaction, alpha emission and X-ray generation in the high current pulsing deuterium glow-discharge with Ti-cathode at the voltages ranging from 0.8-2.5 kV", *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science*., Tsinghua Univ., Beijing, China: Tsinghua Univ. Press (2002)

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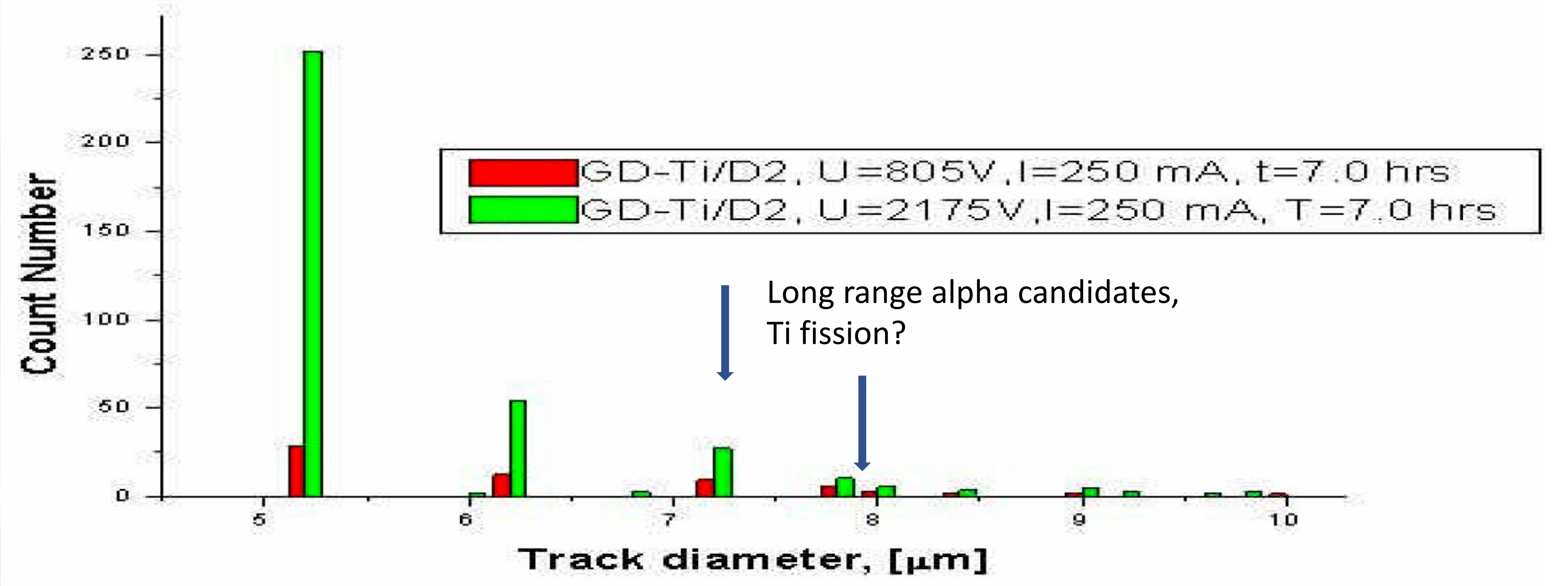
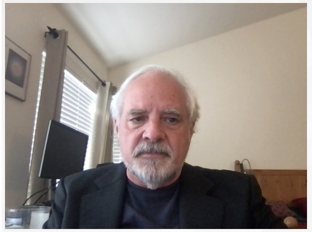
Lipson, *et al.*: Glow Discharge on TiD_2
Fusion Protons with CR-39 and "long range" alphas[1]



long range alphas are a sign of fission.

[1] Lipson, A.G., A.B. Karabut, and A.S. Roussetsky." Anomalous enhancement of DD-reaction, alpha emission and X-ray generation in the high current pulsing deuterium glow-discharge with Ti-cathode at the voltages ranging from 0.8-2.5 kV", *The 9th International Conference on Cold Fusion, Condensed Matter Nuclear Science*., Tsinghua Univ., Beijing, China: Tsinghua Univ. Press (2002)



Godes and Tanzella, (Brillouin Energy): Quantum Pulsed Plasma, Excess Power[1,2]

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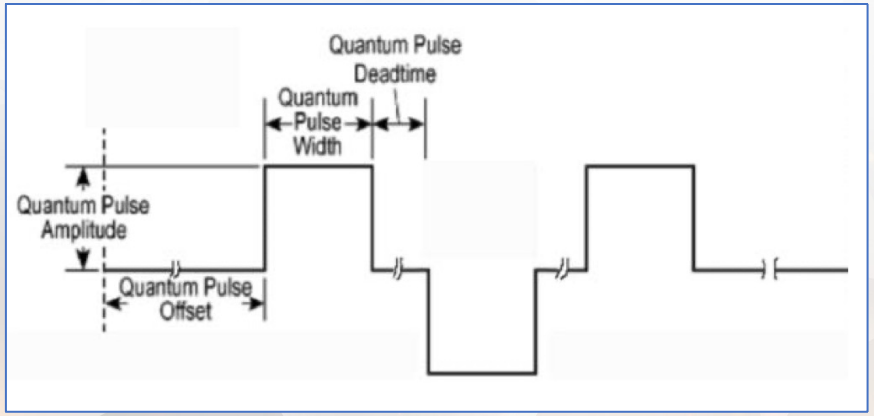
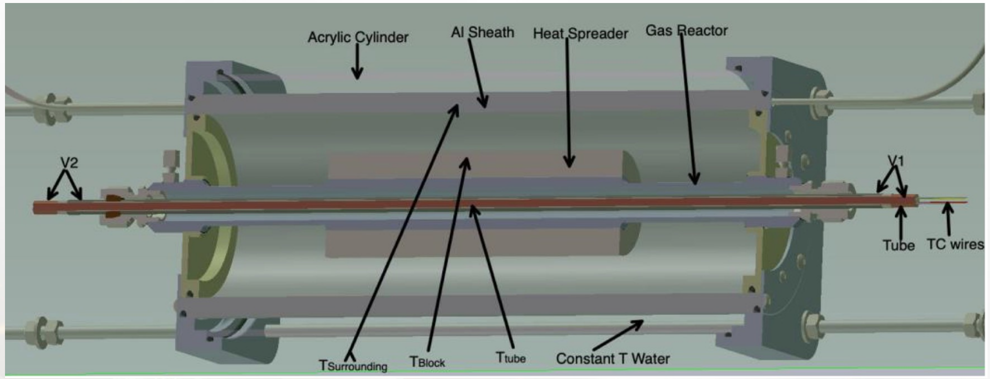
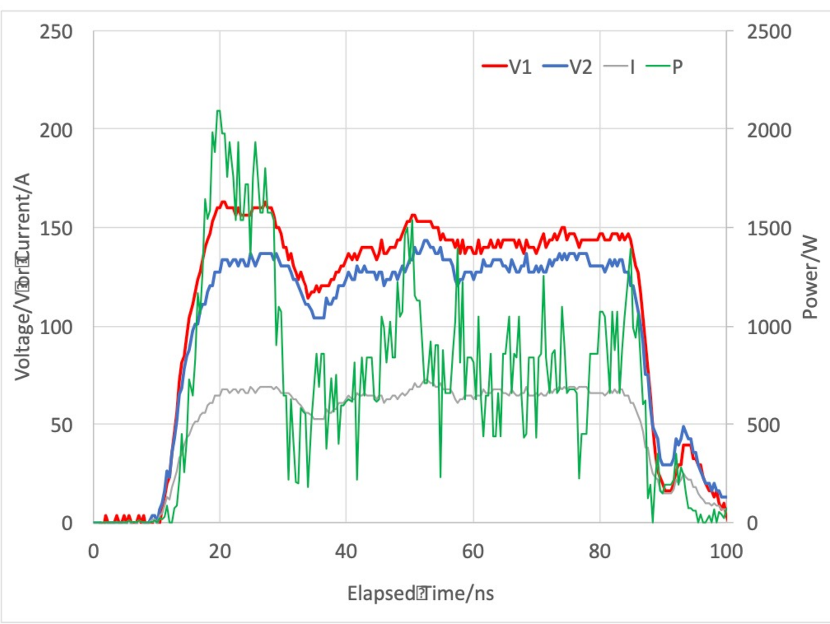
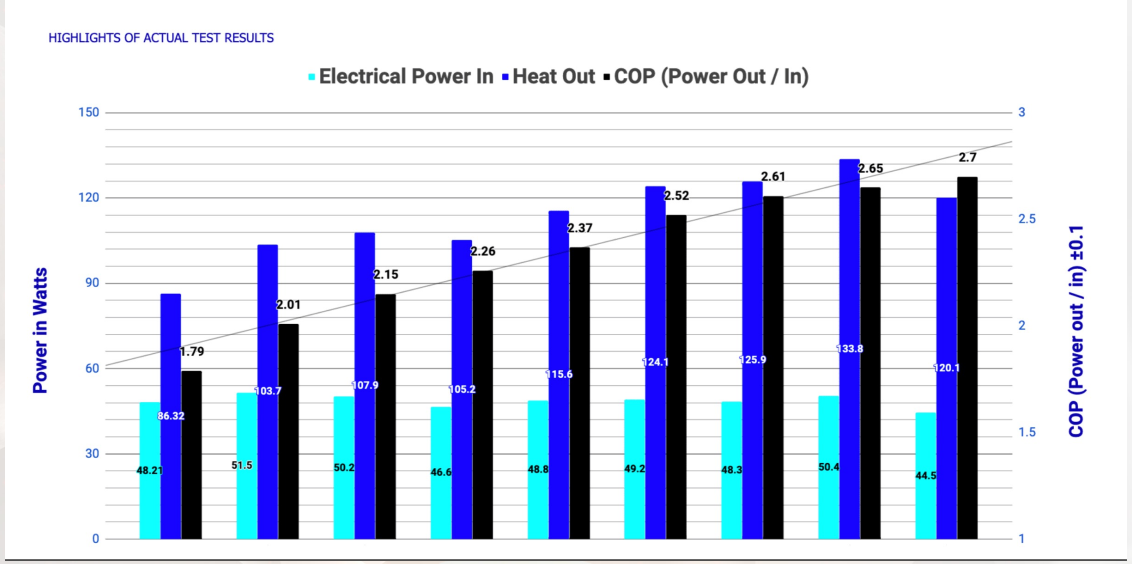


$^1H_2$ [3 – 10 bar]
Inner tube [200 – 600 C]
Q-Pulse™ variable amplitude and frequency *depending upon catalyst*





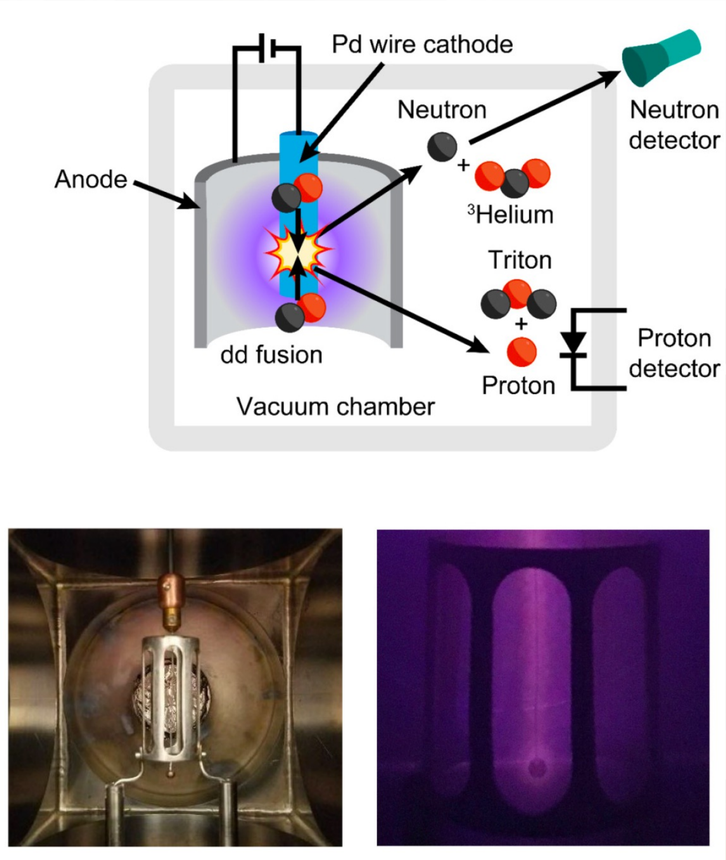
COP of 2.7
Tritium[3]



[1] https://brillouinenergy.com/wp-content/uploads/2019/04/Brillouin-SRI-Technical-Progress-Report-Final-Public-2018.pdf
[2] https://arpa-e.energy.gov/sites/default/files/2021LENR_workshop_Tanzella.pdf
[3] https://drive.google.com/file/d/1fH0175cM87dfj1LpqzJiUhm9QZPXG79j/view

Schenkel, *et al*, (LBNL) Glow Discharge, Fusion Neutrons[1,2]

National Aeronautics and Space Administration



LBNL Glow Discharge

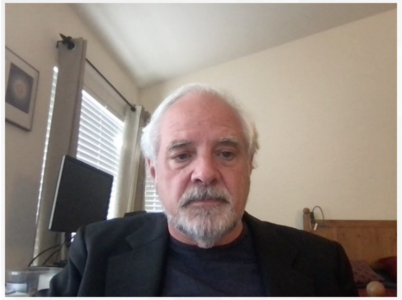
1–5 kV square-wave, glow discharge régime
pulse rate of up to 50 Hz with 20 µs pulses
I - [.1 to several A/cm^2]
D2 pressures – [0.1–2 Torr]

D-D fusion neutrons observed with Eljen-309 scintillator-based neutron detectors.

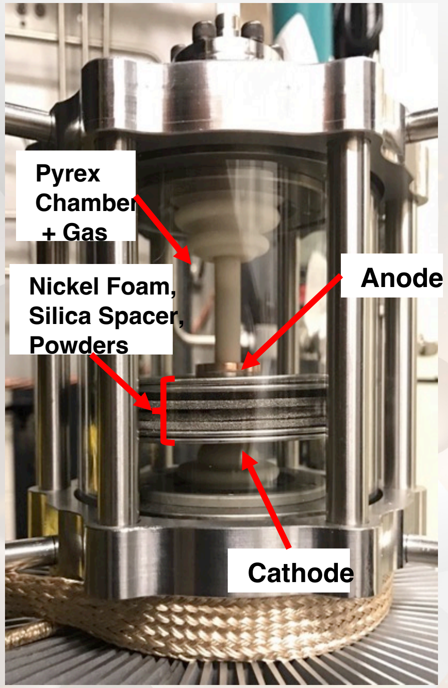
Neutron yield is a function of Pd cathode voltage
Fusion rate 100 times higher rate than for bare nuclei
due to Gamow Factor enhancement f(E)
due to electron screening potential, U_e, = 1000 ± 250 eV
with D^+ < 2 keV (center of mass frame)

Figures reproduced from Schenkel[2] with the permission of AIP Publishing.

1. C. P. Berlinguette, et al., "Revisiting the cold case of cold fusion", *Nature*, **570** (2019)
2. T. Schenkel, et al., "Investigation of light ion fusion reactions with plasma discharges", *J. Appl. Phys*. **126**, 203302 (2019) https://aip.scitation.org/doi/abs/10.1063/1.5109445

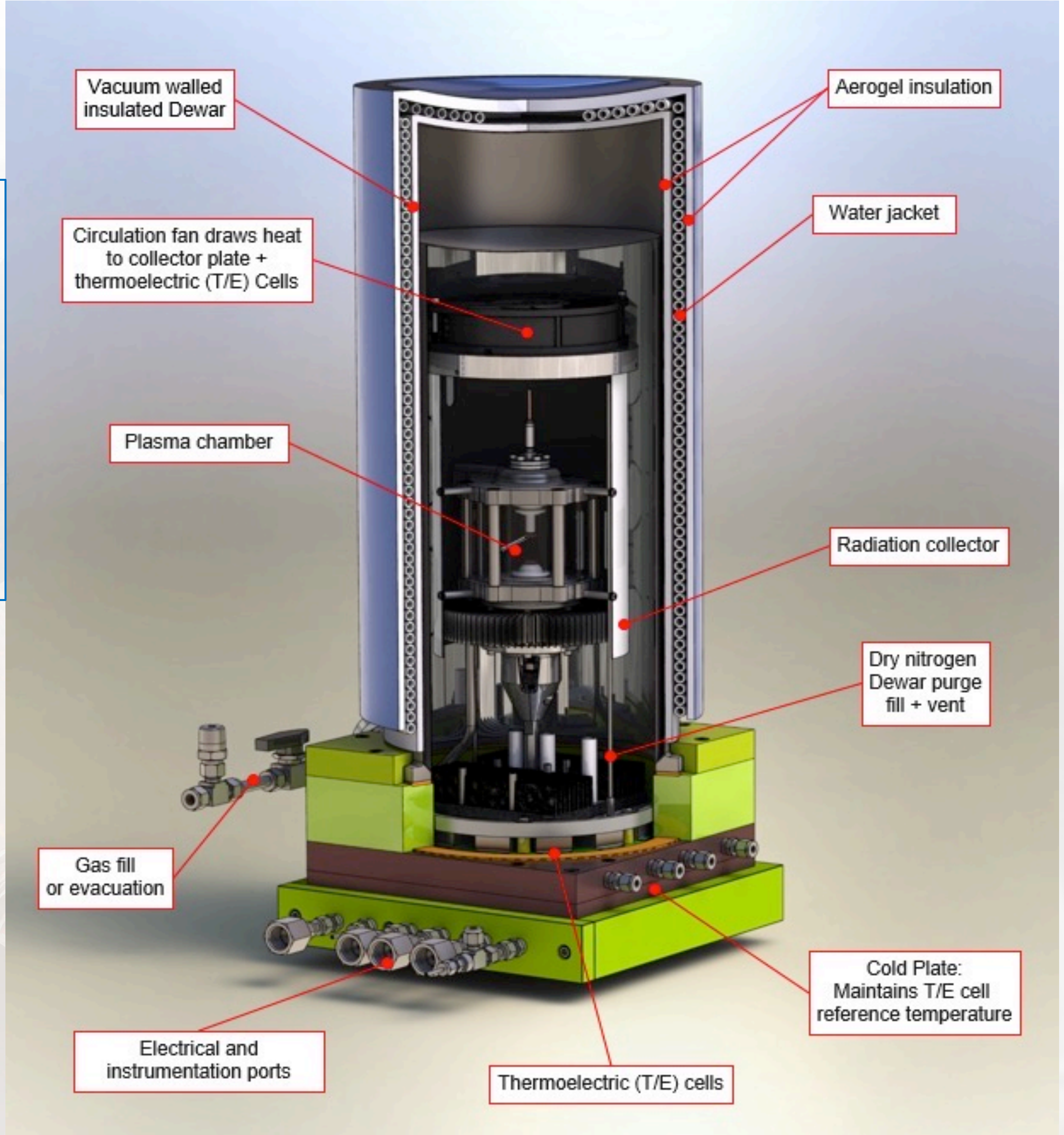


NASA Plasma Discharge Rig A

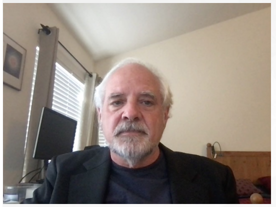


Plasma Chamber
w/ Ni Foam + silica spacer

It is difficult to accurately know the input power, hence the excess thermal power is questionable despite accurate calorimetry. Room temperature fluctuations can comprise an otherwise accurate calorimeter and there can be RF emission losses.



1-10 kV; Current: 20-120 mA
Gas: Fuel - D2; Control –Argon
D-gas + Plasma loaded Nickel foam;
Pd-Ag sputter coated Nickel foam, TiD2 powders
Dielectric Material: SiO2



NASA Plasma Discharge Rig B[1]

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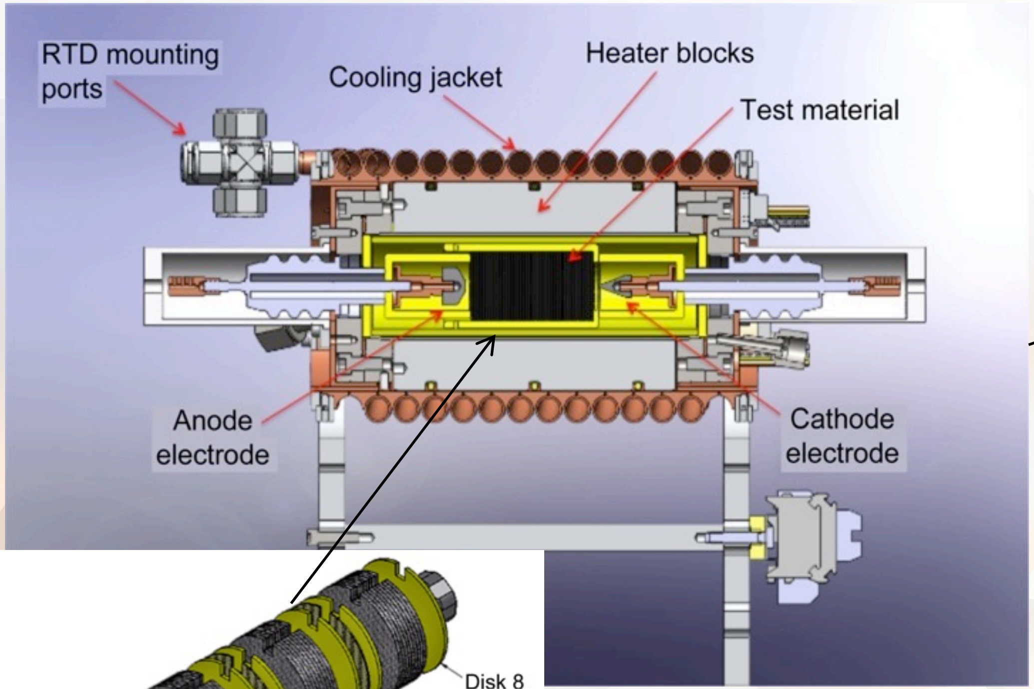
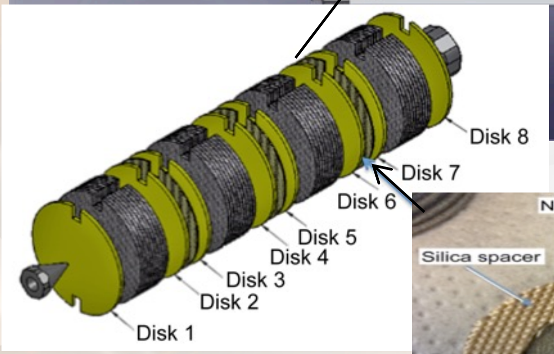
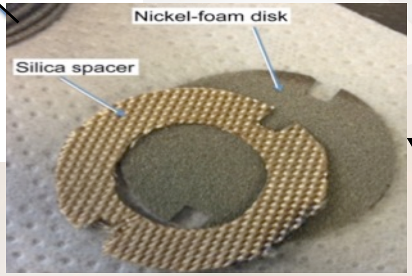
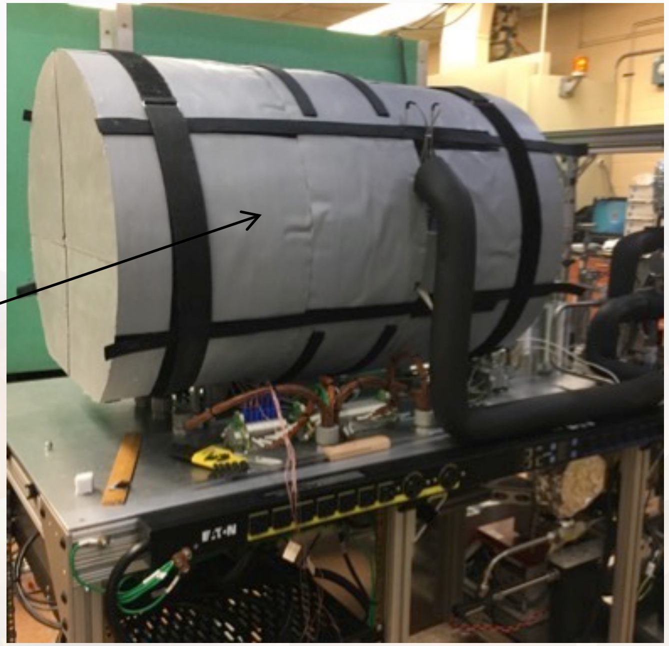


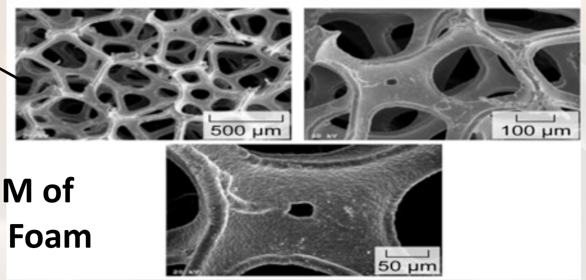




Ni Foam + Silica Spacer
Disk Stack



Plasma Reactor
Wrapped in Insulation



SEM of
Ni Foam

Summary

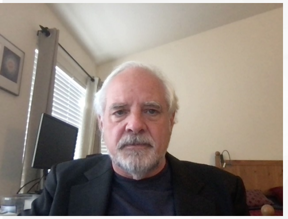
Using Ti-D2 powder

Using Pd-Ag

Anomalous gas changes:
- growth of AMU-2, 3, 5, 6
- decline in AMU-4 (D2)

It was difficult to accurately know the input power, hence the excess thermal power is questionable despite an accurate calorimeter measuring the output power. There were also RF emission losses.

[1] A.J. Colozza, et al., "Plasma Reactor Summary", *NASA/TM*—2020-220344 (2020)



Plasma Rig B Observations

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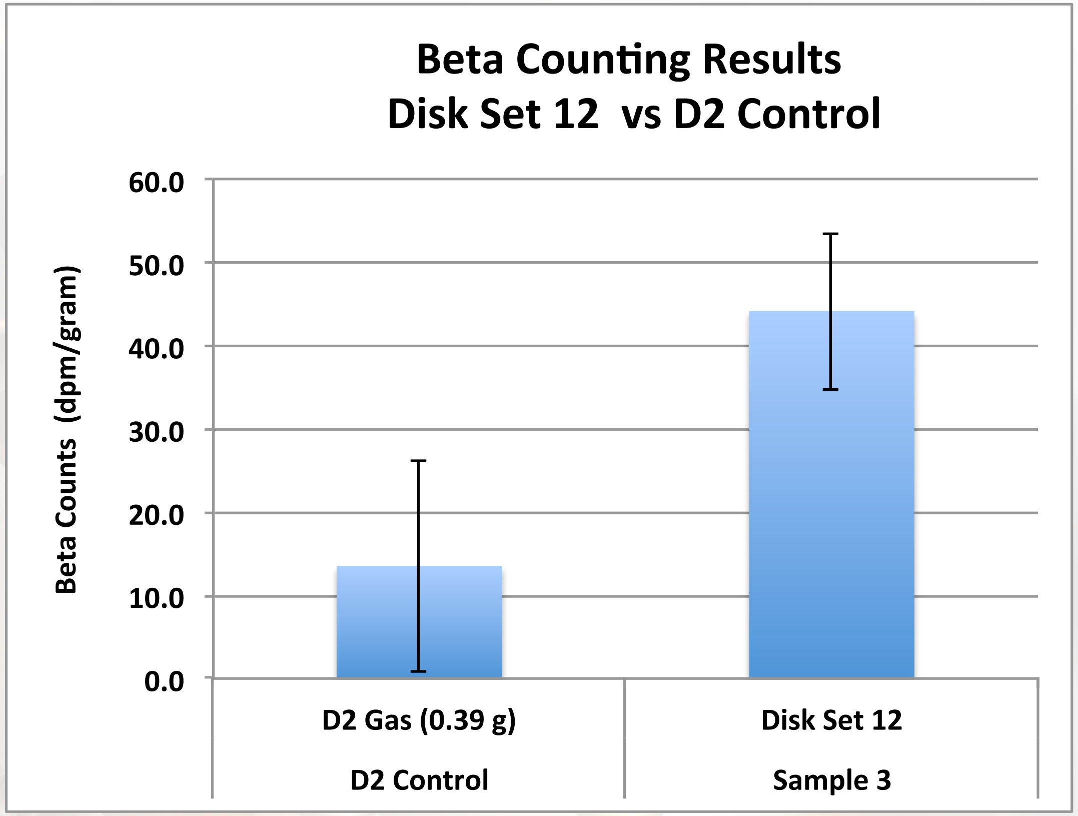
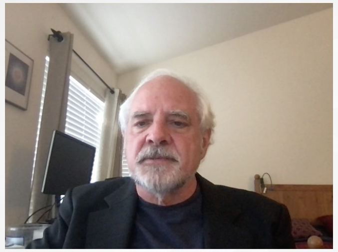
- Voltage: 10 kV start; 1.8-2.5 kV Pulse
- Frequency Sweep from 230 Hz to 7500 Hz
- Gas: Mixed D2 + Argon; 500 Torr
- Harvested gas from reactor and D2 supply gas
  - Beta Counting: Gas to Heavy water conversion then beta scintillation counting
- Key Results:
  - Beta counts in tritium energy band above starter D2 control gas. Hypothesis tests showed: probability was better than 99.99% that the mean of Disk Set 12 was different than the mean of the D2 control gas.
  - *Evidence of nuclear fingerprint of reactions in plasma reactor*





Common Characteristics Across Glow/Plasma Discharge

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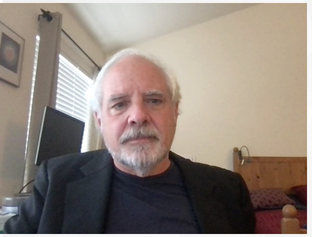
1. Hydrided or deuterided metals present as cathode or on wall: Ti, Ni, Pd, and others
    1. ”Pure” D has protium contamination and H has deuterium contamination on the order of 154 ppm
    2. Metallic or “structured” metallic alloy
    3. Hydrided/deuterided metals are effectively a cold plasma, with U_e screening
2. Glow discharge/arcing region resulting in:
    1. H or D and e^- flux, sometimes with Nobel gas (He, Ar, Xe) participation
    2. Non-equilibrium, gas or liquid based
    3. *Pulsed systems leading to itinerant magnetic fields*
    4. High H/D concentration
    5. Increased electron density → higher electron screening



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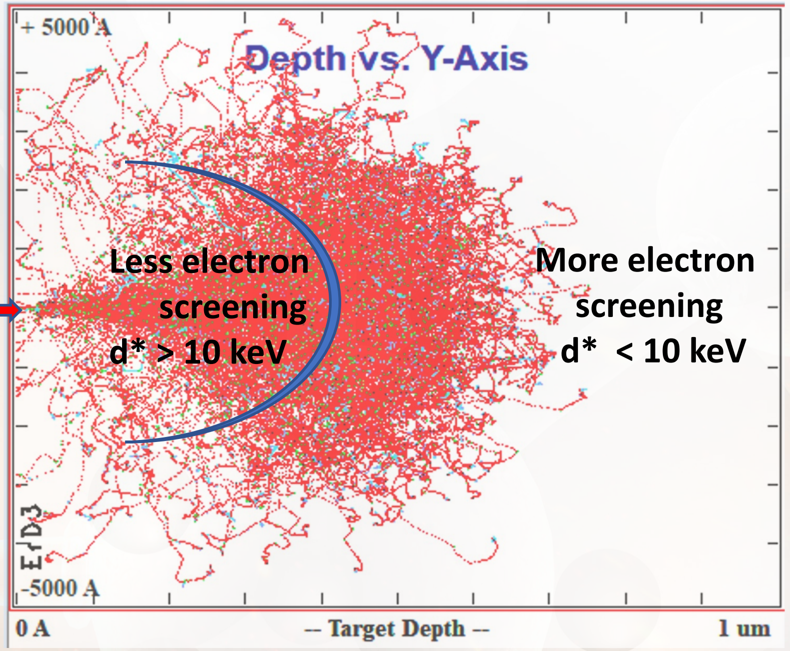
Electron Screened 64 keV Deuterons (d*) Slowing in ErD_3 Lattice

SRIM/TRIM[1] Ion Transport in Matter Model

"Electron screening is essential for efficient nuclear fusion reactions to occur."[2]

d*



10^3 particles tracked

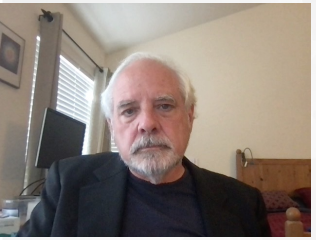
Calculation Parameters		
Backscattered Ions	22	
Transmitted Ions	0	
Vacancies/Ion	29.9	
ION STATS	Range	Straggle
Longitudinal	4358 A	1315 A
Lateral Proj.	1392 A	1707 A
Radial	2197 A	1061 A

Runs of 10^3 and 10^4 particles have similar trajectory spatial and energy distributions.

Ion scattering induces defects.

1. d* ion loses energy by ionizing lattice atoms producing free electrons and *plasma deep screening.*
3. When d* kinetic energy drops below 10 keV electron screening predominates.
4. *Eventually all 64 keV d* slow down by Linear Energy Transfer (LET) to below 10 keV.*

[1] Ziegler, James F. ; Ziegler, M. D. ; Biersack, J. P., "SRIM - The stopping and range of ions in matter", *Nuclear Instruments and Methods in Physics Research Section B*, **268** (11-12), (2010) 1818-1823.
[2] Pines, V. *et al.*, "Nuclear Fusion Reactions in Deuterated Metals", *Phys Rev C*, **101** (20April2020) 044609.



Measurement Difficulties

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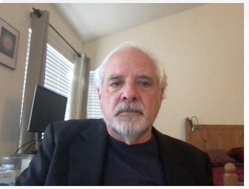
1. Accurately measuring V/I with pulsed systems
   - *High speed data acquisition to oversample V/I rate*
   - *Plasma resonant phenomena with changing capacitance and inductance*
   - *Negative resistance in breakdown region transition*
   - *Effects on accurate calorimetry*
2. Measuring H/D loading
   - *Plasma/Glow discharge H/D diffusion characteristics not known*
     - *But may be determined by neutron diffraction*[1]
3. Measuring energetic particles (x-rays, gamma, ions, neutrons)
   - *EMI interference, x-ray/gamma interference*
   - *Effects on accurate calorimetry*
   - *Distinguishing among charged ions ($^1H_1$, $^2H_1$, $^3H_1$, $^4H_1$, $^3He_2$, $^4He_2$) (Blue is unstable)*
4. Material Analyses
   - *Transportation, or*
   - *Contamination, vs*
   - *Transmutation from fusion, fission or capture*

[1] Tim Koeth, University of Maryland



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Summary

1. **Excess Power**
    1. Claytor: 1.5% excess
    2. Karabut: 150% excess
    3. Godes and Tanzella: 270 % excess
2. **Transmutation products**
    1. Claytor: tritium
    2. Savitimova: Pd and Ti fission products (non-actinides)
    3. Godes: ^{64}Ni enhancement by 125%, tritium
    4. NASA: tritium
3. **Energetic radiation**
    1. Karabut: energetic particles, x-rays
    2. Storms: energetic ions, x-rays
    3. Lipson: 3 MeV fusion protons, long range alphas, x-rays
    4. Schenkel: 2.5 MeV fusion neutrons
4. **Enhanced electron screening**
    1. Claytor “electron shielding” with tritium
    2. Schenkel observed 100+ -fold increase in fusion rates due to electron screening
5. **Scaling**
    1. H or D?
    2. H/D density?
    3. Accelerating voltage?
    4. Current?
    5. Pulse shape and frequency?
    6. Cathode?

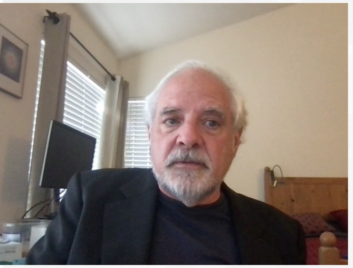
Related Plasma Work

e.g. Celani, high current H and D loading of Constantan™ wires

and others.

Lattice Cold Plasma

Electrolytic systems that load hydrogen isotopes enhance cold plasma lattices with high electric currents > 100 mA/cm^2 further increasing electron screening.



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Conclusion
Weaving a tapestry from disparate threads

Plasma loading via glow discharge (*and other means*) produce:

1. Nuclear products
2. Excess heat
3. Repeatable results

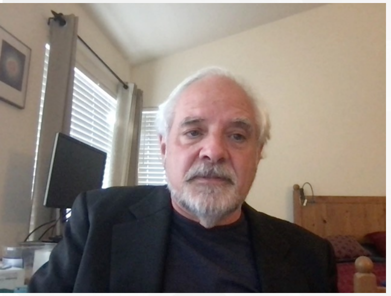
by increasing:

1. Hydrogen isotope loading and flux
2. Electron screening in a lattice

resulting in a:

1. High current, low energy means to measure the enhanced Gamow Factor, *f(E)*
   Currents > 10^3 times accelerator experiments
2. Nascent technology for scaling LENR

However, both real-time diagnostics and calorimetry suffer from intense EMI making measurements difficult.



The Last Word
Dr. Martin Fleischmann
"Keep Going"

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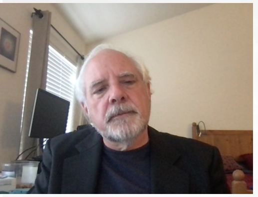

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E. Storms, *KIVA Labs, Los Alamos National Laboratory, retired*
F. Tanzella, *SRI, retired*

Dr. Marianna Pines

In memorium of Dr. Marianna Pines, Dr. Martin Fleischmann, Dr. Andre Lipson, Dr. Alexander Karabut and Dr. Yan Kucherov.

LENR Short Course 2022

Introduction and Issues	Nagel

Experiments

Electrochemical Loading	McKubre
Hot Gas Loading	Narita
Plasma Loading	Forsley

Results

Calorimetry and Heat Data	Storms
Transmutation Data	Biberian

Problems

Materials Challenges	Imam
Theoretical Considerations	Hagelstein

Payoffs

Commercialization	Katinsky
Applications and Impacts	Rothwell

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