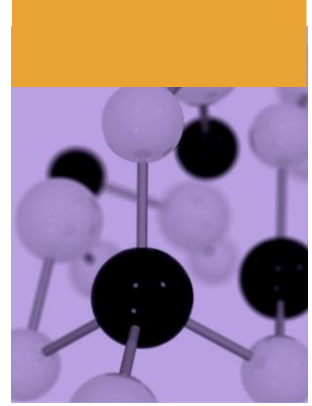
SRI International



What Happened to Cold Fusion?

Michael C.H. McKubre, Ph.D.

SRI International

"Whether it's improving our health or harnessing clean energy, protecting our security or succeeding in the global economy, our future depends on reaffirming America's role as the world's engine of scientific discovery and technological innovation"

President Barak Obama January 2010

October 11, 2011

SRI International Building

The World of Condensed Matter Nuclear Science

Terminology

Problems, Progress and Prospects

Reactions in General

Organization of the Field

BIG Unresolved Questions

Terminology

Cold Fusion: Original and recognized name, but incomplete description
Low-Energy Nuclear Reactions: "Low" is a relative and unclear term
Lattice Enabled Nuclear Reaction: Clear and specific, but very new concept
Lattice Assisted Nuclear Reaction: Also accurate, but not widely used
Chemical Assisted Nuclear Reactions: Many chemists like this
Solid State Nuclear Fusion
Cold Fusion Phenomena
Cold Fusion Nuclear Reactions
} Narrowly used

Cold Nuclear Transmutations: A Russian favorite
New Hydrogen Energy: A major Japanese government program
Metal Deuterium Energy: A current program in Japan

Fleischmann-Pons Effect: Clear and encompassing

SANER: SAfe Nuclear Energy Release

The subject is a part of the field called **Condensed Matter Nuclear Science**
There is an International Society for CMNS in the UK: www.iscmns.org

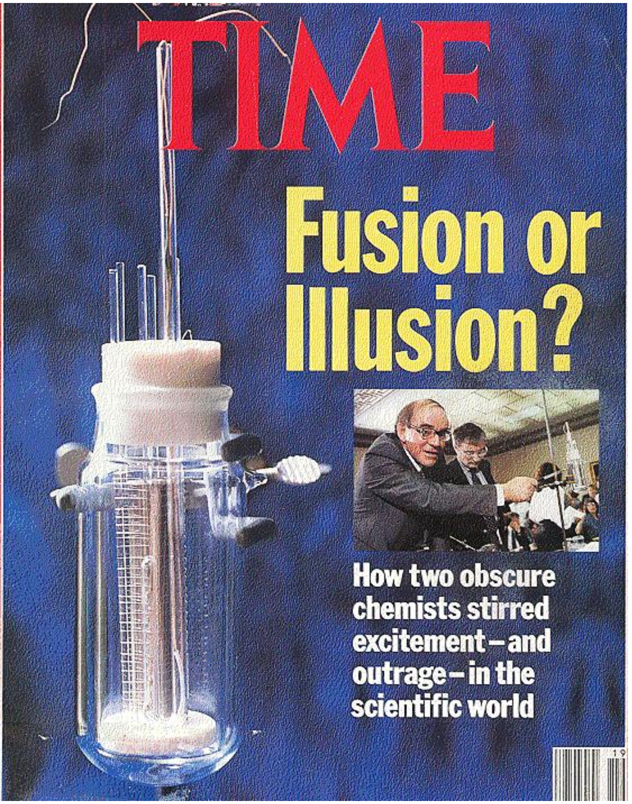
Problems

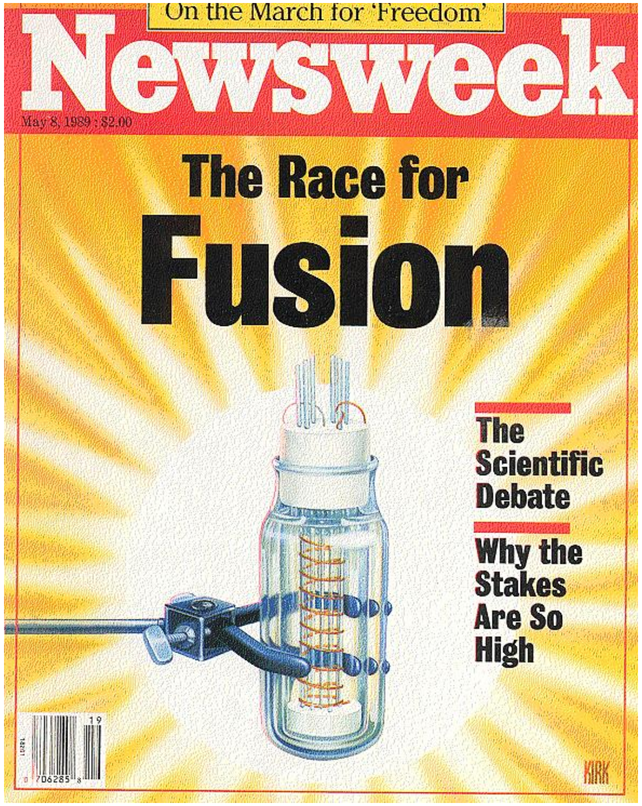
- Potential Importance for Energy
- Polarization of Scientists
- Diverse Mistakes
- Technical Complexity
- Flows of Money and Information

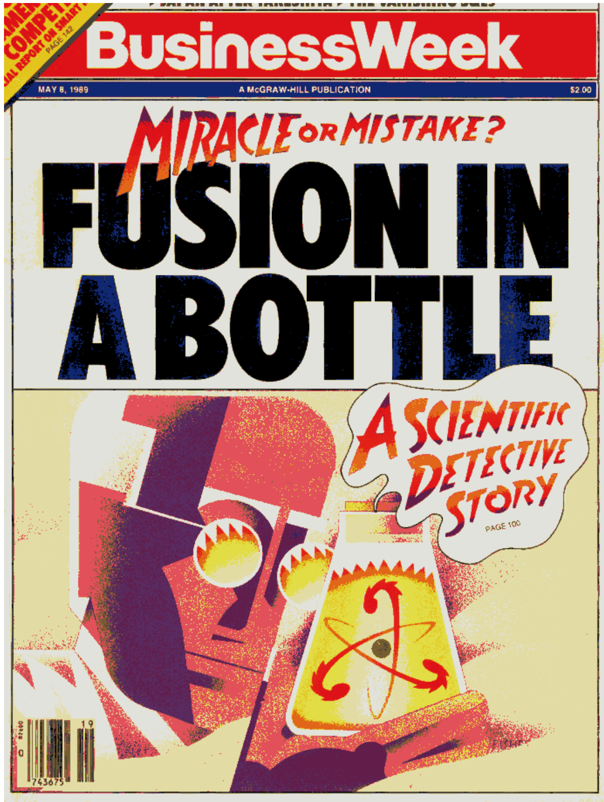
  - disrupted early and remain poor

Magazine Cover Stories

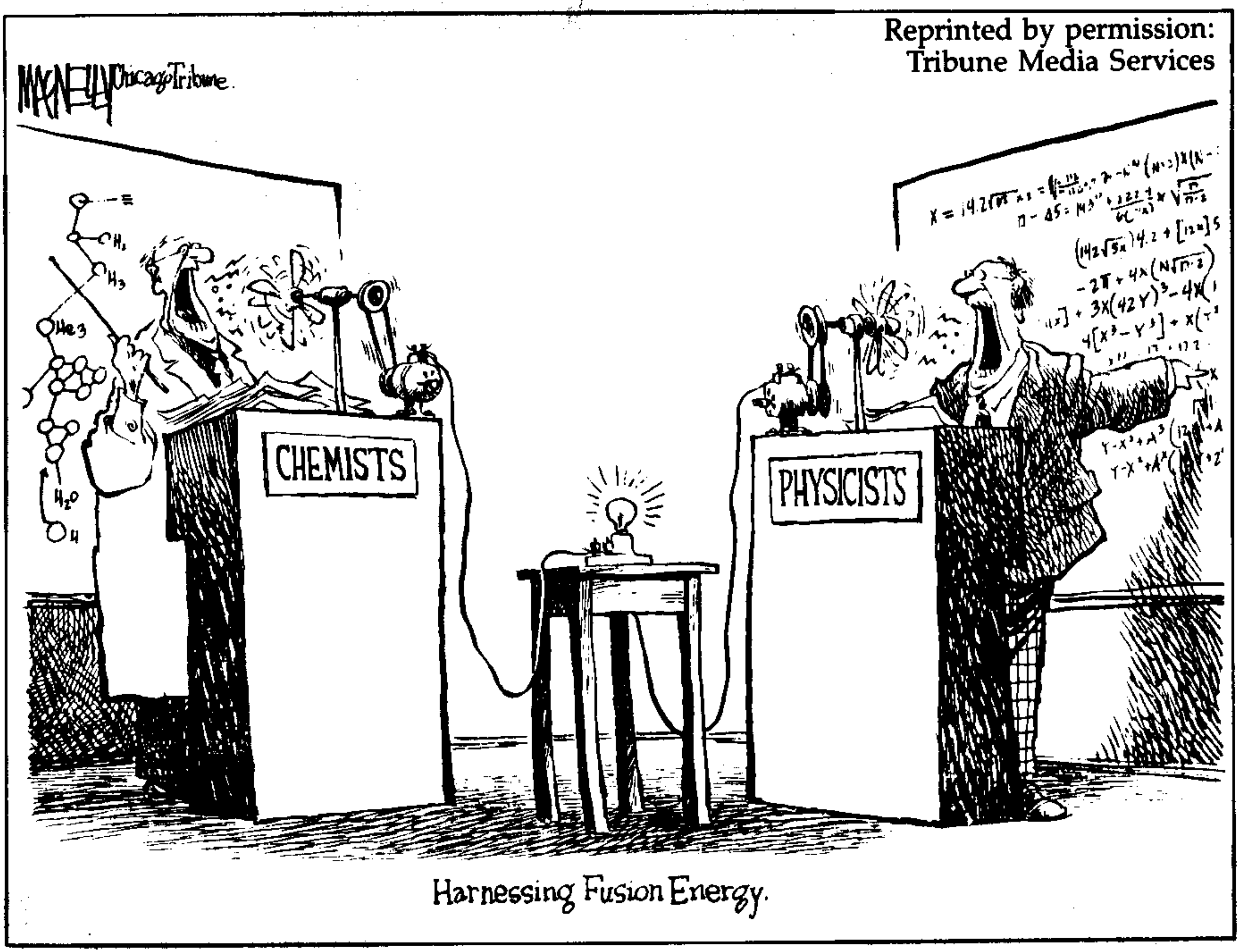
May 1989







Truly Extraordinary Interest

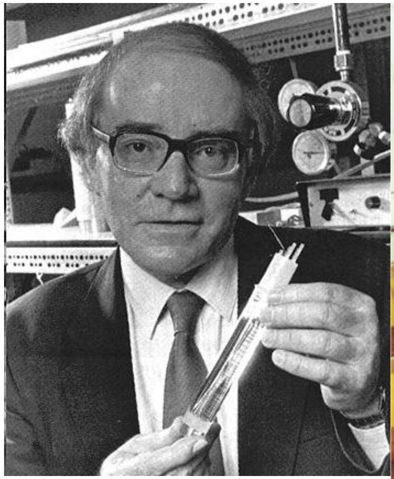


Research and Development Magazine (July 1989)

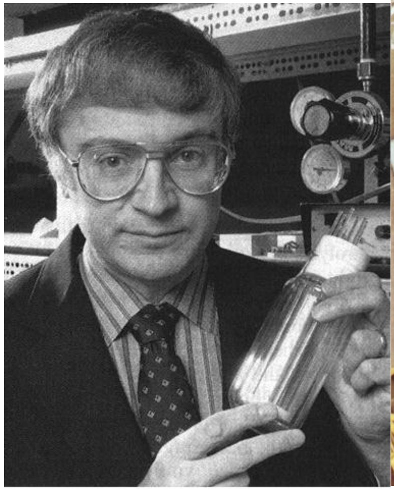
Tokomak Fusion Test Reactor [TFTR]

Princeton University

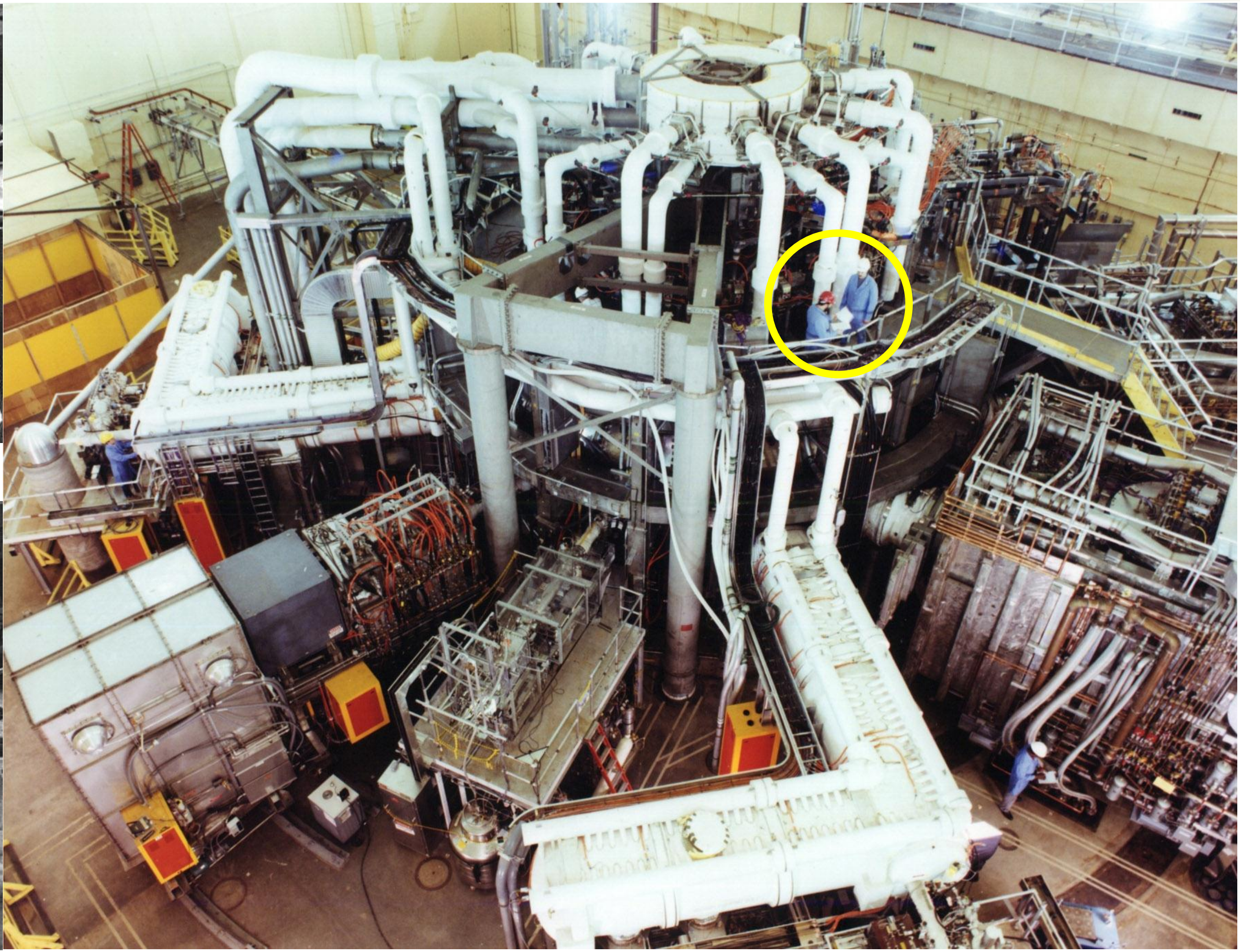
1989



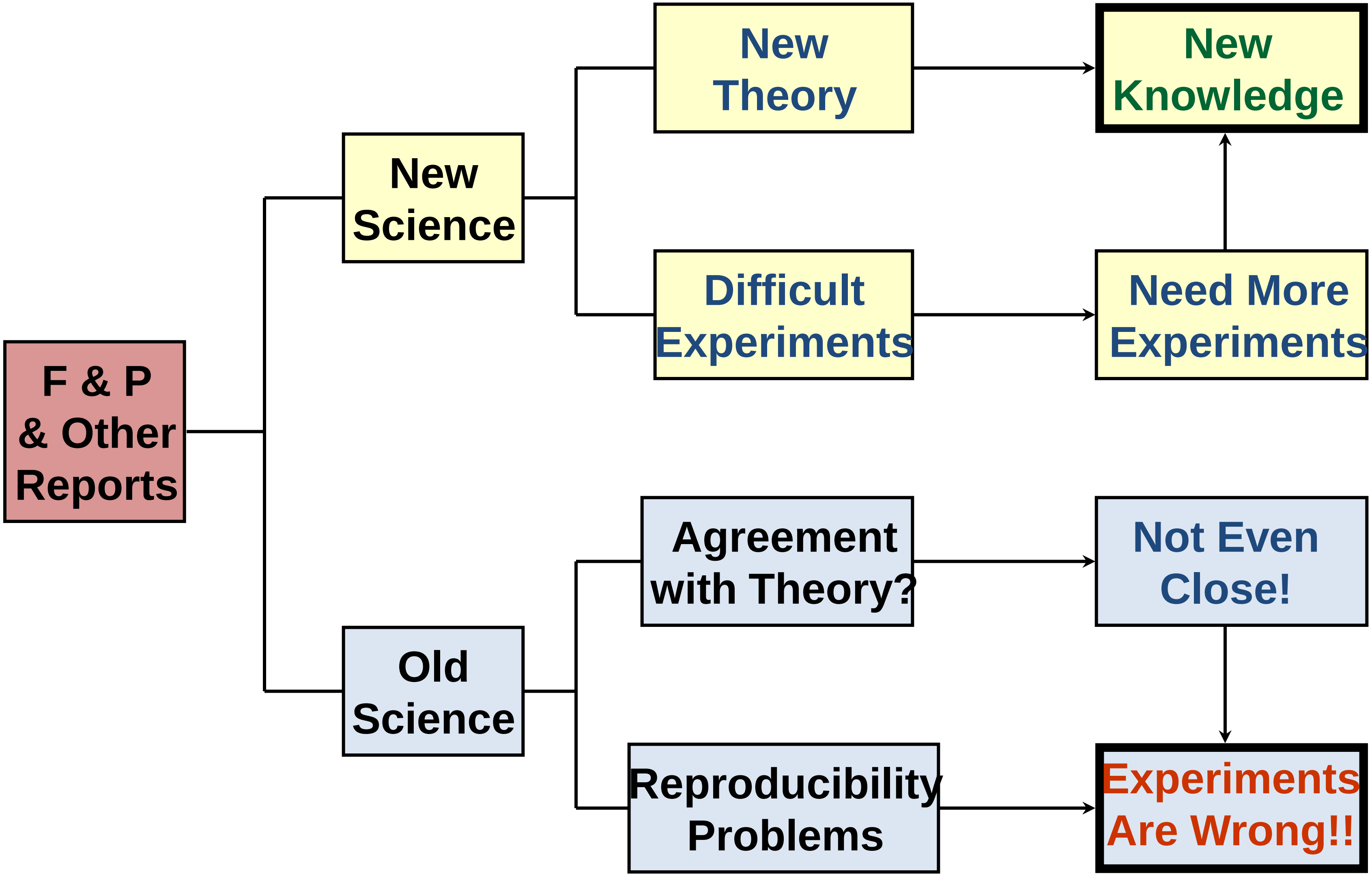
Martin Fleischmann



Stanley Pons



A Major Problem with the Experimental Situation



Two Major Parts of the Field Now

- Electrochemical loading of Deuterons into Palladium
  - The initial Fleischmann-Pons approach
  - Most work in the field has been in this class
- Gas loading of Protons into Nickel
  - Work began by Piantelli in early 1990s
  - Approach used by Rossi in recent years
  - Recent results at SRI

FPE Experiments, Electrochemistry and Calorimetry

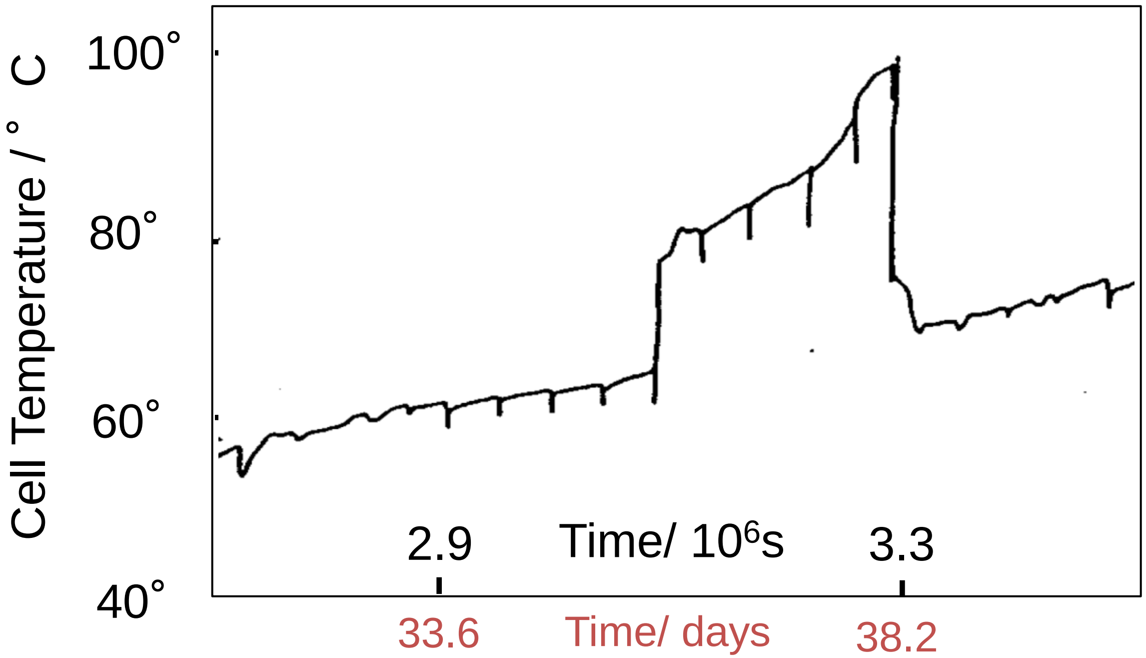
Fleishmann and Pons early results

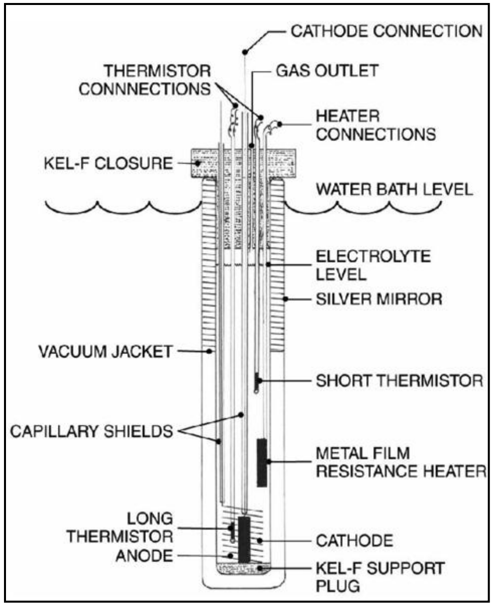
Calorimeters

Electrochemistry and loading

SRI cells and results

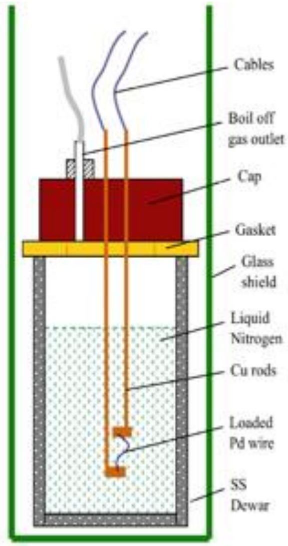
Early Data on Cell Temperature

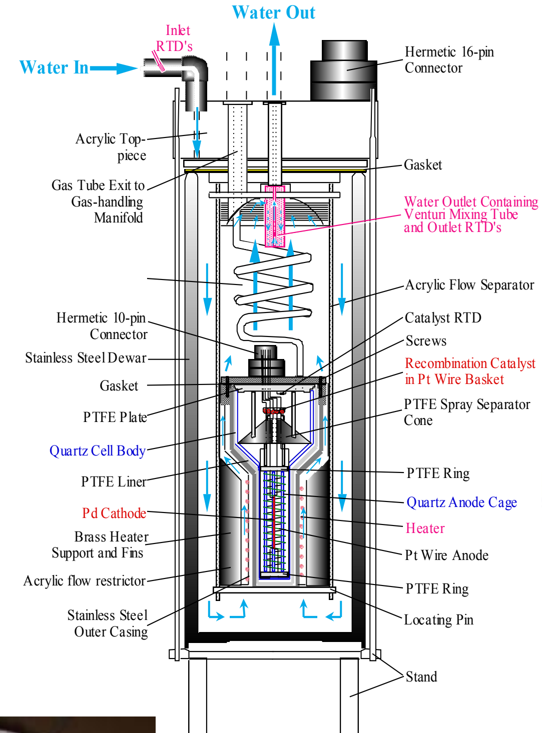


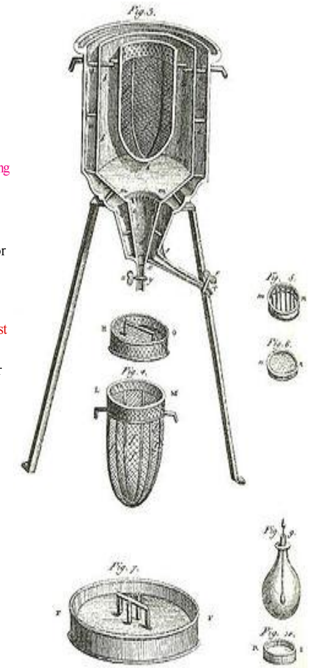


S. Pons, M. Fleischmann, C. Walling and J. Simpson
International Patent Publication No. 90/10935 (1990)

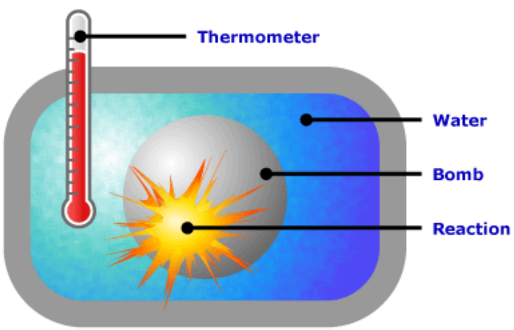
Calorimeters

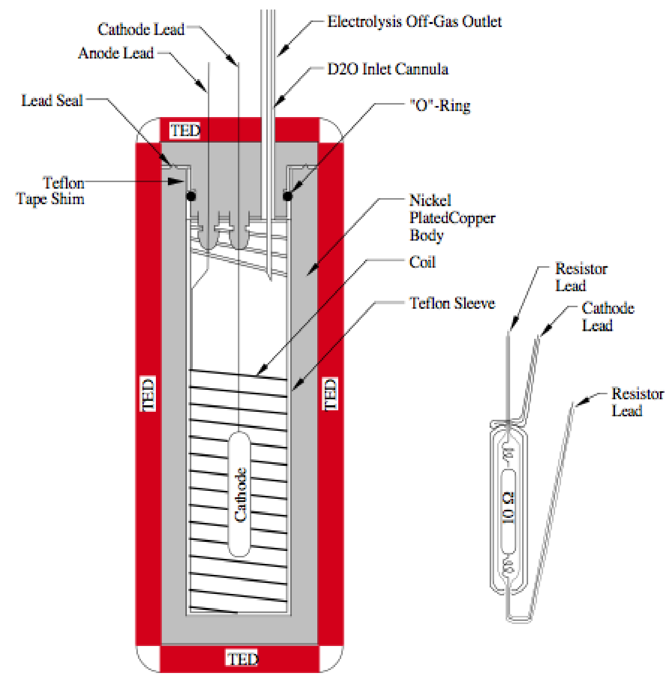


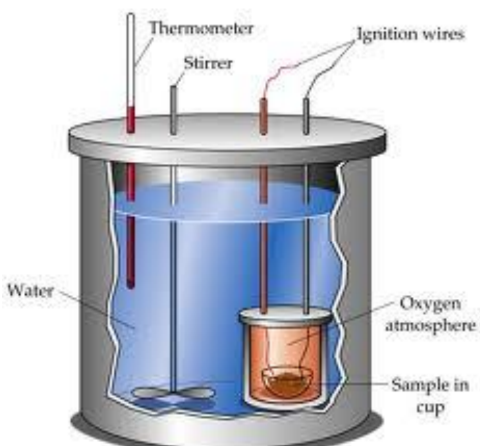




Bomb Calorimeter



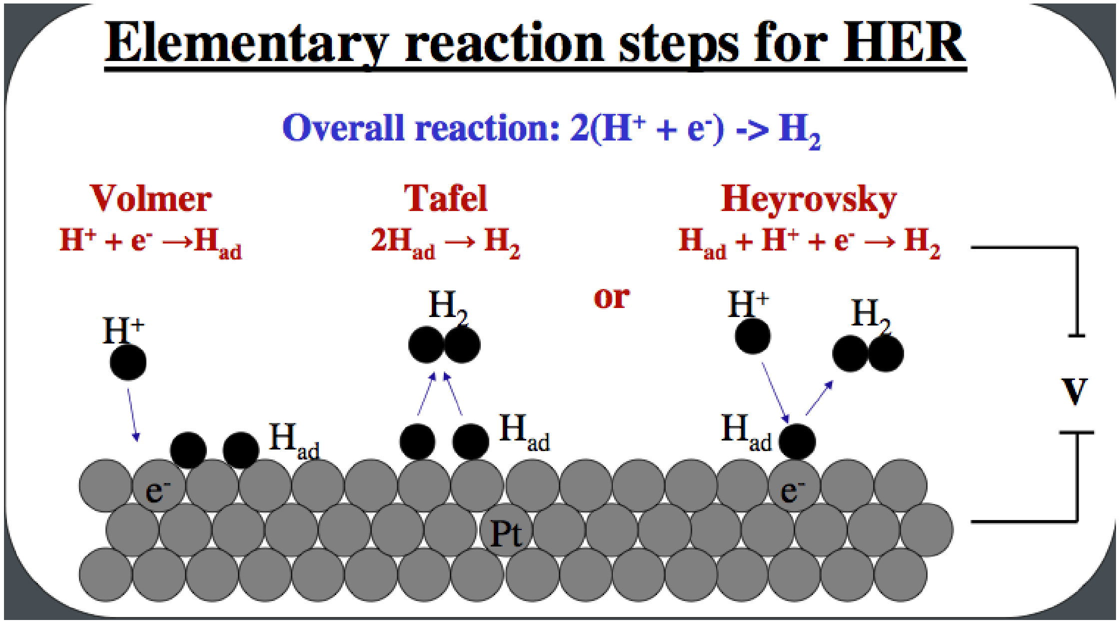




Hydrogen Evolution Reactions [HER]

In under 3 minutes

Volmer



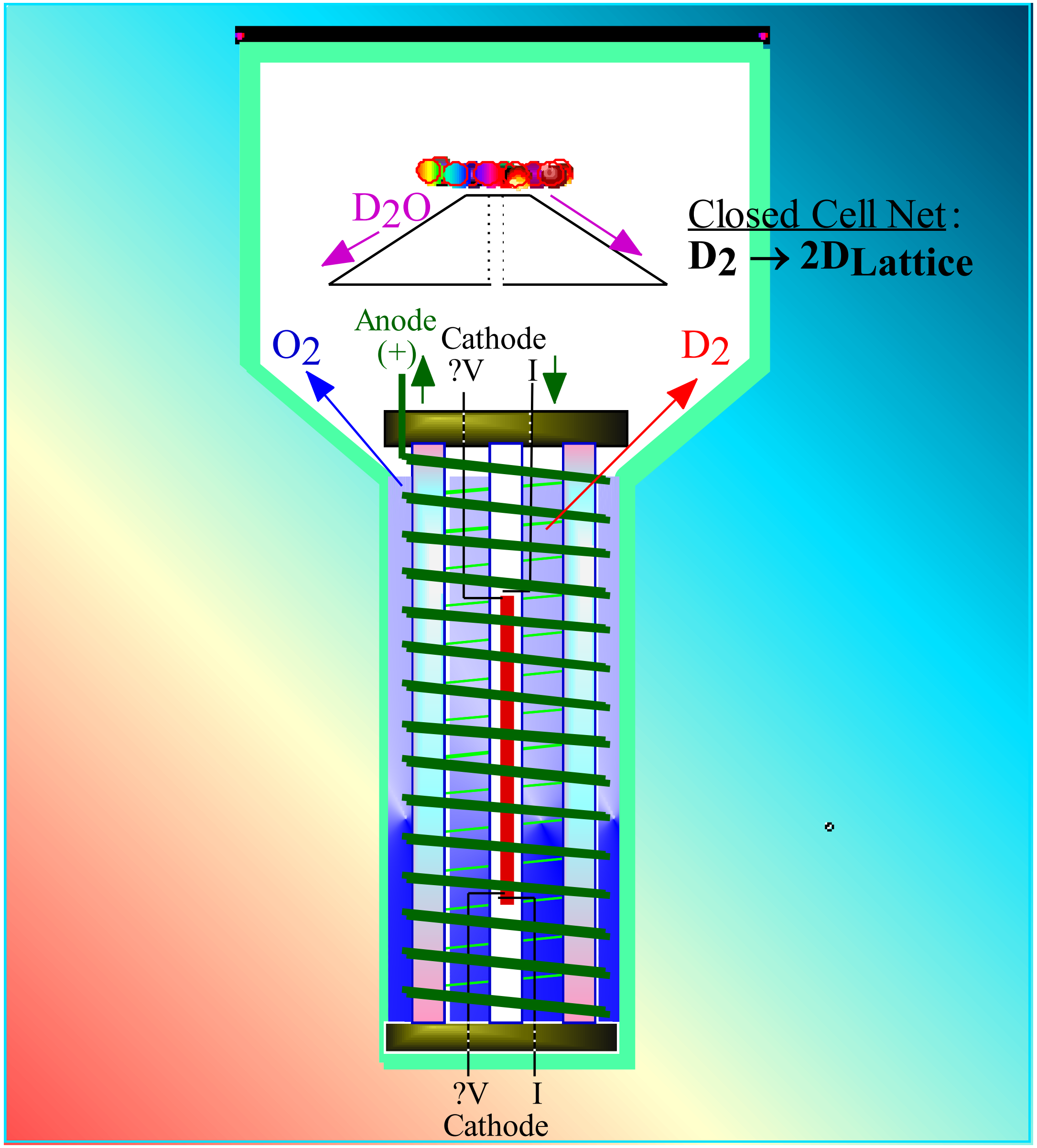
Heyrovsky

Tafel

In Base, for Pd

Volmer	$H_2O + e^- \Rightarrow OH^- + H_{ad}$	(1)
Tafel	$H_{ad} + H_{ad} \Rightarrow H_2$	(2)
Heyrovsky	$H_{ad} + H_2O + e^- \Rightarrow OH^- + H_2$	(3)
Loading	$H_{ad} \Rightarrow H_{ab}$	(4)
Anode	$2OH^- \Rightarrow H_2O + 2e^- + O_{ad}$	(5)
Anode recombination:	$O_{ad} + O_{ad} \Rightarrow O_2$	(6)
Molecular recombination:	$2H_2 + O_2 \Rightarrow 2H_2O$	(7)

Loading Cell and Reactions



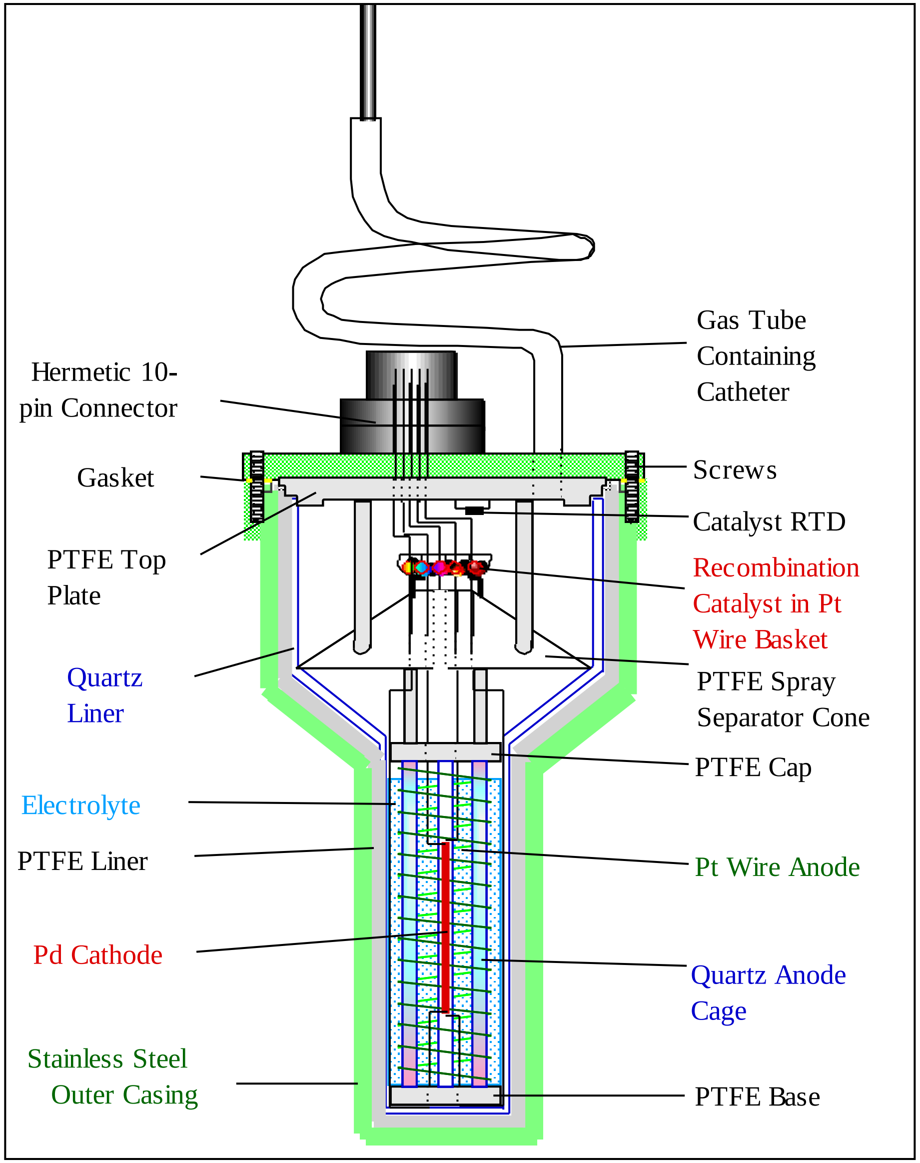
Wires:

1 – 3 mm in diameter

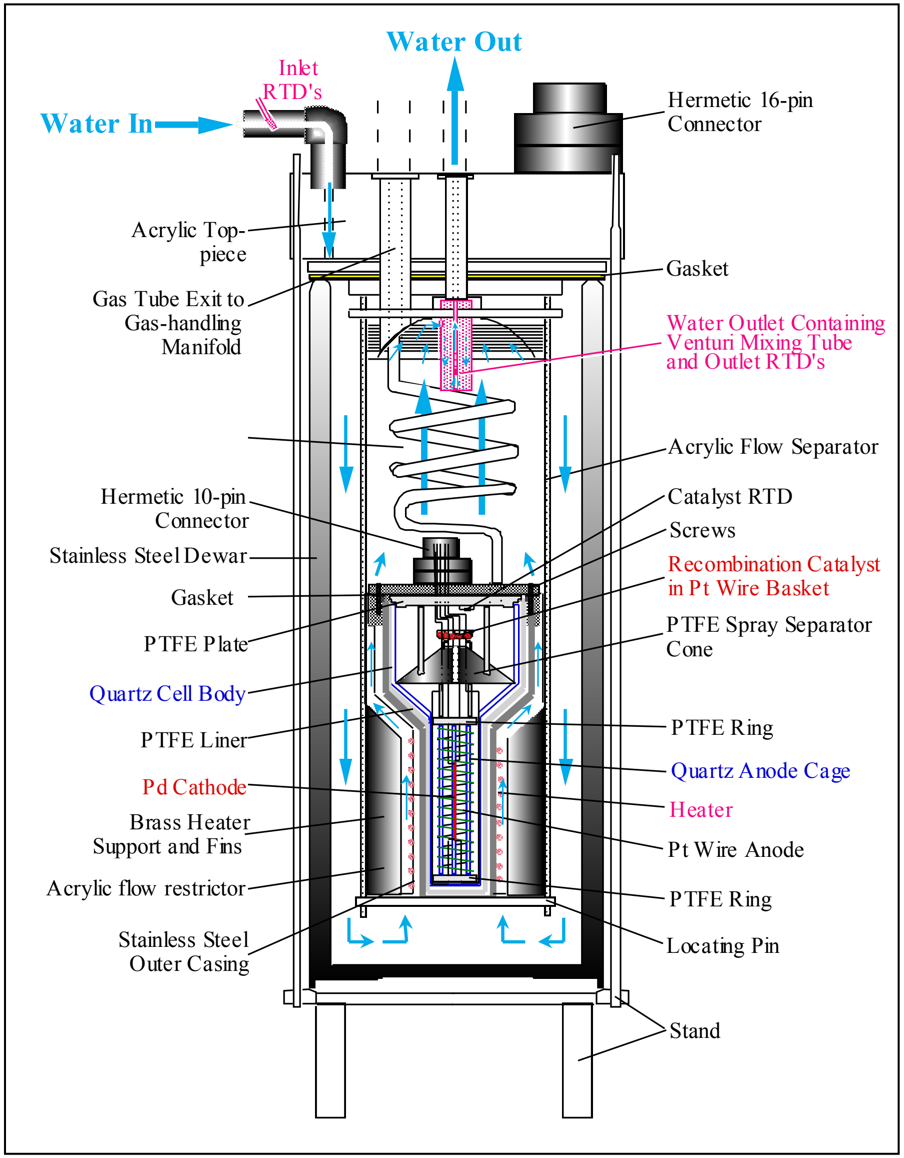
3 – 5 cm in length

1M LiOD Electrolyte

SRI Quartz Calorimeter and Degree of Loading (DoL) Cell



SRI Labyrinth (L and M) Calorimeter and Cell



Accuracy: ±0.35%

Operation:

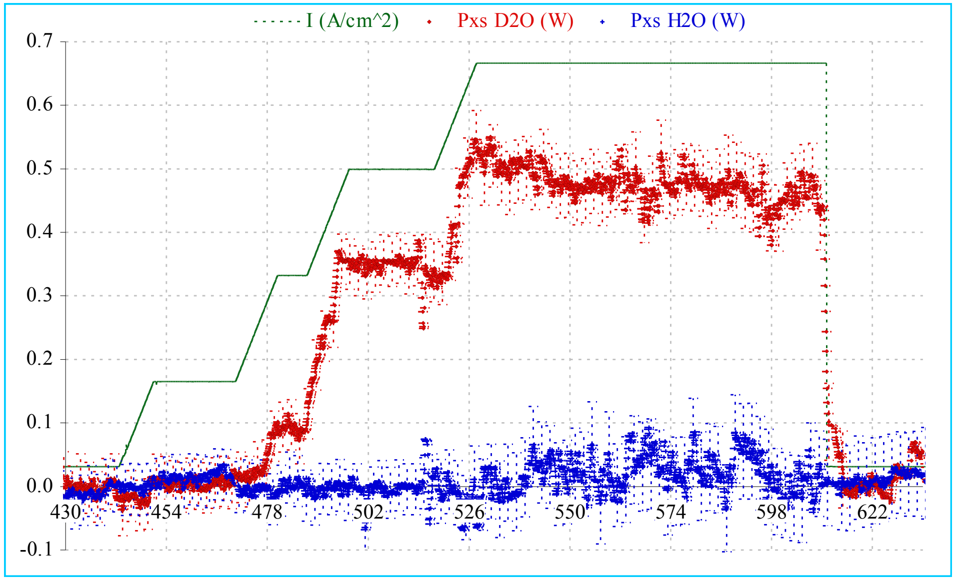
100 mW – 30W

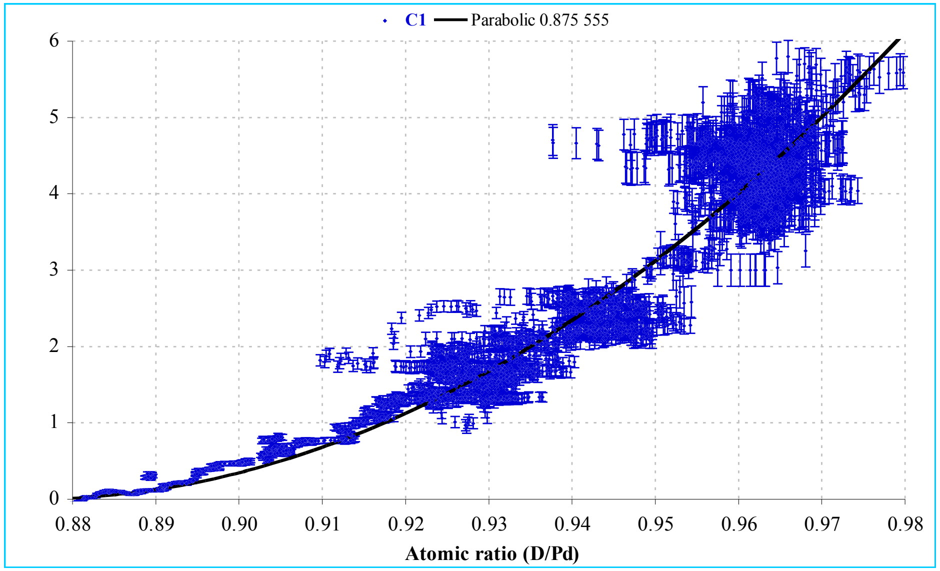
Stability:

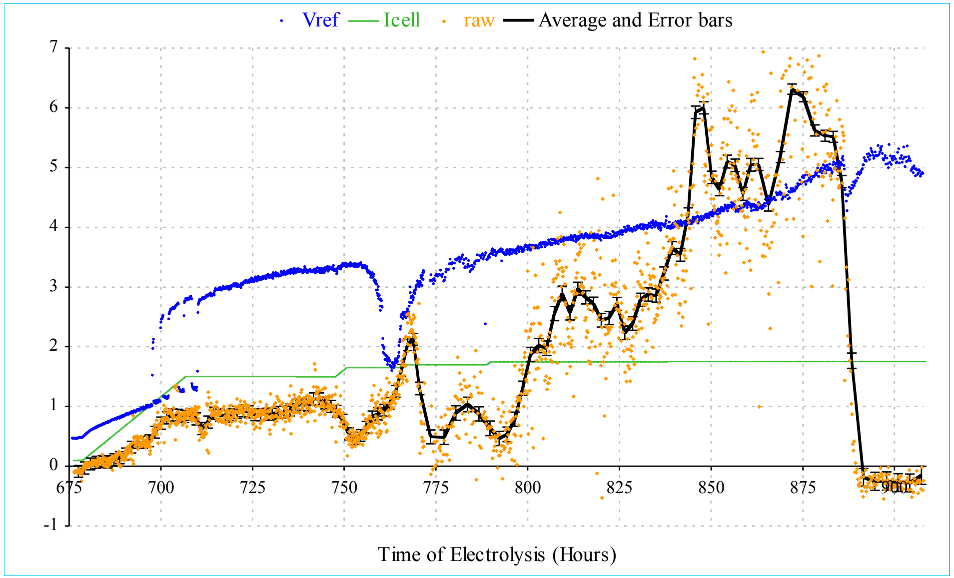
> 1000 hours

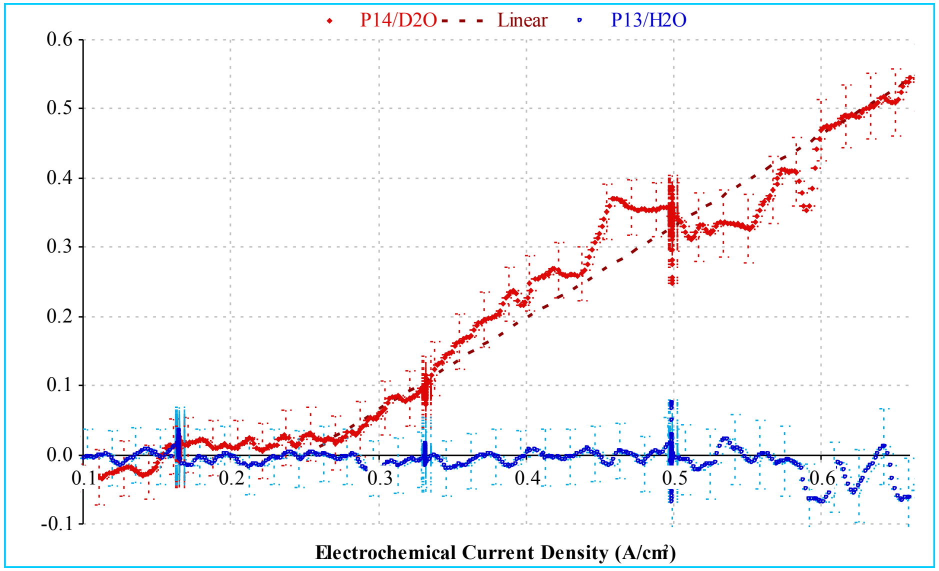
SRI >100,000 Hours
of Precision Calorimetry
using this and
other Calorimeters

DoE Review 2004





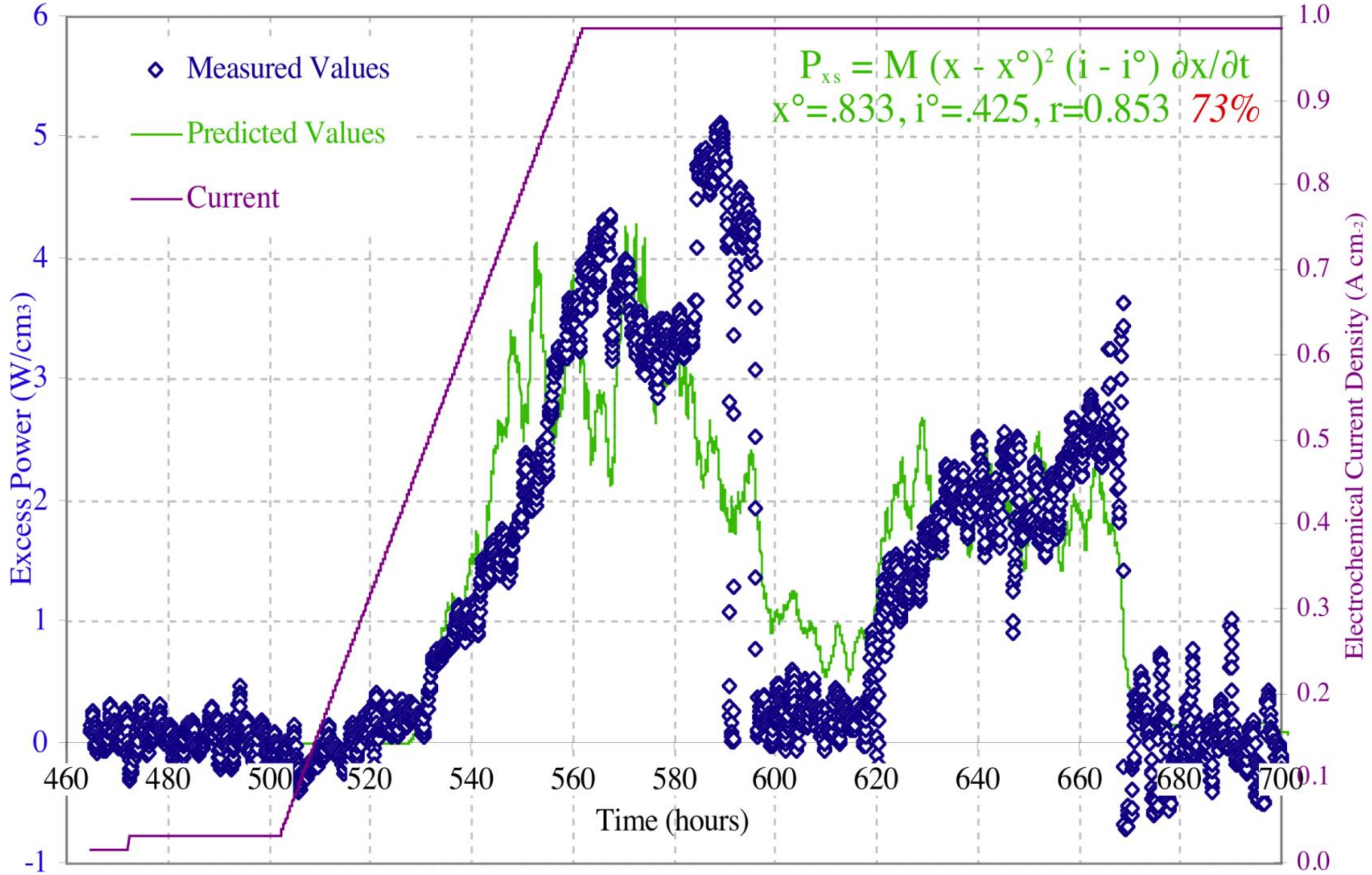




A Predictive Equation

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

$x = D/Pd$, x° ~0.875, i° =50-400mA cm^{-2}, i_D=2-20 mA cm^{-2}, t° >20 □$_{D/D}$



Necessary but Not Sufficient….

- Necessary conditions:

Maintain High Average D/Pd Ratio (*Loading*)

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

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

With an imposed D Flux (*Disequilibrium*)

- Heat correlated with:

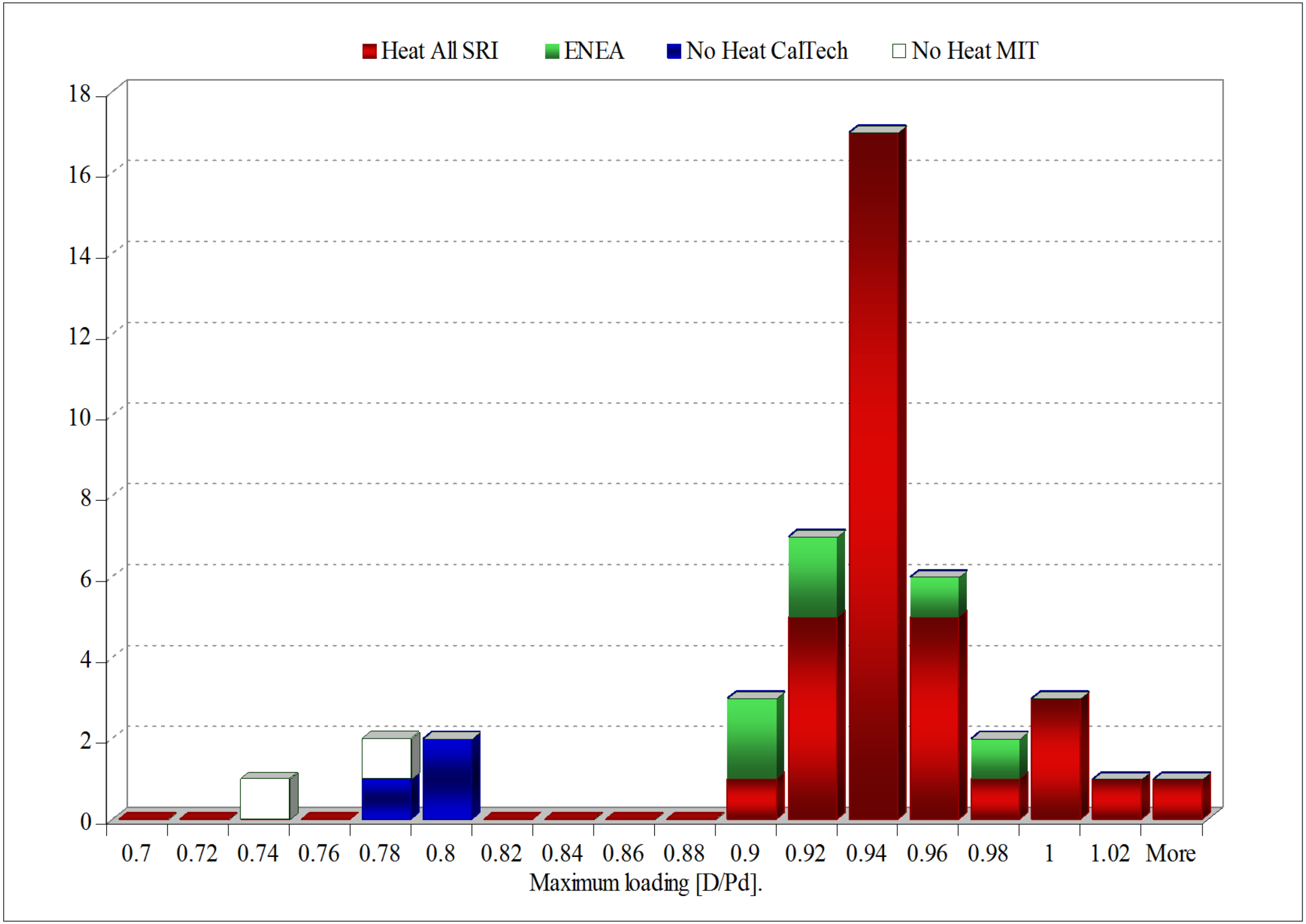
- Electrochemical current or current density
- D/Pd loading
- $V_{ref.}$ surface potential
- Pd metallurgy
- Laser stimulus

- For 1mm diameter Pd wire cathodes:

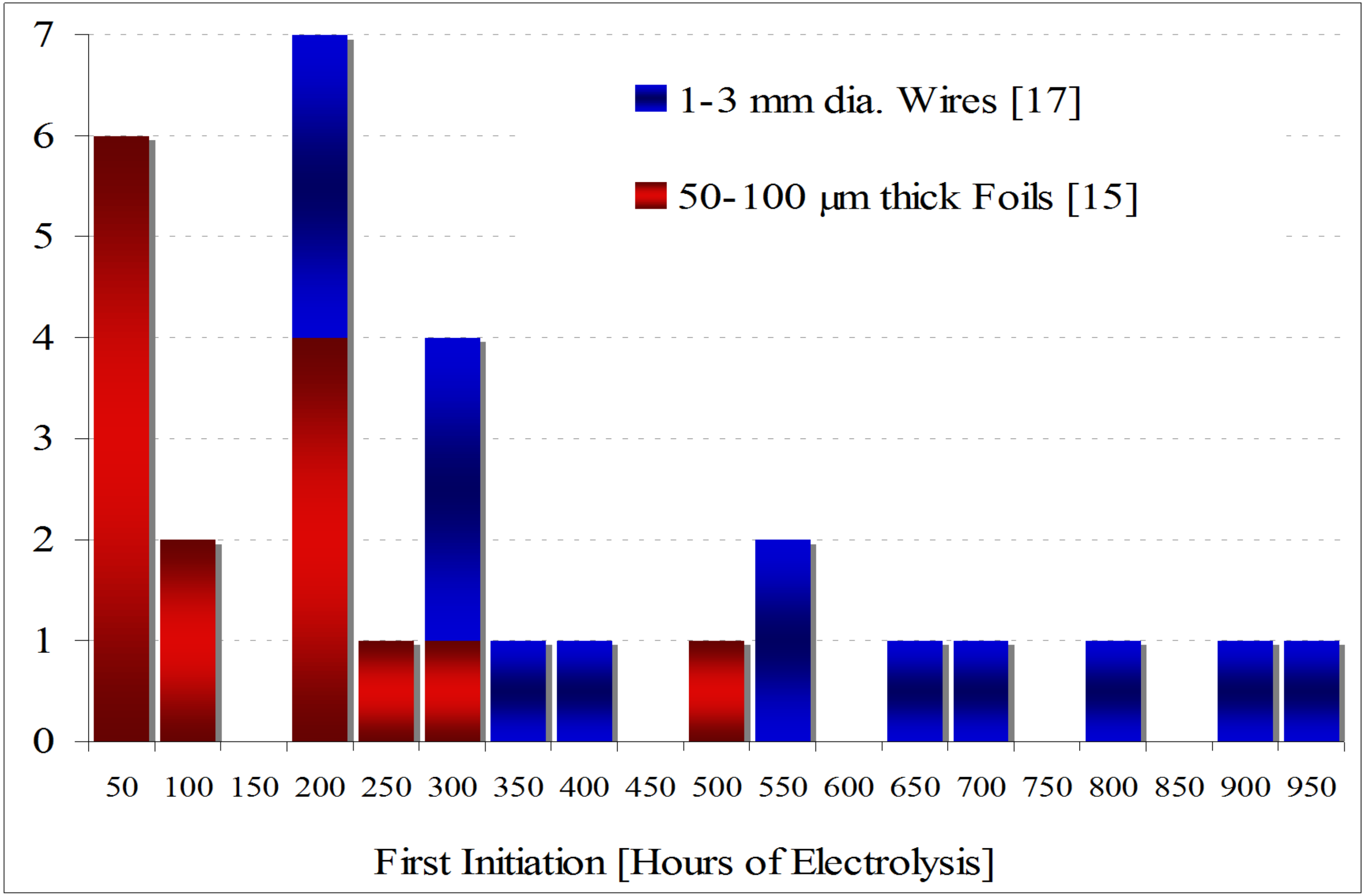
$$P_{xs} = M\,(x-x^{\circ})^2\,(i-i^{\circ})\,\partial x/\partial t$$

x° =0.84-0.88, i° =250-425mA cm^{-2}, t° >200 $\tau_{D/D}$

“Achieve High Maximum D/Pd Ratio (Loading)”



"Maintain High Average D/Pd Ratio (Loading) For times >> 20-50 times $\tau_{D/D}$ (Initiation)"



Gas Loading Experiments, Pd/D_2 and Ni/H_2

SRI results – Les Case

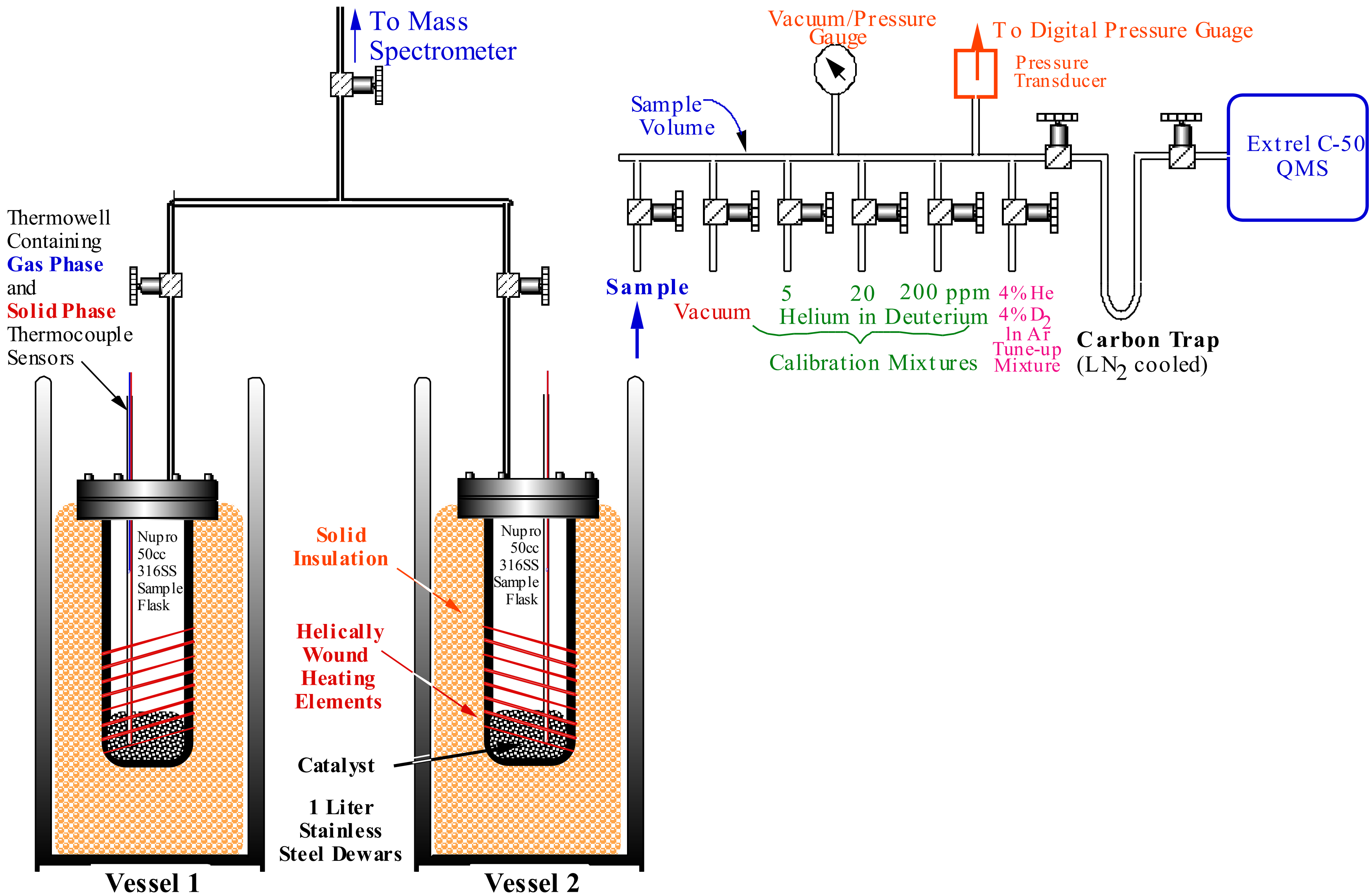
Heat and Helium

SRI gas calorimeter

Piantelli – Rossi – Commercialization?

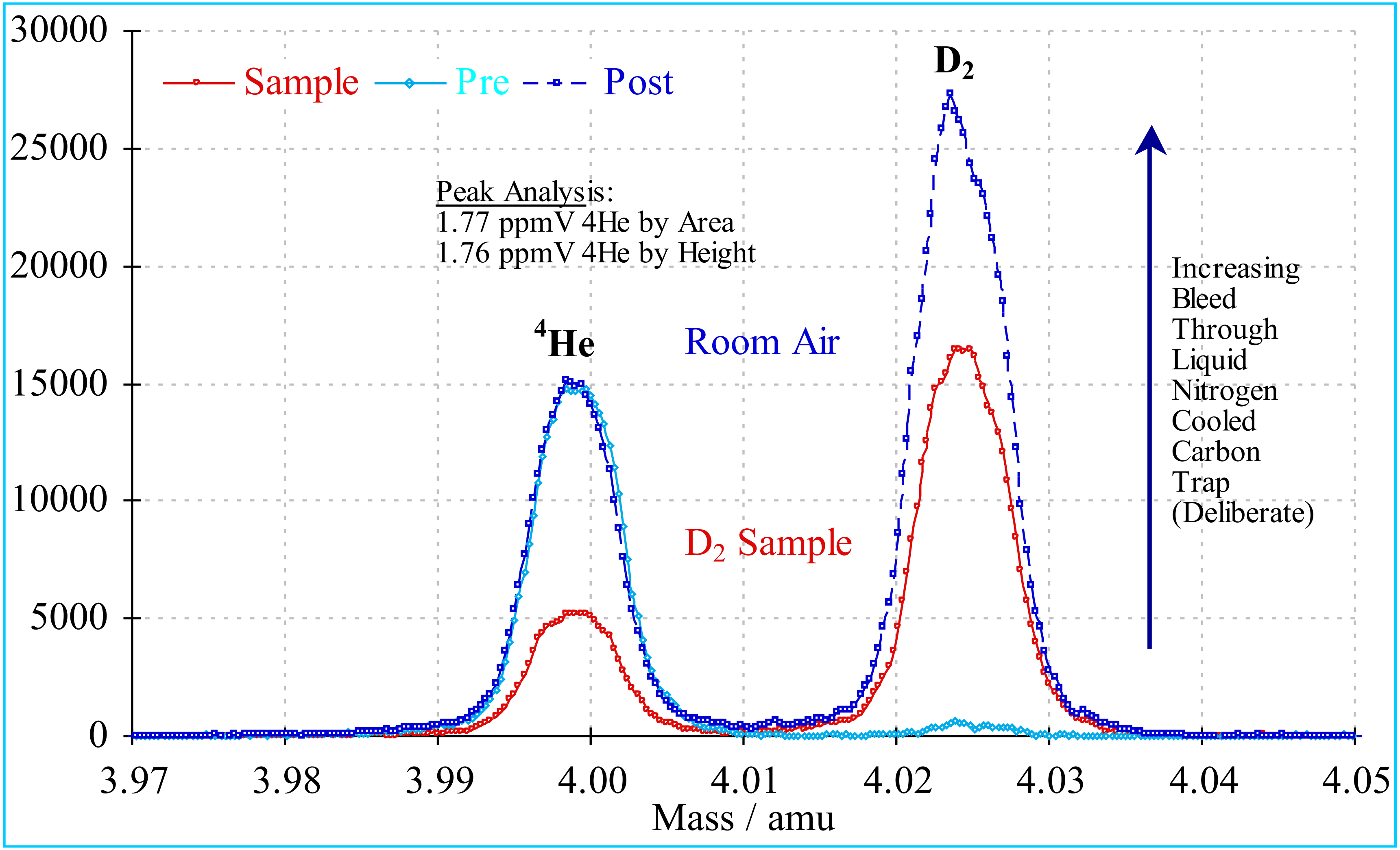
Case Cell Studies:

H_2 and D_2 Gas with Pd/C Catalyst



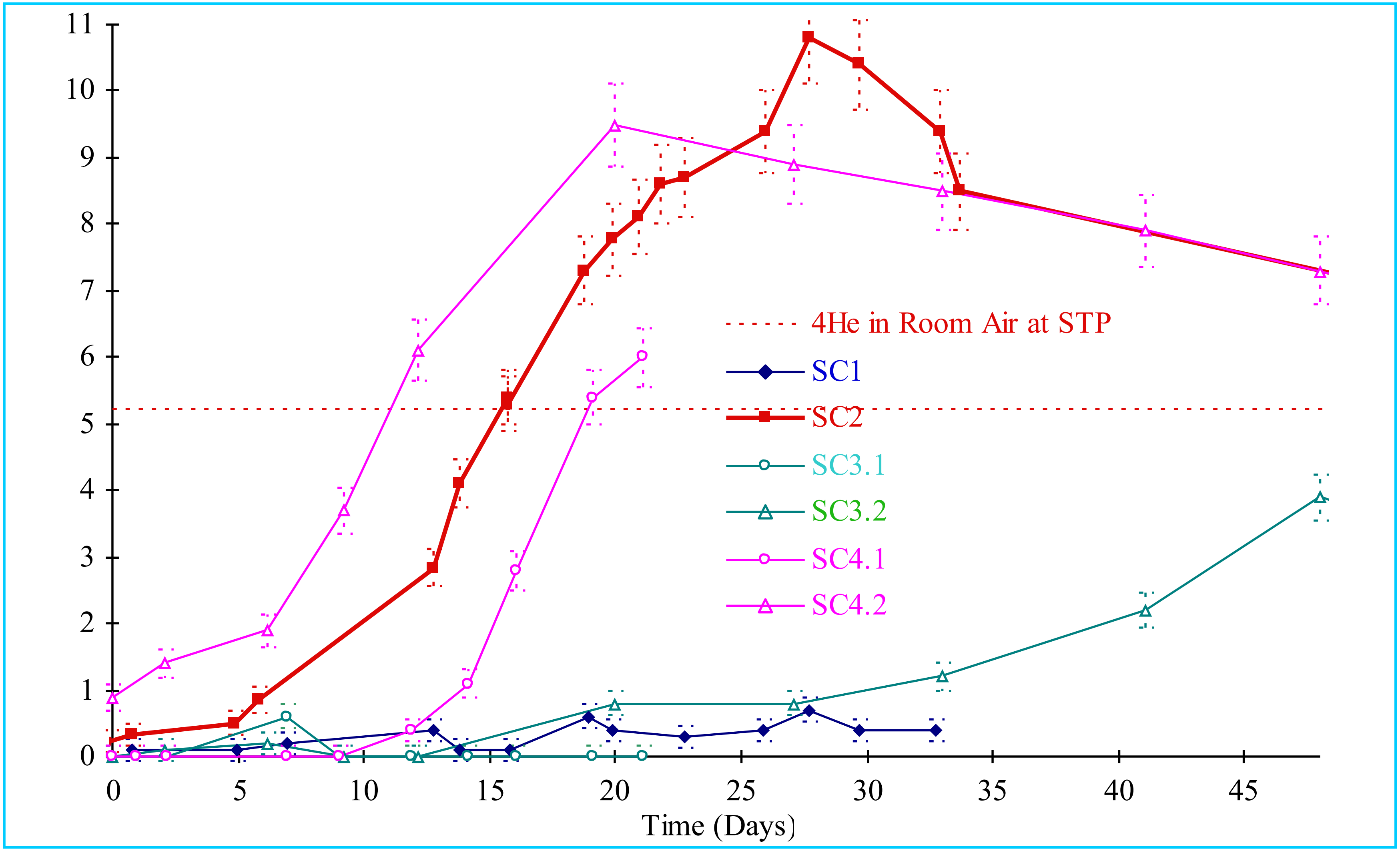
Extrel QMS:

Resolution of D_2 and ^4He



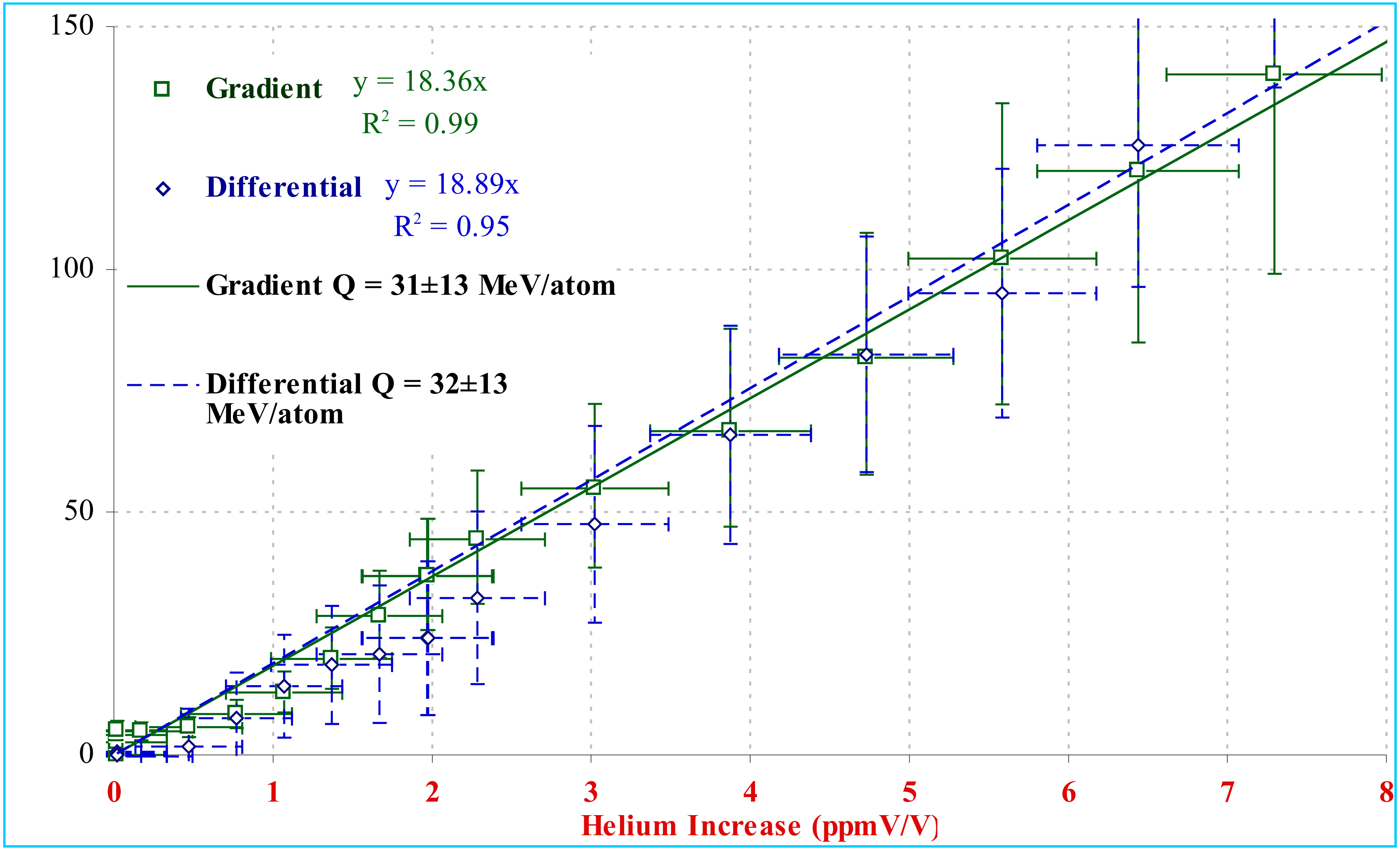
Case:

^{4}He vs. Time



Case:

“Q ”-Value - Energy vs. ^{4}He



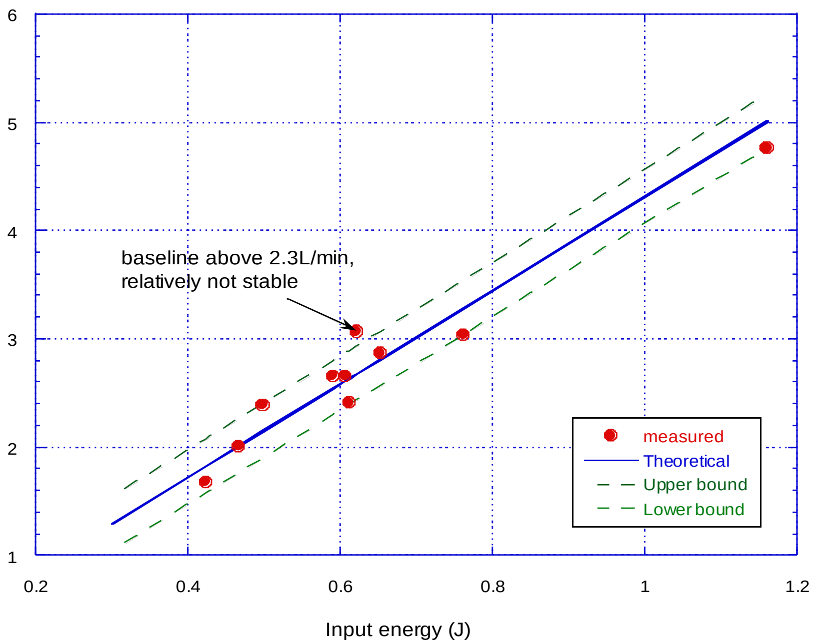
Phase Change Calorimetry:

Liquid Nitrogen Boil-Off

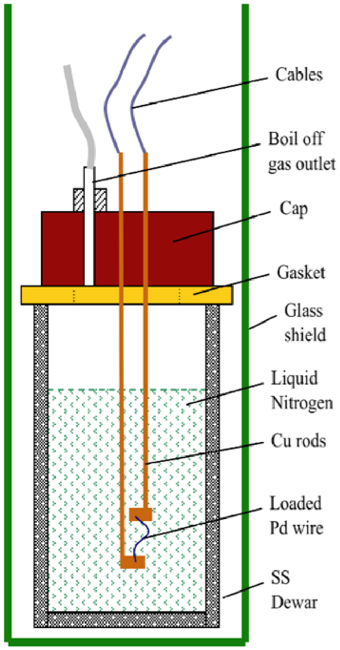
Measurements:

$$Q_o = (\delta m/\delta t)\,[C_{vap.}]$$

mL N_2 gas



Apparatus



Calibration with Joule Heater and Unloaded Pd Wires

Issues:

Heat Leaks (In)

Baseline, Baseline Drift

*Tanzella *et al* Proc. ICCF16 Accepted (2011)

Phase Change Calorimetry:

Results and Conclusions

Table 5: Summary of the cryogenic calorimeter test results for loaded PdD_x and PdH_x wires

Wire#	Composition	Final ratio	x	Input energy (J)	Output energy (J)	Excess energy (J)	Excess%
8	PdD_x	1.77	0.88	0.12± 0.01	0.7± 0.12	0.6± 0.13	500± 100
9	PdH_x	1.27	~1	0.68± 0.01	0.7± 0.12	0.1± 0.13	8± 18
10	PdH_x	1.16	>1	0.64± 0.01	1.0± 0.12	0.3± 0.13	50± 19
11	PdH_x	1.18	>1	0.37± 0.01	0.49± 0.06	0.12± 0.07	32± 16
12	PdD_x	1.58	0.98	0.71± 0.01	0.84± 0.06	0.13± 0.07	18± 8
13	PdD_x	1.7	0.93	0.94± 0.01	1.22± 0.06	0.28± 0.07	30± 6
14	PdD_x	1.65	0.95	0.63± 0.01	0.70± 0.06	0.07± 0.07	10± 10
15	PdD_x	1.62	0.96	0.53± 0.01	0.51± 0.06	-0.02± 0.07	-4± 11
17	PdD_x	1.61	0.97	0.50 ± 0.01	0.70± 0.06	0.20± 0.07	40± 12
18	PdD_x	1.79	0.9	0.82± 0.01	1.25± 0.06	0.43± 0.07	52± 7
19	PdH_x	1.28	~1	0.10± 0.01	0.37± 0.06	0.27± 0.07	270± 60
20	PdH_x	1.31	~1	0.61± 0.01	0.66± 0.06	0.05± 0.07	8± 10

Table 6. Summary of the calorimetric test results for co-deposited Pd wires.

Wire#	Diameter (µm)	Composition	$PdSO_4$ added (ml)	x	Input energy (J) ± 0.01	Measured energy (J) ± 0.06	Excess energy (J) ± 0.07	Excess %
25	50	PdH_x/PdH_x	10	0.92	0.74	0.99	0.25	34± 9
23	50	PdD_x/PdD_x	1	0.85	0.44	0.73	0.29	66± 16
24	50	PdD_x/PdD_x	3.5	0.92	0.29	0.61	0.32	110± 24
26	50	PdD_x/PdD_x	5.5	0.95	0.47	1.26	0.79	168± 16
29	50	PdD_x/PdD_x	3	0.91	0.59	0.88	0.29	49± 12
30	50	PdD_x/PdD_x	6	0.94	0.73	1.99	1.26	173± 10
31	50	PdD_x/PdD_x	9	0.94	0.89	1.92	1.03	116± 8
32	50	PdD_x/PdD_x	8	0.96	0.93	2.23	1.30	140± 8
38	250	PdD_x/PdD_x	3	0.88	0.98	2.20	1.22	124± 7
39	250	PdD_x/PdD_x	13	0.89	0.89	1.39	0.50	56± 8
40	250	PdD_x/PdD_x	10	0.92	3.13	3.51	0.38	12± 2
42	250	PdD_x/PdD_x	5	0.76	5.08	8.98	3.90	77± 1
43	250	PdD_x/PdD_x	10	0.84	1.82	2.56	0.74	41± 9

Table 7. Summary of the calorimetric test results for Pd/D_x co-deposited Ag wires.

Wire #	Diameter (µm)	Material	$PdSO_4$ added (ml)	Input energy (J) ± 0.01	Measured energy (J) ± 0.06	Excess energy (J) ± 0.07	Excess %
33	50	Ag/PdD_x	8	0.31	0.84	0.53	170± 23
34	50	Ag/PdD_x	14	0.98	1.21	0.23	23± 7
36	50	Ag/PdD_x	16	0.48	0.96	0.48	100± 15
41	50	Ag/PdD_x	15	0.55	0.52	-0.03	-5± 13
46	50	Ag/PdD_x	12	0.52	0.77	0.25	48± 13

Table 8. Calorimetry results summary for co-deposited $NiH(D)_x$ wires.

Vire #	Composition	Codep film thickness (µm)	Input energy (J)	Measured energy (J)	Excess energy (J)	Excess %
47	Ni/NiH_x	75.5	0.91± 0.01	1.7± 0.06	0.79± 0.07	87± 8
48	Ni/NiH_x	67	1.57± 0.01	1.55± 0.06	-0.02± 0.07	-1± 4
49	Ni/NiH_x	62	4.53± 0.01	5.56± 0.06	1.03± 0.07	23± 2
50	Ni/NiH_x	20.5	0.87± 0.01	1.28± 0.06	0.41± 0.07	47± 8
59	Ni/NiD_x	36.5	0.25± 0.01	0.76± 0.06	0.51± 0.07	204± 28
60	Ni/NiD_x	33	0.32± 0.01	0.81± 0.06	0.49± 0.07	153± 22
61	Ni/NiD_x	29	1.59± 0.01	2.45± 0.06	0.86± 0.07	54± 4

Calorimeter accurate and precise.

Precision reduced by baseline drift (heat leaks).

12/12 PdD_x on PdD_x (codeposit) produced Excess Heat

Largest amount 3.9 J for thicker (250µm) wire.

2/3 Ni/NiH_x produced Excess Heat

Largest amount 0.79 J or 87 ± 8 % .

It is suggested that "*the nickel/deuteride or mixed nickel deuteride/hydride system may be an appropriate material to produce excess energy*"*.

*Tanzella *et al* Proc. ICCF16 Accepted (2011)

The Italians

Piantelli

Rossi

The October 6, 2011 demonstration

Professor Francesco Piantelli

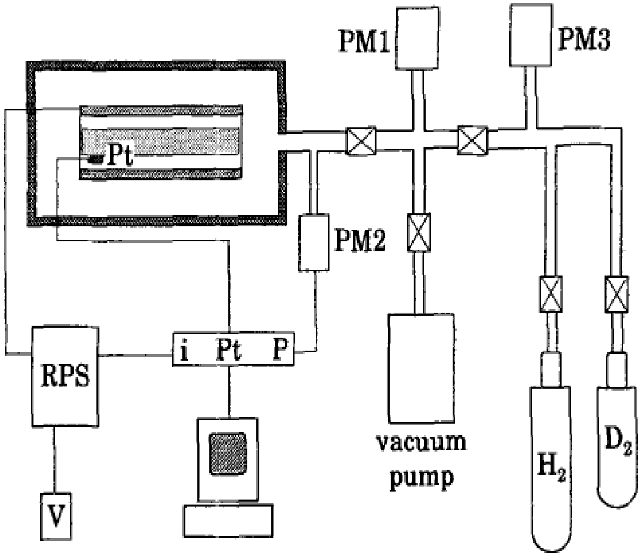
University of Siena

- 1993 excess power from H_2 (gas) / Ni rods (later bars) at T > 400° C
- 1994 Patent (3 more in process)
- P_{In} 140 W; P_{Excess} 20 W – 50 W
- Best cases:
  - 278 days, 900 MJ, (37.5 W)
  - 319 days, 600 MJ, (21.8 W)
- On <u>one</u> occasion
  - Able to reduce P_{In} 140 W to 0 (2W)
  - Maintain P_{Out} 140 W > 300° C
- Neutrons, Gammas, Charged Particles…

Ni or SS rod:

← 9 cm →

0.5 cm diameter

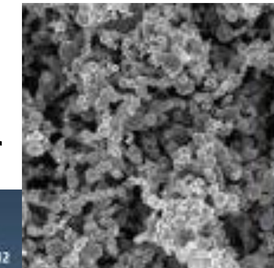


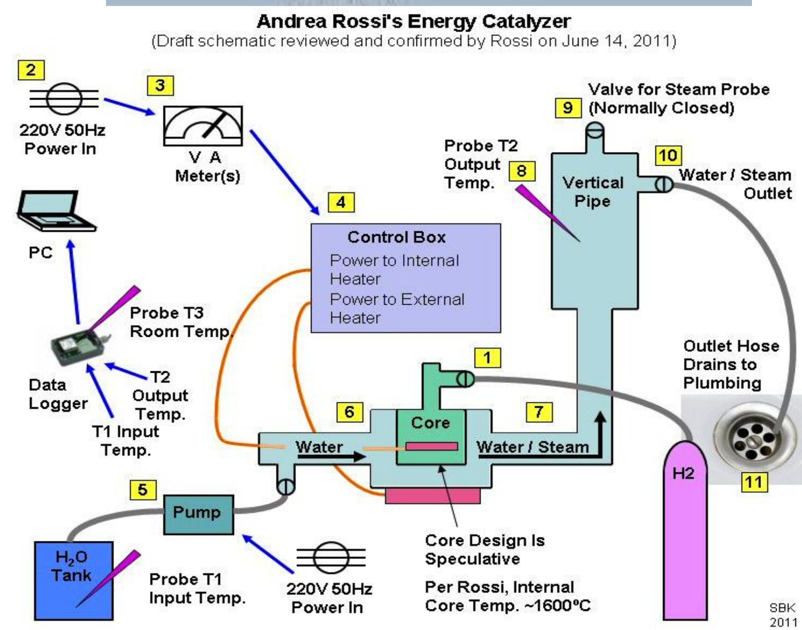
Andrea Rossi E-Cat

Energy Catalyzer

Rossi Core

nano-Ni powder





Andrea Rossi "Energy Amplifier" (II)

- **AmpEnerco Run II**
  - September 25, 2009, New Hampshire
  - 64 liters H_2O
  - T_{In} 23° C, T_{In} 46° C, time 4 hours
  - Average P_{In} <40 W, P_{Out} ~400 W, Gain ~10

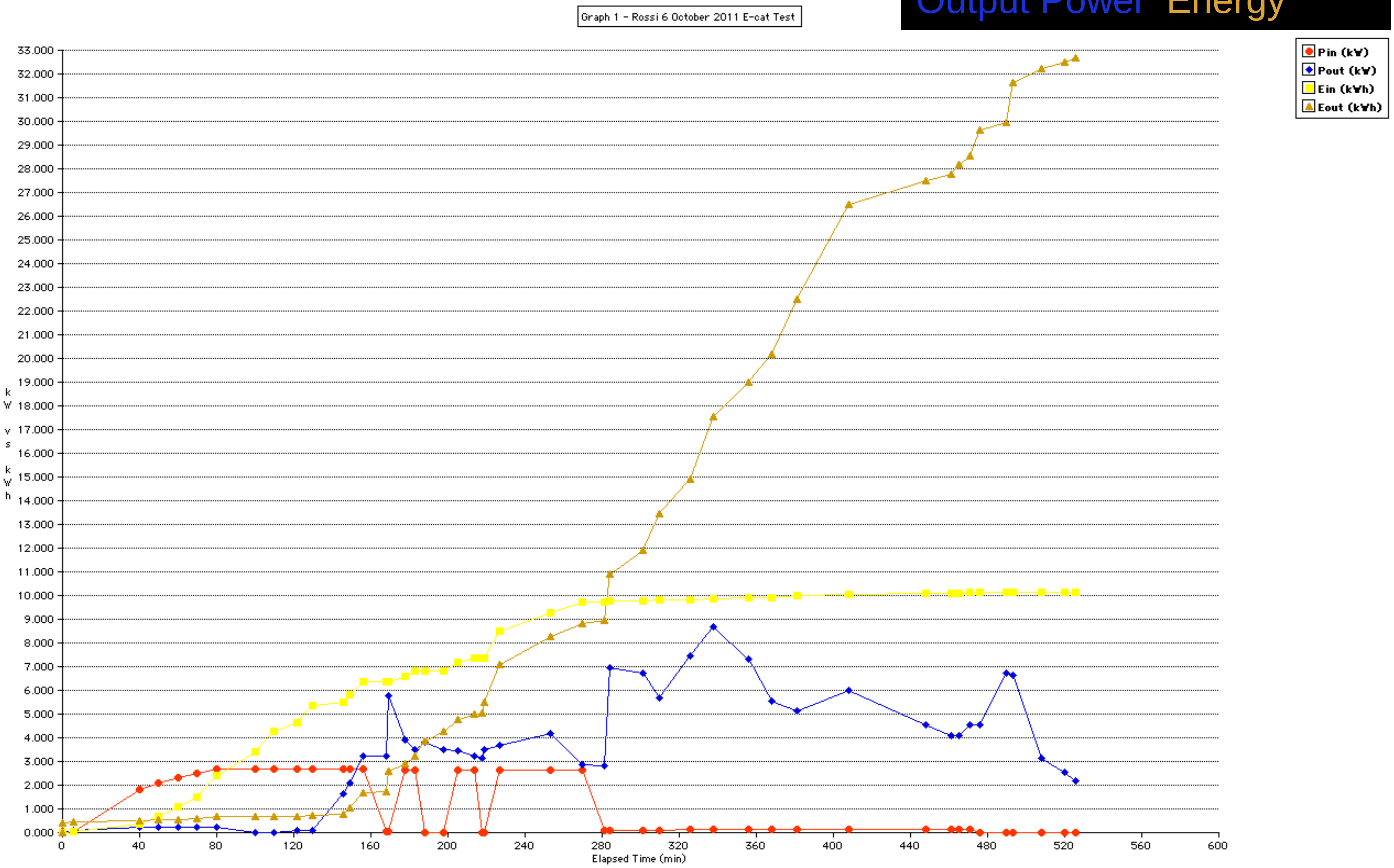
- **Bologna II Jan 14, 2011**
  - 45 minutes generating steam
  - Average P_{In} ~1 kW, P_{Out} 12 kW, Gain 12.7

- **Bologna III Feb 14, 2011**
  - 18 hours, single phase
  - P_{In} 1.2 kW (10 mins) then 100 W, P_{Out} 15 kW, Gain 150
  - H_2 consumption 4 g

Andrea Rossi "Energy Amplifier" (III)

Integrated System Test Oct. 6, 2011

Input Electrical Power, Energy
Output Power Energy



Experimental Summary

- Each of the types of results individually indicates that nuclear reactions occur in diverse experiments at modest temperatures.
  - Measurements of large excess heat
  - Systematics seen for heat production
  - Helium can be produced (^{3}He and ^{4}He)
  - Heat-helium can be correlated
  - Tritium can be produced
  - Neutrons measured in bursts
  - Observations of X-and γ-Rays
  - MeV-energy particles measured
  - Craters in cathodes measured
  - Hot spots measured on cathodes
  - New elements measured ?
  - Possible commercial opportunity ??

The database is robust and the observed effects must be due to nuclear reactions

Conclusions

“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.”

It is possible to initiate nuclear reactions with chemical energies…

The reactions yield significant power and energy…..

Current Major Scientific Problems:

- Reproducibility and controllability
- Lack of quantitative understanding

Exciting (Potentially Historic) Possibilities:

- Distributed nuclear power sources
- Negligible prompt radiation
- Negligible radioactive waste

Many Potential Applications:

- Clean water ?
- Home heating and maybe electricity ??
- Portable power for electronics ???
- Transport ????

Thank you!

Funding Support:
EPRI, MITI, DARPA, DTRA

The speaker is also very much indebted to a group of scientists and engineers which had as its core:
Esperanza Alvarez, Yoshiaki Arata, Jianer Bao, Les Case, Jason Chao, Bindi Chexal, Brian Clarke, Dennis Cravens, Steve Crouch-Baker, Jon McCarty, Irving Dardik, Arik El Boher, Ehud Greenspan, Peter Hagelstein, Alan Hauser, Graham Hubler, Nada Jevtic, Dennis Letts, Shaul Lesin, Robert Nowak, Tom Passell, Andrew Riley, Romeu Rocha-Filho, Joe Santucci, Maria Schreiber, Stuart Smedley, Francis Tanzella, Paolo Tripodi, Robert Weaver, Vittorio Violante, Kevin Wolf, Sharon Wing and Tanya Zilov.

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Department of Energy Reviews

- 1989 Review: Doomed to Fail
  - Done while the field was changing rapidly and confused.
  - Many people were protecting their Intellectual Property.

- 2004 Review: Limited Progress
  - Well organized with competent reviewers.
  - Mixed results and little impact within the government.

BIG Unresolved Questions about LENR

- Are the reactions only nuclear, only atomic, or both?
- Is there one mechanism active or are there multiple processes?
- Do the reactions occur only on the surface of materials or also in the bulk (volume) of the materials?
- What, if anything, is common to electrochemical and gas loading experiments that have exhibited excess power and heat?
- What is the root cause of experimental irreproducibility?
- What external factors can be used to initiate and control LENR?