COLD FUSION LENR; ONE PERSPECTIVE ON THE STATE OF THE SCIENCE

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With recent publicity outside the CMNS field it has become increasingly important to clarify in non-specialist terms what is known and what is understood in the general field of so called Low Energy or lattice Enhanced Nuclear Reactions (LENR). It is also crucial and timely to expose and elaborate what objections or reservations exist with regard to these new understandings. In essence we are concerned with the answers to the following three questions: What do we think we know? Why do we think we know it? Why do doubts still exist in the broader scientific community?

The author will review progress in the LENR field with primary focus on the experimental work performed at SRI by and with its close collaborators (ENEA Frascati, Energetics and MIT) with a view to define experiment-based non-traditional understandings of new physical effects in metal deuterides. This review will be performed using the following methodology:

i. What initial hypothesis was proposed?
ii. What experimental methods were employed?
iii. What results were obtained?
iv. How were these results interpreted?
v. What new understanding was achieved?
vi. How does this fit in the framework of modern physics?
vii. What alternative explanations, or objections have been proposed?
viii. How can these objections be countered or incorporated into an improved understanding?

COLD FUSION, LENR, the Fleischmann-Pons Effect; ONE PERSPECTIVE on the STATE of the SCIENCE

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Overview

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

- 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.

- We are concerned with answers to the following questions:

  - What do we think we know?
  - Why do we think we know it?
  - Why do doubts still exist in the broader scientific community?
  - How do we propose to make progress?

Background

- Critical activities at SRI:
  - 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)
- Encouragement and participation in a number of significant and long-standing research partnerships and collaborations:
  - Stanford University [*Huggins, Crouch-Baker*]
  - Texas A&M, Cyclotron Center [*Wolf, Jevtic*]
  - MIT [*Hagelstein, Smullin, Chaudhary*]
  - Osaka University [*Arata, Zhang*]
  - ENEA Frascati [*Violante, Sarto, Castagna*]
  - Energetics [*Dardik, El Boher, Greenspan, Lesin, Zilov*]
  - University of Rome [*Bertolotti, Sibilia*]
  - NRL [*Hubler, Grabowsky, Knies, Melich, Nagel*]

Object

- To define and develop an experiment-based understanding of new physical effects in metal deuterides with primary focus on:
  - High loading and flux.
  - Lattice heat generation not consistent with known chemistry or storage effects.
  - The appearance of new elements or isotopes.
  - The registration of energetic particles.
- Review methadology:
  - What initial hypothesis was proposed?
  - What experimental methods were employed?
  - What results were obtained?
  - How were these results interpreted?
  - What is the consistency, laboratory-to-laboratory and sample-to-sample?
  - What new understanding was achieved from the analysis of results?
  - How does this knowledge fit in the framework of modern physics?
  - What alternative explanations, or objections have been proposed?
  - How are objections countered or incorporated into an improved understanding?
- What is the status of research?
- What are the prospects and programme for the future?

Order

- Excess Heat from D/Pd
- The “Q" value: Excess Heat and ^{4}He
- ^{3}H and ^{3}He
- Formation of higher mass isotopes
- Energetic particles and tracks
- γ and X-rays

Excess Heat: 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."

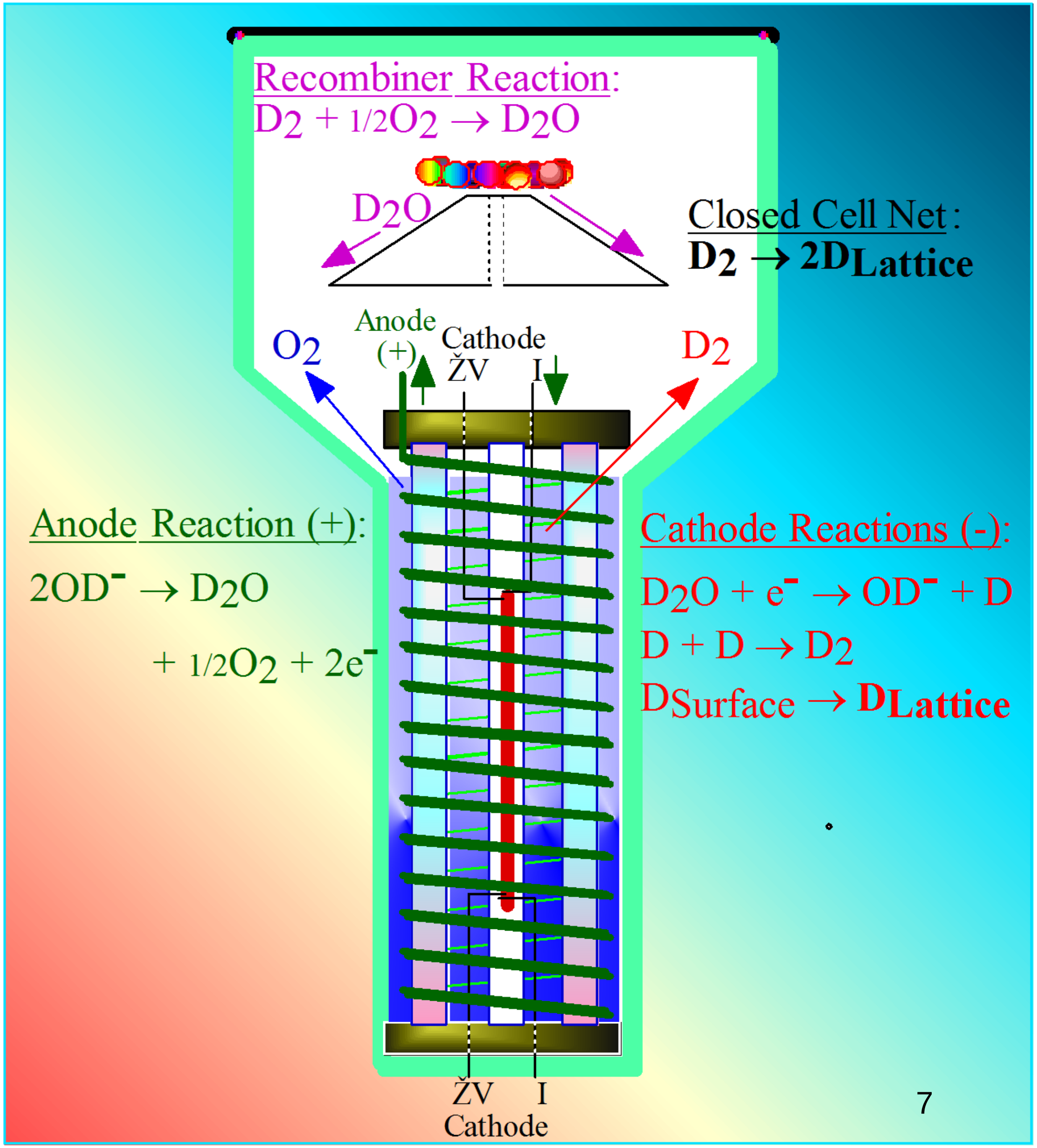
Experiments:

- 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%)*

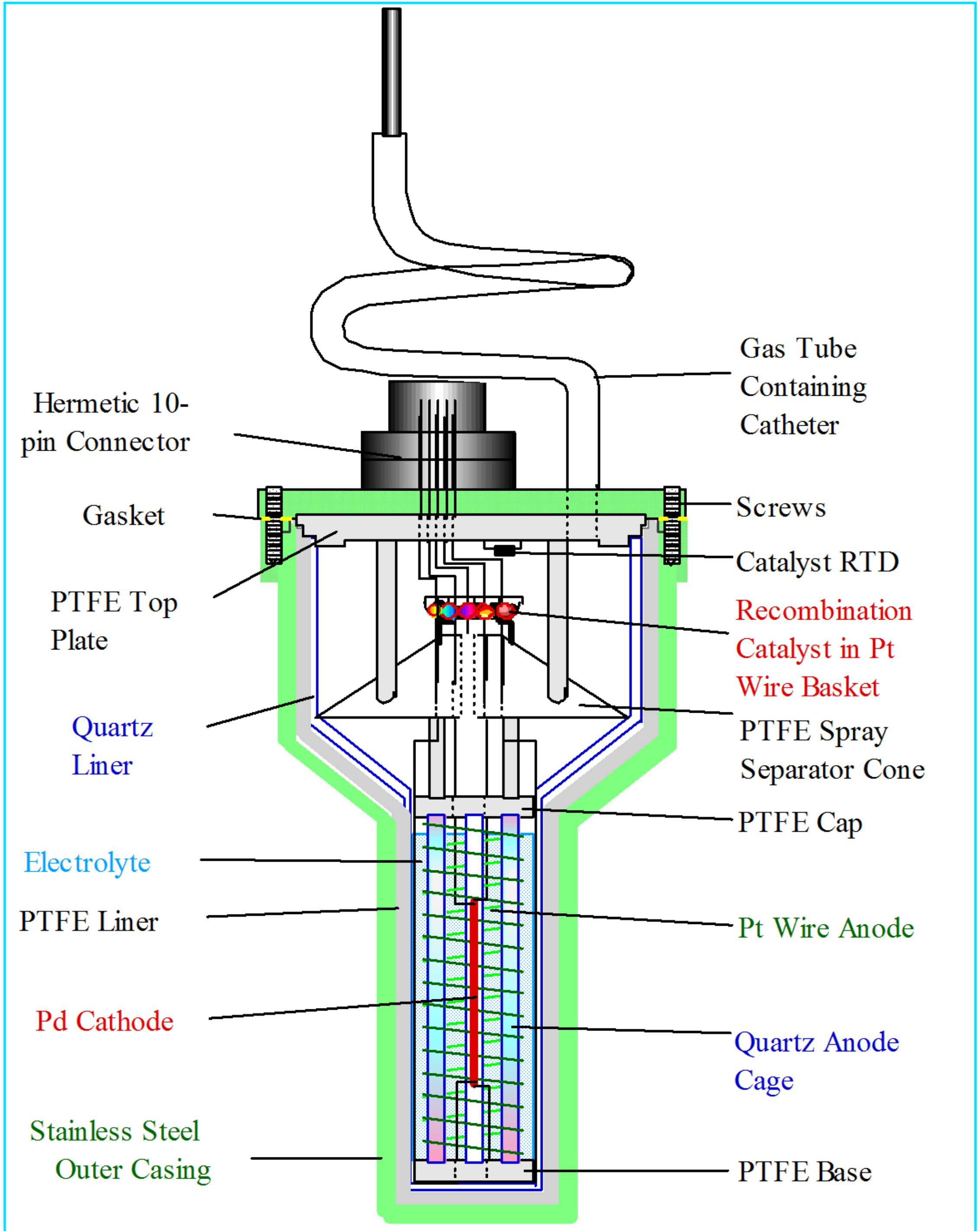
Loading Cell and Reactions.

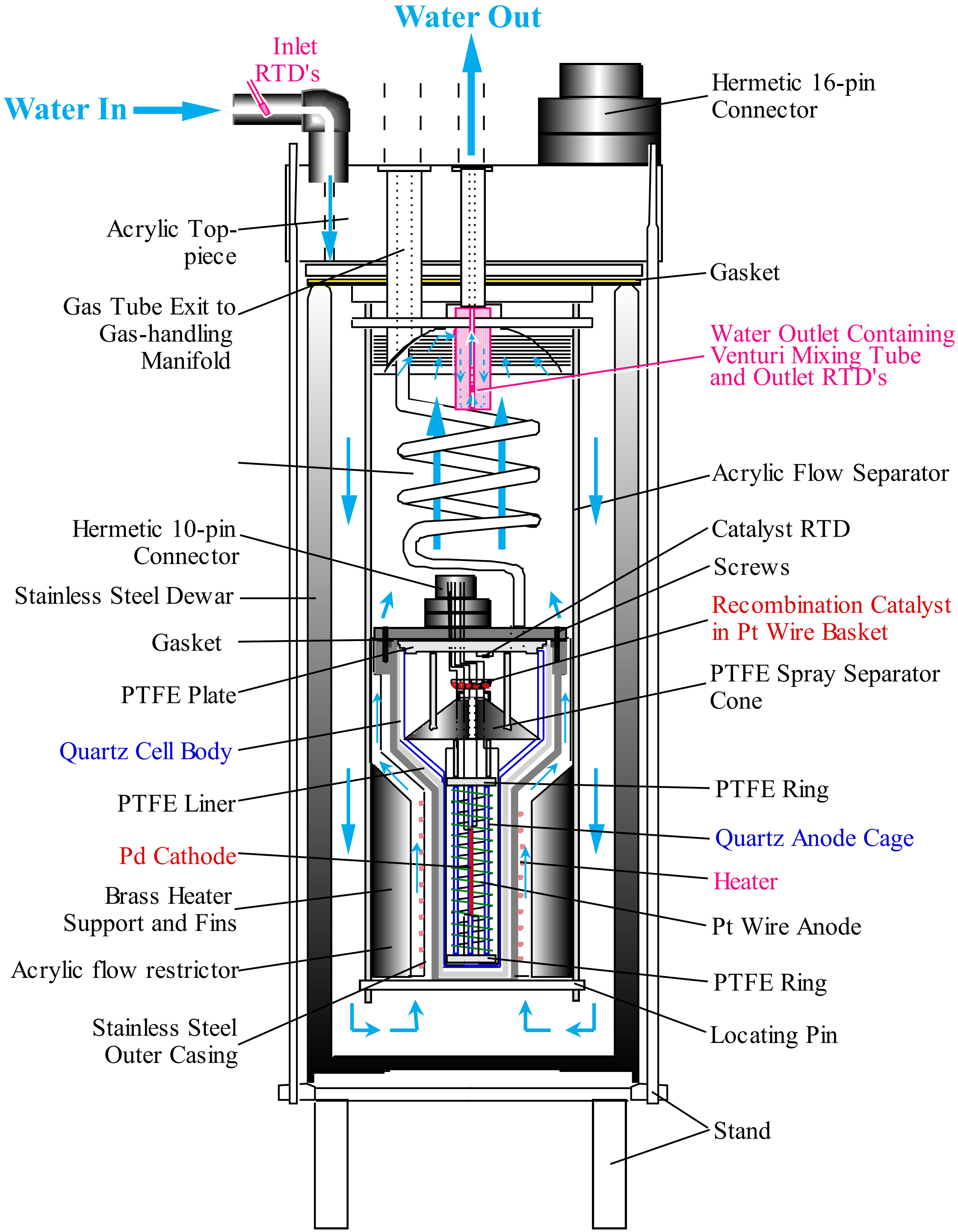
Wires:

1 – 3 mm in dia.
3 – 5 cm in length.
1M LiOD Electrolyte



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





SRI Labyrinth (L and M) Calorimeter and Cell

Accuracy: ±0.35%

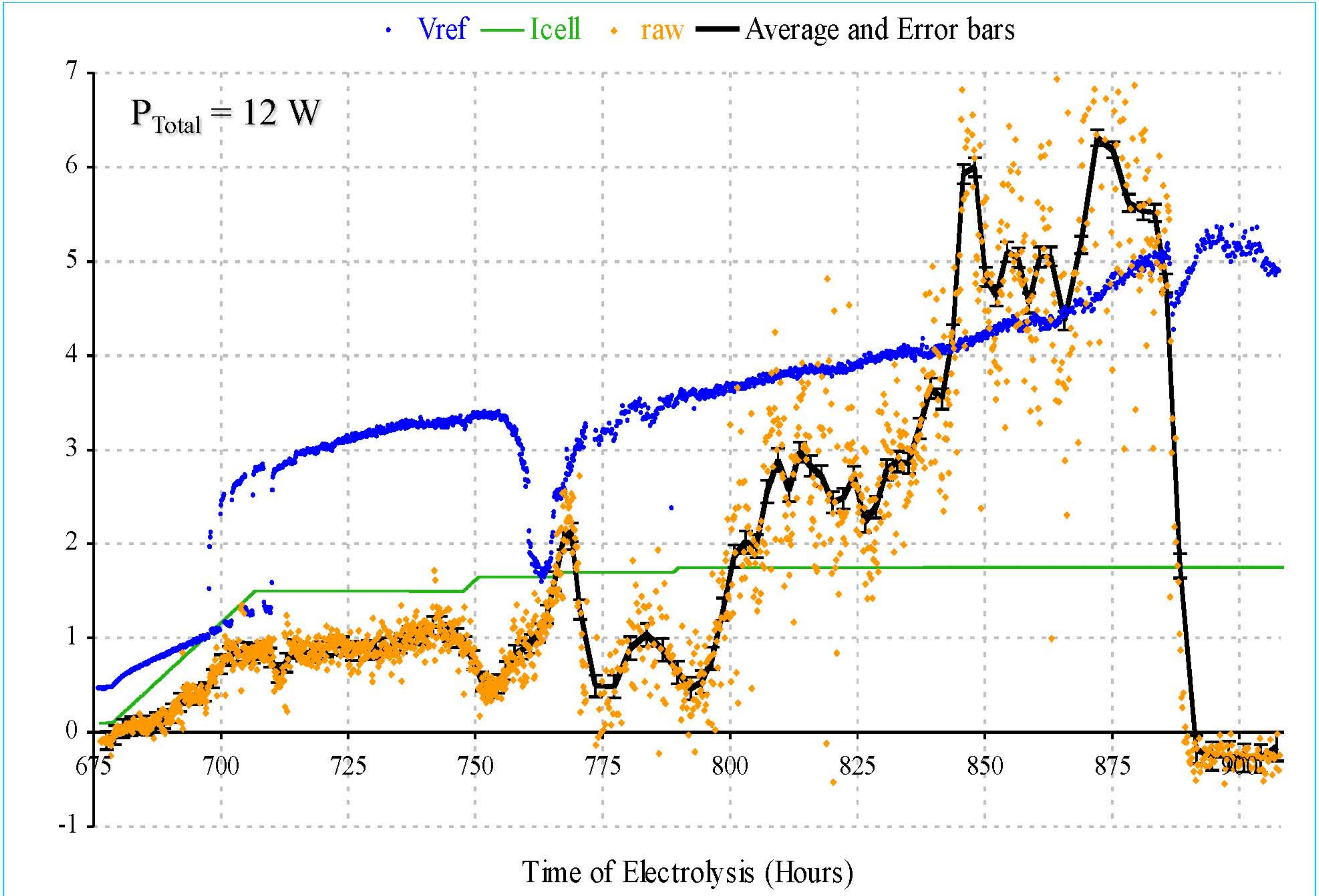
Operation:

100 mW – 30W

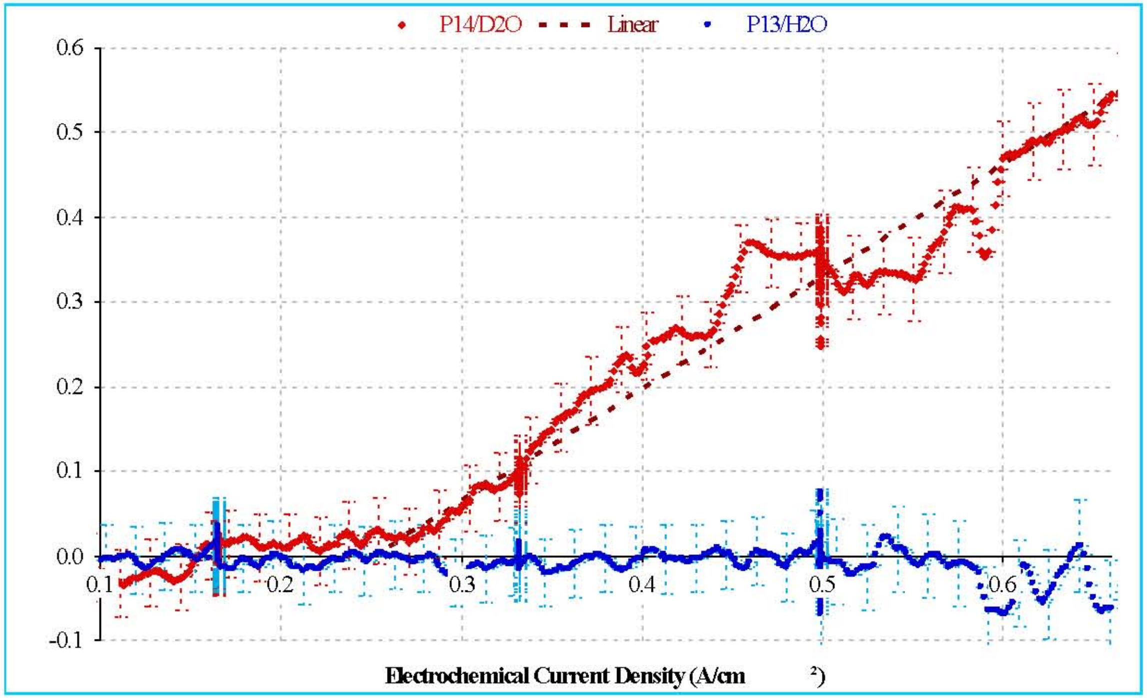
Stability:

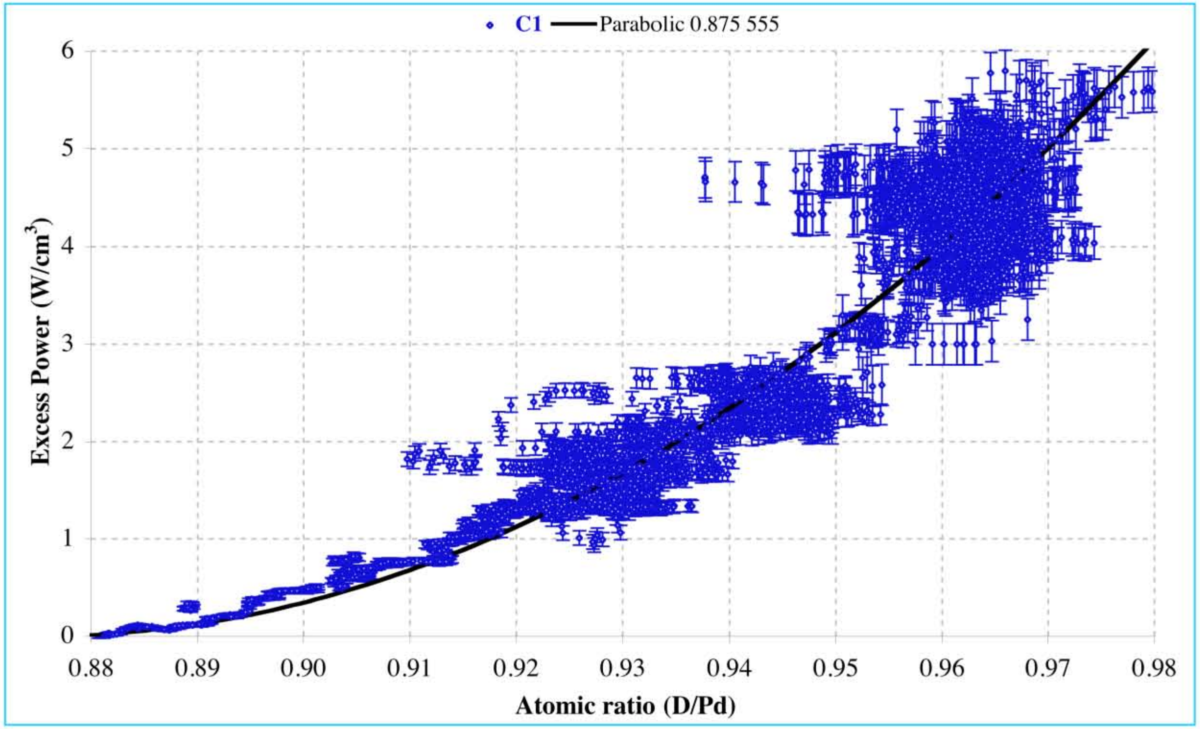
> 1000 hours

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



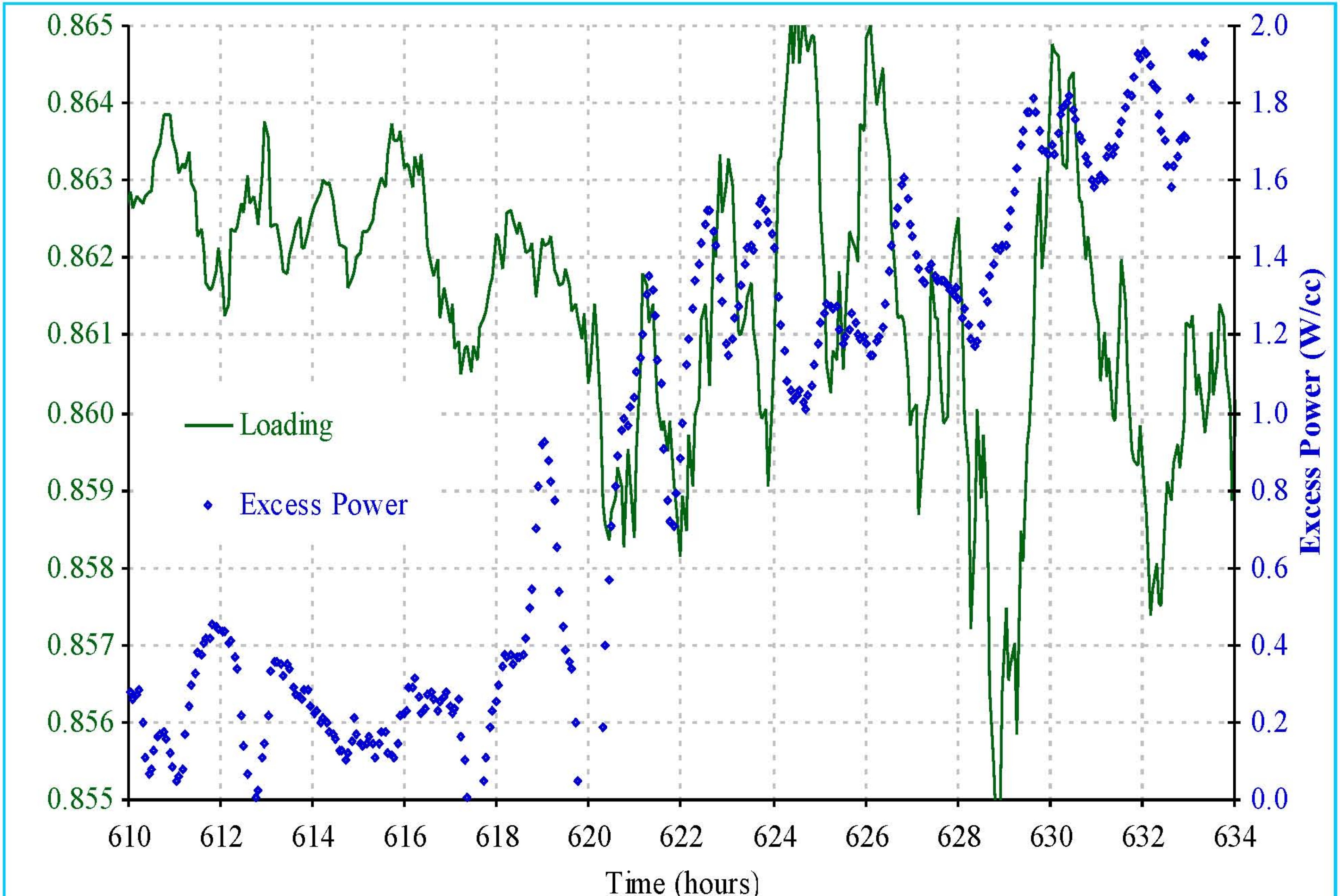
SRI *FPE* Replication



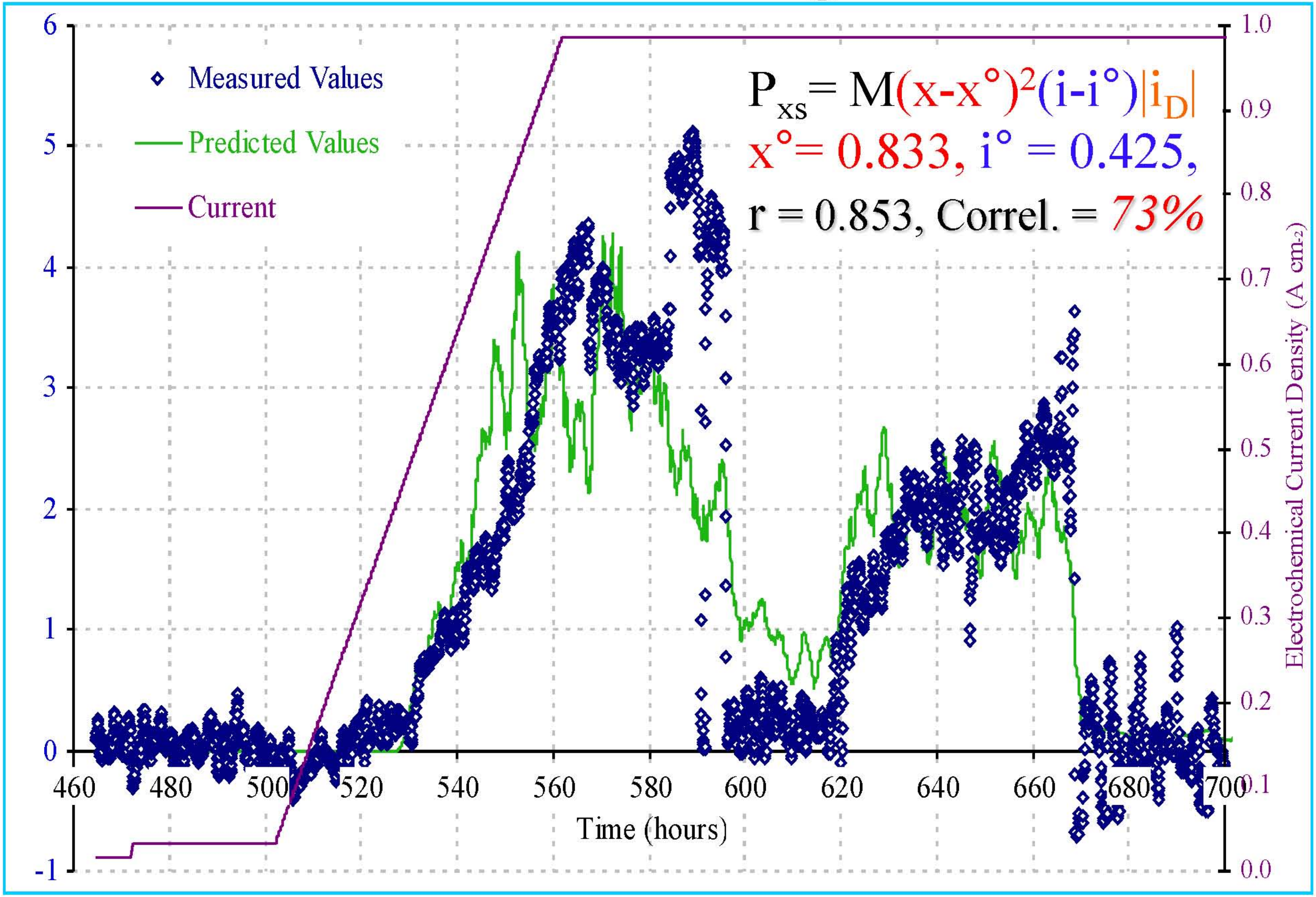


a) Nuclear -level heat release (1000's of eV/Pd Atom).
b) Current threshold and linear slope.
c) Loading threshold and parabolic rise of P_{XS}.

M4: The Dynamics of D Flux



M4: Excess Power Fitting Function



Correlations observed in SRI results

- 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 bulk loading *or* $V_{ref.}$ surface potential
  - Pd metallurgy
  - Laser stimulus

- For Pd wire cathodes* Mode A heat production:

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

x = D/Pd, x°~0.875, i°=75-450mA cm^{-2}, i_D=2-20 mA cm^{-2}, t°>20 $\tau_{D/D}$

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

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_{XS} / $P_{Electrochem.}$ > 3
- E_{XS} > 100 MJ
- 100 – 2,000 eV/ Pd Atom
- Positive Temperature Coefficient

Salient Criticisms*

- ❖ *"The experiments/results are not reproducible"*:
  - Some teams see no results (*football teams / nationality*)
  - Different results in different laboratories
  - Inconsistent results in the same laboratory with similar samples
- ❖ *"The results are inaccurate"*:
  - Mis-measurement of input power
  - Mis-measurement of output power
  - The delta (P_{XS}) is not outside the measurement uncertainty
- ❖ *"The heat is real but is due to unknown or unaccounted chemical effects or lattice energy storage"*:
  - Over-accounting for electrolysis products (V_{TN})
  - Chemistry in the electrolyte volume
  - Energy storage and release (small % ∫ energy)
  - Hydrinos or "new" chemistry [Black Light Power]
- ❖ *"Missing nuclear products"*:
  - Quantitative energetic products not seen ("ash")
  - Difficulty of measuring ^{4}He in the presence of D_2 and ambient

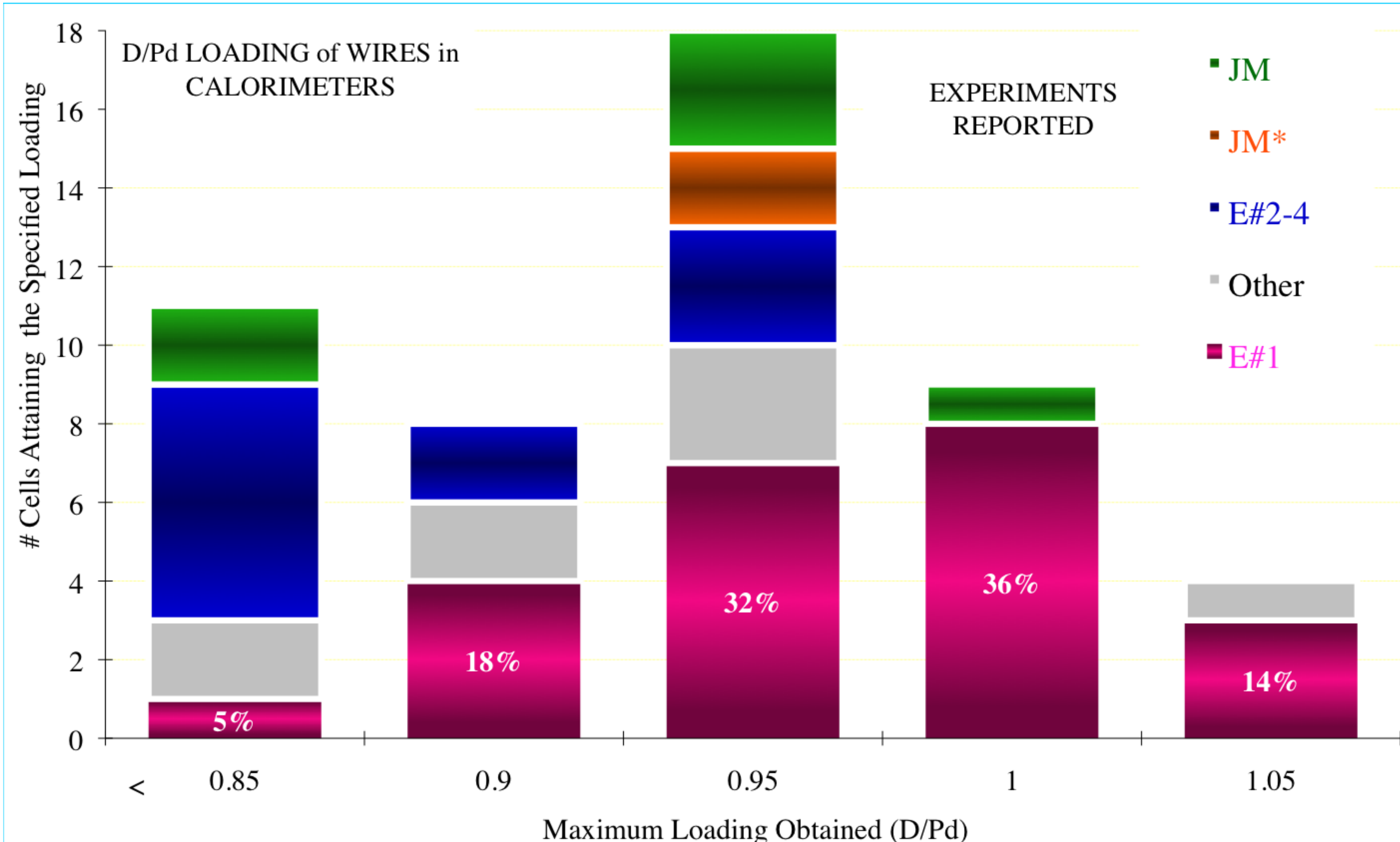
* Salient |ˈsālyənt; -lēənt|adjective

1 most noticeable or important *: it succinctly covered all the salient points of the case.• prominent;*

2 Heraldry (of an animal) standing on its hind legs with the forepaws raised, as if leaping.

"The experiments/results are not reproducible"

- Electrodes made from the same lot of materials (Pd) produce consistent levels of excess heat
- $P_{xs} = M\,(x-x^{\circ})^2\,(i-i^{\circ})\,|i_D|$, $x^{\circ} \sim 0.875$ D/Pd, all terms are important!



Electrodes capable of attaining and maintaining high loading – are capable of producing excess heat

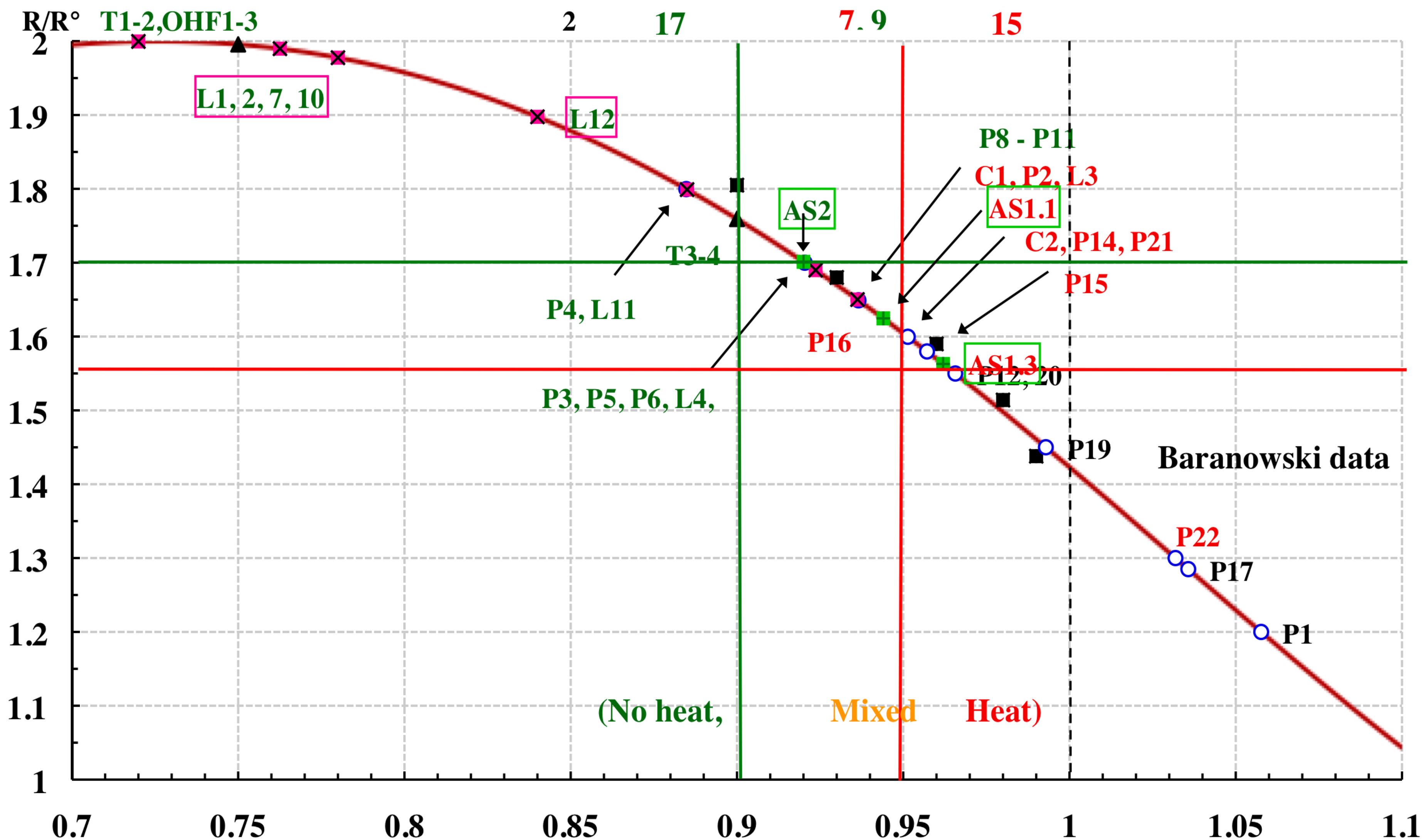
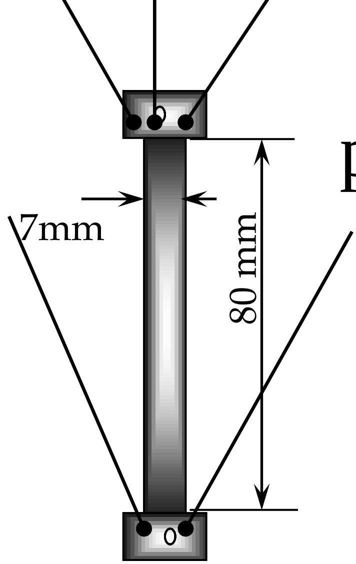


Figure 1 Maximum loading, D/Pd, attained in experiment; determined by R/R°.

Electrodes made from the same Material Lots – produce similar excess heat in different calorimeters

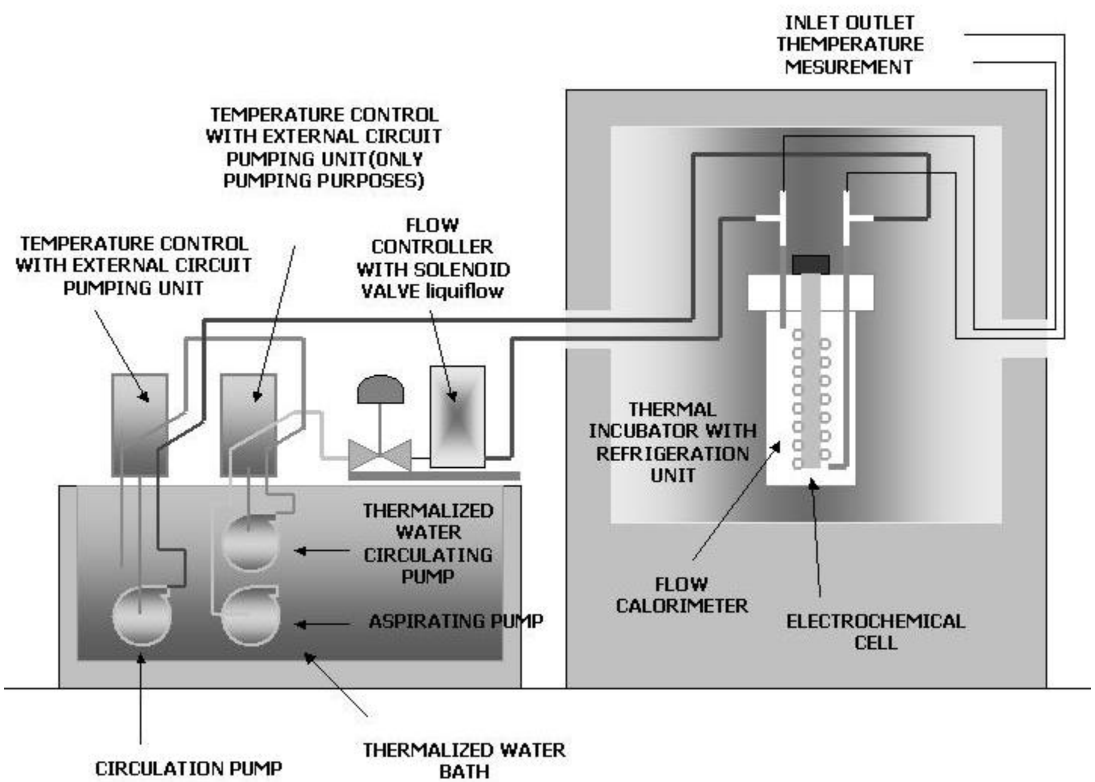


Cathode: Pd foil 50 µm

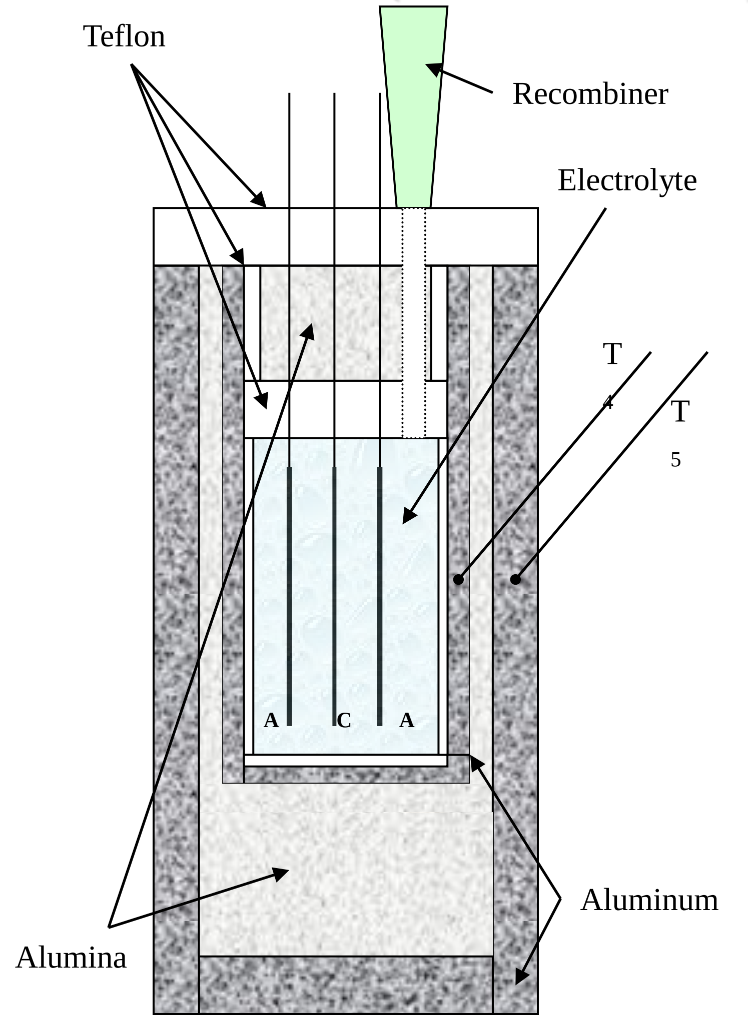
Annealed at 870^0C in vacuum for 1h

prepared by V. Violante, ENEA Frascati

ENEA Mass Flow Calorimeter



Energetics Isoperibolic Calorimeter (also used at SRI)



SRI/ENEA DARPA-sponsored *Energetics (SW)* Replication

15 experiments performed using SRI DAQ,

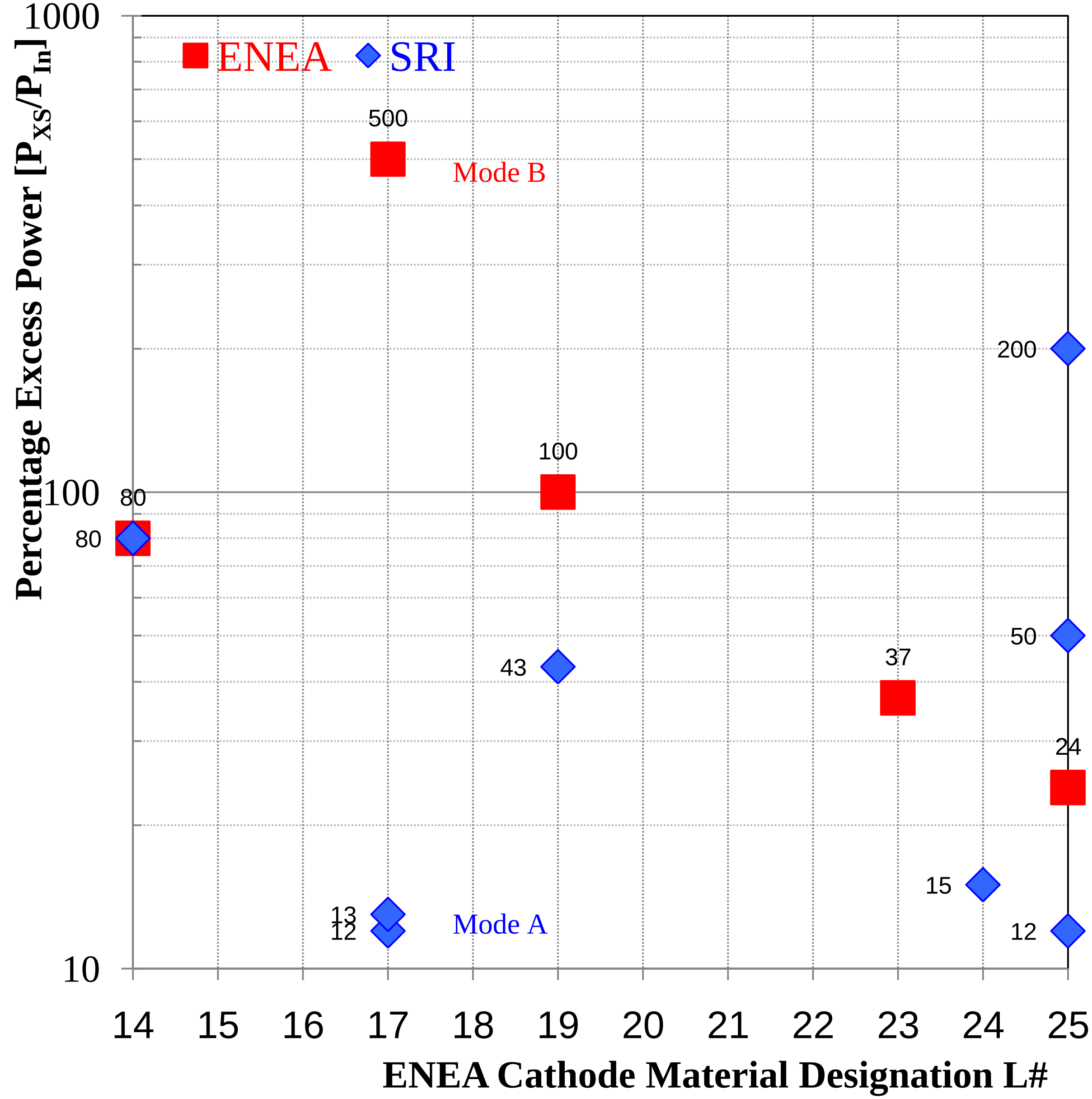
11 (*73%*) produced excess heat above 3σ.

	Cell - Calorimeter	Cathode	Min. R/R°	Max. D/Pd	Excess Power % of P_{In}	Excess 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.

6 experiments performed using ENEA DAQ, and Mass Flow Cal. produced significant P_{XS}.

Data Acquisition	Cathode	Min. R/R°	Max. D/Pd	Excess Power % of P_{In}	Mode
ENEA	L14	1.54	0.941	80	B
ENEA	L17	1.4	0.969	500	B
ENEA	L19	1.7	0.909	100	A
ENEA	L23	1.69	0.911	37	B
ENEA	L25A	1.8	0.888	24	B
ENEA	L30	1.78	0.892	7000	B



McKubre-Dardik-Violante, *et al*, Replication of Condensed Matter Heat Production, in *Low-Energy Nuclear Reactions Sourcebook*, Marwan, J., ACS Symposium Series 998, Oxford University Press, 2008, p. 219.

"The results are inaccurate"

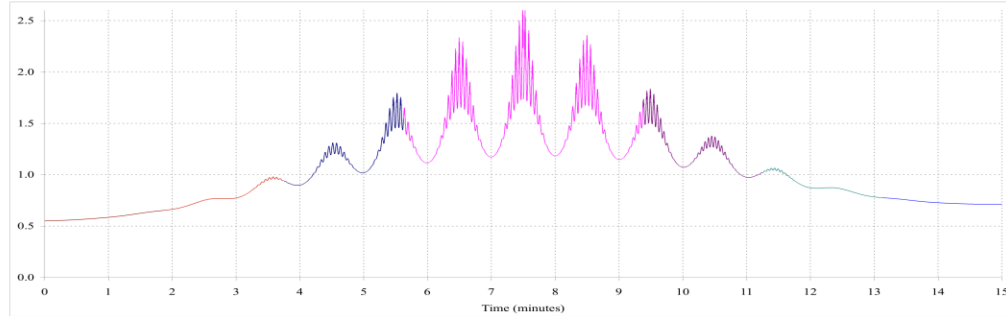
- "Mis-measurement of input electrical power":
  - Relatively simple measurement (I, V, R, t)
  - Slightly more difficult for non-dc input (SW, pulses)
  - Use `scopes and transient analyzers to quantify "hidden" inputs
  - Calorimeter is the best measure and most experiments for most of the time register no thermal imbalance (calibrations, blanks).
- "Mis-measurement of thermal output power":
  - Thermal balance…
  - Different calorimetric methods (multiple) show consistent effects
  - Mass flow calorimeter:
    - Simple device
    - First principles
    - Very little to calibrate
    - In SS operation the qualitative effect is unmistakable
- "$P_{XS} = P_{Out} - P_{In}$ < measurement uncertainty":
  - Pre- post- and interim calibration
  - SRI 90 σ observation (P15 – slide 10)
  - Hundreds of observations of $P_{XS} > 3\ \sigma$
  - Effects persist for hours, days, weeks, (> 1 month)
  - $P_{Out} / P_{In} > 2, 3, 5, 25!$

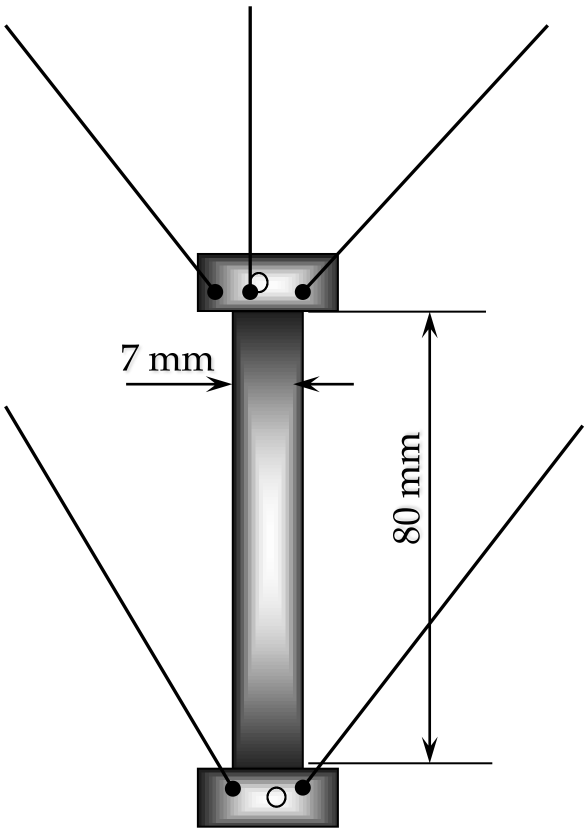
"The effect is due to chemistry or energy storage"

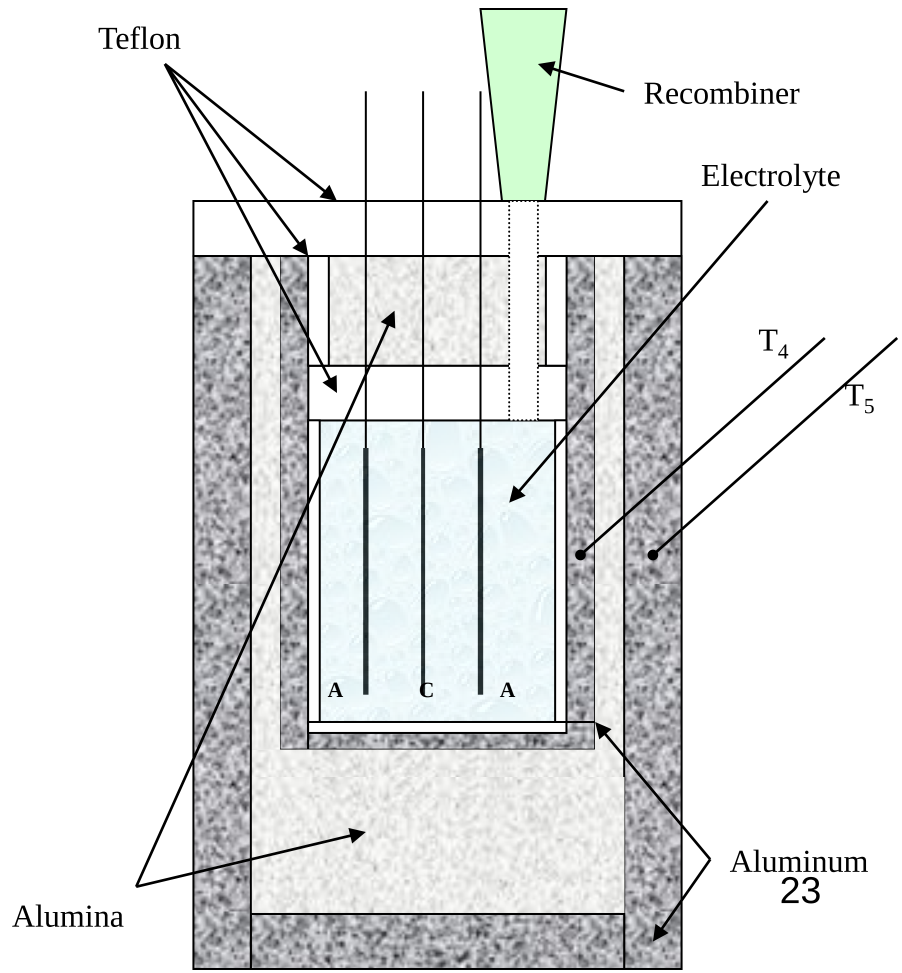
- Over-accounting for electrolysis products (V_{TN})":
  - The effect is seen in closed cells
  - Accurate account is taken for electrolyte watering
- "Chemistry in the electrolyte volume":
  - Effect 100 – 1000 times > sum of all possible chemical reactions*
  - Reactant concentrations are monitored
  - Normalized to Pd (or D/Pd) we measure 10^2 – 10^4 eV/atom
- "Energy storage (slow) and release (rapid)":
  - P_{XS} measured for > 50% of some experiments
  - 10^2 – 10^4 eV/atom would be novel (and useful)
  - E_{XS} / E_{In} > 25 measured in (at least) 1 experiment
- "Hydrinos or other "exotic" chemistry":
  - This effect not considered here

Energetics* Energy Gain [1]

- $P_{In} < 1W$, $P_{Out} > 34$ W, $P_{Gain} > 30$.
- E_{In} ~40 kJ, E_{Out} ~1.14 MJ, E_{XS} ~1.1 MJ, $E_{Gain} > 25$, T>100°C.
- 4.8 KeV/Pd atom
- 2nd burst produced 3.5 MJ and 15.7 KeV/Pd)

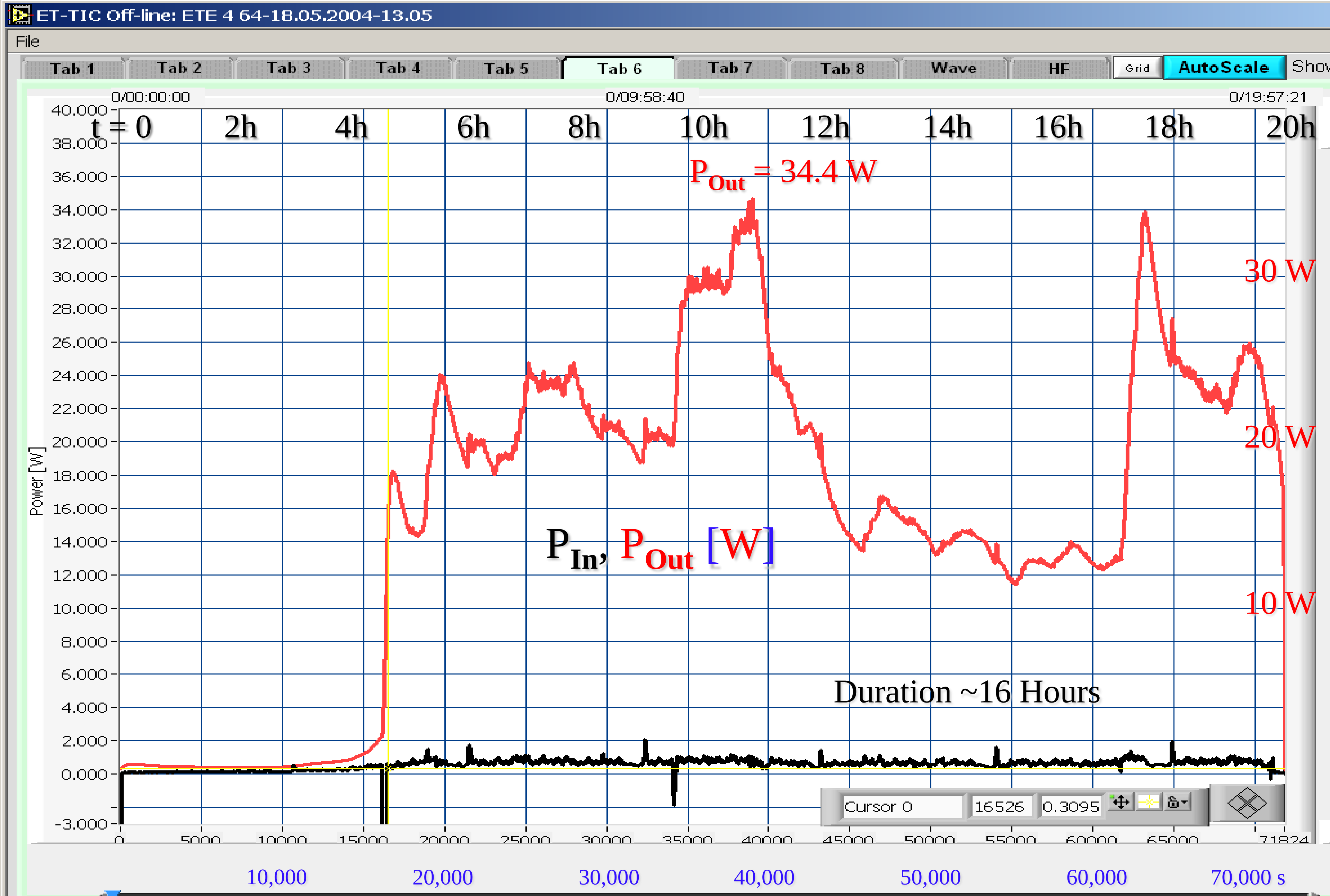




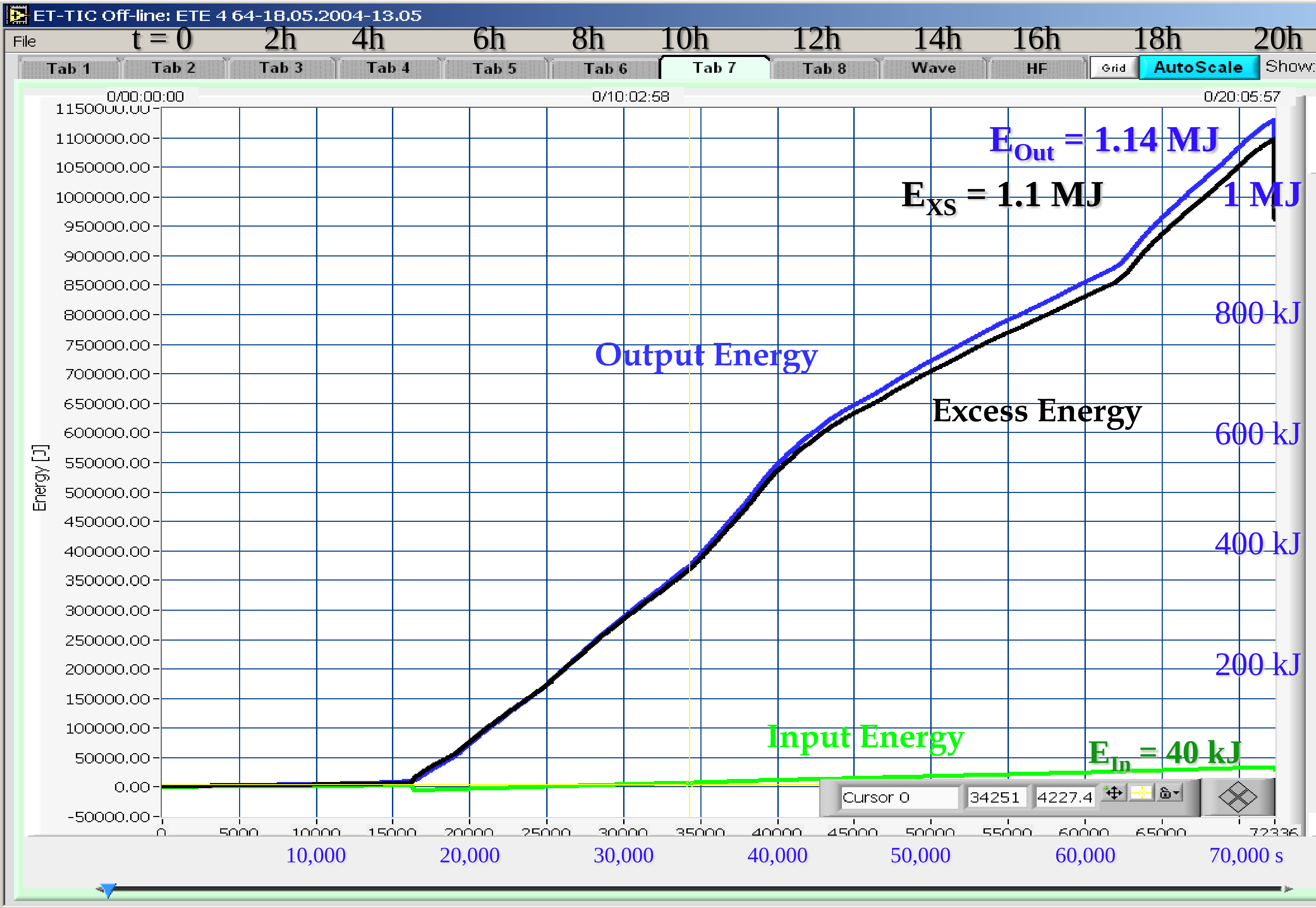


* Dardik, El Boher, Lesin, Zilov, *et al*, Excess Heat in Electrolysis Experiments at Energetics Technologies, in *Proceedings, ICCF11, Marseilles*, Biberian, J-P., World Scientific, 2004, p. 84.

Energetics Energy Gain [2] (P_{XS})



Energetics Energy Gain [3] (E_{XS})



"*Where is the ash?*"

- "The expected energetic radiation does not accompany the (putative) heat production":
  - "*The circumstances of hot fusion are not those of cold fusion*" – J. Schwinger (1989).
- "The nuclear products claimed cannot account for the excess heat":
  - ^{3}H and ^{3}He are produced in FPE experiments – under special circumstances – largely asynchronous with the excess energy
  - Claims for "massive transmutation" at (or above) the levels needed to account for measured excess energy have yet to be verified
- "The claimed quantitative product (^{4}He) is":
  a) Impossible to produce
     - This is an experimental question
     - Theoretical denial is unscientific
  b) Difficult to measure (D_2, ambient)
     - True but reliable measurements can (and have) been made with care
  c) Not found in sufficient quantity
     - Where people have looked carefully they have found quantitative or "semi-quantitative" ^{4}He [more work is needed]

"^{4}**He**: Hypothesis 2"

"The quantitative product of the heat producing reaction is ^{4}He that evolves primarily without associated energetic byproducts"

Experiments:

- ❖ Simultaneous measurement of Excess Heat and gas phase ^{4}He
  - ➢ All metal-sealed apparatus – integral
  - ➢ Self purging – rate
- ❖ Retrospective measurement of metal phase ^{4}He
  - ➢ "easy" to find
  - ➢ difficult to quantify

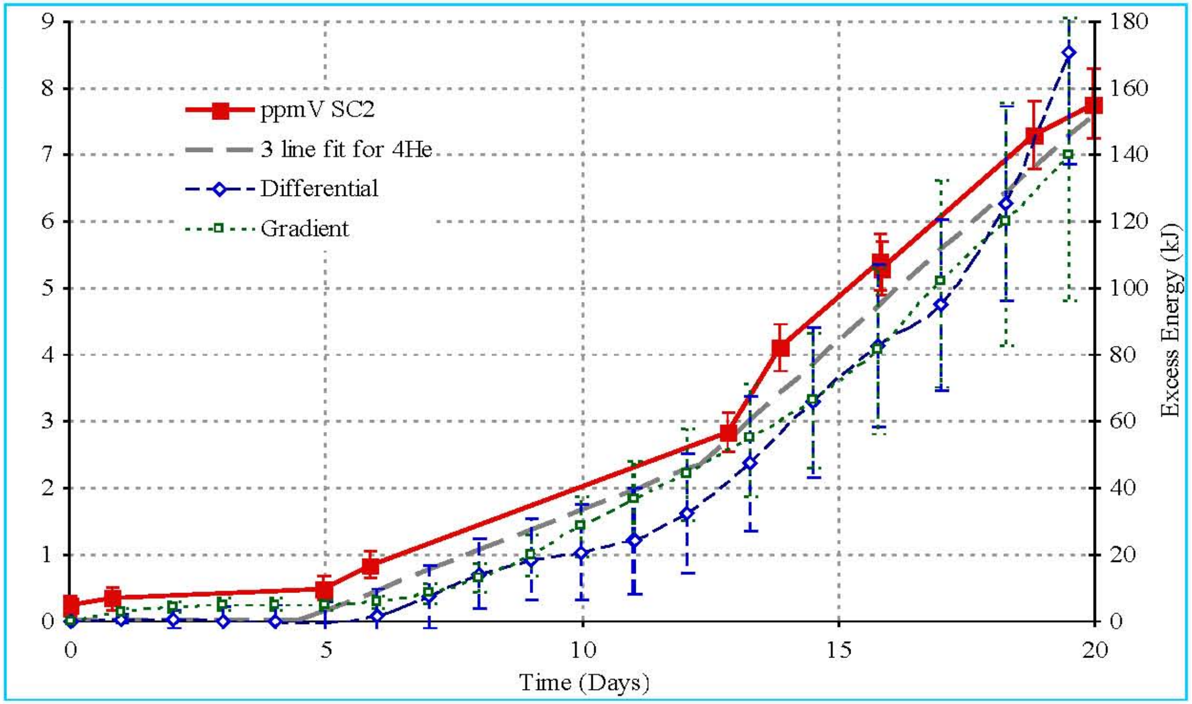
"^{4}He – a little history"

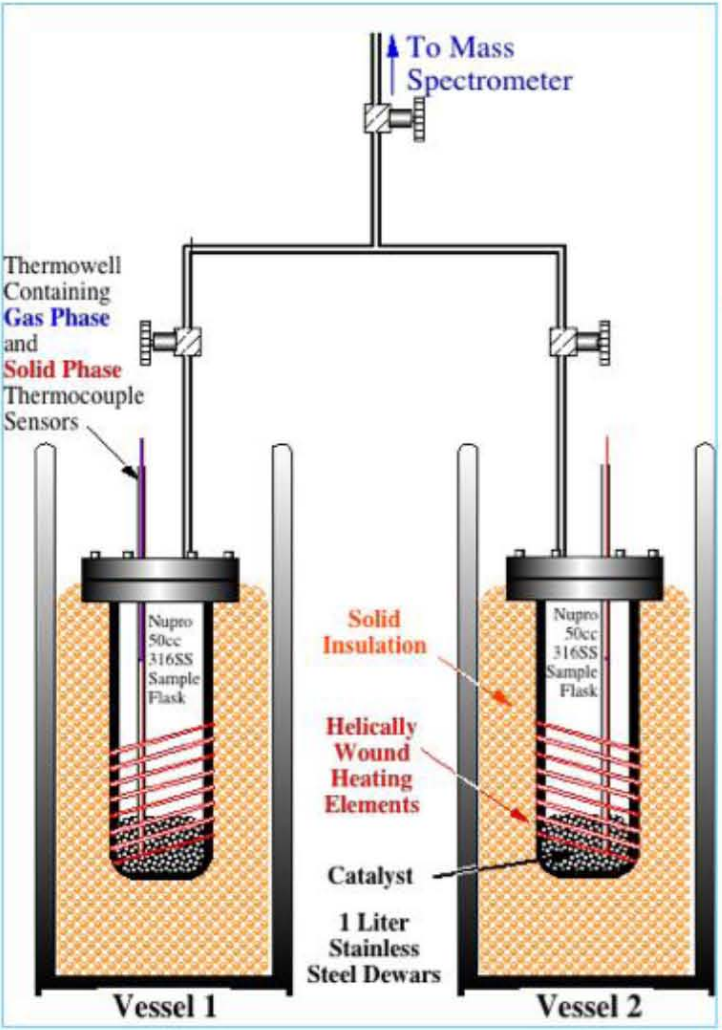
- Miles-Bush
  - Self-sparging "open" cells (1990-1994)
  - Statistical analysis of [Heat|Helium] (1 in 750,000 random chance)
  - $1.4 \pm .7 \times 10^{11}$ ^{4}He s^{-1} W^{-1} (*c.f.* 2.5×10^{11}) - 54% of "expected" value
  - Confirmed by Bush at SRI $1.5 \pm .2 \times 10^{11}$ - 58% of "expected" value
  - Rate (not integral) measurement, small [^{4}He], sealing?
- "The Italians":
  - Gozzi *et al* – simultaneous measurements, time correlation
  - De Ninno, del Guidice, Preparata – "super"-quantitative ^{4}He?
  - Violante *et al* – confirmed SRI/Case – lattice retention
- Arata and Zhang
  - ^{3}He and ^{4}He in gas and solid phases*
  - ^{3}He (from ^{3}H decay) confirmed at SRI
  - *New results from gas-loading studies?*
- SRI
  - Case – Pd/C gas phase
  - FPE electrolysis (M4)

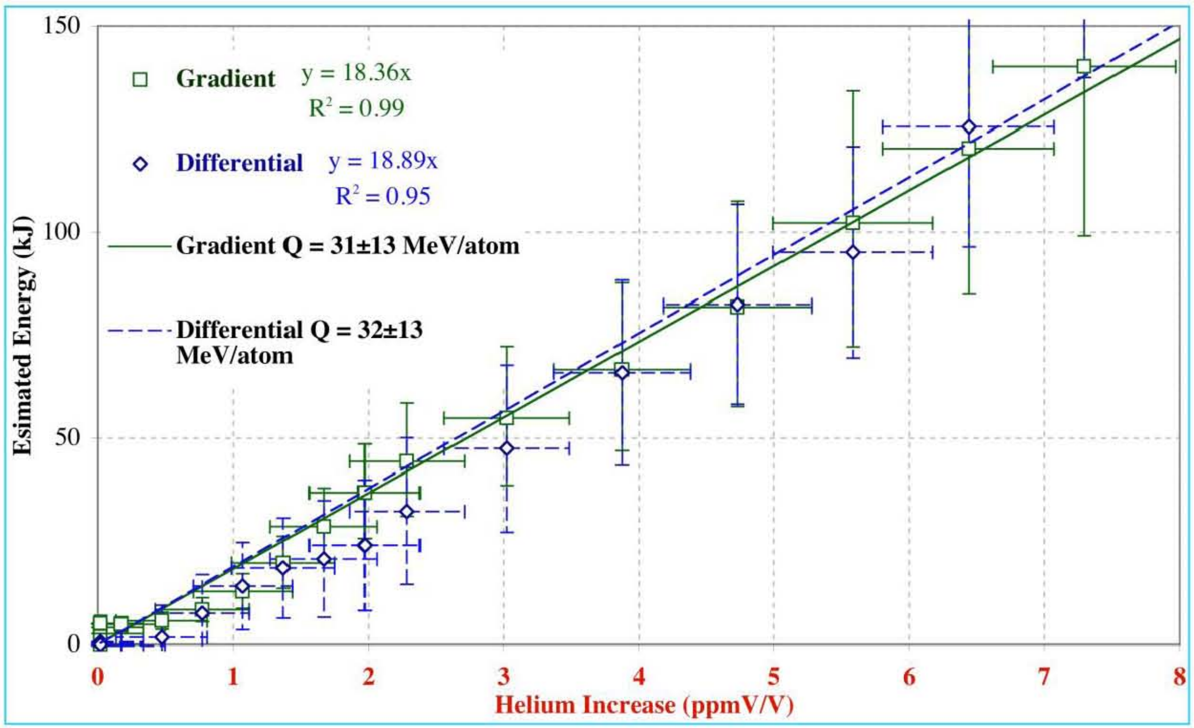
* An additional 15 studies found unexpected ^{4}He in metal cathodes after FPE energy production [Storms].

SRI *Case* Replication

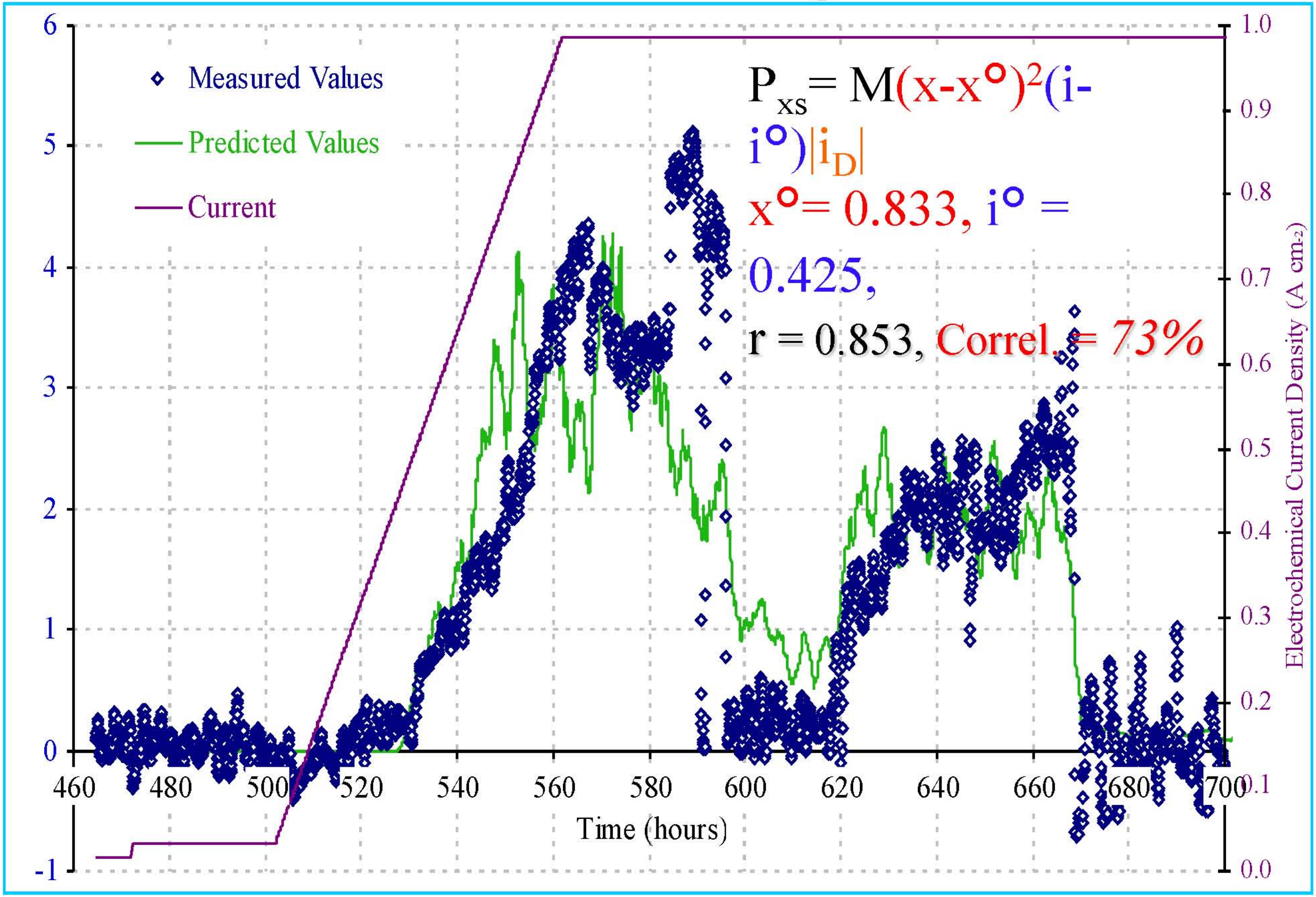
a) Correlated Heat and ^4He
b) Q = 31 ± 13 MeV/atom
c) Discrepancy due to solid phase retention of ^4He.



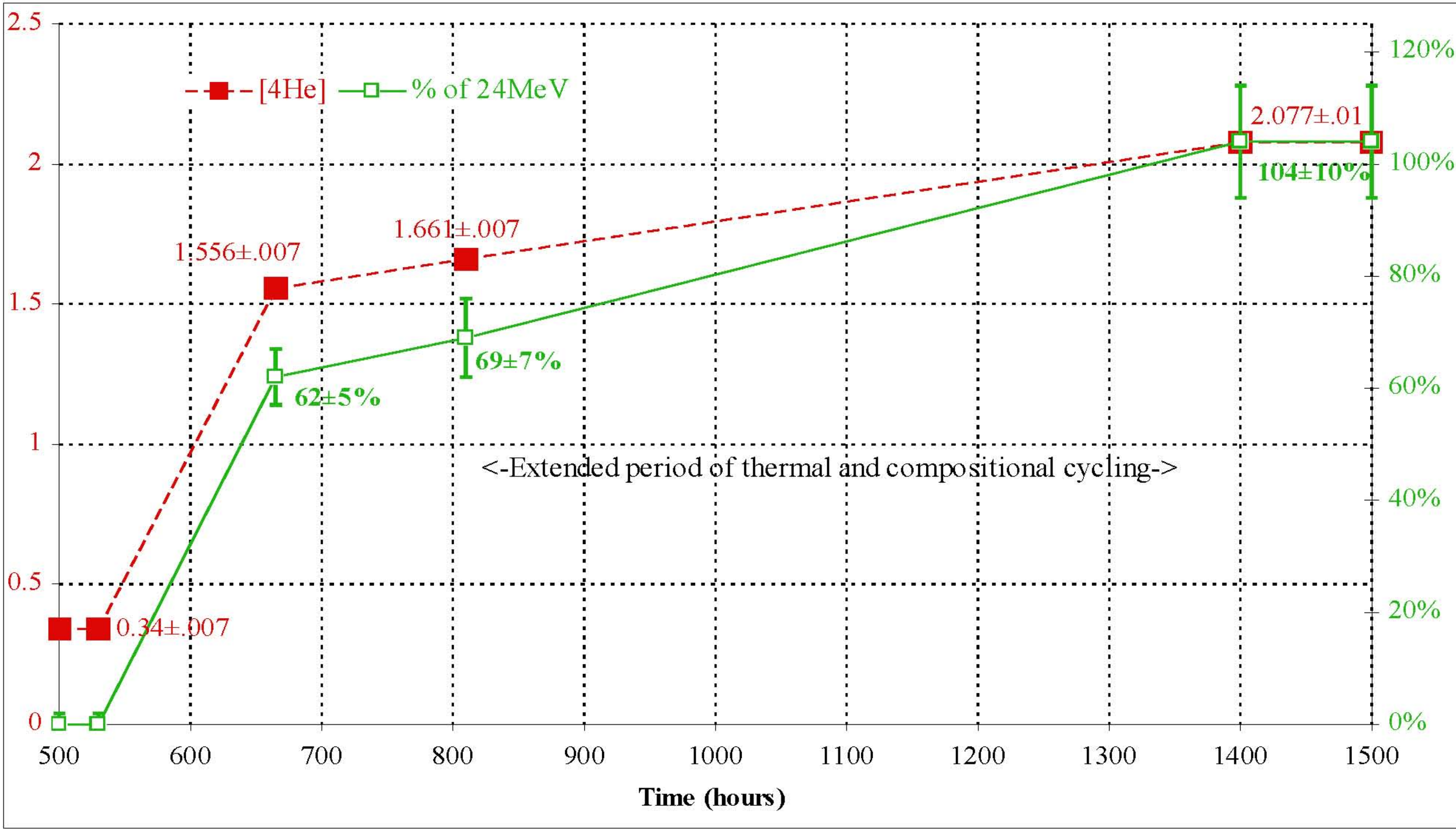




M4: Excess Power Fitting Function



SRI *M4* Helium



- Mass balance of ^4He is quantitatively consistent with

  $D + D \rightarrow {}^4He + 24\ MeV\ Heat_{Lattice}$

- ~ 30 - 40% of the ^4He is bound loosely at or near the cathode surface

Preliminary answers

❖ Is the effect real?

- The FPE is new effect in physics
- Requires a new mechanistic description and explanation
- Very likely associated with a significant number of CMN Effects
- Once explained the underlying effect will not seem “so strange”

❖ What is the effect?

- Heat production consistent with nuclear but not chemical energy or known lattice storage effects
- Temporally and quantitatively accompanied by ^{4}He
- A number of other nuclear products and processes (some of which may be of “more than scientific” interest)

❖ How do we make progress?

- Theory: quantitative, predictive fundamental physics description
- Science: we must engage the broader scientific community
- Commerce: create, market and sell product(s) based on the effect
- Public/Politic: growing public concern/interest in “Alternative Energy” options

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