Studies of the Fleischmann-Pons Effect at SRI International

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Vice Chancellor for Research Seminar Series:

Excess Heat and Particle Tracks from Deuterium-loaded Palladium

University of Missouri

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Background

- March 23rd 1989 Fleischmann and Pons reported results of:
  an anomalous heat effect resulting from the extensive, electrochemical insertion of deuterium into palladium cathodes over an extended period of time by means of electrolysis of heavy water in heavily alkaline conditions.

- This heat effect was at a level consistent with Nuclear but not Chemical energy or known lattice Storage effects, but occurred (*mostly*) without penetrating radiation (α, β, γ, n°) or activation (^3H).

- Nuclear level heat effects have been observed in the D/Pd system with energies 100's or 1,000's times known chemical effects.

- SRI has played an important role in a number of critical areas:

  - The measurement and importance of D/Pd loading
  - The role of chemical additives and poisons in loading and interfacial dynamics
  - Design, construction and successful implementation of a novel, high-accuracy, fully-automated mass flow calorimeter
  - Replication studies:
    - Fleischmann Pons (Excess Heat)
    - Miles and Bush (^4He)
    - Case (Heat and ^4He)
    - Arata and Zhang (Heat, ^3H and ^3He)
    - Energetics (High level excess power and energy)

Hypothesis 1

"An unexpected source of heat can be observed in the D/Pd System when Deuterium is loaded electrochemically into the Palladium Lattice, to a sufficient degree."

Experiments:

- D/Pd Loading.
  - Electrochemical Impedance (kinetics & mechanism)
  - Resistance Ratio R/R° (extent of loading)

- Calorimetry
  - first principles closed-cell, mass-flow calorimeter,
  - > 98% heat recovery (*99.3%*)
  - absolute accuracy < ±0.4% (*0.35%*)

Loading Cell and Reactions.

Wires:

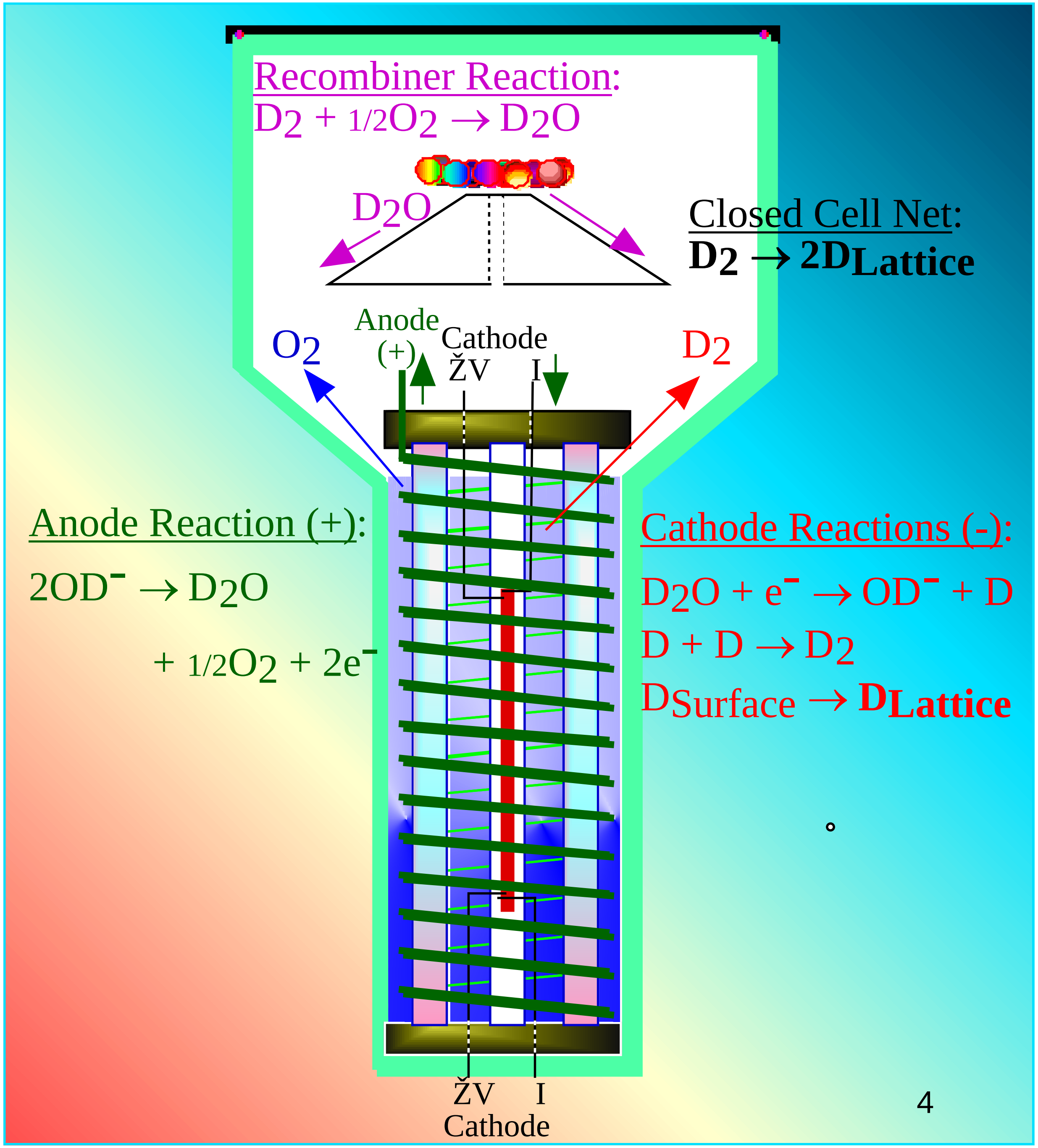
1 – 3 mm in dia.
3 – 5 cm in length.

Foils:

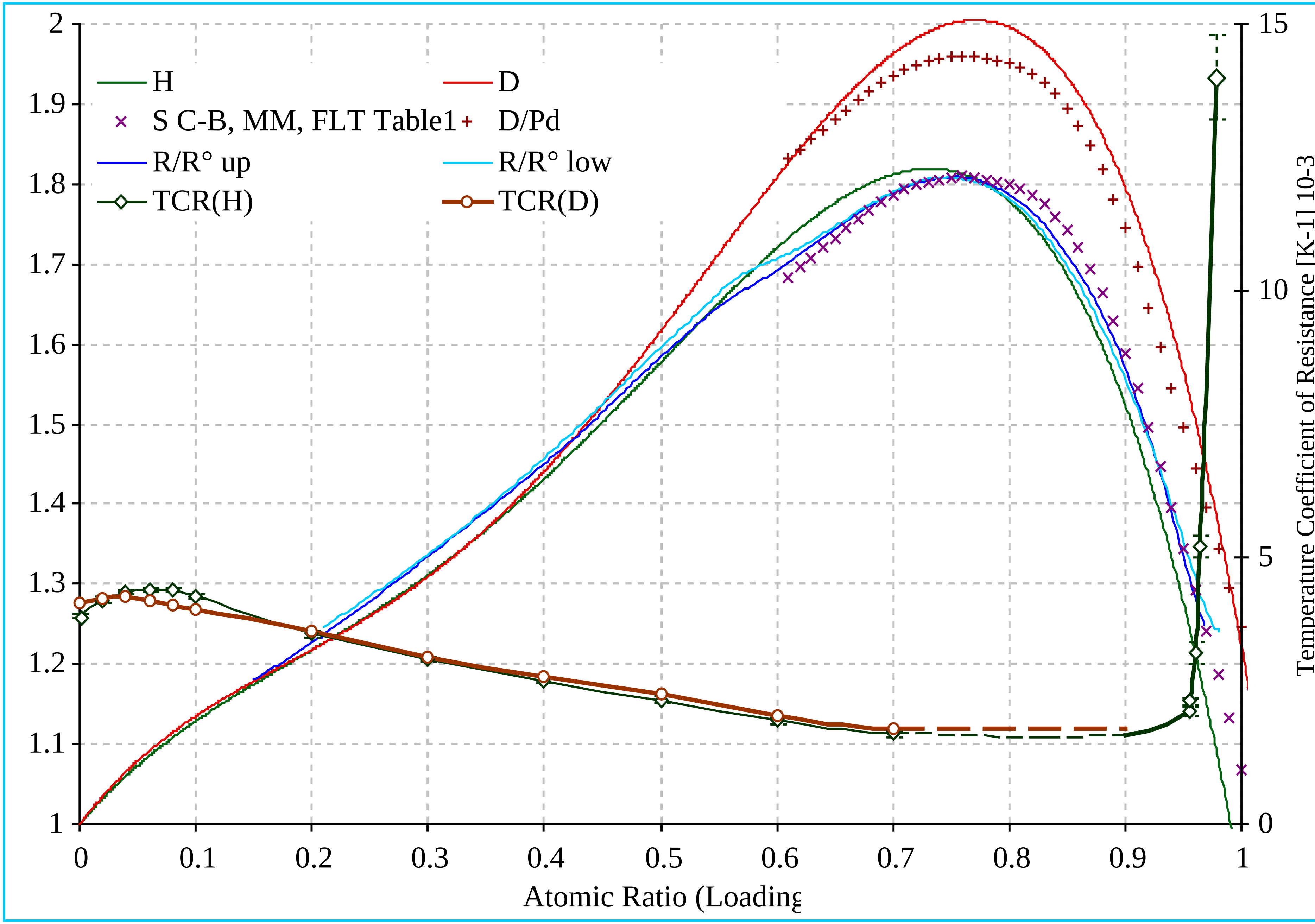
50 µm thick
7 x 80 mm area.

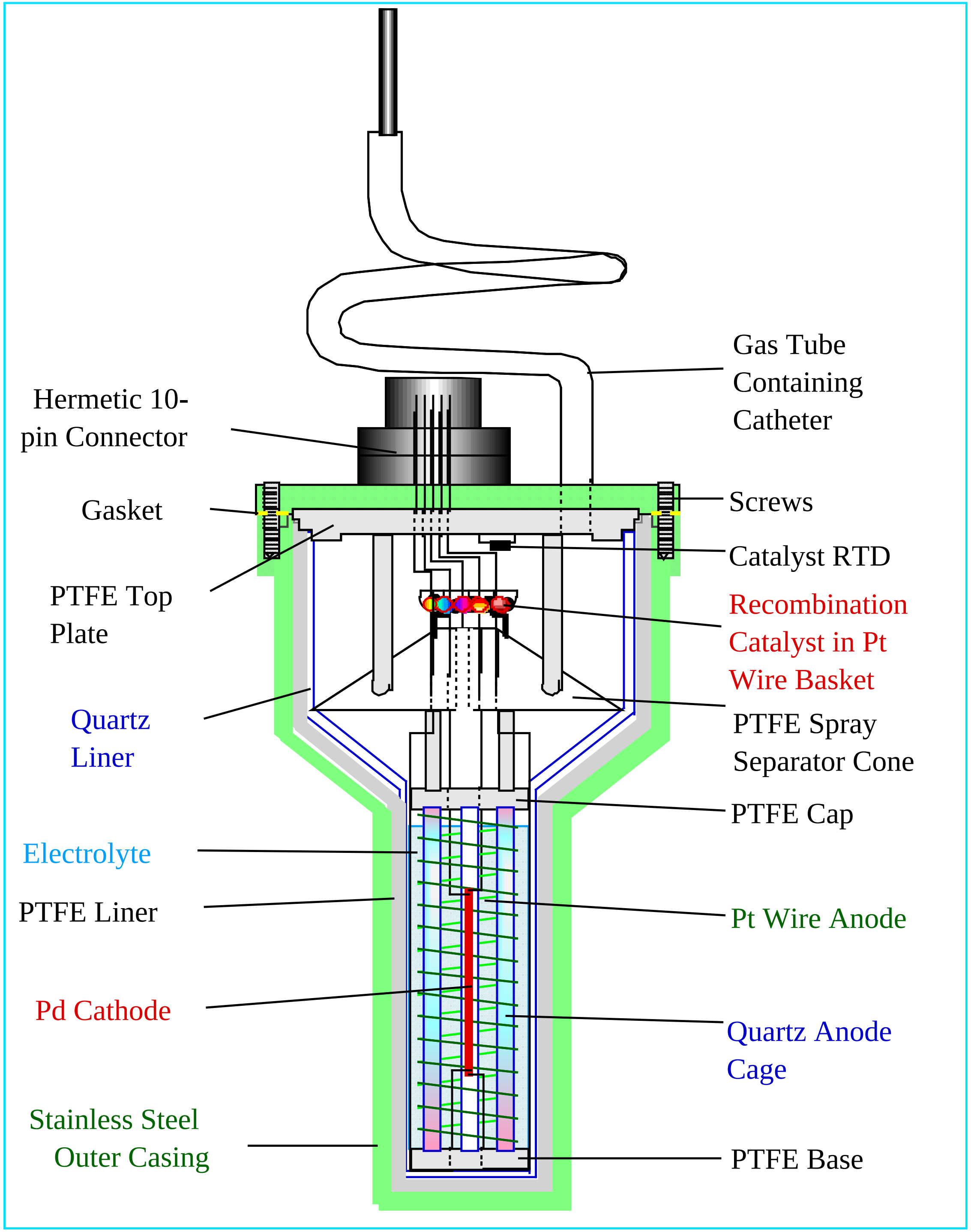
LiOD Electrolytes

0.1 – 1 Molar



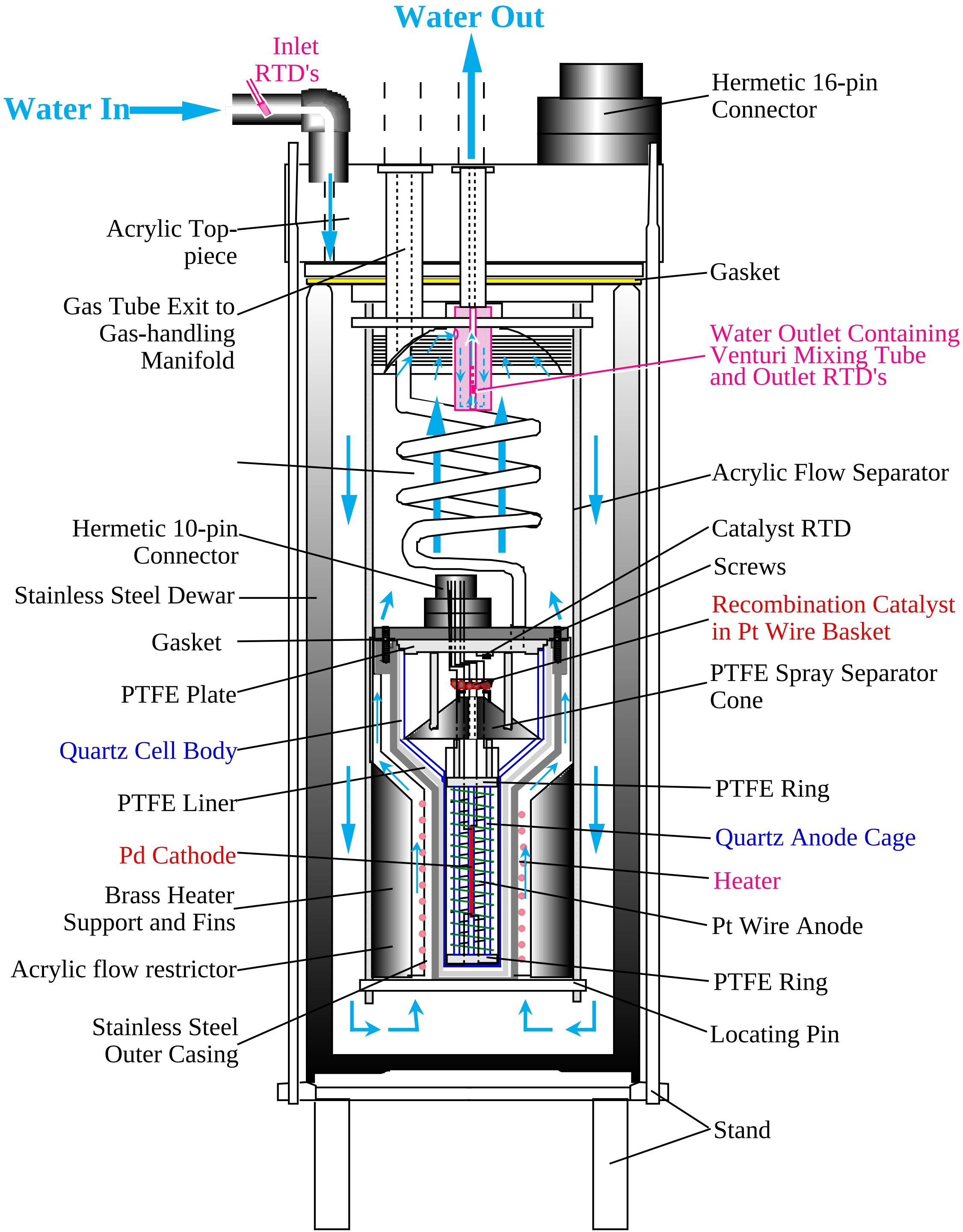
Loading and Temperature coefficient of Resistance



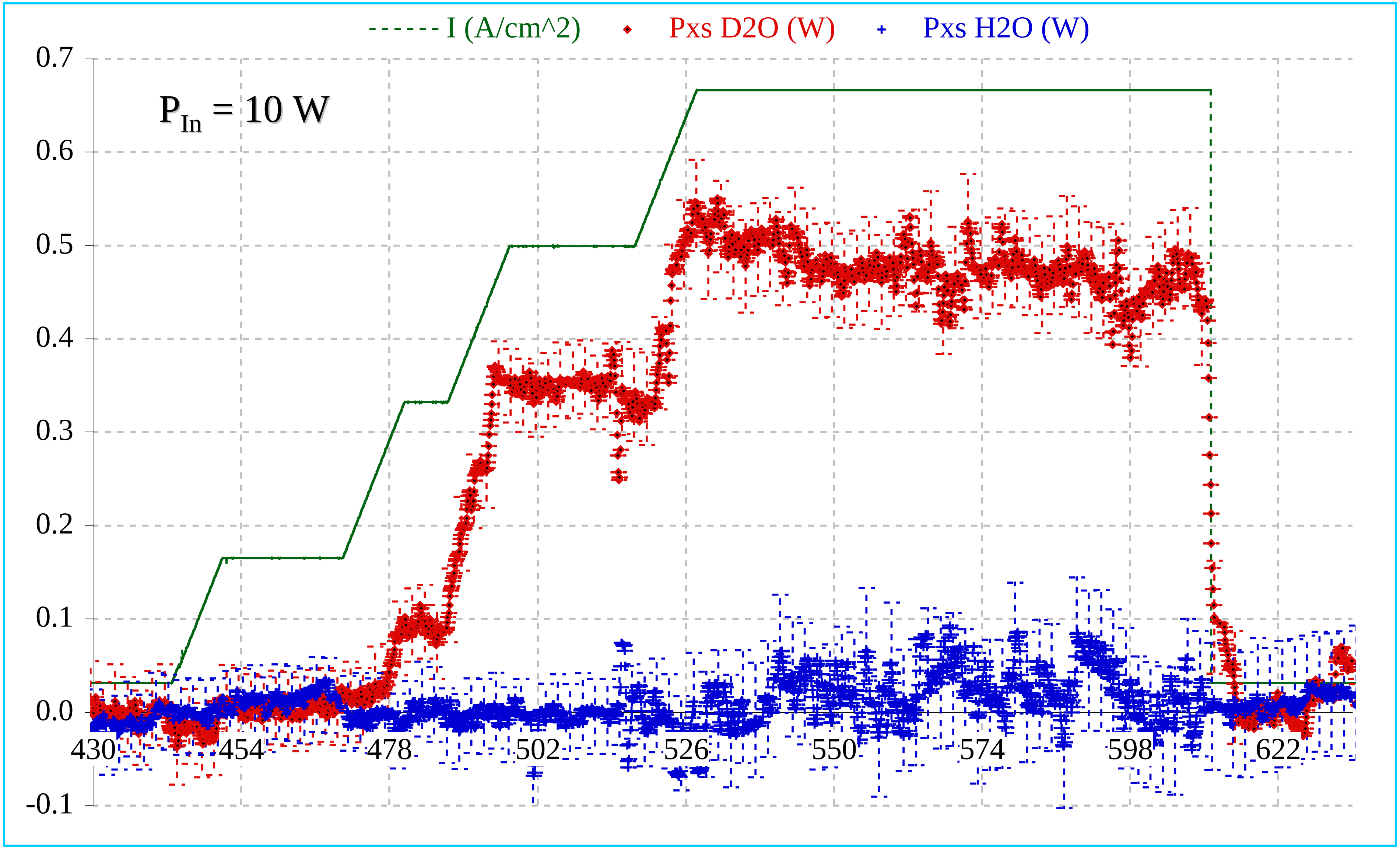


SRI Quartz Calorimeter *and* Degree of Loading (DoL) Cell

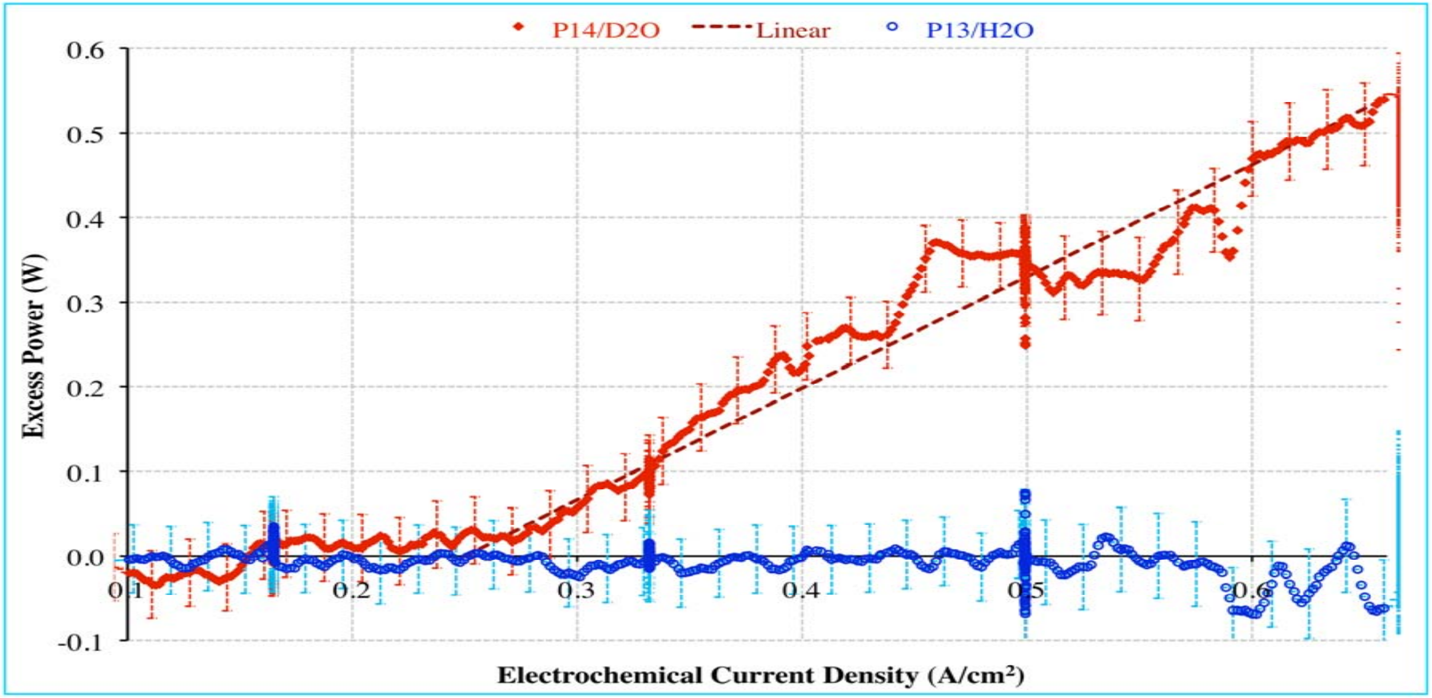
SRI Labyrinth (L and M) Calorimeter and Cell

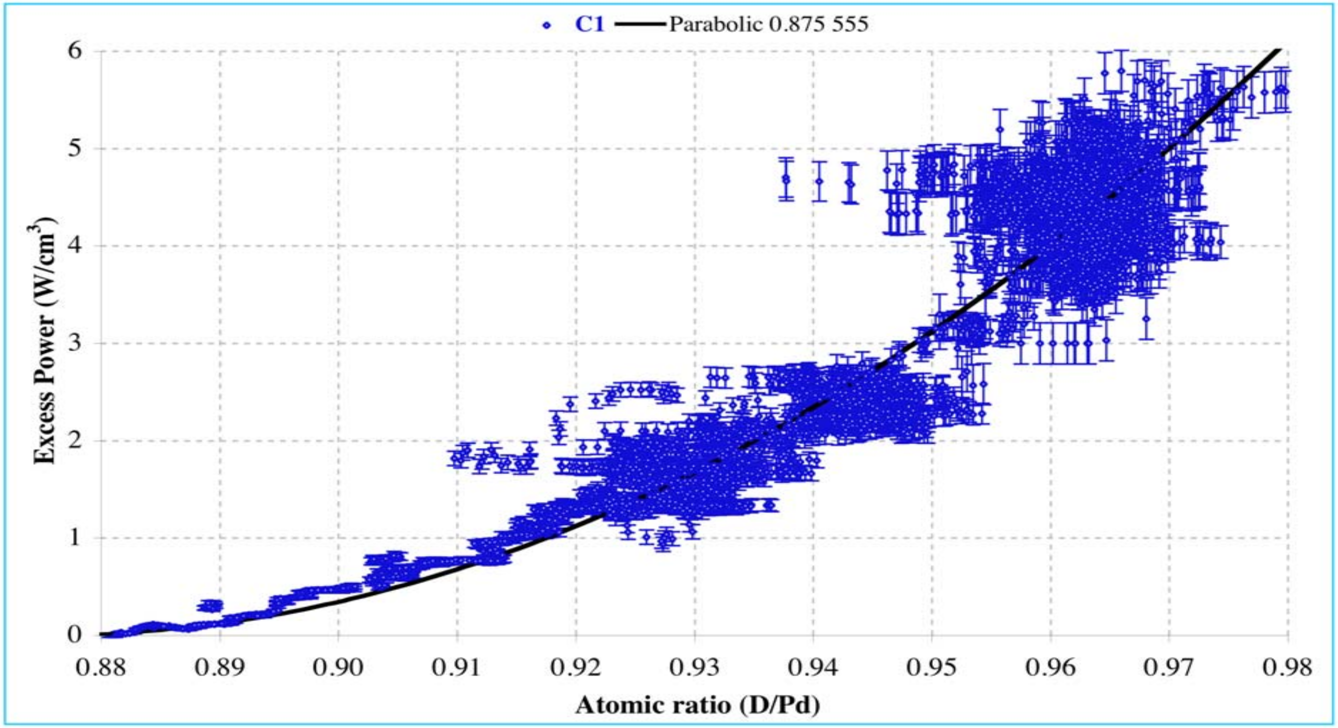


P13/14 Simultaneous Series Operation of Light & Heavy Water Cells; *Excess Power & Current Density vs. Time*



SRI *FPE* Replication





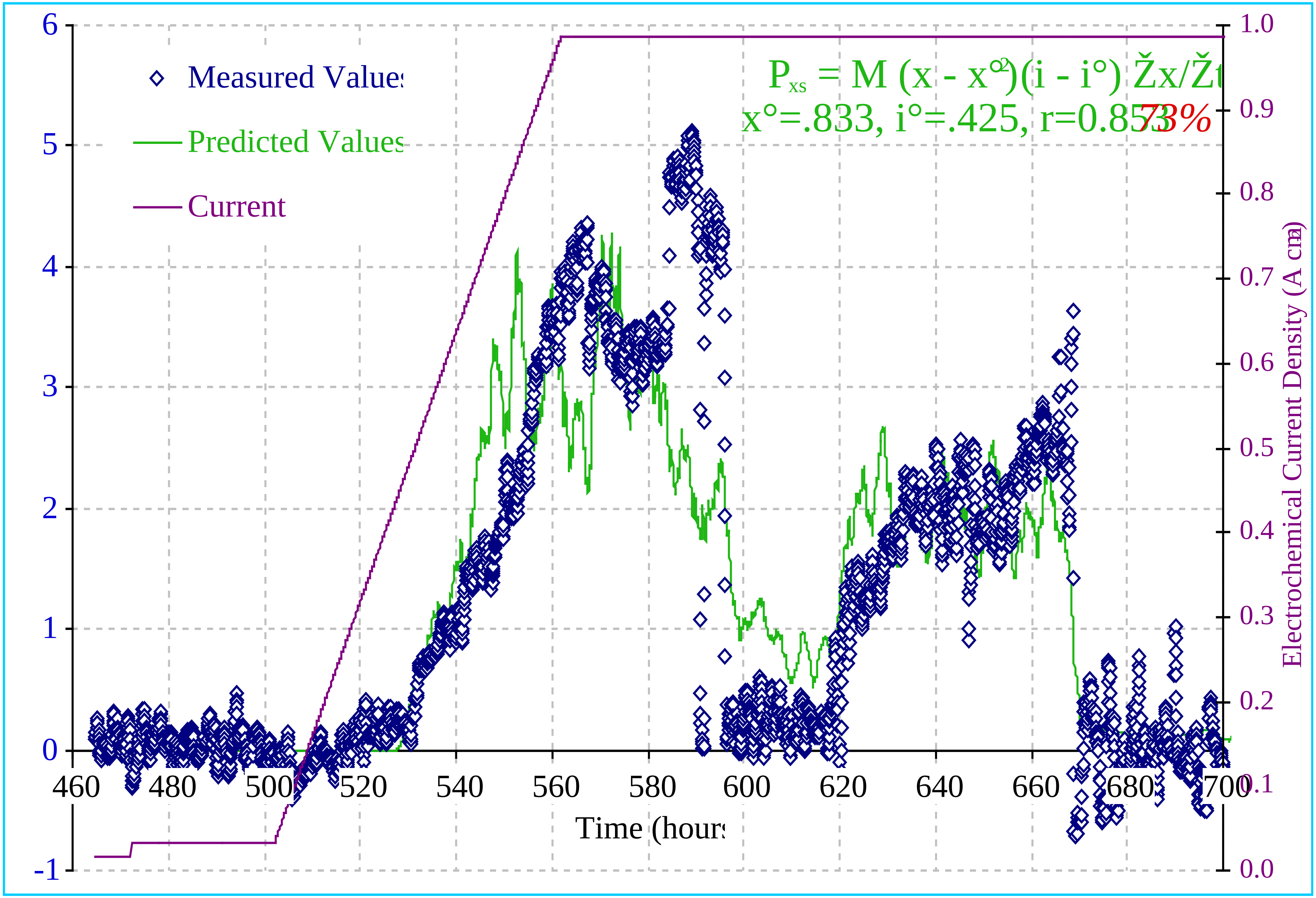
a) Nuclear -level heat release (1000's of eV/Pd Atom).
b) Current threshold and linear slope.
c) Loading threshold.

P15 1M LiOD + 200ppm Al, 3cm x 3mm Pd Wire cathode

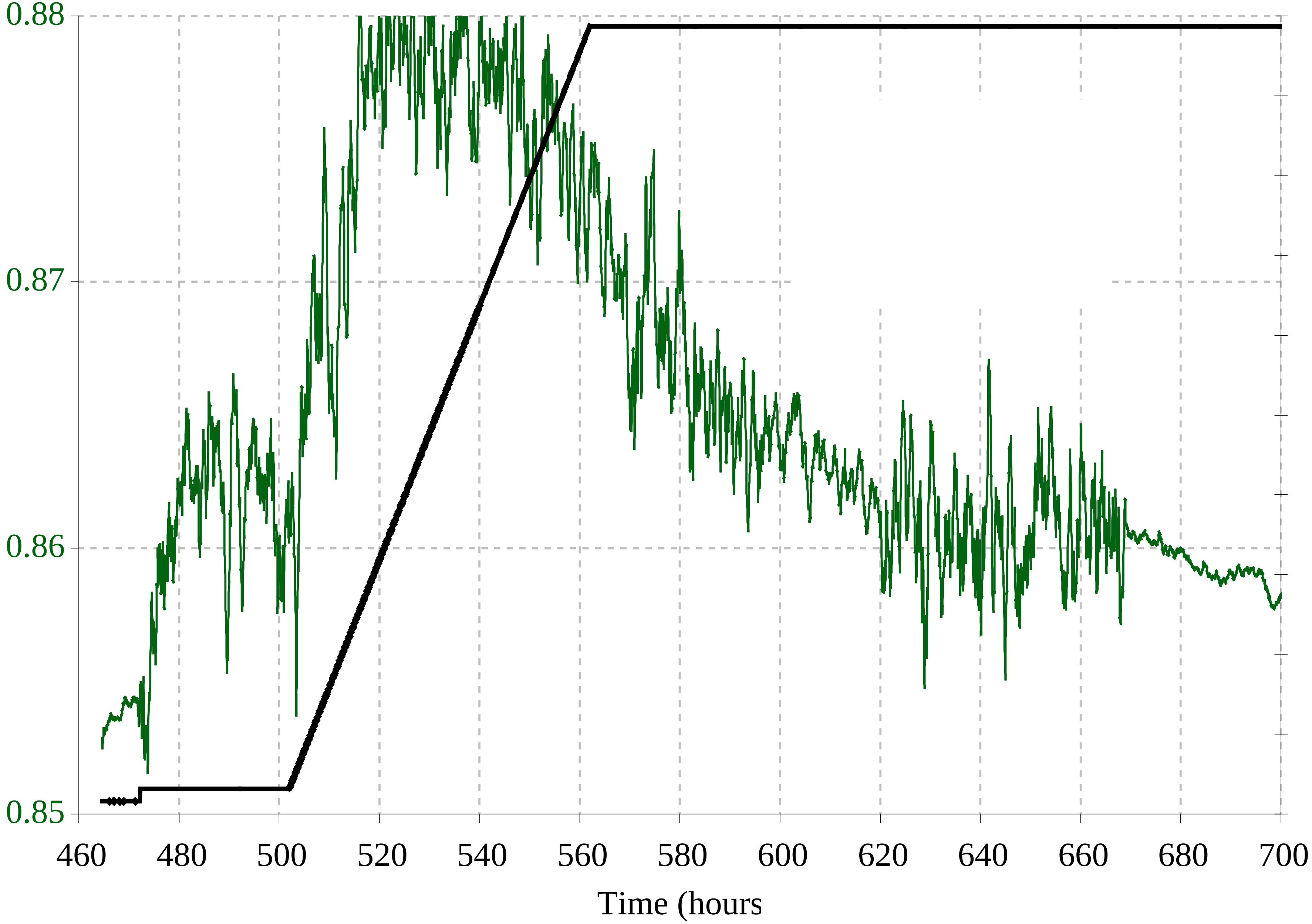
Demonstrating Significance of Surface Potential.

P_{In} = 12 W

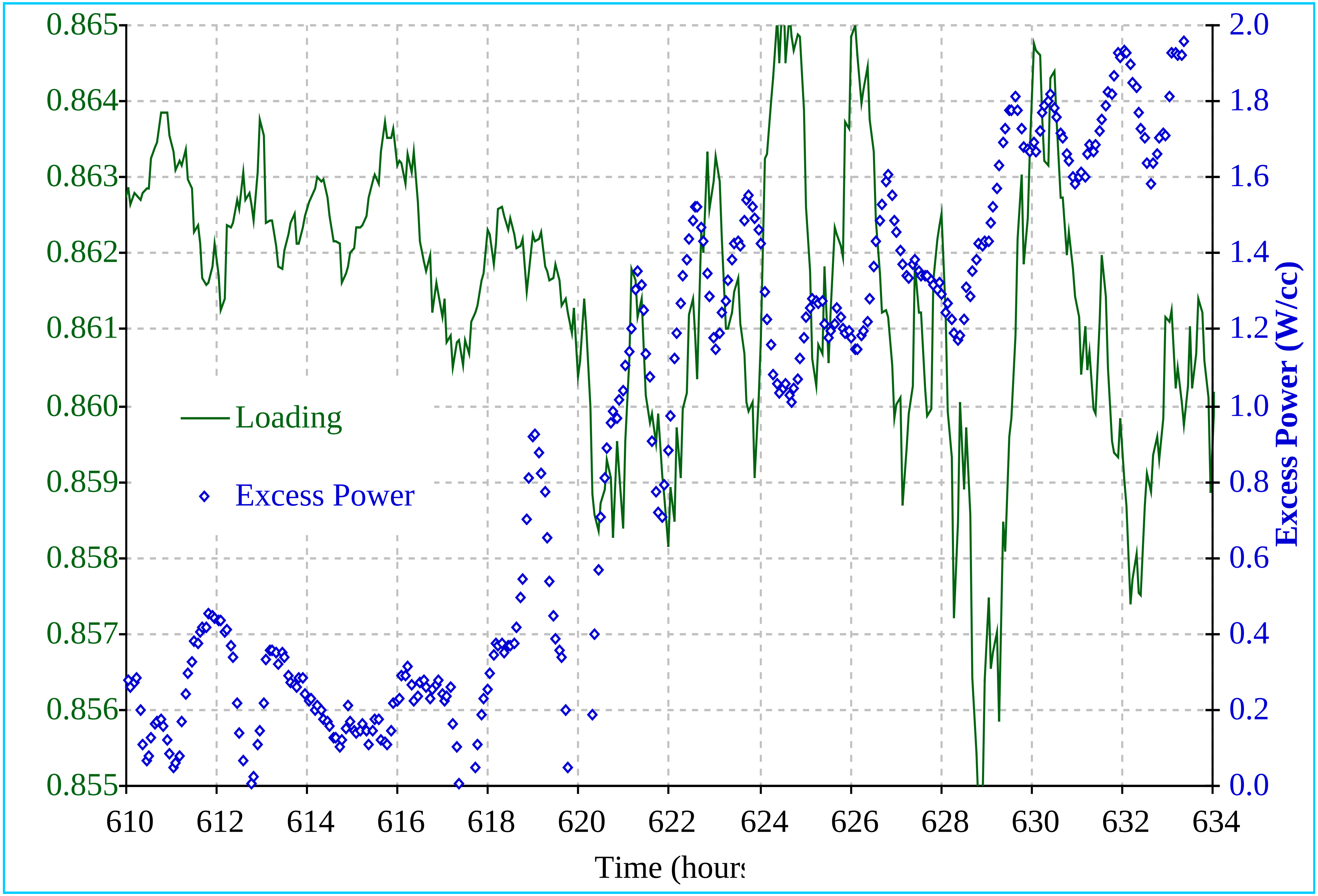
M4: The Dynamics of D Flux [1]



M4: The Dynamics of D Flux [2]



M4: The Dynamics of D Flux [3]

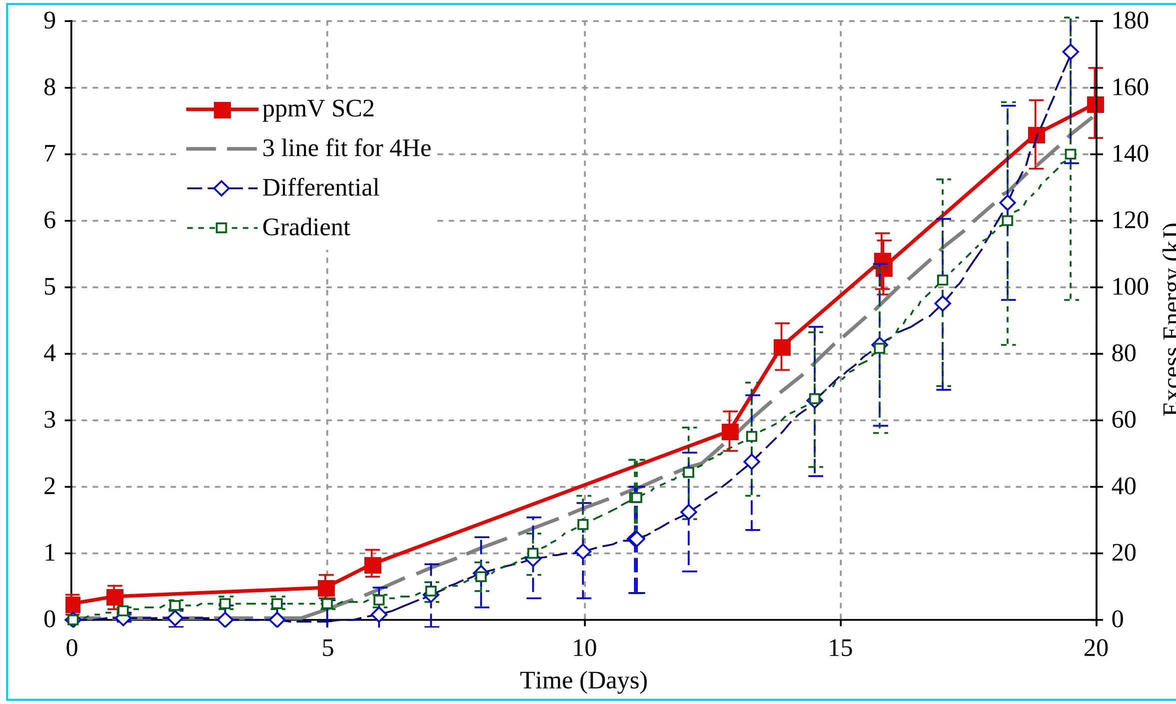


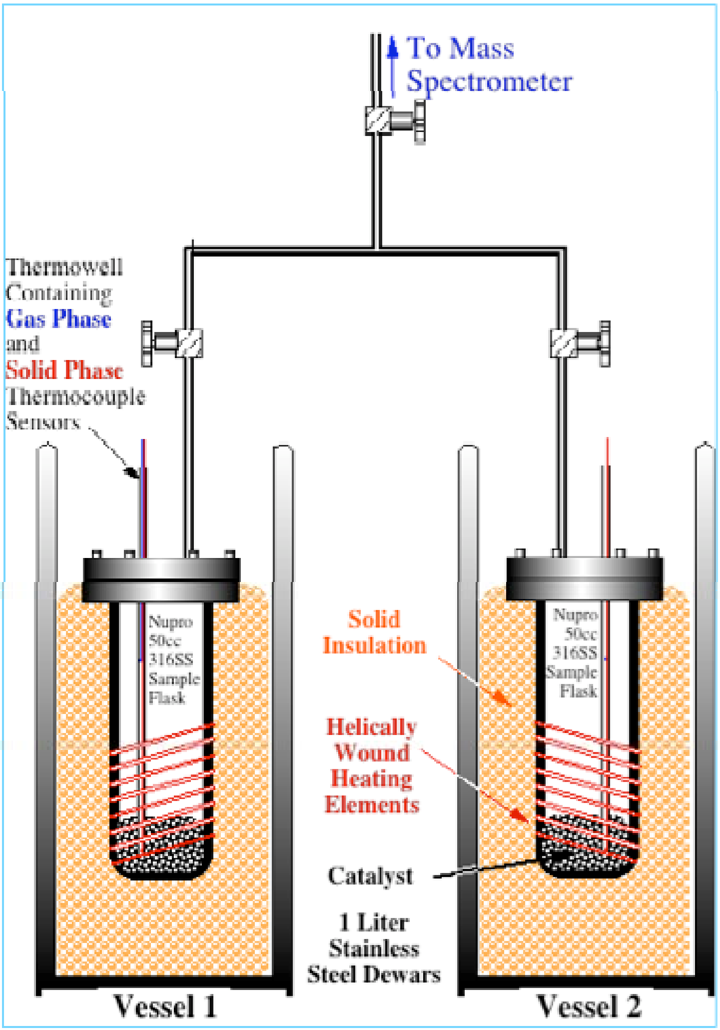
SRI *Case* Replication

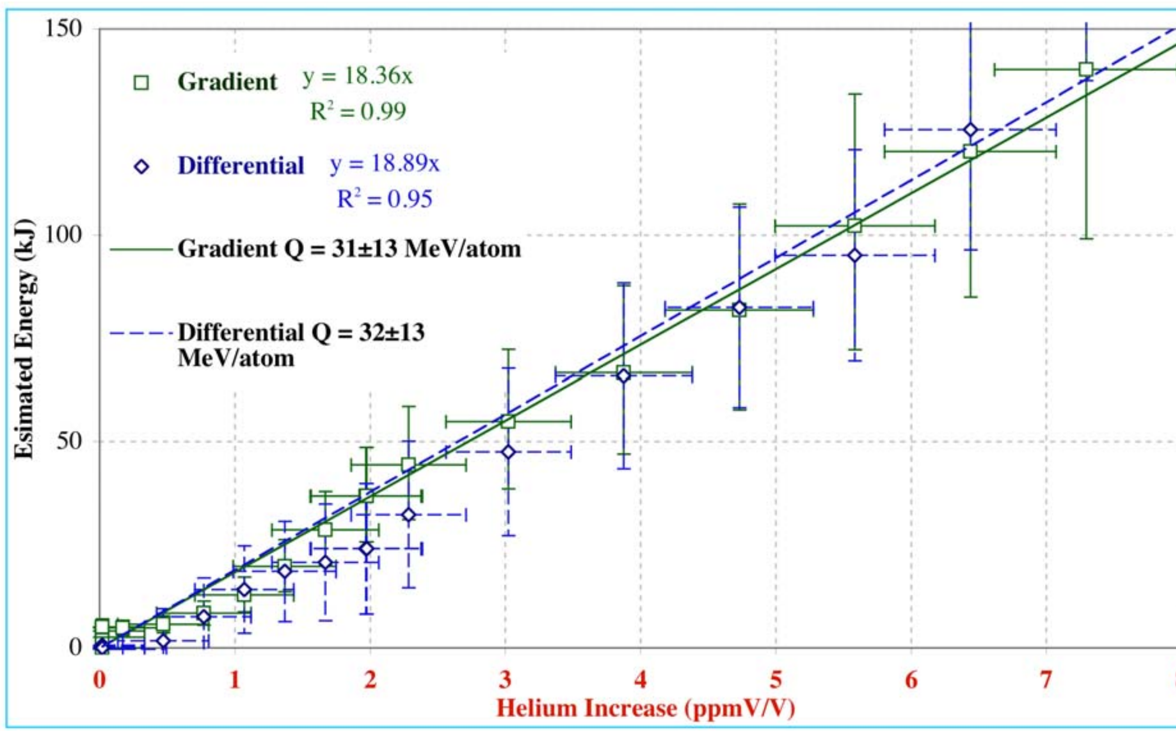
a) Correlated Heat and ^4He

b) Q = 31 ± 13 MeV/atom

c) Discrepancy due to solid phase retention of ^4He.

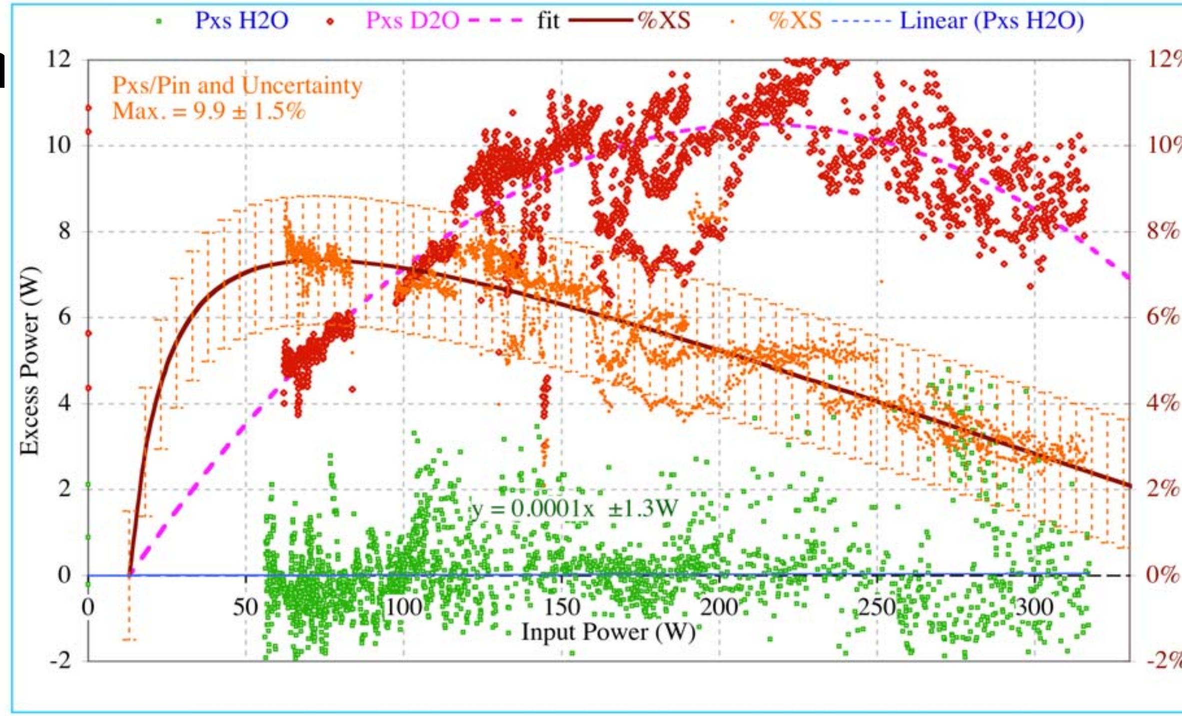


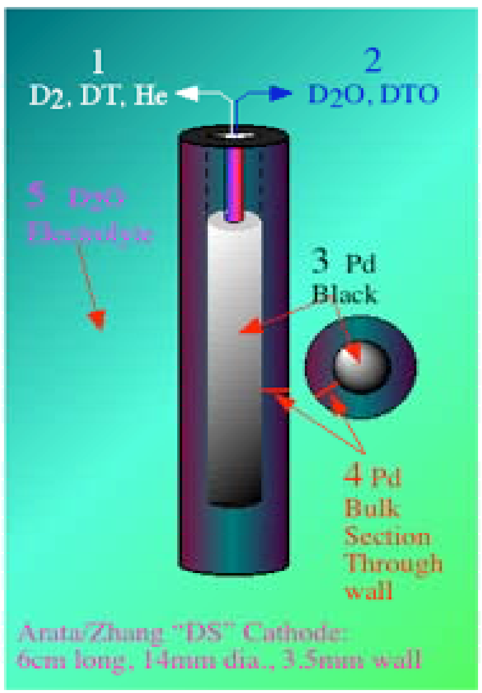


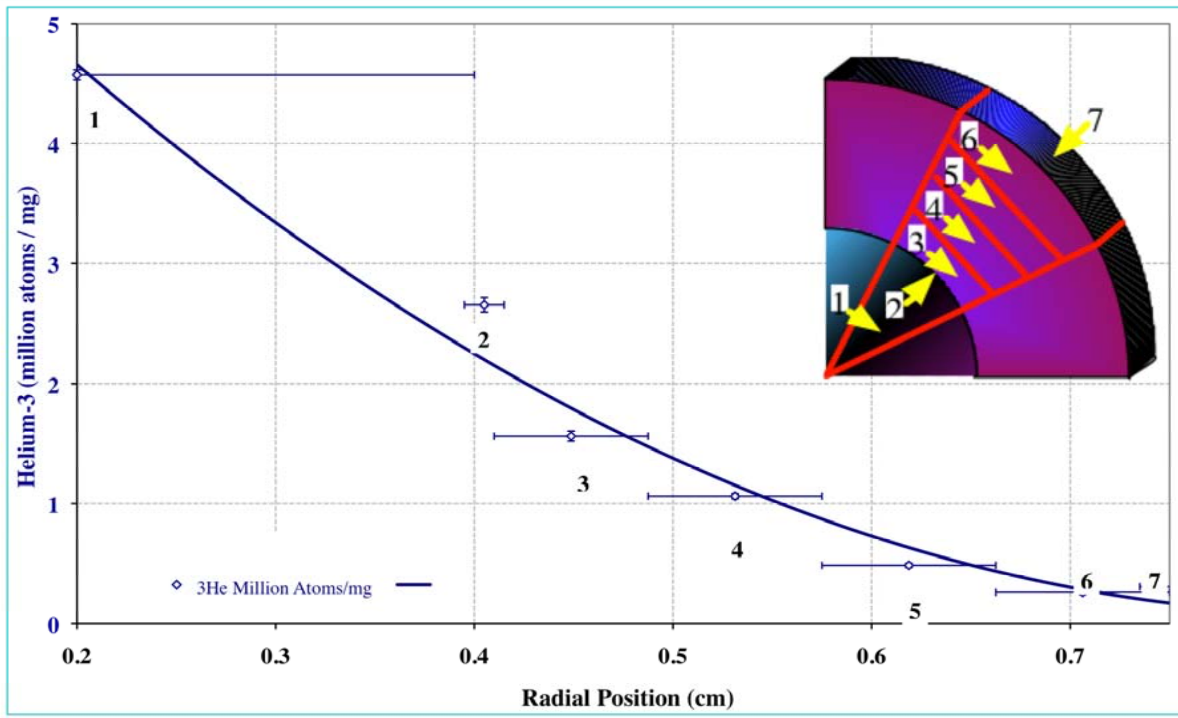


SRI *Arata* Replication

1) P_{XS} from LiOD not LiOH.
2) Tritium in all 5 phases (LiOD):
   a) measured as $\partial^3He/\partial t$ at McMaster in Phases 1-4
   b) measured by scintillation at SRI in electrolyte
   c) Production 2 - 5 x 10^{15} Atoms
3) No ^3He (or ^3H) in LiOH blank
4) ^3He is the decay product of Tritium which diffused from a source inside the electrode.
5) ^4He not seen.



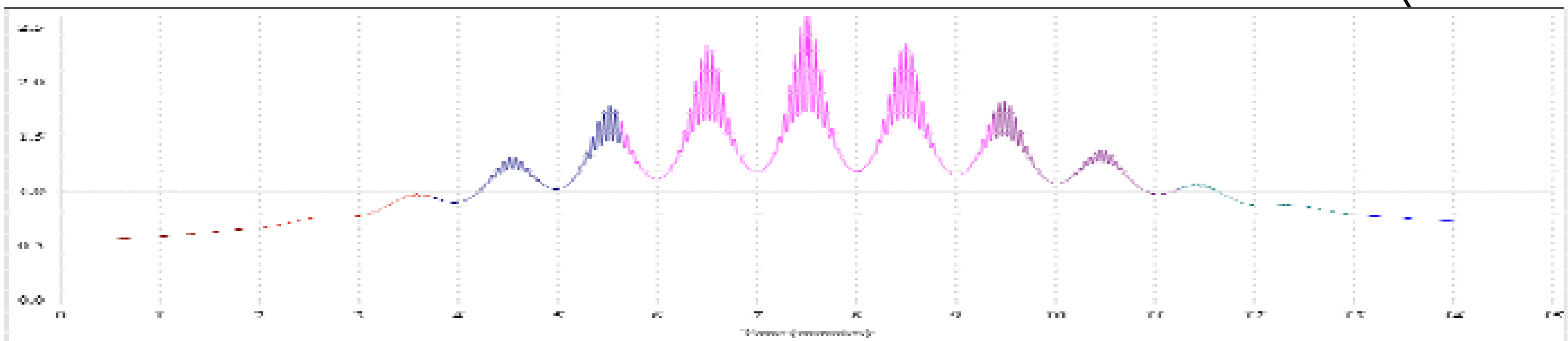


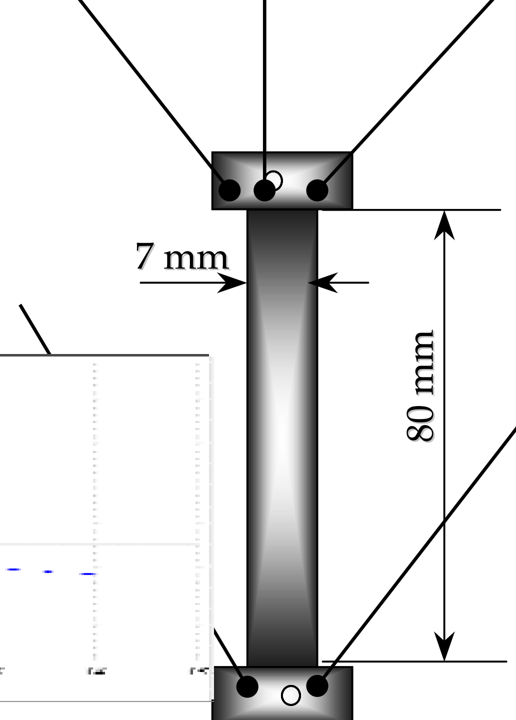


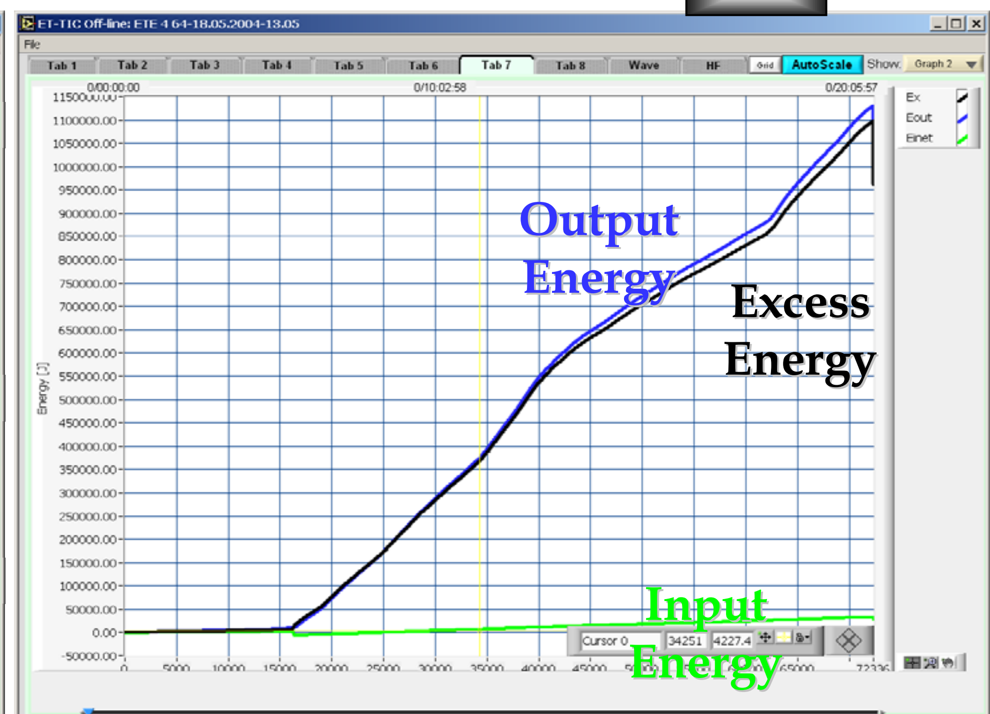
Energetics Results; ETI 64

- $P_{In} < 1W$, $P_{Out} > 34$ W, $P_{Gain} > 30$.
- E_{In} ~40 kJ, E_{Out} ~1.14 MJ, E_{XS} ~1.1 MJ, $E_{Gain} > 25$.
- 4.8 KeV/Pd atom

(2nd burst produced 3.5 MJ and 15.7 KeV/Pd)







SRI *Energetics (SW)* Replication

15 experiments performed using SRI data acquisition,

11 (***73%***) produced excess heat above the 3σ experimental uncertainty*.

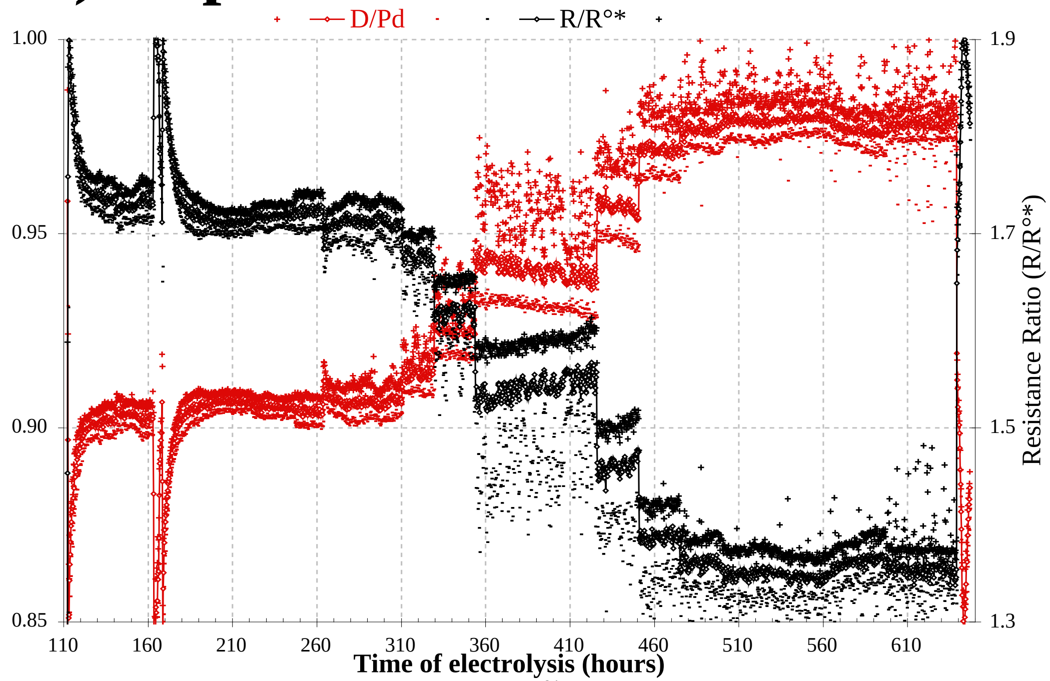
Reproducibility of SW experiments is attributable to:

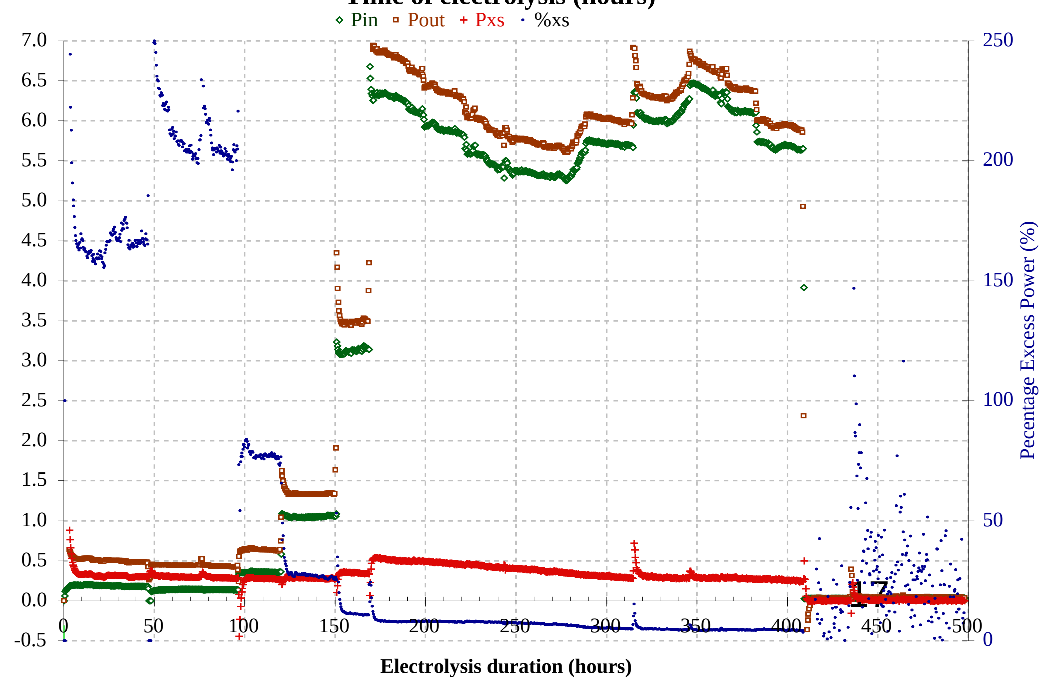
i. high deuterium atom loading,

ii. extraordinarily high interfacial flux

	Cell - Calorimeter	Cathode	Min. R/R°	Max. D/Pd	Excess % of P_{In}	Power (mW)	Energy (kJ)
1	9-7 E	Lot A	1.77	0.895	<5%		
2	11-8 E	L5(2)	1.67	**0.915**	**60%**	**340**	**514**
3	12-9 E	Lot A	1.84	0.877	<5%		
4	15-7 E	L5(1)	1.77	0.895	<5%		
5	16-8 E	L5(4)	1.86	0.871	<5%		
6	17-9 E	L1(1)	1.55	**0.939**	**20%**	**460**	**407**
7	21-7 E	# 830	1.92	0.836	<5%		
8	22-8 E	L5(3)	1.8	**0.888**	**30%**	**200**	**188**
9	35-7 S	L17(1)	1.32	**0.985**	**12%**	**1800**	**553**
10	35-8 S	L17(2)	0.95	**1.059**	**13%**	**2066**	**313**
11	35-9 S	L17	1.39	0.971	1%		
12	43-7 S	L14-2	1.73	**0.903**	**80%**	**1250**	**245**
13	43-8 S	ETI	1.63	0.923	**5%**	**525**	**65**
14	43-9 S	L14-3	1.61	0.927	1%		
15	51-7 S	L25B-1	1.55	**0.939**	**12%**	**266**	**176**
16	51-8 S	L25A-2	1.52	**0.945**	**5%**	**133**	**14**
17	51-9 S	L19	1.54	**0.941**	**43%**	**79**	**28**
18	56-7 S	L24F	1.55	**0.939**	**15%**	**2095**	**536**
19	56-8 S	L24D	1.84	0.877	4%		
20	56-9 S	L25B-2	1.56	0.937	3%		
21	57-8 S	Pd-C	N.A.	N.A.	**300%**	**93**	**115**
22	58-9 S	L25A	1.69	**0.911**	**200%**	**540**	**485**
23	61-7 S	L25B-1	1.63	**0.923**	**50%**	**105**	**146**

E = Energetics and S = SRI Data Acquisition.





* Similar results were obtained at ENEA Frascati

Correlations

- Necessary conditions:

Maintain High <u>Average</u> D/Pd Ratio (*Loading*)

For times >> 20-50 times $\tau_{D/D}$ (*Initiation*)

At electrolytic i >250-500mA cm^{-2} (*Activation*)

With an imposed D Flux (*Disequilibrium*)

- Heat correlated with:
  - Electrochemical current or current density
  - D/Pd loading *and/or* $V_{Ref.}$ surface potential
  - Interfacial kinetics (flux)
  - Pd metallurgy
  - Laser stimulus

- For 1mm dia. Pd wire cathodes*:

$$P_{xs} = M\,(x - x^{\circ})^2\,(i - i^{\circ})\,|i_D|$$

$x = D/Pd$, $x^{\circ} \sim 0.875$, $i^{\circ} = 50\text{-}400$mA cm^{-2}, $i_D = 2\text{-}20$ mA cm^{-2}, $t^{\circ} > 20\ \tau_{D/D}$

* 50 μm foils follow a similar equation with generally lower current thresholds.

Conclusions

Evidence was presented of new physical effects that:

- produce heat in metal deuterides under extreme but closely defined conditions
- are energetically consistent with nuclear but not chemical processes,
- can be observed in both electrochemical and gas loading experiments,
- result in the production of ^{4}He in amounts commensurate with D + D -› ^{4}He + ~24MeV (heat),
- can result in the production of ^{3}H, ~5-6 orders of magnitude less than heat and helium production.

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Observations

- Effect Evidenced on numerous occasions (*>70 at SRI*)
- Up to 90σ observation of excess power effect
- P_{XS} >1kW/cm^3 (transient)
- P_{XS} ~150W/cm^2 (1 month)
- $P_{Out}/P_{In} > 50$
- $E_{Out}/E_{In} > 30$
- E_{XS} > 100 MJ
- 100 – 10,000 eV/ Pd Atom
- Positive Temperature Coefficient
- (Effect observed up to 650°C